Draft September 2005

Bottled Lightning

Creating the Electrical Grid

by
Phillip F. Schewe

Introduction

Text yet to be written

Electrical Book by Phillip F. Schewe

Detailed Table of Contents

TABLE OF CONTENTS

INTRODUCTION

CHAPTER ONE---THE GRIDNESS OF THE GRID

Best way to see the grid: nighttime airplane view of New York City/Blackouts as sociological experiments/Much of modernity is electrical/Stuck in an elevator--the New York blackout of 1959/the grid in antiquity/Faraday's flicker of recognition/the meaning of air conditioning

CHAPTER TWO---GRID GENESIS (1880-1896)

Sarah Bernhardt visits Thomas Edison after midnight/Edison's early career/his invasion of New York/Pearl Street--first grid in America, 1882/Tesla's epiphany/mystery of electricity explained/Westinghouse--first AC grid in America/AC vs DC--the Chicago Exposition/Niagara Falls

CHAPTER THREE---MOST ELECTRIFIED CITY (1892-1934)

Cutthroat competition in the 1890s and 1990s/Samuel Insull gobbles up Chicago/electricity still too expensive/The ad revolution---How long should a wife live?/The birth of electronics: the radio revolution/Insull's empire/Stock Crash of 1929/Insull is pursued abroad and arrested

CHAPTER FOUR---IMPERIAL GRID (1920-1965)

Electricity conquers all other forms of energy/British grid--The Lake District doesn't like power/Parliament finally comes around/Soviet grid--Lenin gets his way/Fuel for Red October/Trotsky under a cloud/Tennessee Valley Authority grid--David Lilienthal and democratic electricity/WW II's deepest secret--energy for Oak Ridge/Con Edison Day at the World's Fair/Big Allis--world's largest steam-electric plant

CHAPTER FIVE---WORST DAY IN GRID HISTORY (November 9, 1965)

The grid is like an internal sea of energy/A TV program from the electron's point of view/the avalanche begins--Rochester loses its grid, then Syracuse/A hurricane in the grid/Hamlet-like drama unfolds at Con Ed's control center/Big Allis tries to save the day/Everything crashes

CHAPTER SIX---THIRTY MILLION POWERLESS (November 9, 1965)

Biggest blackout ever/Pentagon is on alert/Darkness everywhere--elevators, hospitals, subways, Broadway, airport/LBJ launches a probe/At the zoo, Macy's, and Bonwit Teller/New York Times prepares the story by candle light/Big Allis is mortally wounded/The smoking gun: where the blackout began/Turning New York back on/letters to the editor/Stock Exchange reopens--utility are down

CHAPTER SEVEN---OVERHAULING THE GRID (1965-2001)

Too little grid--brownouts in New York/Middle East war, oil crisis, power industry nosedive/Too much grid--nuclear reactors cancelled/Con Ed becomes the company you love to hate/Stop wasting energy/Restructuring the power business from top to bottom/Con Ed divest, Enron goes bankrupt, the California grid crash lands

CHAPTER EIGHT---ENERGIZING THE GRID (now)
Electricity comes to Bolivian mountaintops/A visit to Big Allis/Advanced carbon--converted jet engines/A visit to a smart home--electricity from the sun and from corn/A visit to the Indian Point Nuclear Reactor/A Hiroshima's worth of electricity

CHAPTER NINE---TOUCHING THE GRID (now)
A top-to-bottom look at a single grid--Idaho Power Corporation/How electricity comes into your home/How current flows through your rooms/Check the oil for carcinogens/Holding 7200 volts in your hand/A visit to a hydroelectric plant/The woman who runs the grid/Looking ten years ahead/The Nez Perce get their share

CHAPTER TEN---GRID ON THE MOON
Minimum Electricity--the haves and have-nots/Scraping by in Uganda/Out of touch in Ohio--the great blackout of 2003/In India the rates are too low/Biggest blackout in history/China will come in first/Three Gorges Dam--18 GW of power in one place/Bringing electricity to the Moon--Apollo 11 mission/The grid inside your head

TIMELINE

GLOSSARY

ACKNOWLEDGEMENTS

BIBLIOGRAPHY AND ENDNOTES

THE AUTHOR

INDEX

28 September 2005

Electrical Book

by Phillip F. Schewe

Chapter One

The Gridness of the Grid

The airborne view of New York City surely is a picture fit for the gods. Strapped into your plane seat, with no escape, you might be a bit nervous, but what you see out the window diverts your attention. There it is, a habitat for twenty million souls, all seeable from a window seat. It looks like one of the natural wonders of the world, but consider that much of what you see is deliberately *built*. Even the largest contours one makes out by the light of day---Manhattan's fabled waterfrontage, the inside curve of Coney Island, the bushy green of Central Park---are due in part to purposeful digging up or filling in. Other objects in your visual field are more obviously manmade: the tall buildings, oil refineries, and of course the roadway grid. The railroad grid is harder to spot; you need to look for one of those telltale fan shaped railyards and then trace the radiant lines outward from there.

At night the view is even more splendid because that's when the electricity grid stands out. Buried in the earth and hidden from view while the sun's up, the grid manifests itself after dark in brilliant fluorescently lit rectilinear streets and diagonal boulevards, all geometrical proxies for the electric current running beneath. This luminous quilt is continuous around the horizon with the exception of the watery parts---the rivers, the bay, the sound---where electricity may not go. However, even there, with the help of numerous bridges and causeways, the electrical grid runs irrepressibly onwards.

The Visible Grid

This book is a biography of that grid. We began with this overhead shot of the Big Apple since, besides being one of the most arresting sights in the world, it illustrates more directly than any view from the ground the ubiquitous physical presence of the power grid. Also we started with New York because that's where the grid in America got started and where more electricity is used by more people than in any other single place.

All these people need stuff. New York City is a hungry beast. It has plenty of factories for making things, milelong avenues of stores and showrooms for selling, and fat phonebooks of agencies for providing services. A majority of the raw materials needed for sustaining this gargantuan metropolitan metabolism, however, must come in from outside. As one of the largest cities in the world, New York consumes vast amounts of food, fuel, water, and finished goods arriving day after day by plane, ship, train, truck, pipe, and wire.

One of the most precious of New York's necessary commodities, electricity, hardly figured in the life of cities before the end of the 19th century. Electricity played no role in the administration of Imperial Kyoto or the meteoric rise of Islamic Cairo. Electricity came too late to inspire the artists of Renaissance Florence or contribute to the glory of Paris in the time of Napoleon. Once it arrived, however, it became a big factor---some would say too big a factor---in the rhythm of urban existence. The advent of electric power and its catalog of follow-on products---incandescent bulbs, radio, x rays, and time-saving domestic appliances---radically changed the way things were done. For example, the architecture of buildings (which no longer had to be configured to maximize the sunlight pouring in at windows), the sprawl of suburbs (cheap electric trolleys allowed employees to live farther away from work), the methods for storing and preparing food (perishables could be maintained for days, frozen goods for months), the operation of factories (which didn't have to be situated next to a river and could be kept open for a night shift), and the lighting and heating of homes were all altered by the introduction of voltage.

How did these modifications to city life come about and how much of what we call modernity is fundamentally electrical in nature? One way of addressing these questions is to seek out a position slightly exterior to the grid. After all, what does a fish know of water? Therefore, like sightseers getting a better view of the plain by climbing up a mountain slope, we'll begin this tour of our electrified culture by first reaching a vantage point somewhat *outside* electricity, at least for a short while. This is possible only during electrical failures, those disruptors of normal routine when the grid is drained of power. Most people view blackouts as highly inconvenient, bad for business, and potentially dangerous to life and limb. Nevertheless, for the purpose of this book they are a godsend, for it is precisely from within these brief but dramatic black holes that one can get a visceral feeling for the octopus overgrowth of high-voltage technology.

Let's go back up into the sky for a ringside seat at one of these events. Imagine that you have just flown up the eastern coast of the U.S. In the past half hour alone the captain will have invited you to gander to the left and to the right, where you saw in succession the lights of Washington, DC, Baltimore, and Philadelphia. And then along comes the jewel in this crown of cities, Gotham itself, the most illuminated place on the planet. Here is what happens in that airspace on the evening of November 9, 1965.

The airline captain steers his craft into its designated landing approach. As he does so, he informs you with great relish of the immensity being displayed below: half the state of New Jersey can be seen to the left, Manhattan and its colossal buildings lie directly ahead, and the endless neighborhoods of Queens and Brooklyn are coming into view on the right. The captain is pleased with the sights as much as any tourist, but he is of course professionally alert and regularly darts a glance down to his instrument panel. This time, when his eyes roll up again to reclaim his windshield view, all he sees is black. New York has disappeared. In one half of a second, in a vertigo inducing reversal, the greatest metropolitan cluster of lights in the known universe had been dimmed to oblivion. One captain's exact thought was this: "It looked like the end of the world."

With no landable airport in sight, he turns the plane into a new heading and seeks radio instructions on what to do next. From the standpoint of aeronautical safety it didn't hurt that a full moon had just climbed into the crystalline early evening sky. Although nobody on the plane knew it at the time, right under their noses the greatest power outage in history had just occurred.

Invisible Grid

We started with an expansive view of the city from above looking down. Next let's stare at things claustrophobically from the inside looking out. Please picture yourself in a stalled elevator. Here's what you tell yourself: I'm never going to walk into one of them again, ever. If I get out of this alive I'm going to take the stairs. Why do they make buildings as high as 20 stories in the first place? As for the electricity going down, I know, there's always a chance that something can go wrong. But why did it have to be *this* elevator? I guess the gods of electricity, or whoever or whatever is responsible for this mess, just decided that now was the time and so---zap!---off goes the power.

When electricity stops one of the less fun places to be is the inside of a stalled elevator. Motion is arrested, lighting is doused, and the ventilation, never more than meager, ceases altogether. In a space not much bigger than a luncheonette booth you're left standing in the heat in the dark in the presence of strangers. When an elevator shuts down it's difficult to say which is worse, the growing heat, the short air, or the lack of light. Maybe worse is the suspicion---at first just a queasy feeling, then a looming fear---that gravity could easily finish the job at any moment, overcoming whatever fragile restraint is holding the elevator in check, allowing it to rush to the bottom of the shaft with an acceleration of 32 feet per second every second. And so instinctively some passengers forebear to move at all, as if too sudden a gesture would tip the hidden balance and hasten the rapid ride down. It's like the stomachless feeling you get in the rollercoaster at the top of that first big hill. You admit to yourself: I'm a willing customer. No one forced me to get into the elevator.

Actually, no, many people would not recognize the fact that they were consuming a commodity. So great is the prevalence of electrical culture that at times our powered devices might seem like part of the environment. According to this way of thinking the power grid may as well be a geological formation. We might neglect to think of electricity as a *made* thing, a costly substance deliberately delivered to that location. Rather it would come to take on the aspect of ambient reality, a kind of bubbling organic hotspring of versatile sustenance. For someone on the 20th floor of a tall building, a bank of elevators might seem like no more than the obvious and best path down from the heights. It would take some effort of imagination to see the elevator and the building as an artificial trail inside an artificial mountain. How could an elevator, which had worked all those other times, not work now? Without advanced mathematics it's difficult to perceive a blackout as one niche along a graph of possibilities. It's more instinctive to feel *wronged*: being detained in an elevator is not a happenstance but an affront.

One goal of this book are to help you to see the grid, perhaps for the first time; to *not* take it for granted; to ponder the close surrounding presence of the grid; perhaps even to question its existence, or at least its methods. That's why you've been brought to this dark place.

The victims inside the stalled elevator must wonder whether outsiders, in the part of the world still electrified, even knew of their predicament. The elevator intercom, if it ever worked, certainly isn't working now. So, in addition to the lack of light, ventilation, and movement, you can add lack of information to the list of things lost when energy flows out of the grid rather than in. It can be disturbingly dark in an elevator, more profoundly dark than most people have ever experienced. One thing you can do to cheer yourself up is to strike matches in an effort to push back the darkness. But then some clever person observes that the available oxygen might be in short supply, and so the hostages voluntarily lapse back into the dark. That's when exact spatial coordinates become blurry and the flow of time gets taffy pulled by the forces of disorientation to an extraordinary degree. If it weren't so awful it would be wonderful.

In the year 10,000 BCE, or at any other time during the last 99.9% of the human tenure among the animals, to be in a dark place was the natural state of affairs, while to possess discretionary light was a miracle. Because of the grid all this is reversed: to have light all the time is the custom and to go lightless becomes a memorable anecdote. If, furthermore, someone had told the forlorn riders, and thousands more stalled in various metal conveyances moving through the city horizontally in subways and vertically in elevators, that they had been made prisoner by the calculated flick of a single switch, they would have been incredulous. How did this state of affairs came into being?

Mastering the Grid

Why and how does the grid go down? From the inside of a dark elevator the cause might seem mysterious, even malevolent, but in actuality it would have been partly a hardware problem, involving the breakdown of one or more components, and partly a management problem, signifying a flaw in the way the grid was designed or operated.

Since we're already in New York City, why don't we stay there for a while. And rather than dwell on the generalities of powerlessness, we'll look at a particular event, the Manhattan blackout of 1959, much smaller and tidier from the standpoint of narrative than the colossal electrical failure of 1965 (which will receive the scrutiny it deserves later in the book), but still large enough to illustrate the rise and fall of the grid.

On August 17, 1959, when the lights go out in that elevator, the center of the action, if not the cause of the failure, is at the grid headquarters over on the East Side. First, back up the clock a few hours and have a look at the layout of the room and meet the cast of characters who typically hold your electrical fate in their hands.

The setting could almost be called biblical. Although it doesn't look like a throne, the System Operator's chair at Consolidated Edison is a seat of power greater than that of the storied kings who exercised sway over the early cities of Sumeria. Sitting with the Operator at the same high table are three trusted lieutenants, the separate overseers of steam, gas, and electricity for the city, each with its own grid. These men, and it is always men and not women, dispense energy in its various fluid forms to inhabitants numbering nine million.

The terms of this rulership are anything but reverential or even respectful. No, the fealty is strictly mercantile. It is an oligarchy of seller and buyers, with prices set not by barter or haggle but by regulatory statute. On the one side is the utility company, in existence to clear a profit. On the other side are the multitudes, three million billable households, eager to accept the energy but resentful of the per-kilowatt-hour rate, the highest in the land, and skeptical about the perpetual ripping up of roads needed, they are assured, for underground repairs. The Con Edison grid, the supply side of the formula, possesses a dozen generating plants around the city, give or take a few, and these could be operated in various combinations to achieve an economical and reliable flow of electricity.

We are a corporation, the Company Vice President would declare politely. Although service is paramount, dividends do have to be paid. Nothing wrong with that, is there? Like any other large business we must cover expenses and produce a return on investment for those who lend the capital used to build those massive generators and all the other modern equipment installed on the grid in a process of continual upgrade and improvement. If there were no profit, there would be no investment, no new technology, no new capacity to meet the increase in demand. We are pleased and privileged to delivery electricity, but it has to be paid for.

Meanwhile, the demand side of the formula in the year of 1959 consists of those nine million spread out across the five boroughs and a large chunk of Westchester, the county to the north. The Company Vice President sees the nine million as a wonderfully diverse customer base for the product he has to sell. To the Company engineers, it is more efficient to think not of the throngs but of their high-torque drills, their hedge clippers, their window fans yearning to turn free, as being the aggregate load on the grid. It is, after all, the engineers who designed the grid and who keep designing, since the grid gets ever larger, never smaller. Like a fourteen year old boy, the grid in August 1959 outgrows its clothes almost every day.

To the Company accounting department, the nine million are just so many accounts to maintain on a rolling basis. Payment used to be made in person at the central office but now occurs via the convenient envelope provided with the monthly statement. Included with the bill one sometimes finds heartening nostrums meant to make you feel better about the grid and its overseers. Here's an example from yesteryear:

> *In many lines of business the sale completes the transaction and the job is*

> *finished. With us the sale is only the starting point. It sets up a continuing relationship. When you become our customer you obligate us to meet all your needs for electrical service, whatever they may be (ref 1.1).*

Why is supplying electricity on a grid not like supplying bread from a truck? the engineer would ask with evident pride in the uniquely difficult aspects of his profession. If a baker is short a few loaves, he apologizes and tells the customer to return earlier tomorrow. A few loaves too many and the baker can make breadcrumbs with the leftover. But with electricity there is no leftover: it has to go somewhere all the time and can't lie around unused on a shelf at the back of the store. At all times the generation must meet the load. And it does. We see to that, the engineers says. Supply and demand are squared off.

The delivery not only has to be economical and reliable but also timely and exact. When a room light comes on in Riverdale or a blender in Bensonhurst this represents a sudden additional load on the system which must be answered immediately by a proper measure of watts from the wall socket. Electricity supply is very hand-in-glove. Every step forward Fred Astaire takes must be reciprocated by Ginger Rogers going backwards, in heels. In the electricity business, the idea of supply-and-demand is not merely a formula in an economics textbook but a covenant to be fulfilled continually.

The process is exact in that appliances all over town are calibrated to run at a specified strength and frequency. If the voltage wilts or the frequency speeds up, the resulting brownout---a sort of softened blackout---might injure appliances without actually turning them off. Therefore the operational parameters have to be rock steady. In other words, the grid not only delivers energy but must sculpt it with the finesse of Michelangelo.

We're the ones, the engineers say, who have to think through how this can be done, how to make the big electricity generators flexible enough to crank out more juice, or less, with only a few minutes' or seconds' warning. Fortunately, in a city as big as New York, you can bet that if a light goes on in one place, somewhere else a light is being turned off, so we have the law of averages working for us in a big way.

And yet on some occasions the law of averages runs out, and the grid crashes. To find out precisely how the blackout on August 17 happens, and how that elevator stalls, let's return to the System Operator who from his throne oversees this vast power realm, the largest privately owned utility in America. With the pressing of switches at his curving console he re-routes, diminishes, or enhances the electrical activity pulsing through the largest urban system of underground cables in the world. The Mount Olympus of amperage, the fortress for this Zeus of volts, is located in Con Ed's Waterside Station on Manhattan's East Side. It is here where the bad news first arrives.

Losing the Grid

August 17, 1959, an oppressive day lying on New York like a thick coat of paint, this is not going to be a good day for the man who administrates electricity. Thanks to the near ubiquity of air conditioners, a new record for consumption is being established this day, a peak power flow that will register just a bit shy of 4000 megawatts. You wouldn't necessarily grasp the magnitude of that number yet but at the end of this chapter you will.

Four thousand megawatts is a big load. It burdens the city grid like heavy glass ornaments weighing down the limbs of a Christmas tree. Nevertheless, this uptake falls comfortably within the production capacity of Con Ed's fleet of steam-driven electricity generators. No sweat. But wait, the successful operation of the grid is more than the mere dispatching of power to meet a load. It also includes transforming high voltage into low voltage and vice versa, transmitting current down cable highways beneath the streets, insulating regions of high voltage from their surroundings, and steering or interrupting currents as needed. If things go wrong with any of these transactions, loss of power can occur.

The grid has inbuilt redundancy. If one generator or cable goes bad a second or a third can automatically shoulder the extra burden. But in an elaborately complex system---one made from lots of swiftly interacting components---it doesn't always work that way. The linemen most particularly concerned with the continuity of service, the ones who wear hard hats and drive those tool-crammed vans, do daily combat with a variety of maladies: cracking insulation, expanding joins between fitted parts, frayed materials, settling ground, tarnished contacts, leaking water. All of these unwanted departures from the norm can lead to criticality: the system can work itself into a fragile condition in which even a tiny problem can quickly escalate into a large problem. Small things can lead to big things. The grid is not inert. It does things and things are done to it. The grid can be an amplifier of trouble.

On August 17 it is a relatively small thing that leads to big problems. The System Operator, as watchful as a chess grandmaster mentally playing ten moves ahead, detects a minor defect at the corner of his gameboard. He sees that a feeder cable, a conduit for moving power from the monster generator at the Hell Gate plant in the Bronx into the neighborhoods around Central

Park, has disconnected itself by the throwing of a large switch. This “tripping off” is not only inexplicable but also inconveniently unfortunate since two of the other cables in this sector are already turned off for repair work. The remaining lines, however, are deemed sufficient to carry the impressive supply of electricity that would be needed on this hottest of days as the city bulks itself up on energy for the evening rush hour.

On a day like this the grid is being taxed to the full. The grid is stretched taut. You can almost hear the army corps of air conditioners stationed all over the backs of those teeming apartment buildings. Hot days and electricity go together. In the early days of the grid things were different. Electricity was chiefly for light, not for lifting, driving, or turning. Peak power consumption would occur in winter, when daylight was short, and in the evening when the amount of artificial light produced in electrically heated bulb filaments went up. Long before 1959, this had changed: peak consumption had migrated into the summer, one important reason being those gargantuan air conditioners needing pitchforks of power.

The System Operator understands the network thoroughly and knows how to work around trouble spots. With fingertip control, he can reduce the output of a turbine in the Bronx, and call forth a greater effort from its cousin in Queens. The control console is just like the bridge of a well-run ship on a hazardous ocean voyage. When I see storm warnings I know how to steer a course that avoids the rough seas.

But today things aren't going to be ordinary. The pile of compounded problems is getting too steep for that, and roughness will be unavoidable. With the three cables already gone, four more turn off---they just go down for no good reason---in the space of 42 minutes. This truly is the unkindest cut of all. On some days you just can't win. We're approaching the moment System Operators dread. He can see what's coming, but not the people blithely climbing into that elevator.

The Mid-Manhattan grid is now tottering. The problem is not insufficient electricity but a shortage of available cable. Should the Operator keep power flowing to customers but risk overloading the remaining cables and possibly do serious damage to the grid or, just as painful to contemplate, should he deliberately turn off the power to a block of important Manhattan real estate? In the passing of less than sixty minutes the Operator has become less like an omnipotent god and more like the Wizard of Oz, an ineffectual turner of knobs behind a curtain. The network is misbehaving. It is being irrepressible.

The heavy decision is made: the need to protect valuable equipment from further injury is uppermost in importance, and so at 3 PM a switch is thrown which puts the city on an instantaneous energy diet (ref 1.2). Electricity is snatched away from half a million people, including some of the richest and some of the poorest citizens in the city. Electricity is a great leveler.

The utility company's bit of "load shedding," a term chosen for its very blandness, instantly maroons thousands in elevators and subways, leaves numerous hospitals without light, streets without signals, and ice cream everywhere deprived of freezing temperatures. What happens next? Mostly people try to make the best of it. Many go out of their way to be cooperative. Some are heroic. Volunteers direct traffic, although at some strategic crossroads the evening air is filled with that symphonic sound for which New York is known the world over, namely continuous horn honk. Surprisingly crime is down, probably because of an overriding civic feeling of solidarity. In the New York Guild for the Jewish Blind at Columbus Circle, sighted workers are led out of the blacked-out building by their sightless colleagues. In Central Park a production of *Carmen Jones* gamefully goes ahead, lit by diesel-powered generators. Housewives are advised on which foods to discard because of possible spoilage. This being metropolitan New York, a city big enough to have complications occurring on all levels and at all hours, the electrical mishap around Central Park is of course not the only thing amiss. Further south in Manhattan a water main has burst (ref 1.3).

Fortunately New York has great inertia. It pushes onwards, parting the waves in front. The engineers locate the problem. Power again flows into homes, although there is some grumbling from folks on the West Side as to why restoration took several hours longer than it did on the East Side.

Mayor Robert Wagner is looking beyond the blackout of August 17. Responsible city officials always worry about the future. He seeks reassuring words from the utility on the issues of reliability and capacity to meet the city's growing need for power. The Commission of Water, Gas, and Electricity duly conducts an investigation and concludes that the utility company should have been more flexible in the way current is routed to neighborhoods. If one cable goes down there ought to be other ways for that district to get power. Furthermore, when problems do occur, and some load must positively, unavoidably, be shed, then the damage should be localized and limited in scope. The city's engineer declares that the utility could have done more to keep this kind of thing from happening (ref 1.4). How did a condition arise where a System Operator runs out of options and must deliberately open a circuit, snatching power away from a half million? This is New York. We should do better than that.

Consolidated Edison, in what will be seen as a recurring pattern, rebuts the city's accusations point by point. They assert that the outage arose from a simple and unexpected mechanical failure which had nothing to do with overloading. The Company statement is adamant: "We categorically deny any inadequacy in our system. Our entire system is designed to meet any reasonable contingency."

The utility Vice President, eager to state his opinion, can be just as civic minded as the Mayor. Does the customer have a right to expect reliable service? He does. Is electricity a service for all the citizens? It is. But please recognize that it is not quite a service like the water supply. Electricity can't be held in reserve in a tank and it doesn't flow smoothly through inert pipes. Instead, it leaps instantly across the arms of a branching grid, a highly complex piece of machine filled with reactive components. Electricity is not like coal, something you dig out of the ground. Electricity has be to be made, sent, and used, all in the same instant. The grid is not like a the municipal system of roadways. It can't be patched here and there with a truckload of warm asphalt, poured and smoothed over. Even on the offensive, the Company Vice President is defensive: Should there have been more backup cables available? If so, how many? And how will it be paid for? We are currently studying all of these issues, the better to provide New Yorkers with the kind of service they deserve.

The Company promises to do better next time. They estimate the chance of the same sort of a blackout happening again as being infinitesimal (ref 1.5). Yet a copy of the 1959 blackout once again strikes mid-Manhattan on June 13, 1961, leaving a half million without power. The day after the blackout is another scorcher, and electrical consumption sets another record, 4473 million watts.

How much energy is that? A million watts, or one megawatt, is the power equivalent of ten thousand 100-watt lightbulbs. And since each person exudes roughly the same heat as that bulb, a megawatt of electricity can be compared, in terms of power, to the body heat of 10,000 people, enough to start crowding a place like Madison Square Garden. So 4400 megawatts is 4400 Madison Square Gardens' worth of human heat. Take all those Gardens and put one on each street corner. Manhattan is very roughly 300 city blocks long times 15 avenues wide, or about 4500 square blocks. Cover the entirety of Manhattan street corners with Madison Square Gardens, each filled with a basketball game. Picture all those fans packed elbow to elbow, leaning forward in their seats, the championship game decided as the ball goes through the hoop at the final buzzer, all that moist breath exhaled, that magnificent aura of body heat rising out of the stands at the climactic moment. Add it all together and that's the equivalent to the electrical power New York is drawing at this peak hour. Mayor Robert Wagner wonders where the city is going to get enough electricity for future years. On the next day, while hardly breaking a sweat they break that mark with a new record.

The Meaning of Air Conditioning

Does New York use too much electricity? Look no further than air conditioning. What is the impact of this hungriest of specimens in the zoo of socketed appliances kept in your home. One of the most blessed inventions from the standpoint of ameliorating the summertime discomforture that lingers around concrete encrusted cities or any hot place---humid or parched---an air conditioner is a member of the family of refrigeration devices whose job is to transport heat away from one place and dumps it in another place. Example: you remove heat from an interior room at 72 degrees and dump it outside where it's already 96. Now, unwanted heat does not of itself flow uphill from cold to hot, but it will if you bring appropriate machinery to bear. Here's how it works. You give the unwanted interior heat to an intermediary substance, a pressurized refrigerant fluid, which carries the heat away to be offloaded elsewhere, out in the backyard. It's like barging Manhattan's garbage out to Staten Island, which already has trash of its own.

The net effect of this process, of course, is to warm the outside air even more. But at least that warmth would be somewhere else. Sitting in your chilled living room watching television you could care less about what it's like out back with the trash cans or in the stratosphere, where ozone is being dismembered by fluorochlorocarbons leaking from your machine (or did until the old style refrigerant was banned). The older units used 1000 watts of power, the equivalent of ten 100-watt light bulbs. If you want an even more intimate feeling for wattage, consider that the human body exudes heat energy at about that same rate of 100 watts. An air conditioner therefore consumes roughly the energy output equivalent of ten perspiring people.

In this way electricity, in select areas of human existence, allows you to preempt nature. Ah, but now we have a dilemma. Here is where a miniature moral drama begins. On the one hand, air conditioning must be good: by the flimsiest flick of your wrist, the turning of a dial makes a compressor speed up or slow down, obtaining for you any desired comfort level. But doesn't this separate you from Nature? Isn't that bad? Aren't we supposed to stay close to Nature? If the gods had meant the climate to be nice all the time, they would have made every place just like San Diego. Wait, you say. Does that mean we have to suffer whatever weather comes along? Didn't the first caveman who sat by a fire, soaking up the warmth and roasting his meat, separate himself from cruel nature? Can you blame him?

Air conditioning is bad insofar as it makes a racket, scares away the birds, and cracks the moldings around window frames. Air conditioning is good because it makes a summer's afternoon bearable. With artificial cooling cities like Atlanta and Miami could aspire to being national cities, serious destinations for business and tourists alike, and not just regional cities of the Deep South. Air conditioning must be bad because it leaks bad chemicals into the sky where protective ozone gets denatured, hastening a proportionate amount of skin cancer.

But who will tell the old lady, the one with the heart condition, or the mother of the infant whimpering with an ear infection that they should feel the summer full force? The sweat glands are the body's own private transmission grid for carrying surplus heat from the interior up to the surface, where it's released through an act of evaporation. This process can take its course, as nature intended, or it can be speeded up through the application of electric-powered air conditioning.

So the argument swings back and forth. No single air conditioning unit can be traced to any particular case of skin cancer. And anyway the nasty ozone-busting chemicals aren't used anymore. No extra amount of heat wafting up from all the refrigerators in Boston can be blamed for the general retreat of the Greenland iceshelf, can it? And even if it is partly to blame, which city will be the first to give up its air conditioning voluntarily? How much electricity is too much? We don't yet know. The bigger and better the grid gets the more this question will be asked.

Was the electricity grid inevitable? No, not inevitable. The grid started small and grew and kept growing because it was better than other energy-delivery systems. Stop to consider an ordinary activity, like reading a book after dark. For centuries, if you were fortunate enough to have a book in the first place, you would have lit an oil lamp or a candle. In the 19th century whale oil was popular, so popular that dedicated fleets of ships sailed the world over in search of the leviathan of the deep, a process immortalized by Herman Melville. Shortly thereafter whale fuel was overtaken by other fuels, by kerosene and gaslight, whose procurement, though by no means pleasant, entailed no ships splintered by whales, no voyages into unknown waters, and no Melville. Electric light came next and last. And when the electricity grid crashes what do we do? We return to candles.

What were the alternative late-19th-century energy sources? Steam, gas, water, and wind. What did the rival grids look like? If history had worked out differently and electricity not been developed, could we still have modern appliances? Could one, for example, run an air conditioner compressor on steam power? The short answer: you could. A steam engine can compete with the power of an electric motor, at least up to a point. Generating steam is just like generating electricity; indeed electricity often starts out as steam. The steam pushes turbines which convert the steam energy into electrical energy. For the moment, though, let's pretend electricity doesn't exist. We're talking about the steam grid. Each month you get a steam bill. You have steam outlets in your walls, the steam equivalent of fuses, steam-driven telephones, steam circuit breakers. Occasionally steam-outs occur and then you get an apology from the steam Vice President.

How does steam transmission and distribution work out? Here you run into trouble. Steam can be sent through pipes, but it quickly cools, so it can't go far. Electricity can be sent hundreds of miles, steam only a few city blocks. Couldn't a small steam generator be stationed outside your window and all the other windows, and the power transmitted by clattering belts and pulleys to the air conditioner? Not only would such a shrimpy steam plant be inefficient, but picture all the moving parts of such a Rube Goldberg contraption, and the heat and the noise. Actually, that is exactly what many early mechanized factories *did* look like when motorized by steam or water power. Steam was tried. It had its chance. It worked until something better came along.

How about other 19th century energy sources? Gas jets? Gas is good for cooking and heating and was at one time widely used as the elixir of illumination. It had---and still has---an efficient grid of pipes under the streets. But it gives off unpleasant fumes and flames and heat, and so it wouldn't make for an efficient mode of lighting or air conditioning. Wind power? Wind, when it's up, might produce some cooling. Unfortunately, wind blows hot and cold. On a hilltop it's stiff, in the valley it's limp. How about the power of running water? This might activate the compressor and a fan, but you'd have to live next to a river for this to work.

No, for flexibility, density of power, ease in transmitting energy over long distances into tight corners, and with no leftover mess (at least not in your home), it's difficult to beat electricity as an all-purpose form of energy. Little wonder it's been so popular. All those fancy high-frequency electronic technologies---radio, computers, TV---are impossible without the grid.

These products come now in portable form, and at the end of the day, when you want to recharge the batteries, where did you go? You have to plug into the grid. A 1960s era appliance ad sums up this electrical ethos with words that still apply, now more than ever: "Busier living, easier living." Even if it occasionally leaves us stranded, we can't do without it. It's here to stay, as far as we know.

Anatomy of the Grid

The National Academy, through a poll of its members, determined that the electrical grid was the greatest engineering achievement of the 20th century. What, greater than all the other grids? What makes it so great? Certainly, several other grids rival electricity in pervasiveness: drinking water spreads through an expensive underground network of pipes; urban gas for heating and cooking flows through understreet mains right next to electricity; sewerage lines, constituting the lowest of the grids, ferries unmentionable fluid and particulate matter away from homes and businesses; the telephone grid, is draped overhead on poles, snakes up through conduits in the walls; and the railroad grid, operates both intra-city and inter-city, usually in plain sight.

Does the Academy's claim mean the electrical grid will be around forever? Nothing is forever. Many formerly successful grids are now obsolete. For instance, the network of canals, once a major mover of freight through the countryside in the early 19th century, was largely overtaken by the steel logic of railroads. Roman aqueducts, once vital, are now archeological. Incan roads, the Interstate highway of the mightiest north-south oriented empire in history, were put out of business by a few dozen marauding conquistadors. The network of feeding stations for post horses kept inter-city travel moving. But they're gone now since horse power isn't needed in an age of engines. Ice: frozen water doesn't sound like a grid, and yet there was a time when ice carts moved up and down crowded city streets. Not to chill drink: ice preserved foods for another day. But with the arrival of refrigerator freezers the iceman cometh no more. The list of vanished grids is long.

What all these grids---telephone, aqueduct, ice---have in common is a carefully crafted network of passages or conveyances, supplying an important substance, originating at specialized points of generation. For the power grid the substance is, of course, electricity, sent forth under the action of high voltage. The passageways are metal wires and the generation takes place often at a steam-turbine dynamo. The electrical grid is not in one place, but widely distributed. Its activity is scrupulously engineered: it is laid out but doesn't lie about. It is interconnected: customers get it all at the same time but by many different routes. It is patterned: its circuit diagram often registers with existing roadways. It is in the black: revenue must outweigh expenses. When it doesn't, shortages develop. It is *in loco-parentis*: like a parent it is accountable for the entire city, all its places and people, and all its activities. It has zone defense: networked redundancy helps out in emergency.

The electrical grid, made of metal, is not a living thing, but an impartial observer from Mars might suppose that it comes close to being alive. Like the human body, the grid possesses a sort of nervous system which both senses and actuates. The grid constantly samples its local environment (for example, it affirms that current is flowing through appropriate wires) and sends appropriate commands to outlying sectors. The grid has an equivalent to the endocrine system---electrical instead of chemical---in that it constantly executes fine adjustments of vital parameters (e.g., voltage or frequency levels) as they are needed to maintain proper hormonal balance. The grid has a counterpart immune system (consisting of, for example, protective circuit breakers and relief valves) for the self-healing of various disorders. It possesses a digestive mechanism for the consumption of energy and its transformation into useful work. It has an excretion process for offloading waste products such as smoke and spent cooling water. The grid has a skeletal network of supportive scaffolding (e.g., high-voltage towers). Perhaps the most obvious anatomy analogy between the living animal and the electrified grid is the crucial and centralized position of a heartlike dynamo propelling a circulating, energizing fluidity out and through and around a vast vascular web of arteries and capillaries.

The numerous organs and habits of mammals, optimized by the relentless forces of evolutionary biology, have been working together over a period of millions of years. By comparison, the subcomponents of the power grid, engineered by human ingenuity, have been around for a scant dozen decades. This is far less than the lifetime of a single Sequoia, so it's too early to make predictions about the longevity of the grid in cosmic terms.

A Prehistory of the Grid

We can, however, look at things over the briefer, historical, period. The history of the electrical grid, properly speaking, begins with Thomas Edison and his rivals in the 1870s, and indeed the bulk of this book will recount events from that era and its long, elaborate, and expensive aftermath right up to the present time.

The roots of the grid, its prehistory, stretch back thousands of years. The two physical forces at the heart of the matter, electricity and magnetism, were only crudely understood in ancient times. The Chinese get credit for inventing the compass, which is no more than a mounted magnetized needle aligning itself with Earth's magnetic field sprouting up from underground. The compass proved a good friend to navigation, but that was as far as things went. In China there was no electrical grid. Power for tilling the soil or grinding grain was supplied by bullock and human muscle.

On the opposite side of Eurasia the ancient Greeks played with magnetized rock but they too had no power grid. They possessed electrified materials. Amber, a form of fossilized tree resin (*elektron* was their word for amber), has the unusual property that if you rub it with fur, it will attract certain other materials. This electrical attractiveness was considered a gift of the gods, gods who would reveal at various times small aspects of their true nature through visible phenomena. These phenomena otherwise went unexplained. There were no power tools in ancient Greece. No refrigerators or radio. The only Greek grids prominent at the time were the network of trade routes for wine and olive oil.

It's not surprising that knowledge of electricity came slowly. For one thing electricity is invisible. In addition, if it is understood that electricity is a gift of the gods, something handed over by them, then how can an understanding be gained apart from divine worship? Only when electricity and magnetism were seen as independent aspects of nature---the Greek philosophers were instrumental in making this shift of thinking---could progress begin.

Therefore, right up into the 1700s electricity wasn't much more than an amusement. Clever practitioners built elaborate charging devices, such as the so-called Leyden jar, for accumulating large amounts of electricity which could be transferred, sometimes with a shocking effect, down a wire or onto any human subject willing to touch the electrified end. Indeed, electricity could be dispatched over considerable distance along materials known as conductors but not along other materials, known as insulators. Metal wires are very good conductors, human flesh and other watery materials are medium good, while ceramics are bad conductors, which is the same thing as saying they're good insulators.

Some of the first electrical engineers were part scientist, part vaudevillian. They wanted to learn and also to show off. How better to publicize the new electrical knowledge than with a demonstration before a live audience? A chain of volunteers, linked hand to hand, constituted a sufficiently conductive path to convey electricity. If the built-up charge on the device were large enough, a mild jolt, maybe even a spark, would result. This showed dramatically that electricity was not entirely a static thing. It didn't have to sit in place. It could move. Electricity consisted of the presence or movement of a mysterious substance called "charge." Charge could spread itself a mile if you had a metal wire that long. You couldn't see charge or weigh it, only detect its coming or going and feel its zing. It was like having the tartness of the lemon without the lemon. Eighteenth century Europeans did not build a grid any more than the Greeks had built a grid. But at least serious experimentation was going on.

More dramatic than any parlor trick was nature's own way of getting rid of an overabundance of charge in the sky through the agency of a sizzling charged stroke. The proof that lightning is a form of electricity has entered into common folklore through the famous experiment of Ben Franklin---lucky not to be killed in the process---who induced a passing thunderstorm to discharge its excess charge down to Earth through a conducting thread carried aloft by a kite. Long before he came to edit Thomas Jefferson's draft of the Declaration of Independence Franklin edited the electrical experiences of mid-18-century electricians, and he generally gets the credit for suggesting that there were not two types of electricity, attractive and repulsive, but only one, and for instituting the placement of lightning rods on buildings to ward off the capricious ravages of atmospheric charge.

What we know now, and Ben Franklin did not, is that electricity involves the flow of trillions of tiny particles. More than trillions: a typical 1960 air conditioner ran on a current of about 7 amperes. This turns out to be about 40 000 000 000 000 000 000 electrons coming by per second. This is an absurd number---small in comparison to the number of charges associated with lightning and yet large in relation to the pool of charge collected in those early electrical games. The ancient Greeks, by rubbing fur on glass, could isolate only small amounts of charge. Ben Franklin and his colleagues could separate far more charge with their hand-cranked machines. To make electricity really useful, though, you can't just move some charge from one place to another. You have to *keep* it moving. To turn motors, lift elevators, illuminate bulbs, toast bread, energize trains, electricity must move as a continuous current around circuits.

And for that we can thank Allesandro Volta who closed the circuit. Around the year 1800, he was experimenting with different arrangements of metal disks in contact with a container of chemicals, when he got charges to flow, and keep flowing, through a conducting wire. Volta had invented the first battery. Small in size, weak in energy, trivial in practical effect, Volta's setup wasn't exactly a grid either. Nevertheless, it counts as the first tryout for later grid development. You're going to hear of far larger machines for producing flowing electricity, but Volta's battery of 1800 was the first. You will read a lot about circuits extending hundreds of miles, from Ohio into Michigan over to Ontario and back south into New York, but Volta's tabletop loop including a simple wire hooked up to the ends of his battery was, in effect, the first circuit.

After these inaugural ventures came the first attempts to use electricity in industrial processes, such as the electroplating of tableware (in which charged atoms flowing through a liquid paint themselves onto fancy forks and spoons) and early efforts at electric arc lighting, where one creates a brilliant spark---a small tailored lightning bolt---jumping the gap between two carbonized poles. Chemical science was greatly helped by electricity which, acting like a key put into a lock, is able to unclasp one atom from another in certain otherwise-unbreakable compounds. In this way several new elements were identified. Still, this was no grid. Progress sometimes plods and sometime leaps, sometimes depends on the insight of a lone genius and sometimes on the collective effort of dozens.

Here are two specimens of lone genius. In 1820 in Denmark, Hans Christian Orsted noticed that an electrical current flowing through a wire creates, or *induces,* magnetic forces in the surrounding area. How did he know? Because the current caused a nearby compass needle to swing about. This was, at a single stroke, a great scientific discovery---electricity can cause magnetism---but also a great technological development---or soon would be. If you sent enough current through a coil of wire wrapped around a piece of iron, you could create a powerful magnet. The magnetism induced in the iron made it more powerful than any natural magnet. With a big electro-magnet you could lift hundreds of pounds, even thousands. Furthermore, by flicking the current in the coil on or off, you could make the magnet turn on or off. With a single switch you could lift or drop a thousand pound weight. In ways like this do puny humans gain extra leverage over their environment.

And the second great act? Oersted showed that electricity could create magnetism. Conversely, could magnetism create electricity? English physicist Michael Faraday expected that he could coax a current into flowing through a circuit if it were placed in the right way near a steady source of magnetism. He had a compass needle to indicate the presence of magnetic force, and he had a metering device, with a pointer, to indicate the presence of current in his coil. But the current didn't materialize. Then one day, as Faraday turned off his magnet, an electro-magnet, he noticed the pointer of his electrical meter flicker into life briefly. Was that a current that had flowed in the circuit, for an instant? A little transient occurrence observed out of the corner of his eye: maybe it was a mistake. Maybe it hadn't really happened. Many laboratory practitioners, impatient to get on with things, would have ignored the flicker. The prepared mind, however, might be more open to new things, might be in a better position to seize on serendipity. Faraday was about to have a Eureka moment.

He didn't ignore the flicker. He repeated it, changed it, drew out its meaning. Turning the magnet back on, the flicker at the meter came again, but in the opposite direction. In the annals of science and technology, here was to be one of the greatest acts of deduction and induction. Faraday, correctly, deduced that it was a *change* in magnetism, not a *steady* magnetism, that induced an electric current in a wire. This certainly wasn't what he'd been expecting, but what he had on his hands was a demonstrable form of magnetically-inspired electricity. By inventing a way to move the magnet past the circuit or the circuit past the magnet in a consistent way---usually in some kind of cranked, spinning motion---one could produce a regular current.

Some discoveries are singular, but not this one. On the other side of the Atlantic, in Albany, New York, Joseph Henry was making observations very similar to Faraday's. In fact, Henry seems to have glimpsed the flicker of induced electricity *before* Faraday, but tardily published his results *after* Faraday did. And so, by the contrived rules of scientific precedence, whenever the credit for magnetic induction is to be parcelled out to a single name, the Englishman generally gets the nod. Henry was disappointed, but he didn't want to be seen making a fuss over the matter and apparently accepted the judgement gracefully (ref 1.6).

Notwithstanding his failure to get a full share of the acclaim, Henry received more than a flicker of recognition in later life. He was a Princeton professor, a scientific advisor to President Abraham Lincoln, first head of the Smithsonian Institution and second head of the National Academy of Science. Last but not least on his honor roll of attainments is the palpable fact that the book you hold in your hands at this moment bears on its spine, in the form of the publisher's imprint, the name of Joseph Henry.

So, Faraday (and Henry) had brought something dramatically new into the electrical world: potent electricity was being made not through the chemical reactions in a battery but with a new kind of kind of machine, a dynamo, which converted a mechanical motion (a magnet mounted on a spindle revolving past a stationary coil, or vice versa) into electrical motion in a wire. There had been a practical limit to how big you could make a battery, but larger and larger dynamos (producing larger and larger currents) were a fathomable idea.

Early dynamos, alas, were inefficient, and Faraday's great insight did not overnight revolutionize electrical affairs. Batteries, however cumbersome, were deemed adequate for most applications. Indeed, electrical gadgets at first played only a minor role in the gathering industrial revolution. Steam engines and railroad technology predominated. Dynamos existed, wires carried current, and primitive electric motors were employed here and there, but still there was no grid.

This soon changed. As the 19th century wore on the electrical craft, starting with the telegraph and then telephone, soon became a full branch of engineering and a major facilitator of and influence on western culture. It is at that point that the main story kicks in with a look at the exertions of electrical pioneers like Thomas Edison and George Westinghouse. Here's what you can expect. Chapter two will recount Edison's creation of the first true grid, the Electric District Number One in lower Manhattan, and Westinghouse's exploitation of alternating-electricity's ability to travel long distances, allowing the streetcars of Buffalo to be powered by the Falls of Niagara using a grid stretching more that twenty miles in several directions. The adventures of these men, like the founding of Rome or the Pilgrim landing at Plymouth, are surrounded in legends which I shall attempt to untangle.

Chapter three carries the story forward several more decades. The locale shifts from New York to Chicago which, appropriate to its name of Second City, was forever trying to catch up to New York in all things. In the distribution of power, at least, it succeeded, becoming for a time the most electrified city in the world. Chicago, it turned out, was the place where many of the pivotal innovations that were to turn the grid into a major technology base made their debut---engineering innovations like the development of large turbine generators (and in this business bigger almost always meant more efficient) and marketing innovations like sending appliance-laden carts into residential neighborhoods: trade your flat irons, ladies, for an electrical iron. Diminish washday drudgery. Free hookup.

The Chicago grid was so successful that it started to overflow its banks and spill across county and state lines. This was the era when the electrical grid, then at about the 100-mile mark (Edison's first city grid had been about one mile across), was undergoing its most rapid growth. Overnight, it seemed, municipalities everywhere wanted their own grids. And to pay for a network of wires you needed a network of cash. Innovative forms of investment had to be contrived, such as the open-ended mortgage. Outdoing even the great railroad expansion of 50 years before, the vast and sudden expansion in the grid business, a boom that continued for decades, obliged the electric utilities to borrow money on a perpetual basis and on an unprecedented scale for a non-war-related enterprise. Loans on top of loans. In a sense the grid of 1900 is still being paid for today. Building the grid is one of the great themes of this book. Paying for the grid is another theme.

A third theme will be the grid's impact on society. In the first two decades of the grid, its chief purpose was to deliver soft lighting to dark places. In the following decades, however, the impact broadened. Electricity turned motors, pulled trains, heated flat irons, and powered machines not even dreamt of so many years before---radio, television, computers. Chapter three looks at this early electrical culture and how the grid and its customers came to be locked in their tight embrace. These years saw the advent of massed, assemblyline production of merchandise and the corresponding increase in advertisement-driven mass consumption. The purchase and use of these products is by now so universal that the influence of the grid is practically invisible.

Chapter four will show what happened when electricity finally vanquished its rivals. Consolidation and expansion are the words that characterize electricity in what I shall call the grid's imperial phase. In Chicago, the central utility came to control a regional web of energy and transportation companies. In New York, Consolidated Edison, growing from a wide collection of electricity, gas, and steam interests, formed crucial alliances with utilities to the north, especially with Niagara, a sort of National Park for Volts, where hydro power is appropriated from nearly the whole of the Great Lakes drainage. In Soviet Russia in 1920, electrification was seen as a means of building a new nation and cementing the Bolshevik Revolution. In Britain in 1928, unifying the power industry was seen as the road to economic revitalization. And in the Tennessee Valley in 1933, an immense federal building and planning initiative was about to bring electricity to people who had never had it before.

Reinventing the Grid

Most books about electricity or the grid, at least those not aimed at experts or children, stop with Edison and Westinghouse or, if they go further down the road, wrap up just about the time electricity had colonized middle-class homes in the 1920s. What a pity, since this is just when electric power went from being a luxury or a curiosity to being a way of life. It was to entwine itself into daily routines the way ivy invades a garden. Electrical appliances were on sale everywhere. Maintaining electricity became as important as maintaining access to oil; both were needed for industrial and even military security, and therefore a matter of the highest national importance.

By the 1960s electricity was in place all around the globe, with the conspicuous exception of many millions living in poor or rural regions. Many city dwellers had the grid or knew someone who had it. The demand for electricity seemed always to be growing. New records for power consumption were being set and many utilities were in the habit of operating with less margin for error. Supplying sufficient power at peak hours was getting to be a challenge. If you were a fatalist you would say that something was bound to go wrong in a big way. As the largest and most complicated machine ever built, the electrical grid was as ambitious as the Tower of Babel, and so it should not be surprising that the gods would be resentful and send many bedevilments.

Indeed, the gods struck back particularly hard on November 9, 1965, probably the worst day in the history of the grid, an event that takes up the whole of chapters five and six. If there ever was an event where a small perturbation in a side corner of the system was to snowball into immense consequences---the equivalent of that fatal grain of sand triggering a massive avalanche in a sandpile---this was it. In the space of only 12 minutes, most of the mighty Canadian-Northeast U.S. Interconnection, a sort of NATO alliance of utilities designed to help each other in time of need, all went down together.

Chapter seven considers the consequences of that event across the whole of the 1970s, 80s, and 90s. The 1970s will be remembered as a time of rapidly rising energy prices---a direct result of Middle East politics and the growing power of oil producing nations---and for the quickening concern over the environmental impact of energy use. Consumers wanted it both ways---cheap, abundant electricity but not the radioactive waste (in the case of reactors) or the polluting fumes (in the case of coal-fired plants) that come along with it. Using energy wisely was a popular refrain. Rebates were offered for the use of efficient machines running on less electricity than before.

In the 1980's, in keeping with the movement toward a more conservative, market-based culture, the grid came to be seen more and more as a commodities exchange. Electrical power was a service, yes, but also as a substance that could be sold to the highest bidder. The issue of whether utilities should be privately or publicly owned had never really gone away, but now took a new turn. The banking, telephone, and airline industries had all been the subject of wide-ranging de-regulation and now it was the turn of electricity.

Indeed, the 1990s developed into a replay of the go-go 1890s: every day a new product, a new company, a new slogan. Buccaneering "merchant generators" sprang up. These independent producers of electricity were permitted by law to pour power into grid. The physical fabric of the grid, its wires and transformers, might have been built by a private utility, but others were entitled to use it like an easement. Energy traders, companies that neither made nor distributed electricity, grew in importance. In some cases this new structuring in the business of volts resulted in lower rates, in some cases higher rates. But always the trend was to larger and larger grids and a greater need to be "competitive," and this often meant pushing equipment to its maximum capacity. This predatory-capitalism phase of grid history is epitomized by the bankruptcy of the Enron corporation and the California grid crisis of 2001.

The crusade to stay ahead of the consumption curve in three different and specific ways, will be the subject of chapter eight. First, we will make an inspection call on Big Allis, at one time the largest steam-electric generator in the world. Allis, built for Con Edison and on duty just in time to witness---and play a leading role in---the great blackout of 1965, is still on duty and being adapted to changing business and technological conditions as they come along. The second site visit takes us to home so energy-efficient, one featuring power-sipping appliances and solar cells on the roof, that it practically free of the grid; on some days it even sends power *into* the grid instead of taking it out.

Everyone likes the idea of renewable energy, and there will always be new ways to squeeze more efficiency out of our electrical environment, but will that be enough? For all the new consumers being born at this moment, in developed countries and especially in under-developed countries (where the largest increases in usage will occur), *lots* more electricity will be needed. Because of this perceived need, many energy planners are pondering a return---some with dread resignation, some with enthusiasm---to the nuclear option. Our third inspection tour takes us to a reactor facility, where we will examine the advantages---cheap fuel, no atmospheric pollution--- and disadvantages---safety issues, terrorism issues, and prodigious construction costs. Nuclear power is the wolf at the door: we don't want to let him in, and he won't go away.

Would even nuclear power be enough? When the local population increases, whether by native birthrate or by immigration, traffic of all kinds---vehicles, electricity, water, food, theater attendance, national park visits---is going to increase. The US population has almost doubled in the last half century, and all these extra people have to live someplace. People need food to eat, modes of transport, and electrical outlets to plug into. It’s easy to question unrestrained expansion dictating ever wider highways and larger transmission cables. However, it’s difficult to triangulate a solution that will sustainably supply energy to all the new citizens of the Earth. All the interested parties---government, citizens, utility companies, other businesses---have to work together to find a solution, and not just one solution but a rolling solution to the evolving interplay of burgeoning population, standards of living, and available resources.

How does electricity work in *your* home? Chapter nine looks in detail at how a particular representative utility company, Idaho Power, serves up electricity to a half million customers. Like all the other energy companies described in this book this utility has to worry about limited resources, growing population, environmental concerns, and making a profit. Our Idaho inspection includes roving around a representative home, seeing where electricity goes and how its used. Next we go backwards into the grid in order to see where electricity comes from. We'll see a transmission line repaired, visit a hydroelectric plant, talk to the lady who insures that all the electricity that gets made goes to where its needed, at very instant of the day. We finish this day-in-the-life saga of the grid in the office of the corporate vice president whose responsibility is to look into the future and formulate a ten-year plan.

Perspective on the Grid

The difficult and fascinating thing about history is that you never precisely know where things are going next. As the philosopher/theologian Soren Kierkegaard once said, life is understood backwards but lived forwards (ref 1.7). The grid history about to be unrolled before you will attempt to capture some of that feeling of contingency. The narrative will portray both the uncertainty of the moment---life lived forwards, as if the historical event we see happening *now*---and the hindsight we acquire with experience---life understood backwards.

The final chapter will look at the effort to bring electricity to the billion people who don't have it now and to anticipate the arrival of billions more who will be born in coming decades. The prospects for this vast undertaking will explored through a comparison of the grid in several places---Uganda, Ohio, India, and China. Take India, for example. If the history of the grid were a movie, then India's part in the presentation would be a double feature, with showings on two screens. On one screen we would see the future: millions of people who never had electricity would be getting it or about to get it. Meanwhile, the other screen would feature the past because millions more do not have the grid and are not going to get it soon. And even for many who have it, the grid is, in an electrical sense, abreast of where Europe or North America were in the year 1925. For Uganda, the grid movie would be even older---maybe 1900. In China, by contrast, the grid-history movie would have to be played at extra high speed. Amid China's supercharged economy, ten years of grid development are now being crammed into one.

Having swept through the electrical network of India and China, this book will end with a further broadening of perspective as we ponder how electricity can expand beyond its current boundaries. No, this doesn't mean some science fiction fantasizing about the future. Far from it. Since life is only understood backwards, this whirlwind history of the grid will, at the last moment, actually move backward. The book will finish with the year 1969, a year of notable electrical developments, especially the projection of the grid (in a manner of speaking) onto the surface of another world---courtesy of Apollo 11's trip to the Moon.

For now, in order to begin the proper narrative flow, please consider that the year is 1878. It is said that on a particular day in 1878 Thomas Edison has a clarifying vision in which he determines that electricity can be made to carry energy not just for lighting but also for heating and for performing work, and it can do so economically (ref 1.8). Edison will not merely invent devices---a phonograph here, a bulb there---but the very *system* which nourishes them, a root system for appliances. The grid will not be just the wires but the thought, the will, the financing, the network plan, the motivation behind the wires. In a mere two years, at his headquarters in Menlo Park, New Jersey, the greatest lab dedicated to invention yet seen, Edison has invented a practical light bulb and is quickly inventing all the other devices needed to feed energy into city-wide network of bulbs. He is ready to build the first grid.

For us the grid has been around for more than a century, but for Edison it is new. He has to bring it into existence. Indeed, it exists only in his head, and on greasy blueprints, and in the form of some wires slung out front. Edison is about to do what Ben Franklin could not do. He's about to put lightning into a bottle and sell it. Electricity will be available as if it were water pouring from a tap. Because of him electricity is about to burst forth in the city. It is the morning of the grid.

September 20, 2005

Chapter Two

Grid Genesis

It was the morning of the grid, one o’clock in the morning, in fact. That hour was all that her busy schedule would allow. He was said to be the most famous man in America and she the most famous woman in France. He was dedicated, efficient, indefatigable, ingenious, while she was, to distill the litany of superlatives down to the most often used word, simply "divine." On a chill autumnal night in 1880, after her final Broadway performance, Sarah Bernhardt crossed the Hudson River for a midnight rendezvous with Thomas Edison. If she was an enchantress, he was a wizard, and for her arrival at the lab he set out to dazzle her with the best electricity at his disposal. The first thing she would see would be his forest of lamps against the darkness.

He spoke no French, she no English, so all that was said between them necessarily passed through an assistant present to perform instantaneous translation. Another assistant was dedicated to preventing her layered skirts from being entangled in the apparatus as the couple swept from room to room. At certain moments they even held hands. For him, she was the most extraordinary woman he had ever met. For her, his sagacity made him look irresistibly like Napoleon. His expression had been imperial, confident and skeptical. She had come determined to conquer him and had succeeded.

Before leaving, the Divine Sarah recorded some lines from *Phedre* into Edison's famous phonograph, all of three years old, achieving what the 17th-century French playwright Jean Racine would never have expected---his immortal lines turned into immortal sounds by the inscribing of shallow grooves on a foil cylinder. Joyfully reciprocating, Edison sang a few stanzas of "Yankee Doodle Dandy," making Mademoiselle laugh. Everything about the evening had been incandescent (ref 2.1).

A few weeks later, in the same rooms, Edison was to host a much more consequential visitation, one which would properly launch the electrical power business in America.

Seeing the Light

Thomas Edison is of course indispensable to any account of electricity. He is Moses, the lawgiver of grids. He not only brought the first big city grid into existence but practically invented the concept of gridness, and he did it through (to use his formula) 10% inspiration and 90% perspiration. Behind this simple equation lies decades of 18-hour work days, long nights of laboratory searching for technical solutions to resistant technical problems, tedious expeditions among skeptical bankers for backing money.

Edison's inventing life had been bound up with electrical products: an improved form of telegraph, allowing four separate signals to pass on the lines; an attempt to invent a "speaking telegraph," or telephone; the invention of the phonograph. But until 1878 he hadn't been especially interested in electricity for illumination or the generation of electricity itself. On September 8 his attitude changed. Many were the visits that others made to Edison's lab, but on this day Edison was the visitor to someone else's lab, that belonging to William Wallace, a manufacturer in Connecticut. What Edison saw, brilliant arc lights powered by a noisy dynamo, set his mind racing. In the arc process, a charged current is made to leap across a gap from one electrode to another, tracing out a miniature lightning bolt. In this violent act a metamorphosis takes place: a supply of energy from the dynamo flows to the electrode in one form, as electricity, and is transmogrified. Released from the chrysalis of its wire, the energy becomes a fierce whiteness which hurries away at the speed of light. It *is* light, and it can do nothing but escape in all directions until it splashes up against a wall or the retina of an appreciative onlooker.

On September 8 Edison saw the light. What happened in his retina was only the first in a chain of stimulations, however. Inside Edison's head the pulse of light was converted into a neurological flash and this, in the marvelous reconfiguring we call inspiration, became a network of mental constructs, a vision of what would later become the electrical grid.

On that September day, standing in front of the arclight display, it came to Edison that he could do it better, cheaper, bigger (ref 2.2). He would invent not merely a better lamp, he would invent a system. The lamp existed in order to be plugged into the system. The system would supply the lamp, and other devices too, with energy. The lamps would be mass produced, would come in many forms, and would carry out many tasks. The system of energy and lamp and fixture would be served by a centralized power source and a branching distribution grid. That would be just the start. The same wires would bring energy to other machines, would deliver heating and information. This grandiose scheme was conceived by, and could only be implemented by, one man, Thomas Alva Edison. And this was not the silver-haired septuagenarian of later years. At this point Edison was 31, a man in the pink of health.

The work at Menlo Park, Edison's invention factory hideaway in the Arcadian New Jersey countryside would now be devoted to embodying the mental constructions in a grid made of copper wire. That grid, which today stretches around the world, started small as the experimental tinkering of master mechanics struggling over a workbench. At Edison's lab and at those of his competitors in the US and in Europe (Edison did not have a monopoly on brilliant electrical inspiration) implementation was slow. The time for a 1000-mile transmission lines would come decades later. Now the issue turned on finding the right recipe for a half-inch-long bulb filament that would take the heat and render an effusion of light for months (ref 2.3). He had to ponder the effective formula for an insulator wrap that would protectively sheathe cables destined to lie in the damp earth for years, maybe even tens of years.

The Volts of New York

Edison research unfolded in New Jersey, but the Edison grid was to be deployed in New York City. This is where the potential customers lived and where the financial investors had their affairs. And just as athletes of today often prefer to play ball amid the publicity glitz that accrues from a big city media market, so Edison desired the notoriety that would flow from an engineering success carried out audaciously in the heart of the business capital of America.

What happened on the evening of 20 December 1880 was a prelude to the grid. After dark on that night, up and down a considerable stretch of Broadway, it so happened that gentlemen were able to read newspapers on the sidewalks. It was that bright. What had happened was the startling debut of the first official outdoor electrical lighting in New York City on a large scale. In arc lamps far overhead, impressive currents made their reckless jump from one electrode to another, powered by a dedicated wire. It was a wonder to behold, these bolts of light, safely out of the way on their poles, casting a brilliant pool of light on the ground below (ref 2.4).

This was the high technology of the day, but it was not Edison's handiwork. Charles Brush, inventor extraordinaire and astute businessman, had carried the arclight enterprise to a state of readiness and efficiency over years of trial-and-error toil. He was starting to move ahead of his rivals and had orders from numerous cities for his system of arcs, which would be energized by powerful central generators. Seemingly, urban activity in many places would be extended and improved by the well-placed presence of these tiny, vested lightning bolts.

And yet this day did not belong to Brush, but to another. At the very moment of its inauguration, the arclight grid was being challenged by activity elsewhere. The same evening as Charles Brush's triumph, across the river something more important was happening. The Mayor of New York himself had, at the last minute, regretfully declined the invitation, but on that night a sizeable contingent of city aldermen, accompanied by numerous gentlemen of the press, shipped over the Hudson to see for themselves the marvelous gadgets and to hear for themselves how the Wizard of Menlo Park planned to electrify their city.

The city fathers probably didn't need much convincing, but they did want to extract from Edison a fee for gaining permission to tear up the streets of lower Manhattan for installing underground cables, and it was Edison's job to avoid paying that fee. He did this by impressing the pants off them. After leading the men around the labs (no skirts, this time, to keep out of the apparatus) Edison guided them to a window, where, with the lifting of a lever, he lit his arbor of outdoor lights, producing as it had with mademoiselle Bernhardt a ripple of delight and amazement in the onlookers. This was but a junior version of what he had in mind for their city. The Menlo Park network was only a toy grid. Then, with his audience gawking at the splendid indoor grid of incandescent light, he reversed the lever, dowsing the whole effect. This stunt drew from the veteran politicians an involuntary round of applause. Aye, Edison could turn off the whole system, but could he turn it back up on command? He could and did.

The first half of the evening was devoted to recounting the scheme for delivering electricity under the streets and into homes, shops, and street lamps. Edison had even tested an early version of an electric train. He had ambitious plans for the city and hoped that he could proceed. Thomas Edison was world famous because of his great inventions of the phonograph and of the efficient mass-producible light bulb, but an even greater invention would be the installation, maintenance, and growth of a system, a centralized system, of domestic electricity in the city. First hundreds, then thousands, then millions in the city, and later other cities, would benefit. Those lucky to be alive at this time and those in states unborn and speaking with accents yet unknown were to live in an electrified time because of this extraordinary scheme. Surely the gentlemen would want to share in this historic undertaking.

The aldermen, interested and impressed but perhaps fatigued by the exhaustive reports, were next led to a dimly lit hall. Then came the theatrical coup: with the application of yet another lever, the room was flooded with lights from every side, revealing a sumptuous feast, catered by the popular New York restaurant Delmonico's. The evening finished up with champagne, Cuban cigars, and effusive toasts to Edison's genius. (Picture something like the banquet scene from *Citizen Kane*, but without the dancing girls.) The men who ran New York had come to the lair of the Wizard expecting to be amazed and were. As one of the newspapers summed up the aldermanic evening, "They came, they saw, they marveled." Edison got his permit to dig.

Pearl Street

The mountain had come to Mohammed. The powerful New Yorkers had crossed the waters and come to New Jersey, and now the Wizard would return the favor. He moved his troops and all their equipment to the heart of Manhattan to be near the action. Supreme allied headquarters for the Edison Electric Illuminating Company of New York was a fancy building on Fifth Avenue just south of 14th Street. Other shops and factories for support operations opened up all over town. It was here where the matériel of the grid would come into being, circuit breakers, bulbs, fixtures, conduits, and above all wiring. But the venue of interest to us now, and arguably the most famous address in the annals of the electrical grid, would be 257 Pearl Street, in the Wall Street area just below the foot of the about-to-be-completed Brooklyn Bridge. It was from here that electricity would soon be dispensed to customers over a square-mile zone and, in a larger sense, to people all over the world.

The great bridge linking the cities of New York and Brooklyn (the boroughs hadn't yet been amalgamated into the even larger metropolis we know today) is justly exalted as an engineering feat. The Brooklyn Bridge stood by itself, a one-of-a-kind masterpiece. By comparison, the grid going up (or rather down since it was mostly underground) in the bridge's shadow was to be repeated in every big city in the world in pretty much the same form. The Brooklyn Bridge would change the flow of people and goods in New York City and its environs in a big way, but the warren of wires being sunk in the dirt would change the city even more.

It would be well to say what the Pearl Street operation was *not*. It would not be the first time a building had been lit inside entirely by electricity; Edison's own headquarters on 65 5th Avenue held that claim. Nor was this the first time Edison had served up electricity to customers; several isolated generators of his were functioning in the homes of New York's wealthiest, including Edison's chief financial backer, J. Pierpont Morgan. Being a sovereign nation when it comes to electricity---having a powerplant in your backyard, that is---sounds desirable. In practice, however, it was a headache. The generator often failed to perform. When it did work it put out fumes and noise, causing the neighbors to complain. Also the wiring in those early days left much to be desired. The result was often singed carpeting and browned furniture. Although Mr. Morgan expected the electrical problems in his home to be put right, he was apparently patient with the repairs, and was reportedly fascinated to be part of a historic experiment in the domestic use of electricity.

The Pearl Street operation would not be the first time the streets of New York were illuminated by electricity; those arc lamps, ushered in on the night of the Edison banquet, had served admirably in splashing buckets of light up and down Broadway. It was not even the first time power had been supplied to multiple customers from a centralized station; after all, Edison had lit up part of Menlo Park as a sort of welcome mat for those like Miss Bernhardt or the New York aldermen or the many who had bought train tickets merely so that could gawk at the Edison compound at night lit up like a Christmas tree as they rode past (ref 2.5).

Then too, in January 1882 Edison had set up a station in London and sent electricity to many establishments along the Holborn Viaduct with wires strung along overhead. London gas operators, fearing electrical competition, had prevented Edison from burying his cables. Like normally competing large mammals coming together in nervous proximity at an African watering hole, there was to be much baring of incisors over the right to illuminate streets and buildings. Rivalry between gas and electric interests was to be a notable part of the energy business for decades to come.

What the Pearl Street system *did* represent was the beginning of large scale, centralized city electrical delivery to a diverse clientele for what would soon be a variety of uses. This was no longer an experiment conducted in dark laboratories but the beginning of regular service. Your electricity would be there in the morning and the evening. It would not come from a battery, nor a laboring generator unit in your basement. Instead current came to you unseen from some other place, a dynamo blocks away, then miles away, and later still hundreds of miles away. The Edison system would make electricity more intimate by separating you from the source. Just as water from a handy tap had become routine, so too electricity would seem to become just another everyday flowing fluid.

True, this nonchalant familiarity bred of long usage would, at times, complicate the relationship between human and volt. Electricity was not just a product off the shelf, but a dynamical process, a potentially dangerous substance if touched, a normally explosive form of lightning-like energy tamed and constrained to a wire, a continuous enabler of activity, a *presence* in everyone's life. Unless you're on a mountaintop or a forested footpath you are probably, at this moment, within a few meters of something electrical.

The Edison enterprise in New Jersey had started as an invention sanctuary, a retreat for a monastic order of creative tinkerers. Now the plans called for a more vigorous proselytizing mode of action. Like the Jesuits, the Edison men, trained in secret and inculcated in the electric catechism, were called upon to journey out into the world, first to New York and then farther afield, earnestly to spread their gospel of electricity. Their first parish would be the New York Electric District Number One. Others would follow. Some of Edison's most trusted lieutenants were dispatched abroad as missionaries to London, Paris, and Milan. Berlin wanted to build its own Pearl Street and asked for Edison’s very blueprints (ref 2.6).

Edison always was a busy man, but now his schedule became frantic. For the greatest inventor in US history, his output of patents would peak in these years of grid construction (ref 2.7). He was an inventor but now perforce he was also a manufacturer, a mass producer who extruded wire by the mile and assembled massive machines that combined and controlled all the fiercest manmade energetics then known: fire (in coal fed boilers), steam (for driving pistons), and electricity (cranked out by the best dynamos in the world). Edison was the vicar of volts and necessarily had to delegate tasks to associates to free up more of his own time for further creative efforts. In this respect he was often fortunate in his choice of deputies.

One of these new men brought in was Samuel Insull. Only 21 years old when he entered service, Insull rapidly won Edison's trust and that was sufficient. Insull did everything: he monitored Edison's schedule, bought Edison's clothes for him, opened his letters, and answered much of his correspondence. Insull had power of attorney and wrote many of Edison's checks. Scarcely the age when a man would be graduating from college, Insull was overseeing an immense fabrication conglomerate, arranging loans from bankers, and going on inspection tours with his boss to lathe works at three o'clock in the morning.

What was Edison up to? He audaciously hoped to transform the way people used energy at home and in the factory. Electricity was the energy elixir that could do what all the others---steam, gas, water---could not do. He wanted to bring his remarkable invention---centralized electrification---to all of America and the world. For this commercial Reformation to take place it had to work first in New York. And so far, he was behind schedule and over budget. The financial backers had long been patient but were now eager to get things going. Where was the revolution Edison had promised? When would the currents flow at 257 Pearl Street?

Dividing the Light

On September 4, 1882 Thomas Edison had a full day ahead of him. He took off his coat and collar but kept on his white derby hat. The testing was over, the machines were installed, the wires laid, and now it was time to energize the system with the throw of a switch. Edison, beginning the day with his men in the field, was in his shirtsleeves making a final check of the cables. He relished the attention he got from journalists and appearing at street level helped burnish his folksy image. It was not all sham, though, since Edison did seem genuinely to like being where the hard work was. That's what had brought him into the ditches by the side of the road with the Irish laborers on the morning of the big day.

The grid had been tried out section by section and not without problems. Approval from the fire underwriters had been slow in coming, and for good reason. At one street corner, for instance, faulty insulation had allowed some of the current to come to the surface, giving passing horses a nasty little jolt whenever they trod in a particular puddle of water. Yes, there had been problems. Edison’s system competed with an existing overhead welter of wires perpetrated by numerous smallscale voltage vendors for delivering telegraph messages, burglar alarms, fire calls and telegraph signals. These wires were vulnerable to wind, frost, vandalism, and jostling. Copper had been mined from the Earth, drawn into wires, and now Edison was putting it back into the ground, where it was safer. It was expensive to do this, but Edison's grid, unlike the competitors’ networks, would survive well into the next century.

The business end of the enterprise consisted of a mechanized work gang of six huge steam-generator sets, each capable of furnishing juice for 1200 lamps, making them the new world heavyweight champs among dynamos. These behemoths, about the size of a reclining elephant, known as "Jumbos," after the famous elephant in P.T. Barnum's Circus, could be used singly or hooked up in series, trunk to tail, producing a powerful Elephants-on-Parade effect. Very soon, in fact, they would be performing in the Paris Opera House.

Jumbo wasn’t just a contraption. It contained the world’s largest electromagnet. The purpose of all that magnetism was, of course, to induce powerful currents of electricity, immensely larger than Faraday had ever conjured in his lab, to be dispatched to waiting customers. But magnetism might have other uses too. One of Edison’s chief associates, interested in the possible psychological effects of magnetism on the brain, contrived the following experiment. One of the generators had been undergoing tests and just then was partly disassembled. So, on the eve of the Pearl Street commencement, with the current-producing coils removed but the electromagnet fully activated, the man lodged a mattress between the north and south poles, and spent the night there, submitting his head and body to the potent magnetic forces. Apparently the exposure had little effect (ref 2.8).

Edison, normally quite free with the press, had suddenly gotten shy. He declined to speak this day with reporters until the deed had been done. Only then, he said, when scoffers had been silenced, would he give his opinion of the significant events about to take place. With everything in place, Edison put back on his fancy duds and went over to the offices of J.P. Morgan, the man who had put up a lot of the money for the venture. This had also bought him a say in the matters now unfolding. So far he had been patient with Edison, but the time for gritted teeth was fast approaching. So far, and for too long, the investment had been all out-flow and no in-come. Nevertheless, there was merriment in the room but also solemn concern since a half million dollars had been spent up to this moment and not a morsel of dividend had come back to the investors, some of whom were at Edison's elbow now waiting to see the advertised wizardry.

If the unseen gods of electricity were hovering in the air overhead overseeing the events of this auspicious day, then Edison was the Odysseus of volts---clever, resourceful, brave, and loved by the gods. Edison had done all he could---invented the devices, tested the ideas, hired the engineers, worked prodigious hours, organized efficient means of manufacture, had wrested municipal approval from skeptical politicians, and accomplished the installation. He had built a city within the city, a web of hidden wires, and it was now desirable for it to work as a system as advertised so often by Edison in frequent newspaper interviews. The time had come to throw the switch in Morgan's office. Everyone in the room, especially those who had backed the scheme, needed the electricity to arrive at the designated lamp sockets. Would the electricity flow as promised and would profits flow shortly thereafter?

The answer to the first was a resounding yes, while the answer to the second would be...not for several years. At 3 PM, Edison melodramatically threw the lever, and the bulbs in Morgan's suite successfully energized (ref 2.9). The gods had smiled. Over on Pearl Street, an instant before the climactic moment, the sturdy copper circuits had faithfully borne power to four hundred lamps scattered around Distribution District 1, a region bounded by Pearl, Nassau, Spruce, and Wall Streets. Jumbo Number Nine, performing solo that day, rendered blazing light by converting the rotary motion of a shaft set spinning by a steam engine, which in turn employed the chemical energy stored in a few tons of coal compressed hundreds of millions of years before in the Carboniferous Period from beds of decaying green plants which in life had been sustained by the photosynthesis process powered by ambient daylight sent hither from the photosphere of the sun.

Now that the grid revolution was launched, what did it look like? Probably not like a revolution. Remember, gas lighting had been around for decades and had no intention of surrendering. As for electric illumination, arc lights had been up for almost two years, allowing New Yorkers to walk at night easily up and down the larger avenues. People weren't going to be amazed any more by the sheer presence of massed brightness. It turned out, however, that even those jaded by light were impressed by Edison's lamps, by the mellow glow, especially after darkness had started to close in. You could argue that Edison's filaments weren't as brilliant as the arcs, but *that* was the point. Edison had brought electric light indoors, into shops and parlors. When you sat down to read you didn't want a miniature sun.

In one practical sense, it had been harder to supply low and steady light in a small glass enclosure than it had been to produce an arc, which was, after all, a stunted portion of bottled lightning allowed to come out of its bottle. Arc lights were so big, so powerful, that they were often mounted on immense poles a hundred feet above the sidewalks. Edison changed this. His name comes first on the list of illumination all-stars because he had usefully *divided* the light, had brought the fireball down from its tower, tamed it, packaged it, domesticated it. When you went to bed, perchance the last thing you did before dreaming was to switch off an incandescent bulb. Edison and his grid were there in the dark at the ready.

The electricity revolution was still in its early stage, the Battle of Concord phase. The shot had been heard round the world. New Yorkers, if they had enough money, could have an electric current from a central supply diverted into their homes or offices. Edison had brought electricity indoors, where the chief competition was not going to be arclight but gaslight. This battle of combustion versus incandescence would be fought for years, even decades. It took this long because electricity was then and for years to come just too expensive. The grid was definitely for first-class customers only.

On the first day Edison's wiring had threaded its way through 400 lamps. A month later this had doubled, and two months after that it tripled further. That's where the electricity went: lamps. There weren't yet many other uses. You contracted for lamps. When a bulb blew out, a man with his tools came to your house and replaced the bad bulb with a good one. The electricity itself was free. This introductory honeymoon period would not last for long. On January 18, 1883, the Ansonia Brass and Copper Company got the first bill, for fifty dollars and forty cents (ref 2.10).

The lamps were made to be uniform, but some were more equal than others, such as those in Mr. Morgan's office. More important still, from the standpoint of spreading the word about bulbs and augmenting the Edison legend, were the lamps plugged in at the New York Times Building, which was then not in Times Square but downtown in District 1. In fact, among first-year customers, the Times had the biggest share of lamps, 300. The smallest customer, the National Fire Insurance Company, subscribed for only 3 bulbs (ref 2.11).

The Times reporter, like many others, appreciated the warm even glow of the filament bulbs in contrast to the glare of the high-power arcs. In his report in the paper the day after the big switch-on, the writer goes on to describe both the ethos of the journalist's craft and the sheer curiosity felt by anyone then alive at seeing the light of day extended into the hours normally reserved by nature for darkness:

> *The electrical lamps in The Times Building were as thoroughly tested last evening as any light could be tested in a single evening, and tested by men who have battered their eyes sufficiently by years of night work to know the good and bad points of a lamp, and the decision was definitely in favor of the Edison electric lamp, as against gas. One night is a brief period in which to judge the merits or demerits of a new system of lighting, but as far as it had been tested in The Times office the Edison electric light has proved in every way satisfactory. When the composing rooms, the press rooms, and the other parts of The Times Building are provided with these lamps there will be from 300 to 400 of them in operation in the building, enough to make every corner of it as bright as day (ref 2.12).*

New York was Edison's headquarters, but his business ventures were global. The same year as Pearl Street, Edison light systems illuminated a theater in Santiago, Chile; a railway station in Strasbourg; the ship SS Columbia (Edison's first commercial electrification job); a woolen mill in Orange County, New York; a post office in Budapest; a piano factory in Fall River, Massachusetts; the Grand Foyer of the La Scala Opera House in Milan (where the Edison power plant was the largest in Europe); the Wilhelmstrasse in Berlin; a café in Havana, and the Czar's coronation in Moscow (ref 2.13). Everywhere Edison went there would be competition, but for a magic moment he had a jump on his rivals. He was on the top of the world.

Back in New York, the grid was already falling behind. The first order of business for any grid is supplying power as it is needed. At night, people naturally use more light and the System Operator (whose 1882 routing board was much simpler than the 1961 version) had learned how to match the increased need for electricity by having the men shovel coal faster into the big boilers in order to feed more steam into the generators. At first it was easy: increased darkness called for more light, which called for more electricity, which called for more coal. This art of anticipating electrical load became so well tuned that even the falling darkness from a mid-afternoon thunderstorm, as relayed down to the boiler room by a boy stationed on the roof to keep watch of western skies, could be countered neatly by a calibrated extra shovelfull of coal stoked into the voracious furnace.

Over the longer haul, providing enough power for additional users became harder. As the number of customers grew you could add an extra Jumbo to the generator lineup. Beyond that, however, you would need a whole new power station, and this took time to build. In fact, it came to pass that the Pearl Street system was oversubscribed. Additional "applications" for lamps were being turned down until such time as spare current became available. The company would, if you liked, put down your name on a waiting list (ref 2.14).

For being the first grid, the Pearl Street network basically worked well without interruptions for seven years. New York's first blackout occurred on 2 January 1890 when a fire broke out in the nation's first central powerhouse, possibly because of overheating in some upstairs insulation (ref 2.15). The Pearl Street building was gutted, and the only salvageable piece of equipment was the stalwart Jumbo Unit Number Nine, the star performer back on opening day. The company was chagrined, of course, and messengers were sent to customers informing them of the problem, asking for their patience, and assuring them that service would resume quickly (ref 2.16). Power from an alternative plant (already Edison was colonizing other parts of the city) would soon arrive and Pearl Street itself would quickly be back in operation. In the meantime, could the customers please refrain from using unnecessary lamps?   So, besides being New York’s first blackout, this occasion had brought forth the first electrical energy conservation campaign.

Imaginary Grid in Budapest

The first large centralized grids were conceived, organized, and undertaken by Thomas

Edison, but something as big as electrification---the utilization of power from wires for performing a hundred different chores---is beyond the genius of any individual, even someone with the driving energy and talent of Edison.

It is true too that the resources of no one city or nation or era would be sufficient to bring an invention as big as the grid to full fruition. The 19th century had already brought forth steam power for mills and railroads, the working of steel into the shapes needed for bridges and tall buildings, the electrical marvels of telegraph (binary information by wire) and telephone (voice by wire), and a vast improvement in the knowledge and application of medicine and chemicals. Now in the 1880s the grid itself (energy by wire) was being born and so great was its potentiality that it would attract some dozens of the shrewdest engineering minds.

The immediate next phase of the story will, however, revolve around only a small number of these inspired inventors. In a fairer world, electrical expertise and the principal grid inventions would have been distributed evenly around the globe. After all, technological preeminence in the world had in past centuries variously been associated with China, then the Islamic heartland, but then moved on to Europe and then their former colonies in North America. In a fair world, people with an engineering bent---and statistically speaking right now in India there are probably a dozen Edison's, in China two dozen---would find the opportunity to exert their energy in producing new inventions to benefit the race. This is becoming more true now, but was not yet the case then, and it must be said that the great majority of the great grid builders came from two continents: Europe and North America.

The electrification saga continues now with the case of a young man, Nikola Tesla, who was precisely in the right place at the right time with the right ideas. Tesla moved about within the Austro-Hungarian empire in search of opportunity. Born in what is now Croatia in 1856, he went for technical training to the Austrian city of Graz and then the Czech city of Prague. Tesla was an intense fellow, severely limiting his leisure activities and even his sleep in order to devote himself to the study of scientific, mathematical, and engineering subjects. Not that he was a recluse. He was always a snazzy dresser and liked to recite poetry and was one of those people who are so brilliant and focused as to be almost scary to their friends. Under different circumstances he might have become a pianist or a professor of mathematics. Actually, what he loved more than anything else was electrical devices. He wanted to fix them, make them better, allow them to perform new tasks. Like Edison, he wanted to help mankind by extending the reach of electricity.

One can't write about Tesla without talking about visionary thinking. Mostly daydreams are of short duration and small use, even to those who dream them. But to someone of sharp intelligence and perseverance, such as Tesla, a high-precision daydream can prove substantial, even historical. We've seen how Edison's visionary moment (perhaps one of many such moments)---the one in which he grasped the notion of a complete electrical *system*---led to a grid of efficiently operating machines and lamps nourished by a rainforest of wire. Tesla's mesmerizing moment happened while walking through a park in Budapest. Ever prone to musing about machines by forming vivid mental pictures of them, Tesla on this day pleased himself by solving a problem that he had wrestled with for some time. In this daydream the design for a motor began to materialize. As a mental exercise he could start the machines, stop them, take note of minor problems here and there, noticing, say, some fatigue in the metal or a need for some rewiring. What emerged was a grand, harmonious, efficient, operating grid system, a better system than Edison’s, that would embrace the world (ref 2.17). Who needed a lab when, with creative thinking, all the required tests could be carried out as an act of imagination? But even Tesla the visionary recognized that for his Budapest grid to be transformed from mental wiring into copper wiring, his material prospects would have to change. Actually, Tesla had built a real prototype motor, and it worked exactly like the idealized, Platonic motor in his head (ref 2.18). Now it was time to make the machine available to the rest of the world.

Edison and Tesla: what a pair. Edison lived in New York. He had made a great reputation and had realized his electrical vision. Tesla lived in the far corner of a declining European empire. Edison, in order to create his grid, had merely crossed the Hudson from New Jersey to Manhattan. For Tesla to realize his grid it would be necessary to cross a more substantial body of water.

From Budapest he had made his way to Paris where he got a job with the Edison Compagnie continentale, which dispatched him on trouble-shooting missions to the infant grids in several cities, where Tesla made himself indispensable as a fixer and redesigner of machines. The particulars of his Parisian employment, in the end, did not live up to his expectations, and so the impatient and resourceful Tesla did what millions of other young Europeans were doing in the 1880s. He set off for the promised land of America.

One would not be surprised to hear that a man whose many waking thoughts were spent in a mental universe of mental machines operating on mental electricity should, in the actual streets, have his pocket picked and his luggage snatched. In that way he arrived at the southern end of Manhattan destitute and with an appointment to work for Edison. This arrangement was destined to be invigorating, testy, and short. Both men were industrious inventors, both regularly working fifteen- or eighteen-hour days. Where they came into collision and why they parted after less than a year was over a thing that might seem small but would loom very large in the history of technology. Their great dispute was over the way electricity should be moved through wires. Edison promoted direct current (or DC), current flowing continuously in one direction like blood being pumped away from a heart, while Tesla advocated the use of alternating current (AC), current which flows first in one direction and then flows back in the other. AC electricity comes and goes like a tide, not like rivers twice a day, but many times every second. DC electricity floods away from its generator around the circuit unidirectionally.

Edison felt that anyone who preferred AC, a current that couldn't make up its mind, was a fool. When Edison and Tesla separated in 1886 AC was still a novelty, hardly more than an idea, seemingly headed for niche applications only. By contrast, DC had proved itself. Already the Pearl Street electric district had as many customers as it could handle. Why would anyone, customer or utility vice president, want to mess with a successful formula? Why build or rebuild power stations or wire machines all over again? Did the wheel need reinventing? The historical answer to this last question was yes.

After leaving Edison's employ, Tesla fell much lower in the world---he went bankrupt in a business venture and was obliged, for a time, to work as a manual laborer, including the digging of ditches. He was, however, never far from a lab. He never gave up on that Budapest vision.

To appreciate what Tesla did next, how his fortunes turned, and to see how electricity could become strategically useful in the workings of everyday life, it will be desirable to see the phenomenon at a more intimate level.

A close-up discussion of electricity could have been brought in at any of several points in the story so far: when Ben Franklin brought lightning down from the sky on a kite string; when Volta pushed electricity through a circuit with a battery; when Faraday (and Henry) saw that faint flicker of induction from across the room; or when Edison dispatched energy out beneath the streets of Manhattan. Nevertheless, *now* is the proper time to be initiated into the specific lore of electricity because now is when knowing more about its nature really matters because of what Nikola Tesla had in mind.

The Mystery of Electricity Revealed

Let’s start with the homely but practical comparison between electricity flowing down a wire and water flowing down a brass pipe. What flows in the electrical grid are tiny charged particles, electrons. What flows through the plumbing grid are tiny water molecules. Water flow can increase if you widen the pipe or increase the pressure behind the water. Correspondingly, electric flow can increase if you use a thicker wire or increase the voltage; the force that impels the electrons through the wire. The water flow is how much water goes past per time---gallons per second, for example. Electric flow is measured by the number of charges chugging past per time. Municipal supply, water or electricity, is so convenient you hardly think about it: turn a tap and water spills forth; flick a switch and electricity is instantly summoned. Engineers have made the quick response of both commodities so smooth, so automatic, that you don't have to think about it. You have better things to do.

So far, so good. The visual comparison is pretty direct: moving water molecules and moving charges. This water/electricity comparison serves the purpose of giving you an intuitive feeling for the overall movement of electrical current, but to get nearer to the reality of electricity, a more subtle comparison will be needed. Picture a freight train in a railyard preparing to start up from a dead halt. There is plenty of slack between the cars. At the front end of the train the engine slowly starts up and it engages the first car. This car, in turn, engages the second car; there is an audible clank as the slack between the two cars is taken up. Then successively the slack is taken up with car after car after car, each time with a resounding sharp jerk. This jerk moves quite fast, propagating down the length of the train like a rifle shot echoing in a canyon as the cars, one after the other, get entrained. This is what electricity is like.

Look again at the train. There are two movements. The engine and all the cars are now moving slowly, at first no more than a walking speed, but the moving linkage, the rifle shot connection between the cars moves much faster. This is what electricity is like. In electricity the electrons are moving, yes, but that isn't exactly what the electricity is. The electricity is the moving linkage among the electrons. This rolling linkage, the electricity zipping down a wire like a rifle shot, travels at nearly the speed of light, whereas individual electrons are moving at only a small fraction of that speed.

Electricity is not precisely the charges but the thing that gets passed on by the charges. This is true whether we're talking about a circuit that loops around the inside of a flashlight in your hand or if the circuit goes all the way from the hydroelectric plant at Niagara down to a customer in Brooklyn and back again, a round-trip of 800 miles. Electricity is not merely the river of charge but the rifle shot of linkages passed along by the charges.

Let's simplify things even further. Instead of a locomotive and cars, think of a chain, a belt system, like the kind that used to operate in 19th century factories, stretching from city A to city B. By turning a crank in city A, energy could be sent to city B via the belt, or a series of small belts wound over various pulleys and gears. Sending electricity from Niagara to Brooklyn is like this. In the mechanical example, a belt gets yanked in Niagara and, through a rifle-fast (actually, speed-of-light fast) succession of pulls on a succession of interwoven belts, a moment later a belt gets pulled in Brooklyn. By turning a crank in Niagara you could, with enough interconnecting belts, you could grind a coffee mill in Brooklyn. Let's invent, for the moment, a concept of “belticity,” the sending of energy by belts. If electricity didn’t exist, we could sent energy from Niagara to Brooklyn in two ways. The collective belt motion could proceed in one direction exclusively (DC belticity) or it could alternate back and forth (AC belticity).

You might foresee why such a state-wide belt system would be cumbersome. Intervening belts would rapidly wear out. Pulleys or gears would wear down. The energy lost to producing noise and heat would be a good fraction of the original energy. Now we are in a better position to appreciate electricity, which is analogous to---but vastly better than---belticity. Electricity travels faster and more quietly, doesn’t need a lot of intervening moving parts, and, although it produces some waste heat of its own, wastage can be held to a small fraction of the energy being transmitted.

To summarize the short excursion into the essence of electricity so far: electricity compares, first, to water flowing through a pipe; second, to the sharp, rapid-fire link-up of railroad cars yanked into motion by a locomotive; and, third, to a system of cranked belts whose inter-connected movements could deliver energy to a distant machine. One can, of course, also compare electric force to other forces. Normally we think of “force” as being the push-pull kind of influence. You push a wheelbarrow. A strong wind pushes you. An elevator takes you upward. In these examples the forces are exerted between objects in contact with each other. But what about electric force? Where is it?

Isaac Newton provided the first major scientific explanation of an apparently-noncontact force. When asked what gravity was exactly, he said that he didn’t know. However, he *was* able to offer something just as good and maybe better. He described gravitational force with equations so valuable that one can compute in detail the whereabouts of cannon balls, comets, and (centuries later) space capsules. Gravity, he said, was something that went between any two masses. You couldn’t see the force, and there didn’t seem to be anything physical passing between the Earth and the Moon and yet a force was in action nevertheless. Newton couldn't say what gravity was but he did explain how it worked.

Later, the very useful concept of *fields* came along to help in vivifying the matter in our minds. According to this idea, what goes between the Earth and Moon is a gravity field, a sort of connection radiated or flung across empty space. Actually, the space wouldn’t be exactly empty since it would be filled with the gravitational *fields* (ref 2.19).

The concept of fields applies as well to depicting how electric and magnetic forces operate between or among charged objects or currents. You might have seen iron filings sprinkled on a sheet of paper held above a bar magnet organize themselves into a characteristic oblong pattern. What is happening is that the filings, each acting like a tiny compass needle, are aligning themselves along the lines of force spewed forth by the magnet. The filings help to visualize where the magnetic *field* is going in the vicinity of the magnet.   The fields tell you where the force is and how strong it is. In the case of the magnet, the little tracks of filings (looking like rows of ants) are a map of the field lines, while the crowdedness of the lines is an indication of the strength of the force; the more the filings crowd in close, the stronger the field (and the force).

It was the failure to know precisely where the fields were going that impeded the design of better electric generators in the years after Faraday’s discovery of induction (ref 2.20). In the 1860s and 1870s two big boosts came along to spur the development of better electrical apparatus: a full mathematical theory of electromagnetic fields as derived by the Scottish physicist James Clerk Maxwell and the desire to market a system of electric lighting (ref 2.21). Maxwell’s equations provided the mental push, while the lighting companies provided the engineering expertise.

A powerful synergy came of this combination of concepts and cash. Better generators made for better lamps, which in turn led to still better generators. That’s when Edison came into the picture. He divided light: his system made possible *small*, household-ready bulbs. His grid energized mainly lamps, and this alone would not have changed the way people lived. The next big step forward in the ascent of electricity would be the use of better motors.

Force Fields

Nikola Tesla would be the maestro of motors. Like most people, he embodied a number of contradictory traits. He often worked in a kind of self-imposed solitary confinement, and yet could enjoy the company of others. Frequently he dined alone, although he would sometimes throw lavish parties. He didn't seem to court fame, and yet he grew to enjoy giving public lectures on his favorite subject, providing spectacular demonstrations involving crackling sparks and bright lighting effects. At the podium he was patient and laid out a careful promotion of his electrical ideas. Having a good presentational manner was useful since many of the early arguments over electricity were conducted at lectures attended by engineers wearing formal business attire.

Sending electricity from Niagara to Brooklyn using direct currents, Tesla would argue, is an impossibility. DC power can be generated at low or high voltage, but because the voltage can't be altered once the electricity is on its way, DC current usually operated at low voltage (around 110 volts), the voltage best suited to household lamps. But at this level, it would peter out long before it reached the Hudson River. This is DC's great shortcoming.

The power you send down the wire, the amount of energy per second, is the voltage times the current: flow multiplied by force. You can make the current big or the voltage big. But keep this in mind: electricity moving down a wire will always waste a bit of itself in heating up that wire. This wastage is proportional to the current. More current, more waste. DC power can't go more than a mile or so, because of the waste, at least if it's at low voltage. If, however, you make the current small and the voltage high, things would be different. The waste would go down to a manageable level. High voltage is what you need; low flow, high force. AC can be created at high voltage, transformed to even higher voltage and then shipped without fear of devastating wastage. With AC power you can send electricity hundreds of miles. And at the end of the line, where the consumer and his bulbs were waiting, the voltage could be transformed back to the lower level for home consumption. DC power was not able to undergo these transformations.

Ironically, in more recent decades DC electricity transmitted at high voltage has proved to be an efficient means of long-distance shipping of power. To be compatible with the AC grids at either end of the line, however, the power must be converted from AC to DC or vice versa. This couldn't be done effectively in the 1890s, when the battle between the two kinds of current was being fought. Therefore DC was quickly losing that battle.

Mr. Edison, at this point, would object. High voltage is dangerous, he would assert. Besides, there is no worthwhile AC generator. And AC motors? Not worth a damn.

It's not high voltage by itself that stops your heart, Tesla would have replied, but the current flowing through your body. As for an effective AC generator, I have designed one.

A generator, the machine that makes electricity in the first place, is mainly a motor in reverse. In a motor, currents flowing through competing coils of wire force a shaft to rotate. In a generator, it's the other way around: a rotating shaft (spun up by a steam-fed turbine, say) forces currents to flow in the coil, in the manner of Faraday's flicker.

Tesla had indeed designed a better AC generator, but could he design a better AC motor as well? Early AC motors were poor. They stalled out, whereas DC motors were already being put to use in moving trolley cars through city streets, replacing carriages pulled by horses---along with their feed, stables, and droppings---with quiet electric transport. Could Tesla do anything comparable to that? Could he succeed where others had failed? The allure of AC was tangible---being able to send power miles and miles was extremely attractive---but the motor issue was worrying engineers and investors.

Tesla, always confident, had the answer. He had brought the answer with him from Europe years before. In his Budapest reverie, in his own electric epiphany, he had seen the whole thing: generator, motor, wires, everything. Edison had had a vision of an entire DC electric system. Tesla had the corresponding AC vision. And in all the years since his trip across the Atlantic, even while digging ditches, Tesla had retained and embellished the original vision. In his mind, testing continued, improvements were made, grids were built and the world reordered. Someday, he wasn't quite sure how, his mental grid, inaugurated in the far away Austro-Hungarian empire, would be built for real. It was not apparent how this would happen. Edison had rejected Tesla's AC approach. Utilities had invested millions of dollars in wiring and equipment for DC electricity and wouldn't eagerly switch to another system. How could such a new thing as an AC grid come into existence in the face of such daunting opposition?

Tesla persisted. His first own business venture had failed, but now he had a new set of backers. He erected a lab, in which he built actual, touchable prototypes of the visionary machines in his mind. When he turned it on, the motor made of iron plate and copper wire acted just like the motor he'd previously made of dreams. Just as Albert Einstein supposedly gained insight about the nature of space and movement by imagining what it would be like to run along next to a beam of light, so Tesla could, in that fever-pitched imagination of his, run along next to currents as they circulated around his imaginary machine.

And what happens to those currents depends on the prevailing electric and magnetic forces.

Swirling around inside the motor, like bottled energy, these two types of force feed off each other. When the current flows it's nothing but excitement. A changing electric force can excite, or "induce," a magnetic force. Likewise, a changing magnetic force can induce an electric force. Tesla's motor would use this induction principle in a new way. “I wish much to tell you...I may say I actually burn for desire of telling you...what electricity is,” was the way he once began a public address (ref 2.22). But this time his enthusiasm would not be allowed to overpower practicality. This time he would be careful with the patents. He would do things in a businesslike manner. Neutral observers visited the lab, witnessed the performance, and could affirm the practicality. Now Tesla would tell the world.

His chance came on May 16, 1888, when he spoke before the American Institute of Electrical Engineers in New York. It was then that Tesla revealed his secret weapon, the induction motor, in which the current didn't just slosh back and forth in a single circuit, rising and falling with a sinusoidal shape (the shape of a moving water wave). Electricity in his plan would flow through several circuits. The currents would be slightly staggered so that, as in an automobile engine where various pistons are working in different parts of a stroke cycle (one piston going down just as another is coming up) the electrical motor would gain enormous efficiency and power. The electricity going into and out of the motor would flow in several circuits out of phase with the others but timed so as to be complementary (ref 2.23).

Inside the motor, if only you could see it, the magnetic force was swirling around like a tornado. Electric contended with magnetic, and magnetic contended with magnetic. It was a Civil War between poles, North versus North and South versus South. One magnet would push off against another in a yin-yang of reciprocal, countervailing force. This microstorm was for the most part controlled and beneficent and was put to good use. This was Tesla's "polyphase" system, the centerpiece of his whole thought pattern.

Most of the engineers who attended Tesla's talk were---there is no other word for it---electrified. Tesla had his ideas, he had potent patents to hold off smart inventors panting to build their own AC motors, and he had the admiration of the profession, with the exception perhaps of the Edison DC faction and a few other also-rans in the search for an AC motor design. What Tesla didn't have was money, at least not the kind of big money and influence needed to carry forward his venture into the arena that mattered, the commercial marketplace. To change the world he required help.

And then, as if by fairytale connivance, the one man on Earth who *could* help did turn up in

Tesla's life. This man had already embraced AC electricity, had started to build AC grids, could see the merit of Tesla's claims, and had now come to buy Tesla's patents. There are some disputes even now as to how much was being offered, but between instant cash, stock, installment payments, and royalties to accrue from the sale of future motors, Tesla and his lawyers stood to take in more than a million dollars (ref 2.24).

Dividing Volts

Prefatory to anything else, Mr. George Westinghouse of Pittsburgh liked to examine the facts and weigh the alternatives before deciding on a course of action. His immense mustache, husky build, and riveting eyes would certainly give you the impression of solidity. Although only 42 years of age at the time of his encounter with Tesla, Westinghouse was one of the wealthiest and most powerful businessmen in America. He had reached this status through a combination of shrewd financial calculations, a benevolent management of associates, and bold investment in new technology. In a life full of eventful turns, the purchase of the Tesla patents was probably the most pivotal thing Westinghouse had ever done. The reasons for this will become apparent shortly.

Like Edison and Tesla, Westinghouse had been a brilliant inventor, even in his 20's, and took great delight in the thought that he could produce a device that would make money *and* be a benefit to society. Like Tesla, he had seen some of this inventions snatched away and exploited by others, and consequently he learned to protect his work with protective castle walls of impregnable patents. Like the Wizard of Menlo Park, the Wizard of Pittsburgh attracted a devoted band of engineers who helped to contrive not just workable machines but an industrial *context* in which they could function and interrelate.

Westinghouse had made his name by inventing something practical, a system for slowing the cars of a train using compressed air. This airbrake saved lives and made money. It gave Westinghouse the cushion he needed to proceed with the founding of other companies based on new technology. In the early 1880s, while Edison was turning on his grid in New York and Tesla was dreaming of polyphase motors in Budapest, the man in Pittsburgh was barely dabbling in electrical affairs. He naturally recognized the value of electricity but he had viewed things chiefly from a railroad man's perspective. Electricity was something for signaling down the line or setting a switch.

Then something came to his attention that changed his mind and altered his career. It was again the business of transmission: without the help of big voltages, currents could not be sent very far. And even supposing the current started out at high voltage, how could you bring it back down to low voltage for home use? How could you convert the electricity from wholesale back to retail? What now caught the piercing eye of George Westinghouse was apparently a report of a device invented in Europe for converting electricity from one voltage to another (ref 2.25). You wouldn’t need separate generators for factories and homes. Everything could be accomplished by one generator and several of these converter devices, the modern name for which is transformer.

This versatile metamorphosis of volts could be carried out with AC but not with DC electricity. Here was Westinghouse's chance. He would build his own grids with his own type of electricity. He would do with AC what Edison had done with DC. Edison had built an empire and so would Westinghouse. He too was an able negotiator, planner, marshaller of matériel. Edison had invaded Manhattan, stuck his banner in the earth, and claimed New York for his own. Since then he had seized other cities, but there were still plenty of opportunities. Edison, because his voltage couldn't go higher or lower, was earthbound. He had divided the light, but he couldn't divide volts, but Westinghouse could.

Westinghouse acted quickly. He sent an emissary to Europe to investigate the wondrous transformer. He bought the rights, brought a model back to Pittsburgh, tried it out, stripped it down, adjusted the workings, and built it back up. A month later he incorporated the Westinghouse Electric Company. Two months after that, in March 1886, he unveiled the first centralized AC grid in America, in Great Barrington, Massachusetts (ref 2.26). The press coverage for this event was not as intense as it had been for the Pearl Street debut, but at least Westinghouse had made his point. Eighteen months later AC grids were operating or under construction in dozens of cities.

Thus was launched the war between the currents, AC versus DC. The DC partisans claimed AC was dangerous, that a short-circuited switch could cause an explosion in a house or an instant conflagration. Edison enjoyed the fight. He ate apple pie daily, dressed like a cross between a laborer and a plantation owner, and gave out homespun Mark Twain aphorisms to an adoring press. But he also had his waspish side. He was a scoffer and personally entered the battle with a long pamphlet about the dangers of alternating current, which he claimed was efficient only for executing a man by electrocution.

By contrast, Westinghouse's public profile was much lower. His manner of dress was not discussed and his choice of breakfast food was not legendary. The mustache, yes; the blunt speaking, yes; but not the aphorisms. Westinghouse did not leave behind many writings, things like speeches or letters. His inventions and his AC grid were to be his legacy.

No matter what Edison said, the new grids for AC electricity kept coming. And why not? People living a mile from the powerhouse, those left dangling beyond the reach of the grid, now were happy to receive the benefit of electrification. But what about those shifting currents, always flipping left and then right? Doesn't that mess things up? Well, even though AC power reversed itself many times every second, the human eye could not see any flicker in a light bulb. In most respects a customer would not know the difference between electricity that was steady-on and its rival which would, every 60th of a second, diminish in size, stop, reverse, and then build up again. One great problem remained for AC grids. The energy-by-wire electrical revolution had begun as a way of lighting lamps, but it had promised also to power all those machines that had formerly required steam---lathes, drills, stamps, mills, compressors, and so forth. DC motors were starting to fill that promise. What about AC? Where was *its* motor?

This is why Westinghouse so avidly came to his historic compact with Nikola Tesla who, just at this precise moment, promised an efficient motor that thrived on AC electricity. Westinghouse not only bought the motor, but he bought Tesla himself. Tesla proceeded to Pittsburgh to work with Westinghouse's own engineers to integrate the motor and its associated dynamo into the existing AC framework. And it was then that the true startling nature of Tesla's designs became evident. First, the standard AC grid of the day switched 133 times per second. Tesla argued that this was too fast for his motor, which operated much better at a rate of 60 cycles per second. Second, the standard AC grid used a single pair of wires for hooking up machines, just like their DC counterparts. But Tesla's motor required two or even three circuits, and therefore needed extra wires. Would the grid have to be rewired just because Tesla said so? The engineers balked. They naturally wanted to make everything work with just the one circuit. Tesla, whose creativity was better suited to a solitary environment, left Pittsburgh and retreated back to his base in New York. His motors were going no where.

The stalemate did not happen at a convenient time. The competition for grid business was fierce. Furthermore, a prestigious contest had been announced: the prize was a contract for wiring a World’s Fair to be constructed in Chicago to honor the four hundredth anniversary of Columbus's voyage to the new world. The Columbian Exposition, as it was to be called, promised great publicity to any company that could deliver electricity for the most magnificent gathering of international wares, inventions, and folkways every assembled in one place.

There was at this time a more ominous factor at work. The American economy, like any other complex human cultural institution, has its ups and downs. The stock market crash of 1929 and the ensuing depression of the 1930s is perhaps the most famous business downturn of the last century, but there had been earlier depressions. The year 1907 saw a bad economic slump and the early 1890s was another such period.

So it was that Edison's empire, still strong in terms of grids and sales of manufactured goods, was poor in ready capital. As an inventor Thomas Edison was without peer and he holds the American record for most patents. As a showman and cheerleader for electricity and as an inspirer of men and orchestrator of great events he was remarkable. As a business man, however, he was only fair, and this, coupled with the straitened economy, was causing problems. Edison might still be a kind of Napoleonic figure, but if so he had entered the Waterloo phase of his electrical career. Still an imposing personality, we was gradually being overtaken by a predominating array of forces standing against him. He had become, even with all those creative ideas springing from his head like lightning bolts, a bit in the way.

At this time, in the year of 1891, a triumvirate ruled over the American electrical market: Edison, Westinghouse, and the firm of Houston-Thomson, another great pioneering electrical conglomerate. It was expected by many that the first of these companies would buy out and merge with the third, with Edison in command. Things turned out differently. Partly through the financial maneuvering of J.P. Morgan, the two companies did merge, but with the Houston-Thomson management team in the superior position. Edison was to be paid handsomely, but would lose control over the company he had founded. The new entity would not even bear his name. The newly crowned king of electrical manufacturers was (and is still) called General Electric, or GE for short.

Westinghouse was also being pressed by investors. Successful in gaining customers but troubled by a weak economy and underperforming investments, he was forced by events into an unpalatable expediency. While Edison had seen his name effaced from the company shingle, Westinghouse's ordeal, his personal mortification, was to have to go Tesla and ask him face to face whether he, Tesla, would forego his potentially lucrative royalties on his so-promising motor design. Only in that way, Westinghouse and his financial backers argued, could the company continue. Tesla was profoundly appreciative that Westinghouse had believed in his engineering concepts and was turning what had been in Budapest only a vision into a practical reality. Tesla magnanimously renounced his claims. In what must surely be one of the greatest sacrifices in the history of high-tech patent rights, Tesla physically brought forth his contracts, tore them in half, and deposited them in the garbage (ref 2.27). He received a lump settlement in lieu of future royalties. In the 1890s slump, Edison had lost his company. Through Tesla's generous act, Westinghouse was able to retain his. This left him free to do battle with General Electric for the right to wire the fair in Chicago. Beyond this, an even larger project loomed.

The Age of Discovery

In 1492 Christopher Columbus hove up on the sands of the outerlying islands of the Americas. From the European perspective this was a vast discovery. From the native perspective, Columbus' arrival was an invasion and a pestilence. What the Europeans found was a landmass no less than two continents in extent, a variety of previously unknown peoples, and new botanical and zoological species enough to overflow a thick lexicon. What the Indians got was mostly disease and subjugation. For better and for worse, the Spanish expeditions were staggeringly important for world history.

Four hundred years later the anniversary of this momentous encounter was being celebrated at the greatest World's Fair ever held. The Columbian Exposition of 1893 honored the Genoan admiral of the high seas, but it also honored the rapid rise of the Fair's host, Chicago, a city that had become a leading metropolis in the land. And befitting such a great city, three other major lakeside cultural institutions were coming into existence just then: the Chicago Symphony Orchestra, the Art Institute, and the Field Museum of Natural History (ref 2.28). When cultural historians look back at the Fair, however, what they see even more clearly than the legacy of Columbus or the upstart growth of Chicago was the glittering arrival of electricity.

To see why, just compare the last great World's Fair to be devoted to steam power rather than to electricity, the one held in Philadelphia in 1876, with the one in Chicago. The Philadelphia exposition would virtually shut its doors at sunset each day, whereas in Chicago, the magic *began* at sunset because that's when the power of electricity revealed itself in full force (ref 2.29). There were no airplanes around in those days, so there were no aerial views to be had of lit-up boulevards. The sight from ground-level was impressive nevertheless.

Imagine yourself to be an ordinary citizen in Chicago or one of the many out-of-towners arriving from afar (from Ohio, let us say) on a special exposition train excursion. If economically you were of the middle class, your home would probably have been illuminated by gaslight; you might also have candles on hand. You would have seen bright arc lights on the avenues of your town and seen some incandescent bulbs in the fronts of fancy stores and hotels. Of course these lamps lit with electricity were not for the likes of you or me because they were still too expensive.

The experience of a lady from middle-class Ohio would not therefore have prepared her for the enchanted kingdom set up near the shore of Lake Michigan at the south end of Chicago: an electric Ferris Wheel 200 feet tall, electric boats sailing across an artificial lagoon, electric trolleys moving the length of the fair grounds, a fountain shooting water 100 feet in the air and bathed in rainbow lights all the way up. More than 27 million people saw the fair, and the most splendid sight, the creme de la creme, was the electrical pavilion. On display was the world's largest engine and the largest assemblage of powered machines anywhere. And to keep everything energized, including 100,000 bulbs, was the world's largest generating system.

The extravagance of both the quadricentennial observance and the accompanying lightshow called forth some grand comparisons. The intrepid men of the age of discovery---the first Europeans anyway: trappers, soldiers, missionaries---had moved up uncharted rivers, across dry plains and thick forests. The explorers of electricity, centuries later, were now ushering in their own age of discovery beneath the streets and in the recesses of those magnificent spinning, shaking, thundering machines. These engineers were colonizing not prairies but lighting districts: first Pearl Street, then other city centers, later still the outlying regions. They were discovering not gold nuggets but something more valuable---superior current-carrying materials. If Ponce de Leon had sought the youth-preserving elixir of El Dorado, well, then on the electrical side it was said that voltage rays were sure to have healthful effects of their own.

There had been a spirited battle to win the right for lighting the Fair. Not only did the contract represent a business proposition of enormous proportion but it would be a public-relations triumph for the company illuminating the new El Dorado. Westinghouse won that contract, mostly by entering a money-losing bid, and hoped to recoup losses in the form of enhanced prestige and future contracts for grids and electrical appliances. Westinghouse Electric Company, incorporated only six years before, proceeded in Chicago to build one of the technological wonders of the world. A two-thousand-horsepower engine, the most powerful AC device in the world, joined by a dozen 1000-hp engines, supplied an awesome blizzard of electrical current. With more than ten times the number of bulbs of the Paris exhibition of 1889, the Columbian Exposition of 1893 consumed three times as much power as the surrounding City of Chicago itself (ref 2.30). Westinghouse's display at the Fair was of course quite conspicuous, but even GE (which couldn't afford to sit out an occasion like this) had a large exhibit space of its own, where it showed off the world's largest light bulb, eight feet tall, and Thomas Edison's "kinetograph," which "transmits scenes to the eye as well as sounds to the ear" (ref 2.31).

At the Exposition the electrical building was 690 feet long and its displays were described as the most novel and brilliant sight on the grounds. Here is what the guide to the Fair had to say:

> *Of all the separate World's Fair departments, the Electrical has a peculiar novelty and freshness in the popular mind. It differs also in one supreme particular from all of the others. The rapidity of electrical development finds no parallel in any other range of discovery. To the electrician ten years is a century, and even in one year all of his pet theories may vanish under the light of some new discovery. Further, the science of electrical development has advanced just far enough to teach the electricians that they are merely on the threshold of unbounded worlds of knowledge. The present exhibit, marvelous as it stands when compared with electrical knowledge ten or twenty years ago, may prove to have been crude and insignificant before the rounding out of the present century (ref 2.32).*

What Westinghouse had lost on his operations at the Columbian Exposition, he was shortly to regain in stature and business experience. For another thing, the electrical setup at the Fair had been mostly of the AC type. The war between the currents had basically been settled. Edison had lost not because his electricity was direct-current but because it was low voltage. It wasn’t adaptable for lots of applications because it couldn’t travel far and it wasn’t divisible.

DC was not exactly going away overnight, but AC was now champion. Furthermore, the Tesla conundrum, whether to incorporate the greater complexity necessitated by his multi-circuit (or “polyphase”) designs, was settled in Tesla’s favor. Even his lower operating frequency of 60 cycles per second (also called 60 Hertz, or just 60 Hz) was adopted (although Europe would settle on a convention of 50 cycles per second). Tesla-style dynamos and motors, even with the extra wiring, were suddenly in demand with customers. Ironically, GE, the company founded by Edison, began grudgingly to consider marketing some AC equipment of its own. How the world had changed in just a few years.

In the long course of the Fair, about one fifth of the nation passed through the gates. What did they think? Many, seeing more electricity in one place than they had seen in their entire lives, were amazed and delighted. For a more analytical, and more introspective and ambivalent, look at the Columbian Exposition, we will turn to the historian Henry Adams, grandson and great grandson of US presidents. Always seeking a philosophical perspective on the trappings of civilization, Adams found the Chicago Fair and its display of massive machinery to be baffling. Here he is, writing in his very self-conscious autobiography, *The Education of Henry Adams,* about the sense of dislocation he felt upon entering the electrical hall:

> *Some millions of other people felt the same helplessness, but few of them were seeking education, and to them helplessness seemed natural and normal, for they had grown up in the habit of thinking a steam engine or a dynamo as natural as the sun, and expected to understand one as little as the other...*

For Adams, the pace of technological advance was getting to be too great, a feeling that we, in our time, know well. He was the kind of person who prided himself on keeping up with developments, but now he was falling hopelessly behind:

> *One lingered long among the dynamos, for they were new, and they gave to history a new phase. Men of science could never understand the ignorance and naivete of the historian, who, when he came suddenly on a new power, asked naturally what it was---did it pull or did it push? Was it a screw or thrust? Did it flow or vibrate?...*

Adams' world of 1893 had not yet experienced aviation, or radio programming, or antibiotics, or cyberspace, but he could sense that the new technology would redraw boundaries, change rules, and otherwise alter the conditions of settled existence.

> *Me who knew nothing whatever, who had never run a steam engine, the simplest of forces, who had never put their hands on a lever, had never touched an electric battery, never talked through a telephone, and had not the shadow of a notion what amount of force was meany by a watt or an ampere or an erg or any other*

> *term of measurement introduced within a hundred years, had no choice but to sit down on the steps and brood.... (ref 2.33)*

100,000 Horses

The electrified future, foretold and glorified on the shores of Lake Michigan in the artificial environment of the Chicago exposition, would now begin to take practical shape some 800 miles away, not far from the shore of Lake Ontario. It was at Niagara that the Almighty had providentially caused the collective waters of the Great Lakes to undergo a mighty descent on their way toward the Atlantic. It would be at Niagara that electrical technology would take its biggest step forwards since Pearl Street.

It was evident that a worthwhile share of the energy in all that falling water could be converted to usable electrical energy. Some feeble efforts had already been made to glean this energy by the use of water wheels, but now the officials in charge were getting serious, even grandiose, in their planning. They wanted to employ the very latest engineering concepts in making an immense set of turbines, unprecedented in size and power, for creating more electricity in one spot than had ever before. And then they wanted to send that energy to places far away. Recent tests, including one at an electrical fair in Frankfurt, Germany, had shown that electricity could travel more than 100 miles (ref 2.34). If the voltage were high enough there appeared to be no limit to how far the grid could stretch.

The electrical setup at the Columbian Exposition had been make believe: electricity energized an immense light show and a Ferris wheel and electric boats wafting across an excavated pond. This has been a fairyland grid. Now the competition, again pitting mainly Westinghouse against General Electric, would be for building a much grander grid, a grid that would last, a grid that would change the nature of heavy industry. Even people in New York City, at the other end of the state, were intrigued by what was about to happen in Niagara.

Niagara has the biggest water gradient in one place in the eastern part of the US, so it was inevitable that engineers desired to turn some of that higher-elevation lake water into lower-elevation water and harvesting the difference in the form of electricity. Don't worry, the beauty of the Falls would not be marred by the presence of some huge apparatus. Everything would be out of sight. The needed water would be discretely diverted from a place upriver, leaving plenty still for the tourists to look at but enough to power a giant hydroelectric plant. The ambitious plan, when fully implemented would include water falling through tunnels leading to 20 different dynamos, each rated at 5000 horsepower. Engines of this size did not yet exist.

Let's ponder this for a moment. Recall, that at the end of the first chapter we dwelt on the meaning of *megawatt*, a parcel of power (energy used per second) equivalent to the body heat given off by 10,000 people---Madison Square Garden filled with sweating basketball fans. Now at the end of this second chapter let's ponder the meaning of another power unit, the *horsepower*. The total power of the Niagara operation, if all went well, would be 100,000 hp, equivalent to the work of 100,000 draft horses, or, to make the exertion even more palpable (and considering that one strong horse does the work of 10 men), the earnest labor of one million humans grinding wheat.

This was going to be quite an undertaking. The launch of Edison's Pearl Street plant and the electrical concession at the Columbian Exposition had each needed roughly a half million dollar investment, but the Niagara contract would come in at around the six million dollar level. Westinghouse and GE had sensibly decided on a truce as far as patent lawsuits went, but they still fought hard over the Niagara deal. In the end Westinghouse again triumphed over its great rival, at least in the matter of the powerhouse, but GE was not left out. Its share of the Niagara prize was to transmit the power to distant customers.

You will notice the word *grid* a lot in this book. Depending on the context it will sometimes refer to the wires or electrical making capacity of a particular utility and sometimes refer to the totality of the electrical activity in a whole region, or even (at a later stage) the whole nation or world. The notion of an aggregate grid is pertinent to the hydroelectric project at Niagara since the amount of electricity produced (or about to be produced) was so huge as to vastly exceed the needs of the immediate locality.

At Niagara the wider grid was about to enlarge itself in a spectacular way. Edison had built a mile-wide grid using direct current. Then Westinghouse had pioneered the simple alternating-current grid which, because of its high-voltage oomph, could stretch out for tens of miles. Tesla's struggles had been no less dramatic. He had contended with poverty, skepticism, indifference, and other inventors with rival claims. But on the day they threw the switch at Niagara, it was Tesla's polyphase wiring they were using, Tesla's frequency (60 Hz) they were using, and Tesla's patents immutably inscribed on metal plates bolted to the side of the dynamos---in effect, the license plates for the new grid.

Since Pearl Street, the spread of electricity had been quick but still limited in scope to the upper strata of society. In Berlin in 1886 here is where electricity went: the top customers, in descending order, were theaters, banks, restaurants, shops, hotels, and street lights. At the bottom were industry (2%) and homes (1%) (ref 2.35). With Niagara this would change in a big way. The Niagara grid was about to do more than light a lot of lamps and grind a lot of wheat. Plentiful Niagara electricity would soon turn the Buffalo environs in upstate New York into the greatest high-tech corridor of its day. It would be the Silicon Valley of the 1890s and the electro-chemical capital of the world.

With cheap power coming from the Falls you could give tin spoons a sparkling electroplating of silver. To extract aluminum from its ore would be better to use finesse. Instead of brute pulverizing and melting, the smart way is to tickle the ore with bottled lightning, causing the avaricious silicate to relax its grip on the metal atoms. What was once a production rate measured in ounces would soon be measured in tons or thousands or millions of tons.

History never stops, and the development of technology does not neatly divide itself up into convenient chapters. Still, the Niagara project represented a kind of finishing point and starting point. It represented the high point in the early phase of electrical innovation, a time which had seen the creation of practical generators, bulbs, motors, and electricity fanning out from centralized stations to multiple customers. The time had now come for electricity to emerge from the gilded age. Illuminating theatrical performances and upper-class dining establishments was fine, but other layers of human activity---industrial, domestic, civic---were awaiting electrification too.

On 16 November 1896 the energy from water coming from as far away as Green Bay, water eager to return to its ancestral ocean home, took a shortcut through the apparatus of the Niagara Cataract Company. There it fell against an impressive underground turbine blade, helping to induce an orderly hurricane of electric force with the effective equivalence of thousands of straining yoked draft animals or tens of thousands of men, women, and children grinding grain. This bottled lightning was rapidly transformed up to 20,000 volts, the better to race unimpeded southwards where, having dutifully remained within its wire and sprinted the distance in one ten thousandth of a second, it was converted back to sensible voltage in preparation for making its appointed rounds. As Tesla had envisioned fourteen years before in Budapest machine, energy, and grid could work together as one. In Buffalo that morning, with thousands of curious onlookers ready to be impressed, at just the right time and empowered by a potency twenty-six miles away, the trolleys moved.

September 21, 2005

Chapter Three

Most Electrified City

The setting was Delmonico’s, one of the best restaurants in town. The occasion was a testimonial banquet. Several big ironies hung in the air. First, the man being honored was not at the threshold of retirement. He was hardly in the 30s and was at the early stages of his career. A second irony: although this was New York City, birthplace of the Pearl Street powerhouse and effectively the headquarters for world electricity, the young man was about to move away. And he would take the grid with him.

Few would have recognized this event as a passing of the guard. Although he had decades yet to live, Thomas Edison had largely shifted his interest from centralized electricity to the problem of extracting iron from ore. Later he would turn to developing and marketing an early form of cinema. Meanwhile, George Westinghouse, having bested his great rival in the battle of the currents, was getting more interested in developing electric locomotives. As for Nikola Tesla, he would spend more and more of his creative time exploring the possibility of transmitting power not along wires but through the air.

What these three men had done was instrumental: Edison had invented the grid, invented the *system* of wire, socket, plug-in bulbs, feeder cables, and the dynamos to power it all. Actually what had powered everything was Edison's own personality. He had maneuvered among politicians, bankers, and engineers to create the massive, flexible organism we now call the power network. Westinghouse then reinvented the grid by resorting to pulsing alternating currents and transformers, those hulking machines that jack voltages up and down. Tesla then rewired everything all over again with his multi-phase circuits and his motors that harbored internal blizzards of magnetic force. And the new man? What did he do? Well, what he did will fill up the bulk of this chapter.

Parting Shot

This book is short but the grid is long. Blithely bypassing the dozens of other names who in a longer account would have merited a place in the history of the grid, this narrative has so far concentrated on three founding fathers: Edison, Westinghouse, and Tesla. To this short list there now comes a fourth. He was an inventor like the others, but he probably did more to establish electricity as an industry and as a way of life in home and office, factory and city street, in settings both rural and urban, than any other person. Actually, he's already come on stage. He played a significant part in the saga of volts but you wouldn't have noticed. He was there when the first current sprang forth from Pearl Street. Although only 23 years old at the time, he was indispensable to Edison and Edison's plans. Now he had plans of his own.

Not well known at the time by press or public, Samuel Insull made all the parts of the Edison machine work in synchrony. Having arrived in New York from Britain only the year before Pearl Street, he was hired to be Edison's personal secretary, but his work quickly expanded to include organizing the office, overseeing finance, arranging loans, running errands, and generally keeping up with Edison through work periods that made no distinction between night and day.

In the wake of the Pearl Street debut, business had boomed and Edison directed Insull to consolidate and move the various manufacturing ventures, many of them scattered around New York City, up the Hudson River to Schenectady. The Edison vision of universal electricity had adroitly been brought into reality---but the sudden call for electrical service and electrical apparatus had overwhelmed the Edison company. It simply could not keep up with demand. That is, until Insull created a small revolution in the mass production of parts (and this long before Henry Ford was to get credit for the concept), which allowed the volume of shipped products to go way up and the price per part to go way down (ref 3.1). When the Edisonized central grids for cities all over the US---Boston Edison, Detroit Edison, and so forth---had their own Pearl Street debuts, many of the parts came from Insull's factory.

There seemed no limitation to Insull's ingenuity or energy or resourcefulness. After making a great success of the Schenectady operation, he was stuck in the middle of the incorporation melodrama surrounding the creation of General Electric. He had foreseen the need to consolidate companies, but had also been loyal to Edison and was sorry to observe his mentor eased out of control and the "Edison" removed from the name of the new company.

Things had turned sour. Indeed, after serving at Edison's side for a dozen years and coming to like the bustle of New York City, Insull resolved to leave town. The instigators of the corporate makeover had recognized Insull's skills and designated him as the prospective first vice president---in effect the number three man at GE---but he preferred to be the number one man at another company, even if this meant receiving only one third the salary. Go west, young man, to Chicago. And he was young: having already had the equivalent of several full-length business careers, he was still only 32 years old.

At the Insull farewell banquet all of his "most intimate friends and most intimate enemies" were present (ref 3.2). Who knows if it was the wine or an undercurrent of bitterness, but that night an uncharacteristic small cloud of unguarded speech was to pass Insull's lips. His new employer, a utility company called Chicago Edison, was less than 2% the size of GE, and yet Insull brashly boasted that despite this disparity, he and his new company would overtake GE someday (ref 3.3). He would overtake everyone. Many in the room would have laughed uneasily at this awkward moment because they knew of Insull's steely resolve and his plentiful ability. Certainly they weren't laughing a few decades later when this young immigrant from Britain had indeed built his own electrical empire and was one of the most powerful men in America.

Insull does not now command much attention in the history books, which is a pity. For consider: he probably has had more to do than any other individual with the way in which your home is wired, with the variety of appliances you own, the nature of the electrical bill you receive at the end of the month, the manner of your morning commute on mass transit, even the process by which power is produced and distributed, financed and regulated. And then, at the heights of American power, he suffered a coming-down of epic proportions.

Turbocharged Grid

Those who suppose that the intensity of technological change during their lives will never be equalled are probably wrong. Compare the 1990s with the 1890s. Consider, for example, the 1990s’ electro-tech innovations with large worldwide impact: ever more compact personal computers, wireless communications, email, Internet, and optically-read compact disks for music and video storage. An impressive list. But look at what was happening ten decades before: radio signaling, diesel engines, motion picture cameras, x rays, AC induction motors, radioactivity, and automatic telephone switchboards. One could probably locate many decades when the comparative change in technological life was quite noticeable.

The Columbian Exposition, as you have already seen, was a showcase for industrial innovation, reflecting the buccaneering competition for the high-tech market in 1890s' Chicago, especially in the battle of the currents, and in the separate fight for light. What, didn't Edison's smooth-glowing bulbs settle the issue? No, they didn't. Arc lights, too bright to bring indoors, were still to be found illuminating city streets. Furthermore, good old gaslight had by no means gone away. We talk nowadays about miracle "smart materials," but they had them back in the 1890s too, and the most important of these was the introduction of a new kind of mantle, a little piece of fabric in which the gas jet combusted and threw out its light with much greater efficiency than before. If anyone had thought the electric grid would quickly put gaslight out of business, they were wrong. Gas was still the cheapest way to light a room. The mains were already there under the streets and the fixtures were firmly attached to the walls of people's homes. Why should anyone switch to electricity? This issue of cost was to be Samuel Insull's greatest challenge.

Insull had grown up in London. When he later came to New York he felt that his adopted city was raw by comparison and too full of energy. Later he changed his mind and came to embrace the vitality of New York, a sentiment many share to this day. When next he moved further into the continent, to the prairie city of Chicago, Insull encountered even more rawness and more energy. Here, stuffed with stockyards, railroad sidings, granaries, and smoking factories, was the fastest growing city in America, a metropolis in the process of doubling its population in a decade. Dismayed all over again by the barbarian coarseness, Insull had shrewdly inoculated himself against taking fright and flight by signing a multi-year contract with his new employer. As a conspicuous act of good faith, he also invested a lot of money in company stock. He would force himself to make a go of it in Chicago. No matter what happened this was now his home.

If Thomas Edison was the Invention Wizard of Menlo Park, Insull was about to be become the Organizational Wizard of Chicago: he would build several of the world's largest generators and usher in new forms of rolling mortgages, a form of perpetual borrowing much used ever since in industry. He would silently revolutionize rate-making and load smoothing. His approach to advertising and mass production helped to create the high-consumption culture we have today and the ubiquitous presence of advertisements that comes with it.

When Insull arrived in the summer of 1892, Chicago Edison had about 5000 customers, in a city with a population of a million. His generators were pouring out a respectable 2800 kilowatts of electricity, not enough for a really ambitious man. He needed more power, in several senses of that word. More power from bigger generators, more power over his retail environment, more political power. His first natural advantage---his ante into the great card game of electrical sweepstakes in Chicago---was the exclusive rights to the strategic patents on Edison equipment such as bulbs and switching equipment. With these Insull started to elbow his competitors out of the way. If you can't buy the machines and parts you need because of patent limitations, you're not going to have much of a chance. Insull had started by competing with his rival electrical companies, but his preferred method was to buy them out, one by one. Like the fictional smart-aleck Charles Foster Kane outdoing his newspaper rivals by buying up their best writers, Insull bought himself power stations, patents, licenses, and customer contracts until his was the only grid left.

Chicago Edison's earliest central station---its equivalent of Pearl Street---had been the Adams Street plant, built in 1887. Insull's first order of business after settling into the job was to build something much bigger, the biggest power plant in the world, the mighty Harrison Street Station, where multiple 1000-horsepower generators disturbed everyone in the building with the sound of a hurricane and the shaking of an earthquake. Being there was almost like being at Niagara Falls, but without the beauty of the Falls. The old Adams Street station didn't go to waste because Insull built himself there the world's largest battery in order to have the extra power ready at rush hour or times of peak electrical need, a problem that worried grid operators then and that worries them still (ref 3.4).

Another problem confronting Insull, and all other grid operators too, was AC-vs-DC. That’s right, this was another issue that hadn’t fully gone away. AC could travel, AC was the current of the future, AC could be used at lots of different voltages. But oftentimes DC was what you had. Chicago Edison, bearer of that famous name, had obviously begun life providing DC electricity. The dilemma now was how to use the go-anywhere ease of AC without having to tear out all the DC wiring. Choosing between AC and DC was painful. Insull's masterstroke was to use both, using a handy new invention called a rotary converter. Was Insull the first to use this device for turning AC into DC? No, but he was the first to use it in a big way. You could make current in the old DC style, turn it into AC, then send it through a transformer where it could be boosted up to much higher voltage. In that condition it could travel farther and cheaper than DC. Later, in some farflung neighborhood, send the current through a transformer and down to the lower voltage. Finally, just before shipping it to the customer, you could convert it back to DC (ref

3.5).

Now the company could concentrate on building fewer and bigger power plants. Insull even found a good use for all the obsolete power plants he closed down: they became substations, plants where power is not generated but merely converted and distributed. AC is turned into DC or vice versa or transformed from high to low volts. Was Insull the first to use substations? Again, no, but he was the first to use them on a big scale (ref 3.6).

More efficient generation lowered the unit price of electricity and this brought in more customers. More demand, however, necessitated more generators. In this way, even the colossal Harrison Street plant was quickly pushed to its limit. The mighty piston-driven steam machines already filled every available berth in the building. These electrical leviathans already shook the ground, pushing the parameters of mechanical and electrical engineering to the utmost. Insull needed a new masterpiece of engineering, and this would cost money.

Even in the middle of a national economic slump, things in Chicago were humming. Many businesses were failing, but not Insull's. He had made himself a master of money as well as a master of metal. He succeeded in the loan market, often by using his extensive connections in Europe. By 1898, six years after Insull had taken over, Chicago Edison's load, the aggregate amount of electrical gadgets receiving current, had jumped by a factor of ten. For a man of Insull’s ambition this was still too small.

The load had jumped tenfold, yes, but the number of customers had only doubled, to 10,000. Insull had the monopoly he wanted, but he still acted as if the competitors were at his heels, and in a way they were. Gaslight was alive; many homes were still getting along with gas lighting. Electricity was something fancy hotels and restaurants had but not ordinary homes. Electricity was desirable, fashionable, modern, but it was not yet a necessity. For many citizens electricity was still too expensive, and this bothered Insull.

In the hands of Samuel Insull, the existing reciprocating steam engine design had reached its size limit at about 4000 kilowatts (4 megawatts), and something new would have to be found. The name for the new thing was turbogeneration. In the old reciprocating engines, the horizontal motion of a piston is converted through linkages into the rotary motion of the generator shaft. Picture a giant steam locomotive that doesn't go anywhere. A turbine is different. There the roiling steam presses against blades mounted on the shaft itself. There would be no back-and-forth motion, only the rotary movement of the shaft. A turbine is a sort of windmill in which the force comes not from wind but from steam. The turbine shaft, bristling with blades, is of course confined in a chamber so that the steam cannot escape. Instead, the steam strikes one set of blades after another, cooling down as it does. Before it exits it will have imparted much of its energy to twirling the turbine shaft.

Was Insull the first to use turbine generators? No. Turbines had been used on a small scale---to propel ships and power small grids---but Insull was going to be the first to use turbo on a big scale. He didn't just want turbines, but unprecedented turbines. General Electric, which was in the business of eagerly supplying utilities like Chicago Edison, had to be coaxed into filling Insull's request because it seemed like a risky venture at the time (ref 3.7). The result, the world's first large turbogenerator, cranking out five million watts, 5 megawatts of power, was emplaced in its own palace of power, the newest and most grandiose generating station in the world, on Fisk Street in downtown Chicago. On the big day, when it came time to throw yet one more of those switches that mark the growth of the grid, Insull's chief engineer told his boss to stand back, lest there be an explosion.

"There is just as much reason for you leaving here as my leaving here," Insull said.

To which the engineer replied, "No. My being here is in the line of my duty."

Insull, who had not only pressed the mechanical designers to a feat of extreme contrivance (the contraption exerted itself at the equivalent of 6600 horsepower) but had rallied his investors and board of directors to the breaking point, had the last word. "Well, I am going to stay. If you are to be blown up, I would prefer to be blown up with you as, if the turbine should fail, I should be blown up anyway" (ref 3.8).

The machine occupied a tenth the space and weighed a tenth the as much as its predecessor. It not only worked, but very quickly was generating 10,000 horsepower, more than double the power produced by any steam-driven generator ever built.

Energy Multiplication

What is 10,000 horsepower? How impressed should we be by Insull’s new turbine? It’s no use providing a number like that without giving you a sense of what it means. Already at this point in the narrative, the generators have gotten pretty big, and they’re going to grow even bigger. Actually, 10,000 horsepower is already too big. We should start small. In fact, let’s start with a fraction of one horsepower.

In examining the energetics of food production and energy use in Colonial America, sociologist David Nye begins with this simple proposition: a man grinding wheat is exerting himself (spending energy) at a rate of about one tenth horsepower. One horsepower is the work that can be performed by one large draft horse or two ordinary horses (ref 3.9). In other words, a draft horse pulling a shaft that rotates a millstone can do the work of about ten men. Ever since Adam first earned food by the sweat of his brow, the struggle to acquire food has been just about the most important daily imperative for humans, as indeed it is for the rest of the animal kingdom. Animals will always be hunter-gatherers, whereas humans at least are able to employ their cerebral circuitry to develop, first, agricultural methods and, later, technological implements to enhance the available musclepower.

Nye gives several examples of multiplication of effort through mechanical contrivances. Wind power, for example: in the year 1500 the sails used to propel a 100-ton ship would produce perhaps 500 horsepower (hp), a factor of 50 times the collective muscle power of the human crew of that ship (ref 3.10). Water power: a typical river-driven mill in Colonial times was about 4 hp. Is it any wonder that often a mill was built before the town was built? The 4-hp mill could grind the wheat that would occupy 40 men. With a mill on the job, flour could be made and those 40 men could be freed up for other jobs. If the mill employed a turbine rather than a wheel, the power could be doubled.

So, how much energy does the great Energy Pharaoh, Samuel Insull, command with his 10,000 horsepower? Answer: the equivalent of 10,000 draft horses pulling at the yoke or, even more stupendous for the mind’s eye to fathom, the labor of 100,000 people toiling away on hand cranked mills converting grain to flour. By the way, “horsepower” is still a term used in association with engines, especially automobile engines, where mechanical drive or torque is important. It’s not a term used much anymore to describe the output of an electrical generator, so we'll often stick with kilowatts (one thousand watts, which is a little less than one horsepower) or megawatts (one million watts).

Sociology of the Grid

Once the principle of large turbogenerators had been established, the old power limitation seemed to disappear. It was like the transition from propeller to jet aviation. Chicago and utilities around the world starting building bigger and bigger turbines. First 5 megawatts, then 10, then 35. With this kind of capacity, increased demand could easily be met. For that reason, generation, for the moment, will be of less interest to us than other, more subtle, aspects of the electricity business.

Insull, the engineering juggler, could easily convert between alternating and direct currents, between high and low voltage, and replace piston with turbine. All of the new hardware innovations contributed to a vast economy of scale: generally speaking, the larger and more flexible the machine the more efficiently it would perform. With certain operations, and the grid is a good example, the overhead costs of doing business can largely stay the same, so the more product that is sold or customers serviced, the more the cost of overhead can be amortized. But this by itself didn't make electricity cheap.

There are other, more subtle, but no less profound, ways to make electricity cheaper. We therefore move from the Engineering Insull to the Management Insull. He started by looking at how society used the grid. How much energy was extracted from the grid, at what hour, and to what end was it put? How could this information be obtained? In the early days of the grid, in the customer's meter, a tiny metal strip was slowly consumed by the flowing current. Weighing the strip at the end of the month was how the utility company charged for its services.

Insull wanted more than that. He desired to know what you were up to in the middle of the night, and the morning, and at hours in between. The metering scheme first introduced into the US market by Chicago Edison was able to get readings every half hour, and this revealed the fascinating anatomy of power around the clock. Department store usage, for instance, was big during its open hours, between 8 AM and 6 PM, and almost nil for the rest of the diurnal period. Garages where electric vehicles were charged up had a usage schedule almost opposite: its charging operation stretched from 8 PM until 7 AM. Manufacturers' power needs were pretty well distributed across the workday, with a noticeable dip at noon when workers broke for lunch. For homes, the peak was in the evening when the family was actively together.

Was Insull the first to use such a meter? The answer again is no. Insull got the idea for a time-sensitive meter while inspecting a power station during a vacation in the British seaside resort of Brighton (ref 3.11). When he got back to the US, he made a better meter. The device allowed him to look at his own grid in a new way. In a smoothly run power network, the generating apparatus would be used efficiently around the clock. But this was obviously not the case for the Chicago grid. For big chunks of the day, the dynamos were operating far below capacity.

A graph of the usage during the day is called a load curve. Insull gave as much loving attention to this curve as a cardiologist would give to an EKG readout. If the grid and its users can be thought of as a living organism, then the load curves for subsidiary sectors---homes, factories, mass transit, etc.---provided all the vital signs a shrewd utility operator would need for determining the health and profitability of his franchise. Electricity was still too expensive, and Insull could see why. The load curve revealed all. A generator only working for a few evening hours when homes wanted electricity for lighting was an underperforming capital investment, an underused piece of equipment. That machine's "load factor," the fraction of the time it was actually being useful, was poor.

Here are some examples. A generator in the basement of a high-rise building, servicing an elevator only a minute at a time, maybe a few times per hour, sits idle much of the time. It has a bad load factor. Over in the factory where they make ice (in the days before refrigerators) steadily around the clock, a generator will be well used. It has a good load factor. Some of the load-factor disparities will be smoothed out by virtue of the fact that a centralized generator---in this case Chicago Edison---is there churning out power to a spectrum of customers.

Insull illustrated this point in a lecture before the YMCA by analyzing one particular block in Chicago. The little cross-section of Chicago contained 193 apartment customers and 34 garage customers, for a total of 227 electrical meters. Here is Insull speaking before the Young Men's Christian Association:

> *If you take each customer by himself, that is, each apartment by itself, the use of energy in each separate apartment is so slight that the investment to take care of that particular customer, if you trace it back to the generating station where the power is produced, would not be used on average more than between six and seven per cent of the time. But so varied are the ideas of human beings, and they so seldom do the same thing at exactly the same moment that, if you take the whole 193 apartments together, and then find out how much energy as a whole they use at one particular moment, the fact is developed that the diversity of their demand is so great that instead of using your investment only between six and seven per cent of the time, they use your investment, when taken as a whole, twenty per cent of the time (ref 3.12).*

And if you were to add in the stores around the block, you would find that the investment was being used at the 30% level, which is better than 6% but still not as good as 100%.

Using the investment fully and gainfully was vital not only to staying in business but to expanding. Moreover, with Insull efficiency seemed to have been not just a business imperative but also an intellectual pleasure and moral attainment, as if by wringing out the last drop of electrical utility from a pound of coal one were fulfilling a quest, begun when the coal was first fabricated in the earth eons before and finished with the exertion of a motor or flash of a welder's arc.

"So varied are the ideas of human beings..." Insull saw that he could use human diversity to help smooth out his load curve. The way to increase productivity was to diversify his customer base. To get customers to use electricity whenever possible in off-peak times, Insull offered rate incentives. In the old days the customers were charged a flat rate, so many cents per kilowatt-hour, a kilowatt of power consumed for the space of an hour. Later this was changed to accommodate the really good customers: the more you used, the cheaper the rate got. This was fine for the big spenders, but what about new users?

To solve this rate problem there was a new policy. The new algebra worked this way: rates would be made of two parts, a fixed charge proportional to the size of the user's load (a simple home with but a few bulbs would benefit because if was only a flyspeck on the system as a whole) plus a decreasing variable rate above a certain minimum (this rewarded big users---the more they used the more they saved). In effect, Insull's grand scheme was to increase profits by *lowering* rates. Go after a larger market share, or in this case building the market in the first place, in the hope that increased volume of sales would make up for the lesser charges per unit of production

One of the biggest boons to making all this work was winning contracts for powering the trolley business in Chicago. Formerly these electric trains had had their own power supplies, but Chicago Edison essentially made them an offer they could not refuse. With Insull's electricity providing the traction for pulling trolleys up and down long boulevards, all these expensive underused turbines suddenly had something to do during two formerly slack periods---the time just before the work day began, when people were commuting to their jobs, and the time just after the work day ended, when people went home.

These two segments in Chicago's daily rhythm, what we now call the morning and evening rush hours, greatly helped to straighten out the grid's load curve. Trolleys, at least for a time, were the biggest users of electricity in the US; they accounted for two-thirds of Insull's load (ref

3.13). And what had all the electricity replaced? Well, a few decades before, the way workers got to their jobs was on foot or in omnibuses pulled by 100,000 horses, at an average speed of 5 miles per hour, and leaving behind on the streets a millions pounds of manure every day (ref 3.14).

The price of electricity kept falling. Chicago Edison had built more efficient turbine generators, had through the use of AC transmission and substations brought the grid into many new neighborhoods, had through astute metering come to a familiarity with the hourly habits of the grid, and had instituted a creative tier of rates to induce customers to sign up. But yet they resisted. Electricity for the average citizen was still too expensive. Samuel Insull never gave up. In fact, he was just getting started.

Faustian Bargain

In 1898 Insull was elected president of the National Electric Light Association (NELA). Speaking at their convention he proclaimed his evangelical message of lower rates as the way toward higher profits. He had been one of the greatest proponents of the necessity for monopoly, and indeed had arrived at that condition in Chicago when his final competitor succumbed (ref 3.15). His argument? Utilities, to deliver energy at the lowest rates, had to be free of wasteful duplication of expensive wiring and heavy equipment. He was far ahead of his brother utility operators in recognizing, however, the need for public regulation of privately-owned utilities. Yes, he would say, you heard me right. The customer, and just as importantly potential investors, will have greater trust in the course we steer if our operations and our profit margin are negotiated in public view.

Commonwealth Edison, as the company was known by 1907, had done as much as it could on the production side. Now what needed work was the demand side of the grid equation. Insull did not, and never would, have enough business. When he started in Chicago, he had 5000 paying customers. By 1898 it was 10,000; by 1906 50,000; by 1909 100,000; by 1913 he had 200,000 ratepayers. Commonwealth Edison was larger than New York Edison, Brooklyn Edison, and Boston Edison put together (ref 3.16). His company had become the model for utilities all over the US. Trolleys were electrified, factories increasingly had powered equipment, and electric lights illuminated the streets, train stations, and the better hotels and restaurants. But for ordinary people, electricity was still special. Reaching into homes, getting people to change their habits, would take time.

Insull's first attempts at advertising the benefits of home electricity were aimed primarily at rich folks. These included a monthly magazine, *Electric City*, and a store specializing in electrical appliances. "Buy something electric for Christmas" was the slogan one year. He toured a portable "Electrical Cottage," displaying various impressive wares. Then came the ploy that started to change things and which earned Commonwealth Edison a place in the history of the early golden days of mass advertising. It worked like this: a cart would be sent through residential neighborhoods. The cart was piled high with electric irons and the man in charge was offering a bargain that would rival the tasty apple offered Eve in the Garden of Eden: ladies, allow electricity into your home---installation charges spread out over two years, with no financing charges applied---and you could replace your old, heavy, cumbersome flatirons with modern electrical irons. We have ten thousand new irons to give away (ref 3.17).

Here at last was temptation difficult to resist. Electric toasters or electric fans: these were luxuries, symptoms of a pampered life. But ironing---well, everyone needed clean clothes. After lighting, the next most used electrical contrivance in the home was to be the iron. Heating and maneuvering the old flatirons from stove to flat surface to shirt, back to stove for reheating and then more shirts, was muscle-aching and finger-blistering work, especially in summer. With the electric iron, there was still plenty of work to be done, but the energy arrived in thin wires. There would be much less hefting and less sweat.

In this way electricity gradually came into Chicago homes. It didn't happen all at once but in stages. The utility kept building more power plants, kept extending its lines into more neighborhoods, kept lowering its rates. Electrical current was no longer some novel, invasive vine but something more like a native species. Even if you didn't yet take the service, you knew people who did, and you were aware of the wires strung overhead from those poles. You looked at them every day and wondered how exactly the system worked. You couldn't see the current flow and there wasn't any detectable smell as there was with gas. Now and then an associated low hum could be sensed, but otherwise it didn't have much of a sound.

What the utility was offering was highly attractive and for many increasingly affordable. Not that a housewife would be overly indulgent with her electricity. No, it would be doled out sparingly. Just as she would continue to use gaslight in the evening, saving the electric lights for when company was over, so the lady of the house would often go on using the flat irons in winter---you had the stove going anyway, so why not use the irons---and save the electric irons for use in summer. Electricity in your home was a thing to be noticed and nourished. It was not taken for granted, at least not yet.

What was electricity like in those years? Here are some particulars. The average apartment with electricity had a dozen sockets. Homes had twice as many. The cord bringing power into an appliance had to be screwed into one of the dangling light sockets since the standard plug didn't come along until the late 1920s (ref 3.18). The bulbs used were typically rated at 50 watts, but gave off only a small fraction of the light emitted by a comparable bulb now. It had taken Edison and his engineers a year or more to fix the recipe for the light bulb filament, and after that they went on improving it. It took years more for Edison to emplace the system for supplying energy to those bulbs. The next great electrical product for the home, the iron, also underwent many design changes before it was taken up by women in large numbers.

Presently we will look at the third great product of the electricity age. It took longer to develop than the bulb or the iron, but once it had been perfected it caught up quickly. Five years after it was introduced, 60% of Chicago homes had them. Five years after that it was everywhere. It was practically more popular than the grid itself.

On the Air Live

This book is about sending energy by wire. We can't yet send food or other bulk goods by wire, so the next most important thing to be transmitted electrically is information. Here are six great electrical-information inventions associated with the grid: (1) *telegraph*, the movement of binary code via wires by interrupting a simple electrical circuit; (2) *telephone*, the movement of voiced sounds via wires by vibrating a membrane with modulated signals; (3) *wireless*, the movement of telegraph binary code via waves sent through the air; (4) *radio*, the movement of voiced telephone-like sounds (and later pictures) via waves sent through the air; (5) *computers,* the programmed processing of information via wires (or optical fibers), wires that are microscopically small and integrated by the million on tiny grid platforms; and (6) *Internet*, the combination of inventions 1-5 in a globally linked network.

The first two of these came before the electrical grid. The last two came very late in the grid's history. Because the time frame in play in this chapter is the first third of the 20th century, we'll concentrate on the fourth invention, radio, which was the next big thing to come along. Actually, radio didn't just come along. It wasn't a single invention or insight. In fact, it was built on clever ideas, scientific discoveries, and investments spread across the better part of a century.

To start with, the time from Faraday's flicker of recognition of the true kinship between electricity and magnetism to the development of practical electrical generators---having the ability to crank out lots of power---was several decades. The time from Maxwell's insight that electric and magnetic forces together conspired to constitute ordinary light (full technical name: electromagnetic radiation) and, furthermore, that light comes in many varieties (such as ultraviolet and infrared) which the human sensory system cannot apprehend to the time that Heinrich Hertz created and detected some of that nonvisual radiation (what we now call radio waves) was 20 years. From Hertz to Guglielmo Marconi's throwing radio waves across the Atlantic was more than a dozen more years. And it would be another couple of decades before regular radio broadcasts came into the home. Here's how it happened.

Radio waves are, first of all, a subtle form of electricity and magnetism mixed together and able to propagate great distances. They can, under the right atmospheric conditions, even reflect off the undersides of clouds and thereby travel a fair away around the curvature of the earth's surface. To be useful for mass communication, however, the tiny electromagnetic disturbance needs to be amplified and manipulated using special circuitry. To make the transition from a *radiant thing*, a wave phenomenon moving through the air, to a *circuit thing*, a smallscale burst of electricity moving along metal wires, and finally back into a wavetrain of sound crossing the room to our ear, a whole new arm of the electrical industry had to come into being: electronics.

And now, for two or three pages, it will be useful to let the history of the broadcast grid unfold in parallel with the history of the electrical grid. It was in the early radio years that the particulate nature of electricity, in the form of electrons, was discovered. In 1897, while regular electrical service in Santiago, Chile was being launched, J.J. Thomson, in England, built himself a glass tube containing two electrodes at opposite ends, one hooked up to the positive terminal of a battery and the other one to the negative pole. Even with no wire stretching between the electrodes, and with all the air in the glass pumped out, if the negative electrode was heated up, a current would flow across nothingness toward the positive electrode.

Years earlier Edison had seen this odd behavior (now called the "Edison effect") but had made no sense of it. But Thomson did. From his simple laboratory setup several important things were learned: an electrical current consisted of tiny lightweight particles, electrons. The first true elementary bits of matter to be detected by scientists, electrons were lighter by far than atoms would prove to be, even the lightest element known, hydrogen. They were, in fact, later construed to be small detached components of atoms. Moreover, the tube with the electrodes could be modified to function as an important circuit component, a "diode," which allowed current to flow in one direction but not the other. For one thing, diodes could be used to rectify current---turn it from AC into DC.

And while the Edison Company in Milan was branching out beyond the city limits to Venice and to other parts of northern Italy, the diode was, in a manner of speaking, branching out too. By adding a third electrode to the glass tube, the current leaping through vacuum from the negative (cathode) to the positive (anode) electrode could be controlled with great sensitivity. Once again, a plumbing analogy will be useful. Picture a huge gush of water entering one end of a water main and flowing out the other end. By turning a small knob, that gush can be turned off. The knob acts like a gate, permitting a big flow or no flow. The knob also acts like an amplifier. The small motion of a human wrist turning the knob, exerting a pressure of mere ounces, can be magnified into a mighty force able to stop a water flow equalling hundreds or thousands of pounds of water pressure. So it is with the third electrode in an electron tube. A very small current sent into the third electrode can turn on or off the much larger current flowing from the cathode to the anode. The third electrode has acted like a gate and an amplifier (ref 3.9).

The glass tube in these experiments, called an electron tube or a vacuum tube, became the central component in electronics. Many years later the tube would be replaced by transistors and crammed by the million onto a chip the size of a breath mint. Instead of flying across a centimeter of vacuum, the electrons would move through a micron's worth of solid silicon. Besides acting as a switch or gate or amplifier, the electron tube (or transistor) can be used as an oscillator: it can help to convert electrical impulses from one frequency to another, from the 60-hertz time scheme of the electrical grid up to the hundred-megahertz time scheme of radio waves, or back down again to the kilohertz time scheme for audio waves. This one device, then, can act as a universal translator for converting energy pulses to suit the very different pace of the grid world, the broadcast world, and the acoustic world. It changes not only the temporal signature of the signal but magnifies, by adding oomph at the crucial moment, changing and deciphering and embellishing the practically-nonexistent energy of the radio signal arriving at a rooftop aerial into the sounds that we can assuredly recognize as a Beethoven symphony.

As soon as the full sound of the human voice or a polka band, and not just the prosaic dot-dash of the telegraph, could be conveyed on the back of an invisible wave, free of all wiring, then radio could fully break out into public use. Adventuresome local "stations" could set up and broadcast to a fraternity of nearby listeners who had built themselves receivers. Weather, crop forecasts, crime reports, Bible school, an up and coming local fiddler, election returns, a baseball game in progress: these were things that would make people gather 'round and listen. With time the programming got more ambitious, stations broadcast for longer periods and over greater distances.

While on one side of the world, in Japan, 700 separate utilities were consolidating into five large electrical conglomerates (companies which survive to this day), on the other side of the world, in the US, the first stations with regular programming were delivering the results of the 1920 presidential election: Harding beats Cox.

While the German firm of Siemens was building a large hydroelectric dam on the Shannon River in the newly independent country of Ireland (a project which constituted the largest foreign project undertaken by a German company---ref 3.20), the Radio Corporation of America (RCA) was building up a network of affiliated stations into a sort of radio grid spread across the country. This became the National Broadcast Corporation, or NBC. Electricity had certainly made radio possible, the fact that some people were submitting to having their homes wired in order to receive the broadcasts meant that radio was returning the favor.

By the early 1930s nearly every home in Chicago had a radio unit. Samuel Insull was interested from the start. His company was part owner of a local station. He could see that so great was people's eagerness to have radio that some of the last holdouts signed up electrical service in their homes so that they too could receive the broadcasts that all their neighbors were talking about. It can be said, incidentally, that the possibilities for advertising products in conjunction with radio programs that penetrated thousands and millions of parlors was not overlooked by certain enterprising individuals.

Maximal Gridification

Cities in most places were laying more wires, but the most aggressive laying was in Chicago. The 1920s was a roaring decade. The Great War was over and the Windy City was the capital of jazz, in the musical sense and the electrical. It was one of the largest urban centers in the world, partly because of the jobs that come with booming productivity. Chicago's factories, between 1900 and 1930, went from an electrification of 4% to 78% (ref 3.21). Samuel Insull had succeeded, finally, in making electricity affordable. In that remarkable 30-year period, the rates charged for power had fallen to half even as the price of the fuel used to make electricity had tripled (ref 3.22).

On an atlas of electrical history, the brightest zone, the very most intense phase, would center around Chicago in the decade from 1918 to 1929, when a majority of homes in the city were wired up (ref 3.23). Electricity in the city's suburbs grew even faster---50% growth per year over that decade. In 1925 Chicago was the most electrified city in the world, with an average per-capita annual consumption of nearly 1000 kilowatt-hours (ref 3.24). In a later chapter we observe the impressive electrification surge in China in the early years of the 21st century, but nothing can compare with the earnestness and early voltage ascendancy of Chicago in the 1920s.

This was the Jazz Age and also the Machine Age. It wasn't just electricity and radio that were jumping, but also aviation, the film industry, and especially automobiles. In 1915 one in sixty families had cars in the US; in 1925, the number was 1 in 8 (ref 3.25). And of course that fraction would grow further. One victim of this latter development? Trolley ridership fell.

And how did all this technology change things? In the catalog of energy-transforming devices, incandescence-bulb lighting had come first, changing the way people used the night and day. The next to be institutionalized were electric irons, which also altered the rhythms, or at least mitigated the sweat, of housework. And what a salubrious effect this would have on the woman of the house! One not-so-subtle ad for electrical appliances got right to the point: "How Long Should a Wife Live?" it asked (ref 3.26). Third, the advent of radios changed the way families approached their evening entertainment and the way people got and processed news. Runnersup in this electrical roster were vacuum cleaners (rugs didn't have to be whacked outdoors as often), coffee percolators, and refrigerators.

How did things change? Thomas Edison went so far as to suggest that electrical devices would accelerate human evolution. In times to come a woman, executing her home duties, would be more like "a domestic engineer than a domestic laborer, with the greatest handmaiden, electricity, at her service" (ref 3.27). The wife's brain would come to equal that of her husband's.

To say that it didn't work out that way in practice would be an understatement. Doing the family laundry, for example, had always been done by hand, an ordeal that could take many hours. Later, for many middle-class households, the wash was then given out to a professional laundry. Later still, with the arrival of electrical home washing machines, the dirty clothes stayed within the home. Net result of electrification? More labor than ever for the "domestic engineer" in the family (ref 3.28).

Had electrification come too quickly? Our technological civilization was older but was it wiser? Before rocketing ahead with the story of grid development, we need to look at this issue of grid impact. We need to build some perspective on the coming of widespread electricity. This era of the 1920s, plus or minus a decade or two, is sometimes referred to as the Machine Age, which is somewhat unfair. One could argue that the steam engine had been just as important and culture-changing in its day. Developed in the mid 18th century to help drain mines, improved by James Watt, and then applied to ship travel and railroads and finally electrical generators, steam has had an enormous impact on culture.

And if you're going back in history looking for the start of the Machine Age, don't stop with the steam engine, says Lewis Mumford, a frequent commentator on the connections among cities, machines, and social habits. Go back to the 13th century and the invention of the mechanical clock. With his clever bulbs, Edison was able to divide light into small samples. Westinghouse and his transformers divided volts. Tesla's motor design enabled horsepower to be divided, offering a refined version of powered machinery. Individual electric sewing machines became possible. But the monks of the 14th century monasteries, with their clocks, Mumford says, were able to divide the hour into minutes (ref 3.29). Time was no longer a fluid thing but something abstract and divisible. Starting with the monks themselves, with their devotions and chores dictated by a strict hourly schedule, life become much more regimented around time. Thereafter people would increasingly eat by the clock, not necessarily when they were hungry necessarily, and sleep by the clock, not necessarily when they were tired.

Mumford uses this example of the clock to illustrate how machines, and their large effect on our lives, become assimilated to our thinking and to our daily routine. We cease to think about them. Mumford had great respect for scientists like Faraday, whose work had led to new knowledge of nature. He even appreciated the development of electrical technology which made life easier for millions of workers in factories and elsewhere, and had led to cheap aluminum which, among other things, had made available affordable utensils and appliances for the public (ref 3.30). As early as his writings in the late 1920s (just about the time Insull's technological hold was supreme), though, Mumford was worrying whether technological development---the engineered products and the use to which they were put---was "organic" enough:

> *...A good technology, firmly related to human needs, cannot be one that has a*

> *maximum productivity as its supreme good: it must rather, as in an organic system, seek to provide the right quantity of the right quality at the right time and the right place for the right purpose...*
>
> *The center of gravity is not the corporate organization, but the human personality, utilizing knowledge, not for the increase of power and riches, or even for the further increase of knowledge, but using it, like power and riches, for the enhancement of life.*
>
> *The greatest contribution of science, the most desirable of all its many gifts, far surpassing its purely material benefits, has been its transformations of human consciousness, through its widening illumination of the entire cosmic and historic process, and its transfer to man of the power to participate with its whole being, in that process (ref 3.31).*

Not strive for maximum productivity? Enhancing "life" at the expense of corporate organization? Transforming human consciousness as science's greatest contribution? With attitudes like these Mumford was a thinker to be respected but seldom heeded, at least over the period of years covered in the next few chapters. Nevertheless, his viewpoint---that massed modern technology, however convenient it might be, brings with it troublesome consequences---will be a necessary counterweight to what could otherwise seem, in a history like this, to be outright boosterism. The electrical grid, and its impact on people, has its upside and its downside.

Assyrian Empire

In surveying the coming of these gridborne changes, emphasis has centered on Chicago and the role of Samuel Insull because he did so much to establish electrical modernity during his tenure at Commonwealth Edison. He not only built the largest and most efficient generators over a period of 30 years, but had extended service to strata of society (poor and rural) and outerlying towns left out of previous electrical endeavors. It's true that to achieve these ends he had sought out and achieved a monopoly over grid activity. If you wanted to be on the grid you had to come to him. His rates, however, were lower than almost anywhere else, whether New York, Philadelphia, Boston, or Baltimore (ref 3.32). For these actions he deserves to be considered a hero of the grid. This is the Good Insull.

We will also now have to review what history has come to see as the Bad Insull and to explore why in general his reputation, if he is recognized at all, is under a perpetual cloud. Insull's lone biographer, Forrest McDonald, sees Insull not as a greedy or evil man, but one whose main fault was the pridefulness to believe that he knew more than other people (ref 3.33). Past experience had taught Insull that he could solve any problem; he was better at organizing large companies or cajoling politicians into giving him what he wanted; he was shrewder at discovering cheaper and more reliable ways of getting the raw materials he needed for feeding his grid; he was abler than other merchants in procuring new customers, customers which he dearly needed for smoothing out his load curve.

Arguably he was better at running other people's businesses than they were. He helped fix and improve the Chicago transit system, both intra- and inter-city. His greatest performance in a supporting role was his action in rescuing Chicago's insolvent gas company. Against all advice that he had nothing to gain and everything to lose, Insull had taken on the role, once again, of savior and guarantor. He reorganized, refinanced, trimmed, and conserved until the firm was solvent once more. Insull's credit, and the credit of his home company, Commonwealth Edison, had the strength of granite. Investing in Insull was a sound investment. His companies always paid dividends.

As a boss he was benevolent. The wages he paid were better than those at other utilities. Insull's ethos of energy conservation and social responsibility and pride in the Company was impressed upon his workforce. His employees were encouraged to contribute time and money to charitable and civic causes. Often the senior managers were leaders in community activities. He offered his workers affordable life insurance and the company owned a resort in Wisconsin for family vacations (ref 3.34).

As World War I began the mobilization of troops, materials, and morale was essential. Appointed by the governor to head of the defense council for Illinois, Insull, the great mobilizer, approached his assignment with all the zeal he used in dealing with electricity. He raised relief funds and sold government bonds but also took on the task of organizing the state economy on a war footing. He petitioned the federal government to distribute work contracts more fairly, especially in non-eastern states like Illinois. Those such as coal companies which had, he believed, unreasonably raised their rates, he accused of war profiteering. When patriotic admonitions failed to work, he threatened to seize coal mines and jail malefactors. By the end of the war his impressive civilian war effort earned commendations from President Woodrow Wilson and congratulations from other national and international leaders. His was the only large steam-driven utility in the US not to raise its rates right after the war (ref 3.35).

What's so bad about all of this? Where is the *bad* Insull? Shouldn't crooks be made of sterner stuff? Compare, once more, the life of Samuel Insull and the sage of *Citizen Kane*. In the movie, the newspaper baron marries a singer and builds an opera house in Chicago. In real life, the utility baron married an actress and built the *actual* opera house in Chicago. In the movie, we see Kane increasingly caught up in the process of self aggrandizement: he revels in performing noble deeds and in pulling the levers of power. He desires the public to love him and he enjoys influencing events. The same with Insull. He didn't need to be mayor to be Chicago's premier citizen. The opera house, looking somewhat like a high-backed chair, became known as "Insull's Throne." "I am not a musician," he said, "nor am I in any sense an authority on grand opera, except as to what it costs" (ref 3.36).

Like the Assyrian empire, Insull's fief had started small---a minority utility, with 5000 customers, serving part of the central business district. Then with dynamos as his sword and patents as his shield he had conquered the rest of Chicago. Next was the North Shore Electric Company, a confederacy of grids lying along the rim of blue Lake Michigan as far as the Wisconsin border, as well as a few petty dukedoms to the south. Insull secured sovereignty over the northern regions by building the first 132-kilovolt transmission line, as practical and potent a symbol of imperial sway as the Roman aqueduct had been twenty centuries before.

He had bought suburban and trans-urban grids wholesale, along the Illinois River and other swaths around the area. The Public Service Company of Northern Illinois, as this venture became known, even extended high-voltage feelers into Wisconsin and Indiana. Insull's domain now covered thousands of square miles. Confident in his vision, Insull's transmission lines even went where previous grid builders had been reluctant to venture, namely rural regions. If he had heard that there were potential customers on the Moon, one suspects he would have found a way to traverse the vacuum of space and begun laying wires in the lunar dust.

Insull had himself an empire, he operated a monopoly, but its operations were regulated by the state, and his rates continued to be lower than most. He would argue that this was the greatest good for the greatest number. He encouraged his employees to buy stock in their own company, as he had done himself. They should buy stock and their friends should buy stock too. You, the employee, could earn a small commission even as you helped your friends. All would benefit from the health and advance of the company. What's bad about that?

Insull had long conducted his affairs upon several sound principles. One of these was to use available resources to the fullest. For operating a power grid this meant leveling the load curve---that is, trying to even out the delivery of current all around the day---by getting more customers with a variety of diurnal habits.. For managing the grid one also desired to amortize the company's financial investment and power delivery schedule by acquiring or cultivating new businesses in fields allied with grid work, such as gas pipelines or elevated trains. In other words, knowledge and connections in the business world were themselves valuable assets to be further invested in seeking wider growth. Nothing wrong with that, is there?

With the advent of Middle West Utilities, Insull's reach grew to the continental level. This corporation, of which he was the head, was a holding company. It advanced money or equipment or patent licenses to struggling new utility companies which in return gave stock. The early Edison company operated along these lines: the new grid affiliate in Cincinnati, say, could hardly afford to buy equipment *and* operate as a grid without surrendering some ownership to the larger company holding the patents and making the machinery. The holding company, better known and better trusted than the subsidiary operating company, could then sell *its* stock using as collateral the stock held in the operating company. Insull's holding company, came to control utilities all over the place---California, Ohio, Kentucky, Louisiana, New England (ref 3.37).

The grid was now virtually everywhere, and Samuel Insull had done much to make it what it was. In the US, only some rural areas had been left out. To mark the gigantic transformation electricity had made, a special occasion was being marked. The 50th anniversary of Edison's development of a practical light bulb was to be observed in October 1929. Henry Ford had built a museum to honor Edison, and the centerpiece was a painstaking reconstruction of the Wizard's Menlo Park lab complex, the scene of Edison's greatest research as well as his enchanting encounter with Sarah Bernhardt and his dinner with the aldermen of New York. The resurrected lab was built at Greenfield Village, not far from Ford's mammoth auto factories in Detroit, and the day was memorable. Edison, now 82 years old, was lauded by the President of the United States, Herbert Hoover. Edison and one of his original assistants re-enacted the lighting of Edison's 1879 bulb (ref 3.38). The re-enactment of the historic moment of 50 years before was historic itself because it was unfolding to a trans-oceanic listenership of millions. The re-lighting of the bulb, narrated anew as if it were a championship sporting event, and the remarks made by Edison and by President Hoover, were beamed across the US and to other lands.

And beamed in the opposite direction came greetings from Germany, from President Von Hindenburg and also separately from the famous Albert Einstein. From the Antarctic came felicitations from explorer Robert Byrd. The domestic part of this "greatest hookup that radio has yet attempted" was an ensemble of more than 130 stations coast to coast, beating the previous record of 111 stations which had covered the acceptance speech of Alfred Smith at the Democratic National Convention the year before (ref 3.39).

More memorable was what happened three days later: the greatest stock market crash in American history. The economic downturn of the early 1890s had led to Edison's removal from control of his company. The great market tumult of 1907 did in Westinghouse. But these events were small in comparison to the crash of 1929. This notable episode would soon touch the entire nation, and other lands too. Consider, as part of this vast turn of events, the plight of utilities. When suddenly the price of many stocks fell simultaneously, then obviously companies that regularly borrowed huge sums of money on the strength of stock holdings were going to be nervous. Insull's empire, with utility operations in 32 states, had a total value, if you added up the assets of all the companies that he controlled directly or indirectly, to something like three billion dollars. With his index finger he controlled the flow of about one eighth of the nation's power. One million people, from laborers to millionaires, many of them enlisted through the grassroots level, were investors in Insull's companies (ref 3.40). They all waited to see what would happen. A week after the crash Insull's face was on the cover of *Time* magazine.

Holding companies, especially those that layered many corporations within other corporations in pyramid fashion, were shaky in an uncertain economy. Against terrific pressures, Insull kept his operations solvent, but many people were worried. Already the issue of public versus private ownership of utilities had become a major point of debate in American politics. Insull was seen as the leader of what had come to be called the Power Trust. The utilities, and Insull in particular, were seen as using undue efforts in influencing political affairs. Insull had long made it a policy to make generous campaign contributions, sometimes to both parties.

Entangling himself in a 1926 senatorial race, Insull had outdone (and partially undid) himself by giving a reported $125,000 to the Republican candidate. Although this was not an illegal contribution, the size of the gift and other factors at the time provided fuel for those who saw this as a grab for political power by the purveyors of electrical power. The senate voted not to seat the victorious candidate, a man named Frank Smith (ref 3.41). In our time the argument continues over what constitutes a spirited political endorsement or an outright bribe. Franklin Roosevelt, in his 1932 presidential campaign, singled out Samuel Insull by name, and the other utility holding companies, as being interested in acquisition and not service (ref 3.42).

Samuel Insull's empire finally collapsed. By June 1932 too many holes had sprung up in the dikes, too many loans were being called in, and Insull was forced to surrender his management positions by the New York bankers, the ones he had always tried to avoid. He even had to give up his beloved Commonwealth Edison. Insull, quietly taking train for Montreal, sailed for Europe, and moved into a Paris apartment. Then worse: Insull was indicted on charges of fraud, embezzlement, and other crimes related to his Byzantine holding company.

Leaving for the next chapter the question of his guilt or innocence, the story now concentrates on Insull's escape. The conqueror of the known electrical world had become a fugitive. He fled to Greece, where there was no extradition treaty with the US. There was even a possibility that he would assume Greek citizenship and be put in control of the national grid (ref 3.43). Insull, in his memoirs, tells of an even more poignant what-if scenario. Years before, he writes, Prime Minister Stanley Baldwin had secretly invited him to return to Britain and take charge of the commission that was to reorient the British national grid. After giving the matter serious consideration, Insull regretfully declined. "It seems my life would have been pleasanter and both myself and others would have been saved lots of trouble if I had accepted Mr. Baldwin's offer" (ref 3.44).

He hadn't accepted the offer but had stayed in the American arena, and why not? He had been present at the birth of the grid, standing at Edison's side on Pearl Street. Insull had gone to fashion his own powerful grid, the Chicago grid, a million times bigger than Pearl Street. But he never forgot his origins. Insull's employees referred to him respectfully as "The Chief," but for Insull himself there was only one chief. He idolized The Old Man of Menlo Park. In the bound version of Insull's most famous lectures, the frontispiece illustration is a photograph of Thomas Alva Edison (ref 3.45).

But there is also the matter of that boast, the promise made at the banquet sending him off from New York to Chicago forty years before, a vow to outdo General Electric. It was an assertion half made in jest and half in earnest, but it does seem to have captured the essence of the man and what he subsequently did in Chicago. Little Sammy Insull, Edison's secretary, had gone on to the big time. Accepting custodial duties over Britain's grid would have taken him away from a culture where governors and senators were his friends. Whole cities had electricity because of him.

Many other great men in history had suffered great reversals of fortune. Napoleon had conquered all of Europe as far as Moscow and then was himself conquered, his empire shrinking from the size of a continent to the size of his jail on St. Helena Island in the south Atlantic. Agamemnon, breaker of cities, supreme leader of the Greek army at Troy, returned home, where his rulership constricted with lethal rapidity. Stepping from the bath he was swaddled in a blanket and axed to death.

For Insull it wasn't nearly as bad. Leaving Greece and heading for Turkey, he was finally apprehended through the vigorous efforts of the United States government. Shanghaied from one ship and placed in another and suffering weeks of blazing front-page newspaper coverage, he was ignominiously transported back to New York, driven to Chicago, and remanded to a jail cell, where he spent the night. In the breadth of his career, the magnitude of his influence, and the height of his fall, Samuel Insull's saga could almost be compared to Greek tragedy, and somebody someday should write a play about it.

September 21, 2005

Electrical Book by Phillip F. Schewe

Chapter Four

Imperial Grid

Enthroned on a mesh of wire, electricity had triumphed. It had become the paramount utilizable energy. Wind, water, steam, gas, fire, muscle---all had their turn. All were still present at some level, but if you could afford it, electricity was how you toasted your bread and lit your rooms. Electricity had been caught from the sky by Franklin and induced to race through wires by Faraday's invisible force fields. It was standardized by Edison, motorized by Tesla, dispatched miles by Westinghouse, and domesticated by Insull, whose legionnaires first conquered all competitors and then hunted mercilessly for consumers house to house armed with rates too low to ignore. Electricity had become an affordable convenience. The grid had become an institution. You trusted it: there it was in the lamp next to your pillow and in the wall beside the baby's crib.

The grid encloses a wild thing---electricity is a form of bottled lightning, after all---which would escape from its wires if it could. But the grid itself, its towers and its machines, shows no signs of being contained. In the 1920s the power network had become large and would get larger, far outpacing Insull's grandest schemes. Electricity would travel to the Moon with the astronauts, would enliven computer-controlled robots for assembling Japanese autos in Argentina, and would ever so gently actuate microscopic sensors that deftly spot sick from healthy blood cells in serum samples.

Like the banking, insurance, manufacturing, shipping, and railroad enterprises that had transformed western culture, the networked distribution of energy by wire was now quickly and decisively settling into place in the overall scheme of modern life. There were, not surprisingly, many great issues as yet unresolved. Was electrical power a basic service, as basic as drinking water and roads, to be enjoyed by citizens by right, or was it a commercial commodity, like food and automobiles, to be paid for at a price established by marketplace competition? Even roads and water have to be paid for, of course, and one can't expect to get electricity for nothing. But how would the price be established? Should energy flow be under the control of the state or private investors, or some combination of the two? The answers to these questions will vary depending on where you live. Knoxville, London, Petrograd, and Manhattan all had their own special way of doing things. These are the headquarters of grid empires that were to rival or exceed the one built by Insull. How these four systems developed across the early and middle decades of the 20th century and what they added to the storehouse of electrical tradition will be the subject of this chapter.

The Lake District

Can we have poetry and electricity at the same time? Can alternating current at 50 or 60 cycles per second coexist with intimations of immortality as expressed in stanzaic parcels of insight?

There was a time when meadow, grove, and stream,
The earth, and every common sight,
    To me did seem
  Appareled in celestial light,
The glory and the freshness of a dream.
It is not now as it hath been of yore;---
  Turn wheresoe'er I may,
    By night or day,
The things which I have seen I now can see no more (ref 4.1).

In this poem, William Wordsworth examines how perceptions evolve during an individual life. People change and so do cities. Wordsworth did not live to see the coming of the grid. But those who dwelt later in his beloved Lake District in the northwest nook of England were not keen on the idea of high voltage transmission towers striding lonely across the moors (ref 4.2).

Falling real estate values aside, would Wordsworth have suffered from the imposition of power pylons into the greenery surrounding the lakes? Would he have gotten writer's block? We don't know. Lots of things in modern society, not just the intrusive presence of equipment from the Central Electricity Board, stand in the way of attaining the visionary gleam Wordsworth sought. Lewis Mumford, for one, asserts that modern technology has carried us further away from the spiritual aspects of life. Even if this hypothesis could be proven, if it could be shown that the presence of powered machines and the hectic workplace routine they engender detracts from (or distracts us from) poetical appreciation, it could be counter-argued that these machines have also extended the average lifespan, shortened the workweek (at least compared to Wordsworth’s time), and provided more, not fewer, opportunities for entertainment and self-fulfillment.

Before seeing how things were organized in London, let's remind ourselves of how things were done in Chicago. There, you dig up the streets, lay new cable, buy out the competition. If yesteryear's generator (maybe a dozen years old) isn't big enough then turn it off and build a much larger one. Want to diversify the load curve? Then buy up trolley companies or extend the line up the lakeshore as far as Wisconsin or down the Illinois River or across the border into Indiana. The City of Chicago might have a few words to say on the matter, but generally officials could be made to see the light. The State of Illinois would be listened to obsequiously, but in the end Samuel Insull was the man. His idea of the grid is what the grid became.

In Britain things were different. Britain, the birthplace of steam power and railroads, had been forward too in advancing the electrical revolution. Was not Faraday's flickering recognition of the magnetic-electric kinship, a discovery of the same magnitude as Columbus's discovery of the new world? Joseph Swan's filament bulb, although not as practical as Edison's, had come ever so slightly earlier. The Holborn Viaduct in London and the Surrey seaside town of Goddalming had had centrally powered strings of bulbs months before New York's Pearl Street grid. Britain had sped into an early lead in this high-tech race for lucrative electric patents. Then things slowed down.

Consider first the investment and legal problem. According to laws then in force in Britain a company could build a grid and earn a profit, but then the city at its discretion could exercise an option to buy out the company. This was hardly an incentive for potential backers to favor utility stocks. Furthermore, in England what the Lord Mayor and the aldermen thought still carried great weight. In Britain some power companies were, like Insull's, owned by investors. But in general grid control was concentrated at the city or even sub-municipal level.

A second problem was the Balkanized tumult of multi-cultural engineering. In Insull's Chicago one company served energy from just a few fortress generators. In London in the year 1913, by comparison, 65 utilities delivered electricity at nearly a dozen frequencies and two dozen voltage levels, each combinatorial permutation requiring its own compatible appliances (ref 4.3).

The man who would be king of this cacophony of volts, or at least who aspired to instill uniformity and efficiency, was Charles Merz, the nearest thing in Britain to Samuel Insull. Like Insull, Merz had helped to build a large grid while still a young man in his 20s. Grasping the lessons of load leveling, understanding the daily cycles of factories, shops, and trams, Merz ran the most efficient power network in England, a block of power stations and lines stretching along the eastern seaboard centered around the city of Newcastle. He used, even pioneered, the latest turbine generators and was an advocate of ever higher transmission voltage, the better to ship power long distances from where the fuel was---where they dug coal out of the ground---to where it was needed, in a place like London. Wouldn't this coal by wire make more sense than bulk coal by rail?

In 1905 Merz proposed to the British Parliament a scheme in which some utilities would pool resources, streamline operations, and achieve greater efficiency and lower rates. This in turn would lead to greater industrial growth, especially in the area of east London. Britain, as anyone could plainly see, had been falling behind some other countries, such as the US and Germany, when it came to electrified production. London only used one fifth as much electricity per capita as Berlin and one tenth as much as Merz's own city of Newcastle (ref 4.4). But here is where the local burgher insisted on his ancestral rights. Magna Carta and all that. The small utilities didn't like the idea of being in the shadow of larger businesses, and the local governments affected by Merz's scheme didn't want to surrender any of their prerogatives over ratemaking, and so the political tide turned against Mr. Merz. Parliament said no.

Was Merz being sensationalistic? Was he exaggerating things in order to obtain more electrical business? Not at all. What were the numbers? In 1912, electric sales per person in London was 49 kilowatt-hours per year. In Berlin it was 83 and in Chicago a whopping 291 kilowatt-hours. How much did a kilowatt-hour cost? In London it was 4.8 pennies, in Berlin 3.9, and in Chicago 2.2. What you paid depended at least in part on how big your local generator was. Bigger dynamos generally made electricity more cheaply. In London the average generator size was 5 megawatts. In Berlin it was 23 and in Chicago 37 megawatts (ref 4.45).

Merz bided his time and in 1914 submitted yet another plan to the Commons. In effect he was offering to do on a larger scale what he had done for the east coast: set up or promote a regional grid. But for the second time the same fears arose. Londoners, used to city control, didn't want to place themselves in the hands of a private company, even one that in Merz's plan would be regulated by the state. Besides, the plan called for regiments of unsightly overhead transmission lines hither and yon. Let the Germans stick with their well ordered and supremely efficient regional grids in the Ruhr and Bavaria. Chicago could do what it liked. The British would nicely handle things in their own way. Parliament again said no.

Again the main reason was politics. Parliament, local magistrates, and the small utility companies weren't ready for large scale consolidation (ref 4.5). One can imagine that the debate, at least as it had a bearing on how to run metal wires through poetic places like the Lake District, was haunted by the ghost of William Wordsworth. If he had struggled to find sufficient repose for crystallizing in dazzling odes his poetic vision of life, imagine how much harder it would be if an electric-drive washing machine agitator were whirring away in the next room over. And if you had gotten him to admit, yes, that the time saved in washing clothes with energy by wire freed up more hours for penning verse, he would still have been stressed by the sight of his beloved daffodils put into the shade by stanchions of a 132-kilovolt transmission line.

Charles Merz did not give up. The Great War descended on Europe and, among the other sobering realizations unloosed by that ruinous conflict, it became apparent even to former skeptics that a more concerted electrification was needed to buttress the British economy and, coincidentally, to keep up with the Germans. Even the ruling Conservative Party reluctantly had to concur to the idea of more centralized energy supply. In 1926 Parliament voted to establish a national network. This wasn't yet full nationalization---that would come in 1948, following the next world war---but rather a grouping of existing utilities, some private and some public, into a unified system of power distribution. Merz himself was not appointed to the ruling body, the Central Electricity Board, but he would become a frequent consultant. He observed once, when looking at the map of prospective long-distance transmission routes tying the system together, that the lines looked like a gridiron pattern, and hence it became popular to refer to the aggregate paths of the system as a *grid* (ref 4.6). And that's what a large, networked set of power lines has been called ever since.

There are many ways to build and operate a grid. In Appleton, Wisconsin, city government ran the power works. In Rio de Janeiro the urban electrical supply was operated by a private company, one owned not by Brazilians but Canadians. The grid there consisted almost entirely of hydro power, so when the rivers were low, the electricity was scarce, and had to be rationed (ref 4.7). Meanwhile, in northern California, a consortium of private companies benefitted from the kind of pooled operation advanced by Charles Merz, but without the entanglements of government control. Stuck with the prevailing geographic reality---the bigger cities on the coast but the source of plentiful hydro power hundreds of miles east in the Sierras---these enterprising Californians pioneered the use of high-voltage transmission over long distances (ref 4.8). In Berlin the grid was in private hands, but then was taken over by the city.

Wherever it was, though, the grid would spread out and take over. Look at Milan. Like Hannibal crossing the Alps to conquer northern Italy with his war elephants, so Edison's Milan company conquered the Lombard plain and territory as far as Venice with his elephant-sized "Jumbo" generators. The company was privately owned, later nationalized, then later still partly re-privatized.

Fuel for Red October

In Tsarist Russia things were different again. Electric lighting had arrived early; the German firm of Siemens had built a telegraph system in 1853 and some of Edison's bulbs had burned at Alexander II's coronation in 1881. After that, growth had been sluggish. Russia, lying at the eastern geographic extreme of what counts as Europe, was often off the map when it came to trade, finance, and scientific and technological innovation. Government involvement was either repressive or, just as bad from the standpoint of encouraging development, neglectful. Huge import duties, illicit payoffs, delays, indifference, mistrust between government ministries: Russia was not the investment environment to attract the kind of big money needed for building an energy infrastructure.

Here’s where things stood on the eve of the Bolshevik revolution. The grid was twenty years, maybe more, behind the other parts of electrified Europe. In and around the two major Imperial cities of Moscow and St. Petersburg the grid depended on elderly generators of Belgian origin. As for fuel, you had to freight coal all the way from Britain or haul it from districts in Russia so far away that they might as well have been abroad. Electricity cost four times more in Moscow than it did in Amsterdam, and electrifying a tramline in Omsk meant that no new customers could be added to the grid for years (ref 4.9). Then things got worse. So much worse that it will require some considerable space to tell the tale.

The lore of nations emphasizes heroic deeds and oversized characters. Britain has its King Arthur and Henry the Fifth. The US has Washington the Father and Lincoln the Liberator, while the Ottoman Turks have their Suleyman the Magnificent. The Soviet Union had Vladimir Ilyich

Lenin. In the golden stories, Lenin is always earnest, idealistic but pragmatic, visionary in his designs and frantically eager to begin the task at hand. One of the biggest tasks in revolutionary Russia was the restoration and expansion of the electrical network following the devastating years of back-to-back wars, including World War I, the Bolshevik takeover, and the civil war between the Reds and Whites.

War and revolution, retreat and retribution, wrecked just about everything. The grid would have to be built from the foundation back up. And this time the way things were done would be very different. According to the glorious legends (and here, I confess, I find it difficult to pass up the temptation to write in the fervent tone of the times), the Commissars were desirous of showing the world what a communist grid would be like. No pooled ownership, no consortia, no state regulated private utility, no bourgeois equivocating of any kind, nothing but full government operation. What follows is an account of how this socialist grid came into being.

Lenin, always eager to reach boldly for anything that would advance the revolution, was tantalized by the transformative attributes of electricity. Consequently, he sent for the top electrical engineer around, Gleb Krzhizhanovsky. The animated discussion between the two of them, conducted by candle light since electricity was scarce, was concerned with fuel. There was no question of getting coal from Capitalist Britain anymore, and fetching forth much coal from the Russia's own Donets Basin far in the south was problematic considering the crippled state of the railroad grid.

Local fuels were the answer. "We must declare a proletarian crusade for peat," Comrade Krzhizhanovsky declared in the robust speaking style of the time (ref 4.10). Bog world: Russia possessed an enormous carpet of potential energy in the form of its 240 million acres of peat. Peat, if you compress it in the Earth for eons, is what becomes coal. But even taken as is, it was still a usable fuel. Turn it over, stack it up, dry it out, send it through a furnace to make steam. This was Socialist ideology in action. Decisive, direct, strategic!

The next day, Krzhizhanovsky, hardly having slept after spending a night conversing with the revered leader of the revolution, was startled by the arrival of a motorcycle messenger from Lenin. "Your report on peat was most interesting," the missive asserted (ref 4,11). Lenin wanted a more forceful text, something longer, inspirational, something to go into the newspaper *Pravda*, where it would arouse a larger audience. Krzhizhanovsky went to work and produced a letter, "Peat and the Fuel Crisis," which was duly published along with a letter from Lenin called "The Fight Against the Fuel Crisis." In the same issue was another letter from a certain Comrade

Lurge, "Firewood and Administration," arguing that wood as a fuel should not be overlooked. There ensued numerous other letters to Pravda debating the merits of local fuels (ref 4.12).

Soon another motorcycle message from Lenin ordered Krzhizhanovsky to bundle his various studies of the grid situation (hurry, please) into a pamphlet which Lenin needed as ammunition for a speech he would make at the All Russian Central Executive Committee in February 1920. With the greatest of urgency the required task was again accomplished. Just in time, printed on a crash basis, 585 copies of Krzhizhanovsky's report, accompanied by hand-printed full-color maps, were distributed to delegates.

Lenin quoted from the report to urge the necessity for electrification: "The age of steam is the age of the bourgeois; the age of electricity is the age of socialism." What came of Lenin's emphatic urgings was the creation of a panel, the State Commission for the Electrification of Russia, whose transliterated acronym is GOELRO. This organization, Lenin hoped, would be the vanguard of a movement allowing Russia to out-develop the bourgeois powers. The electoral world was to be another theater of the People's struggle. Two hundred engineers shut themselves into a building and went to work. The kind of power network that in the West had evolved piecemeal over several decades, mostly through the actions of entrepreneurs like Edison and Merz, would in Russia be dictated by a government edict assembled over ten months.

Lenin ordered extra firewood for keeping the commissioners warm during their work. He saw to it that they received Red Army food rations, better than ordinary members of the government received. Lenin phoned occasionally to see how things were going, to cheer them along and exhort them in their business. With V.I. Lenin looking over your shoulder you didn't stop for want of a salary or for family matters. What were these petty inconveniences when the nation was waiting for their plan. Lenin was excited and therefore so were you.

Still another motorcycle missive arrived from the Kremlin. Lenin demanded more speed and spoke joyously of "melting church bells for copper wire" and "placing a light bulb in every village" (ref 4.13). The report had to be ready for the Party Congress. Already breakneck, the work pace accelerated. Once-in-a-lifetime exploits were at hand. Now was the decisive moment. If the events of the crash program were to be made into a film, the director would have to be Sergei Eisenstein. As a sound track he could reuse Prokofiev's martial score from *Alexander Nevsky*.

Done at last! Another blitz copying job was required. Five separate print shops around town were commandeered to produce the needed copies of the 600-page GOELRO document, intended to be the nation's electrical blueprint for the next ten years. Future ages will marvel at the audacity. (Further disclaimer: my mock-heroic expositional treatment of Bolshevik electrification should be juxtaposed with the grim facts of life in Russia in those years---many died before firing squads, and many more of starvation.)

The hypothetical grid film continues. It would now cut to a snowy city street in front of the gorgeous Bolshoi Theater. Delegates arriving at the Eighth All-Russian Congress of Soviets are questioned before entering by sentries of the Red Army. December 21, 1920 is Lenin's big day, and so it is a mere trifle that there isn't enough heat in the auditorium. The esteemed participants will keep their greatcoats on. Parts of Moscow are blacked out in order to provide enough electricity to light the auditorium. Here he is. Lenin, coatless, is soon welcomed to the podium, where he will speak without notes, casting off that charismatic glow that sets him apart (ref 4.14).

His speech, and the purpose of the Congress, is much concerned with nation building, but it takes its place also in the roster of famous electrical lectures. Faraday considered it his duty to inform the public, which turned out in great numbers to hear of his newfound mastery of electric currents. Edison, in a boastful little sermonette in 1879, had prophesied the universality of energy spreading across wires into people's homes. Tesla, in his 1888 lecture before a roomful of attentive engineers, spoke of a revolutionary motor that would henceforth do civilization's heavy lifting. Samuel Insull, addressing in 1898 his fellow utility operators, not one of whom was anything short of a capitalist, made his mark by greatly enlarging the number of people who could use electricity. He did this by paying attention to load curves and ratemaking.

Now it was the turn of Lenin to address a rapt audience. Lenin who would alter grid history. Lenin, arch conspirator, who had been in and out of jail, who had personally ordered the executions of many men and women, was now proudly standing before a roomful of his fellow revolutionaries, many of whom had fired a gun into a man's head or liberated a factory while holding a red flag. Lenin had been the chief architect of the main program of the Bolshevik Party. This First Program of the Party had been to overthrow the existing order and set up a socialist government. Now, to the delegates of the new regime, he was promulgating a Second Program for the Party, namely the vast enlargement of the Russian economy through electrification.

Here were some of his practical pronouncements. If he had his way, at congresses such as this, "the politicians will speak less, engineers more." Hereafter there would be "less speechifying, more economic results." The engineering ethos had to be inculcated: "Every single electrical station that we build," he said warmly, should be "a center of enlightenment, occupying itself with what we might call the electrical education of the masses" (ref 4.15). His most famous slogan was later emblazoned on the wall of every power station. The force of the remark and its formulaic, almost incantory, nature obliges the use of capital letters:

> *COMMUNISM IS SOVIET POWER PLUS THE*
> *ELECTRIFICATION OF THE WHOLE COUNTRY.*

Whether or not we believe eyewitness accounts that at this point in the speech listeners actually leaned closer to hear every word, whether we believe that during the technical presentation of the plan the revelation of each new power station on the display map was met with delighted murmurs and gasps, and whether or not we suspect that the voting members of the Soviet would always keep in mind that the man at the podium might devise a quiet liquidation for non-cooperators, we should all recognize the audacity of the proposed program.

Actually, Lenin's electrification plan did not enjoy unanimous acceptance. Indeed, in its call for vast funding and political support for untried technology, the Bolshevik electrification plan of 1920 has been compared to Ronald Reagan's "Star Wars" missile defense initiative of 1983 (ref 4.16). Both plans wanted to alter abruptly the existing political framework through the confident use of technology which did not yet entirely exist. History is almost always ironic: Lenin's dream of a huge industrial revival based on electricity would, to an impressive extent, be fulfilled; but the Soviet Union itself would later pass out of existence. Meanwhile, Reagan's dream of a missile shield against Soviet warheads did not materialize, but the Cold War itself, and the massive Soviet threat, went away.

In the case of the Soviet grid, what exactly did the skeptics worry about? Here are some of the potential problems. First was the issue of local fuels for firing the dynamos. There was plenty of peat lying about, but peat---essentially solidified swamp---is a low grade of fuel. Even dried out it is still somewhat moist. How efficient can a power plant be running on stuff like that? Other problems: one of the first and biggest proposed Russian hydroelectric plants was to be built on a bed of clay-like material. Won't the foundation fail under so heavy a load? Also the preferential construction of 30 large regional power plants---the heart of the Electrification Commission plan---seemed to bypass or neglect many cities that had little or no electricity in favor of

Petrograd and Moscow. It was a national plan; shouldn't the whole nation benefit, not merely the two historical capital cities? And, patriotism aside, was it really wise to insist on using made-in-USSR heavy machinery when there was little expertise for doing this? Finally, how could one sector of the economy, the electrical, command such backing when the rest of the country was in collapse?

Soviet historians liked telling the story of the famous English writer H.G. Wells' 1921 visit to Moscow, his inspection of the ruined economy, his intense interview with Lenin, and his gloomy prognosis for the coming years. Wells was an astute observer of many things, and so his predictions concerning the proposed electricity-centered industrial revival, as described in his book, *Russia in the Shadows*, were particularly troublesome. Basically Wells saw Lenin as an impractical dreamer:

> *Can one imagine a more courageous project in a vast flat land of forests and illiterate peasants, with no water power, with no technical skill available, and with trade and industry at the last gasp? But their [projects for such an electrification] application to Russia is an altogether greater strain upon the constructive imagination. I cannot see anything of the sort happening in this dark crystal of Russia, but this little man at the Kremlin can; he sees the decaying railways replaced by a new electric transport, sees new roadways spreading throughout the land, sees a happier communist industrialism arising again. While I talked to him he almost persuaded me to share his vision..." (ref 4.17)*

Lenin suggested that the skeptical Wells return ten years later to see if the vision had been carried out or not. One can almost get the feeling that the subsequent history of the Soviet grid was geared toward wiping the condescending smile off Well's face. Dark crystal? They would show *him*.

Construction went ahead. Rail lines had to be built to the sites of some of the new power plants. In Petrograd, the big power plant changed its name and its fuel type. The new name, "Red October," came from the overthrow in October 1917 of the interim government that had itself overthrown the Tsar earlier in the year. As for fuel: in Tsarist times, coal was fetched all the way from Cardiff, in Wales. Now, sensibly enough, the fuel would be peat from Mother Russia. The engineers hurled themselves into locating faster methods of digging up this fossil fuel. It lies right at the surface; retrieving peat is like rolling up a carpet. In went carpet, out came electricity. Red October returned the favor by sending a portion of its output to energize the very harvesting machines that were bringing in the new peat.

Red October was still on duty when the Germans laid siege to the city in World War II. By the time their tanks rolled up in 1941, the city was called Leningrad, in honor of the founder of the Soviet state. Lenin's passing in 1924 marked a turning point in Russian history, featuring the rise to prominence of Joseph Stalin and the rapid decline of Leon Trotsky. Trotsky, creator of the Red Army, found himself on the wrong side of many ideological issues and, more lethally, on the wrong side of Stalin's ambition. Following Lenin's death Trotsky's comeuppance was meteoric. He quickly lost his post of war commissar and given various lesser jobs, including the directorship of electro-technical activities. Trotsky was in effect ruler of the Soviet grid and, although he did not know much about the electrical world at first, he turned with characteristic relish to engineering matters. "I was taking a rest from politics and concentrating on questions of natural science and technology." He read books, consulted experts, drew up reports, inspected power stations, and formulated recommendations (ref 4.18).

Unfortunately from the Kremlin point of view, and more particularly from the Stalin point of view, Trotsky was too important a personage and too great a threat to be allowed even the relative peaceful and politically innocuous work of administering electricity. Once, after returning from a visit to a prospective hydroelectric project on the Dnieper River, Trotsky dutifully submitted an enthusiastic summary of the solid results attained, to which Stalin reportedly replied that "The project would be about as much use to Russia as a gramophone to a peasant without a cow" (ref 4.19).

Having worked in the corridors of Soviet operations for so long, Trotsky had come to know his adversaries well and soon realized that he could never "take a rest from politics." Writing years later in his autobiography, he summed up his intolerable situation:

> *The electro-technical board and the scientific institutions began now to worry them [Stalin and his colleagues] as much as the War Department and the Red Army previously had. The Stalin apparatus followed at my heels. Every practical step that I took gave rise to a complicated intrigue behind the scenes; every theoretical conclusion fed the ignorant myth of "Trotskyism." My practical work was performed under impossible conditions. It is no exaggeration to say that*

> *much of the creative activity of Stalin and of his assistant Molotov was devoted to organizing direct sabotage around me. It became practically impossible for the institutions under my direction to obtain the necessary wherewithal. People working there began to fear for their futures, or at least for their careers (ref 4.20).*

Trotsky had earned his paranoia. In short order he resigned his electricity and engineering jobs, was relieved of all further government positions, was expelled from the Party, then exiled to a distant border town, and finally deported abroad. He lived in Turkey, then France, then Norway, and lastly Mexico. In 1940 the days of this onetime giant of Soviet life, master of the army and of the grid, ended when an assassin buried an axe in the back of Trotsky's head.

Progressive Grid

The lives of other greats from the age of electrical exploration did not end so dramatically. Thomas Edison lived on peacefully until 1931, inventing the whole while. On the occasion of Edison's final departure, his old associates inquired respectfully into the possibility of New York City's power being turned off for one minute in tribute. The request was denied.

In 1907 George Westinghouse lost control of his own company, as Edison had done in 1892. Seven years later, Westinghouse died. As for Nikola Tesla, the ever energetic whirlwind of ideas, he pursued many imaginative schemes---robotics, radio broadcasts, power transmissions through the air, and speculations about neurology---that have earned him a sort of cult following to the present day. He lived on until 1941. Charles Merz, like Leon Trotsky, died a violent death in 1940. Merz fell victim to a German air raid seeking to obliterate the enclaves of massed factories in East London, the same intensified, electrified industrial concentration that he had worked so hard to create.

As for Samuel Insull, he like Trotsky had been pursued across the world. He too had been stripped of his posts and scorned by government officials who had once been his admirers. In the wake of the 1929 stock market crash and the collapse of the utility conglomerates, Insull had been indicted on numerous state and federal counts alleging fraudulent methods in attracting investments for his holding companies. In a way, Insull's trial was a sort of show trial. He stood as the epitome of all greedy, manipulating robber barons. He was the leader of the Power Trust.

His trials received intensive news coverage---celebrity jurisprudence, 1930s style---and his accusers hoped for a long jail term. Insull claimed, basically, that he was in it for the electricity, for the energy, for the adventure of building something really big, and not so much for the money. He had indeed raised an empire, had helped companies in need, had combined corporations into larger corporations, had made a lot of money, to be sure, but had not committed, or intended to commit, crimes. He had sought to enlarge, diversify, economize, and strengthen the grid, and not to defraud or default. At his several trials the juries must have believed him because he was acquitted on all charges.

The great Depression of the 1930s had weighed heavily on everyone, especially those who owned stock, especially stock in utility companies. Owners of stock in Insull companies actually did better, on average, than other companies which sold stock. The utilities under Insull's personal command did not go bankrupt (ref 4.21). Commonwealth Edison, his flagship enterprise, flourishes to this day.

With little to hold him in Chicago, Insull moved to Paris where he lived modestly, but not poorly, in an apartment. In his elderly years, what does a man who had controlled the conductance of energy across generous swathes of the North American continent do with himself all day? Mostly he was shy of working in electricity, but he was pondering the building of a network of radio stations in the US. One day in 1938 in the Paris Metro his heart stopped. As it must for every man, death had come for Samuel Insull. If one were to fashion a *Citizen Kane* style movie out of this story, the last words to cross the dying mans’ lips would probably have been “...Pearl Street.”

Charles Merz had not been as mighty a figure as Insull. But then Insull, even had he wanted to, could not have done what Merz had brought about in Britain, namely a national grid. In the United States of America there could probably not be a national grid. So great is the anathema against anything nationalized that responsible officials, public or private, business or government, could probably not call for a national energy network, at least not one under the technical ownership of the federal government. True, it could not be denied that the government had helped to build some giant dams out west, such as the Hoover Dam on the Colorado River or the Grand Coulee Dam on the Columbia, but the electricity flooding from these projects was sold to private utilities, which in turn sold it to customers. This, American citizens would be reassured to know, was not socialism. Nevertheless, the US Government *was* about to get into the electricity business in a big way, owing to the confluence of certain economic and political factors.

During World War I, as a military measure, the government had built a dam on the Tennessee River in order to power a plant for producing fertilizer and explosives, both of which use lots of nitrogen obtained from an electrically-intense chemical maneuver known as the Haber process. The dam was completed but not until after the war had ended. What, economically minded critics wanted to know, would be done with the facility now that explosives were no longer required? Henry Ford, the premier capitalist in the land, offered to buy or lease the site and to develop it at his own expense. He did this not out of pure patriotism, for he had it in mind to tap still more of the hydroelectric potential of the Tennessee River Valley. And if he could do that, so could others. The Tennessee Power Company, a private utility, sought permits for building a whole series of dams of its own on the River.

It was at this time, in 1926, that Samuel Insull and the Power Trust were riding high. Some in Congress felt that these companies were too powerful and exercised too much influence over government. Without actually saying that capitalism was bad or intimating that it was immoral to run a corporation solely on the basis of turning as large a profit as possible, certain reformers wanted to clamp down a bit on what they saw as destructive greed. Senator George Norris of Nebraska, a Republican no less, succeeded in leading the passing of a bill to deny the use of the Tennessee to private power "predators" and instead to cede custodial care---including conservation of resources, navigation, and possible electrification enhancements---to federal jurisdiction. This unorthodox legislation was promptly vetoed by Republican President Calvin Coolidge.

The stock crash of 1929 and the ensuing economic downturn put the Power Trust and their alleged abuses even further into prominent infamy, and again Senator Norris passed a Tennessee reclamation bill in 1931 which was again vetoed, this time by Norris's fellow Republican, President Herbert Hoover.

Two more years went by. The Depression deepened, Insull's corporate framework was dismembered in spectacular manner, and utilities in general were beset with debt. Most importantly, a man itching for reform was elected to the White House. The new president had a long record of rancor against the producers of electricity. As a state senator he had tried to get New York to supervise development of the Saint Lawrence River for producing power. As governor he had sought to curb the rates and influence of the utilities. And as presidential candidate he had railed against the holding companies and had singled out Insull by name (ref

4.22).

With the exception of George Washington's first term, or the embattled tenure of Abraham Lincoln, no presidency had gotten off to a faster start than Franklin Delano Roosevelt's. The so-called Hundred Days saw the passage of many major pieces of legislation. Senator Norris, so persistent, now had his chance. Finally he had a president, albeit of the other party, willing to sign into law Norris's dream of an integrated regional development for the Tennessee. On 18 May 1933 the Tennessee Valley Authority, or TVA, came into being, and the federal government, after so much reluctance, was finally in the power business.

How unusual was the TVA? It was established as "a corporation clothed with the power of government but possessed of the flexibility and initiative of a private enterprise" (ref 4.23). Beyond this, the exact programs of the Authority, its methods, its goals, and its building projects were largely left to a triumvirate of directors. Two of the three FDR chose had been college presidents, one with an agricultural background, the other with expertise in flood control. The third director, a man of only 33 when he took the job, will receive all the attention because he was the person most associated with what the TVA became as a force in the lives of Valley people. He would also become a prime figure in establishing the ways in which the federal government would relate to private utilities to this day.

FDR's crash program in 1933 to redirect the efforts of government to inspire the citizenry and invigorate the economy resulted in many programs with notable acronyms. The most notable were the Works Progress Administration (WPA), the Civilian Conservation Corps (CCC), National Recovery Administration (NRA), and the Securities and Exchange Commission (SEC). Of these, the creation of the SEC and the passage of The Public Utilities Holding Company Act (aimed partly at companies like Insull's) had a considerable immediate effect on the way large utility trusts were configured (one company owning another company, which in turn owned another company). But of all the New Deal programs, perhaps the one that had the greatest impact on the way electricity was made and delivered would be the TVA, especially in the hands of the young director who, I shall argue, should take a place with the likes of George Westinghouse and Charles Merz in the electrical hall of fame. The age of the patriarchs might have closed out, but great grid developments still lay ahead.

A short history of the TVA, then, will constitute the next act in this drama of volts. The TVA was not just one of many New Deal programs for President Roosevelt, but the epitome of what he thought government could accomplish and the essence of what he was trying to do in the

American heartland. It was, he said, "the apple of my eye."

Potentiality for the Future

David Lilienthal was not Samuel Insull. Insull, immigrating from London as a young man, had not gone to any proper college but instead had learned the electrical trade in the most practical way imaginable by working for Thomas Edison. Lilienthal, by contrast, was a product of farmbelt Indiana and Harvard Law School. Insull came to Chicago in 1892 at the age of 32. He made his name building a vast grid empire. Lilienthal came to Chicago thirty years later at the age of 24. He made *his* name as a lawyer, first in labor disputes, then in utility matters (including one case against Insull), and later in politics at the state, national, and international levels.

They're paired here, Lilienthal and Insull, because despite their great differences---the one a conservative, the other a liberal; one a businessman, the other a government official---they had much in common. Insull is under-appreciated in the social and technological history of America and Lilienthal even more so. Insull achieved his importance by vastly enlarging the layout of the grid in Chicago, making it the most electrically-intense city in the world, and also by widening the universe of human activities served by electrical energy. Lilienthal also achieved fame by going to a place where previously only small amounts of electricity flowed and then building a mighty grid, a grid consisting partly of wires and partly of government statutes. He too helped widen the scope of electricity both by making electricity tangible in the lives of poor people and by re-inventing the role for government in energy transactions.

While still in his 20s Lilienthal was regarded as one of the top lawyers in the country on utility matters, and he was often consulted by prominent people in Washington. So it happened that when in 1930 the new governor of Wisconsin, who had come into office on the same reformist tide that would two years later carry FDR into the presidency, needed to appoint a state commissioner who could do battle with local utility companies, he knew where to look. With a mandate to lower rates and curb the influence of electric and telephone companies, Lilienthal took to his new job of public service commissioner with gusto.

In Wisconsin, as in many places in the US, the local electrical utility was typically a private business operating as a monopoly. In that case, you ask, why can't the utility charge whatever it wants? Because the utility would have been regulated by a city or state agency. This is the way most utilities had done business since the time of Edison and Insull. The method for arriving at rates was to grant the company a certain profit on top of its expenses. Exactly how much profit, and what counted as an expense, were two of the matters that regulators were paid to investigate. How much should electric power cost? Often difficult to say. The cost of an apple is pretty much set by the free market. Stores charge as much as they think they can get, making due allowance for the store across the street which also sells apples, and for the customers' option simply not to buy apples at all if the price is too high.

With electricity it's different. You can buy fewer or more efficient appliances, but mostly you have to go on using electricity. You wouldn't say to yourself, "Alright, today I'm not going to consume any power," in the way that you would say, "Today I'm not going to buy an apple." In addition, there is usually no competing utility across the street willing to send current into your home at a lower unit price. Most consumers are stuck with the utility they've got. Hence the need for regulation.

Establishing the fair value of electricity isn't easy. Nevertheless, one can poke through old publications and see how it was done. Here is a snapshot enumeration of Commonwealth Edison's balance sheet for one year, including both the expenses incurred and the profits allowed through the mechanism of regulated monopoly. For every dollar of income brought in by Sam Insull’s company, in the year of 1913, this is how the pie was divided: labor accounted for 17%; 11% went for fuel; 23% for materials, supplies, and miscellaneous expenses; 7% for taxes; 11% for depreciation, that is, for the cost of decaying equipment; 9% interest on all the borrowing the company had done in the past; 15% for dividends, which are rewards to the stock holders in the company; and 7% surplus to be plowed back into the company (ref 4.24).

In the 1920s the utilities, often banding into larger and larger holding companies, were making very healthy profits. Senator Norris found it bothersome that the prices charged for electricity by Hydro Ontario on the Canadian side of the Niagara border were much lower than those charged on the American side (ref 4.25). Franklin Roosevelt was also bothered, which is why he had wanted New York to get involved in developing the energy resources of the St. Lawrence.

Now, in 1933, Norris and Roosevelt could finally conduct their experiment in power production and pricing. The Tennessee Valley Authority would try to integrate the best federal and business methods. Their testing ground would be a watershed region of the Appalachian Mountains, their tool would be the TVA, and their point man in the enterprise would be David Lilienthal, an avid litigator known for his lawyerly skills and his crusading verve, just the qualities needed to sustain a project that would succeed or not depending on success in a number of arenas: the law courts, Congressional hearings, and in hundreds of small-town meetings in the affected communities to discuss the merits of the plan.

For being FDR's favorite New Deal program, the Tennessee Valley Authority had been rather loosely defined. Some argued that it was a gigantic welfare project. Others thought of it as a massive, concerted government effort to jumpstart the economy of the communities adjoining the Tennessee River. This is one of the great rivers of the American interior, a waterway wandering from headwaters in the mountains of eastern Tennessee, Virginia, and North Carolina, and then west and south into Alabama, and finally north up through Tennessee and Kentucky, where it meets the Ohio River at Paducah. This geographic region, an emerald realm the size of England, seemed to be singled out by President Roosevelt for special treatment. What that treatment would be had not been written explicitly into the legislation. TVA's mission, in generic terms, was to produce the greatest good for the greatest number of people.

The TVA *was* a welfare program, the most extensive and coordinated such project in US history. It set out to restore forests, build dams, counteract the loss of soil, improve navigation, promote the manufacture and use of fertilizers, mitigate health hazards such as malaria, and even to bolster local cultural activities such as the construction of libraries and the development of adult education classes. The TVA helped farmers and businessmen to set up new agricultural ventures, such as a cheese factory. All of these tasks had in the past been addressed singly by state or federal authorities, but never before altogether by a unified governmental approach. The TVA was to be a great social experiment, and if it succeeded maybe it would be tried elsewhere. The president had said often that if things weren't working---and in Depression-era America, there was plenty of failure---new methods had to be tried.

The TVA proceeded to carry out these tasks. It changed the lives of millions of people in the Tennessee Valley, mostly for the better. But what TVA is best known for, what it *appeared* to be to most observers, especially those living outside the Valley, was as a producer of electric power. The TVA would build a lot of dams which filled up the riverine system of Appalachia with a succession of massive concrete walls, each with its own gigantic reservoir behind it. Each dam construction project had its poignant saga of work camps, home clearance, evacuation of households above flood level, and the creation of a new ecosystem, replacing what might have been a sluggish stream with an extensive lakeshore. People had to move and cemeteries had to be relocated. One man, claiming that the flame in his family fireplace had been burning without stop down through the generations for a hundred years, agreed to move only if the fire, continuously lit, could be moved too, and so it was (ref 4.26). Whole towns were covered by the gathering waters in what could be seen by some Bible-minded skeptics as a miniature Noah's-arc flood. In reality, Lake Norris, the body of water behind Norris dam, extended for 47 miles: this was long but not exactly of Biblical proportions. The collective impounded water covered a total area the size of Rhode Island (ref 4.27). Birds were obliged to nest elsewhere, fish were presented with new habitats, roads were rerouted. The Tennessee was no longer a mere river. It had become "The Great Lakes of the South," with associated shipping ports and recreational parks and resorts.

New homes went up. Old homes got new paint. A literacy campaign went forward. What got most of the scrutiny, however, was the electricity created as billions of gallons of water pushed past turbines on its way through those dams. Skirmishes erupted over how much fertilizer to use or how to keep down the mosquito population, but the big battles were over volts. Some had expected that as in the case of Hoover Dam the federal government would help out in the construction phase but not in the marketing and distribution phase. Many assumed that the energy produced at the dams would be sent out over wires and then sold to existing private utilities which would then deliver it to paying customers.

David Lilienthal disagreed. Harking back to Senator Norris's view that the waterway resource was not there merely to serve privateers, Lilienthal saw to it that those utilities did not necessarily take possession of the Tennessee's electricity. TVA just might market the energy itself. On this issue Lilienthal came into quick dispute with one of his fellow TVA directors, Arthur Morgan. Morgan was a high minded man. *His* TVA would be an idealized version of public-private cooperation, government funds married to individual initiative, New Deal politics working seamlessly with traditional capitalism.

Lilienthal, also an idealist but more familiar with the pragmatic world inhabited by lawyers, lawyers both on the government and on the utility sides, was eager to joust with the companies. Lilienthal's TVA would be the means for determining once and for all the true cost of making electricity. With all the mechanisms of generation at its disposal, the TVA could furnish the yardstick for production costs that Lilienthal had never quite achieved in Wisconsin. No, if he had anything to do about it, TVA would not mutely surrender its electricity to private utilities. The TVA would sell power to cities and factories directly. It might even build its own long distance transmission lines.

The private utilities screamed. TVA paid no taxes, they charged. TVA had access to guaranteed government loans. It had cooperation from the Army Corps of Engineers and other agencies. What TVA was doing was unconstitutional. Improving navigation on the Tennessee was a proper federal prerogative. Reducing flooding through the use of dams was permissible. But making and selling a product, commercial electricity, was against what the Founding Fathers ever would have been recognized as a proper government activity. Did the TVA represent the beginning of a socialist takeover? Here is what the *Chicago Tribune* had to say in an election-year editorial entitled "Vote for Republican Congressmen."

> *Another Congress like this one which has authorized the NRA [National Recovery Act] to put small businessmen in prison, the AAA to destroying food, and the TVA to establish a little Red Russia in the Tennessee Valley, will do unimaginable damage to the American people (ref 4.28).*

Wendell Wilkie was president of the Commonwealth and Southern Holding Company which had power lines in and near the TVA region. Young, an eloquent industry spokesman, and ambitious (he proved to be FDR's future Republican opponent in the 1940 presidential race), Wilkie happily took TVA to court.

Lilienthal was ready. He had plenty of utility litigation practice in Chicago and Wisconsin. The Tennessee Valley would be Wisconsin times a hundred. Lilienthal was not anti-business, not against private enterprise, but he did feel that he had received a mandate from the President, as he had earlier received a mandate from the governor of Wisconsin, to win lower electric rates for consumers and to increase thereby overall consumption, particularly among the disadvantaged who had previously been left off the grid. And there were plenty of disadvantaged in the Tennessee Valley. Lilienthal wanted to be their champion. He was in effect a territorial governor operating at the energy frontier. TVA was his Wild West, his NASA.

He explored ways of producing cheaper power, selling cheaper appliances, stimulating higher consumption. Indeed, by twisting some arms, Lilienthal got the major manufacturers (then as now: General Electric and Westinghouse) to build models that sold for roughly half the previous price, thus encouraging a new era of electrical conveniences in the home (ref 4.29). Lower rates and greater consumption: Lilienthal was, in a strange way, a federal version of Samuel Insull.

FDR was so pleased with these efforts that he ushered in the Rural Electrification Administration (REA) in order to promote electric use among other have-nots in the rest of the country.

Ten years into the history of TVA it was clear that Lilienthal had won. Wendell Wilkie and the utility lawsuits had been unsuccessful. Decisions all the way up to the Supreme Court had validated the constitutionality of TVA and its role as a distributor of power. TVA's grid was now the largest government-controlled power network in the US.

David Lilienthal wrote a popular book, *TVA: Democracy on the March,* to explain the purpose and achievements of the agency on its tenth anniversary. The first thing he does in the book is to deny that TVA was meant as a threat to private business or that it was intended as the first step in a socialist plot to take over America. "The TVA experiment has been carried out under the existing rules of the game of American life. It required no change in the constitution of the United States. Congress maintained full control. Property rights and social institutions have undergone no drastic amendment" (ref 4.30).

There was, moreover, much to be proud of. TVA jobs, Lilienthal reminded his readers, were awarded on the basis of merit. He could boast that congressmen had expressed frustration at having little success in extracting any political patronage out of the project. The TVA system consisted of dozens of dams, constituting the largest engineering feat in US history undertaken by a single organization, the excavation and construction amounting to the equivalent of 20 Empire State Buildings. The internal lake and river shoreline created in the process was thousands of miles long and rivaled in magnitude the Atlantic and Pacific seacoasts of the country (ref 4.31).

In his writings and speeches, Lilienthal emphasized the multi-purpose aspects of the TVA's work, such as its promotion of fertilizer and better navigation. Once, when the New Orleans water supply was threatened by a backflow of water owing to the slackness of the Mississippi River, TVA had helped out by releasing more of its water (ref 4.32). The genius of the dam system allowed for this contingency: a few levers were pulled by engineers in the Appalachian Mountains, and 1500 miles away New Orleans got the water it needed. Inevitably, however, both Lilienthal and his critics were drawn back to the electricity issue, and this is what he will be remembered for.

Waxing philosophical about the lamps, refrigerators and electric farm implements newly possessed by Valley inhabitants, and citing impressive superlatives, such as the fact that the TVA would eventually become the largest power producing region in the US, Lilienthal liked to promote the production of electricity as being practically an *ethical* undertaking:

> *Such figures as these [the amount of TVA electricity] are more than figures; they have deep human importance, for this must be remembered: the quantity of electrical energy in the hands of the people is a modern measure of the people's command over the resources and the best single measure of their productiveness, their opportunities for industrialization, the potentialities for the future (ref 4.33).*

The TVA had outlasted its critics. Its legal staff, called the best of any federal agency, had defeated Wendell Wilkie and his utility cohorts in court, and then had bought him out, at least within the TVA region, making TVA the sole power producer in the Valley. Some argued that the TVA had itself become a power trust. Lilienthal disagreed vehemently. The TVA, he asserted, was in the business of helping, not gouging, ordinary folks. Liberating, not coercing. True, the idea of an energy "yardstick," determining the cost of producing a kilowatt of electricity, had not exactly panned out. It could not be absolutely proved that federally-produced electricity was cheaper than privately-produced electricity, but Lilienthal liked pointing out that the TVA *had* succeeded in doing two big things: lowering the prevailing rates (in its own and in neighboring regions) and substantially driving up demand for electricity. Before TVA, Lilienthal said, consumption in the Valley area was 50% less than the US average. After TVA had been in place, the Valley average had risen to 25% more than the US average (ref 4.34).

David Lilienthal was an effective administrator for several reasons. He possessed great energy, was a charismatic speaker, remained a friend of congressmen and governors even as he remained largely unencumbered with the sort of payback usually required in return for political support. He thrived in public meetings and was noticeably dedicated to his great enterprise. His enthusiasm, intense to the point of lyricism, showed up vividly in his writing, especially on the topic of electricity and how it transforms the land and the people. He is not normally classified as a poet, and yet some of his prose bears a comparison to some of Wordsworth’s verse. Here is Lilienthal describing his own Lake District. He talks not of daffodils or passing clouds but of hydroelectric power:

> *There is a grand cycle in nature. The lines of those majestic swinging arcs are nowhere more clearly seen than by following the course of electric power in the*

> *Tennessee Valley's way of life. Water falls upon a mountain slope six thousand feet above the level of the river's mouth. It percolates through the roots and the sub-surface channels, flows in a thousand tiny veins, until it comes together in one stream, then in another, and at last reaches a TVA lake where it is stored behind a dam. Down a huge steel tube it falls, turning a water wheel. Here the water's energy is transformed into electricity, and, moving onward toward the sea, it continues on its course, through ten such lakes, over ten such water wheels. Each time, electric energy is created. That electricity, carried perhaps two hundred miles in a flash of time, heats to incredible temperatures a furnace that transforms inert phosphate ore into a chemical. That phosphatic chemical, put upon his land by a farmer, stirs new life in the land, induces the growth of pastures that capture the inexhaustible power of the sun. Those pastures, born of the energy of phosphate and electricity, feed the energies of animals and men, hold the soil, free the streams of silt, store up water in the soil. Slowly the water returns into the great man-made reservoirs, from which more electricity is generated as more water from the restored land flows on its endless course (ref 4.35).*

Top Secret Grid

However removed this green valley of the Tennessee might have been from international broils, when the nation went to war in 1941, so did the TVA. Soon 75% of its electricity went for war work. In fact so much power was needed that hydroelectric generation was no longer enough. The Tennessee River had given all that it could and so the directors (Lilienthal was chairman by now) did what other utilities would do: it built some coal-fired steam-electric plants. In an earlier time critics might have said, see, the TVA is a power company like any other. We told you so. The TVA doesn't even pretend anymore that the dams are there to help navigation. The dams are there mainly to make power. And now, look, they're adding thermal generators too. But complaining was scarce since this was war and the country needed more electricity.

Lots of electricity is what you need to extract aluminum from the embrace of its rocky ore. Hydro electricity is what had attracted heavy industry to the Niagara and this is what now brought the largest aluminum plant in the world to the Tennessee Valley. Electricity went into the metal and the metal went straight into the bombers dispatched out over other valleys, such as the Ruhr. How much power was needed? Lots: the amount of electricity used in making a Flying Fortress bomber was equal to the power used in an average American household over about 400 years (ref 4.36).

There also came at this time a particular request from the army for more energy, much more energy, for a peculiar facility it was building near the town of Oak Ridge, in the remotest part of eastern Tennessee. Lilienthal, the man who presided over that hoard of power, was not taken into the confidence of the higher officials as to the plant's purpose even though it was located in his province. The TVA network had always been a sort of sovereign grid within the nation's overall grid, and now here was a grid within the grid within the grid. All Lilienthal knew was that the secretive site constituted an immense energy sink: every day more and more electricity went in but nothing ever seemed to come out. What could they be building in there? What kind of strategic metal were they extracting?

Only at the end of the war, actually on August 6, 1945, did the world learn what had been going on at Oak Ridge. To make the needed military electricity, TVA had for years been harvesting gushing water, so called "white coal." When that wasn't enough TVA resorted to scraping the more traditional black coal from the surrounding Appalachian hillsides for burning in steam-electric plants. Now a new energy-rich material, uranium, a sort of yellow coal, was being put to controlled use for the first time in human history. When separated from its ore, and when the specific variety of this element had been selected out through laborious enrichment, a process carried out at Oak Ridge, inside the largest building in the world, the net product would be the most precious and dangerous lump of matter in the world. From the bowels of the TVA had come the working substance for the device, delivered by one of those electrically-crafted aluminum aircraft, that flattened the city of Hiroshima in an instant. The regular war was over and the nuclear campaign had begun.

Cold War Grid

It was time to take stock. If the TVA were a person, it would probably have received a medal for meritorious efforts during wartime. TVA's military work aside, however, one could ask now whether the TVA experiment had been successful. David Lilienthal was unequivocal in saying yes. In its first job, that of helping to relieve the Depression-era plight of the Valley people, one can say that living conditions had definitely improved. Literacy, libraries, and soil conservation were up. There had been a huge increase in power consumption. But were the costs worth the investment? Things had improved for Valley citizens, but who had paid for this? The taxpayers of the nation. Wendell Wilkie was fond of saying that "The Tennessee River flows through seven states but drains the nation" (ref 4.37).

Power consumption in the Valley had gone up, but consumption just outside the Valley had gone up just as much, or even more (ref 4.38). Navigation on the river was improved and Knoxville was now a "seaport," linked through locks with the Ohio River. Through its system of dams and locks, the Tennessee was, as Lilienthal liked to say, the most controlled major river in the world (ref 4.39). But getting to Knoxville from the ocean was expensive; from the level of the Ohio River at Paducah up to Knoxville is a vertical climb of 515 feet over a distance of 648 miles. The volume of river traffic might not have justified the expense (ref 4.40). The steam-electric plants built by the TVA augmented its power to an immense degree, so much so that the hydroelectric component became only a minority of all TVA power produced. Other turns in the tale of TVA: it would eventually become the largest consumer of coal in the nation (ref 4.41) and, in the course of time, the largest violator of the Clean Air Act (ref 4.42).

World War II had seen the defeat of Germany and Japan, but quickly these nations were on their way toward being allies while, conversely, the wartime ally, the Soviet Union, was becoming more of a menace every day. The bomb technology perfected at Los Alamos and the fuel enriched at Oak Ridge were now at the center of a critical debate over the future use of nuclear energy (a debate to be explored in more detail in chapter 8).

Lilienthal, with his extraordinary expertise in operating a large government energy agency, participated in the deliberations about how to handle the new and dangerous form of energy. Partly because of Lilienthal's persuasion, Congress decided that all of the nation's nuclear knowledge, assets, and future missions, should be transferred from the army to a new civilian entity, the Atomic Energy Commission, or AEC.

Looking over the annals of TVA history, several large epochs present themselves. In the 1930s the TVA was viewed as a tool for declaring war on Depression misery in the Tennessee Valley. In the 1940s the TVA helped to fight the war against the Axis powers in Europe and Asia. And on into the 1950s and beyond, the TVA would use a majority of its power to wage the new war of Communist Containment. The TVA would be the power supply for the AEC. The TVA grid had become and would remain partly a military grid.

It was not surprising that David Lilienthal, chairman of the TVA, should become the first chairman of the AEC. The man who had carved out a hydroelectric empire in the rivercourse of the Tennessee would now launch an even larger and more strategic empire spread out in a dozen labs around the country, an empire based on the nuclear activity of uranium and plutonium. He and his associates, and those in a handful of other countries, would constitute a nervous new plutocracy controlling---or at least threatening or preparing to use---the most extravagant form of energy yet devised by the human race.

Electricity had been used to forge the primordial nuclear device, the atom bomb. Vice versa, years later a different nuclear device, the reactor, was used to make electricity. This two-way marriage of convenience between nuclear and electric forces, although apparently sanctioned by wartime or economic necessity, has never ceased to cause anxiety. Extraordinary that Lilienthal should in succession have had both these tigers by the tail.

Soviet Grid

The reason why the US had such an overriding concern for things nuclear, now that the Axis threat had been put to rest, was the Soviet threat. Although suffering more than 20 million dead during the World War, the USSR was soon more powerful than ever, and aching to match US technological attainments, particularly in the nuclear and electrical departments. The many Russian power plants destroyed at the hands of the fascist invaders were replaced and the grid was put back in place. Peat was no longer the life-or-death fuel it had been in the 1920s.

Early critics of the TVA had complained of government dictating power policy or coercing new habits of energy consumption. But the TVA's dictation was nothing compared to the People's Commissariat of Heavy Industry which, in the interest of leveling out the load curve for a power station (that is, putting the expensive dynamos to more efficient use all around the clock), could order factories to stay open on through the dark times (ref 4.43). Soviet scheduling did not divide Sunday from the week. Russian factories did not sleep. We want volunteers for the midnight shift: you, you, and you.

The TVA was indeed "interfering" with the consumption habits of poor rural folk in Appalachia, insofar as they were running wires to these people for the first time and were encouraging the making of affordable washers and vacuum cleaners. Compare this to the far more regimented command economy of the USSR where, for example, the architects of the

1959-65 plan ordered by decree that refrigerator sales should rise by a factor of 5.8 (not 5.7 and not 5.9), washing machines by a factor of 9.1, and TV sets by 4.6. "In 1965, the number of radio receivers is to rise to almost 30 million," said one directive (ref 4.44).

To read Soviet publications about their grid is to see ever-upward-sloping graphs and always-reached quotas. Russia had catapulted past all the European nations in total (although not per-capita) electric production and now set its sights on overtaking the world leader. In the late 1950s, sensing victory in the lap ahead, Soviet planners decided to delay the time-consuming construction of hydro-electric plants. Why? The party organ explained the approach:

> *The point is to give priority to the construction of thermal stations so as to make the most of the time factor in the competition with capitalism and to overtake and surpass, the United States of America in production per head of population (ref 4.45).*

In other words, in order to pass up the US in the shortest time it was better to build steam- plants because they're easier and faster to construct than hydro-plants. H.G. Wells had been wrong about the Soviet grid. Russia was no dark crystal but a world contender.

The Soviet electrical network, completely owned and managed by the government, was at one end of the jurisdictional spectrum. At the other end was the privately-owned, capitalist grid which, while often operated under state regulation, was out to make a profit. Somewhere in between these two extremes were the TVA grid and the nationalized grids of democratic nations such as Britain and France. A tangible artifact of these three types of grids can be found in the signature slogans mounted onto the sides of the respective powerhouses. In the USSR, Lenin's maxim about communism being the sum of Soviet power and electrification was riveted to the walls (and can still be seen at some installations). At the TVA, the inscription carved into the dam structure (and still there) reads simply: "Built for the People of the United States." Meanwhile at the Niagara generators, a simple plaque bearing numbers was proudly bolted to the dynamo. On closer scrutiny the visitor would see (and can see nowadays at the Smithsonian Museum) that the plaque specified legal claim to the generation process being used to make electricity; the numbers were those of the famous Tesla patents sold to, and proudly owned by, the Westinghouse Electrical Corporation.

In this chapter we have looked at three grids that had an impact on electrical history in the

20th century. The story of the British grid showed how one could turn a tangle of uncoordinated utilities into a unified regional or national grid. (Grids in Germany or France could have served equally well.) Next, the Soviet example showed how a nation's electrical network, shattered by a series of violent overthrows, could be rebuilt from practically nothing to a mighty place in the rank of world electrical networks (right behind the US) through heroic work and through the kinds of pressures a totalitarian regime can muster.

The third wide-ranging grid, that of the TVA, was chosen to illustrate how federally-owned power production fits into an American grid subsisting largely of the joint activities of privately-owned utilities. For the fourth setpiece grid, we will now return to the first grid, the one that Edison built at the foot of the Brooklyn Bridge in 1882. Owing to its historical role in setting electrical trends and in practically epitomizing the idea of the arch-capitalist company, we circle back to the story of the company that became Consolidated Edison of New York.

The World of Tomorrow

The Wizard of Menlo Park had overseen in person the building of the grid in New York, and went on to sire many other offspring, 185 of them in the US alone by the year 1888, in places from Spokane Falls in Washington Territory (it wasn't yet a state) to Boston and at many places in between, such as Anna, Illinois (with a complement of 275 bulbs), Cazenovia, New York (500 bulbs), and Salidia, Colorado (500 bulbs) (ref 4.46). Edison's company underwent many changes; the affiliates went their own ways, the Edison research and manufacturing operations were absorbed into General Electric in 1892, and the part of the business that operated the Manhattan grid was bought by the Consolidated Gas Company in 1899.

It is that grid fragment of the old Edisonian kingdom that will be of interest here. Though it had begun as a subsidiary, this first of all the big-city electrical networks never behaved like a vassal. New York Edison was destined always for greatness. From its base in Manhattan the company ran wires along the side of the Brooklyn Bridge in order to hitch itself to Brooklyn Edison. By 1902, the whole of Manhattan and Bronx were electrified, with the other boroughs close behind. In the 1920s, a period that saw more electrical capital expenditure than any single decade of spending during the railroad boom of the previous century (ref 4.48), New York reclaimed from Chicago the honor of having the world's most powerful steam-electric generators.

In 1936 the combined gas and electric company changed its name to the one it bears to this day: Consolidated Edison. Its motto was "Dig We Must" because they never seemed to stop ripping up some street to repair or expand the wiring. By now they were connected with that other big power center at the diagonally opposite corner of the state, the Niagara-Mohawk company, via a robust cable kept at 138 kilovolts. Such lines were creating what could be called a United States of Electricity. Its confederated members---Syracuse, Rochester, Providence, Boston, Buffalo, Hartford---could buy and sell surplus energy in the span of seconds. Observing this power pool in action will occupy the whole of the next two chapters. Other such electrical leagues were becoming common, in the US and elsewhere.

To see how much inter-grid cooperation works, look at what happened in 1944 when a fire in the Bronx knocked out two huge generators. A moment before the accident, New York had been exporting 70 megawatts of power *to* the north. One second after the breakdown, 100 megawatts of relief power *from* the north came galloping to the rescue (ref 4.49). The New York City grid had stayed intact because of the outside help. Twenty years later, New York returned the favor. On the very day a new tie line was opened between New York and Connecticut, a blackout in Hartford was averted by swiftly-switched reinforcement energy from the south (ref 4.50).

Con Edison was in business to do business, but when war came the utility did its patriotic duty, the same as TVA. TVA had its aluminum plant and so did New York. There was a problem though. To feed power into the plant you need thick copper cables. But this was wartime and copper, like most draft-age young men, was already spoken for. Recognizing the strategic need for the aluminum and the electricity that would be needed to extract it from its rocky ore, the Army reluctantly lent from its famed vault at Fort Knox several thousand pounds of silver bouillon, just as good a conductor as copper, but posted armed guards to watch over the wires made from the precious metal. The silver being energized up to a level of 132,000 volts was even more of a deterrent to thievery (ref 4.51).

Con Ed and the electricity industry in general were on the march. Even through the terrible Depression of the 1930s, electricity consumption had mostly been going up. The 1939 World's Fair, held in New York, was the ideal place to show off. At the General Electric pavilion, for example, one could glimpse an artificially-produced 10-million-volt streak of lightning. One could see a portable radio the size of a suitcase, and be among the first to observe the demonstration of technology that would permit pictures to be broadcast along with sound in one unified radio signal. This early sample of television was powered by Jumbo Number 9, the same generator that had played the starring role on that first morning at Pearl Street in 1882. Jumbo had survived the powerhouse fire of 1890, had been a star at the Columbian Exposition in 1893 and another exhibition in St. Louis in 1904. It retired to Henry Ford's museum in Detroit, where so much other Edisonia is stored. It managed to exert itself once more in 1932 on the 50th anniversary of Pearl Street. And now here at the New York fair of 1939, its internal battle of magnetic fields once again compelled electricity to flow through wires (ref 4.52).

The world-of-tomorrow theme at the Fair was especially prevalent at the Con Ed pavilion, where a gigantic diorama, a stylized rendering of the five boroughs, vividly juxtaposed the past and the future. The City of Light, as the display was called, depicted activity all over, under, and through the metropolis. Electrification, the viewer was reminded, was pervasive in daily life, but still charmingly new:

> *Yet it is amazing to think that most of the magic we see today---our skyscrapers, our great bridges, even the automobiles and subway trains moving to and fro beneath our rivers, and the great winged ships in the sky overhead---all these man-made miracles have happened in the short span of a human lifetime. For less than sixty years have passed since Edison gave the world its first power station. There, at Pearl Street in 1882, in the shadow of the construction of Brooklyn Bridge, our world of today began (ref 4.53).*

The Fair brochure congratulated its readers on their embrace of electricity over the previous six decades. But this was to be nothing compared to the ardor for voltage shown after that. In the period between the World's Fair of 1939 and the one in 1964/65 (also in New York), power consumption in the US tripled (ref 4.54). David Nye, an expert on early American technology, draws a vivid portrait of the tremendous amount of concentrated energy available to Americans courtesy of their 1960s-era machinery. For example, the average home had the use of more energy than a small colonial-era town; a color TV, played for four hours, used more energy than a team of horses rendered in a week; a typical automobile possessed more horsepower than the output of ten small water-driven mills (ref 4.55).

This chapter has looked at four grids---those in Britain, Russia, Tennessee, and New York---that were big and always striving to be bigger. Utility planners must be close to their demographics: more customers means more electricity means more ways of making electricity.

On the eve of that second New York World’s Fair, Con Ed was preparing for the future with an ambitious slate of new construction, including (1) the largest pumped-storage power plant in the US, a facility where river water is carried uphill to a reservoir in the middle of the night and then, at rush hour the next day when electricity was needed the most, the water would cascade downhill, like a small Niagara on the Hudson, to be turned back into electricity; (2) the nation's first privately-financed nuclear power plant at Indian River, also to be situated on the Hudson; and (3) the world's largest steam-electric plant, the first to reach the billion-watt level. The story of what happened to the pumped storage plant and the nuclear plant come for later. The gigawatt plant, on the other hand, for reasons that will soon become apparent, deserves our attention right now.

The Everest of Generators

A leading generator manufacturer of the day, Allis Chalmers of Milwaukee, had once built a relatively small 7-megawatt generator (although in 1903 it would have been the world’s largest), known affectionately as Little Allis, for Con Ed's East River Station. So when the same company was called upon to build an unprecedentedly big machine for the Ravenswood power station, the newcomer was dubbed Big Allis. For engineers, the building of this behemoth was to pass a psychological threshold analogous to breaking the sound barrier (ref 4.56). This would be the first steam-electric dynamo to reach the 1000-megawatt plateau.

Why build something that big? Economy is the main reason. In a business where sales are measured in hundreds of millions of dollars, if by choosing one generator design you could save even a few percent on costs in the construction or operation of a plant, then you would be highly motivated to adopt that design. From Sam Insull's day right up to the 1960s, when Big Allis was built, it was the case that bigger was better: cheaper to build (cost per installed kilowatt of capacity) and cheaper to run (cost per kilowatt of output). Facing the East River just north of the 59th Street Bridge (and within visual distance of several other former world's-largest generators---the whole constituting a Pearl Harbor of topline dynamos) Big Allis brought Con Ed's total capacity up to 7000 megawatts, double what it had been only ten years before.

Just as Jumbo unit 9 had been the star of Edison's 1882 grid, so Ravenswood unit 3 was meant to be the star of the 1965 Edison grid. More than any Dreadnought battleship, Big Allis was a world unto itself, what with a million feet of cable, 360 miles of tubing, 50,000 electrical connections, 12-story-tall double boilers for making 1000-degree steam, a smokestack half the height of the Empire State Building, and pumps for forcing 530,000 gallons of water per minute through its condensers. Allis was an energy omnivore, swallowing 1000 gallons of oil per minute or 2 million tons of coal per year (ref 4.57).

Naval powers of the world have usually been worried by rival builders of battleships putting their ships aggressively into the common ocean. So it can be with utilities watching dynamos of overwhelming power being wired up to the common grid. From across the Hudson River, engineers at the Public Service Electric and Gas Company of New Jersey, the main power company just to the west of New York, viewed Big Allis with some trepidation. The fact of interconnectedness meant that in a certain sense generators forming part of the grid next door were part of *your* grid too. A generator from the next jurisdiction could pose a danger. Utilities mostly appreciated the usefulness of a working alliance with other power companies, but they were mindful too of the price of grid imperialism. Like a miniature sun, a 1000-megawatt power plant could look like a ball of energy; flexing its potency, could such a machine burn out other grid's circuits? One New Jersey engineer, seeking extra insurance, argued for installing extra circuit breakers between the systems (ref 4.58). Just in case.

There might be suspicion in New Jersey, but to the residents of New York, the new sun in the firmament was welcome news. To great fanfare, Big Allis exerted itself for the first time on July 16, 1965. A month later another day for celebration came along. It was "Con Ed" day at the World's Fair (built on the same grounds in Queens where the 1939 Fair had been), and some 22,000 employees, spouses, and kids thronged through the turnstiles. The 64/65 Fair, attended by tens of millions, was hardly a fizzle, but by some accounts it did not quite match the magic of the '39 Fair, especially when it came to the allure of electricity. According to sociologist Morris Dickstein, "1939 had been the promise, 1964 the fulfillment." "By 1964 the future had already happened" (ref 4.59).

In 1939, television (radio with pictures) was a dazzling expectation. By 1965 television had not only arrived but was highly embedded in the visual landscape. Other wonders: electronic brains, automatic figuring machines, were now performing thousands of times faster than the smartest mathematician. In the oceans, voyagers had visited the seafloor. In the sky above, men had circled the globe in 90 minutes and had walked in outer space tethered to a frail craft. The Moon was next.

Why did Con Ed deserve a whole day to itself at the World's Fair? Why? Because they were

Con Ed. With 26,000 workers, they were the largest business-managed utility in the country. They had 180,000 stock holders and were the biggest real-estate taxpayer in the city (ref 4.60). If you went to work for Con Ed, it was not uncommon to work there the rest of your life. It was not unusual that your father, grandfather, and maybe some aunts and cousins, sisters, and daughters worked there too.

The company was a small civilization by itself. It had its own softball leagues, an Emerald Society for Irish-American employees, generous widow benefits, and a bureau for veterans' affairs. It had clubs for blood bank gallon donors, and had regular banquets for 25-year and 40-year staffers. Athletic and culture clubs? They had them for angling, bowling, archery, bridge, skiing, chess, camera, organ playing, stamp collecting, and many more. There was a Con Ed Society in Florida. Safety records were proclaimed in the company newsletter, along with new babies, deaths, baking awards, civic voluntarism, and scouting merit badges. This all-encompassing company had earned special treatment.

The Con Ed employees were met by Fair president Robert Moses who, having built the Verrazano Narrows Bridge, Shea Stadium, Lincoln Center, and dozens of other major architectural landmarks around the metropolitan area, was one of Con Ed's few historical rivals in shaping the physical landscape and environment of New York City. Moses welcomed the utility employees with timely flattery: "Consolidated Edison Company, which heats, lights, and powers our city. Without you, we would be paralyzed and our future would be dark indeed" (ref 4.61).

This proposition would soon be put to the test.

22 September 2005

Chapter Five

Worst Day in Grid History

The electrical grid is too big to encompass in your head. Its thousands of miles of overhead high-voltage transmission line and the many more miles of smaller wires spooling out underground and through walls are too numerous to count and too spread out in area to be easily grasped. Even a portion of what counts as the North American grid is dauntingly huge. Nevertheless, we shall now attempt to fathom the unfathomable. We will try to wrap our minds around the Eastern Interconnection, a geographical electrical network which, on November 9, 1965, took in much of southeastern Canada and northeastern United States.

To set the stage for the exciting event taking place on that day, please picture the extended grid as being a vast internal sea of energy. If Genoa and Tunis and Barcelona and Tel Aviv and Beirut all look out onto the same Mediterranean Sea and draw fish from it, then so, in an important sense, do Rochester and Boston and Toronto and Providence all look out onto a common voltage seaway and draw energy from *it*. A curious and useful property of electrical circuits is that power made in Queens, New York can be ladled out of this sea a fractional second later in Hartford, Connecticut. All the cities of the grid are coastal whether or not they abut actual saltwater.

This energy ocean can’t be seen but it's there. It edges right up to your home. Waves are lapping 60 times per second, and not just on some shore out back, but between the joists beneath your parlor rug. This sea sends waves up every single cord. Plug in another machine in the corner of the room, and instantly the energy sea extends in that new direction.

Instead of a universal sea level, the internal electrical sea is maintained at universal levels of frequency and voltage. Not only do the waves arrive everywhere at the same rate---60 times per second in the US, 50 time per second in France---but in the same phase with the same choreographed movement. That is, the waves are totally synchronous: when the electric force is swelling to a maximum inside the wires running through a stoplight in Orange, New Jersey, a similar swelling of force occurs in a television in Hamilton, Ontario.

Despite the rich diversity of electrical commerce around the internal energy sea, all aspects of power movement---whether into or out of the sea---are neatly timed, adjusted, and transformed with pinpoint control, so that when Niagara makes and Syracuse takes, all the electricity that's needed gets sent and all the electricity that’s made gets used. What other area of civic life, carried out across so a field of play so oceanically large, delivers a product in huge volumes a microsecond after receiving the request? It works really well and according to plan more than 99.9 percent of the time.

That means, conversely, that for about 8 minutes per year things don't go as planned. Actually, the span of time that concerns us in this chapter is something more like 12 minutes.

Shaping the Wild West

On November 9, 1965 ten people die in a stampede on a rail bridge in India. In Vietnam hundreds are killed in jungle battles between Vietcong forces and the American army. In the US former president Dwight Eisenhower has a heart attack and a man sets himself afire in front of the United Nations headquarters, where the diplomats are debating whether the mainland Chinese delegation should be seated.

These events all appear in the newspapers but are more vivid when they appear on television, the electrical machine that does so much to sculpt popular culture and fill up free time. The human mind craves entertainment and television is only too glad to oblige. Air conditioning coddles our outsides, but television tickles our insides. Air conditioning merely brushes the outer dermal layer, whereas a TV program splashes against the retina at the back of the eye, and from there moves nervously along to the visual cortex at the back of the brain. If electricity were a religion, then the glowing box of television would qualify as the most venerated object, the totemic device before which more people spend more worshipful hours than for any other electrified object.

A favorite show can be a regularizing influence in one's routine. Coming at the same time on the same night of the week, the show induces anticipatory pleasure. It becomes practically addictive. Many plan an evening's schedule around the airing. What happens if, say, an electrical disturbance intrudes? (Did the lights flicker just now?) Some might experience a syndrome of withdrawal symptoms---irritability, a vague feeling of letdown, even desperation.

Other electrical gizmos aren't nearly as ingratiating or potentially debilitating. We've looked at the impact of other grid-based products---bulbs, irons, radio, air conditioners---but how about TV?

Recall that in this book “grid” is deliberately defined loosely; the grid doesn't stop at the wall socket but continues right into the appliance. The grid is not just the wire or the utility making the current humming through the wire. It's also the *consumption* of the energy and, maybe to push the concept of grid to the edge of usefulness, the *functionality* of the appliance as well.

Television uses electricity several times over. The incoming radio wave, weak though it is, provides enough energy to excite some of the electrons in the antenna to scurry about in a significant pattern. In fact waves from several competing networks excite the antenna simultaneously, each at a different frequency, as if numerous naval flags were being raised and lowered on the same pole at the same time. The channel selector adjusts a small internal circuit which filters out the ABC or CBS signals and zeros in on the NBC signal that you do want to receive. (Cable TV wasn't a factor in 1965.) A turn of a dial separates the chaff from the wheat, giving you the waves you want.

We now encode big parts of our national mythos in those waves. To hear of the eternal truths, the ancient Greeks made pilgrimage to the oracle at Delphi, where vapors came out of the ground. We instead visit the oracle of television, which casts forth potent rays. The most popular program in November 1965 belongs to a genre known as the Western. Future sociologists might be surprised that modern city folks, marooned on their asphalt islands, should be so interested in cattle drives, shootouts, and the European conquest of trans-Mississippi North America.

Over the years this thirst for vicarious western adventure had been satisfied through a variety of media: by Buffalo Bill's Wild West shows held in a tent, or in the form of penny-dreadful comics sold in pharmacies; later in pulp novelettes, then radio dramas, and finally on TV. Why inhabitants of highrise apartments in the Bronx should be obsessed with the wizened inhabitants of lowrise barns in Wyoming cannot be answered in a few pages.

It is more appropriate in a book like this to look not at the cultural significance of the West but at its electrical significance. So, as we wait for the start of the sequence of events that made November 9, 1965 perhaps the most meaningful day in grid history since the debut of Edison's grid four score and three years before, we will now return to this yesteryear to re-create the West from the electron's point of view.

Therefore please picture in your imagination the radio-wave encrypted version of *Wagon Train* or *Bonanza* or *Rawhide* reaching your rooftop aerial, where electrons, perfectly preserving the blueprint for depicting a herd of cattle crossing the wide prairie, must make their way from aerial to receiver. Surviving the rigors of a tuning circuit---where rival electrons corresponding to rival shows are sent to oblivion---the desired signal is amplified by the intervention of fresh electrons from the TV's power supply, which is, no less the energy sea. To portray wagons forging across the Colorado Plateau in a snowstorm, a microscopic trek inside your set must take place: squads of electrons are sent on their drive across the electric equivalent of mountain passes, river fords, and desert plains.

The electron batches for re-embodying the western saga or, for that matter, the weather report or a magician on a variety show or a production of *Hamlet,* are sent to a set of electrodes which control a concentrated charged flow coming from the back of the set toward the front. This "electron gun" boosts the electrons to high velocities and shoots them in the direction of the picture screen, the business end of any TV. If anyone tells you that you have a particle accelerator in your home, you should believe them. (The projection of images relies now more on solid-state technology, but in 1965 bulky picture tubes were necessary.)

At the screen, the cattle drive is rendered as pinpricks of light when the electrons excite phosphor molecules embedded in the screen. Bits of bright or dark are systematically splayed out in thin stripes across the face of the TV. A new set of stripes, each a necklace of shaded grade tones, is refreshed thirty or sixty times per second across the screen, giving the eye the impression of vivid presence and continuous motion. The light from these molecules gets captured by the retina of your eye, which is a sort of biological antenna, and your brain then does the rest of the work.

In summation: symbolic images of make-believe characters representing a reconstructed West have been transcribed into a carefully crafted series of electrical waves rippling through a tiny inlet of the larger internal electrical sea spread from Ontario to Virginia. These waves, in turn, are transcribed into neuronal patterns inside your head. All this constitutes, in my opinion, the electrical grid's most profound and subtle task: stocking your neocortex with vicarious experience.

And then it’s interrupted. Miles away, maybe hundreds of miles away, something happens. The last radio signals arrive at the rooftop antenna. The last signals are amplified, a final burst of electrons are aimed at the phosphor screen, a partial streak of pixels lights up on the screen, giving the viewer a fractional view of a cowboy on a horse. But just at that moment the cowboy fails to make his scheduled appearance one thirtieth of a second later. The cattle drive ends, the West evaporates, the set goes blank and the room along with it and the neighborhood.

At Consolidated Edison's Energy Control Center on Manhattan's Upper West Side, the first sign that something was wrong came not from the high-tech console readouts. Not from the computers. No, it was the fact that the lights in the room were dimming (ref 5.1). The chief grid operator on duty, Edwin J. Nellis, was congratulating his colleagues on their having successfully matched generated power with customer load. Millions of residents were just then maneuvering through the high moment of that day's evening rush hour. Many were still riding in numerous planes, trains, and automobiles. The cusp of peak demand for the day had already been reached. Con Ed's home team of generators was working normally. Furthermore, the city grid was importing a modest amount of energy from the friendly allied utilities up the Hudson and elsewhere. So far so good.

But then dials on the control board started acting strangely. What had been a net import of power abruptly flipped, in the course of a minute of so, into a net export. Energy was being sucked out of New York and at an increasing rate. Some strange eruption on the grid was happening to the north. The dials swung rather more to the right now. This was no mere flicker of recognition. A rather loud alarm was sounding, obliging Mr. Nellis to reach for his telephone.

Storm Warnings

Consider how actions have consequences. On November 9 in Conway, New Hampshire an 11-year-old boy is walking home. As he goes he smacks upright things with a stick, imaginary foes, alien invaders, a rampant panther. With true force he hits a streetlamp post and, blink, off it goes. And the other lamps on the block, and the homes across the way. He did it. He's to blame. The boy's guilt and the magnitude of what he'd apparently done grew as he ran home. He weepingly tells his mother he's sorry for putting out the lights (ref 5.2).

In Rochester, New York a workman is doing a bit of soldering. Don't worry, I know what I'm doing, he tells a friend. Just then the lights all around flicker for a moment. It must be my solder gun. Watch the lights go out, he says, half in jest. He persists with his work, and the lights *do* go out, everywhere. What the hell? (ref 5.3)

In Albany a family is left in the dark when the electricity goes out. This has happened before. They know what to do. You call the utility to let them know, you get out the candles, wait for the crew to arrive, and soon it's over. Before long they get a call, not from the power company, but from a friend in Florida asking how it's going in the dark. Now how could they know in Florida that the power has gone out in some corner of Albany, New York? It is then that the family learns it isn't just their house, or the street (ref 5.4). The problem is bigger, much bigger.

Let's go backwards a few minutes. It is 5:16 PM on November 9 and in the next twelve minutes the largest electrical blackout the world had yet seen would unfold, but the participants in places like Hamilton or Elmira or Pawtucket don't yet know this. To people around the shore of the great electric sea, the disturbance at first will seems to be something that is happening to them alone. By looking out the window they will notice, perhaps with relief, that it has also affected their neighbors, and maybe their town, possibly the whole state. Later, from the radio, if they have access to a working radio, the wider implications finally start to register. The physical fallout of electrical shutdown can spread in seconds. The social fallout would take more time.

On November 9, the storm that strikes the Eastern Interconnection is not some external storm gathering strength in the tropics and moving north. Rather it is an internal storm of indeterminate origin. In the first minutes even the size of the storm is not known because it exists only on and in metal pathways hidden from human vision. Wires for hundreds of miles around know where the problem is, but *they're* not talking, except to each other. It is fair to suspect, however, that two power centers might have played a role in any disturbance on the great Northeast internal energy sea.

These two places correspond to real places on the map. They happen to be two large concentrations of hydrodynamic potential energy, one of them the famous set of falls near Niagara sending water from Lake Erie down into Lake Ontario, the other the descent of the St. Lawrence River east of Lake Ontario. The immense electrical energy churned out by turbines spun by these northern waters is often a lot cheaper than the power made by burning coal, and since there isn't a lot of need for the power in the Niagara vicinity, this hydro-made energy is put up for sale and sent into the Eastern Interconnection. Let’s see where some of that energy goes.

The City of Rochester, famed for its snow and its music school, liked Niagara energy and had come to count on its availability. It so happened that the water level in the Great Lakes had lessened in these last few dry years and this had pinched somewhat the amount of power they could make at Niagara. Consequently Rochester Gas & Electric (RG&E), the local utility, had started to produce more of its own energy in thermal (steam-driven) generator plants. Nevertheless, it was still buying 200 megawatts from the supergrid. In other words, Rochester was taking more energy out of the sea than it was putting in, the difference being made up by places like Niagara.

Suddenly at 5:17 PM on November 9 it stops. Rochester's imported energy just stops coming. With no warning, it vanishes entirely, and along with it the ability of the local grid to deliver energy. Niagara authorities would later declare that RG&E had "stopped taking" the power. Au contraire, RG&E would argue, Niagara had stopped sending it (ref 5.5). Much of the city is merged with the gloom of oncoming evening. Not just light is gone, of course, but other electrical-enabled services as well. Traffic lights, elevators. Filtration stops and so no more drinking water is being made.

What had happened? No one yet knew. Rochester is not to be alone in its deprivation. Further along the coast of the energy sea is Syracuse, and it now turns black. If you were a resident of Syracuse you too might think you were being singled out for the dark treatment, but you’d be wrong. Erosion of electrical service was accelerating. Why should Utica be spared? It went like this on through a thick tier of population across the waistline of the Empire State. The bottled lightning normally coursing safely through the natural gates and alleys of the grid is at this moment seriously misbehaving.

In some undefinable way the electric sea has roused itself. This rebellious act does not got unnoticed by the sensors tirelessly keeping watch. Even if humans cannot literally watch the squall coming, the detectors see it well enough. Designed to sniff out irregularities in voltage (the pressure behind the electricity), current (how much electricity is flowing), frequency (the repeat time of the electricity), or phase (how far along into the present electricity wave), the faithful auditors of the grid are hectically at work. Their micro-bookkeeping is reported not quarterly or monthly but secondly, and the findings are not good. The energy sea is turbulent and small craft warnings are issued.

In some cases the warnings are heeded automatically. For instance, the defensive mechanism guarding the Pennsylvania-New York border senses the trouble to the north, determines that the state of affairs has swayed an intolerable amount outside prescribed levels, and it acts. It triggers the opening of a circuit breaker. After a convulsive retraction of metal contacts---interrupting current humming at hundreds of kilovolts is a process that can be accompanied by a spark several feet long---the local hookup between the Pennsylvania-New Jersey-Maryland (PJM) system (a power pool within the larger pool) severs itself from the Eastern Interconnection. No human intervened in this action. One machine had talked with another, and in a consultation lasting less than a second a decision affecting millions was made. The breaker was told to open and it did. Pennsylvania had put up its hurricane shutters.

O Cursed Fate

Things are different at Con Edison's Energy Control Center. Clearly something is rotten in the state of New York. Instruments are indeed screaming the news of troubles to the north, but no automatic action has been triggered. The decision to sever the city from the regional grid would be in human hands. On November 9 the hands belong to Edwin Nellis, a dedicated Con Ed man for 41 years. In the Shakespearean drama about to unfold, Mr. Nellis will play the part of Hamlet, a central character overtaken by events not of his making, a man whose conscience is stricken by conflicting forces and obligations.

Quickly now. What do we know? First there had been a surge of power *into* the New York City network, and not just from the north but also from New Jersey. The Jersey surge quickly tripped breakers, isolating New Jersey, parts of Brooklyn, and Staten Island from the rest of the boroughs. So, already some of the city was no longer under Edison control.

But the greater danger lies to the north. Nellis is on the phone with Syracuse, where they know nothing. They're already sitting in the dark. Rockland and Orange Counties are still up and running but they're desperate. Send us energy, they say. An operator up the Hudson, near West Point, has worried himself to a decision point; he cuts his sector of the grid loose from the rest.

In the coming minutes, the problem for Con Ed will not be one of surplus but of shortfall. There was now, you could tell by the dials, a huge *withdrawal* of power up the Hudson. The electricity balance is bad north by northwest. The man in charge has to decide what to do. The controller might address the problem by shedding some of his load---cutting off power to specific neighborhoods, a thing he does not like to do---or quickly increase generation of electricity, or both. He must be cruel in order to be kind: he prepares to shed load. As for more power, this has already been requested. The Con Ed machinery was taking action against the sea of troubles---the furnaces were banked and the steam rising---but could the generators make enough extra electricity in time?

Things had been going so well. Rush hour had been smooth. Now, energy was deserting New York. Problems were coming not singly but in battalions. Why was the system coming down in so many places? It wasn't the weather. There had been no telltale thunder, no fall of snow to weigh down the lines. No reports of failure at any major station. With weeks or months of coal piled up near the boilers, no responsible powerhouse could have run out of fuel. There had been no foreign incursion, at least none that we know of.

Edwin Nellis could be forgiven for asking himself why all this was happening to him. Why today? Why on his shift? Here’s what Hamlet said when he too was in a tight situation:

> *There is providence in the fall of a sparrow. If it be now, ‘tis not to come; if it be not to come, it will be now; if it be not now, yet it will come. The readiness is all.*

On November 9, Nellis is not ready.

No, it seemed as if it were just some colossal mistake. Could the gods of electricity, who had taken pity on mankind and who had entered into a firm covenant with them, be revoking their blessing? Edison and his tribe down through several generations had been in awe of electrical power. But the old fervor was gone. Although mortals still tendered their burnt offerings in the form of broiled coal, they now seemed to take for granted the potent gift of high voltage. It was no longer special. So perhaps the gods had sent a vivid sign. And there was, lo, a great departure of energy throughout the land. If you were apocalyptically inclined you might say at this moment that the cities of the plain were being smote.

Toronto had been one of the first to be cheated of its energy. Subways, streetcars, and trolleys had lost their means of moving, and airports had switched to auxiliary power. With the energy gone, molten copper re-solidified in the furnaces of the Wolverine Tube Company. At Christie's Bread Company, where conveyor belts slugged to a halt, 2000 loaves were stranded in the middle of the oven, where they solidified in a horrible way (ref 5.6).

The primary utility for this area, Ontario Hydro, was mystified as to the cause, although preliminary indications showed that the problem lay to the southwest, near Niagara, probably on the US side of the border, or else farther off, near Rochester. On the other hand, there had just been a confusing blast of energy whipping around the *eastern* end of Lake Ontario. How do you explain *that* if Rochester were to blame? Neither country wanted to have been the one responsible. No utility wanted to be the goat.

Grid weather was unseasonably mixed. Gusts of energy were showing up in unexpected places. To the south, dominoes continued to fall. "God was very good to us," said Sister Elizabeth Ann, at the Our Lady of Victory Hospital in Buffalo. "We didn't have anybody in crucial areas that needed electrical equipment. There were no surgical emergencies or maternal delivery cases." At the Milliard Fillmore Hospital energy was gone for only a few seconds. Auxiliary power wasn't even necessary.

No lives were lost in the energy crash in Buffalo, but in plenty of places, monetary losses were considerable. Buffalo, if you will recall from chapter two, had been a mecca for big business precisely because of its proximity to Niagara and its cheap hydro-electric power. So when all that Westinghousian alternating-current power was withdrawn, when all those motors operating in the Tesla manner were bereft of their missions, then there was bound to be industrial trouble.

For example, at Chevrolet the assembly of automobiles halts as if someone had flipped a switch. At Du Pont several batches of chemicals are spoiled at great cost. At Dunlop Tire and Rubber Corp. 1700 tires, curing in molds, are wastefully lost. At the Worthington Corp. great damage occurs at those surfaces where powered blades in drill tools and milling cutters dig into resistant materials. At Republic Steel some water-cooled doors for the big hearths are ruined. At Bethlehem Steel a voltage fade-out automatically trips off the production process. Three employees of Hooker Chemical Corporation are overcome by escaping phosgene gas (ref 5.7).

The misbehaving energy sea makes quick work of Albany. The governor of New York himself is gone, as well as the lieutenant governor, so a lesser official steps in as emergency coordinator. Where does he get *his* news? From a transistorized radio tuned to a rock-and-roll station that stayed on the air. Around Albany the blackout has differing effects. In the Dolliwog Lounge at the Ten Eyck Hotel, for example, Suezenne Fordham braves the dark and goes on with her piano artistry. At the capitol, Jackie Robinson, famous for breaking baseball's racial barrier, cannot overcome the electrical barrier, and his civil rights press conference has to be cancelled (ref 5.8).

The cities situated around the internal energy sea are widely spaced in the geographic sense. The Interstate highway between Buffalo and Boston takes hours to traverse. In the electrical sense, however, that same distance can be covered in a fraction of a second. In terms of copper wire, Boston and Buffalo practically coincide. A power drill in Ottawa, tethered to the universal grid by an extension cord, and a dehumidifier in Amherst were scarcely a heartbeat removed from each other in terms of the electron's own secret time frame. Two very different perspectives are at play: the intercostal cities see the grid as a go-between, an extended *extrinsic* thing, a servitor bringing sustenance over wires. Complementarily, the grid would see itself---if it were a sentient being---as a centered *intrinsic* thing, a gathering of energy. It would regard the cities as being just so many loads, mere bunting hanging pendently from the grid's banisters.

For the beleaguered dispatchers of grid energy, this gusty squall of confused currents had come so suddenly that there had been no time to stand back and look for clues or patterns. There was, however, one great observation that could be made. The problem mainly to the west of the Hudson had been the sudden presence of too much current. The surge quickly bore down on the utilities in its way, triggering relay mechanisms which, operating according to correct procedure, protected the rest of the transmission line downstream and other valuable assets such as generators and transformers from harm by opening a gap in the line.

East of the Hudson the problem is now more one of too little current. The main tide of power supply across New York from Niagara to the east has broken down somewhere between Rochester and Syracuse. And once this normally beneficent energy supply along the east-west axis is cut off, New England to the east and Gotham to the south are left in the lurch.

The Last Best Hope

In this province of the Eastern Interconnection, the nearest thing to a Niagara-sized concentration of energy is Consolidated Edison's colossus generator, Big Allis. Before the storm blew up, Allis had been coasting, spinning out only about half the electricity she could actually achieve. Woken to the spreading peril, Allis is now cranking up to full potential. If the electrical crisis were being told as a tale in a child's storybook, Allis right now could be identified with the little train engine that attempted to climb the mountain and rescue the boys and girls on the other side: "I think I can...I think I can...I think I can."

In the Con Ed system as a whole, more than 1000 megawatts are held back for emergencies, and this "spinning reserve," in the form of extra output that can be summoned from generators already operating. This is exactly such a moment, and extra energy is frantically being called forth. The New York grid is one of the mightiest in the world and can furnish all the energy needed for its own grid, but like many other utilities it is availing itself of the cheaper electricity made available elsewhere in the pool. To be exact, it was importing 360 megawatts from the

Niagara/Mohawk Power Corporation when the crisis began. Now, in a matter of only a few minutes---hundreds of seconds---the whole flow has turned around. A 360-megawatt deposit had become a 750-megawatt withdrawal. Connecticut was drawing another 250. With this kind of run on the bank, the vault soon would be empty. They say it is better to give than to receive, but this was too much. New York was, as the seconds sprang forward, dispatching 600, 800, 1000 megawatts away from its own grid. Big Allis, working hard to save the city, has already brought up 100 extra megawatts. If only there were more time.

The Eastern Interconnection, what's left of it, is foundering. The levees are weakening. As the power gets spread too thinly, the frequency starts to drop. It ought to be 60 cycles per second, but as the emergency unfurls, it has dipped down to 59.8, then 59.4. This is equivalent to an organism losing blood pressure. When the frequency thins out too much, the pumps serving the big generators turn themselves off, and this in turn cuts off the generator itself. As you can plainly see this only deepens the crisis. Too much and you faint. Death by under-frequency.

Edwin Nellis and his confederates race from dial to dial. They turn cranks, make calls. What is their next course of action? Shouldn't they cut loose from the decaying grid and at least preserve their city against general ruination? But what about their pledge of assistance to those in need? Only three minutes earlier, Mr. Nellis's life had been so simple. In that short interval the opportunity for greatness had been thrust upon him. To cut loose from the grid or not to cut---that is the question.

At 5:21 PM the blackout has come to Boston. Electricity itself is ephemeral, so the *absence* of electricity should be even more of a nothingness, but it's not. A blackout, as it settles over a large city, is a *something*. It's like wet snow. It has weight. It's a form of anti-energy. In Boston this un-energy is everywhere. Immediately there is the same paralysis: stoplights, gas pumps, conveyor belts. In the voltage headquarters for the city, at Boston Edison, 18 folks are stranded in one elevator alone. The Massachusetts National Guard issues its first general alert since World War II. In nearby Chelsea, officers attending the annual Police Benefit Association banquet pin their badges right over tuxedo lapels, bid their wives adieu, and head out into the chill night to face the situation.

Reactions to a dramatic shift in one's environment can bring out the best and worst in people. The sudden loss of power all over the Northeast is being met, in these first minutes, with a combination of resignation, dread, and resourcefulness. Mostly the fabric of civic life is holding together. Aren't New Englanders supposed to be tough, stoical? And so it is: people are generally friendly, many jovial. Some direct traffic.

At the State Prison in Walpole, MA, however, the prevailing sentiment is rage. Rage at jail confinement, bad food, mean guards---the exact spark is not yet identifiable. What is known is that the inmates are furious, and that their pent up emotions are being vented against any furniture within reach, or exposed plumbing. These desperate men, residents of the maximum security area, are looking for hostages to take. Tear gas is fired by retreating guards and reinforcements have been summoned (ref 5.9).

Across the state line, Rhode Island has lost its power and its government. The top man, the governor, is out somewhere over the Pacific Ocean returning from a visit to Viet Nam. Number two, the lieutenant governor, is in Boston, presumably in the dark with everyone else. No. 3 in the order of succession is the president pro-tem of the state senate, and he happens to be in Puerto Rico. The fourth man, the secretary of state, is in Hawaii. Number five, the first deputy secretary of state, is actually in Rhode Island, but doesn't know that as of now he's the acting chief, so it falls to the governor's executive secretary to get emergency procedures started (ref 5.10).

For Connecticut the blackout descending in all directions will be the first interruption of power since the time of the huge hurricane back in 1938. Now in 1965, Hartford's grid is moving rapidly toward the same critical tipping point of no return that has obliterated circuits to the north and west. But wait. Here there is a bright spot. A control operator, with his hand on the switch, is about to make his decision. Automatic shutdown is seconds away but at the last moment the operator acts. He throws the switch and ruptures the ties to the power pool. This has the practical effect of closing the fortress gate to the city and pulling up the drawbridge. His action preserves electricity in much of Hartford, which remains an island of light in a sea of dark (ref 5.11).

Down in New York City something else happens.

The Rest is Silence

For Edwin Nellis, also poised at the switch, choosing a course of action is difficult. He works for Consolidated Edison. His duty is to the shareholders of that company and their customers. Millions, although they do not know it, are trusting to his judgement. And what does he trust to?

He's been a company man since the 1930s. He plays by the rules, trusts the guidelines, which clearly suggest that a utility company should help its allies in time of need. And he has seen to that. Meetings of officials from the various utilities and frequent phone calls among the participating operators all testify to the unified nature of the grid. They talk with each other every day. You can't just throw that away because of some troubles to the north. Hartford or Orange County might cut themselves off from the pool, but this is New York City we're talking about now. Con Ed, the mightiest powerhouse anywhere, doesn't just cut and run.

News of Long Island's defection from the interlink comes at 5:23 PM, not that Long Island customers will be spared, because minutes later their grid crashes too. At Brookhaven National Laboratory, 60 miles out on Long Island, the power goes out at the research nuclear reactor and the control rods, exactly as they are supposed to do in case of emergency, automatically slide down into place among fuel elements, cutting off interactions inside the reactor's radioactive inventory (ref 5.12).

As the moments zip past, still more power is being squeezed from Big Allis and her allied generators. These machines are practically busting their rivets and still it isn't enough. Shedding load, long a procedure of last resort, is now seen as an absolute necessity. Sacrifice some specific neighborhoods? So be it. Off goes Yorkville, a posh part of eastern Manhattan. Not enough? West Bronx gets sacrificed. East Brooklyn is axed (ref 5.13). How could it have come to this? After the 1959 and 1961 blackouts, had Con Ed not buffered itself with a series of nimble measures to protect the New York grid from future shock? All these "improvements"---the new more computer-automated control room, the new tie-lines to the other grids, Big Allis itself---are proving to be a Maginot Line. The outer edge of the Eastern Interconnection is in retreat on every front.

This is no small calamity. It is certifiably the *big* one. Electrical avalanches of all sizes---piddling, middling, and engulfing---are working together at this instant, spawning yet more avalanches in a fractal orgy of outage. Trying to stand up against the deluge is Edwin Nellis. Does he have the proper, heroic Hamlet-like emotions---pluck, courage, and perhaps the fatalistic feeling of being crushed by some malicious outside force---or is he just overmatched and confused?

Another guideline in the operator's manual suggests, sensibly enough, that if an overload or power drain on the interconnected grid persists, and puts your own grid in danger, then the operator is justified in cutting free of the problem. Here is the central dilemma. How can you reconcile these two recommended actions---cutting free and holding firm? Which guideline was more important---self-protection or standing by your friends? Edwin Nellis would soon find out. The storm was not abating. The quality of the energy---volts and cycles per second---was now suffering and soon the machines that make the electricity would themselves start failing, all within seconds.

Time, the passing of one moment after another, is an eerie thing because you can't grab hold of it. Even millionaires can't buy more of it. You can measure intervals, elapsed time, but not time itself. Two different system operators make their respective decisions, two seconds on either side of an invisible blink of time. The consequences will prove to be very different. On one side of the blink, the gesture works. The operator in Hartford throws a switch, sequestering his circuits. His city is saved.

In New York the operator throws a switch, but it's two seconds too late. Edwin Nellis, the logbook will show, gave the order to secede from the union. He made the decision to break Con Ed free from the albatross around its neck, a process requiring the pushing of eight separate buttons in the Manhattan control room, which in turn activate giant circuit breakers at the Con Ed substation in Duchess County (ref 5.14). But it all comes too late. The trip-offs, marking interruptions along myriad circuits, resound through the system like un-celebratory champagne corks popping. The murderer's row of mammoth generators ranked along the East River, were, just a moment before, capable of more power production than several Niagaras, which is to say that they could liberate more energy in a day by frying West Virginia coal than could be extracted upstate from the gathered waters of the entire Great Lakes watershed. Now nothing.

A long time ago, at the height of the ice age, so much of the world's water was invested in northern glaciers that many other aqueous preserves were left destitute. Consequently, the Mediterranean came to be an empty bowl of dust (ref 5.15). And so it was, eons later, at that still moment on November 9, that the internal Mediterranean---my fanciful name for the Eastern Interconnection---came to be empty as well. No electricity flowed between Syracuse and Montpelier or from Plattsburgh to Providence. No electric waves rose and fell in the manifold sea of copper wire. The energy that twelve minutes earlier had coursed across among the allied cities had retreated backwards into machines now already cooling off. By just such an amount, a like measure of coal went unburnt in furnaces, trillions of scheduled uranium-235 nuclei did not fission at the cores of reactors, and millions of gallons of water at Niagara plunged down to the level of Lake Ontario without producing electricity.

When the wall clocks stop in New York it is 5:28 PM. For the first time in the history of Consolidated Edison, nearly the entire system thuds to a halt. No one had contemplated the possibility of there being *no electricity* in the wires anywhere, and so even as the massive central shaft at the heart of Big Allis, the largest single machined part in the world, is gradually spinning down. There is no power for the oil pumps that should be lubricating the many places where metal rubs against metal. Accordingly, there is soon going to be a painful grinding.

Allis's rotor has so much inertia that it will continue to spin for many minutes. Left alone it could go for more than an hour. And this spinning, this gradual coming to rest, will be the ultimate end to the historic blackout of 1965. This dovetail of technological collapse, taking its full course, will grind to a halt here in the middle of this billion-watt energy machine in Queens, New York. The fretful final moments will not be so smooth, unfortunately, since Allis's bearings, deprived of their lubrication, are starting to melt.

24 September 2005

Chapter Six

Thirty Million Powerless

Now that the grid has collapsed into stillness, let’s keep it that way for a minute of two. Before citing all the impressive statistics relating to the events of November 9, before showing how the grid got itself going again, before inquiring into the cause of the crash, before allowing the sizzling hum of 1960's electrified culture to distract us, let’s take this occasion to ruminate on the colossal presence of powered technology.

The colossus is older than you think. It didn’t begin with electricity. It didn’t even begin with wind/water/steam-powered machines, says Lewis Mumford. If you count human muscle, it goes back to at least the time of ancient Egypt. The evidence, the Great Pyramid, is still sitting there at the edge of the desert:

> *Was it possible to create such a structure without the aid of a machine? Emphatically not. I repeat, the product itself showed that it was not only the work of a machine, but of an instrument of precision. Though the material equipment of dynastic Egypt was still crude, the patient workmanship and disciplined method made good these shortcomings. The social organization had leaped ahead five thousand years to create the first large-scale power machine: a machine of a hundred thousand manpower, that is, the equivalent, roughly, of ten thousand horsepower: a machine composed of a multitude of uniform, specialized, interchangeable, but functionally differentiated parts, rigorously marshaled together and coordinated in a process centrally organized and centrally directed: each part behaving as a mechanical component of the mechanized whole: unmoved by an internal impulse that would interfere with the working of the mechanism (ref 6.1)*

The “megamachine” that built the Pyramids, Mumford suggests, still operates to this day. The modern megamachine is still a machine consisting of human parts. Only now, instead of building a Pyramid, we create products for a thousand corporations and other modern institutions. In ancient Egypt, the megamachine served the whim of the Pharaoh. In the modern city, the machine serves the market economy. In Egypt the work on the Pyramid might have stopped because of plague or harvests needing to be brought in. In New York, on November 9, work stops because lubrication for megamachine, electricity, had just failed.

In Pharaoh’s day the bureaucrats were star watchers, time keepers, record preservers, calendar makers. Their expertise insured that the Pyramid would align with high precision to the latitude and that construction would be kept on schedule (ref 6.2). The Organization Man of today, by contrast, doesn’t worry about latitude or calendars or the phase of the Moon. Generally, he can come or go as he pleases. In fact, he might object to the assertion that he were part of some super-machine. I can always switch jobs or move to another city, he would say. I’m not a slave compelled to move 10-ton blocks of chiseled stone.

From the top of the Empire State Building, however, it might seem as if New Yorkers *were* parts of a megamachine. On November 9, from way up, the millions scurrying along the avenues on their appointed rounds would look, in their ant-colony formation, as if there were parts is some larger single enterprise, after all. And then the blackout came, and it was if a boot had given the anthill a good kick. The ants were still there, still swarming, but in different trajectories than before.

This is of course unfair. People are not ants. They have their own individual goals and plans---getting home, shopping for the evening meal, going to a ball game. Many of these plans had been disrupted by the blackout. The narrative view will therefore come down from the Empire State Building, down from generalizations to particulars, in order to see events closer to Earth.

Officially Big

Defense. On November 9 the authorities in Rome, New York, home of Griffiss Air Force Base, were thinking mainly of defense, national defense. Something big had happened, something electrical. Beyond that, it was a mystery. It wasn't merely a city emergency, but a complete disruption affecting an important corner of the country. Therefore higher imperatives had come into play. Is the president safe? Are the missiles at the ready if we need them? Did the dials show any hints of suspicious movements or hostile overflights anywhere remotely near the defense perimeter? What do the Joint Chiefs say? Had Defcon, the nation's Defense Condition, stayed at its normal level or been ratcheted up? Had there been any foul play? Were the Russians or Chinese mixed up in this?

Although information is still flooding into government bureaus, the initial indication at this early hour of the crisis is that sabotage was not involved. Military bases, with their own supplies of power, report an undiminished readiness. All strategic forces, according to customary practice, are alert but not otherwise put into action. Major military air bases in the effected area are extending help to stranded airplanes needing a place to land.

The President of the United States, Lyndon Johnson, recovering from a gall bladder operation, is at the Western White House in Texas. His press secretary, Bill Moyers, begins what will become a marathon news briefing, providing seven hours of information as it becomes available. The first order of business, after seeing to national security, has been to investigate the cause of the electrical failure. The President, according to Moyers, has ordered the Federal Power Commission (FPC) to look hard into the matter, use all government services, including the FBI and Pentagon, and get back to him promptly. It is going to be a long night.

The largest power failure yet recorded came to rest at half past five in the late afternoon of November 9, 1965. In rough round numbers electricity had been snatched away from thirty million people in parts of 9 US states and a Canadian province over an area of some 80 thousand square miles. In twelve minutes 26,000 megawatts of power had been pulled back in off the wires when dozens of generators stopped singing.

In every locality there were stories to be told. The last chapter recorded what happened to a number of the cities scattered around the shores of the internal sea of electricity. Now we turn to the chiefest city among them. It is a mark of Gotham's command of attention that no description of the great blackout of 1965 could leave New York out of account. In Buffalo, or Hartford, or Burlington, the local story might well take preference, but the impact of the blackout on Broadway theaters or the 800,000 stuck in New York's subways would necessarily be part of the general impact of the blackout no matter where you lived, from Toledo to Tokyo. It's as if the seriousness of the event had been affirmed by the fact that it had befallen the Big Apple. If the lights can go out there they can go out anywhere.

For many newspapers the main story wasn't the blackout. The main story was the blackout in New York. It's not hard to see why. The broadcast booths from which the national television networks would normally have reported the news of so large an event were themselves *right there,* and victimized by the event. A third of the nation's overnight check clearing in the big downtown banks had not occurred. One fifth of the nation's mail was left unsorted in New York's cavernous postal facilities. Because the power failure had struck New York, the biggest of the big, the blackout could unhesitatingly be deemed as officially “big.”

Yes, there was also a bit of envy at work here. Misery is companionable, and what better darksome companion to have than the number one city, brought down a notch or two. It was good to see that the center of the universe, sometimes reckoned by New Yorkers as being located at Times Square, could be traduced by something as ordinary as electricity. In the dark, the corner of 42nd Street and Broadway was no better than downtown New Haven or Schenectady.

Yet, even in the dark there is something grand about New York. Here, all the good points and bad points of other cities come together and amplified. And this proposition certainly extends to the deprivation and restoration of electrical service. Herewith a rundown of conditions in the moonlit but otherwise dark metropolis.

In New York there were plenty of people whose first thought was not of national defense but of personal survival. Dozens were trapped in the upper echelons of the Empire State Building, where in some case rescuers had to break down walls to get to the blocked shafts.

In hospitals auxiliary power was available in most cases. What are the critical uses for power at a hospital? Operations are the most important: they require electrical machines and intense light allowing surgeons to peer into the deep crevices of patients and refrigeration for chilling medicine and blood. The city's hospitals used on an average day about 1000 pints of blood, and kept a reserve of about 3000 pints. Of this only about 100 pints spoiled, and even this was because the temperatures, kept cold by the use of dry ice, had been too *low* (ref 6.3) Dozens of babies were born that night around the city. In one case a pair of twins were born at the very edge of the event, one just before the blackout, one just after.

Except for the thirty million---the aggregate population in the dark realm---the blackout number that seems most to seize the imagination is 800,000, the count of those in transit through the New York subway system at the fateful moment. Some of these 800,000 were in stations at the time, and could easily or brusquely jostle their way to the surface. Others were on trains in or near a station, and these could be emerge relatively unscathed. The ones that weren't so lucky, the thousands in elevated sections or underworld tunnels, were sentenced to penitentiary periods stretching from minutes to many hours.

For example, if at 5:20 PM that night you had climbed into the IRT train (now the 7 Train) from Grand Central in Manhattan on its way toward the Vernon-Jackson Station in Queens, you would have found yourself at 5:28 PM, the moment of electricity's abdication, in a dead halt in a tunnel beneath the East River. For two hours passengers sit in the feeble illumination of the car's emergency light before being led along the damp trackway the mile or so to the Queens-side station.

The thought of being in that train under that river amid that gloom for two hours is unpleasant enough, but now please cast your imagination into another stalled train. Skim the slimy East River bottom a half mile to the north, and there inside a parallel tunnel beneath the silt and accumulated sunken settled castoff grocery carts, in its own tomb, an Astoria-bound train reposes. At the two-hour mark, when the passengers on the Vernon Train were being liberated, those on the Astoria Train were just settling in for what would be a longer stay.

Unique New York

There's no business like Show Business, where the product is not some material thing but a dramatic situation, expensive sets, and lots of dancing legs, all burned into customers' minds with the help of 1000-watt bulbs. With the theaters shut down and 30,000 high-priced tickets to refund, Broadway was particularly hard hit by the absence of electricity. The movie houses: total disaster. No electricity means not projection means no movie. At Radio City, where they sometimes have a live organist accompanying the feature presentation, when the film being shown flicked off the screen the music continued. Some viewers, with nothing to view but nowhere to go, spent the night. It was useless to ask, but millions did anyway: when was the power coming back on in New York?

At Carnegie Hall another trouper went on with the show. Vladimir Horowitz, rehearsing on the piano before an audience of students, was so practiced in his art that even after the stage went black, his knowledgeable fingers flawlessly finished Chopin's Polonaise Fantasy. At the Metropolitan Opera, the show was to have been Madama Butterfly. Instead of a stabbing followed by a blackout, there was only the blackout. A substitute performance went up a few days later.

New York was a hub for television broadcasting, an exercise which turns visual and aural information into waves and then beams them forth with a powerful transmitter from a large antenna, often on top of the Empire State Building. At the receiving end are 1965 television sets, which are fat, power hungry, and often ensconced in a piece of mahogany furniture.

Not so radio. With many of the sending antennas positioned conveniently across the Hudson in still-lit-up New Jersey, many radio stations continued with little fuss. And with only aural signals to transmit, power requirements are more modest than for TV. Furthermore, radio receivers, needing less electricity than TV receivers, can fit snugly into auto dashboards. New hand-held “transistorized” units were also popular on evening of November 9. Because of this mobility, radio became *the* populist medium for passing the word, whether it be the status of Air Force bombers or the likelihood of power coming back. *Variety* magazine summed it up:

> *The day radio men dream about---when TV disappears and there is only radio---finally arrived without warning. Disk jockeys became news gatherers via telephonic quizzing of officials (governors on down), utility execs, and private citizens with graphic sidebar data to convey. Nearly all stations were yeomen in the breach, giving the AM medium one of its finer hours (ref 6.4).*

New York's airports lost regular power and planes everywhere in this very crowded air corridor had to devise a plan for landing safely somewhere. Seeing the lights disappear, one pilot was reminded of Pearl Harbor. Most captains, deprived of the normally dazzling visual markers strewn over an approach region which extends from Boston to Philadelphia, were amazed by the darkness, but all responded carefully and there were no mishaps. The nearly full Moon and clear skies, everyone agreed that night, helped to prevent a catastrophe. On the ground at JFK, American Airlines used its grounded fleet as a sort of collective welcome lounge. Each plane had its own internal electrical grid, air conditioning, food supply, and movie-projection provisions. So at least in this small sector of New York, life went on as if there had been no power outage (ref 6.5).

Several hours along, and power is returning in some places. Rochester has lights and water filtration restarts. A preacher, representing the Negro community in Rochester, speaks out forcefully against the false accusation that there had been riots and looting in his community. Over in Massachusetts, where a real riot is making a mess of the state penitentiary, tear gas proves decisive. Although the guards in the Death Row part of the prison are nearly overcome by their own tear gas, backup officers from around the state have pretty much quelled the uprising. The lights are back on in Toronto and Vermont but not yet New York City. Why is that?

An even more basic question, one that haunts engineers everywhere: what caused the avalanche in the first place? Can it happen all over again an hour after we turn the lights back on? Are we raising a house of cards that will tumble with the merest nudge? The Federal Power Commission, or FPC, has jurisdiction over the inter-state movement of electricity, and has already set up a mandatory meeting of utility officials for the next day. Representatives of the companies involved are to report on what they know and a reconstruction of the disaster is to be undertaken. Placement of blame, the government assures nervous utilities, is not as important as preventing a recurrence. Changes in power policy will come later.

Between now and the morning, thousands of miles of transmission lines have to be inspected, breakers checked, computer printouts scanned, and equipment cautiously turned back on . The cause, or at least the symptoms, have to be found. Was it machine error or human error? Was malice involved? The idea of sabotage, although discounted early in the evening, never quite leaves the collective thinking. The rumors of utility men being murdered near Syracuse or of fireballs in the air just before the blackout are checked out and dismissed. Although somewhat reassuring, the fact that there seems to be nothing *physically* wrong with the grid is baffling. If there were no marks on the body, what was the cause of death?

The night wears on and most creatures great and small need a place to sleep. In New York's zoos, the non-human residents don't control their own fate so keepers have to make the appropriate arrangements. In a few cases, blankets are stuffed into the bars at the monkey house to preserve a bit of warmth. For some of the more difficult lodgers, such as the cobras, propane heaters are procured.

As for the homo sapient residents of New York, many make it to their own homes, some after walking ten miles or more---most likely the longest hike since childhood camp outings. For others, in elevators and subway cars, they haven't budged at all. For in-between cases---you're not exactly trapped, but without trains neither can you go the 30 miles to your home---you might make do with an office couch. At Macy's, which advertises itself as the world's largest store, thousands of customers are allowed to stay on for the night, and are treated to extemporaneous dinner in the employee cafeteria. Afterwards, many settle into the home-furnishing department as if it were a huge hotel suite with accommodations for hundreds (ref 6.6).

It's 11:30 PM and Bonwit Teller, the jewelry store, hires two buses to take their staff out of town. So as not to get lost in the trek to the buses, they decide to hold hands. Maybe inspired by *Fiddler on the Roof*, playing over on Broadway (at least it had been the night before), the dealers in precious stones emerge hand-in-hand from their store singing and dancing.

Putting Humpty Together Again

The New Yorker magazine, which prides itself on taking impressionistic notice of goings-on about town, certainly took notice of the great darkening. Its idiosyncratic coverage of November 9 concentrated on two qualities: the beauty and the fear. The fear, at least at first, was that the electrical disaster might be the start of nuclear Armageddon. This was, after all, the heart of the Cold War years. As the hours crept past peacefully, however, the fear dissipated. The beauty part was being able to see the silhouettes of the skyscrapers against the bright moonlight and the firefly blinking patterns coming from cigarette lighters and matches struck by other lost souls visible in buildings across the street. The *New Yorker* writer was, in the course of recounting his walk home in the dark, practically giddy in his sense of being cut adrift. Surely this was a non-disastrous disaster, a mere "festival of inconvenience." Moreover, it was practically a pleasure to realize that things were getting on despite the fact that no on knew what was going on, not the Mayor, not Con Ed, not the President. Earth, or at least our technologically built-up part of the planet, was being taught a lesson in humility, as if by some omniscient other-worldly intelligence (ref 6.7).

Actually, the hard working crews of Consolidated Edison *did* know what was going on, or shortly would know. Yes, there were complaints about the fact that Rochester had largely been back up since 7:30 PM and Toronto an hour later. Why not New York? Several good reasons. First of all, when the world's most complex urban power network comes unhinged, you don't just turn it back on with the throw of a switch. The city power stations work not by simply converting falling river water into electricity. No, the New York plants, all fire and brimstone, use steam at a thousand degrees. Steam is a dangerous fluid requiring very careful handling. It's a high-pressure, high-temperature, high-voltage, heavy-metal environment, and all the parts would have to be inspected from the inside out. Before you could put Humpty Dumpty back together again you might even have to break him into smaller bits. You have to make sure that everything is truly *off* before you start turning anything back *on*. Not only does New York have to be isolated from the rest of the Interconnection, but the boroughs and all the 42 separate sector networks have to be severed from each other.

Lines have to be inspected, and fuses, relays, and breakers reset. The engineers have to insure that the system could absorb the new disaster if yet another outage occurred. Before taking heat again furnace valves must be oiled. The roundness of all those spinning turbines has to be verified before they can be set rotating again. These monstrous machines twirl so much weight around so quickly that even the tiniest imbalance would cause the turbines to tear themselves apart. You know the racket an imbalanced washing machine can make? Amplify that by a million.

Mostly this scurrying activity by utility workers is invisible to city dwellers with problems of their own. They're stuck in an elevator, or trying to hitch a ride home, or attempting to hire at extortionate rates a taxicab ride out of midtown. Schrafft's loses $200,000 worth of ice cream. Out in the bay, light beams so gallantly streaming continue to emanate from the Statue of Liberty, which gave proof through the night that it was hooked up to the Jersey side of the bay, not the New York side.

The electrical megamachine might not be working, but the telephone megamachine was up, owing to backup generators. Therefore a million calls go through, a record number. Where are you? I'm stuck in the office. When will you be home? No way of telling. When are they turning the power back on? No one knows.

Reconstructing the story of what happened, not just resuscitating the machines, is an important duty. Journalism proceeds in tandem with electrical engineering. Some of the blackout incidentals related here come from government or utility reports. Many more come from daily newspapers, those great, buoyant diaries of town life. Each edition of a newspaper is a time capsule of that day's activity. Stories, headlines, pictures, advertisements---all are valuable in vividly revealing the existential inventory of a city's physical reality: the particulars of domestic, artistic, political, and economic life. It is all food for thought and becomes one of the most tangible ways, decades or centuries later, of telling what it was like then. Even if the participants of those events could somehow be kept alive and made available for questioning, the accounts would still be untrustworthy owing to the inevitable drift of fallible memory. The ladies and gentlemen of the press necessarily become the abstract and brief chronicles of the time. Of course, not everything you read in the paper is true. A lot of facts are left out either because a particular editor thought they weren't important or because there wasn't space. After all, the stories, as newsmen cynically like to say, are what fill up the space between ads.

In New York City, all the morning newspapers but one decided to give up trying to get out an edition for the next morning since the power outage was proving to be not a momentary deprivation but something more serious. The one holdout, the so-called paper of record, the publication where the staff take the news, and themselves, very seriously, declared that it would be full speed ahead. Setting aside the originally planned 96-page spread, the managers at Times Square decided to trim back to a slim but practical 8-page version featuring, naturally, the story that was going on all around them. The other stories of the day were going to be there too but would take backseat to the unprecedented technological pratfall.

These tribunes of the people, the writers of *The New York Times*, worked that night by candle light, not unlike the Timesmen of yore before the coming of incandescent light. By 1965, all the gas pipes were gone, so it would have to be candles or nothing. But where does one procure candles enough for a whole newspaper staff? A few are garnered from the Astor Hotel and some from another great New York Institution, the Catholic Church---in this case, Holy Cross and St. Malachy's (ref 6.8). There was still, however, a daunting lack of mechanical power. You could write by candle light, but you can't run a printing press powered by wax. To publish a paper by morning, something else would have to come along, maybe a miracle.

No, you can't believe everything you read in the papers. For example, correspondents from the Soviet Union couldn't get the story straight. *Tass* reported that the streets of New York were relatively quiet and orderly, while *Izvestia* reported hysteria; politicians and citizens alike were said to be in a state of panic. Reports from British papers quoted utility executives in the UK that such a blackout could never happen on their grid. To readers in France, whose nationally-owned grid was said to be flawless, it appeared that the Canadian-American failure sprang from reluctance by stingy privately-owned utilities to invest in the right equipment. In Germany, a more far-seeing engineer suggested that a completely reliable power system was impossible to achieve, and that local officials should prepare for the day when it would happen in Germany. Photographs of New Yorkers camping in Grand Central Station were fascinating to Londoners who only 20 years earlier had been forced to rough it in that way during the Blitz (ref 6.9).

On the evening of November 9 electrical engineers in the US were not worrying about the grids in Germany or France but they were thinking of their counterparts in Canada. Utility officials on either side of the US-Canada line had the early impression that the blackout had begun on the other side of that long border, and the pursuit of the truth would have to be handled gingerly.

Representatives from all the affected utilities converged in Washington, DC with log books and possible explanations at the ready. According to the Chairman of the Federal Power Commission (FPC), Joseph Swidler, he received mostly cordial cooperation that night, except for Consolidated Edison which did not at first want to divert its logbooks from New York to Washington. When Mr. Swidler mentioned that the President of the United States had assured him of unlimited access to agencies of the federal government, including the FBI, Con Ed quickly agreed to bring their books (ref 6.10).

As soon as the government had any new information it was whisked to the Western White House, and thence to Bill Moyer's ongoing press conference. Pentagon chiefs, the president's science advisor, FPC reports, Congressional opinion, aviation summaries, engineering assessments, updates from utilities with crews in the field, preliminary FBI investigations, and civil defense authorities: all the strands of data led to Texas, where they were released to the press. The President himself, according to Moyers, was receiving updates every five minutes (ref 6.11).

As the evening hours wore on there was, among all the contributories to the Eastern Interconnection energy pool, still scant evidence of any physical damage. For an event that wrenched 30 million people back into the Dark Ages you'd think that there would be some clues of violence somewhere. Actually there had been some damage done, serious damage, but this had been the result, not the cause, of the blackout. The news from Queens was not good.

As at Shakespeare's depiction of the aftermath of the Battle of Agincourt, when those still living gathered around the king to listen solemnly as the roster of the fallen knights was haltingly read out, so the engineers at Con Ed responsible for restarting the system gulpingly awaited the casualty report. One of the big units at the Astoria station was damaged, another at the East River station. And when the name of Ravenswood unit number 3 was read aloud, the men groaned. Big Allis, Con Ed's most valuable workhorse---with a rating of 1000 megawatts---had been wounded in action. With these three generators, all of them lying lifeless along the East River shoreline like beached whales, Con Ed had lost a fifth of its capacity to generate electricity, an amount exceeding the power-making ability of most cities.

The loss at Ravenswood was the unkindest cut of all. With a mighty heart Big Allis had valiantly tried to sustain what was left of the Eastern Interconnection in its dire moment. It had raised more than 100 megawatts in the handful of minutes before the final avalanche. At the core of the leviathan, the 540-ton, 145-foot-long rotating shaft had been crippled when its bearings burned out. The lid on the turbine itself weighed 150 tons and before taking out the tension bolts holding the whole thing together, gas torches had to be used to warm up the metal. The doctor's prognosis: the patient would be disabled for at least a month (ref 6.12).

And what was the cause of the blackout? Where had it started? The generalized forensic inquiry would proceed down to into the grid’s lower depths if necessary. Since no visible damage had been found, investigators would look at the second-by-second printouts of the devices that monitor voltage levels and power flow in all the important passageways of the network from Michigan to Quebec, from Boston to Philadelphia. The sleuths were confident that they would pluck out the heart of the mystery. Like deducing an arrhythmia of the heart by deciphering excursions on an electrocardiogram, so the arrhythmias of the grid could be gleaned from the seismic waveforms representing the critical high voltage levels at or around 5:16 PM on the night in question. This remembrance of electricity past revealed possible sequences of causality, likely scenarios lurking behind the avalanche of November 9.

The disruption certainly had manifested itself at an early moment on the transmission line between Rochester and Syracuse, but this had not been the epicenter of trouble. The true cause, the experts later learned, lay further west, right at Niagara, where the two friendly countries come together with power plants on either side of the river but conjoined by an international spaghetti entanglement of high-voltage lines. To triangulate the cause of the crash and propose a remedy would, in the coming days, require persistent investigative work combined with sensitive diplomacy.

The Particular Fault

Achieving a grid that never crashes is like trying to reach the speed of light or a temperature of absolute zero; it can’t be done. Planets, baseballs, and human bodies must all obey the laws of nature, and the electrical grid is no different. One of the most general laws of nature is decay and death, and not just for living organisms, but for all composite things. Even mountains and stars are expected to fall apart.

One way to study this falling-apart process, particularly in complex systems with lots of interlocking parts, like the grid, is to look at what happens to large piles of sand. If grains are added to such a pile, one at a time, mostly nothing happens. Sometimes an extra grain---plop---will cause a small avalanche here or there for a second or two. Then everything gets quiet again. Another grain is added, and not much happens. Conditions are gradually changing, though, even if you can't see them. Inside the pile, all the grains communicate with each other through subtle nudges and scrapes. With every new grain added, the internal ordering of things gets readjusted. Stability is never more than provisional as the conical shape gets more precariously steep.

Now and then---plop---a new grain will cause a more substantial portion of the pile to give way. A new stability is established. And then the process begins again. More grains---plop, plop---are added, causing more internal adjustments. Lots of small avalanches happen, and some medium avalanches. Fragile stability is always heading for a larger instability as the pile gets steeper and as the angle of repose becomes more acute. The system, the sandpile, is moving toward still another avalanche event. The placement of one tiny grain can trigger the placement of all the others. This system of thousands or millions of parts can be placid on the outside while moving toward catastrophe on the inside.

Here comes the big generalization: the electrical grid and its collection of thousands of rapidly-interacting components can resemble the behavior of the sandpile (ref 6.13). It’s as if the grid, and maybe the rest of inter-connected modern technology too, were built on the side of a steep slope. With complexity comes an inherent instability. For an electrical grid, the grains of sand correspond to peevish problems with the myriad wires, valves, switches, relays, transformers, and circuit breakers. And the avalanches? The electrical analogue consists of all those unsettling events when power goes out. Maybe the duration is a second, maybe a day. The cause might be a fuse or a faulty hair dryer. The pile as a whole keeps organizing itself. As each new grain is added you can never be sure whether this will be *the* grain that sets off the super avalanche.

The question now is: for the 1965 blackout, what set off the whole thing? No individual, no utility, no country wanted to be singled out for blame. No one would relish having to apologize to the 30 million. Investigators uncovered many imperfections: faulty system architecture, poor procedure, errors in judgement, insufficient readiness. But was there a single, locatable origin to the sequence, an immediate cause for 26,000 megawatts to disappear in succession across the face of an 80,000-square-mile service area?

Yes, there had been a fateful grain of sand. When it landed on that pyramid of electrified complexity we call the Eastern Interconnection, the avalanche began. The dead center of the fiasco lay placidly inside a vault at the Sir Adam Beck hydroelectric power plant in the town of Queenstown, Ontario, not far inland from the Niagara River. Operated by the Ontario Hydro power company, the Beck facility supplies its own customers to the north and west on the Canadian side of the border and also ships huge blocks of power south and east to the US side.

Re-run the phenomenon. For the moment, picture in your imagination a set of five metal cables coming out the back of the Beck plant and traveling all the way to Toronto, the largest city in Canada and a prime load center for electricity. A cable carrying electricity is a simple thing. It has no moving parts and does one thing---carry energy. To insure that the cable itself and the attached assets such as generators and transformers are protected from burning out, circuit breakers are ready to interrupt the flow in a fraction of a second by retracting a large metal contact.

What happens when a line is opened? At first the electricity isn't fully aware or the interruption. Like a stream of cars driving off into the river after a span of a bridge has collapsed, the electricity is inclined to continue flowing, at least for another instant. It does this in the form of an arc, a miniature lightning bolt leaping across the now-widening gap. A high-voltage breaker of circuits provides muscle, sinew, and pivoting joints. What it lacks is a brain. Brainpower, or at least the sensory capability to discern a change in the local environment and then to do something about it, is supplied by a device called a relay. It tells the breaker when to flash into action. Like expressway on-ramp traffic lights that sense when it is safe for a car to enter (green light) or when it is too crowded (red light), an electrical relay continuously monitors traffic conditions and allows current to continue or to be cut off.

If, as in the old days, we believed that it was the irony-loving Greek gods who set disasters in motion, then you could not ask for a more appropriate chain of disproportionate causality. The misbehavior of something small, no bigger than a breadbox, would bring disrupt something big: the grid from Buffalo to Boston. It was a safety device, one of those relays designed to limit the flow of current that was inadvertently to unleash ruinous amounts of current. The parts of the grid nearest at hand would generally be affected the least, while the hardest hit would be the parts of the grid far removed from the source. We no longer hold the gods accountable. Now we believe in nonlinear dynamics and complexity theory.

Here specifically was the problem: those five cables pointed at Toronto were doing fine and carrying current well within their ratings. But the relays standing guard had been set too low. No one in several years had rethought the purpose and operating range of these simple components. During these years Toronto's electrical consumption had grown, the currents in the cables had grown, and consequently the Ontario grid---let’s again invoke the idea of a steepening sandpile---was moving, without knowing it, ominously up a slope of instability.

Also without knowing it, *other* parts of the Eastern Interconnection were moving up slopes of their own. The different parts of this collective sandpile had been self organizing and reorganizing for months, maybe years, toward a condition of greater vulnerability. The parts, being made of mute metal, do not communicate with each other in the meaningful way that humans do, but they *do* communicate. They are in physical contact with each other. The parts of a networked power system are components of a single all-encompassing machine. It is sensitive, dynamic, and in extreme cases of rapid propagation of faults...totally unpredictable.

The whole system was silently waiting, inadvertently evolving toward an indefinable arrangement of parts prone to be set off by a trigger mechanism. If it didn't happen on this day or the next, it might happen later. And then finally, without anyone knowing or expecting it, the day had arrived. The fatal grain of sand was being added to the pile. The toboggan ride was about to begin.

This then is the retold tale of how electrified civilization came unzipped on November 9. At 5:16 PM Toronto was in the middle of its rush hour and a slight upward tick in the current drawn from the Beck plant was enough to actuate the relay, which quite properly (it was only obeying orders) signaled a circuit breaker to open, taking the line out of service. Denied the use of that route, the energy adroitly detoured to the four companion lines. Not surprisingly, the relays doing sentinel duty on those lines also hastily determined that too much current was flowing. Breakers on *those* lines were now activated and suddenly, in a matter of a few seconds, all of Beck's Toronto-bound energy was stymied.

About 1100 megawatts from Beck, plus about 500 megawatts of power from the New York side of the river now had to reverse course and try to get to Toronto in the only way it could---by going the long way counterclockwise around Lake Ontario. So a huge wave of electricity now came surging down into New York state in addition to the current that was flowing there already (ref 6.14). This threw the generators to the south into asynchronous confusion. Waves of electricity have to be in phase with each other, and when they’re not, emergency procedures are initiated. Relays everywhere went crazy, lines opened, generators tripped off, cities went dark.

This was the too-much-energy part of the blackout. Then, with most of the power from the Niagara end of the Eastern Interconnection blocked off because of open circuit breakers, the not-

enough part of the blackout began. With the general network now undergoing fibrillation, the avalanche dynamics dictated that localized portions of the grid should scramble for extra power wherever they could find it. In the minutes after the Beck failure this meant, in practice, the power plants of the Consolidated Edison system. The most put-upon machine that day was Big Allis. You have already seen what happened next and last---how a cascade of shutdowns put more strain on those generators still active, how this sank nearly the entire Con Edison network, how this shut off the vital power needed to run the oil pumps, how this left Big Allis's bearings dry of lubrication, how this roughened the rotation of so large a machine at 3600 rpm,
and how this brought the whole thing
to a quite unsatisfactory
and complete
stop.

Naval Maneuvers

In many cities the storm's visitation was short lived, in some cases for only an hour or two. In a few places the power had not failed at all since someone had adroitly intervened at a decisive moment or because an automatic switch had done the job. Hartford was one of these fortunate islands of light, owing to the splendid stand-in performance by an old power plant, affectionately known as Old Gal, normally kept in service now only to help meet the nightly peak power demand. Because it did not hook into the regional grid, as the other generators did, but only into Hartford itself, Old Gal remained up and running. She had kept her head of steam even as others were losing theirs. Once the largest powerhouse between New York and Boston, Gal was still capable of a respectable 242 megawatts. The inside of the old brick riverside generator building could get up to 116 degrees on a warm summer day, but the men, especially after November 9, were proud to be working there (ref 6.15).

Things weren't so providential in Rhode Island. In Providence, as in New York City, the local grid had no provision for auxiliary power, thinking that they would never run completely out of electricity, and so the Narragansett Electric Company had to wait for help from outside, which arrived from Millbury, Mass. With this startup electricity in hand, Providence began to restore energy in a process which was repeating itself all over the Eastern Interconnection: cautiously turn up the generation, deliver power to one sector, monitor the frequency and voltage, crank up the boilers some more, increase still more the current going into the large copper conductors (the bus bars) leading out of the plant, light up another neighborhood, and so on. If the power wasn't quite enough for the load, some feeders had to be turned off, at least temporarily, then on again when the electricity *was* available. The golden rule always to be observed: supply and demand must be in balance. In Providence, though, they were going for broke. Five main lines would be activated all at once. Dispatchers were waiting at their switches and then came the count: one, two, three...and voila! The circuits were closed, power ran its course, and the city had light again.

But how about New York City? Why didn't they have power? All through the night exasperated New Yorkers were asking this question. Help was on the way. The *USS Bristol*, a Navy destroyer, was dispatched under cover of darkness on a special mission from the naval shipyard in Brooklyn to a point where the East River reaches over to meet the Long Island Sound. Finally at its post, the *Bristol* prepared to fire. At the last minute, however, the action was aborted. The intended target had been Con Ed's Astoria plant. The ammunition: the *Bristol*'s considerable supply of electric power, which was to be shot into the darkened generators ashore. Fortunately, just at this time, a trickle of power was starting to come in over a land line and the assistance by sea was no longer needed. The *Bristol* next went over to the Manhattan side of the channel, intending to provide help at a power station there, but again their help was respectfully declined. Where was the energy coming from?

Because of an oddity in the way the power failure had arrived, Staten Island and a beachhead in Brooklyn had been left active and attached to the New Jersey grid. This segment of the Con Ed system wasn't exactly a ward of New Jersey, however, because the powerhouse at Arthur Kill on Staten Island ("kill" is the Dutch word for “stream”) commanded nearly 400 megawatts of power. Its smoke stack was the highest thing on the island. Arthur Kill was to the be the lifeboat of the New York system. From here the other parts of the city would be resuscitated, starting with Brooklyn.

And so, as it had in other places for hundreds of miles around, the procedure was repeated: re-ignite the boilers, build pressure, open valves and let steam come full tilt at the turbines. With electricity now makeable, blocks of load would sequentially get back their due ration of energy. The task of energizing neighborhoods went according to plan with all deliberate speed. But to those on the outside, the restoration seemed delinquent. At 1 AM still only 25% of the city had power. Why did they have energy in Albany or Toronto or Syracuse but not the Borough of

Manhattan or the Bronx? The main reason is how much *more system* there was to be activated---hundreds of miles of high voltage cables filled with a Niagara's worth of energy---the largest underground network of wire in the world (ref 6.16).

Back in Texas at the Western White House enough emergency information had been imparted and enough concern for the nation's defense had been expressed, so Bill Moyers brought his long-running press conference to an end. The source of the blackout, at this hour, had not been located, but the possibility that it had begun by deliberate sabotage on the part of a person or persons unknown was virtually ruled out. The mystery would be technological, not criminal. The failure would be in the realm of electrified equipment, not Communist aggression. It was 2 AM in the east, and there would be no further news until the sun rose. The President was going to bed, and Mr. Moyers said goodnight.

There would no further news, but the news in New York that was fit to print at that hour was about to be printed. The fullest account of the blackout, at least the civilian version of the affair, and not the official federal report that would be assembled by engineers, bureaucrats, and utility officials a month later, was coming together at the offices of *The New York Times*, where three dozen newsmen were straining toward their self-appointed, publish-at-all-costs goal. And it would come at great cost since in the pared-down edition coming into being there would be little room for ads. The paper would go out practically gratis, all for the greater good.

As the evening hours wore on, it was more likely that the *Times*' own press would be unavailable. The facilities of the *Newark Evening News* were therefore secured for two obvious reasons: first, they were located in New Jersey, which was blessed with power. Second, they were an evening paper and wouldn't be needing their press for the next few hours. Text for tomorrow’s edition, some of it still unedited, was shuttled beneath the Hudson River through the Lincoln Tunnel. In all, some 21,000 words were shipped west.

Newark not only gave the *Times* a press to play with but also a set of complete Wall Street stock closings, so at the last minute the *Times*' edition was bumped up to 10 pages. After all, business is business and even in the middle of the greatest blackout ever it would be convenient to know what your holdings were doing on November 9.

Meanwhile, at the Waterside plant, the oldest continuously serving power station in New York and the energy provider for the heart of Manhattan, things were moving to a head. The plant's apparatus was inspected, steamed up, and ready to go. Now it was time to move power back to where it was needed, in the homes of New Yorkers. It was time to pick up load.

And to do this they adopted the old fashioned method, just the way they'd done it in Providence a few hours before. To shoot energy back into circuits, the engineers had to take the system into their own hands, literally. It had all come down to this single moment of truth. Here, according to an engineer on duty at the time, was the scene in the wee hours of the morning:

> *After the station bus was energized, 12 men were stationed at the high board and were told to take a switch in each hand. With controls for each of the 24 feeders thus in hand they were instructed to operate the switches instantly at the count of three...24 switches slammed into closed position, instantly transforming the Grand Central network from a sea of blackness to a sea of light."* (ref 6.17)

Standing by, those who didn't have a hand on one of the switches were watching at the windows. When the energy went through, the results came back at light-speed. The city was relit! Grand Central was grand again. Relieved, the men let out a cheer of delight.

The city was almost back from the dead. What about those poor souls on the Astoria Train trapped beneath the river? Some of them had walked out on their own legs, traipsing up the track towards the Queens side. Others, fearing to make the long tunnel walk or worried about emerging into a neighborhood they didn't understand in the middle of the night without benefit of street lights, had decided to sit tight. How long did they sit? When the power finally came on for that train, when things finally moved, the time was 7:15 AM, almost 14 hours after the train had launched itself into that tunnel the night before (ref 6.18).

Not all the blackout narratives had happy endings. Vange Burnett, in town from Florida for a trade show got lost in the corridors of the Windsor Hotel. He did not show up the next day, nor the one after that. Could he have just left for home? No, because the family hadn't heard anything either. Sad to say, his dead body was discovered six days later in the pit of his hotel’s elevator shaft. The hand of the dead man still clutched a candle (ref 6.19). Perhaps the candle had gone out and the man had taken a fatal turn in the dark.

There are a million stories in the naked city. If you had wanted to delve just beneath the surface reality for many of the named figures in this book, such as Tesla or Westinghouse, you would find whole books. For Vange Burnett there are no books, but there are a few Internet websites where, for example, you can learn that he served as a lieutenant commander in the US

Navy during World War II. You can see Vange's high school discus and shotput records enshrined for the year 1931. On other pages you can view his picture taken at a Northwestern University football commemorative, or his place in a Burnett family tree that proceeds lineally downwards to grandchildren now alive and upwards to forebears preceding him by a hundred years or more.

The great blackout of 1965 was over. When the engineers had finished their valiant job of correcting electrical faults, the editorialists began their job of finding fault. *Life Magazine* declared that the crisis had had its good points since "it deflates human smugness about our miraculous technology." The skyscrapers, glimpsed against the fading sunset glow over New Jersey were, *Life* said, "as lifeless as the hulks of Angkor Wat." (ref 6.20) Most newspapers showered scorn on the utility companies for sloppy work or the government for failing to anticipate such a catastrophe. The award for vitriol goes to the Rochester Democrat and Chronicle:

> *This editorial is written under shameful conditions. It is written by the light of a single candle stuck to the bottom of a wastebasket upended next to the typewriter. And this is the 20th century? This is primitive; it is the abject capitulation of an over-mechanized society to a single flaw in its complex machinery* (ref 6.21).

Their front page opinion piece on November 10could hardly cram it all in: shameful, enemy force, rubbish, scandal, a specter walking through the city, brooding tragedy, farce, distraught, chaotic, far-fetched, and thievery were some of the choice words used.

The letters of many papers provided space for the citizenry to react. One reader, a past commander of the Pearl Harbor Attack Veterans Post, compared the thought-to-be-impossible blackout of 1965 with the impossible-but-real attack on the Hawaiian fleet in 1941. Another letter writer, a Vermont high school student, chose to emphasize the cooperative spirit of the night before:

> *Part of the purpose of man was to associate with other men. It is certainly gratifying to know that in a world where everyone is crying war and racial prejudice, men will come to each other's mutual aid an assistance in time of need. It's nice to know Society isn't so bad after all* (ref 6.22).

For sociologists at Columbia University the blackout provided a huge laboratory experiment, the kind you can't plan beforehand. Interviewing more than a hundred New Yorkers that night, the professors found that most citizens had stayed informed of developments by transistorized radios or by word-of-mouth. Most had acted calmly and expected things to get back on track before long. As to why women seemed to have weathered the event better than men, one sociologist offered this explanation:

> *Perhaps this is an indication of the fact that many women in our society lead lives of boredom and enjoy the chance to partake in an unusual event...The men, on the other hand, may feel that it is something to take seriously and certainly not "enjoyed."* (ref 6.23)

The New York Times made it to the streets even as the last shreds of tardy voltage were toddling into place in the grid. The 400,000 copies quickly sold out at corner newsstands the morning of November 10 and became keepsake possessions to preserve in lower drawers of attic wardrobes. Not only did the *Times* detail the events that had unfolded just a few hours before. There were also, as a bonus, those closing stock quotations for November 9.

How about quotations for November 10? What did investors make of the largest ever single-day technological outage? Well, the New York Stock Exchange did open (one hour late), and traders quickly told the manufacturers of electricity what they thought of the night before. Consolidated Edison was off 3/8, Niagara Mohawk off 3/4, and Pennsylvania Power & Light off 1/8. Meanwhile, the makers of heavy duty power equipment did better: General Electric was up 15/8 and Westinghouse 5/8. A circuit breaker company's stock closed much higher.

26 September 2005

Chapter Seven

Overhauling the Grid

Utility stock wasn't the only thing down the morning after November 9. So was confidence in the idea of shared electricity. If a problem in Rochester or Toronto could ripple all the way down to New York City then why they don't just cut the connecting wires. But that's not what happened. Not only did the connecting wires stay where they were, but new ones were added. The energy sea would become more like an energy ocean.

Nobody would have said, the day after November 9, that the course of the grid business was about to swerve. Grid history, like all forms of history in the making, is hard to assess while you're living through it. It might be easy to see changes being made---the construction of new power plants, say---but difficult to fathom the meaning of the changes until later.

Still more difficult to achieve is an appreciation for the irony of the situation. The Greek playwrights made irony the centerpiece of their depiction of the mysteries of life. We intend to do one thing but often something very different happens. We pursue a course of action and can be swamped by the unintended consequences. Surface appearance can be the opposite of the underlying reality. Irony is a part of virtually every human endeavor, including the management of complex technology.

This chapter in the history of the grid, devoted to the aftermath of the 1965 blackout, is rich in irony. It is a tale of missed opportunities and occasions when a problem’s symptoms were completely misread by those in authority, who the took a course of action which only compounded the problem. One of the great lessons of life, and of Greek drama, is the realization that no matter what you’ve been told or come to believe (and here I quote from that great American drama, George Gershwin’s *Porgy and Bess*) “It ain’t necessarily so.”

Not Enough Grid

The bigger they are, the harder they fall. This modern cliché, very Greeklike in spirit, applies nicely to the November 9 catastrophe and to other electrical events yet to come. Ever since the days of Pearl Street, power plants had been getting bigger. For the amount of coal thrown on the fire, ever more electricity was coming out onto the wires. The cost of a kilowatt-hour kept tumbling down. For the better part of the century, economic growth in America, in Germany, in Japan, in Argentina, benefited from electrical innovations. Graphs showed that the more electricity a place had the more prosperity it had. Greater efficiency and lower prices---they would just keep going forever, wouldn’t they?

All the studies had shown that bigger was better. Bigger boiler, bigger pipes, hotter steam, higher pressure. All the engineering experience had pointed to what seemed like the inevitability of the Big Allis approach. If your utility could afford the financing or had a big enough revenue stream or the workforce or experience to grapple with a machine of such monstrous proportion then you’d want a 1000-megawatt producer of electricity too. This would seem logical, but as we will see it ain't necessarily so.

The immediate consequence of November 9 was the effort by grid planners to make sure it didn't happen again. Improvements in sensors and in transmission lines were mandated. An organization, the North American Electricity Reliability Council (NERC), was created in order to foster growing regional ties among utilities and to insure that prudent safety measures would be observed. Prudence might have been the watchword, but something more pressing, an ineluctable factuality, was lurking inside the pipes and valves of the big power plants. This intestinal disorder, ignored or not noticed for several years, was to lead to major complications ahead.

The problem was this: bigger was no longer better. There weren’t yet enough data points to clinch the case, but it would soon become evident that a bigger boiler wasn’t necessarily a better boiler. Efficiency had reached a plateau. If you factor in the maintenance downtime for the biggest generators, then efficiency was actually on the decline. The soldiers of the grid at the platoon level---the electricians, plumbers, pipe fitters, welders---could see firsthand that the big machines were troublesome. At the extreme pressures and temperatures needed to operate the battleship-class machines, corrosion seemed to occur sooner than with the more forgiving conditions.

And why not? It was like an inferno in there. Components might do well in lab tests, but running continuously for months at unprecedented high temperatures took its toll. A failed part, even a small one, could mean that the whole 1000 megawatts would have to be taken out of service. A bridge with four lanes can carry twice as many autos as a bridge with two lanes, but a single overturned truck can still shut down either bridge.

So it was, in the late 1960s, that Big Allis was sick a lot. The wisdom of bigger-is-better became questionable. Especially in those summertime heat waves, when the living is anything but easy, the flagship of Con Ed's fleet was often in drydock. And with so much of the company's fortune sailing along with the one large vessel, everyone started to sweat on those days when Big Allis was off. After years of successful ads extolling the benefits of electric air conditioners, dishwashers ("Roll in a dishwasher...roll out work."), and clothes dryers ("You can't always be sure of sunshine, but you can always count on a clothes dryer."), the utility's efforts to fulfill electrical obligations with existing generating capacity came to be more fraught with danger. Isn't it ironic? Having created aggressive consumers eager to use more electricity, the utilities were now having trouble keeping up with the demand.

On the seesaw of power delivery, what you have on the load side---all the customers and their plugged-in appliances---must be exactly balanced every second by the generation side---all the current shooting out from all the plants. What happens, though, if a power plant is disabled, and the new plants are not yet installed, and the company has used up all its extra reserves, but the customers keep asking for more?

At a moment of stress, one thing the company can reluctantly do is to lower voltage. This is referred to as a brownout. Not as drastic as a blackout, a brownout is an anemic condition in which the regular 120 volts might be allowed to deteriorate by a few volts. Appliances don't like this lean diet. Motors will struggle, as if having an asthma attack. Incandescent bulbs, designed for 120 volts, will only emit half their normal light at 100 volts. Air conditioners can overheat and subways go slow.

Let Consolidated Edison serve as the example of late-1960s grid operation. On some hot days, when some of their own generators weren't up to the task, Con Ed dispatchers went searching for extra power wherever they could, to Long Island, to Canada, even to Tennessee and the TVA (ref 7.1). Of course, this was not a satisfactory state of affairs. The company was hardly standing still. In fact, it planned an ambitious program of expansion. It asked to build a nuclear reactor at the Ravenswood site, home to Big Allis, but was turned down after much rancorous debate.

An even more contentious battle swirled around Con Ed's proposal to build a pumped storage facility at Storm King Mountain, on the Hudson River. Imagine moving a small piece of Niagara Falls a few hundred miles closer to New York City. It worked like this: at night, when demand was low, electricity would be used to pump water up the slope of a mountain into an 8-billion-gallon reservoir. The next day, at times of peak demand, the water would be allowed to pour back down off the mountain, re-generating electricity as it fell. True, you would only recoup about two-thirds of the power you used to pump the water uphill in the first place, but it was worth the effort since the rush-hour power would be *premium electricity*. It would be a supply of energy when you needed it most. If Storm King had existed earlier, the company argued, the 1965 disaster might have been averted. The brownouts that came later might not have been necessary.

Pretty much used to building plants whenever and wherever it thought fit, Con Ed was taken aback when a number of conservation organizations, such as the Audubon Society and the Sierra Club, joined local critics in combating the plan in court on grounds that it was bad for the scenery, bad for fish and fowl, and bad for property values. The company was frustrated. Not only did the delays hamper the utility’s long term planning, but it brought them much bad publicity in the newspapers. Furthermore, the case galvanized many who had previously not been particularly vocal when it came to conservation matters.

Blocking Storm King was seen by some as a pivotal step in the evolution of the environmental movement (ref 7.2). The critics who had found their voice and the appropriate methods for standing up to the giant corporation, would hereafter be a regular part of the culture of electricity, whether it concerned the siting of transmission lines, the release of sulphur into the sky from a smokestack, the killing of fish by heated water returning to a river from a power plant, or the falling of coal particles into lungs or onto property. A ton or more of dust sprinkled Central Park every day (ref 7.3). Things that used to be normal operating procedure, were being questioned now.

The critics of the critics liked to ask how all the expected improvements, the non-polluting generators and repairs made without digging up streets, would be made without raising rates. Where, the utilities wanted to know, did the citizens and elected officials of the city want the needed generators to be built? Answers were often lacking.

Con Ed became “the company you love to hate” (ref 7.4). It was seen as an arrogant, indifferent, uncaring institution. What used to be held up as virtues, such as the habit of family members---fathers, cousins, nieces---working side by side or managers staying loyally at the job for 20 or 30 years, were now viewed as points of detraction. The company, some said, was out of touch with the people, and their machines were out of date. *The Wall Street Journal*, interviewing a consulting firm that had looked over the utility's management style, reported that "a survey of the 240 top executive jobs at Con Ed found that the duties of 71 executives consisted solely of supervising one other executive each" (ref 7.5). Late night television talk shows offered plenty of Con Ed jokes. The mayor, John Lindsay, adroitly refrained from working too closely with the main energy provider for his city. To an ambitious politician, having Con Ed as an opponent was much more advantageous than in having them as a partner (ref 7.6).

A new man, Charles Luce, was brought in as Con Ed chairman to shake things up. He vowed to make customer service the highest priority. He reduced the payroll, changed the company motto from "Dig We Must" to "Clean Energy" and the color of its trucks from orange to the blue-white-gray scheme used to this day. The company responded faster to reports of power troubles from homeowners. The promotion of energy-gulping appliances was ended and a "Save a Watt" program encouraging customers in the summer to use 10% less electricity was initiated. That's right, Con Ed was actually encouraging people to buy less of its product. Helpful hints on how to do this were placed in newspapers: turn off air conditioners when you aren't home, run clothes washers and dryers before 8 AM and after 6 PM if possible, and save the use of power tools for the weekend (ref 7.7).

Economizing on power was nice, but the main item in the company's plan to meet the rising demand, as you might expect, was to build more plants, including several nuclear units along the Hudson like the one already operating at Indian Point. Other utilities around the US did not necessarily have all the problems plaguing Con Ed, but they too were being scrutinized more carefully now by state regulators and by those special interest groups which seemed to put considerations for waterways or air quality or small animals above the imperative of supplying the city with energy.

More energy would be needed. You couldn't deny that demand never went down. How could it? Once accustomed to a certain standard of living, society was not going to settle for less electricity. Some things were almost too obvious to be worth saying. The grid had to balance generation and demand second by second and year by year.

While electricity planners in New York were putting fine touches into their blueprints for future service, there occurred an event, thousands of miles away which almost overnight would cause grid history to take a great swerve. On Yom Kippur, the High Holy Day in the Jewish calendar, a barrage of gunfire erupted in the Sinai Desert on October 6, 1973, and war between Israel and neighboring Arab nations broke out on several fronts.

Too Much Grid

If westerners didn't know much about the Organization of Petroleum Exporting Countries (OPEC) before, they would now learn quickly. OPEC had as members such nations as Venezuela and Nigeria, but its most potent bloc consisted of the Islamic lands of the Middle East, and officials there were bent on economic revenge for frustration on the battlefield. An embargo on oil sales to the United States and the Netherlands was imposed in retaliation for their support of Israel.

The embargo lasted only five months but its effect was profound in demonstrating the political muscle of the exporting states and the fragility of world energy supply. The cutoff and the subsequent huge oil price increases had an immediate effect on petroleum-related industries, such as automotives. A sideways impact was then felt by other heavy users of energy, such as the electrical business. Prices at the gas pump and at the kilowatt meter shot up.

Then the unthinkable happened: the growth in electric demand slowed. For the first time since World War II, the use of electricity in the US for one year, 1974, was less than for the previous year. Many utilities, confident that demand would quickly return to its old gradient of ascent, stuck with the game plan. They pushed ahead with the gigantic construction plans. In the 1960s they'd been embarrassed by a shortage of generation and weren't going to let that happen again. Even with higher-priced fuel, even with the new environmental restrictions on smokestack emissions, even with the escalating construction costs for nuclear reactors, the building continued (ref 7.8).

But demand did not go back up, or at least not at the old rates. One of those heavy ironies that characterize our tale fell into place: in the space of only a few years, in the 1970s and 1980s, the US had gone from having a shortage of electricity-making capacity to having an uncomfortable surplus. Gradually it became apparent that some of the plants weren't necessary, especially the expensive new nuclear facilities. In a few cases, there was talk in the back room about abandoning some of the plants (ref 7.9). It had come to that. Which was more painful, throwing good money after bad or declaring to your board of directors and investors that you had planned wrongly? One hundred nuclear plants begun between 1974 and 1982 were cancelled, with billions of dollars of losses. Reactor construction costs had quadrupled, and only a small part of that was due to inflation (ref 7.95).

A new problem, a finance problem, loomed. Making electricity had always been a capital-intensive enterprise. That is, it had taken several dollars of infrastructure to make one dollar of product. Now it was getting worse. Bond ratings for some utilities dipped here and there. Con Edison failed to pay its shareholders a dividend in April of 1974, a very cruel month, when the largest monthly utility stock decline since the 1930s occurred (ref 7.10). For those who operated the grid, the 1970s would have seemed like a deep pit with slippery sides and no apparent way out. It was a wacky world: demand had stopped growing at the old rate, fuel was expensive, OPEC was ascendent, and inflation was moving up. Was there any good news?

Certainly not on the nuclear front, where the 1975 fire at the Brown's Ferry plant in Alabama (a reactor owned by TVA). The core-melting accident at the Three Mile Island (TMI) reactor in Pennsylvania in 1979 underscored the problematic nature of deriving electricity from splintering nuclei. At TMI no one was killed but great psychological damage had been done. The cleanup would prove to be more expensive than building the plant in the first place. The government suspended the granting of new nuclear licenses. The history of nuclear power, at least in the US, had taken a swerve.

How the grid business had changed. Giant figures on the order of Thomas Edison or Samuel Insull were no longer to be seen. The generation and transmission of electrical energy, once a forefront engineering domain, now had all the excitement of accountancy. The distribution of voltage *was* a type of accountancy: was it not the movement of a commodity in different denominations to various jurisdictions, followed by a bill at the end of the month?

The greater part of the power industry consisted of investor-owned utilities operating under monopoly conditions, which meant that only one electricity provider was available in that town. This arrangement avoided a costly duplication of wires and poles and generation plants. And for the privilege of being the sole source of power, the utility submitted itself to the oversight of a state regulatory body which set the rates in such a way that the company made a profit but not a big profit. The whole system was sensible, dependable, and dull. You could make a living, but not a killing, in electric power.

If there were little motivation for change, how would innovation ever come about? Altered circumstances---a war in the Middle East and high fuel prices---had imposed changes from outside the power industry. From the inside the realities of physics, in the form of thermodynamic laws curbing the efficiency of steam engines or the wayward behavior of atoms inside nuclear reactors, had imposed new limitations on the way power was generated. Surely there must be some way that the managers and engineers of the grid could take fate into their own hands and turn things around. But how? We thought electricity consumption would always grow. It didn't. Fuel prices had been reasonable for so long. In the 1970's the price of oil had more than quadrupled. We believed utility stocks were totally reliable. They weren't.

Compare and contrast: In the computer business, the phrase "Moore's Law" refers to the prediction made in 1965 by Intel official Gordon Moore that the computer power of a central processor---the number of transistors on a microchip, or roughly the amount of calculation performed per unit cost---would keep doubling every two years or so. This prediction has been (and at least for now, continues to be) borne out, which helps explain the robust condition of the computer industry and Internet-related commerce.

Something like this had also been at work in the grid business, where through succeeding decades the amount of coal (or comparable fuel) you needed to make a kilowatt-hour of electricity kept falling. This made electricity more and more of a bargain and helped to amplify its already huge role in industrial and domestic life. It was nice while it lasted: ever improving dynamos making electricity and central processors making calculations. But then Moore's law for the grid started sputtering out in the 1970s, and grid planners had to look elsewhere for new forms of economy. (If ever Moore's Law, as it pertains semiconductor microcircuits, ever comes to an end, then the history of computers will probably take a swerve too.)

Change in the grid business would come, slowly at first and then more quickly. Some of the changes were to come through engineering innovations, some through legislation, and some through business reorganization. In presenting the saga of these changes this chapter will, for reasons of economy, reduce many complex events to a few representative actions, and the cast of characters will be limited. The deeds of decades will be telescoped to a few dozen pages. What you're getting here is not a comprehensive or scholarly *history* of the grid but rather the essence of the *story* of the grid.

Greener Grid

Foreign Affairs magazine, not exactly a primary outlet for news and views about the grid, carried an article in its October 1976 issue called "Energy Strategy: the Road not Taken." The author was a young physicist named Amory B. Lovins, and he was eager to contrast two rival scenarios for the way society uses its resources and how business and engineering circumstances shape the petroleum and electrical industries.

Right now, Lovins argued, technologically advanced nations were following a "hard path." In this scenario, primary energy originated mostly in immense oil and coal fields. After trans-shipment, the raw fuel was processed in massive refineries and generating plants (the bigger the better) and dispatched into extensive sophisticated networks of pipes and transmission lines. The metabolic result of this activity produced both desirable consumables, in the form of electricity and numerous petroleum products, and many undesirable byproducts in the form of noxious greenhouse-effect and acid-rain-forming gases or radioactive residues that would, if spilled, become a nasty contaminant of farm and city.

Compare this, Lovins said, to a "soft path" approach to energy, one employing a smaller-scale, more decentralized but no less efficient, production and distribution system. Fuelling this system, whether for transportation or for making electricity, would involve the gradual phasing out of fossil or fissile materials and the phasing in of renewable sources such as solar and wind power. This was not a new idea. In the mid 1970s solar cells had already been around for some time, and windmills had of course been used for centuries. Unfortunately, the direct use of sun and wind were still too expensive to deploy on a large scale for power production. The machines were unproven, couldn't provide energy in large quantities, and didn't seem to be compatible with the existing grid. Lovins's quest to chase after windmills seemed quixotic and was easy to dismiss.

Why was this energy outline published in a magazine devoted to foreign affairs? For one thing, the Arab-Israeli war and the subsequent oil embargo were then only a few years in the past. Moreover, energy was playing an ever more strategic role in all the immense issues on the world stage: economic development, climate change, health, and security. Lovins's essay was certainly not the first or longest assessment of energy or sustainable growth, but it received plenty of attention. It was a finely-argued examination of the complex technological conundrum of how we can match rising world population with available resources and it arrived just when anxiety in the West over access to energy supplies was quickly mounting. This essay was also the opening salvo in Lovins' prominent career as gadfly and persistent reformer. The *Foreign Affairs* article spoke plainly of the problems of the energy system then in place and how it could be improved in a major way.

The greatest compliment to Lovins's seriousness was the quick and pervasive chorus of praise and detraction that ensued, especially the latter. If Lovins emphasized the efficiency and ideal features of the soft path---a call for using only a fraction of the energy then being consumed---then that is what his critics seized upon; this was not a soft path but a soft-headed path, they would say. It would guarantee a lower standard of living, the critics said. It was a return to the simpler life of the Dark Ages (ref 7.11).

Some skeptics made the mistake of believing Lovins was some mere hippie, a countercultural complainer. Counter he might have been but not a complainer. He was not Tiresias or Jeremiah come to prophesy doom. He had suggestions, lots of them, and he wanted to put them into practice. Lovins would keep pushing the great idea of energy efficiency. Again, the principles of energy conservation and energy efficiency were not new. What Lovins did was to package the ideas, present them in book after book, lecture after lecture. He sought to get the ear of government officials, businessmen, and trade groups. It helped too that generally he was better informed than his critics. President Carter named him the first head of the Solar Energy Research Institute.

What was the heart of his plan? To start with, he argued, the biggest source of *new energy* was right in front of us, not buried in the ground needing to be mined but hiding in our own homes and factories. Begin with 100 units of primary energy, coal, say. In generating electricity in a typical power plant, 66 units of energy go right up into the sky as waste heat. For automobiles the waste is even worse. It's as if, when you cooked a meal, you were to take two-thirds of the food and immediately dump it into the garbage. You might have grown the food, or paid someone else to do it, and then cooked the food, and then thrown two-thirds of it away. In other words, in making electricity, we typically waste 2/3 of the input energy.

Then, when we *use* the electricity, there is further waste, as when inside a lightbulb heat is made along with light. To continue with the meal analogy, it's as if, after you served the food, each diner threw away half of what he'd been given. Wouldn't that be appalling? You'd have to say that there was something wrong with any food plan that operated in this way.

Many things could be done right away to reduce energy waste, especially if you have a personal stake in the matter. For example, on a freezing day you put on a coat. You don't think to do this because it is morally right or politically correct or energetically efficient. You put the coat on to stay warm. The coat keeps the cold out by keeping the warmth in. That warmth comes from food energy, and on a cold day you don't want to waste any of it, so you instinctively insulate a warm region (your body, at an internal temperature of 98.6 F) from a cold region (the snowstorm all around you, at a temperature of 23 F). You can also put a coat on your home in the form of additional insulation in the roof, walls, even the windows. On a cold day you wouldn't leave your coat unzipped, so why leave your home unzipped?

The general concept of energy is pretty direct. You put food into your mouth, gasoline into your auto, or electricity into a lamp. The energy is either visible to the eye or palpable to the mind. So is the result: you move, your auto moves, the lamp emits light. Saving energy seems like a simple idea, but is rather more difficult to visualize. What does "saved" energy like do? Therefore Lovins devised the idea of "negawatts." If, he says, you replace an ordinary 100-watt incandescent bulb with a compact fluorescent bulb that casts the same amount of light, and fits in the same socket but only draws 20 watts of power, then you have done something extraordinary. By *not* using 80 of the 100 watts, the new bulb is in effect a *producer* of 80 watts. It's as if your lamp were a tiny electrical generator sending 80 watts of power *back* to the grid. The 80 watts *not* used in that lamp are free for use in some other appliance or some other home. Or maybe they didn't need to be dispatched from the power plant in the first place. An equivalent amount of coal *wasn't* burned in any furnace. A small puff of polluting gas *didn't* go up the flue. True, by not using that small increment of electricity, the utility's revenue declined by a tiny amount, but then too it *didn't* have to make that much electricity, so the cost of doing business just went down a tiny amount. The customer consumed less, the utility produced less, and the atmosphere was less burdened with carbon dioxide.

A negawatt is an absence but a commodity nonetheless, one that has value. To create this value requires investment. You have to buy the efficient bulbs, which are more expensive than ordinary bulbs, and you have to buy extra insulation for your ceiling. However, it is usually the case that these investments pay you back. They pay for themselves in energy savings. One of Lovins's main points is that the saving should be viewed not just at the domestic level (the individual consumer lowering *his* energy bill) but at the city level. If each home saves 80 watts per bulb, times five bulbs per home, that works out to 400 watts saved per home. For a city with a million homes that becomes 400 million watts saved. That corresponds to the power put out by a new generating plant. Which costs more, the cost of that new plant and the coal that goes into it (and the pollution put into the air) in perpetuity, or the extra cost of those fancy bulbs plus replacement bulbs over the years? Buying efficiency is cheaper than buying a new power plant.

This is one of Lovins' cardinal principles: *saving* electricity is cheaper than *making* electricity. (This might have been on reason Con Edison started its "Save-a-Watt" campaign during the brownout years: in the company's dire need to meet a growing power demand, it was cheaper and quicker in the short run to have its customers use less electricity than it was to bring new power plants into service.) Ben Franklin's adage, "A penny saved is a penny earned," applies directly to watts.

Suppose we do that, buy all those bulbs, and save all that energy. Isn't that the end of the story? No, it isn't. Saving energy on lighting is just the beginning. Energy efficiency is not just a short effort, a onetime purchase of a better product. The first step in exploiting energy efficiency is to see it as a rich source of energy, a mine from which great riches could be hauled. The second step is to recognize that this mine is quite deep and that we have only extracted the uppermost layer. In later sections we will look at what some of those other economizing layers might be.

It might have been a season of discontent for the power industry but was a golden age for energy efficiency. From 1977 to 1985, US gross domestic product (GDP)---that handy, single-number register of the nation's economy---grew by 27% even as oil imports fell by 42%, and imports from the Persian Gulf were down by 90% (ref 7.12). This lowering of imports was, unfortunately, to be reversed years later, but for a brief time the notion of energy reform took on a substantive form. Consuming more energy usually means greater national prosperity, so countries with large economies usually have large per-capita energy consumption. Poor countries use less energy. Beyond a certain point, however, this correlation breaks down. The really sophisticated societies are those that make clever use of energy. Their prosperity rises even as they use *less* electricity than they before to perform the same task. This cleverness is embodied in a parameter, the *electric intensity*, defined as the ratio of GDP to per-capita electric use. If a country is being smart in its use of machines, its economy will keep going up even as their electric intensity goes down.

A distinction needs to be made between energy conservation---using less energy---and energy efficiency---getting the same or better service using less energy. Promoting efficiency is not a program for deprivation. It does not mean a lesser standard of living. Furthermore, the whole process of efficiency engineering, whether built into a system in the first place (a home with lots of insulation or an office where lights turn themselves off if no one is in the room) or retrofitted afterwards as new equipment becomes available, is profitable. Efficiency is not castor oil. It is not sacrificial or charitable in nature. An efficient machine saves resources, saves on repairs, and saves money.

If energy efficiency is such a good thing, if it's so economical, why isn't it better known? Why don't we see more of those miracle lightbulbs? Lovins, who has spent a career in explaining the rewards of energy efficiency and trying to cajole individuals and companies into saving energy and making money at the same time, has an explanation:

> *Saved energy is invisible. Energy-saving technologies may look and outwardly act exactly like inefficient ones, so they are invisible too. They are also highly dispersed, unlike central supply technologies that are among the most impressive human creations, inspiring pride and attracting ribbon-cutters and rent-and-bribe seekers. Many users believe energy efficiency is binary---you either have it or lack it---and that they already did it in the 1970's (ref 7.13).*

But efficiency is not a "thing" you do once and for all. The refrigerators and lightbulbs, requiring only a fraction of the electricity used by its counterparts a few decades earlier, are getting better still. Since the 1970s, efficiency measures have saved US consumers about $100 billion per year. Lovins estimates that this is just the beginning; another $300 billion could be saved per year through further efforts. In other words, in our exploration for negawatts---saved energy or avoided energy---we have already located rich deposits, and there are reasons for supposing that far bigger reserves are yet to be tapped.

Consider the problem at the architectural level, where vendors are often paid not on the basis of how low the cost can be for operating a house or factory, year after year, but by how low they can make the initial cost of construction. One favorite Lovins' example: electrical contractors will install the minimum-thickness wire prescribed by law. Using thicker wire would reduce resistance and therefore the cost of using electricity thereafter, with huge savings, but would cost more to install at first. A second example of "whole-system engineering" concerns the purchase, installation, and use of a pump for sending a fluid through a pipe. Usually the pump is planned and installed first. Then comes the pipes which, to fill the remaining available space, must often be narrow and made to follow a bent trajectory. This adds a greater electrical burden, however, since pumping fluids through narrow, angled pipes is much harder than through thick, straight pipes. Planning the pipes first, says Lovins, and paying for the more expensive fatter pipes, permits buying a smaller pump, requiring less power. There would be a huge saving over the long run, but the initial cost would be higher.

It's that higher up-front cost that makes many pause. It takes time to accept and institutionalize new habits. It took time for Thomas Edison to gather financial backing for his electrical grid scheme and for his inventions to move from the lab to the marketplace. It took time for Samuel Insull to convince people that electric irons and refrigerators would make their lives easier. What concerned them was affordable electricity. But with energy efficiency, it's a harder sell: what are the incentives? Well, when the price of electricity stopped falling, and when there were environmental reasons as well as financial reasons for using less energy, interest in efficiency and conservation grew.

What to do about electricity---its cost, its pollution, its management---would take time and experimentation. In the late 1970s there was with President Jimmy Carter a willingness, as there had been with Franklin Roosevelt in the 1930s, to try something new in energy policy. FDR's main achievements had been, first, to curb the abuses of the utility holding companies and, second, to launch that great experiment in developing social-technological approach to government, the Tennessee Valley Authority. Carter's main energy achievements were to spur innovation in automobiles, leading to much greater gas mileage, and to secure the passage in 1978 of sweeping energy legislation, including the Public Utility Regulatory Policy Act (PURPA).

The ostensible goal of this law was to obtain more electricity without using more fuel. It did this by fostering the existence of fledgling non-utility companies devoted to producing power through solar cells or windmills, or the simultaneous production of electricity and heat. In the co-generation scheme, in which the steam that has gone through a turbine to make electricity isn't just thrown away but used to heat homes or drive industrial processes. This was an old idea. In fact, if you go far enough back in the history of electricity, back to 1900 or so, combined-heat-and- power (CHP) was an important way of doing business. The fraction of the energy in a shovelful of coal turned into usable power or heat could be as high as 80%. If you just kept the electricity but threw away the heat, the efficiency would be less than 30% or so. But as power utilities became more focused on making electricity and as the size and locations of the generators made it less convenient to sell steam (electricity can be brought to customers hundreds of miles away but this doesn't work for steam), the co-generation scheme went out of fashion. The co-generation companies that remained were likely to prize the heat more than the electricity, rather than the other way around. It would be understandable if these companies would want to sell their surplus electricity to the main grid utility in the area. The new legislation insured this.

Utilties now had to buy electricity from the independent producers (including factories with surplus electricity) providing the cost was lower than the cost it took for the utility to make power for itself. Utilties were not thrilled. They were in the business of making and selling electricity, not buying it from others. Furthermore, since the *scheduling* of electricity---the perpetual balancing act between load and generation---is a tricky thing, it would be an imposition to have to buy orphan power in small amounts and at odd hours. The utilities didn't like being forced to accept this mongrel electricity and fought the whole thing in court for years.

Eventually the independent-producer law was upheld. Here in the making was one of the great ironies of grid history. Here was a piece of social engineering, a law passed by Congress, that was aimed at wringing out a bit more efficiency from the power production process. In this it succeeded. However, here was the unintended consequence: what had started out as only a small provision of the 1978 energy legislation would become a lever which pried open the entire century-old electricity business.

Unbundling the Grid

The 1970s were messy for the power industry, and the 1980s looked to be more of the same. There had been a power plant shortage, resulting in a building boom. Then there were too many power plants. The prospect of nuclear energy, which once seemed so promising, was souring: disturbing accidents, massive construction cost overruns, and bitter licensing disputes began to give a sinister edge to anything atomic.

The grid was stuck in a rut. Look at the fundamentals. The monopoly status of most big US utilities, a historic fact extending back to the early 20th century, didn't exactly motivate creative management. With a modest but guaranteed profit built into the business model, what incentive was there for changing the system? A utility's profit could not fall below a level. That was reassuring. But also it would not rise above that level. Where was the thrill?

The best engineering students, as if smelling the complacency, seldom went into the power business any more. Computer science is where the action was. Initiative was rewarded, new products appeared often, and R&D was moving up, not down. There was a sense with computers, as there had been with electricity in Edison's day, that you could invent something that would have a positive impact on millions of people: the advent of personal computers, the growth of software, the first wiring up of what would become electronic mail and the Internet. In addition---and this was hardly a drawback---you just might make a great deal of money in the process of changing the world.

Could the electricity business change? Could it be exciting again? Although utilities didn't necessarily want to give up their monopoly status (it's nice having the market to yourself), most could see that regulation by the state was both protective and encumbering. This might have been one reason Edison and Westinghouse, having launched their respective direct-current and alternating-current utilities in cities all over---the National and American Leagues of electricity---decided to sell off their operating companies in order to concentrate on the inventing side of the business (ref 7.14). Wasn't it more fun to be a maverick, going where you please and charging whatever you wanted for a product (subject to customer demand, of course) than to be king of the hill and rule placidly over that single city under the tiresome guidance of some state regulatory body? Could a time ever come again when one could strike it rich selling electricity?

Then it came: the first sign of glacial melting. To see how evolutionary change came to the electrical industry we must first look at changes in the natural gas industry. Also previously hemmed in by regulations, the capture of gas from underground reservoirs and its transport in vast pipeline networks across the country was being overhauled. Price caps were being removed and new exploration had led to a much greater supply and to lower prices. And where was this fuel going? Into a new kind of electricity generator.

Actually, it wasn't really new, but it was newly economical. In a gas turbine the fuel (natural gas is essentially methane, molecules made of one carbon atom and four hydrogen atoms) is mixed with air and encouraged to explode. The force of this controlled combustion spins a turbine, which in turn activates an electrical generator. Converted from mass-produced jet airplane engines, the new gas turbines were still a bit expensive for the amount of power you got out (gas had come down in price but was still pricier than coal). However, they could be built quickly, were relatively compact, and could be fired up quickly. Therefore they were often used as a backup, or for use during hours of peak demand. Even better, if you captured the escaping hot gases made in the combustion, and used them to make steam and sent the steam into a second turbine, you could crank out even more electricity. With the old once-through process your energy efficiency was 30 to 40%. With the newer combined cycle operation, using both gas and steam turbines, your efficiency could go up to 50% or more.

This was something new in the electricity business. A small company, an unregulated company, could build modest generators and find a niche market. A gas turbine could dispatch power at peak times and sell it, under contract, to the local utility. Here was an opportunity for an energy entrepreneur to fit into the cracks between existing monopoly grid giants. This was a real incentive: if the independent producer could reduce its costs while supplying the contracted power, then its profits would rise. This wasn't necessarily true for the utilities themselves, whose profit margin was pegged at a fixed amount above expenses.

Not only was the profit mandated but also the obligation to have an extra cushion of electricity-generating capacity at the ready in the form of numerous dynamos. The upstart independents could often make power more cheaply with their new machines, and the utilities had to buy that power. But what about all those older dynamos the utilities had built years or decades before? In many cases these machines were still being paid for. These extra "stranded" costs had to be covered.

The utilities could say, "Yes, it's fine for the independent producer to do whatever it wants. It doesn't have the solemn responsibility, as we do, of delivering power to all customers all the time." But the law was the law: the independent producer could make power and the utility had to buy it, providing the price was below what it would cost the utility to make the same amount of power. Some of the independent producers, or "merchant generators" as they were sometimes called, started to grow bigger and bolder. They asked, "If we can sell power to the local utility, sending electricity over its wires, can we use those same wires to ship power to a different utility in a neighboring state?"

The US Congress, in the Energy Policy Act of 1992, provided an answer. Yes, you may. Here was another new thing in the electricity business: long-distance wholesale shipment of power involving multiple interested parties. Now the independent producer had even more incentive to streamline its operations. It could sell to the highest bidder, even if that meant bypassing the nearby utility in order to deliver, or "wheel," power to a distant grid. Not only was the local utility left out, but its own transmission lines might be used to convey the current from the independent producer to the third-party buyer.

Yet another new thing in the electricity business: the company that sold the power might not be an independent producer, or a utility, but a broker. Without a single generator to its name, an energy trader could buy big blocks of wholesale power in one place and sell it in another. The most famous trader, Enron, didn't always sell at low rates but they did offer to sell commodities other than electricity, such as insurance against future fluctuations in the price of electricity. Enron grew and grew. It came to sell as much electricity as any other company. It was the biggest trader of gas in the US. It bought and sold in many commodity exchanges, undertook colossal projects in developing nations, and was a pioneer in marketing Internet services.

Fresh players had been allowed into the game: unregulated producers of power could sell power wherever they wanted. Energy traders, companies that didn't even make power, could sell it. In the space of only a decade or so the electricity business had spun around. Many utilities were still strong but no longer exercised total sovereignty. As regulated monopolies and long spared the rigors of competition, the utilities now had to go on a crash diet. They trimmed their payrolls and started to sell off their own generators.

Why sell their dynamos? Because the utilities were finding themselves in an awkward situation: part of the corporation (the generation part) was operating in an increasingly unregulated market. Meanwhile, other parts of the corporation (the distribution part, say) were still strictly regulated: the government told you how much you could charge your customers. For the utilities, it was sometimes easier if they just got rid of their unregulated departments. However, if they sold their generators, they put themselves in the odd position of becoming customers themselves, customers of those same independent producers they had fought off years before.

A great transformation was underway. It's as if the Ice Age were ending and the emergence of a new climate was altering the landscape. Some of the old superpowers of the electricity world were unbundling their functions. What had been vertically-integrated enterprises---some of them incorporated in the 1880s---were now being dis-established layer by layer in the 1990s. As the nature, size, and look of utilities changed, the company name changed too. In the very earliest days of the grid (1880-1900) the word "Illumination" would have been prominent (example: Edison Illumination Company), befitting the principal responsibility of supplying currents to filament bulbs. Later, as effective electric motors became available (1900-1920), the firm's name was altered to incorporate both light and power. Then as the power part of consumption grew to be the majority product, the firm was often referred to simply as the "power company." Later still, in the age of diversification and trading and deregulation, and as the corporate mission grew more vague, so did the name on the letterhead. The fashion was for names that evoked the idea of energy without being too specific about it. Examples include

Cinergy, Dynergy, and Entergy (ref 7.15).

A great fuzziness had settled in around the concept of monopoly grid management. The wires that fed electricity into your home were owned by the local utility, whose operations were still regulated, meaning that the rate you paid each month was set not by market forces but by a set of commissioners sitting at a table in the state capital. Retail rates were fixed, and yet that same power, a millisecond before it reached your house, might have been subjected to some unregulated, computerized, wholesale negotiation among companies hundreds of miles away.

Then people started asking, "why not go all the way and deregulate retail electricity?" In a number of countries, such as Britain, Chile, Norway, and Australia, reducing controls on retail pricing for electricity had been tried, with many complications, yes, but also with some success. In many of these cases, the power industry had previously been run entirely by the government, so the transition to denationalized/deregulated electricity would have been even more of a contrast. So why couldn't it work in America, home of free markets and high octane competition?

Besides, a number of other industries had been deregulated and, as entrepreneurs would say, liberated. They had been turned loose to try new ideas and offer new products. Here are some prominent examples. Deregulating the natural gas industry had encouraged investment, and this led to new exploration and new supplies and, among other things, to the craze for gas-turbine electric generators. Deregulating the airline industry, after some initial heartache and bankruptcy, generally resulted in lower prices and more services. Deregulating the phone industry generally led to lower prices and more services. By contrast, deregulating the financial services industry in the US led to...the savings-and-loan disaster, in which many small savings institutions, suddenly free to invest in more lucrative but also more risky ventures, slid into an immense pit of default. No one had said that deregulation was devoid of risk.

For many business leaders and capitalist-minded legislators, the lure of free markets was worth that risk. The gung-ho argument is simple: get government rules out of the way and thrift and innovation will follow. Inefficiency would be penalized and ingenuity rewarded. Lower prices and more services would result.

The go-slow faction was more skeptical. Would markets be as free as advertised? Just because ten power companies were supposedly competing doesn't necessarily mean lower prices would result. Just because consumers would have more energy choices doesn't mean that they would choose wisely. Wouldn't all the large electricity consumers like factories, shopping malls, and chain restaurants, work out their own electricity deals, getting low rates, while ordinary customers would face uncertainty? The traditionalists cautioned that maybe it would be better to leave things alone. Electricity service wasn't getting much better, but also it wasn't getting worse. Play it safe.

Inertia, personal and institutional, is indeed a considerable force in human affairs and a brake on possible change. The desire to improve things, however, is also a powerful tendency. Gradually in the argument over what to do with the electricity business, the scales were tipping toward deregulation. Most people were pretty satisfied with their deregulated phones and deregulated airplane tickets. Why not deregulated electricity?

The federal government, with sway over energy that zips across state borders, had already moved wholesale power in the direction of deregulation, at least the generation part, thanks to those laws of 1978 and 1992. The distribution part, the delivery of voltage the last mile or so to the home or factory, was a matter for the states to handle one by one. The Federal Energy Regulatory Commission (FERC), the successor agency to the old Federal Power Commission, readily admitted the states's sovereignty in the local cases but, just to be sure the overall dereg message was getting through, it pressed utilities to sell off their power plants and their transmission lines, or at least to segregate these parts of their business from the distribution part. Why do this? Because the transmission lines were now considered a quasi-public conveyance to be used by the utility that owned the lines *and* by other makers of power, and it would be unfair (although understandable) if the utility favored power originating in its own generators.

To look at the overhaul of retail electricity, one has to go to the states, and the prime example is California. Not only does California have the fifth largest economy in the world, making it much like a country, but its determined effort to reform the electricity business was to be the most conspicuous and illustrative case history in the short annals of restructuring in the US up to this time.

The California Assembly, after much consulting with the designated state body in charge of power, the California Public Utility Commission, decided in 1996 that controls over power rates would be phased out over four years. If the whole marketplace machinery could turn freely, the thinking went, then the competing companies would become evermore effective and service oriented. Inefficient companies would lose the race and disappear. Enterprising companies would thrive and expand. Consumers would win too. If deregulated air transport meant lower prices and deregulated telephones meant lower prices, then shouldn't everyone get lower priced electricity too?

Crash Landing the Grid

Here's what actually happened. In March of 1998 the great deregulation experiment began. Caps came off all wholesale power prices, and the California Power Exchange opened for business with a lineup of wholesale producers offering to sell power to wholesale traders and distributors. At the end of this first day the price of electricity had actually dropped a bit, just as you would expect (ref 7.16). As for retail rates, the caps would be coming off in stages. At first, the deregulation would apply only to customers living in the San Diego area and environs. Residents there would be "free" to order electricity from several competing companies. The old utility, which owned the wires going into homes, would receive a carrying fee, but wouldn't necessarily be providing the energy. The arrangement was not unlike modern phone service.

Rates were reasonable for about two years and then started to climb. There now followed a cause-and-effect roller coaster ride of pricing events. Customers screamed at seeing the much higher prices. Because of this the state put caps back on wholesale electricity purchases. Because of this the independent power-producing companies started to seek more out-of-state sales, where there were no caps. In response, one arm of the federal government, the Department of Energy (DOE), used emergency powers to force the producers to sell more electricity in California, while another arm, the Federal Energy Regulatory Commission, removed the state-imposed caps once again.

By this point wholesale prices were so high, and not just in California but all over the western states, that some aluminum manufacturers in the Northwest discovered that they could make more money by suspending their metallurgy and going into the power business. Instead of operating the power-intensive smelting machines, they deduced it was more profitable to turn them off and sell the unused power, bought on contract at low prices, in the open market for high prices (ref 7.17).

The crisis reached its peak in the early months of 2001. Two of the largest utilities in California, Pacific Gas and Electric (PG&E) and Southern California Edison (SoCalEd), were caught in a deadly bind: they were forced to pay five times more for power (in a deregulated wholesale market) than they were allowed to charge their customers (in the still-partially-regulated retail market). These companies had to borrow money to buy power, which they then proceeded to sell at a loss. Every day they remained in business they went millions of dollars further into the hole. The utilities's credit ratings fell, and the independent producers, fearing they wouldn't be paid, started balking at making deliveries. In some areas on some days there were rolling blackouts, the first since the Second World War. Governor Gray Davis declared a state of emergency. The state itself started to buy power on behalf of the beleaguered utilities. PG&E declared bankruptcy anyway.

Retreat was the better part of deregulatory valor. By the autumn the Assembly and the Public Utility Commission had essentially undone their previous handiwork. For the time being at least, deregulation was suspended and the price of electricity stabilized again at levels not so different from where they'd started. The immediate threat of power shortage was over. The spectacle, while it lasted, had drawn a huge audience. Many other US states and several governments abroad, anxious onlookers of the great California experiment, now rethought their own plans for deregulation. Some states have since proceeded, while others have held off.

Affixing blame for the electricity fiasco now intensified. California only got what it deserved, some said. Many residents, not wanting a generator in their backyards, had been happy to see power shipped in from elsewhere, which is fine providing that the residents of those other states aren't having a power shortage of their own. California wanted the benefits of electricity but didn't want unsightly power plants, didn't want risky nuclear plants built near seismically active faults ("quake and bake"), and didn't want pollution pouring out of smokestacks. Another factor: continued drought in the West meant that rivers were low and therefore hydroelectric generation was diminished accordingly. A further factor: natural gas, which was now fuelling more and more of those fancy new turbines, suddenly got much more expensive.

No, the problem was greed, others argued. Independent power producers and traders such as Enron and Dynergy had manipulated prices higher and higher. They discovered that they could make more money by holding back power, selling less of it, but at vastly inflated prices. They had "gamed" the markets. That is, they had applied the mathematical rules governing game theory to direct their sales and purchases, to determine when to withhold and when to come forth, so as to maximize profit. Lost completely was the notion that delivering power was a civic service and an important obligation for the public good. As Californians had suffered through blackouts, the power producers' profits had in some cases gone up more than 100% that year.

We're in business to make money, these companies would respond. Maximize profits? What else are we supposed to do? We played by the rules. If you don't like the results, then change the rules.

The people who had made the rules, the State Assembly, had forbidden the use of longterm contracts. Power was to be bought wholesale by utilities at very short intervals in the spot market, the better to get the very lowest prices at that moment. The thinking here was that prices would indeed be low since all the producers would be competing, gladiator-like, in the energy arena. Sellers struggle for existence while buyers get to pick and choose. This is capitalism at its finest.

But it ain't necessarily so. For one thing, the number of wrestlers in the ring---the independent producers---was never that big. For another thing, the lack of longterm contracts lent a perpetual instability to the whole enterprise of buying and delivering power to millions of customers. This wasn't capitalism, some critics would say. The markets weren't free. Some parts of the business were deregulated while other parts remained regulated. You can't just take the caps off wholesale prices. What about retail? So don't call it "deregulation." Furthermore, and most obvious of all to anyone who has ever invested in the stock market, prices can also go up as well as down. Many ordinary customers, and state legislators too, seemed to have thought that electricity prices could only go down and were surprised when they went up.

And then at the worst moments of the energy shortage and price crisis, the utilities had been stuck in the middle, having had to supply power to customers at regulated low prices and, at the same time, to buy power from independent producers at high unregulated prices. What could they have done? Undercutting the utilities' plea for sympathy, though, was the fact that they had, right up toward the end, been paying dividends to their stockholders as if there had been no crisis.

There were plenty of losers in this adventure, starting with customers suddenly forced to absorb huge rate increases. State regulators criticized federal regulators and vice versa. The feds, eager for increased competition, were inclined to cut the markets loose from all controls and let the going rate find its natural position, whatever it might be, until the rate ascended into the heavens. Federal regulators, recurrently reluctant to intervene, later admitted that they should have intervened (Ref 7.18).

Irony overflows. Instead of new services there were blackouts. Some of the large energy companies, which had made a fortune at the height of the crisis, were a year or two later themselves struggling near the edge of bankruptcy. Finally, Governor Gray Davis, who had nourished hopes of living in the White House, couldn't even hang onto the State House. He was turned out of office in a recall referendum, in large part because of his handling of the electrical mess. He was replaced by a movie star.

So, who was to blame? A factor consistently cited by many commentators was the sluggish growth of generating capacity. The California economy was getting bigger faster than the inventory of dynamos. Should it be any wonder then that power shortages should develop, whether or not prices were deregulated? On the other hand, as Amory Lovins points out, in the summer of 1999 the California grid successfully handled a peak load of 53 billion watts, whereas in the crisis moment of January 2001 a peak load of only 29 billion watts was enough to trigger partial blackouts (ref 7.19). About this time 10 to 15 billion watts of generating capacity were "calling in sick." That is, the plants were down for repairs when they were needed the most. The power companies answered: We needed to do routine maintenance on our machines. You can't fault us for that.

Or can you? The California regulators issued a report which asserted that many service interruptions could have been avoided if the big independent power companies operating in the state had kept available generating capacity in use (ref 7.20). Later, federal regulators also asked several of the energy companies to document their actions during the months of acute power shortages (ref 7.21).

Numerous lawsuits against the power producers were filed in order to recover some of the heavy payments for electricity made during the crisis. The plaintiffs charged that the companies artificially contrived the energy shortages in order to jack up prices. In one of the proceedings, a tape recording was released of a conversation held between an Enron trader, identified as Bill Williams, and a Nevada energy company official, identified as Rich. Here, rendered in the pages of *The New York Times*, is a brief transcript of the conversation between Bill and Rich. It took place a day before the power plant in question was taken out of service on the very day of a rolling blackout in California:

> "This is going to be a word-of-mouth kind of thing," Mr. Williams says on the tape. "We want you guys to get a little creative and come up with a reason to go down." After agreeing to take the plant down, the Nevada official questioned the reason. "O.K., so we're just coming down for some maintenance, like a forced outage type of thing?" Rich asks. "And that's cool."

"Hopefully," Mr. Williams says, before they both laugh." (ref 7.22)

And what about Enron? Their profit-making potential had impressed many investors. The impressiveness, by many accounts, was helped along by fraudulent accounting practices. Declared by Fortune Magazine as "America's Most Innovative Company" several years running, Enron's own investments and projects came to grief and the company was forced to declare bankruptcy in 2001. It was the largest business failure since the Insull crash in the 1930s. Enron's questionable bookkeeping scheme came to light and criminal convictions followed.

One of the main reasons for the turbulent flight the grid had had in California in 2000/2001 was the stormy marketplace. Robert Kuttner, who writes frequently about economic matters, says that a market brings together willing customers and willing buyers around a price mechanism which "functions to apportion economic forces efficiently; they signal sellers what to produce, consumers how to buy, capitalists to invest" (ref 7.23). But, Kuttner argues, capitalism in practice doesn't work this way. Instead what we have is a mixed economy:

> *...the idea was that market forces could do many things well---but not everything. Government intervened to promote development, to temper the markets' distributive extremes, to counteract its unfortunate tendency to boom-or-bust, to remedy its myopic failure to invest too little in public goods, and to invest too much in processes that harmed the human and natural environment (ref 7.24).*

Capitalism and regulation are not necessarily polar opposites. They can, and often are, compatible with each other. Kuttner asserts that many of the most dynamic industries of the past century in the US---telecommunications, aviation, electric power---have been subject to regulation, and that the independent regulatory bodies---such as the Federal Communications Commission, the Federal Aviation Administration, and the Federal Energy Regulatory Commission---constitute practically a fourth branch of national government (ref 7.25).

Is the grid a business or a service? This is a question worth revisiting since it is at the heart of the ongoing debate over how much government oversight to inject into an otherwise public business. The grid delivers a *thing*---a fixed voltage across electrical terminals leading into your home---that is both an economic commodity which gets consumed and a force of nature which, in domesticated form, actuates most of the appliances and powered infrastructure (stoplights, elevators, telephones, computers, wallclocks, etc.) surrounding you at this moment.

Lean But Mean

What hath Thomas Edison wrought? To celebrate the 100th anniversary of Edison's lightbulb invention a symposium was held in 1979. The various speeches presented were bound into a book called *Science, Technology, and the Human Prospect (ref 7.20),* and the names of some of the talks easily convey the importance of Edison's achievement and of electricity's place in the world: "Science, Technology, and Economic Growth"; "Energy and Civilization"; "Industry and Energy: Moral Dimensions of the Tasks"; "Democracy and Technology." An essay by historian Thomas Hughes differentiates the technical from the technological. The technical, he says, are the things we bring to bear, the devices, the tools, the machines. The technological partakes of the technical, but also includes economic, political, scientific, sociological, psychological, and ideological factors (ref 7.26).

Every one of these factors is involved in the overhaul of the electrical industry, and the California escapade in particular. Even ideology? Very much so. The redrawing of electric regulations hasn't exactly polarized into a Republican-versus-Democrat division, but it has become part of a larger debate over the economic rules of conduct for our Western, capitalist society. How much risk do we take? With a thing as vital as electrical energy, shouldn't we play it safe? Or does that preclude innovation? How much money should we invest, and what return can be expected? At what point does enlightened self-interest become rapaciousness? How large a role should government play? Indeed, how big should government be?

Congressional hearings are held. Research moves forward on new ways to make and maybe even store electricity. The California mess gets cleaned up. Other states advance deregulation plans of their own, and it's a good bet that the ending of monopoly service and price controls for electricity will come.

There are many causes of the grid overhaul now underway. The shortage of power and engineering limitations that became apparent in the late 1960s; the fuel shortages initiated by the 1973 Mideast war and the 1979 Iranian revolution; reactor accidents and ballooning nuclear construction costs; worries about energy efficiency and environmental degradation; and a succession of new laws which, deliberately or inadvertently, started to open up a business environment that previously had been chiefly a monopoly preserve of large utilities. The turbulence of the California experiment notwithstanding, many of the innovations have been welcome. In some cases, in some US states and some countries, a bit of re-regulation has been necessary to correct various imbalances caused by the lack of true market competition. But restructuring goes forward. There is no going back.

Go back to what? The world of 1965 didn't exist anymore. That's when the great blackout came and when the decades-long cooperation between grid power and costs, what I have called Moore's Law for electricity---the cost of electricity going down through the years---came to an end, or at least slowed considerably. After that, the grid, seeking to reinvent itself, swerved through some tumultuous decades during which, to summarize the events of this chapter: (1) there were too few generators and then for a time too many; (2) skyrocketing costs and fear about safety caused nuclear reactor construction to slow and then halt; (3) energy-efficient appliances and methods helped to reduce per-capita electric consumption and this encouraged the development of renewable-energy sources for electricity; (4) new legislation governing who could make electricity and how it could be transmitted and sold altered the longstanding hierarchy of energy companies, including the divestitures by many utilities of their generating capabilities; and (5) efforts to deregulate retail sale of power began in many states, often amid great uneasiness.

The grid of 1965 was gone. The replacement grid was leaner. Utilities had cut their budgets. Unfortunately, some customers would say, in the effort to "stay competitive," their power providers had often scrimped on service. Repair trucks were slower to respond to problems. Power interruptions seemed more frequent. Research and development of new equipment started to decline. The construction of more transmission lines was not keeping up with the demand for new electricity. The amount of surplus generating capacity---the standby power a company keeps for emergencies---was declining. The need to stay competitive means costs have to be kept down, the utilities say. They have to sail closer to the wind, and further away from the grid of yesteryear.

There is no going back to the old grid. Consider that before restructuring began in earnest in the mid 1990s, much of electric technology was basically a scaled-up version of the grid as it had been in the 1940s. Customers were getting pretty much the same electric services in 1995 they'd been offered in 1945. What if, one critic asked, the airline industry had stagnated in the same way? Then modern aviation would look something like this:

> *...top speeds limited to 200 mph, only short hops between adjacent cities, with*

> *transcontinental travel requiring many frequent stops, low altitude operations that make flight bumpy and cause frequent delays due to storms, and prices affordable only for the wealthy" (ref 7.27).*

September 26, 2005

Chapter Eight

Energizing the Grid

Nature energizes the sky with bolts of lightning because of the impersonal buildup of static charge on various surfaces, such as the undersides of clouds and the tips of tall trees or church steeples. The bolt is a quick and automatic way of restoring balance. An excess of negative charge in one place gets neutralized by dashing itself into a positive excess somewhere else.

Human-made electricity, the sending of charge through wires, is, by contrast, artificial and deliberate. It’s like the lord of a manor, sitting in his parlor, pulling a chord, ringing a bell in the basement servant’s quarter, quickly bringing forth the butler in reply. With bottled lightning, as I like to call electricity riding in its wires, there isn’t a bell and the servant (energy) comes much quicker. Dispatch usually occurs through an elaborately engineered network of dynamos. Sometimes the generators are small or even portable. Wristwatches, submarines on patrol, a spacecraft going to the Moon all have their own way of loading energy into circuits.

In the mountains of Bolivia, beyond the end of the auto road and farther up than the electrical wires are strung, several villages get electricity from modern solar panels. Some homes have dinner-plate-sized solar arrays mounted on their roofs, courtesy of Canadian volunteers. Rays of sunlight falling on the array can liberate electrons from some of the atoms in the array. The electric force moves through a wire to charge a battery which in turn powers a light-emitting-diode, or LED for short, a sort of solar cell in reverse; an electron falls into place inside a crystal and throws off a tiny ray of light. In this way brightness harvested during the day can be regenerated at night when it's needed. The power used by the LED is only 1 watt, but it is so efficient that it broadcasts as much light as a 20-watt incandescent bulb. This cool light is the alternative to a kerosene lamp, which fills the air with unpleasant and unhealthy fumes and is expensive to operate. The petite crystalline shine is not plentiful but it's enough to read or cook by. With no combustion, no pollution, little waste, it's a smart form of energy (ref 8.1).

Isn't electricity something of a luxury up there? But why bring it to the mountaintop? Not if you're paying attention to what you get out for the amount of energy you put in. Take lighting. Kerosene lamps were an improvement over candles in terms of the amount of light produced for the energy consumed; the candle yields only a fraction of one percent of its chemical energy as light. Edison's incandescent bulbs were much better (ref 8.2). Later, bulbs got better still, but not as good as fluorescent tubes, which beat bulbs by a factor of three or four. And light emitting diodes are better than the tubes. In this whole line of succession, there is a reduction in pollution and cost and an increase in efficiency and light. Electricity is the great carrier and concentrator of energy.

Even the most un-modern of nomads use fuel for cooking, lighting, and heating, whether it's seal blubber in an igloo at the edge of the Arctic Ocean or dry grass at the rim of the Gobi Desert. Now, burning blubber or grass in an open vessel is just about the most polluting and least efficient method for obtaining heat or light, but for a portion of humanity local fuel and open combustion is all there is. Better access to electricity could change this.

Will the concentrated energy of electricity make Bolivian mountain society better? David Lilienthal, who probably did more than anyone to bring the grid to poor people in the US, through his work with the TVA. Later, as a development consultant, he also helped bring electricity into the lives of millions in other countries too (a story to be continued in chapter 10). Here is Lilienthal describing the coming of electricity to the mountains around the Tennessee Valley:

> *Except for saints and great ascetics I suppose most people would agree that poverty and physical wretchedness are evils, in and of themselves. But because extreme poverty is an evil it does not follow that a comfortable or a high material standard of living is good. A Tennessee Valley farm wife who now has an electric pump that brings water into her kitchen may or may not be more generous of spirit, less selfish, than when she was forced to carry her water from the spring day after day (ref 8.3)*

Electricity changes the *conditions* of society. It provides additional *potentiality*. The rest is up to you.

The Hall of Dynamos

Let’s sweep down in elevation from the mountain to sea level, whisk up in latitude from Bolivia to New York, flash over from village life to the bustle of the great metropolis, shift from electricity made at the watt level with sunlight to the 1000-megawatt level made in a roaring furnace kept banked up to 1000-Fahrenheit temperatures. And this time, rather than merely recite facts from a chart, I’ll bring you inside the door at the place where they make a quarter of New York City’s electricity.

The Ravenswood power plant, home to Big Allis, is a fenced off compound in close proximity to teeming apartment buildings at the western fringe of the Borough of Queens. Once the largest steam-electric generator in the world, and still the largest energy machine in New York City at a rating of 1000 megawatts, Allis cohabitates with several smaller dynamos. When you remove an ice cube from a refrigerator on Staten Island, ride the N Train through Brooklyn, or charge a wireless phone in Yonkers, a little piece of Big Allis is there helping you along.

Ravenswood's smokestacks are half as big as the Empire State Building across the East River, and the main plant building is one of the biggest things in a big city. You'd think it would be on the itinerary of more motor tours of the Big Apple, but it's a bit hard to get to if you're starting out in Manhattan. After going through the security check the first thing you see is the big scoop once used to lift coal, tons at a time, out of barges bobbing in the East River. To keep Allis fed required up to two million tons of coal per year. That changed in 1971 when her taste turned to oil (ref 8.4). The conveyor belts used to escalate coal up to the top of the building are still there: its cheaper to leave them standing. On this particular day there is an oil barge bobbing at riverside but the fuel being used inside is actually natural gas. Allis can adapt to gas or oil: in a world of uncertain fuel availability and price volatility it helps to be an omnivore.

A visit begins with a badge, a hardhat, and a background briefing. On the wall is an aerial photo of New York at dusk: in the foreground is Ravenswood, alight with the urgent task of converting fuel into electricity, while in the background, west across the East River, are the recipients of that power, the massed office buildings of Manhattan. Spanning the two banks is the luminous Queensborough Bridge, also a heavy user of the locally-contrived currents. Right next to the photo is a color-coded map of all the power plants in North America. One can readily see how many hydroelectric plants there are in the Valley of the Tennessee, but the real hydro riches are in the Pacific Northwest and Canadian North. We'll investigate that water-drenched electricity territory more closely in chapter nine.

Here in the Ravenswood office, a digital readout tells everyone how the big three resident electricity machines are doing: unit #10 is producing 300 megawatts, unit #20 is down for maintenance, and unit #30 (Big Allis herself) is revved up to 510 megawatts. This is about half of what Allis is capable of doing; the rest is being kept in reserve.

We now get down to business. Walking along several coldly lit hallways, up steel stairs, through a series of doors, one enters the vast turbine room. Here, oddly, you get the impression of movement although you see nothing. Numerous fluorescent fixtures hang about and yet, because of the immense volume to illuminate, all the visible surfaces seem dim. You can hear but not see the moving parts. That's because you're *at* but not *in* the dynamo. All the important stuff is out of sight beneath or behind thick armor plating. This is the place where steam is shot against the blades of a heavy pinwheel, turning a shaft, rotating one coil of wire past another coil, inducing powerful electric forces, propelling electrons down a fat chunk of copper, heating up secondary wires and carrying quick currents toward circuits waiting elsewhere. The flooring is made of the dimpled metal sheeting one sees on the deck of a battleship.

The main things that hit you in the room are sound and warmth. The sound comes from a mixed chorus of motors and pumps, while the heat comes from the ceaseless burning of fuel. Electricity is being produced, not lava; otherwise, you'd say you were inside a volcano. Unfortunately, all that warmth is wasted. Of all the chemical energy contained in the fuel consumed every moment only one third is converted into electrical energy, while two-thirds goes toward making New York hotter. It's those two-thirds you feel the whole time you're indoors at Ravenswood.

Big Allis lurks at the far end of the hall, a sort of grimy white in color, looking like Moby Dick beached. The company's nameplate, "Allis Chalmers," from which the unit gets its familiar name, is still affixed to the side, looking a bit rusty. The rust and our host's cheerful nonchalance, and the noise and grime do not lend poignancy to the moment, and yet one can experience the kind of self-consciousness one feels standing at the high altar of a great cathedral, even for a non-believer.

Here, just a few steps away, is where grid engineering culminates. This is the crux of the power industry. It all comes down to these two great complementary machines: the turbine---focal point of the steam cycle, where thermal energy is converted to mechanical rotation---and the generator---focal point of the electrical cycle, in which the rotation of a wire coil induces powerful currents. In between turbine and generator, in a gap of only a meter or so wide, one can see the common central shaft, blurred out by spinning at 3600 revolutions per minute. This is the shaft that lacked the oil, that spun to a halt, that ended the great blackout of November 9, 1965. Today, forty years later, it's alive with energy.

Standing so close to this concentration of bottled lightning, furnishing power for a hundred thousand homes or more, the visitor might be wondering how to feel at this moment in this place. The machine is impressive, and shouldn't one also feel emotion commensurate with the force at work? If there is a mismatch between the expected feeling and the actual perception, perhaps this is because the visitor will have lived his whole life with electricity. It's been assimilated into the scaffolding of everyday living and is now taken for granted.

In search of an articulated feeling, let's return to Henry Adams, the historian and wry observer and questioner of social and technological change. On one occasion, he too had been brought to a hall of dynamos, by a scholar friend. Adams stood very close to the spinning apparatus; here is his impression:

> *To him [the scholar], the dynamo itself was but an ingenious channel for conveying somewhere the heat latent in a few tons of poor coal hidden in a dirty engine-house carefully kept out of sight; but to Adams the dynamo became a symbol of infinity. As he grew accustomed to the great gallery of machines, he began to feel the forty-foot dynamos as a moral force, much as the early Christians felt the Cross. The planet itself seemed less impressive, in its old-fashioned, deliberate, annual or daily revolution, than this huge wheel, revolving within arm's-length at some vertiginous speed, and barely murmuring---scarcely humming an audible warning to stand a hair's breadth further for respect of power---while it would not wake the baby lying close against its frame. Before the end, one began to pray to it; inherited instinct taught the natural expression of man before silent and infinite force. Among the thousands of symbols of ultimate energy, the dynamo was not so human as some, but it was the most expressive (ref 8.5).*

Divested Energy

Beneath the Ravenswood turbine deck, below all that metal flooring, is more metal: insulated metal pipes carrying steam from the furnace to the turbines, metal pipes carrying cooling water from the East River into the plant, and the twelve-inch-wide copper blocks carrying the primary electricity out of the generator coils. If Big Allis is the heart of the New York City electrical system, then these thick conductors constitute the aorta, the first and largest of arteries for conveying the precious energizing fluid through to other parts of the circulatory system. When Allis' workmates, the other dynamos under the same roof, are active, the amperage is even more munificent

After Genesis comes Exodus. The freshly made electricity flies forth at 22 thousand volts but is quickly transformed to an even more fabulous 345 thousand volts for dispatching to the surrounding grid. Stepping out onto the roof, one can see how it happens. The torrent of electricity in their heavy wires emerge from holes in the wall and then run upwards toward the roof. The side of the building looks like a huge bass violin. Instead of producing sound waves, though, the Ravenswood facility produces electric waves of a particular purity. The waves pulse out into the grid at a rate of 60 cycles per second. If things go well, this continues 60 seconds per minute, 60 minutes per hour, 8760 hour per year. If you multiply all those numbers you get 1,892,160,000 cycles in a year. So good is the clocklike precision of spinning turbine motion in general that some generators, if they've been running without interruption for a year, will come within a cycle or two of this exact number. A few machines will hit it dead on (ref 8.6).

Having been steered to the roof, the electricity goes through a circuit breaker, an immense on-off switch twelve feet long and eight feet thick, before descending again to the ground-level switchyard to the north. The tri-state area has many notable markets or staging areas for the distribution of commodities---fish, vegetables, shipping containers, railcars, refined petroleum. Ravenswood is such a market. Once the site of a 19th century gasworks, the switchyard is now one of the great trans-shipment points for electricity.

The best vantage point for viewing the yard, and for seeing how municipal power flow arises, is from an opening in the Ravenswood facility at the 12th-floor level. Through this gap they hoist supplies into the building. Standing at this gantry, the visitor is kept from stepping into sheer air by only a frail cord. One could easily be touched by a flicker of vertigo by looking down onto the massive switches and transmission lines which fan out to supply electricity to all parts of the city.

The sensory effect of vertigo, the trick of the mind in which we realize (in order to save our lives) the horrible mismatch between the human scale and the daunting height of the cliff in front of us, ought to apply to high voltage but doesn't. Electricity wasn't around in the long Stone Age when the mental faculties of our species were being formed on the East African savannah. Therefore we don't have the visceral dread of electrical things as we do for heights or for spiders and snakes. It's hard to appreciate the magnitude of energy. You can see the energy manifest in Niagara Falls: there it is, all that water thundering downwards. But how do you gain an intuitive feeling for the 345-kilovolt currents emerging from the Ravenswood switchyard?

To take another example: the visible height disparity between the size of a man and a perch at the 12th floor is more than enough to make one queasy. But how can one account for the even greater disparity between, say, the 2 volt battery that powers a flashlight and the hundreds of thousands of volts that power a city? Even the much lesser 120 volts delivered at the wall socket will give you an unpleasant or fatal jolt, if felt. The full electricity supplied by Ravenswood, by comparison, provides too great a kick to calibrate. The effects of high voltage electricity on the human body will be taken up in the next chapter.

Ravenswood is no longer owned by Con Ed. The whole plant, along with Big Allis, was sold in 1999 to another company entirely, a side effect of the massive restructuring process which obliged or encouraged large utilities, the companies who actually deliver electricity to homes and factories, to divest themselves of some or all of their generating capacity. Many utilities now distribute electricity but don't make it. With the stroke of a pen across a complicated legal document, Big Allis, the pride of Con Ed's energy lineup, suddenly found herself playing for a different team. Allis was transferred from one immense company to another.

The new owner, KeySpan Corporation, also has electricity or gas interests on Long Island and much of the Northeast. It is one of the largest gas distributors in the country and is, with a capacity of 6600 megawatts vested in several power plants, the largest single generator of electricity in New York State. Restructuring has changed things. And yet things are also the same. New owner, old electricity. Under longterm contracts, Big Allis's output still goes where it has always gone, homes in and around New York City.

One of the closed-circuit videos in the control rooms shows a continuous picture of the firebox, the part of the furnace where the combustion takes place. This furnace, 12 stories tall, is one of the largest in the world. It occupies the larger part of the building and certainly accounts for the pervasive heat felt everywhere. Remember the inexorable formula: roughly one third of the energy in the fuel turns into electricity. The other two thirds is thrown away as heat.

Even with extensive insulation all around, the temperature on one of the gantries we visited must have been 120 degrees Fahrenheit. The operations manager approaches a tiny viewing port in the side of the furnace, swivels it open, and the inferno within becomes visible. All one can see is a swirling orange flame, a sub-volume of the hydrocarbon hurricane in the furnace. Don't get too close, you’re told. If for some reason the pressure were to be reversed, some of that glow, at a temperature of 3000 degrees, would come shooting out at this outlet like a laser beam, incinerating anybody that had been spying through the keyhole.

The continuous combustion heats water in pipes lining the inside of the furnace. This is clean water, cleaner than the regular city water supply. If it had contained the minerals you drink at home the pipes at Ravenswood would become coated on the inside and much less effective for conveying scalding steam. The business end of Big Allis, its generator, is rated in terms of megawatts of electric power. But the main part of the job here is actually making and transporting steam, more than six million pounds of steam every hour. The outside world wants those megawatts, but the inside world, the internal architecture of the Ravenswood facility, seems to devote more piping, pumps, valves, gauges, rivets, airspace, bracing, insulation, and all other manner of engineering ingenuity to that furious river of clean steam tempestuously shooting from boiler to turbine to condenser and back again.

In many countries, a majority of electricity is made the Big Allis way, with fossil fuels going into the plant at one end, electricity coming out at the other end, and in between huge volumes of bottled up steam racing about. The technology is well known. Indeed numerous large firms have been making steam generators for over a century. You saw them being founded, under the names of Edison, Siemens, and Westinghouse, in chapter two. But we suspect it can't go on like this. Leaving aside the argument over whether fossil fuels (coal, gas, oil) will be all used up in a few decades, there remain two major issues: efficiency and pollution. We can't afford to throw away 2/3 of all the chemical energy embedded in the fuel. Nor can the planet's inhabitants endlessly tolerate the devilish chemistry by which various atoms in the carboniferous fuel---such as nitrogen, sulphur, and of course carbon---combine with oxygen atoms to form undesirable tri-atomic greenhouse gases and pollutants.

The rest of this chapter will look at alternatives to the popular carbon-nitrogen-sulphur fuel cycle. All of the candidate replacements, I warn you now, will have costs or side effects of their own. Fossil fuels will be with us for decades to come. Before we can banish them we are trying to tame them.

Advanced Carbon

How can we make the same amount of electricity more efficiently and with less pollution? The ironic answer, over the short run, is to burn even more fossil fuel. Not coal, but natural gas, essentially methane, whose combustion produces no sulphur, fewer nitrogen compounds, and far less carbon dioxide. How does it work? Just to the north of the Ravenswood's factorylike building, is Big Allis's baby sister, the newest large generator to be built in the city in ten years, a sleek, relatively low-emissions gas turbine, cleverly squeezed into a space of about 2 acres. It uses the latest noise-abatement equipment, which makes all those nearby apartment dwellers happy, and has a high-efficiency, dual-turbine architecture It won an award for being one of the top power plants for the year 2004 (ref 8.7).

Gas turbines are quite popular at this moment in the history of the grid. They can be built quickly and can be as large or small as a company wants, depending on the amount of extra electricity needed. They've got models in the multi-hundred megawatt range or all the way down to kilowatt size. In a gas turbine you mix pressurized gas with air to produce an explosion. The hot escaping gas directly spins a turbine to generate electricity. The process is even more attractive when you capture the hot exhaust gas coming out the back, gas which turns a second turbine to generate extra electricity. In such a "combined-cycle" approach---making electricity in a gas turbine *and* a steam turbine---the energy efficiency goes from 35% up to 55%. Efficiency isn't just a clever thing to do; it means using less fuel and producing less carbon, to produce the same amount of power. Result: more profit and less pollution. The utility comes out ahead, so does the customer, and so does the atmosphere. Now, if only the price of fuel could be kept low, things would be nice.

Still more efficiency can be wrung out of the whole operation. In Edison's day the centralized power house at Pearl Street coexisted with many smaller generators owned by individual factories or homeowners. Because of the primitive state of technology in those days, these small generators (and Edison's too) were highly inefficient at making electricity but had a compensating virtue: the steam, once it had spun a turbine, could also be used for heating or for driving a chemical process. The total energy efficiency (electricity plus heat divided by the energy input) for the combined heat-and-power (CHP) process could be as high as 80%. Think of the food passing through a restaurant kitchen. An able chef uses leftovers to the fullest. What can't be deployed in a salad can go into a soup or at least onto a compost heap. Only as a last resort should the scrap be thrown out. Why not do the same with steam?

Not every power plant can use its leftovers in this way. For one thing, a factory needing steam is not always sitting conveniently next to a power house. So, instead of the factory coming to the powerhouse, the powerhouse might go to the factory. That is, the factory could buy its own generator, as it might have done a century ago, a generator that makes all the electricity the factory needs in addition to all the heating it needs. Finally, it could sell surplus electricity into the grid. Co-generation operations like this are making a strong comeback. This is partly what legislators had in mind when they passed the law encouraging independent generators.

Another way of rethinking the traditional hydrocarbon combustion process is to do away with the explosions and the moving parts. In the fuel cell approach, hydrogen atoms in the fuel enter from one side of the cell, oxygen molecules from the other side. They meet in the middle under the auspices of a catalyst, a matchmaking chemical that allows the direct formation of electricity (no turbines are necessary), along with some water. Fuel cells have been around for a few decades but are still used pretty much for niche applications. They come in a variety of sizes and, since their pollutant products are minimal, they come in handy where emissions standards are a major consideration. Furthermore, advanced models are extremely energy efficient. Why aren't they more prevalent? They produce low voltage, their power has to be converted from DC to AC, and the more efficient models tend to be expensive.

Can fossil-powered machines be made better still? Well, it would be nice not just to reduce but to eliminate pollution from the generation process. Some schemes under study would make gas from coal, and would do it in a way which allowed for the removal of troublesome chemicals, such as nitrogen and sulphur, even before any combustion takes place. In so called zero emission power plants, even the carbon dioxide emission would be captured before it could escape into the open air (ref 8.8). This would be possible if the whole gas combustion process operated at temperatures so high and pressures so great that carbon dioxide were present in liquid form. The carbon dioxide would then be pumped into a long-range storage zone, perhaps beneath the seafloor or in underground cavities that had lately been emptied of petroleum or natural gas.

Imagine this scenario: carbon atoms (bound up in methane, say) might come out of the ground in Texas, be piped to Illinois for combustion in some future zero-emission plant, and then, now locked into a carbon dioxide molecule, be returned by pipeline to Texas to be interred in the ground in a deep cavern. This would be a better place for that atom. It wouldn't be up in the sky, where it might trap a little too much sunlight and, through some weird greenhouse mechanism, force an unnaturally nasty turn in the weather.

Cutting Butter with a Chainsaw

A growing share of electricity is being made in medium and small sized generators, but a majority of power is still produced the old way, in large generators like Big Allis. Studies show, however, that the larger machines are less dependable on the average than smaller plants in terms of downtime (ref 8.9). The leviathans, however, are still a dependable presence on the organizational spreadsheet. A big plant with a big number of megawatts is easier to fathom for planning purposes than a bunch of smaller units, especially if, as in the case of wind turbines or solar cells, they're dispersed in scattered locations and subject to variable conditions such as windspeed or available sunlight. These views are changing as the smaller units' efficiency and reliability win them acceptance into the grid club.

For Amory Lovins, the restructuring of the power industry over the past decade was something of a distraction. Yes, it changed how electricity is marketed, and how innovation is rewarded, and how energy companies relate to federal and state regulators, but it served to complicate an even more important evolution underway: the prospective evolution, or devolution, back toward smaller, *distributed* forms of power generation. Lovins draws attention to the huge mismatch in energy scale between the powerhouse level, generally 1000 megawatts (a billion watts), and the home level of a kilowatt (a thousand watts). The main grid delivering electricity to your doorstep is like trying to cut butter with a chainsaw, Lovins says, or sipping water from a firehose. There is bound to be lots of wastage (ref 8.10). Larger plants no longer have the great advantage of efficiency (lower priced electricity) but still retain many of the disadvantages of being large.

Here is a quick list of factors that go into the new small-vs-large math: smaller plants are, on the average, available for service more often, have a shorter lead time to build, are easier to site, and easier to finance (ref 8.11). Consequently, for the crucial task of planning future power demand, the plants can more easily be built as they are needed, "There is less time for reality to diverge from predictions," he says. There is less room for regret. Errors in anticipating future loads are reduced (ref 8.12).

A hundred years before, Samuel Insull had established the underlying framework for the power industry: large generators, centralized control, and monopoly operation. Now, this legacy is being undone. The restructuring revolution somewhat dismantled the monopoly part of Insull's legacy, at least at the wholesale level, and presently the dominance of big generators is being undercut by smaller generators. It took Insull a whole chapter, chapter three, to build up that dominance, and it's taking two chapters, seven and eight, to take it down.

Two prospective movements are at work here. One is the reversion to smaller plants. The other is a possible return to shorter transmission distances. Again, this would represent a great historical reversal. The ability to send alternating-current (AC) electricity over great distances allowed power to be made in one place and used in another place, sometimes hundreds of miles away. Niagara could dispatch power all the way to Buffalo, and later to New York City. This expanded capability, in which large territories hundreds of miles across became unified energy *realms*, practically defined what it meant to have a grid. This unity, this oneness, was manifested in some countries like Britain and France in the form of consolidated national grids. The dark side of consolidation is that when part of the system goes down a much larger region might be blacked out as well owing to the tightly coupled nature of the extended grid. Prime examples are the great Northeast blackout of 1965 and the collapse of the French grid in December 1978.

One problem with sending power over long distances is the loss of energy along the way, which can amount to as much as 10% or more. Another problem: transmission bottlenecks, which arise when too much power is being sent such long distances to wholesale customers on the far side of an increasingly congested network of transmission lines. Why not just build more lines? Because they're expensive to construct, politically painful to plan (I don't want them in my backyard), tricky to finance (in a volatile business with huge price swings), and difficult to regulate (conflicting state and federal statues).

Taking into account all these various costs---transmitting, routing, transforming, movement across jurisdictions, the accounting that goes with various levels of buying and selling---we arrive at a curious development. The delivery of electricity now costs more than the making of electricity (ref 8.13). This is true for many things in the top-heavy merchandising world. The cost of making the product is less than the packing and sending.

What can you do? If a family were contemplating taking a driving vacation on the Interstate highway system, with the prospect of traffic jams, lots of tolls to pay along the way, lines at the gas pump, and the engine making weird noises, you might be tempted to stay home. This doesn't sound very glamorous. Where's the adventure?

But with electricity there should be no adventure. Electricity doesn't need to be glamorous. Power is power. What if the grid stayed home? This is the microgrid concept, a scheme in which a confederation of small electricity generators and electricity users are wired up to a semi-autonomous network. The users could be homes, factories, or farms. The generators might be wind turbines or housetop solar cells, fuel cells, or basement gas-powered turbines with ratings as low as a kilowatt. A microturbine of that size might not be as energy efficient as larger models, but if the heat in some of these small machines could be captured and exploited for warming a house, say, or contribute to a factory process, the economy of this microgrid might start to rival that of the macrogrid. The goal would be to attain all the good features of *big* while retaining all the virtues of *small*. The microgrid would be to the grid what desktop publishing is to mainline publishing. The hardware and software are now becoming available for creating a desktop grid.

The goal of the participants in a microgrid is not necessarily to secede from the macrogrid. The dispersed grid would still continue to be connected to the central grid through a common hookup. The electricity generated internally would be used internally. But outside electricity could be imported as needed. If, for example, the microgrid's solar cells weakened when clouds passed in front of the sun or its wind turbines became limp when the wind died, then extra power could be brought in. The microgrid would appear to the macrogrid like any other customer (ref 8.14). There might even be times when the microgrid had an energy surplus---more than it could use by itself---in which case the current flow would actually flow back into the commercial grid.

If microgrid power production isn't yet cheaper than the macrogrid power, then why bother? Partly to reduce energy losses suffered in long transmission; if the microgrid is the size of a town or a neighborhood, the electricity doesn't have far to go. Partly to meet growing needs on a modular basis; you just add a few more modest units as needed. Partly to shut out external cascading blackouts arising in the macrogrid and to provide extra flexibility in meeting internal emergencies. Microgrid customers could designate different service priority levels: in an emergency some electricity-using devices such as irrigation pumps could be instantly turned off, while some loads such as hospitals would be maintained no matter what. In this way the microgrid could ride out the storm.

Microgrids don't have to use renewable energy. A microgrid could consist of nothing but small gas-consuming turbines. However, the desire to partake of energy that grows back after you use it, energy deriving from sunlight or plant matter, and not just from the once-through energy archived in coal, has been a mighty motivator of small grids. Traditionally macrogrids have been resistant (at least at first) to what microgrids have to offer. After the 1978 legislation, mandating the acceptance of smallscale (later large-scale) production of power, often with gas turbines by companies independent of the utilities, was one of the first steps toward turning the whole industry upside down.

Can the macrogrid not merely tolerate microgrids but emulate them? In other words, could utilities themselves use strings of small generators? At first there was resistance to energizing a grid with distributed resources. For one thing, the maverick generators seem harder to fit into the macrogrid hierarchy owing to uncertainties over such things as dependability (wind turbines might run out of wind just when you need them), regulatory concerns (does a particular microturbine come under state jurisdiction?), and cost (renewable energy is still more expensive to produce than using coal). There are signs that the resistance is softening. Partly to address the issue of pollution, partly to add investment flexibility, partly to speed up construction, and because engineering advances and mass production are bringing down prices and increasing efficiency, utilities are more open nowadays to alternative power concepts; *small* and *renewable* are not necessarily dirty words.

The Home Grid

A single home can be a microgrid unto itself. To see how this works, let’s visit a model home in the town of Takoma Park, Maryland dedicated to maximizing the use of "clean energy." In general, clean means leaving a small footprint behind in the surrounding environment. The first thing you see, coming out of the cold blustery morning into the warm living room is a curious enclosed fireplace fed from above by a hopper filled with corn kernels. Now, burning corn to make heat may well release as much carbon dioxide as burning an equivalent amount of gas so, right off, how is this an example of "clean energy"?

It's because the corn, as it was growing, was *absorbing* carbon dioxide, as all green plants do as part of their regular metabolism. In an important sense the corn has, in effect, pre-paid for the carbon pollution it makes at the combustion end by reducing a like amount at the growing end. That's why certain municipal biomass power plants---burning things like pecan shells, apple pomace, or straw to make electricity---can be considered a renewable source of energy.

Once you produce all this warmth you need to hoard it. You can do this through the use of thick insulation in the walls and ceiling and high-tech windows that tells light in but doesn't let heat out. Another crucial step in using energy sparingly is to have the right appliances. So, for example, the clean-energy home naturally uses those high-efficiency fluorescent bulbs and the kind of refrigerator that uses half the power of models only ten years old. The federal government has encouraged the sparing use of energy by mandating minimum-efficiency standards on some appliances such as refrigerators and air conditioners (ref 8.15).

The establishment of a clean-energy house is not an act of defiance or secession from society. It's like making the decision to eat sensibly. You increase your chances of feeling better and living longer. Putting your home on an energy diet is one way of shaping the material circumstances of your life. Instead of merely taking energy out of the socket as it comes you can do something about it. Does this mean you have to make your own energy? Isn't that what they did in the old days? Time-consuming scrounging for wood and making inefficient fire in the home---isn't that what mass-distributed electricity and gas put to an end? Doesn't the modern network work pretty well?

Yes, the utility system does work pretty well, and it can be made even better, say proponents of renewable energy sources. Forget for the moment the argument over whether these continually-replenished sources can ever be incorporated on a large scale into standard grid operations. They can at least be employed, where appropriate, on the homefront. At the Takoma Park home, for instance, the water heater still is warmed with gas energy. But the water first is diverted to the roof, where it slides through pipes warmed by sunlight. The conventional water heater is not eliminated but rather *assisted* by the solar heating device which, in this case, contributes about 60% of the energy needed for making the water hot. Electricity was saved, and just that much coal or gas went unburned.

If we think of the model home as a showcase for green energy, then the main display would be the photovoltaic panels parked on the roof not far from the warm-water pipes. These solar cells imitate photosynthesis, the marvelous process which serves no less than the basis for the entire food chain on Earth. Photosynthesis happens when a piece of light from the sun strikes a chlorophyll molecule in a leaf. This liberates an electron at one end of the molecule, and the electron gets handed around like a dish of food being passed around a dinner table. Eventually glucose or some other sugary substance is built up in the plant. Thus the plant does not contain the energy: it *is* the energy. An animal eating the plant will inherit this energy-packed material, which will in turn be used to build up the animal’s own body, and so on up through the animal kingdom. We are all rearranged atoms and repackaged sunlight.

A solar cell, or photo cell, or photovoltaic cell, is an artificial leaf. It tries to reproduce nature, which is often a good strategy in engineering since, after all, natural systems have had millions or billions of years to adapt and improve themselves. In a solar cell the absorption of light occurs not in a chlorophyll molecule but in a thin layer of semiconducting crystal. As in a green plant, the sunlight liberates an electron. Instead of helping to make glucose, the electron in a solar cell moves into an external wire where it can be used to charge a battery or feed your appliances. The solar electricity runs to a box in the basement where it is converted from DC into AC and sent pulsing at the same 60-cycle-per-second throb as the regular gird.

The advantages of getting electricity this way: you don't make pollution and the fuel, sunlight, is free. The disadvantage: the solar cell is expensive to buy. So it was with most early electrical apparatus. Samuel Insull kept saying that electricity was too expensive---we have to do something to bring the price down. The economics of solar cells are improving, unit costs are coming down, but the price per kilowatt-hour is still too high for solar to play an important role right now. In the case of clean-energy house, some tax credits helped to make the solar cells affordable. And as soon as they're operating they start paying for themselves by reducing the monthly utility bill. It might take a number of years, but eventually the rooftop grid will have paid for itself.

The cells work well, so well that on some sunny days the power coming from the roof more than fulfills the household energy budget and electricity can actually be sent out into the macrogrid. At that moment you really have a new thing in the electricity business: homes taking power *from* and giving power *to* the grid. The river of current has reversed and the wallside meter runs backwards. The homeowner gets a breath of satisfaction that in a small way she gets to influence the way the system works. Every home is a castle, and now every home can be a minor power station.

Is decentralization the future of electricity? It's too early to tell. Certainly, for many decades the momentum had been in the opposite direction. Not just in the distribution of power, but in many departments of modern urban and suburban life, centralization seemed to be the rule: consolidation and merger, economy of scale and mass merchandising.

The combined effects of restructuring and engineering, however, have reduced the vast preponderance of central generation in massive, largely fossil-fired or nuclear plant over uncentral generation in windmills or small gas turbines. Amory Lovins points out that in the year 2005, decentralized sources of power---including small and medium-sized gas turbines used for cogeneration of heat and electricity and renewable generation via wind, photovoltaic, biomass burning, and small hydroelectric facilities---delivered more power worldwide than nuclear reactors. Lovins, when he argues in favor of decentralized power production, never appeals to save-the-world sentiments; instead he trusts to market forces which, he says, will increasingly favor power sources that are flexible, modular, quick to build, and more resilient in the face of regional collapse or hostile attack (ref 8.16).

The owners of the clean-energy home don’t live a monastic life. Even with the rooftop solar panels, they have need of the utility and its empire of wires.   Those who seek to use low-impact energy still generally resort to gasoline-fueled cars. They fly on airplanes sending fumes into the air. They reduce but don't eliminate the need for macrogrid electricity made in fossil-fired mega-turbines. What can they do about this? What they do is purchase wind-powered electricity. No, they don't have windmills on the roof too. And they are not connected directly by wire to the nearest sizable wind farm 140 miles away on a West Virginia mountain ridge. They *are* connected to the wind in West Virginia, however, at least symbolically. It bears repeating that a consumer never receives power from any one particular power plant. Rather, all the plants, including far-flung distributed energy sources like wind turbines, pour their output into a common lake of energy from which all the customers draw their share.

Wind power, like photovoltaic power, is clean but still more expensive than that produced in old-fashioned steam-electric plants.

The customer, on a volunteer basis, can pay a little more on the monthly bill to offset the higher cost of wind power. Why willingly pay more? To be sure, it's an act of charity, a gesture. The symbolism is this: the microgrid at home can't produce all its own energy so it will continue to depend on the macrogrid, but at least it will reach out to, or help sustain, in some measure, a cleaner approach to power production. Paying extra money for what is, physically, the same generic electricity that everyone else gets, involves an act of imagination: you get to *visualize* a departure from business-as-usual. By paying for the cleaner production, you're keeping thousands of pounds of pollutants out of the air. You're saving a tree somewhere from succumbing to death by acid rain. Smog, and the wheezing that comes with it, will be reduced by a increment. This is the green view of electricity.

In the US acceptance of wind power has been a bit slow but is now catching on quickly.   The not-in-my-backyard problem is serious; people who own land with a nice view don't want that view interrupted by gangly propellers whirring away in the distance. In places like Long Island and Massachusetts, where many people might otherwise be friendly to green energy, opposition to coastal windfarms (compromise ocean-front real estate, it is said) has been fierce. The solution might be to build the wind turbines several miles out to sea, where they will be beyond seeing, or at least only a dim blot on the horizon. Wind blades have been known to kill birds and bats. These problems are minor. The cost of wind power is coming down. In some windy places like Denmark wind power already accounts for as much as a fifth of electrical production, and that fraction is expected to grow. Some countries, especially in Europe, are counting on wind energy to help them meet their pledge, under the Kyoto treaty, to reduce the cogeneration of electricity and greenhouse gases.

On the way out of the clean-energy home you see two cars parked in front, each meant to illustrate the energy reform idea as it applies to transportation. One car is entirely electric. An electric motor converts more of the input energy into motion than does an internal-combustion engine, and yet you see few electric cars. Except for dedicated fleets of vehicles, such as the postal service would use, electric vehicles don’t have a nationwide or worldwide network of service stations for recharging. Also, the batteries needed by these cars are expensive and difficult to dispose of.

The other car out front of the home, a so-called hybrid model, has two engines, one electric and one combustion. This clever design confronts the infrastructure problem head on. The gas-fueled engine, as it moves you down the road, is what recharges the electric engine, which can take over some of the propulsion chores in order to exploit its higher efficiency. Gas mileage goes up, pollution comes down. The hybrid approach used to be a novelty but might soon become a mainline (maybe *the* main) automotive architecture.

The car you don't see out front, because it is extremely rare, and not out of the experimental stage, is the hydrogen car. Some things to do with hydrogen are quite simple. It is the lightest and simplest of all atoms. It's the first entry in the Periodic Table of elements and is the most common commodity in the universe. Combined inside an engine with oxygen it is the cleanest of fuels, producing only water vapor as an exhaust. It's that simple: the hydrogen-consuming engine---a variation on the fuel cell design used in some factories---produces electricity and water. The electricity could be used to power a car or even, at a moment of peak need, be plugged into a socket and sent into the general power grid at rates as high as 20 to 40 kilowatts.

In some possible future society, the aggregation of hydrogen cars on the streets, thousands or millions of them, would constitute an immense auxiliary, ambulatory network of electric generation, a sort of rolling grid (ref 8.17).

Everything else to do with hydrogen is complicated. It's difficult to store. It's flammable and therefore dangerous if misused. There is currently no means to distribute it on a wide basis. The main complication is getting the hydrogen in the first place. The trouble is that hydrogen atoms are often to be seen in the company of other atoms. They might be plucked free from some hydrocarbon molecule or from water, and this often involves the use of large amounts of electricity. So it would seem that to make electricity from hydrogen you first must make the hydrogen...using lots of electricity.

This is not pure folly since, for one thing, hydrogen can be stored in large quantities, whereas electricity cannot. Hydrogen could be dispatched or brought into factories or cars but (because it can be stored, albeit with some difficulty) could be used later. You just add oxygen and, voila!, you have electricity. It's like having freeze-dried electricity. Electricity is itself a derivative form of energy. You don't pull it out of the ground. You make it by transforming other, less convenient, forms of energy. The same would be true of hydrogen. Furthermore, in some circumstances it might be more efficient to have some of those distributed energy resources like solar cells or windmills labor to make and store hydrogen, which could be used later, rather than electricity, which has to be used *now* (ref 8.18).

Many experts believe the use of hydrogen as a fuel or as a serious electricity substitute is decades away. It won't have done much good to make a pollution-free hydrogen automobile engine if the process of making the hydrogen adds a pollution toll on a par with the old combustion engines. Scientists and engineers ardently address these important issues. There's lots of work to be done before hydrogen kicks in.

In the meantime, how do we energize the grid? That's the central issue of this chapter. Gas turbines have come to shoulder a greater share of US power production and in other countries too, especially in light of huge gas fields being developed in central Asia. The turbines are made in many configurations (large and small), can be quite energy efficient (particularly if they make use of the combustion heat), and their atmospheric imprint is much kindlier than coal-fired turbines. The downside: gas prices have been volatile.

As for energizing the grid with renewable energy looks more hopeful than it did. Prices are coming down, options are multiplying. Wind power especially is coming on strong. But the absolute amounts---a few percentage points of the US electricity---are still scant. Will this, and an ever greater crusade to eliminate energy waste, be enough to meet future power needs and displace coal---relatively plentiful but polluting---from its majority role in power production in the US, China, and many other countries? Amory Lovins and other champions of renewable energy and efficient usage, believe that it is. Others aren't so sure. For them the numbers just don't add up. Consequently there has been a renewed discussion in industrial circles and in government of an old-fashioned approach to massive power production. Old but free of airborne pollutants. The technology is well known and the fuel relatively cheap.

It is time to talk about nuclear power.

Cracking Atoms

For some, the nuclear option is the Rock of Gibraltar, a refuge and saving resource which a lot of carbon-dioxide-free electricity can be extracted from a tiny amount of enriched fuel. It is the once and future stalwart producer of baseline electricity. For many grids even now, nuclear reactors do the heavy lifting, operating around the clock. Most of the largest generators in the world, those that produce the most kilowatt-hours, are pressurized water reactors.

For others, nuclear operations are a darkness, a dread prospect to be rejuvenated only if all other alternatives prove inadequate, and maybe not even then. However unreasonable it is to compare nuclear weapons with nuclear power plants (a reactor cannot explode as a bomb), visions of mushroom clouds seem to loom up in many minds at the mere mention of the word nuclear. To them, greenhouse effects and clouds of smog set loose by burning coal seem harmless by comparison.

Should the grid be energized by nuclear reactions? To have a closer look at this tangled issue, another visit is in order. Visiting a nuclear reactor is not like going to the castle of the evil witch in the *Wizard of Oz*. Here at the Indian Point facility, there are no crenelated battlements, no flying monkeys, no direful singing. There are plenty of razorwire fences here and guards with automatic weapons. This is said to be the most heavily defended industrial facility in the US (ref 8.19).

Nuclear activity at the site dates back to 1962, when Consolidated Edison started operating the first fully privately-funded reactor in the US. This machine didn't last long. In these years, reactor technology was in its adolescence, new things were being learned, the fresh knowledge would be incorporated into readjusted safety guidelines, and the new rules applied to all facilities whether in the planning stage, under construction, or up and running. So it was that Con Ed, confronted with the prospect of an expensive retrofit, decided to abandon its first reactor altogether. As consolation, two other reactors, units 2 and 3, came into operation only a few years later, one sitting on either side of the retired unit 1.

It is to this nuclear park, some 40 miles north of New York City on the east bank of the Hudson River, that we have come for a look. To reach the operational center you must negotiate a series of barriers: checkpoints, offices for visitor badges, fences, concrete traffic baffles, body-armored officers, metal detectors, trunk search, and the scrutiny of men in the kind of observation towers one sees at the perimeters of penitentiaries. To be sure, some of this security apparatus can be encountered on a visit to any international airport, and the whole intention---to exclude people who shouldn't be there---is rather more reassuring than intimidating. Out on the river a Coast Guard ship patrols. Once inside it is all smiles, informative discussion, helpful pamphlets, and a guided tour. Indian Point is one of the premier nuclear operations in the country. It produces 2000 megawatts of electricity, most of which is sent over transmission lines down the river to supply the great metropolis to the south.

Indian Point is no longer owned by Consolidated Edison of New York but by the Entergy Corporation of New Orleans. Restructuring at work once again: one of those huge energy companies which have come to dwarf many of the old mainline utilities, Entergy controls 30,000 megawatts of electricity, some of which it distributes to its own customers, some of which it sells to other distributors like Con Ed under longterm contracts. Some energy Entergy sells on the spot market for as much as it can get.

While many power companies were eager to get out of the nuclear business, Entergy embraced nuclear in a big way. It owns a fleet of ten reactors in six different states and holds down costs by sharing parts and experience among the sites. Although several decades old by now, nuclear technology is still a youthful field in comparison to coal- and gas-combustion technology, so the shared engineering experience gained from numerous locations under various conditions is valuable.

Actually, nuclear and conventional (fossil) power plants have a lot in common. Both use a lot of 19th century physics. Both employ thermal technology: take a lot of steam and aim it so that it keeps a turbine spinning for days, weeks, or months at a time without stopping. Both use electrical technology: the spinning turbine shaft sets up gusts of electric force which are sent through wires to the far-flung corners of the grid. Where nuclear and conventional generators differ greatly is in their manner of making steam.

Before going any further at Indian Point, one must visit the Health Physics Department, where one receives two separate devices to be worn around or near the neck. One measures the total amount of radiation you might encounter (although little or none is expected) and is read out at the end of the day. The other, fancier, unit measures radiation moment by moment and radios the results back to this office. On the wall are injunctions to be careful, to observe a meticulous list of precautions. To drive home the point, the poster tells the sad stories of those who were sloppy in following the rules. The workers bustling about all bristle with badges and monitors.

It is in the realm of Health Physics where 19th-century science gives way to 20th-century science. That's because of the fundamental and profound difference between the two furnaces used to heat steam. In a fossil-fuel furnace---the 19th century kind---hydrocarbon molecules (in the form of coal or natural gas) are mixed with oxygen molecules in that age-old combustion reaction that results in fire. In the fission-fuel furnace---the 20th century kind---uranium atoms, struck by subatomic particles called neutrons, fly apart in a reaction only first observed and recognized by humans as they were preparing to fight the second world war.

In the fire reaction no atoms are destroyed, only rearranged. In the fission reaction, atoms are emphatically dismembered. That's what fission means: to break apart. The leftovers from this microscopic devastation consist of a couple of daughter atoms, some surplus energy, and a few extra neutrons which can proceed to trigger further fission reactions. The fire reaction involves only the outermost part of the atoms, the part where electrons reside. The fission reaction all has to do with the nucleus, the innermost part of each atom. If an atom were the size of Madison Square Garden, then its nucleus would be the size of a sugar cube. Nevertheless more energy is latent within that tiny nucleus---the sugar cube---than in the whole rest of the atom. A carbon atom has a nucleus too, but it is not ripe. It can't fly apart the way a uranium nucleus can. Hence the great disparity between carbon fuel and uranium fuel. The fission reaction releases, on average, millions of times more energy than the fire reaction.

Let’s differentiate between two kinds of nuclear reactions: radioactivity and fission. In radioactivity the nucleus casts off a tiny fragment of itself. In fission the sundering is more complete: the nucleus essentially breaks in half. Radioactivity, insofar as it can produce penetrating particles, can do biological damage and is potentially dangerous. Fission packs much more of a wallop and has generally been exploited only for two specialized applications: nuclear bombs and nuclear reactors. The million-to-one ratio characterizing the fission-to-fire energy difference is so difficult for the mind to fathom that for the moment I shall move past the atom-nucleus comparison and concentrate on the waste products produced in the two kinds of furnace.

In a fire-filled furnace, the kind used by Edison at Pearl Street or by Big Allis at Ravenswood, all the atoms in the fuel, once combusted, leave the premises. Most of them go up a stack and drift out to sea, or over a forest, or some distant kingdom or republic on another continent. This long-distance dispersal of molecular pollutants is a matter of great importance and diplomatic discussion since the molecules might be killing trees or melting the polar ice caps.

In the fission-filled furnace, the kind used at Indian Point, the byproducts are very different, so different that there needs to be a Health Physics office at every reactor. After making heat, the atoms in the fissionable fuel don't go anywhere. Some of them have been transformed into other atoms (uranium atoms break into such secondary atoms as iodine or strontium) but these do not fly up any stack. They stay embedded in the fuel material. And this is both welcome and troubling. Welcome because there is no greenhouse gas sent up to be stored in the atmosphere. Troubling because the waste that stays behind, those radioactive daughter atoms that never left home, must be stored for years in special underground, water-filled tanks nearly as heavily monitored and protected as the reactor core itself. Often there is room in these tanks for many more years' of reactor waste yet to come, but a longer-term storage solution will be needed. The leading plan under discussion? Store the waste from all US reactors in a cave within Yucca Mountain in Nevada.

On to the power producing part of the plant. The turbine room looks the same as the one at Big Allis. Loud almost to the point of deafening (you wear earplugs at this point) and hot (steam races through pipes beneath the floor), this is the place where thermal energy is converted to electrical energy. This is straight 19th century physics. Much of the power made in this room ends up in the same form as Big Allis' power, 345-kilovolt electricity, and goes to many of the same places, namely the five Boroughs and Westchester County. You can't tell one volt from another. When you turn on your computer, nuclear-made and fossil-made electricity mingle.

Standing in the turbine room inspires self-consciousness. Why are we here in this loud place? Because of the importance of nuclearism for the evolution of the power industry.

Nuclear reactors account for about a fifth of the electricity made in the US right now; the worldwide number is similar. At one time many thought the fraction would be much higher. Others, citing the notable nuclear accidents like Three Mile Island and Chernobyl, expected the fraction by now to be much less. Even though the financial burden of building or starting (and later abandoning) reactors back in the 1970s and 1980s was so great (still influencing investment decisions decades later), and even though no license has been granted for new US reactor construction in decades, the nuclear option is still a considerable factor. In France, it constitutes 80% of the power industry.

Why are we at Indian Point on this particular day? Because one reactor is temporarily shut down, and this might allow us a peep at the room where the core sits; things will depend on work schedules. If cranes are operating overhead, then visitors will not be allowed in.

Unit #3 is humming along at near full capacity. Its turbine room is full of noise and vibration but practically devoid of human traffic. Over at Unit #2, turned off for refueling, it's the other way around; its turbine room is quiet but filled with activity. For the 28 days of downtime, #2 will receive $100 million worth of improvements, not only replacement fuel but also a new high-pressure turbine and other equipment that will add 40 megawatts to the power output.

The main task at hand is to install new fuel in the core. What does uranium fuel look like? It's metallic in form and shaped into half-inch-wide pellets, which are stacked like poker chips inside rods made of zirconium, a metal with a high melting temperature. The rods in turn are gathered into bunches called assemblies. Finally, the assemblies are loaded into the reactor core vessel, a stout pressure-cooker inside of which fission heat warms water circulating through the fuel assemblies.

Uranium isn't just uranium. Like Toyotas, it comes in several models. The main version is U-238, meaning that each uranium atom has a nucleus containing a number of neutrons and protons adding up to 238. A slimmer version of uranium is U-235, whose nucleus contains several fewer neutrons than U-238. Both cousins have the same chemistry but very different nuclear behavior: U-238 is radioactive, meaning that over millions of years there is a good chance that it will lose a small portion of its mass in the form of radiation. U-235 is also radioactive. However (and this is the big difference), it is fissile, meaning that if its nucleus is struck by a neutron of just the right energy it will break in half like a pinata, not millions of years from now, but immediately.

This makes U-235 valuable as reactor fuel. It is the U-235 nuclei which provide the potent energy to keep a reactor going. The reactor could go for a year or more without stopping, and this is sometimes the case why nuclear powered vessels can stay at sea for long periods. But after a while, the U-235 atoms with all this pent-up energy are used up and the fuel rods lose their effectiveness. How are the fuel rods like members of the US Senate? Because every two years one third of them come up for replacement. Every two years about one third of the fuel assemblies in a reactor are replaced with fresh rods in which the U-235 concentration is at the 4% level rather than the 1% level in naturally-found uranium samples.

The control room (to be more exact, the full-scale replica of the control room, used to train new operators) looks like the one at Big Allis. It has the same appearance of an air traffic control center, and indeed the man in charge refers to the bank of dials in front of him as "the flight panel." Just as many commercial pilots get their start in the Air Force, so many operators of commercial reactors get their experience from the Navy, where they "fly" nuclear powered submarines.

The most important meters are those that give you the temperature in the core, where the nuclear action is, and the instantaneous power being sent into the grid. The power is controlled in two ways: the amount of boron atoms in the water sent through the core and by control rods which can be moved into and out of the core. A word or two about the water, about the boron, and about the control rods: the water is what keeps the core from getting too hot; the heat it soaks up is what creates the steam. The water also "moderates" the nuclear reactions taking place in the core. The neutrons released in each reaction can be used to trigger further fission reactions, but only if they're slowed down a bit, and this is what the water can do. The presence of the boron, which can absorb the neutrons, is how engineers can moderate the moderation, making the reactor run somewhat slower or faster. Last but not least are the control rods. They are designed to absorb the neutrons which otherwise keep the nuclear chain reaction going. Insert the rods and the fission reactions stall out. Pull the rods out, and the reactions can resume. The rods are designed in such a way that no matter what kind of accident might occur, even a loss of electrical power at the reactor itself, the rods will automatically insert themselves into the core and shut off the flow of neutrons. Starved of neutrons the nuclear fission process stops within a few seconds.

In the US right now 104 reactors are on duty. About 10% of these are owned by Entergy, making them one of the largest nuclear vendors around, and their corporate reports indicate that they are making a nice business out of their reactor fleet. Much of the Indian Point electricity is spoken for: it's destined for the Con Ed grid to the south.

Just at this moment, for example, electricity could be selling in upstate New York for $30 per megawatt-hour, while in New York City it might cost you (the wholesale buyer) $60, and on Long Island it would be worse. Why the widely different costs? Insurance, taxes, transmission bottlenecks, and so on. By holding power back until a utility somewhere was desperate for it, the generator company could, in theory, make more money by selling less electricity. This state of affairs played a role in the California electricity crisis, and is of concern to those trying to plan an efficient, open electricity marketplace.

A power plant sells more than power. Consider this scenario of a utility making an arrangement with an independent generator: "We want 200 megawatts. Not right now. Maybe not at all. But if we want it, we'll need it in a hurry." What the utility is buying is not power but capacity to get power. It's buying backup power, contingency power. With this contract in hand, the utility might not have to have one of its own generators standing by. This contingency, standby power, is one of the services provided by Entergy.

Pollution, or pollution abatement, is another "commodity" which can be bought and sold. Legislation might soon prescribe that each power plant could emit 100 units of pollution without penalty. A plant that emitted 80 units of pollution could sell its surplus of 20 units as a waiver to a plant that emitted 120 units. Nuclear reactors, which emit no pollution into the air, would have plenty of pollution rebates to sell. (Of course, reactors have a pollution problem of their own, namely the buildup of radioactive waste, which one day will carry a huge price tag of its own.)

We’re in luck. Sticking ones head inside the containment building, but not much more, will be allowed today. This is the inner sanctum protecting the reactor itself. This is the last of the day's barriers to get past: the four-foot-thick, steel-rod-reinforced concrete wall surrounding the reactor pressure vessel which holds the fuel assemblies. Standing in the doorway is the limit. Any further and you’d have to don the protective suit worn by the workers scurrying about inside. In the distant part of this cavernous room one can spot the removed top of the reactor. From the doorway it is impossible to see the fuel assemblies being put back into the reactor, but this can be watched on numerous video screens.

Questions of safety and security are ever present. For instance, an engineer, seeing us look over at the reactor top, explains that the caps on the pressure vessel here at Indian Point are nothing like those at the Davis-Besse power plant in Ohio, which suffered a large crack. Had the crack (in Ohio) broken all the way through the vessel wall during normal operation, the reactor's cooling water, laden with radioactivity, might have spewed out into the containment room. Bad as this would have been, the mess at least would have been contained within the reactor room. That's why it's called a containment structure. But the crack was spotted in time (ref 8.20). And besides, that was Ohio and this is New York.

The Indian Point containment structure can sustain the direct hit of a commercial jetliner without rupturing, one is solemnly told by plant personnel, although no direct test of this proposition has been made. Standing in the doorway, the walls look sturdy. Still, it's creepy to think that only a few days after Entergy purchased this reactor in September 2001, a hijacked jetliner passed overhead, or not far off, on its way down the Hudson Valley toward a rendezvous with the World Trade Center.

We've been as close to the core as possible. Returning to the normal world, one passes back through a gauntlet of detectors. First a wand is passed over the hands and the shoes, the surfaces most likely to pick up stray radioactive residue. Next, you stand in a telephone-booth-sized device which sniffs for radiation over the whole body. After that you surrender the radiation badges, which are scanned for activity. Back out through the security checkpoint, past fences of wire, brick, and concrete. Surrender the identification badges, and one is free.

Nuclear Reactions

Physicist Richard Garwin, credited with being one of the developers of America's hydrogen bomb back in the early 1950s, distills the essence of nuclear power down to a few absorbing facts. For operating a typical 1000-megawatt reactor for 3 years, he says, you would install about 75 tons of fuel. At the end of 3 years, having supplied about 25 billion kilowatt-hours of energy to upwards of a million people, you would remove 75 tons of spent fuel, minus 3 kilograms, or about 8 pounds. Those 3 kilograms of matter---originally solid material---were turned into pure heat energy not through any chemical burning process, but by nuclear reactions. And of that only about one third ends up as usable electricity. In other words, three years' worth of electricity for a good-sized city came from the conversion of a kilogram (between two and three pounds) of uranium-235 (ref 8.21). That, in a nuclear nutshell, is why reactors exist.

As you can see, nuclear power is a fact-rich subject. It's also opinion rich. Just take, for example, the match up of fossil-fuel and fissile-fuel power generation. Fossil generation, through its worldwide respiratory effects and coal mining accidents, in an ordinary year, kills more people than the accumulated radiological effects of fissile generation. And yet the very idea of a nuclear disaster, with images of the Chernobyl explosion spreading contamination over a wide area and the vague blurring of nuclear power with nuclear weapons in many minds, seems to inspire a visceral dread disproportional to the real-life mortality rates. The design of nuclear reactors and the comparative risk analysis of fissile and fossil power production is so hedged with actuarial factors, game theory mathematics, and probability science as to make the subject practically a branch of quantum physics, which, technically, it is. Whether dread of all things nuclear is reasonable cannot be settled definitively. Instead, let’s look at a few prominent views on this prominent topic.

The first view belongs to the owners of the Indian Point reactors, Entergy Corporation. Their motto is: "Safe. Secure. Vital." Safe, as in maintaining a good safety record and in keeping its inventory of radioactive material where it should be. Secure, as in having a multi-layered defense system against theft, intrusion, or mayhem. And vital, as in accounting for a sizable fraction (up to a fourth on any one day) of New York City's power needs (ref 8.19).

The second view, that of Riverkeeper, a private conservation organization seeking to close Indian Point, is 180 degrees apart from that of Entergy. Indian Point and its radioactive store of isotopes is, to Riverkeeper, another Chernobyl waiting to happen. (Nuclear proponents never tire of pointing out that the core meltdown and explosion at the Chernobyl site in the Ukraine, history's most serious reactor accident, was more lethal partly because it lacked a sound containment structure, an unthinkable architectural omission from designs in most of the rest of the world, resulting in a wider dispersal of radioactive material outside the immediate compound.) Riverkeeper, without saying how Indian Point's fissile material would come to get loose into the environment (by accident or terror attack), does paint a vividly apocalyptic scenario, one in which 40,000 short-term deaths and as many as a half-million long-term deaths would accrue (ref 8.22).

The third view summarized here is that of Richard Garwin and Georges Charpak in their book, *Megawatts and Megatons: The Future of Nuclear Power and Nuclear Weapons*. Charpak won a Nobel Prize for his development of instruments to detect subatomic particles. Garwin is a longtime Pentagon consultant and critic, expert on numerous defense matters, a former research fellow at IBM, and a recognized authority on condensed matter physics. Garwin and Charpak, who know more than most the perils, the technology, and the costs associated with nuclear power, believe that fissile generation of electricity, even with all the complications, can have a viable future, but only if certain things happen. The first thing is a safer reactor design. Saying this forces one to ask about current safety? Are reactors safe right now? "Risks of normal operation are at present acceptable," Garwin says (ref 8.23). Fuel availability, he believes, seems secure. As for spent fuel: it can pile up at current temporary storage areas (often right next to the reactors) for decades to come. The rate of unplanned reactor shutdowns at US reactors has been declining (ref 8.24).

Nevertheless, arguments in favor of the continued (or even expanded) use of reactors often return to a comparison of the relative risks of power production. The argument goes this way: society tolerates many risky things. Here are a few. Putting gaseous pollutants into the air (from burning coal, say) increases respiratory disease and might be triggering deleterious climate change. Eating fatty foods, with its associated cardiovascular peril is a risky habit. Driving an automobile is hazardous; more than 40,000 annual highway fatalities in the US, however, hasn't dampened the desire to drive. Seen in this light, the cracking of atoms in order to obtain electricity seems tenable to Garwin. His considered opinion: "...normal operation and even occasional disaster still leave nuclear power with a health benefit over competing sources such as coal" (ref 8.23).

We have to do better, proponents admit, if nuclear power production is to thrive. A statistical analysis might appeal to the heart but often does little to allay a lingering dread in the gut. And not just among the uninformed general public. During hearings in 1961, no less than David Lilienthal, the first chairman of the Atomic Energy Commission (with jurisdiction over nuclear matters in the US), said that he would not care to live in Queens, New York if Con Edison had their way and built a reactor there (ref 8.25). Several problems with nuclear operation will have to be addressed if these doubters are to be won over. For instance, a long-term solution needs to be found for disposing of radioactive waste, probably by shelving it in a geologically stable underground cave.

Another important and related issue (some would call it the highest national and international security issue of our time) is nuclear proliferation, the spreading acquisition of nuclear-technology know-how and of nuclear materials, whether by nations or by rogue organizations. The U-235 used in commercial reactors and one of the by-products of reactor operation (the plutonium atoms created when neutrons strike U-238 nuclei) make spent fuel rods a natural repository for exactly those materials needed for assembling potential homemade nuclear explosives. Consolidation of vulnerable nuclear inventories and greater international monitoring of the flow and handling of radioactive and fissile substances is urgently needed.

All these points have been made in a recent study prepared by scientists and engineers at the Massachusetts Institute of Technology. Their report describes the efforts to reduce by tenfold the risk of a reactor accident by making reactor design simpler and foolproof (ref 8.26). The MIT report, and the nuclear power industry itself, readily concede that for the amount of electricity you would get out of it, building a new reactor is too expensive when compared to power from already-operating coal or gas-fired plants. The disparities can substantially be leveled out, however, through two means: by assessing a carbon tax on polluting fossil-fuel-produced electricity and by subsidizing the building of the new reactors (ref 8.27).

The financial, regulatory, and public-relations obstacles for a nuclear renaissance in the US are formidable. No company is talking yet about seeking a license to build a new reactor, but several are attempting to gain "early site approval" for locating new plants if the go-ahead decision comes through later (ref 8.28).

Should the grid be energized with nuclear power? The National Commission on Energy Policy, a private committee supported by foundations, looked at the wide picture and, not surprisingly, endorsed a diverse spectrum of candidate solutions: higher-efficiency appliances, better vehicle fuel standards, taxes on carbon emission, diversity of energy supply, cleaner use of coal, sequestering carbon, tax credits for renewable-energy sources, and so forth. On the nuclear issue, the commission favors funding for further research into the design and deployment of advanced nuclear facilities (ref 8.29).

We can't satisfactorily answer the question "Is nuclear power safe?" (safe compared to what?) so we have to keep searching for additional ways of viewing nuclear reactors in the context of other complicated machines. Charles Perrow's book *Normal Accidents* looks at how, in an engineering sense, the total is more than the sum of the parts:

> *Most high-risk systems have some special characteristics, beyond their toxic or explosive or genetic dangers, that make accidents in them inevitable, even "normal." This has to do with the way failures can interact and the way the system is tied together. It is possible to analyze these special characteristics and in so doing gain a much better understanding of why accidents occur in these systems, and they always will (8.30).*

Perrow singles out two attributes as being paramount in contributing to normal accidents in systems, whether they're airplanes or power plants or space missions. One is the *tight coupling* of components in the system: the behavior of one component will readily be linked to, or even cause, behavior in other components. The other attribute is *interactive complexity*. This refers to unexpected feedback loops in parts of the system or jumps from one sequence of events to another in such a way that the output of the system is disproportionate to the input. Another way of saying this is that the system is behaving in a nonlinear way.

Any system with interacting parts can be classified within this scheme. For example, Perrow says, a single-goal agency like a post office is generally loosely coupled (people sorting or delivering mail mostly work independently of each other) and linear in its behavior (twice the number of mail sorters sort the mail twice as fast). Second example: a hydroelectric plant is, like the post office, rather linear in its operation. Double the amount of water into the turbines and you get double the electricity out. However, the hydroelectric plant is, by Perrow's definition, more tightly coupled. A problem in one area (the level of the river, say, or loss of hydraulic fluid) can quickly create problems in other parts of the plant. Still more tightly coupled and more complex in its interacting parts than a hydroelectric plant is the power grid itself. The numerous routes by which electricity (or conversely the effects of a cascading blackout) can flow over the network of transmission lines makes for nonlinear behavior: the output may no longer be proportionally to the input. This starting-the-avalanche phenomenon has been amply illustrated by such events as the 1965 Northeast blackout.

All these instances of complicated systems can be placed on an organizational chart with the horizontal axis, "interactions," running the gamut from linear to complex. The vertical axis, "coupling," runs from loose to tight. And the system in the upper rightmost corner? The system with the extremity of tightly coupledness and nonlinear interactions? The system with the greatest propensity for complicated, unpredictable behavior? On Perrow's chart it is nuclear power plants (ref 8.31).

This does not mean that nuclear plants are doomed to having serious accidents, only that the linkages and pathways of causation in this system are plentiful. When Perrow wrote his book, he expected more serious nuclear accidents to occur. As if to prove his point, the Chernobyl disaster happened only a few years later. In the last few decades, however, the number of unscheduled shutdowns at nuclear reactors has been dropping. Furthermore, one can point out that other complex systems are vulnerable to accidents too. Petrochemical plants are highly coupled and nonlinear systems, but they have been around a lot longer than nuclear plants and there has been more time to gather precautionary experience. Then too, there is a difference in scale between hypothetical chemical and nuclear accidents. Consequently, Perrow says, we have a Nuclear Regulatory Commission for spying on reactors but no such thing as a Chemical Regulatory Commission for snooping on refineries (ref 8.32).

Three Contenders

We’ve made three site inspections in this chapter to illustrate three approaches to energizing the grid. Big Allis epitomizes the fossil method for electricity production. Since a lot of carbon atoms are burned this way, let’s designate this path with the letter C. Then there was the clean-energy house, exemplifying the renewable approach (earning the letter R) which includes things like wind and solar power and energy gained (or energy use avoided) by greater efficiency efforts. Finally, there is the nuclear (N) approach used at Indian Point.

In Amory Lovins's designations, R represents the preferred path to energizing the grid while trying to minimize damage to the environment. Modular and compact, solar cells and wind turbines are tailor made for decentralized, distributed grids. N is the opposite: it is very hard. Nuclear reactors come in only one size: big. C is generally also big. Big Allis is big. But owing to all those polymorphous gas turbines---machines that can render kilowatts or hundreds of megawatts---C could go either way, allying itself with N in sustaining the traditional macrogrid scenario or with R in a hybrid macro/micro grid system.

There are of course a few generators that don't fit these categories. Not all renewable-energy plants are small: biomass generators can be big. And not all small generators run on renewable energy: those microturbines run on gas. For right now, let’s concentrate on C, R, and N as if they were the only choices.

N produces radioactive waste but no gaseous pollutants. With C it's the other way around. R produces little waste. N's metallic uranium fuel was made in exploding stars billions of years ago. C's hydrocarbon fuel was made in the form of green plants millions of years ago. Meanwhile, R's fuel is sunlight pouring down now or wind set in motion by the warmth of sunlight six months ago. N's fuel can be made into a bomb, which makes it an inviting terror target. C's fuel cannot explode but it can and often does enter into international security discussions. R's energy generally falls from the sky.

N, R, and C should all compete in a free and open market. But markets are often not that free. Favoritism, implicit collusion, and poorly designed government regulations all play their part in skewing the exercise of capitalism. N, R, and C all receive subsidies to varying degrees, sometimes at the research stage, or through regulations, or through failure to exact payment for environmental depredation (stressed skies, depleted habitats, and species driven extinct).

C is the grid's traditional power source. N has been around for half a century but has been coasting for the last 30 years or so; no new plants have been ordered in that time. R is making inroads. It comes in small batches. Will this add up to a big thing or will it always be small?

These studies say that R should be encouraged in order to offset the polluting effects of C and because it’s the right thing to do. They also suggest, however, that the anticipated rise in electrical demand in coming decades will necessitate the renewed growth of N. Still another report, issued in 2005 by a US Department of Energy advisory panel, makes essentially the same points. Why should we be more confident of nuclear power now than 20 years ago? More operating experience, a low reactor accident rate, a growing capacity factor (the fraction of time the reactor is up and running), typically 90% or better, and the prospective advent of an inherently safer and simpler reactor design, are given as evidence (ref 8.33).

Recognizing the huge up-front cost of constructing a first-of-a-kind new reactor, and the great trepidations for a company or consortium being the first to seek a nuclear license in a third of a century, the DOE report suggests that the federal government pay up to half of the cost of the newcomer plants. One of the report panelists, physicist Burton Richter, who won a Nobel Prize for his discovery of a subatomic particle, said that once you get the startup costs out of the way, and if you impose carbon taxes on emissions from fossil-fired plants, then the nuclear approach becomes surprisingly competitive with the coal approach to energizing the grid (ref 8.34).

Of course, a nuclear reaction is still a nuclear reaction, whether it’s subsidized or not, whether it’s “competitive” with coal or not. For Lewis Mumford, even decades of extra experience might not be sufficient to be confident that nuclear forces had truly been tamed within a manmade machine. Nineteenth century scientist-inventors such as Faraday and Tesla helped to bring the electrical grid into being by taming and understanding the electromagnetic force. The twentieth century scientist-inventors who harnessed the nuclear force to human goals, people such as Niels Bohr and Robert Oppenheimer, have often been more ambivalent about their work, and not only because of the city-destroying power implicit in the nucleus, but also because of the longevity an potency of radioactive waste.

The prospect at hand is the following: (a) we will energize the grid at an ever greater rate and (b) to do this without wreaking climate havoc we will trade one pollution---carbon compounds sent into the sky---for another type of pollution---radioactive waste sent into a protective vault, perhaps to cool off there for many centuries to come. Nearly a dozen views of this one important energy issue---the efficacy of nuclear power---have now been reviewed without arriving at any definite conclusion.

Lewis Mumford, always trying to place our technological aspirations and anxieties in a wider cultural context, compares our search for engineering “fixes” to a recurring theme in folktales, namely the hankering after magic solutions to life’s problems:

> *When some deep-seated human wish is gratified by magic in these stories, there is usually some fatal catch attached to the gift, which either makes it do just the opposite of what is hoped. This catch is already visible in atomic energy. We know how to turn nuclear fission on, but, once we have created a radioactive element, we must wait for nature to turn it off if we cannot use it in a further reaction (ref 8.35).*

At the end of a day at Indian Point one must drive out beneath the massive transmission lines carrying away the reactor's harvest of electrical power on down to New York City. A typical 1000-megawatt reactor, like Indian Point's, possesses at its core the fissionable-material equivalent of 1000 nuclear bombs (ref 8.36). The reactor, it must be emphasized again, cannot explode because all that fuel is not rich enough U-235. Nevertheless, having all that captive energy in one place, quivering at the heart of all those nuclei in all those atoms in all those fuel rods, is an impressive fact. Take the nuclear capability of the device tested in the New Mexico desert by the Manhattan Project scientists, multiply it by a thousand, and that's what's being loaded into the Indian Point Unit #2 right now on this sunny autumn afternoon.

And at the same time, 100 meters away, working like a beaver, Unit #3 has been churning out electricity at a mighty clip. Final fission fact: those transmission lines leading off the property have just carried down to New York City, during the hours we’ve been at the plant, an electrical equivalent roughly equal to the energy unloosed by the bomb dropped on Hiroshima (8.36). Depending on how you configure the forces, you can use uranium to energize or crush a city.

28 September 2005

Chapter Nine

Touching the Grid

Halfway through the 19th century Henry David Thoreau composed two notable books in which, outwardly writing about naturalist themes, he essayed forth on the subject of how society works or doesn't work, how people conform, and how they are pampered by the modern mechanical conveniences of everyday life. What happens in these books? On the surface, not much. In *Walden* Thoreau spends a year and a half near a pond, and in *A Week on the Concord and Merrimack Rivers* he takes a leisurely sightseeing trip with his brother. Both accounts give Thoreau an excuse to digress deeply into favorite subjects, such as poetry, religion, government, the use of machines, and a dozen other topics.

In this chapter, inspired by Thoreau's example, I describe a week spent on or near a river with *my* brother, Mark Schewe. The river in question is the Snake River. The official reason for the trip will be to examine the workings of Idaho Power, a utility company closely tied to the hydroelectric energy generated by dams on the Snake. In proceeding this way, I intend to look, from top to bottom at how a specific electrical grid works. Specific and yet generic. What happens in Idaho, electrically, also happens where you live. Think of this as *your* grid.

The events of the past few chapters have been a bit frenetic, so the pace in this chapter will be slower, and the narrative more ruminative. Thoreau achieves this effect by plopping insights in the reader's path from the writings of Emerson, Homer, and Chaucer. I shall limit myself to pithy quotes from Thoreau himself. Where he ponders the meaning of life as he repairs a boat or hoes some vegetables, I ponder the meaning of electricity as I visit a dam or a machine shop.

Thoreau considered himself a poet, but was careful to define poetry loosely, so that just about everything he wrote could be considered poetic. Not only that, but in his view, what people thought and did could also count as poetry. Here is a first taste of Thoreau:

> *As naturally as the oak bears an acorn, and the vine a gourd, man bears a poem,*

> *spoken or done. It is the chief and most memorable success, for history is but a prose narrative of poetic deeds. What else have the Hindus, the Persians, the Babylonians, the Egyptians done that can be told? (Ref 9.1)*

Is the creation of a vast electrical grid a "poetic deed," worthy of being compared to the heroic early achievements of the Persians and Babylonians? I guess if I didn't believe this to be at least partly true, then I wouldn't be writing this prose history of the grid.

Thoreau would insist that it is not the *bigness* of the subject (pyramid or electrical grid) that commends itself to the poet but its *potentiality* for producing insight. For Thoreau his point of departure was the cultivation of vegetables in a plot of land between some pines and a pond. For me it will be the cultivation of volts amid the doings of a modern electrical company. Instead of paddling up two New England waterways, I shall float through a dry Western landscape, sticking close to the Snake River and the river of electricity it spawns. The water river moves unidirectionally toward the sea. The electrical river, and my narrative, will begin in the home and spiral outwards from there into levels of ever higher voltage.

The Parallel Lives of Appliances

Picture a person in bed early in the morning. At the first moment of consciousness, electricity stirs in two very different forms---in the person's brain and in the alarmclock radio on the nightstand next to his pillow. The electricity in his head consists of waves of charged potassium and calcium atoms moving in and out of nerve cells. The electricity in the clock consists of waves of electrons rushing in and out of the wall along tiny wires.

The energy behind the brain electricity can be attributed to the food eaten yesterday, maybe a midday apple. The energy in the clock radio, and the light in the bathroom, and the blender in the kitchen, is harder to trace since it is of uncertain paternity. Did it come from the giant Brownlee Dam on the Oregon/Idaho border or from the Jim Bridger coal-fired steam-electric plant all the way over in Wyoming? You really can't tell because the utility draws and mingles energy from many sources. Recall that electricity is not a parcel sent from a particular generator to a particular customer. Rather it is like drawing water from a lake filled by several tributaries. Consider that Mississippi River water flowing past New Orleans might be coming from Cincinnati or Minneapolis or Tulsa or Bismarck. The service area for Idaho Power, some 20,000 square miles, isn't as big as the Mississippi watershed, but big enough to render anonymous the electrical power arriving at the socket the instant you turn on that blender.

At 6 AM my brother Mark does not ponder the metamorphosis of his own apple-fed bio-electricity nor the snow-fed hydro-electricity twirling the blades in his shaver. In Idaho a hundred years ago electricity confined to the dusk-to-midnight hours, with the exception of three hours on Tuesday afternoon so that women could operate electric irons (ref 9.2). Those days are long gone and Mark can count on the fact that electricity is on duty on through the night, so that he won't have to pump water for his morning scrub, or set fire to wood for heat, or put match to candle for light. With grid-based amenities there are no fumes, no throttle, no pull cord or primer, no ignition, no general exertion at all except to throw a switch or select a speed setting on the side of the appliance.

One utterly takes this same-second delivery of energy for granted. On through the house, on through the day, through your life, you are probably within an arm's length of an electrical circuit supported by some form of grid, whether at home or in the car. Even battery-powered hand-held units are dependent on the grid since at the end of the day they will inevitably be plugged into a wall outlet the way a rhino must return to its mud wallow.

In the home, all the circuits form a confederation. Each room, or couple of rooms, gets a circuit separate from the others. When you walk down the hall you pass from one electrical jurisdiction into another. All these circuits extend their wires down through the walls. They meet in parliamentary assembly at the circuit box (also called the service panel or fuse box) in the garage or basement. There the home's electrical allotment is doled out; the total budget cap in your home is usually something like 200 amps. (The amp is the standard unit for current, and is named for Jean Jacques Ampere, one of the early pioneers of electrical knowledge). All the circuits together cannot draw a current more than this amount.

Under the constitutional rules of the service-panel parliament, the room circuits are also under constraint. Each bedroom, for example, may appropriate no more than 15 amps of current. What does this mean? So far in this book I've been talking about electricity in terms of *power* (the amount of energy delivered per second) or *voltage* (the force under which the electricity is supplied, analogous to the pressure pushing water through a pipe). No less useful in describing the river aspect of electricity is the concept of *current,* the number of electrons passing down a wire per second. The current is related to voltage and power in this way: power is just voltage times current. Or, to swing things around another way, current is power divided by voltage. All these units are named for various inductees into the electrical hall of fame: in addition to amps the list includes watts (James Watt), volts (Allessandro Volta), and ohms, the unit of resistance, or the amount of electrical drag imposed by the appliance (and named for Georg Ohm).

The limit on current circulating through the bedroom is15 amps, but what does that mean in terms of actual appliances? To determine the current flowing through a 100-watt lightbulb, just divide the power (100 watts) by the voltage (120 volts); 100 divided by 120 is a little less than one amp. In other words, an amp is the current of electricity flowing through a 100-watt bulb. Know your electricity. And it *is* your electricity; these are not electrons coming in from the grid, but electrons there in your wires to begin with. What you buy from the utility is the electric force to drive the electrons already present in the circuits within your appliances.

The lamp drinks only a small part of the room's quota of current. You could burn fifteen 100-watt lamps and still get away with it. An ancient Babylonian or even Henry David Thoreau would of course have been amazed to light even one such bulb, but we get to light fifteen. In practice the current goes to a lamp or two, a clock, maybe a computer or television. In other rooms, the allowable amps are divided up differently among the appliances.

Some appliances are more equal than others. They are so power hungry that they get a special dedicated circuit all to themselves. These exceptional appliances include those that produce lots of torque (turning power) in compressors dedicated to lowering the temperature (air conditioners and refrigerators) and those that raise the temperature (ovens, water heaters, clothes dryers). Upper limits on allowable currents for these monsters can be 20, 40, or even 80 amps. All these appliances, strung out on their separate circuits, with their separate wiring running behind the wall boards, know nothing of each other's existence. Their parallel performance only becomes problematic when the current maximum for the house as a whole is exceeded.

The rules are enforced with fuses or other devices for interrupting the flow. Fuses are to amps what canaries are to miners. If the bird keels over from the built-up cave gas the miner knows to get out. Fuses don't keel over, but they will melt when the current gets too high. And since they're positioned *in* the current path---they are the narrow footbridge over which the electricity must flow---when they perish the current halts entirely, and you're left in the dark. The reason for the cutoff isn't stinginess on the part of the utility. They love to sell you power. No, the reason for limits is the continued well being of your circuits. With too much current flowing, the wires inside your bedroom wall might have melted or shorted or started a fire. Much better for an inexpensive, plum-sized fuse to fail, and for you to lose power in a room, than for you to lose the whole house. When such a minor disaster strikes the first thing to do is to understand why the fuse blew. (In some homes your circuits are protected by small circuit breakers, in which case the fuse box is called a breaker panel.) Chances are you had too many things on all at once, or perhaps one of the appliances has an internal fault or short which causes it to malfunction, including drawing too much current---so be careful. Once you've corrected the problem, usually by turning something off or down, you can replace the fuse, or reset the breaker, and you're in business again. The power resumes its regular course.

Do we need so much power, so much current, in the first place? Don't we have too many appliances? Electric lighting is one thing, but do we really need *blenders*? Couldn't we mash and sieve pulpy foods in the old way? Must we accelerate fruit to high velocity? Thoreau would have said no. He argued that too many material possessions distract us from a profounder appreciation for the better things in life:

> *A man is rich in proportion to the number of things which he can afford to let alone (ref 9.3)*

Indeed, with the price of appliances and electricity comparatively low, it is hard to resist the temptation to acquire more gadgets. This morning Mark has a blender problem. After twenty years of service the thing conks out. On this occasion, pushing the button brought not a consistent whir but an ugly grinding noise, an uncertain convulsive vibration, an acrid smell puffing up, signifying burning insulation, and then silence. A blender is a rotating blade attached to a rotating shaft powered by a motor, and a motor is really just a generator in reverse. So here you have, in a single device, a microcosm of the electrical world. The motor/generator, run in forward or reverse mode, is the hand that rocks the cradle. In a motor, electrical energy is converted into the rotational motion of a drill or an irrigation pump or blender blade. In a generator it's the other way around: rotational motion energy is turned into electricity: the spinning turbine, itself pushed by steam or water, turns some coils through the magnetic force field established by a second coil, inducing current to flow in the first coil.

A tabletop autopsy is undertaken on Mark's blender. Undoing a few screws reveals the inner workings: the wiring, gears, contacts, bearings, tiny dabs of solder. The main viscera are those two coils of wire, one stationary and one that rotates with the central shaft. It's easy to see the cause of death. A spindly wire forming part of one of the coils has a frayed insulating sheath.

All those cycles of heating up and cooling down can lead to weakening and corrosion. Some of the electricity tried to take a short cut, too much current built up, and the internal fuse blew.

Big deal. The world does not stop. An avalanche does not begin. Thirty million people in nine states do not lose power. If you had a sure enough hand, you might try to repair the wiring. In the present network of quick manufacture, chainstore retailing, and cheap electricity there is little motivation for fixing or even recycling the old appliance, so it gets tossed on the rubbish heap. Mark could actually reach in, grab the wires, and repair the thing---not many are able to do that---but won't since it isn't worth his time. Indeed, he could probably do without the blender altogether, but he'll get another anyway because it's part of his customary kitchen routine. It represents a bit of marginal convenience. He owns a blender because he can. Mark gives up on the fruit. He is already five minutes behind schedule and must report for his job at Idaho Power.

Thoreau, coming upon this scene, would have frowned. First, he would disapprove of anyone regulating his life so closely by the clock. Secondly, he would point to this machine ownership, and all other forms of material possessiveness, as a sort of bondage. The objects---home, appliances, automobiles---serve our turn, but in return we must keep them in proper running order, furnish them with fuel, and worry over them when they malfunction.

Thoreau, living in his humble shack by Walden Pond, questioned his neighbors' approach to living, entailing as it did long toil in the field and bondage to costly implements and a perpetual mortgage:

> *And when the farmer has got his house, he may not be the richer but the poorer for it, and it be the house that has got him (ref 9.4).*

Metamorphosis

It's up about 30 feet off the ground, the thing looking like a garbage can bolted to the side of the power pole. In the Idaho Power system there might be a hundred thousand of them. A transformer is the device that converts electricity from the industrial scale of 7200 volts down to the domestic scale of 120 volts. The circuit panel or the meter on the wall outside might be the formal boundary between the utility and the customer, but the changeover really occurs up that pole and inside that can. These drop-down transformers, as they are called, are the offramps of the electrical highway system.

It's only midmorning and already the air conditioners are coming on, and that means a full workout ahead for the grid. Among the sturdiest of strands in the knitted fabric of the grid, transformers are built to brave out the elements and heavy electrical traffic for decades. Some are sexagenarians and still lead productive lives. They are hardy but not eternal, and eventually they succumb to one sickness or another and have to be taken down and brought in for repair.

I have it in mind to designate transformers, in their capacity as ambassador between customer and company, as the official representative component of the grid. And to see how they are maintained in good working order, I shall follow one particular transformer on its journey to the doctor for a checkup. Just as this chapter traces a day in the life of a single grid utility, so this section traces a day in the life of a single transformer. I shall refer to it as JK67.

Mark shows me around the Boise Operations Center, where JK67, like any patient at a prim medical clinic, will get the full treatment. First comes the preliminary inspection and a flow of documentation starts up. Date of birth? Time of last checkup? Obvious external damage? Leakage from orifices? Internal bleeding? JK67 is bigger than a blender but surprisingly has fewer parts. What you see when you peer inside are two coils of wire wrapped around a common steel yoke, and that's just about all. Nothing moves. Only energy moves and is transformed, and this is the whole point and destiny of the grid.

Here is how the metamorphosis works. Here is how electricity comes into your home through the transformer parked on the pole outside. Electricity flows from the grid into the first coil, the primary coil, and this creates a magnetic force which streams through the yoke as surely as the Moon creates a gravitational force that extends all the way to Earth, a force that induces tides of water to move into bays and up rivers. On the other side of the yoke the lines of magnetic force pass freely through the secondary coil and---through a reciprocal action whose technological development must rival in importance the invention of the wheel and the discovery of penicillin---a counter-flowing current is induced there. This current of electrons, a tiny tide more periodic than any lunar tide of river water, is what proceeds out of the transformer, down the pole, into the service panel, and on into those parallel circuits inside your home assigned to all the blenders, bulbs, and dehumidifiers.

What you buy from the grid is power, energy per time. You’re not buying a current (a flow of electrons) but voltage. The electrons flowing in your wires were there to begin with. What you’re getting from the utility is the oomph to move your own electrons around. What you’re buying is a sort of zest across two terminals, a forcefulness, a gradient that zooms the electrons along.

Why not just take the electricity directly from the grid? Why pass it through a can perched up a pole? To see why, consider the following banking transaction. Suppose you were fortunate enough to have a million dollars in your account, and you wanted to withdraw this full amount. The bank could give you the money in several ways. They could give you a thousand $1000 bills or they could give you 100,000 $10 bills. The former might be preferable if you wanted to fit all the cash in your pockets. But for other purposes, for settling a myriad of trifling accounts, you would naturally prefer the $10 bills. Why? Because they're easier to use. Home electricity, 120-volt electricity (or 220 V in many other parts of the world), is the $10 approach: humble and practical. The million dollars is still the same million whether it comes in big or small denominations, and the same is true for electrical energy. It's more efficient to send electricity at high voltage but more practical to use it at low voltage. The secondary voltage (on the home side) is a fraction of the primary voltage (on the utility side) in the same fraction as the number of windings in the secondary to the primary coil.

The metamorphosis of energy from the high-end 7200 volts used by the utility to the low-end 120 volts used at home takes place synchronously all over Idaho, and in the same way wherever electricity is in use. And every time voltage is transformed, whether it's on that pole outside your home or in the back of your computer (where higher voltage is needed to run the processor), what's happening is a reenactment of that famous flicker across the dial which David Faraday noticed out of the corner of his eye back during the famous experiment of 1831. Turning circuits on or off can affect another circuit nearby. Energy moving in one coil can become energy moving in a second coil. And from this simple correlation comes the entire electrical industry.

Now, if Thoreau were here he would jump in and challenge, or at least gently question, the need for such a teeming zoo of electrical things. Electricity for lighting? Okay. For irrigation, maybe. For an air conditioner? What, you can't put up with a little heat? Circuits for video play stations? What, you don't have any books to read?

Yes, Thoreau was a scold. He felt out of place in his own time and would have been even more alienated by ours:

> *I delight to come to my bearings---not walk in procession with pomp and parade, in a conspicuous place, but to walk even with the Builder of the*

> *universe, if I may---not to live in this restless, nervous, bustling, trivial Nineteenth Century, but stand or sit thoughtfully while it goes by. What are men celebrating? They are all on a committee of arrangements, and hourly expect a speech by somebody (ref 9.5).*

The celebration nowadays would take the form of a television advertisement. The speech Thoreau would want to avoid, if he were alive in our bustling 21st century, would likely be extolling the virtues of some piece of powered machinery.

The energy for that machine, and machines worldwide, is supplied in homogenized form by a transformer. Inside the transformer is a swimming pool, a miniature spa for electricity. The coils soak peacefully in a bath of about 10 to 15 gallons of oil, a grade of oil not very different from motor oil. Why oil? Why any fluid? The oil is there partly to cool the coils, which get warm carrying all that energy, and partly to insulate the wires of the coils from each other. If two wires touch or come too close to any metallic surface, a short-circuit will result. When current takes such a shortcut---when it flows outside its allowed path---bad things can happen. Electrical shortcuts can lead to a blender breaking down, a home burning up, or an enormous multi-state regional grid turning off.

JK67 shows signs of exactly this sort of short-circuit. Dark smudges on the walls tell us that sparks must have erupted unseen, intermittently lighting up the transformer's interior like an x-ray scan. If electricity is a form of bottled lightning, then here is an example of the bottle (one small corner of it) developing a leak.. There is in this case also a report from the chem lab testing positive for acetylene, a ring-shaped molecule made in the oil when electrical arcing---tiny thunderbolts tracing the path of the shortcut---break out like a disease in the transformer's innards. The chemistry analysis also looks for another troublemaker, PCB, a very complicated molecule which used to be added to the oil to make it a better insulator. But when PCB became known as a cancer-causing agent they stopped using it. The findings are good: JK67 does not carry the dreaded PCB.

Like the human body, JK67 can get sick in a number of ways. Its brass fittings, the electrodes where electricity enters and departs from the can, get tarnished. The gaskets, the rubbery layer that forms the snug fit between the can and its lid, can crack, giving oil a chance to escape. Less oil means less insulation and less cooling. And this can lead to arcing.

Bushings can be at fault. A bushing is the bell-shaped ceramic cowling that girdles the power line where it enters the transformer. Stop now to consider the bushing's role in maintaining the around-the-clock flow of electricity. Half of the power industry is devoted to making and sending electricity, the other half to keeping that electricity in its proper path. The bushing's job is to keep the lightning bottled. It must at all costs prevent the incoming power from taking a shortcut by leaping from its own wire at 7200 volts over to the shell of the transformer itself. Electricity, as you have already seen in a number of ways, is an exuberant conveyance of energy and like a frolicsome child playing a game will often make up its own rules. It will gleefully seek out the shortest, easiest path for itself. Wherever this arcing temptation is greatest, there the engineer must insert insulation. Insulation, the opposition of conduction, is designed to frustrate electricity into behaving itself.

In this respect, the bushings stacked up on top of transformers, or power lines, or switches (all places where surfaces at very different voltage are in dangerous proximity) are a vital means of keeping electricity in its groove. If the electrical grid were a gothic cathedral, then bushings would be its flying buttresses. They have a flaring geometry, are positioned on top of or next to each other in functional orderliness, are stationed on the flank of the main architectural element (in this case the power-carrying cable), and in general support the work of the grid with sturdy, yeoman service.

Bushings, like human appendages, are built to last decades but can wither and crack with too much exposure to sunlight. Indeed solar ultraviolet is harmful to human flesh, ceramic bushings, and many other organic compounded materials. A glaring day like today, a delight to recreationalists, is a detriment to the grid. If you want to make your plastic lawn furniture last longer, Mark advises, rub it with sunblock lotion.

Like a surgeon, the technician plunges in. JK67's short-circuit problem is soon mended. The oil is replenished. (The old oil becomes an additive in explosives or, if it is too far degraded, sent to a place in Utah to be burned.) Gaskets, bushings, and fittings are replaced as needed. Then the can is closed up and tightened down. Rust spots are sanded off and new paint applied. The unit is given a road test where it is forced to carry twice the maximum current handled in ordinary service. JK67 is labeled, given one last inspection, and then lovingly staged on the loading dock where it waits to be taken out to active duty as if it were a pet at the pound waiting for loving owners to show up and give it a home.

In its previous tour of duty it might have delivered electricity to a family on through its childrearing years, a number of graduations, a wedding, a funeral, and war in Vietnam. Very soon a line crew will take JK67 out, hoist its 500 pounds up to the top of a pole. Returned to active work, it will spy on grazing cows and pickup trucks, and will deliver enough energy to power many holiday dinners yet to come. In all likelihood no human eyes will peer into its oily depths again for a half century or more.

They All Hunt Elk

The people closest to the grid---it is fair to say closest since they literally *touch* electricity---are the men who service the wire network over the entirety of it geography. The linemen go wherever the line goes. This can mean a conduit beneath a suburban shopping mall or, since there is plenty of desert and forest in the state, it can mean a wolf-inhabited ridge or forlorn alkaline gulch. Someday, if electric power is beamed through the air as waves, the companies will use wave-men. But as long as power is sent across bulk metallic lines, they'll need linemen.

It is to a dry terrain of sandy soil we go today because of a report of a warped cross arm on a power pole. This particular imperfection was spotted by a circuit-riding engineer referred to as the Troubleman, an inspector who does nothing but find fault. He looks at lines, poles, breakers, and all the other physical sinew and organs of the grid. Like the tax collector touring ancient empires, the Troubleman comes to each province of the grid only about once in ten years. He makes spot judgements: will this equipment perform well for the next decade? If not, then it needs tending.

Thoreau, as a poet and philosopher and self-nominated inquirer into the general nature of things, was also a troubleman. He sought what others might miss and then to transform his observations into shrewd aphorisms about things that needed tending.

> *For many years I was self-appointed inspector of snow storms and rain storms, and did my duty faithfully (ref 9.6).*

As for my own self-appointed job as inspector of storms on the grid, and all other matters relating to electricity, both technical and cultural, I am faithfully examining the hardware and procedures used on this forlorn part of the system seldom seen by the customer. To do this I have come with a line crew. Our three-vehicle convoy lumbers down Interstate 84, then along a narrow blacktop secondary road, and finally out onto a gravel route winding through quiet rangeland.

Jim Terrell is the foreman. He is swarthy from long afternoons like this one spent under the solar ultraviolet. Today's job is routine, he says, nothing compared to some of the emergency tasks his crew is asked to perform. Generally held in reserve for first-responder duty in the toughest cases (like the Marines: first in and last out), Terrell's team does non-emergency work as the schedule permits.

The Troubleman (sometimes called the troublemaker) has questioned the efficacy of several segments along a stretch of desert power line. The utility trucks have reconnoitered at the appointed spot and pulled off the shoulder. Blueprints spread out on the dashboard. Even from the road it's easy to make out the specific crossarm in need of help. You can see the warping---it looks like the curved yoke used for driving oxen, not the straight-across wooden support it's supposed to be. Wouldn't last two years, much less ten.

Terrell, with 34 years on the job, is a jack of many trades, including the maintenance of good public relations. He could claim the company's right-of-way ability to cut the fence that protects the property, then just charge up the hill like Teddy Roosevelt and manhandle the pole. But diplomacy is always good policy and, walking up past a battery of barking dogs and suspicious looks from inside the house, Terrell politely asks the homeowner if she would mind, please, if the power company proceeded with its necessary repairs. Permission is granted.

Actually, the crew has been this way before, just a short way down the same road. While they were at their work on that occasion some other men had driven up not more then a hundred yards away and---again with the permission of the property owner---had set up for bit of target practice. So here they were, the guys doing their job handling high voltage equipment, and gunfire going off nearby. This led to an exchange of words. The four linemen on the job weren't against shooting. In fact they all hunt elk. This is the West. On the weekend, they go off the grid and up into the mountains. Like Mark, three of the four even use bow and arrow to make the pursuit of game more sporting. But on this day the sound of bullets flying was disconcerting to the fingertip-control needed for attending to 7200 volts, and so the target shooters where politely asked if they wouldn't mind moving farther off, which they did.

No gunfire today, and things proceed speedily. The men carefully pull down a few fence posts, snip some barbed wire, and then drive off the road and move jarringly up an uncomfortable incline. These aren't compact off-road vehicles. The flagship, a rig about the size of one of those towtrucks used to rescue buses in distress, is called a bucket truck since its main accouterments is a crane that lifts two men, each in his own steerable pod. Presently it will serve as their elevated workshop for the next three hours.

The bucket truck is parked at an odd angle with respect to the hill but then deploys retractable struts that brace the vehicle billy-goat style, hoisting it off its own back legs. Once the vehicles are settled, the men deploy. The designated twosome climb into the movable gantry with their specialized gear and start moving upwards, maneuvering the buckets in three independent directions upwards to within inches of their quarry. Now, truly, they are at eye level with the grid, whose lines stretch out laterally for miles behind and for miles ahead. Big cities might bury many of their conductors, but most of the world grid is up *here*, 30 feet in the air---a couple of tons of metal wire per mile---by the weight-lifting exertions of utility poles and their affiliated limbs.

The job is straightforward: affix a new arm, transfer the power lines over, and then remove the defective arm. The men riding the buckets, in their protective gear, look like astronauts but this is not a space mission. They're at an altitude of only thirty feet, not a hundred miles. Their forward velocity is zero, not 17,000 mph, and they do not confront the hazard of interplanetary vacuum. On the other hand, the linemen do have to worry about something the astronauts do not: the hair-raising presence of 7200 volts.

Today's work is being done hot. That is, the voltage has not been turned off. There will be no inconvenient interruption of service and current will continue to flow along the un-insulated cables during the procedure. Sometimes the linemen use a "hot stick," a hockey-stick-sized insulated pole with a controllable hook at one end, for close-order gaffing and manipulation. You'd think that this would be like doing precision jewelry settings with a pair of chopsticks, but actually a practitioner can get very good with it, and accomplish many intricate repairs.

This time they're not using sticks, but gloves, an approach Idaho Power has helped to pioneer. With rubber gloves rated up to 40,000 volts, rubber arm protectors up to the shoulder, rubber blankets draped over the surrounding surfaces, the line can be touched. Now, this touching of a fully energized high-voltage line does not come naturally. A cavalry steed will not gladly jump a hedge or charge an opposing foot soldier. It's against his instinct to run into things. Going against instinct can, however, be attained with sufficient training. The horse can do it and so can the man. The man does not gladly grab a hot line, but he can be trained to overcome the dread of volts taught in childhood.

The company has a special school for lineman. At this electrical West Point the rookies shimmy up tall poles and are confronted with some of the grid's sternest lessons. Training, the passing on of technical knowledge with life-or-death implications, is a crucial part of the present activity. Therefore, to further the training process on today’s outing, seniority will be turned on its head. Thus, the man with the least experience, an apprentice lineman with only 6 years on the job, has the bigger share of work. In the other bucket only two feet away, and performing the second most important tasks, is the man with the second least amount of experience, a mere dozen years. Next up in seniority and next down in order of importance to the immediate proceedings---indeed he does the ground-level grunt-work supporting the men above---is Rick Haught, a lineman with a round quarter-century of work behind him. He is always looking up, checking, fastidiously assuring himself that the safety procedures are being honored.

Finally, there is Jim Terrell, who orbits the scene at an even greater radius and perspective. He broods over the whole production, circling around the pole and truck like a border collie, saying little but recording everything. He insists that the apprentice be foremost in the work. He wants the youngster above to think through the issues, especially the 7200 volts, and to do the whole job. How else do you learn? Idaho Power linemen, Jim insists with his cool Marlboro-Man assurance, are much in demand at other utilities all over the West.

On the work site the mood is serious but not solemn, the talk spare but not nervous. "You have to have your head cut in," says Jim. You can't afford to let your concentration wander. The 7200- volt current is always there waiting for its chance to jump to a new surface. Hundreds and thousands of repairs at 7200 volts have been carried out with no ill effect. But then there is the case of Scott Pinkston, and perhaps the men are thinking of him today as they try to finish up their chores.

The dangerous Pinkston mishap would remind them, if anyone needed reminding, of the power in their hands. In their elevated position high by the crossbar beneath the noonday sun, the linemen are the very priests of the gods of electricity. Wearing the appointed vestments and gingerly arranging the special implements around their electrical altar, they are the individuals most reverently close to the thunderbolt. This electromagnetic bottled lightning streaking about in wires near light speed is a force of nature. And yet it is also obviously unnatural since it is patently manufactured by humans for their convenience and pleasure. The advantage of domesticating lightning is so high that society pays these four crewmen extra hazard compensation for voluntarily grappling with the ragged, lethal edges of the grid’s intrinsic ferociousness.

The men still up in the buckets at the 7200 volt level know that Scott Pinkston was released just a few days ago from the hospital. What happened to their fellow lineman is by now well known, at least within the company. The incident took place not up a pole but down in the dirt. He reached out for a line at 120 volts with gloves rated up to 600 volts. Still, he should have tested the wire with his meter. Always measure the status an of unknown line. Kneeling down close to his work, what he found in this grasp was not a wire at 120 volts---the wire on the home side of a transformer---but the industrial-strength side. His wire was at 7200 volts.

This was full, undiluted bottled lightning, more than enough energy to send you from here to eternity. The bolt, ever eager to find a shortcut, instantly went up the arm, through the body, and out the two points closest to earth, the knee of one leg and the foot of the other. The man was flaming so much that his nearby workmate emptied a whole fire extinguisher putting him out. A burn like this is beyond burn. It is a roasting from within. It's an intensive laying on of external energy to an internal place it should not be. The ordeal was horrific, he was in a coma for three weeks, he should have died, but he came through. The treatment was not pretty, his heart is forever weakened, but he's alive.

Nothing remotely resembling this happens on today's outing. Like surgeons sewing up a patient after a successful transplant, the grid, at least this small part of it, has been restored to health. The men retract the tools and shrouds, make their final check of wires, bushings, and bolts. Gantry down, paraphernalia stowed, refuse picked up out of the dust, and the job is done. As if seeing a movie of their work shown in reverse, we see the trucks back down off the hill, fence posts go back up, and barbed wire is reattached. Everything is neat and professional. No loose ends are left behind. You'd hardly know that 73 years' worth of experienced know-how had been allocated here for several hours sprucing up the grid.

The greatest investment by the company is not in buildings or equipment, but in people. Those 73 years of collective experience clearly outrank all other grid figures of merit. The wires carrying the electricity will last 15 to 20 years, which is longer than the expected lifetime of an elk in the state of Idaho. The crossarm just installed with the new bracing system and more long-lasting resin bushings should go 30 to 40 years. The pole, even with its tarred base sunk in the dirt where moisture can get at it, will last you some 50 to 60 years. This is impressive, but it can’t match the longevity of a lineman---80 years or more---who's been careful at his work.

A Tight Fit

The grid in Idaho lies mainly in the plain. That's where the people are and where the water is. The Snake River, starting east in the Teton Mountains in Wyoming, flows in a graceful arc across the dry, flat southern portion of the state before turning toward the mountains in the north and on into Oregon to the west. A large river provides lots of things: water for irrigation, a picnic destination, transportation, fish, means of communications and, since the coming of turbine generators, a source of electrical power. Most electrical energy comes ultimately from the sun. Sunlight from hundreds of millions of years ago, invested in coal, reemerges in a steam engine. Sunlight from six months ago was invested in evaporating water from off the vast plain of the Pacific Ocean, water which wafted inland, collided with mountains, and tumbled down the gravity gradient back toward the sea. Some of the energy reappears as electricity when the water passes through dams.

The utility in Idaho came into existence to facilitate this conversion. In the beginning there was Swan Falls, the place where the company that became Idaho Power built its first serious hydroelectric plant more than a century ago. The dam sits within a steep canyon in a beautifully forlorn remote location far south of Boise. The only road leading in passes through the heart of the Snake River Birds of Prey Natural Area. When I arrive in the warming part of the afternoon, the men running the installation are outside on the dam itself and doing the daily dredge. Before Swan Falls can harvest electricity from the passing water it must first harvest grass and other debris snagged on the filter guarding the intake ports. The stuff comes out in dripping bales and is taken away by truck. This must be one of the more homely tasks of maintaining the grid, and you wouldn't say that the operation was grand on the level of the Egyptian Pyramids. In counter-argument you could fairly say that the Pyramids, spectacular as they are, never generated any electricity.

The original turbines at Swan, constructed not long after those at Niagara, have been retired, and the old powerhouse, still sitting on top of the dam wall the way Tudor homes used to perch on Tower Bridge in London, is now a relic of the old days when gold prospecting was still a big reason for coming to Idaho. In fact the powerhouse has become a museum where schoolkids can see the big machines and photos of linemen now long dead. Actually, the museum itself has now become a relic since security concerns have recently caused the place to be closed to all but the occasional special visit. Unpadlocked for an hour, the main hall seems, like many other exhibits of obsolete heavy machinery, to be a shrine to past power. The old dynamo is still bright green and looks as if it could work again if asked. It gives out a faint smell of lubrication.

This being the end of summer, the annual reserve of Teton snow is now much depleted and so the melt-fed river flux is impoverished. Without enough gainful employment, one turbine takes a rest and its mate shoulders all the work. When winter snow is down, the river is down, and consequently power is down. The plant pretty much runs itself. The few personnel on duty get regular computer diagnostics on what is happening. The dam speaks to them. Hundreds of indicators provide water facts, such as river level and wind speed (wind can push water up against the dam), and electrical facts, such as the amount of power being produced at Swan right now. Besides the trim banks of dials, switches, and lights, what strikes a visitor in the byways of the building is the color-coded piping. Pipes run everywhere, hinting at the kind of movements quickening all around: orange pipes for oil (at a dam you need hydraulic pumps for opening and closing things), green for compressed air (for actuating more pumps and switches), blue for cooling water (anything carrying power gets warm), and red for fire water (that is, water for extinguishing fire).

The business end of this energy factory is the turbine, the contraption through which the entire Snake River squeezes onwards by passing down a tunnel and being forced to dash itself into a huge pinwheel, which in turn bequeaths its rotation to the generator apparatus for cranking out electricity. The process is pure aerodynamics---all fins and flaps and streamlines. The angle between the turbine blades and the oncoming aqueous whoosh can be pitched to vary the torque, and in this way the desired power can be obtained. In effect the turbine is forever swimming against the whole of the river without ever getting anywhere.

It's all in a good cause, this swimathon. With the watery husk of the river spiraling out downstream of the dam, the sweetmeat, the protein part of the Snake---water flow turned into shaft rotation turned into electrical current--- is sent up to the powerhouse roof where it energizes three thick cables in the form of 7000-volt electricity, quickly jacked way up to 138,000 volts in a grander version of the transformer on the pole next to your home. Given its new suit of clothes for long distance traveling, the Swan Falls electricity runs through its wires, up the steep canyon wall, makes a straight-arrow sprint to join the general grid, and might, after nary a second's delay, make an appearance in Mark's blender.

And would the customer know, as the blender blades spun, that the enabling energy had only a millisecond before been an organic part of the Snake River, forty miles away? Not likely. All over the map tiny pieces of the river were being peeled off and teleported to distant appliances without any fuss being made at the audacity of it all. Our awareness of the process, if there had been any, would be dulled into oblivion by familiarity.

> *The longer the lever, the less perceptible the motion. It is the slowest pulsation which is the most vital (ref 9.7)*

Hyroplants like Swan Falls consume no costly fuel, spew no carbon compounds that defrost the Arctic icepack, and form no acidic sulphur compounds that slay trees 500 miles downwind. To meet new energy needs and keep all the blenders whirring, why not just build more Swans? The short answer: damnation. Or not enough of it. Or maybe too much of it already. In North America and Europe and other built-up places, most of the suitable hydro locations are already taken. Furthermore, some of existing dams have proven to be mistakes. They collapsed or silted up too quickly or sacrificed too much topsoil. Some will have to be dismantled (e.g., in the Florida Everglades) or altered since they have messed disastrously with the food chain, that universal and complicated woven linkage among living organisms in which homo sapiens are but one part. A dam is not taken down for sentimental reasons. Even when authorities aren't particularly concerned with the extirpation of some exotic species of minnow, they do have to pay attention when the sport fish that fed on some other species that fed on the minnow becomes endangered.

Like the inhabitants of the Tennessee River Valley, the citizens of the Snake River Valley also had become greater in number, more avid in their enthusiasm for powered machinery, and more assiduous in their pursuit of hearty agribusiness, and so new forms of power generation were needed when the river became fully subscribed. With more mouths to feed and more blenders to spin both of these river-region grids founded on hydro power, the TVA and Idaho Power, were forced to turn to fossil fuel.

Squeeze and Bang

To see how the combustion-side of the company functions, we go from Idaho Power's oldest installation, the hydro plant at Swan Falls, to their newest installation, the Danskin gas turbine unit sitting near the town of Mountain Home. Here the fuel is natural gas---basically methane---

and is delivered to within a few hundred meters of the fence by a pipe network that stretches all the way to Texas. This gas grid is practically invisible. Unlike the electrical grid which lopes along for miles out in plain view, the methane pipes often lie beneath the landscape. For security reasons, gas merchants like their anonymity.

What you do with the gas is to shoot it into a chamber where it meets with a blast of air compressed in a two-story structure which, though it lacks a Mercedes hood ornament, looks like the huge front grille of an automobile. This is appropriate since the whole operation gives you a sense of automotives or jet aviation. The fuel and air meet and produce, as they do in a jet engine, a potent combustive blast that spins a turbine connected to a generator. They don't bother making steam; the exploding gas itself makes the turbine go. Once the gas has done its job it zooms out a chute and up a stack.

Gary Felton, the operator on duty, reports that the familiar names for these crucial sequential steps are *suck, squeeze, bang, and blow*. What you've got, Gary says, is a jet engine that goes with an oomph of 60,000 hp. Instead of applying this turbo-energy to sustaining trans-Atlantic flight, you produce a pounding load of high-voltage electricity. This up-to-date dynamo was built by Siemens-Westinghouse, a composite name which sums up the strange-bedfellow reconfiguration of the power industry. The Danskin facility will never rival the historical importance of Jumbo Number 9, or Red October, or Faraday’s coils. Instead, its great virtue is its very anonymity. The turbines are anything but custom built; they were made and assembled quickly.

The two 45-megawatt units throw their output onto the grid for only a portion of the day. That's because Danskin is designated as a relief pitcher to be kept in reserve for late innings. Its energy is not considered as part of the company's base load, the power supplied all day, but rather as peak load, power added at times of greater consumption. Gas turbines, although prized for their flexibility (they can be started more quickly than coal-fired steam turbines) and for their lower greenhouse emissions, are generally pricier to operate than their coal cousins, and so they are used more sparingly. Indeed, this week gas prices bumped upwards again.

Here at 3 PM only one of Danskin's two units is busy. It's only because unit one is off that we can have a look inside. Normally it's too hot and noisy to be in the generator room. Gary encourages us to reach under the covering and touch the drive shaft, the rotor usually spinning at 3600 rpm by the force of the gas combustion hitting the turbine only a few feet away. Although it’s not producing power, the shaft is kept slowly rotating so as not to deform as it cools down.

So, here I am, not exactly holding a high-voltage line in my hand, but I am holding, ever so gently, the revolving central part (mechanized, but fortunately not electrified) in the machine that makes the high voltage. At the one end of the shaft is the turbine, which feels the heat of the gas. At the other end of the shaft is the rotor-mounted coil, which feels the load of all those blenders. Thus, a ribbon of force connects puffs of gas coming out of the ground in Texas with fruit being pulped in Idaho.

The day is hot but not particularly hot, and the air conditioners of the valley are not screaming for further sustenance. Danskin is helping to handle the expected rise in demand in the hours running up to end-of-workday bustle and the stirrings of dinnertime preparations. Things were very different some months ago on a particular very hot day when certain events, which I shall narrate shortly, caused the river---the river of electricity, that is---to slow down. On that day both Danskin turbines were laboring overtime. The accelerator pedal was to the floor.

Do our social engines run at full throttle too often, thus compromising some of the simple pleasures in life? Thoreau thought so. He believed we lived too quickly.

> *Men think that it is essential that the nation have commerce, and export ice, and talk through a telegraph, and ride thirty miles an hour (ref 9.8)*
>
> *We are in a great haste to construct a magnetic telegraph from Maine to Texas; but Maine and Texas, it may be, have nothing important to communicate (ref 4.9).*

Indeed, in the century and a half since Thoreau's time, we have labor saving devices and conveniences far beyond the scope of telegraphy. Most of these machines tend to make us live life even faster than before.

One thing that hasn't changed in Idaho is the desire to hunt, a pursuit that largely proceeds at a very slow pace. Gary and Mark have sought elk together in the mountains above the valley far from the grid. Next week, by special arrangement, Gary's quarry will be buffalo. Mark suppresses his disappointment at not being asked along.

Chopping Volts

Years before, in July 2, 1996, Marsha Leese was on the hot seat, hot not because the day was in the upper 90s, but because she was at the helm of Idaho Power's grid and something awful was happening. She occupied the kind of seat held by Edwin Nellis in the Consolidated Edison control center in November 1965, when the entire Con Ed system and much of the Northeast power grid sank to the bottom. Tape recordings of that Titanic moment from 30 years in the past, the pathetic sounds of a person in authority not knowing what to do, have been played out to a generation of apprentice grid dispatchers as a lesson in how *not* to behave under stress.

Marsha had heard the tapes of that moment and now *her* moment had arrived. She knew what Edwin Nellis had felt. On July 2 it was *her* grid going down and there was nothing she could do about it. Not only that, but parts of the grid in neighboring states were going down too. Not only that but the root cause of the whole thing, the sand grain that set the avalanche into motion, proved to be a short circuit in a transmission line taking power out of the Bridger coal-fired generator, the Wyoming plant partly owned by Idaho Power.

Here's how it happened: blazing temperatures, air conditioners running overboard around the clock, immense currents flowing through malleable wires which sag when they're warmed, and an untrimmed tree branch offering itself as a shortcut for the bottled lightning. The result: a hot flashover, circuit breakers flipping out, lines taken out of service, more overload, more breakers, and a cascade of outage. When it stopped, more than two million were missing power in 11 western states in places as far apart as Denver, Los Angeles, Reno, and Boise (ref 9.10).

An event like that stays in the memory of a grid dispatcher. And if memory is not enough, a photograph of the misbehaving transmission line out in the desert is mounted on the wall not many feet away from the chief control console for the system as a reminder to anyone who sits in *that* chair and takes the fortune of the electrical network into her hands. In 1996 Marsha Leese was the controller. Now she is chief power dispatcher for Idaho Power. By the way, to be a woman in high places within the company is no longer such a rarity. Marsha's boss is a woman.

Marsha is at the fulcrum. On the one side are generators subsisting on fuel in gaseous, liquid, and solid forms---methane, hydro, coal---and on the other side of the supply/demand equation are the teeming mass of customers. She tells the generators how much to make and when. Selling electricity has gotten more complicated over the past ten years owing to the restructured way of doing business. The dispatch of power is now handled by two different departments within the company. The federal government likes to make a distinction between *transmission*, defined as the sending of power over long distances (especially the wholesale transfer to other energy companies), and *distribution*, defined as the sale of retail power within the company's own service area. They should be as separate as possible, the better to encourage and maintain a climate of competition. And this, the government and customers fervently hope, will lead to low rates. Therefore, the sale of power outside the state is processed by another office on another floor. That department undertakes all "merchant" matters such as handling money and making contracts with other utilities eight hundred miles away. They don't worry about the moment-by-moment manufacture of electricity.

Marsha does that. She is the managing editor of the grid, with the solemn duty of perpetually keeping the lights on. She administers all the various voltage realms. At the top end is the level of hundreds of thousands of volts. In this major league, the players are the generators themselves and the largest of transmission lines, the ones stretching hundreds of miles and leading out of state or leading to Idaho Power's main switchyard. The next level down is 69,000 volts, where all the lines go from the main switchyard to the substations in the many towns and large suburban jurisdictions that make up the company's customer base. Each substation has a minor switchyard of its own, where the voltage is lowered and the power divided. At this point we go from the town level to the neighborhood level. Coming out of the substation is power at 7200 volts running along lines that typically travel a few miles or less. The final editing consists of stepping down the voltage to domesticated 120 volts. Much of this volt chopping is left to automatic adjustment mechanisms.

Here, in lightning form, is a recapitulation of how electricity gets to its goal. This is how Mark gets his power; where you live the sequence would be essentially the same. It starts with GENERATION: primary energy, in the form of moving water or burning coal or exploding gas, twirls a turbine which induces currents to flow in thick wires. Starting out at around 10-kilovolts, the power is transformed up to the 100- or 200-kilovolt level. It now enters the big-league TRANSMISSION part of the grid: power is either sent to Boise to be distributed to Idaho Power in-state customers or shipped to wholesale buyers out of state. We’ll stick with the in-state power, which goes to the flagship substation, where power from various generators around the system is merged, transformed back down to 69 kilovolts, and then divided up and sent to the lesser substations. The DISTRIBUTION part, the last-mile phase of the utility business. In Mark’s case, electricity arrives at the Cloverdale Substation, a few miles from his home, where it gets transformed again, to 7 kilovolts (7200 volts, to be exact), and divided again, into further “feeder” circuits. These are the lines that actually come into neighborhoods. The 7200-volt power shoots down a side street; where it comes abreast of Mark’s home, a small portion is shunted into the final transformer---the kind described earlier, doing sentinel duty near your home---where the voltage gets lowered for the final time, to 120 volts. Coming out of the transformer, current runs down a wire into the ground, snakes about 100 feet underground, and pops into the circuit-breaker panel (in Mark’s garage), a sort of sub-sub-sub-station. The current here is taken up as needed by the various rooms. There, like pressurized water waiting at the taps of all the sinks to spring forth, electricity---in the form of a voltage difference across the slots of each wall socket---is ready to energize your appliance.

Most of this vast activity and transformation and potentiality remains unseen. Do you worry about what Marsha Leese worries about? Federal jurisdiction, substation voltage levels, wholesale markets. Are we, the ordinary customers, aware of any of this? The grid is either too close---an electrical socket at the level of your shin---or too far away---out there at the horizon where you can barely make out the high voltage towers---to come into focus. Can you see it? Probably not. We've got other things to worry about. Besides, the utility is happy if you're happy with the electricity you get. The government regulators are content if the grid is up and running and rates are reasonably low. Retailers of appliances are content if you have or want the latest model, and maybe a service contract along with it just in case it should break down.

You only notice when an unforeseen event snatches or threatens to snatch it all away. Then you'd prefer to have someone like Marsha Leese, and not Henry David Thoreau, to be in charge of grid dispatch. A proper dispatcher worries not about eternity or daffodils but about having enough power at the right moment and having reserves you can count on in an emergency. During an energy crisis, knowing what to do in the next five seconds is how a good dispatcher earns her salary. When there is plenty of energy in the network the distribution of power is routine. When, however, production runs low and transmission options are few, then the dispatcher's seat becomes very hot.

So it was a few months ago when, on a 97-degree day and air conditioners everywhere were all set on “Hi Kool,” the gods of electricity decided to make things difficult by disrupting the flow along two separate lines on the same day. The lines brought power from Idaho Power's dams in Hells' Canyon, one of the deepest canyons in America. As the name of the place suggests, the terrain is rugged and the power lines are more likely to be visited by mountain goats than humans in any given week.

There began now a race against the clock. Out-of-state power was being rerouted in, but would it be enough to make up for the loss? After the Hell's Canyon line went down, the company issued a request to customers to reduce their demand. But with the missing transmission lines, the climbing mercury, and the oncoming rush hour things were moving to a head. As the minutes went by the options narrowed, and it grew apparent that the utility was coming up short in its effort to fill all the circuits with energy. Load shedding, the process of deliberately turning off part of the system in order to save the rest, now presented itself as a distressful possibility.

The power dispatcher's instinct tells her to keep the power flowing and not to snatch it away. Her sacred duty always is to keep the lights on. But on sober reflection the dispatcher remembers an even higher duty, which is to keep the *system* on. Consequently, at around 5:30 PM that day off went the lights for about 35,000 customers in several counties. About 170 megawatts of load was disconnected (ref 9.11). For three hours no blenders spun in numerous homes and irrigation in many fields ran dry. On the positive side, the rest of the grid went on performing.

As if to underscore the difficulty---technological, economical, and moral---of overcoming the dispatcher's creed of keeping the lights on, Marsha points to another picture hanging on the wall near the control console. This framed declaration specifies that no dispatcher will be reprimanded for shedding load, providing that all other avenues of matching available power with the instantaneous demand had been tried.

The company does not make public the procedure it uses in sequentially shedding load of varying sizes when push comes to shove.

Forecasting the Grid

Still somewhat shy of a half million customers, the company's population base lies mostly along or near the Boise and Snake Rivers. Energy supply for this realm is administered from the upper floors of the utility's headquarters in Boise. If many of the other departments of the grid---repair, generation, dispatch---are scarcely visible to the customer, corporate management is even more opaque to an outsider. The officers of Idaho Power, like leaders at any utility, must worry about energizing circuits right now and for years to come. They have the Janus-faced task of looking both in the direction of short-term profits, much beloved by the investor-owners of all companies, and in the direction of stable, long-term growth. Immediate gratification and prudent planning are like two oxen yoked together, the result being that the cart sometimes lurches to the left, sometimes to the right, but seldom straight. James Miller, Vice President for power supply, is one of those who has to drive the team as best he can. He doesn't expect a smooth ride.

The annual report is sobering but encouraging. Profits are down just a bit from some previous years but this, the officers make clear, is because of the lingering effects of California energy crisis, which is itself part of the even larger, ongoing, at times tumultuous, evolution of the energy marketplace---how electricity is made, shipped, and sold. Overall, the company is in good shape. The rates Idaho Power charges its customers are among the lowest in the nation and the company was recently awarded a high place on a list of the best managed utilities. As part of the slimming down process, several subsidiary businesses, those not related to the company's core mission of delivering power, are being sold off (ref 9.12).

A more interesting document for looking at the way the company operates, and indeed for epitomizing the dilemmas faced by the whole energy industry, is the Integrated Resource Plan, the utility's grocery list, or wish list, for the next ten years. Projects to be undertaken, facilities to be built, contracts and licenses to be renewed, risks to be run, expected regulations to be imposed, unavoidable hazards to be faced---they're all here. It is here that they visualize future volts. And right off, underlying assumptions have to be made. Like generals overseeing the national defense, the Idaho grid specialists must prudently allow for the most inconvenient combination of conditions: low flow in the Snake River (less water means less hydro-generated power); higher than usual loads (temperature extremes lead to more cooling and heating); continuing volatility in the fuel markets (assume security instability abroad and political wrangling at home); and a steady influx of new customers moving into the service region at a rate of 10,000 per annum.

Having looked at the big issues likely to shape Idaho electricity over the coming ten years, the plan then tries to develop a business plan for dealing with future needs. It formulates a dozen rival packages, or "portfolios," of recommendations for action. At the end of the report a winner among the portfolios is declared and that then becomes the ten-year blueprint.

Skimpy riverflow, high summer temperatures, more people, fluctuating fuel prices; what are some of the other issues pressing in on the utility? One of the most urgent problems is crowdedness in long-distance, inter-state power transmission. Everyone recognizes that there isn't enough superhighway to send all the power that needs sending, at least not enough if you want to have some standby emergency carrying ability---the equivalent of having a wide shoulder and extra lanes for rush hour traffic. And here the company is in a bind.

Idaho Power is a sovereign business and yet it is subject to the rulings or guidelines of numerous governing bodies. On one side, the Federal Energy Regulatory Commission (FERC) would like the company to divest itself of its transmission lines---sell them off---in order to increase competition among rival energy companies. On the other side, the Idaho Public Utility Commission (IPUC), which regulates Idaho Power's activity, views things differently. They're not against encouraging competition. But they do want to insure that state residents get their electricity without fuss. Therefore they wouldn't mind if the company kept its transmission lines. And that is what the company intends to do. Some utilities that went from vertical (owning generation, transmission, and distribution facilities) to horizontal (retaining just the distribution part) regret it now.

Nobody wants another California crash landing. However, even if Idaho Power continues to own its transmission lines, operational control of those lines might partly or wholly be turned over to a regional transmission organization (RTO), the kind of multi-state grid dispatcher whose decisions---and ability to turn off some lines or divert power from one place to another---would overrule the dispatcher in Boise (ref 9.13).

Another issue: everyone wants power but no one wants a transmission line built in her backyard. Most would prefer the power lines to be buried in the earth out of sight. But that costs more money and no one wants rates raised to pay for it. Concrete example: one Idaho town was happy that the utility had extended a large transmission line to its vicinity. Having enough power helps the city to market itself to potential businesses and homebuyers. The line was built. The utility now wanted to extend the line to the next town west, but the first town said no. We won't allow you to build an ugly line through the center of our town. Okay, the company said, we can go around your city center or we can go underground, but that will cost extra. The town's answer: no, you can't go through our town and no, we won't pay extra for underground installation (ref 9.14).

An issue that is guaranteed to get more attention: our common habitat of earth, sky, animal, and plant, otherwise known at "the environment." The combustion products associated with burning fossil fuel---mostly tri-atomic molecules such as carbon dioxide (CO2), sulphur oxides (SOx), and nitrous oxides (Nox)---produce things that are bad for our lungs (pollution), for trees (acid rain), or for climate in general (greenhouse warming). The idea that these emissions are a burden on society and should be taxed is now being assimilated into energy planning not just by environmentalists and public health officials but also by legislators and by the energy companies themselves. Idaho Power now expects to take into account the "social costs" of gaseous emissions. This doesn't mean the utilities will forego hydrocarbon-burning plants, but it does mean that the emission-producing side effects of electricity will be taxed. Just as you pay to put your garbage into a truck that comes by once a week, so utilities would have to pay to have their “garbage,” their generator emissions, put into the sky. Accordingly, starting in the year 2008, the company might be charged as much as $10 or $20 for every ton of CO2 it sends up the flue (ref 9.15).

How will Idaho Power keep the light on ten years from now? That's what the Resource Plan tries to settle. The contestant portfolios include twelve different recipes for reaching the future. Let the competition begin. One plan suggests that all electricity would come from the old fashioned but reliable way, by burning fossil fuels. Coal prices are pretty stable, but, oh, all those emissions.

Another portfolio calls for 1000 megawatts in wind-generated electricity (ref 9.16). This proposal is quite green---no emissions, so no extra carbon taxes---but how reliable is the wind? Is it blowing when you want it? The company's working assumption is that for 100 megawatts of wind harvesting machinery, what you actually get on average would be about one-third of that.

Each portfolio has its own way of grappling with contingency. Will a carbon tax be imposed? Will the state regulators grant a nice rate hike? Will the federal government renew the licenses for operating all those hydro plants? Will some exciting new scientific discovery lead to a new energy source we can't dream of now? There are no answers.

Do we live in an age of unprecedented social unease or technological change? Almost surely not. All ages are beset with their own problems. In Thoreau's day railroads multiplied tenfold the distance a person could travel in a day. The telegraph multiplied by ten thousand the distance a human voice could carry. Here is Thoreau again, as if he were contributing to Idaho Power's Integrated Resource Plan, except that he's speaking from an 1840's perspective:

> *...facts are being so rapidly added to the sum of human experience, that it appears as if the theorizer would always be in arrears, and were doomed to forever arrive at imperfect conclusions (ref 9.17).*

The conclusions will be imperfect because knowledge of future events is imperfect. The

Heisenberg Uncertainty Principle has not yet been extended to business administration, but it should be. There is, for example, the uncertainty about resource timing. A new plant might well be needed but what if it's ready a year too soon---then it underperforms and has, in the meantime, tied up capital that might have done more good elsewhere. Or, worse, what if it arrives a year too late. Then the company scrambles to make up the shortfall by purchasing expensive power from out of state. Cost overruns can throw everything off. What about borrowing interest rates? Will they be 7%, or 5%, or more like 9%?

The word risk appears in the Plan repeatedly. By the end, at the point where the winning portfolio of options is declared, no reader would be under the impression that the ten-year prognostication is a sure thing. Each of the rival plans has certain points which make it robust or vulnerable relative to each of many engineering, environmental, business, and regulatory risks. The only certainty, in addition to death and taxes, is that the future will come. A plan has to be chosen. Electricity has to be delivered around the clock, now and forever.

And the winner is Portfolio No. 11, a plan for all seasons. The highlights of this plan include adding a 500 megawatt coal fired plant in the year 2011; upgrading transmission lines; and 100 megawatts of wind-power capacity added in the years 2006, 2007, and 2010, for a total of more than 300 megawatts. The forecast anticipates that a carbon tax of $12 per ton *will* be imposed. Moreover, the company will strive to encourage customers, through rate incentives, to shift more power consumption to off-peak hours. They’ll want to expand the “demand-side management” schemes whereby customers, such as large-scale irrigators, voluntarily trim back their use of power at peak times. This is not hard medicine: these customers would be rewarded for their cooperation in the form of lower rates.

Here is what the energy future looks like in Idaho. In ten years the company expects to get 38% of its power from hydro, 48% from thermal sources (coal and gas), 9% from non-hydro renewable sources, and 4% from purchases outside the system (ref 9.18). There is plenty of history imbedded in these mundane numbers. For one thing, the 9% will seem small to those who hoped for a more speedy embrace of green electricity. To those who have struggled with keeping the lights on with available technology, a 9% fraction looms large, particularly compared to previous years. The small 4% purchase from outside (down from the current 20% level) reflects the ready desire to insulate the state from the violent price fluctuations that occurred during the 2000/2001 western electricity crisis. Some outside power will always be necessary---a hot day in July combined with a small stream flow practically guarantees the need for bringing in some outside hydro-power from Washington State or elsewhere. But the company means to hold this import to a minimum..

Perhaps the most the most poignant number is the fraction of power coming from the hydro source. The 38% seems modest for a company that was built around energy taken out of the river. As recently as five years ago, the number was 50%. This percentage is bound to decline further because no new dams are being built, nature isn't making any more water, and the number of thirsty customers is constantly rising. There are also ominous signs that the riverflow itself is falling, falling not just in the way that the river level rises and falls with the season and swings back and forth in multi-year cycles, but in an absolute sense. The aquifer that hides beneath the northwest states, and actually most of the larger west too, is losing water to irrigation, and the natural forms of replenishment of ground water are not keeping up. In Idaho many years of well withdrawals has driven the water table lower, and this in turn subtracts water that would have found its way into the Snake and thence into the turbines of Idaho Power. What state, farming, and business leaders are going to do about this looming problem is unclear (ref 9.19).

Jim Miller must prepare not only a 10-year plan, but even a 75-year plan. Visualizing the grid, or society itself, that far into the future makes even the most pragmatic engineer into a philosopher. After all, the utility official, in his corporate office at the top of the building, has the final authority and responsibility for delivering energy, now and into the future. Except for an the odd unheated hut in the mountains, every human domicile within two hundred miles of the headquarters building gets electricity or not depending on what he does.

Thoreau often reflects upon individual effort and its consequences:

> *It is something to be able to pain a particular picture, or to carve a statue, and so to make a few objects beautiful; but it is far more glorious to carve and paint the very atmosphere and medium through which we look, which morally we can do. To affect the quality of the day, that is the highest of arts (ref 9.20).*

Is the delivery of power a moral action? It probably can be, if done the right way.

Jim Miller is proud of his company's traditional connection to the river running through his state. On the wall he has two photographs. One shows Shoshone Falls on the Snake River. Besides being a wondrous spectacle of nature, Shoshone is also the site of an Idaho Power hydroelectric plant. Mr. Miller enjoys the outdoors and loves to take his children hunting. "It's practically a law in Idaho that you have to hunt," he jokes.

The other picture on the wall depicts a ceremony in which company representatives, leaders of the Nez Perce Indians, and government officials signed an agreement securing hunting and fishing rights for the Nez Perce who, after all, were on the scene long before 138-kilovolt electricity ever flowed (ref 9.21). And before even the Nez Perce arrived in Idaho, fish had been there in the river. The stressing of fish and the lowering of the water table might be an ecological and civic disaster in the making, but in terms of geological time it will be of small account. Nature and the river always will trump human technology.

Not surprisingly, Henry David Thoreau was keen on this subject. In our day the issue is hydroelectric power on the Snake River. In his day it was the textile mills on the Merrimack River at Lowell, Massachusetts, powered by dammed water and serviced by canals. These engineering marvels made Lowell an economic powerhouse and huge employer of factory workers. But this human intervention in the landscape had ended the free run of fish up the river. Nevertheless, what man had put asunder nature might one day restore. There is a season for everything, Thoreau felt, and the time of the fish might come again:

> *Perchance after a few thousands of years, if the fishes will be patient, and pass their summers elsewhere meanwhile, nature will have leveled the Billerica dam, and the Lowell factories, and the Grass-ground River [the Indian description for the Concord River] will run clear again, to be explored by new migratory shoals, even as far as the Hopkinton pond and the Westborough swamp (ref 9.22).*

September 22, 2005

Chapter Ten

Grid on the Moon

> *Erst kommt das Fressen, dann folgt die Moral.*
>
> *(First comes feeding, then morality----Berthold Brecht)*

The grid: who gets it? Where will it go next? Is it a luxury? Even as this history of the grid begins to wrap up, there are still plenty of questions to address. Is electricity an absolute necessity of life? Is it a human right? The answer to both these question is no. Great civilizations obviously got on without electricity before telegraph and telephone came along in the mid 19th century and the grid for light and power a few decades later.

No, electricity is not an absolute requisite for life, but it helps a lot. How so? Having more electricity correlates with higher literacy, longer life expectancy, better nutritional intake, and lower infant mortality. Furthermore, a peasant's lack of electricity didn't mean that he made more sparing use of energy. In fact, it was often the case that pre-industrial dwellings used more primary energy per capita than their 20th century counterparts. How can that be? A greater use of wood (a very poor, polluting form of fuel), inefficient open fires for cooking and heating, and inefficient types of transport are typical in centuries of yore. Even now, the amount of primary energy required to produce a unit of gross domestic product (GDP) is typically three time *more* in poor countries than in rich countries (ref 10.1). The difference between old and new is particularly stark for lighting. Electricity made a tenfold and then a hundredfold improvement in the amount of illumination per energy used over methods using flames.

This should settle the issue of whether electricity a luxury. It is not. Having it saves energy and improved lives. Not having it hurts.

Minimum Grid

You can have too much electricity, or at least make wasteful use of the electricity you have, but how about too little? What is the *least* amount of grid you need for a decent life, decent meaning being able to eat, sleep, and a bit of reading without great harm. The least you need is 1000 kilowatt-hours per year per person, says the Electric Power Research Institute (EPRI), a nonprofit organization founded by the US power industry and based in Palo Alto, California. In their comprehensive report, *Electricity Technology Roadmap*, EPRI argues that for basic lighting, communications, refrigeration, and doing local agriculture, you need that 1000 units of electricity---call it Minimum Electricity---to *begin* the journey out of poverty (ref 10.2). Having the 1000 units is a floor. Having this amount of electricity doesn't guarantee a good life; it's the amount you need to *get started* toward a good life. According to EPRI, roughly 4 out of the current 6 billion people alive get less than Minimum Electricity. More than a billion have no electricity at all. The *Roadmap* goal is that everyone on Earth would have Minimum Electricity by the year 2050.

Massoud Amin, one of the authors of the EPRI report, knows from experience growing up in Iran how electricity can, in just one generation, boost a village from Medieval times into the 20th century. He points to a set of four designations used in the *Roadmap* to quantify the role of energy in human life. If between food and fuel you consume only 2500 calories per day (calorie being not just a unit of food intake but of energy in general) then you're at the bare-survival level. You're probably a hunter/gatherer. A higher level of energy intake, 10,000 calories per day (total energy, food plus fuel), is typical of an early agrarian way of life; here you scent the first hints of quality-of-life things such as material comfort, modest food surpluses, and maybe elementary literacy.

The next step up in the chain of human habitation, corresponding to an energy consumption of 50,000 calories per day for food and fuel, transportation, and all other energy transactions, came about because of machines, and was prevalent only after the industrial age had begun (ref 10.3). Here the amenities really start to accrue: education (at least for boys), a secure food supply, some medical care, and so forth. The final level, what we can call modern society, uses still more energy, 100,000 calories per day per person. In electrical terms, modern consumption would be something like ten times Minimum Electricity. In places like America it's more than that.

The *Roadmap* goal of 1000 units of electricity would is just about the amount of energy the average person had in Chicago in the year 1925. In other words, the Minimum Electricity goal for everyone on Earth, by no means an easy thing to achieve even by the target date of 2050, would in effect bring the poor person no further along in technological terms than Chicago around the year 1925.

Thus far we have looked mainly at the one-third of humanity that consumes electricity at better than the minimum rate, so it is appropriate for a book about the grid to look also at the far-flung two-thirds of humanity that fall below the line. By far flung I don't mean in the sense of being geographically or culturally distant from the Europe/North-America/Pacific-Rim centers of economic might, but in the sense of being distant from the grid. Like a person excluded from a warm place on a cold day, if you are far from the advantages, then you can be said, figuratively, to have been left behind in the year 1925 or the Middle Ages or earlier. You have been held back while the rest of the class moved on.

In the early part of this grid narrative, when Thomas Edison switched on his connected warren of energy-filled wires beneath Manhattan's streets, one could say that this was the morning of the grid. But for a village in India getting its first electrical hookup only now, it is *still* the morning of the grid. For millions of others, those not scheduled for power installation over the foreseeable future, it isn't even morning yet but rather somewhere before the dawn.

Making Concrete in Uganda

Working in the heart of darkest Tennessee in the 1930s, David Lilienthal helped to make a poor and sparsely-electrified region blossom. The two organizational pillars of the Tennessee Valley Authority, as enunciated over and over again by Lilienthal, were (1) taking a unified approach to development of the river valley, including navigation, flood control, electricity generation, soil conservation, and the sensible use of fertilizer; and (2) the grass-roots involvement of local residents in making decisions. The balance of Lilienthal's career, after he left US government service in 1950 and right up to the late 1970s, was essentially devoted to trying to recreate the TVA experience and ideals in other countries. A self-appointed do-gooder, Lilienthal founded a company called Development & Resources (D&R) whose mission was to advise, and often to lead, in the economic/agricultural/hydroelectrical development of poor regions in places like Colombia, Brazil, Puerto Rico, and Iran.

Some of the projects succeeded, such as in Iran's Khuzestan region, but many others foundered or performed disappointingly. Why was that? And why has development foundered in so many other places as well? In Lilienthal's case, his efforts met up with some potent real-world forces: entrenched commercial and bureaucratic interests, mediocre local management, envy and resentment of Lilienthal's access to senior officials in the country's government, insufficient funding, and exaggerated expectations. But all these forces had been at work in the struggle to create and maintain the original TVA, the great model so admired around the world. Why hadn't it worked elsewhere? Perhaps Lilienthal's earlier success could be attributed to American institutions or to conditions unique to that period in American history or to a vigorous patron in the form of Franklin Roosevelt or to the later wartime need for TVA's plentiful electricity. An additional explanation of why TVA was not reproduced abroad (nor in the US itself), was that the world was getting ever more complicated: the Cold War, the end of colonialism, racial sensitivities, chronic poverty, high illiteracy, and epidemics have all been big factors.

Lilienthal thought that if he could arrive with the cavalry---in the form of his team of experts, loans from the World Bank, and the beneficence of the local leader---he would be able to overcome decades of stagnation and make the deserts bloom. Unfortunately, it didn't usually work that way. Tennessee got electricity but many other places did not. Many people did not get Minimum Electricity. Many poor places stayed poor.

One of the poorest of the poor places is the so called Great Lakes region in East Africa, the cluster of countries---Burundi, Kenya, Rwanda, Tanzania, and Uganda---surrounding Lake Victoria and Lake Tanganyika. In Uganda, the first notable grid development came in the 1950s with the advent of the Owens Falls Dam, a construction job so big that it took most of nation's existing electricity just to get the job done. Even when this dam was finished, there wasn't much of a grid. Most of the power went to a few big industrial users---the Kilembe copper smelter, the Nyanza textile factory, and the Sukulu fertilizer plant.

Compare 1950s' Uganda with 1880s' New York. Edison's accomplishment was to replace small kerosene electrical generators with a big unified central grid. That was also the aim for Owen Falls. New York in the 1880s was wealthy, while Uganda in the 1950s was poor. There were plenty of rich customers in New York who could afford the high rates, and there were millionaire financiers like J.P. Morgan who could put up the money for the vast infrastructure needed. In Uganda there was no Morgan and few wealthy customers.

Furthermore, in Uganda when one looked at electricity, race was a factor. European whites in the country had most of the energy. In Western electricity terms, Europeans in Uganda in

1950 might have lived in the equivalent of the 1920s. Asian residents had the next most electricity; for them it might have been the year 1895. Black Africans generally had less than Minimum Electricity.   You couldn't specify an equivalent year. They weren't even on the energy chart.

In a study of expected power patterns for the period 1955-1970, the Uganda Electricity Board began by saying that most European residents already were connected and that by 1970 the Asian residents would catch up with the Europeans. Making predictions for African residents was more difficult, the report suggested, because of their different situation. Here's the assessment as of 1950:

> *The actual benefit which the African may derive from a given commodity may be very much greater to him than to a European, because it represents such a very great advance on what was previously available, or because of the circumstances under which he lives. The bicycle, for example, has revolutionized in no small way the manner in which the African peasant lives. The tin roof, which gives protection; the radio, which widens his horizon; and the electric lamp, which transforms the interior of his hut---all of these things have made such a profound change to the African's life that the value which he puts upon them is relatively very much greater than with the European (ref 10.4).*

The African is different, the report intimates, because he is starting the game further behind. In other respects, though, he is just like other people: "The African's liking for consumer goods such as radios, electric lamps, irons, appears to be quite as strong as the Europeans's." The report went on to predict that the power from Owens Falls would be fully subscribed by 1965, by which time more dams would be needed. There is no coal in Uganda. The primary energy source in Uganda remains wood and animal waste. How are people in Uganda supposed to achieve Minimum Electricity? No one knows.

Massoud Amin believes the answer will be a combination of old and new. Old: high-voltage power brought in by large transmission lines from the north end of the continent (rich in oil energy) or from the south end (rich in hydroelectric and nuclear generation) toward the energy-poor midsection of Africa. New: with better and cheaper renewable-energy machines---wind turbines and solar panels or solar concentrators---Africans might be able to bypass the older, capital-intense, wire-heavy, fossil-burning habits of the grid in the developed world, just as in some places cellular telephones are coming to places that never had wired-up land lines to begin with. In the meantime, only 3-5% of people have regular access to the grid. An enhancement of the Owen Falls Dam (now called the Nalubaale Dam) came into operation in the year 2000, but further World Bank supported dam projects are on hold while allegations of corruption are investigated (ref 10.5).

For electricity in Uganda, in the Lake District of East Africa, it is still the morning of the grid, and will be for some time to come.

Situational Awareness in Ohio

Massoud Amin spends much of his time, as a professor of electrical engineering at the University of Minnesota, thinking about large electrical networks, the fat part of the worldwide grid where customers use electricity in amounts far above Minimum Electricity. He looks at the grid like a doctor examining a patient. One can be malnourished by eating too much or too little. The African patient is underweight while the North American patient tends to be overweight. Too little electricity and economic performance is anemic. Too much electricity---too much for the existing grid---brings about different problems.

The saga of the 1965 cascade blackout illustrated how the grid, owing to its interconnectedness and the speed with which problems escalate, is inherently vulnerable to even minor perturbations. In this regard, failures on electrical grids---which have been compared to sandpile avalanches initiated by adding a single grain to the top of a steep pile---actually bear a resemblance to other disaster phenomena. If you drew up a graph showing how often hurricanes of a certain size occur, and compared it to the graph showing how often blackouts of a certain size occurred, the two curves would look a lot alike. The curve for forest fires would be the same, and also the one for earthquakes, and for flooding patterns for major rivers. All of these systems have something in common, complexity arising from reactive interconnectedness. In the case of the grid, there are all those wire connections. For hurricanes it's the tangle of pressure fronts and warm ocean water. For earthquakes it's all those overlapping fault lines deep underground. For a sandpile it's all the grains of sand rubbing past each other (ref 10.6).

Floods and hurricanes are natural phenomena. What about an electrical grid; surely it isn't a *natural* thing, like a river. What does a flood-of-the-century on the Missouri River have to do with a 30-million-person blackout? Power networks are laid out by engineers over decades, whereas the Mississippi was carved by geologic forces exerting themselves for millions of years. How can we compare such apples and oranges? Well, wires do snake through a city grid the way tree roots spread underground. Wires don't grow, but they are planted in the ground, overlap each other, can be influenced by groundwater, and remain lifeless until nourished by an energy source from far away. Weather fronts, sandpiles, geographic faults---they are all places where *complexity* plays out. These diverse networks look very different but they're related.

The grid in Ohio is more advanced than the grid in Uganda, but they have things in common. They are, in a manner of speaking, both built on sand. The steepness of the sandpile, its angle of repose, increases with the complexity of the energy network, which includes the grid carrying the energy and all the gadgets we plug into the grid. The complexity grows and grows. Be aware, say the physicists, that the chance of an avalanche in the pile will grow. We just want you to know this. We won't be able to say exactly when or how, but it will come. Does this mean that blackouts larger even than the 1965 event are possible? Yes, the failure curves allow for this. That it should occur on August 14, 2003 in Ohio would be an accident. Also not an accident.

In 1965 it started in a power line going from Niagara to Toronto. A safety device, set too low, tripped off, forcing extra electricity into circuits that weren't ready for it, initiating a cascade of failures. This electrical hurricane raced all around Lake Ontario and spun off from there, like a pinwheel, into Boston, Providence, New York, and dozens of other cities.

In 2003 it started in a power line in the middle of Ohio. The day was hot, causing air conditioners everywhere to draw more current, causing the power line to heat up, causing it to sag right against some trees that should have been trimmed but weren't. The line shut off, forcing extra electricity into circuits that weren't prepared to take it. And from there a hurricane of failures spread, including an end run of heavy current around Lake Erie.

In 1965 they didn't know what was happening. A huge surplus of current arrived in some places, while a huge deficit of current was the problem in other places. Widespread disconnection followed in only 12 minutes. In 2003 they also didn't know what was happening. Coming some 40 years after the 1965 mishap, the grid managers had much more sophisticated computer controls. Alas, because of human and software errors, the sophistication did them no good. The managers had lost "situational awareness" of their own grid. They didn't know about the calamity befalling them and, worse, they didn't know that they didn't know. It didn't take minutes this time but mere seconds to wrap up the proceedings.

In 1965 the dominoes fell one after the other---Buffalo, Rochester, Syracuse---the territory of the old Iroquois Nation. In 2003 these same cities, and many more besides, were participants. Some of the same power lines were involved, almost surely some of the same atoms. The very same electrons would have been yanked around on those two days separated by forty years.

Can blackouts get bigger? In 1965, an estimated 25,000 megawatts of power were lost, leaving 30 million people unplugged in 9 US states and 2 Canadian provinces. In 2003, the numbers were roughly 70,000 megawatts and 50 million people in 8 states and 2 provinces (ref 10.7). The 2003 event was the largest in North American history. In terms of total power lost all at one time, it might have been the largest electrical failure in history. Picture the statisticians enrolling a new data point on the catastrophe curves.

The Eastern Interconnection drama of 1965 had been replayed in 2003. Cleveland and Detroit stepped into the role formerly played by Boston, but otherwise Act II looked pretty much like Act I. Thousands were stuck in elevators, trains stalled beneath the East River, hospitals heroically finished hazardous operations under emergency lights, and newspapers were printed on borrowed presses. Big Allis and the reactor at Indian Point shut down without incident. Endless traffic jams, lower-than-usual crime rates, refunded Broadway tickets, ice-cream give-always, rampant jumping to conclusions ('65: suspected Communist aggression; '03: Muslim terror attack), and querulous how-could-it-happen-again? essays. Because New York City had been involved, the blackout was again certifiably Big and deserving of lots of press coverage everywhere.

The 2003 blackout was inadvertently an immense chemical experiment: when the electricity stopped, so did the pollution coming from fossil-fired turbogenerators in the Ohio Valley. The before and after air quality levels were dramatically different. On August 15, only 24 hours after the blackout, sulfur dioxide was down 90%, ozone down 50%, and soot particles down 70% from "normal" conditions in the same area (ref 10.8). Less electricity, in this case, meant cleaner air.

Flying the Grid

To put things in perspective: as bad as the electrical collapse was, somebody somewhere has it worse. Uganda is worse. Detroit's or Cleveland's grid made a full or nearly full recovery within a day or two. In Baghdad, where the insurgency obliterated much of the oil and electricity systems (and many other major infrastructure), things were far worse. Asked what he thought of the big power failure in the US, one Iraqi resident said that mostly Americans live like kings. If they are bothered by a few hours at temperatures of 90 F, they should try going days or weeks at 120 F (ref 10.9).

Europeans were especially incredulous as to how the North Americans could have such frequent and extended blackouts. Yes, in the month or so after the August 2003 blackout there were minor power disturbances here and there: a million lost power in London for a few hours, 4 million in Denmark and Sweden. But the general feeling was that an avalanche on the order of the North American disasters---30 million in 1965 and then 50 million in 2003---could never happen in Europe.

And yet, you never know about that failure curve. The curve is a simple geometrical way of expressing the underlying complexity. Hurricanes destined to hammer the Carolinas can start out as no more than a few dozen tiny swirls of dusty air above the baking sands of West Africa. Energy gathers, invisible interactions take place, a wider system of linkages gathers, medium-sized storms combine into larger storms, and out we slide onto the wide edge of the catastrophe curve for hurricanes. And in like manner something like avalanches start to form in other complex systems, and with little warning we have flu epidemics, or traffic jams, or electrical outages.

Can the failures get bigger? Sure they can. On September 28, 2003, hardly 6 weeks after the August 14 extravaganza, almost the entire Italian grid collapsed. An estimated 57 million were without power. How had it happened? They weren't sure at first, but it seemed to involve French-produced power passing through Switzerland and then on into Italy. At one point in the public relations battle, the Italian grid operator, GRTN, was blaming France. The French company, RTE, blamed the Swiss company, ATEL, and the Swiss were blaming the Italian grid operators (ref 10.10).

We don't have to take this sitting down. The electrical business and its various regulatory and support organizations regularly carry out self-appraisals. A courteous, carefully-worded speaker, Massoud Amin often addresses mixed audiences of industry insiders and governmental officials. In his professional role as consulting physician to the grid, he shows graphs, quotes numbers, provides a full body scan. Here is the fever chart for the electrical industry: blackouts are on the average getting larger and more frequent. In mathematical terms, the catastrophe curve (how big and how often) is moving sideways to the right, in the direction of greater failure.

Grid construction is declining, Amin reports forthrightly. Sometime around 1995 investor-owned utilities started spending less on new construction than the annual amount of asset depreciation (ref 10.11). In other words, the energy companies are eating up their past investment. New customers are welcome---power lines are being extended to freshly built homes---but the construction of big transmission lines, the main boulevards for wholesale electricity, is not keeping up with increased demand. The roads are getting clogged.

Research: as a fraction of total sales, R&D in the electric power business is less than half a percent, whereas for various peppy industries, such as computers or telecommunications, it's more like 10%. How can electricity move into the future with such a meager endowment?

Part of the remedy for grid congestion is more hardware: more high-voltage lines, more solid-state (no moving parts) devices for steering power flexibly from one line to another to optimize traffic flow, and more fault current limiters, which act like emergency airbags to soak up---at least for the short time it takes to open critical circuit breakers---the grid-breaking tsunami of excess electrical energy released in some regional network failures.

Other remedies fall into the category of detect-and-control. It would be desirable to install a timelier all-seeing, quick-responding, sensory system---using cell-phone, Internet, and global positioning system technology---that can maintain a better moment-by-moment situational awareness of grid activity, in order to prevent an Ohio-class event from happening, or at least to diminish its effects. This overall scheme, which Massoud Amin calls the "self-healing grid," would isolate the immediate problem by selectively breaking up the regional grid, in the moment of crisis, into smaller units. This adaptive self-islanding would help to limit the scope of the cascade failure and would also help speed the recovery phase along, a recovery which might take minutes or seconds rather than hours or days (ref 10.12).

The cost of the supplementary equipment and software is not cheap---something like $10 billion per year. But the cost of *not* making the upgrade is far higher. Estimates of the cost of electrical disturbances to the US economy range up to $100 billion per year (ref 10.13). A majority of this loss, surprisingly, comes not from the headline-grabbing regional disturbances but from smaller outages or voltage irregularities lasting minutes or seconds. Even a fraction of a second is enough for an electricity glitch to turn off a computer, leading to a business loss of millions of dollars for companies like microchip manufacturers or processing centers for credit-card-sales. Keep in mind that running the grid at an efficiency of 99.9%---a level referred to as "three nines"---sounds pretty good for any human-built system, but this still leaves 8 hours of downtime per year. That can be a little or a lot, depending on who you are or what you do for a living.

Selling the better-grid proposal to those frequently-gathered councils of businessmen, scholars, and government officials, is generally frustrating. They listen, applaud, ask polite questions, later compliment the speaker on his assessment. They agree with you, support your view of things, can't help but see that the sensible reforms and needed research should be implemented. Privately, however, the Congressman or Member of Parliament or committee staffer will say, with a lowered voice and with a look of resignation, that the plan, terrific as it might be, will, owing to political considerations fully as complex as the grid itself, inevitably be postponed until next year.

In the meantime, the grid keeps flying along as best it can. Massoud Amin tells the story of an Israeli fighter pilot who, in midflight, accidentally smacked his craft into a second plane flying beside him. The other guy parachutes safely, but the first guy sticks with his plane. Only when he lands and can see the wholesale damage---one wing almost completely gone and extensive damage everywhere----does it strike him how lucky he is. The Air Force can't believe it either. His survival defies notions of how much plane you need to have in order to stay flying. They take the plane back to its maker, McDonnell Douglas in St. Louis, so engineers can study the hulk. More remarkable than the plane, though, is the pilot, whose years of dangerous and expensive training over the battlefields of the Middle East have given him a fingertip finessed in maneuvering his craft. The engineers studying the ruined F15 deduce that the pilot, through subtle adjustment of engine thrust, must have kept the craft's center axis aligned to within a degree or two of his forward motion. Any greater divergence from Forward would have meant instant death: aerodynamic forces would have obliterated what remained of the plane.

Amin, who helped develop some of the software used to help pilots fly fighters, suggests that electrical grids are sometimes "flown" in this way, very close to the break-apart point. Expert power dispatchers can, with very little electricity in reserve and with frequent and incessant demands for power coming from many directions (not quite as dire as missing a wing or dodging enemy missiles, but still a serious drain on one's mental resources) keep the grid functioning and yet be within a hair's breadth of instigating a million-person blackout. It is the combination of expert human operator and sophisticated software, some of it modeled on the adaptive software designed to help fly advanced combat airplanes, that keeps the grid running (ref 10.14).

Wait a minute. Isn't service pretty good as it is? Is additional huge investment all that important? Those catastrophe curves: do they apply only to the dense, overly-subscribed grids of North America and Europe or can they happen elsewhere, for instance in Asia? Can blackouts get bigger still? Bigger than Italy? The answers: investment is important, lack of investment even more significant. Complexity is a natural phenomenon so the curves apply everywhere, not just in Ohio or Italy. Blackouts can get bigger. They already have.

Having Refrigerators in India

Uganda would love to have some of Ohio's grid problems. In Ohio everyone has the grid, in Uganda almost no one. In Ohio, it might be said that some of the computer control equipment used to fly the grid is fifteen years out of date. In Uganda, large parts of the grid are ninety years out of date.

Somewhere between Uganda and Ohio is India. Is electricity in India different from Western electricity in the way that the Indian elephants are different from African elephants? Is power in India, the subcontinent beneath Asia, different from power in Italy, that peninsula hanging south from Europe? No, of course not. Electricity is the same everywhere. You burn fuel, spin a turbine, induce a high voltage difference across a set of wires, and send power out amongst the citizens, who use it to warm filaments and activate machines. The voltages might be different and the arrival rates might be 50 or 60 waves per second, but otherwise there is no difference from place to place. There is no Hindu electricity, or South American electricity, or electricity just for women or kings.

And yet with so many people below the Minimum Electricity line, with millions having no access to the grid at all, the aggregate electrical experience *will* be different from Ohio. In India, as in Uganda, it has been the morning of the grid for many years. Here's the way it was in the 1930s:

> *I am often asked what are the greatest changes which have taken place since I landed in Bombay in July 1897. Undoubtedly the most beneficial is the advent of electricity...nothing has increased so materially the amenities of life in the City or Island, and raised the standards of health more, than the general use of electricity.*

Thus begins a history of the Bombay Electric Supply & Tramway Company (BEST) prepared on its fiftieth anniversary in 1936. Despite a tone which indicates a very slight disdain for the "softness" in living brought about by the grid, these introductory remarks, written by an Englishman, reveal an evident pride in the spread of electricity not just to affluent customers but to the common man:

> *Quite apart from the abundant supply of "White Power" [referring here to hydroelectric power] for industry, it is not generally realized that through the very low rates it charges to small consumers---I might even say unprofitable rates---the B.E.S.T. has carried the benefits of electricity down to a humbler class of citizen than any other corporation in like circumstances. There are many thousands of users of electricity whose monthly bills are under two rupees, and statistics show that a much higher proportion of the population is connected with the supply system, as compared with any other city in India. Last, but by no means least, we have the electric refrigerator (ref 10.15).*

Having the refrigerator was a much more advanced stage of electrical ownership than mere bulbs, since coldness in summer is more difficult to achieve (since it requires moving parts) than illumination after nightfall. It made you a stakeholder in the new order. It meant that a perishable bit of food might thrive for days. A chilled drink could set you apart from those in the home next door. Unfortunately, many Indians did *not* get a refrigerator and have lived, in an energy sense, as if it were still Bombay in the 1930s.

Bihar State was particularly poor and far from being hooked up. In 1950, for example, less than 1% of villages there had electricity, and so a program was launched to carry lines to rural areas. Thirty years later the fraction of villages served had only reached 30%. In other states the numbers weren't much better. The main problem is poverty. The states didn't have the resources to wire the villages, much less send electricity on a regular basis. Customers would not have been able to pay at the prescribed rate anyway, and indeed often their lives were not arranged around the presence of electrical energy in the first place. Tribal life had been arranged differently. You'd get up at daybreak, work as long as there was light, and then go to sleep. When electricity did arrive, it was amazing. In some hamlets in Bihar State the first electricity would be cause for celebration. People were drawn to a home to see the first lighting of the bulb.

It could be said that a god had descended upon the house (ref 10.16).

The first benefits of electricity in small-town India were pretty much the same as in small towns on other continents: electric lights extended the work day, making after-dark dinners possible. If there had been pre-electric lighting, it would have been kerosene. As in other electrified parts of the world, saying goodbye to smelly, expensive kerosene was a pleasure unless, perchance, the new electrical setup proved unfaithful. In such cases, some said, it was better not to have had the electricity at all. Indeed, in some cases, the service is offered but refused. Among the reasons given for *not* taking service: "communication gap between people and functionaries and lack of education, fear of exploitation, variation in consumption, manipulation of rules by functionaries,...afraid of shock from electricity, afraid of catching fire, inhibition to see official, and fear of cheating by functionaries" (ref 10.17).

Utility customers the world over have at various times complained of slow restoration of service after a power failure. Where I live, only a few miles outside Washington, DC, my neighborhood has twice gone for about a week without power following a storm, a thing which would not be tolerated in Europe. Things can be far worse. Consider the case of several villages in West Bengal. After a storm, some power poles were knocked down and along with them all regular electricity vanished. In the first weeks and months, the villagers complained and were promised a fix. More than 22 years later, they were still seeking a restoration of service (ref 10.18).

Many in India are far flung. Hundreds of millions are far from the grid or only weakly attached. It can also be fairly said that hundreds of millions *are* plugged in, and this makes India a major electrical nation. It is the third largest producer of coal and the sixth largest energy consumer in the world (ref 10.19). But does India resemble the robust-economy countries in having a complex, multi-connected grid vulnerable to cascading failure?

It does. On 2 January 2001, an event to rival the Ohio or Italian collapse arrived. If you were superstitious you would say this was a bad omen coming only 2 days into the new millennium by the official calendrical reckoning. The failure of a transmission line at a substation in Uttar Pradesh, the most densely-populated state, brought down a considerable portion of the grid across northern India. The number of people left without power was estimated to be about 220 million (ref 10.20). This bears repeating: Because of a malfunctioning piece of electrical equipment, the largest deprivation of electricity in history, in terms of people all at one go, came into the record book. Nearly a quarter *billion* were without power. (Possibly a larger number of people were involved in an earlier blackout in West Bengal in June 1990---but numbers were hard to determine; ref 10.21).

As you are absorbing the human magnitude of the number *quarter billion*, consider that the Indian government reports that in the 2001 event about 15,000 megawatts was shut off (ref 10.20). Comparing to the US/Canada outage of 2003, we see that the Indian event stranded roughly a factor of four or five times *more* people but a factor of four or five times *less* power. In other words, electricity is spread more thinly on the ground in India than in North America.

There are several reasons for this thinness. One is the remaining, persistent, high number of rural residents without electricity. Another is the near bankruptcy of the state power companies which, to satisfy popular demand, artificially keeps rates low. Because of this less-than-breakeven revenue stream and a rate of pilferage (illegally tapping the lines for power) in some places as high as 20%, the state-run regional grids are in a weak position. In Uttar Pradesh, where the huge outage took place, no new electric generation had been added for the preceding decade, although many new mouths to feed had been added during the same period. Consequently, outages are common; ten for fifteen minutes every other day. For savvy companies that can afford it, expensive standby diesel generators are the solution (ref 10.22). For those that can't afford it, there is darkness.

Like all other grids, the Indian grid is built on the side of a sandpile; a small disturbance in the network can lead to a major disturbance in the delivery. The financial footing of the Indian grid is also very sandy. Consider the difficulties arising from the need for a poor company in a developing country to seek private investments from abroad. The lender naturally seeks a good return on its investment and guarantees to protect the loan in case of default. The borrower naturally seeks the easiest terms and loosest guarantees. Case history: a consortium of lenders, led chiefly by the US company Enron, signed a contract with the electricity board in Maharashtra State to produce an immense power plant fired with liquid natural gas. The new energy company, called the Dabhol Power Corporation, ambitiously hoped to produce as much as 2400 megawatts of power, as much as the Ravenswood plant in New York, home to Big Allis.

Alas, the multi-billion-dollar deal, the largest foreign investment project at the time in India, was troublesome from the very beginning (ref 10.23). Complaints were made that the contract was signed too hastily, that the plant charged too much for power, that it produced electricity whether it was needed or not, and that its construction violated various environmental and safety standards. Then the state electricity board fell behind in its monthly payments, and legal proceedings began. At the time of the gigantic January 2001 blackout in Uttar Pradesh, the plant was asked to ship power northwards to help with restarting the grid, but Enron's power plant, still seeking to be paid for previous service, insisted on an emergency rate three times higher than normal. This further incensed local authorities, and emergency power was found elsewhere. Enron was at this time having trouble not just in India but also in California, where its energy dealings were linked to skyrocketing electricity costs and the rolling blackouts, and in Washington, where Enron's financial records were being scrutinized. Enron eventually went bankrupt and its chief officers indicted for irregularities.

India's energy problems continue. Other foreign companies, such as Electricite de France (EDF), have cancelled or pulled back on plans for power investments in India owing to worries about payments or the very solvency of the state electricity boards (ref 10.24).

Making electricity and selling it a price the customer can afford and that allows the company to expand has been a struggle for utilities in all lands ever since the first grids went up in the 1880s. More than a century later it's a special struggle in the subcontinent. How can India produce power for a burgeoning population, attract the involvement of outsiders and their much needed expertise and cash and yet remain sovereign is a problem still to be worked out. In countries with a mature grid, an important issue seems to be improving reliability from 99.9 (three nines) to something even better. In countries like India where the grid is not exactly immature since it's been around as long or nearly as long as Edison's grids, the chief issue is that of mustering resources for a nation where large sections of society do not have Minimum Electricity or where service regularity is not at the level of three nines or two. It many places it is at the zero level.

Hydraulics in China

China can't be left out. India is immense but China is vaster still. No account of electricity or technology or energy procurement, or for the consequential heavy toll expected from such a vast command of resources, can fail to speak of China. Its economy has bounded forward over the past decade, growing in some of those years at double or triple the rates of most western nations. Long a poor country, and still a poor country in many respects, China wants to catch up with the industrial world, and it is well on its way.

China sprawls out in time and space. It has all the zones one can find in a geography textbook: mountains to the south and north, deserts to the west, steppe and grasslands, and broad flood plains to the east and south. The Chinese spectrum of electrical infrastructure extends from the 1900-level diesel-generated electricity in hamlets, to 1940s-era coal-fired heat-and-power production for keeping 24-hour-a-day steel mills rolling out their product. At the top end they're building late-model nuclear reactors for supplying power to the bustling eastern coastal metropolises now competing with Manhattan for skyline honors.

You can't talk about China without brandishing big numbers. Some of the numbers have positive import, some negative. So, just to tick off the hottest economic figures, one must begin with an economy that grew in 2004 more than 9%. Most nations would be pleased and proud of a rate one third as great. Electricity demand grew even more---15%. Disposable income, one measure of how well people do when they get home with their satchels of groceries, went up 11% in cities, 16% in rural areas.

More surprising still is that growth's usual sour companion, monetary inflation, remained low. What then is the price for success? In China now, for example, highways are much more congested, partly because there are more people in the cities and partly because there are more cars. Of the ten most air-polluted cities in the world, seven are in China. With this atmospheric burden comes a connected increase in respiratory disease.

It's tempting to look past the downside and concentrate on the positive. Look at what is happening to the average Chinese urban woman. She now possesses more personal floor space than before; uses more water for drinking, washing, and other chores; eats more meat (increasingly beef); acquires more steel in the consumer products she is now able to buy and requires more electricity to run them and a larger, more complex, grid to carry the extra power. And she wants her own automobile. She generally wants or aims to get what the modern woman in Italy or America has. China is the largest maker of electrical gadgets (ref 10.25).

As measured by actuaries, living is better in China: life expectancy has overtaken that of Russia. Gross domestic product (GDP) is equivalent to that of 1950s Japan. Infant mortality has dropped to the level of Argentina (Ref 10.26). One gets the impression that China will arrive at the recommended per-capita electric consumption of 1000 units well before the target date of 2050. India maybe. Uganda probably not.

Back to the downside: the toll for this turbo expansion is heavy. China is now the largest user of chemical fertilizers, which are good for the plants in the cultivated field but bad when they run off into the rivers and feed blooms of algae. China is the largest excavator and combustor of coal, and perforce the greatest releaser of sulphur compounds which come back to earth in showers of acid rain, helping to kill forest and deface buildings. The nation is being drained, shrunk, parched, leached, nibbled, silted up, fouled and turned to desert.

China has impressed the world with its growth, but how long can it continue? In his book *Collapse*, Jared Diamond chronicles the ways that great civilizations of the past do themselves in, sometimes starting the downward plunge at the very pinnacle of their greatness. By his methods of historical calculation, China is in trouble. With enough engineering and scientific process thrown into the national effort, and with enlightened political management, a lot can be accomplished. But not if you have no trees or topsoil. China's per capita cropland is half the world average, not much different, Diamond claims, from the low level of available land that helped trigger the genocidal struggle in Rwanda. China's cup is no longer even half full: its per capita fresh water is a fourth the world average and its per capita forested area only a fifth the world average (Ref 10.27).

Too much human energy and not enough electrical energy. High expectations and ambitious industrial plans but insufficient resources. And even if the electrical generators can be mustered and coal pulled from the ground more quickly and shoveled into the furnaces, there is still the problem of how to suppress the billows of pollution coming from those generators, which are gradually tinting the air above the new eastern skyscrapers an unpleasant shade of brown.

What can the government do? Chinese planners are doing what their engineering counterparts elsewhere are doing: they're giving more thought to the nuclear option. Reactors' high construction costs, accident and proliferation perils, and waste storage dilemma notwithstanding, reactors do, as proponents like to point out, run on cheap fuel and emit little pollution into the air. Even in those parts of the world that have reactors, a revival of nuclear building is, for now, an idea held in contemplation. In China, by contrast, they're doubling, redoubling, and then re-quadrupling the number of nuclear facilities underway or planned (ref 10.28).

Perhaps the most conspicuous response to the combined problems of electric shortage and pollution surplus is the dam being built on the middle reaches of the Yangtze River. Called the Three Gorges Dam after its picturesque setting, the project is the largest electrical construction job ever undertaken. And here the big numbers overtake all the other big numbers used so far to describe China's big push forward. Two kilometers wide, 175 meters high, costing a minimum of $30 billion, the dam is a gigantic experiment in flood control and power production. The 26 turbines, when they're all in place, will pour 18 billion watts into the high voltage grid. This is half again more than the output from the world's largest existing hydroelectric plant, the Itaipu Dam on the Parana River near the Brazil-Paraguay border, and three times the output of the Grand Coulee Dam, the largest hydroelectric installation in the US.

Already the waters are rising in the giant reservoir lake behind Three Gorges, and the first turbines have begun to operate, which helps to explain the huge jump last year in Chinese hydropower production (ref 10.29). A building project as big as Three Gorges, often compared in magnitude (and maybe in folly) to the great Pyramids, is a provoker of opinions and fantasies, even within China, where information flow can be severely controlled. Some critics are shouting, "Stop, stop before it's too late." Others fear that this largest of generators will lead to massive avalanches on the Chinese grid. Could we see the first billion-person blackout? Probably not---although a transmission failure near the Itaipu Dam caused most of the turbines there to turn off, snatching away a fifth of Brazil's electrical power, and stranding people in several big cities such as Rio de Janeiro and Sao Paulo (ref 10.30).

Can Three Gorges affect weather? Can the weight of all that water lodged in a 600-km-long lake cause an earthquake? Skeptics have plenty of questions. The amount of pollution-free electricity will be highly prized by economists who plot the fortunes of factories and the schedules of trollies, but not by naturalists who foresee a great silting of waterways and a wholesale loss of habitats and farmland. Demographers, and certainly the residents in the way of the rising waters, have taken note. An expected million-plus migration is now taking place.

In China there is great pressure to keep enlarging the economy, although maybe at not quite at the recent red-hot level, so that Chinese people can enjoy electrical levels comparable to other leading nations. And why should they not have these aspirations? As for the extra pollution this brings to cities, well, this problem might well be dealt with, seriously, but maybe not until a *future time*. If so, the delay would only be part of a larger electrical leadership dilemma. In Ohio costly upgrades to the transmission need to be made, but political realities dictate that these not be started until "next year" at the earliest. In India they need to raise electric rates and attract foreign investment. Maybe next year. In Uganda, which comes first: good government or good dams? Suspicion of corruption holds up construction of a new hydroelectric which would greatly enlarge the national grid, and along with this national literacy, and along with this democratic institutions. When will this happen? Perhaps starting as soon as a year from now, it is said (ref 10.31)

Massoud Amin, besides his other duties and research interests, is the director of the Center for the Development of Technological Leadership at the University of Minnesota, would seem to have his work cut for him. He says that when his students---who continue to hold down jobs in engineering or construction companies during the leadership training---consider which nation should be picked as the site for their foreign-visit instruction, they invariably propose China: big nation, big economy, big problems, big opportunities, big potential for practical leadership lessons.

How big is China? How important is it? Consider this poignant anecdote from not so long ago. The occasion was an Olympic diving event being shown on television. The man favored to win, an American, had come first in the previous competition. This time around he was being pushed to the limit of his ability by two Chinese athletes. China, viewers were told, had not had an Olympic diving team or even a diving program for many years. And yet the Chinese team was suddenly striving for a gold medal. It was a dramatic catching up. As it happened, the American diver, Greg Louganis, did win the contest, and a Chinese diver, Tan Liangde, came in second. China had won respect and something else, since it had succeeded in changing the existing order of things: this time it was springboard diving, but soon perhaps it would be other endeavors---designing computers or inventing a non-polluting way to make electricity.

If we can operate on the assumption that innate talent is spread evenly around the world---talent for creating art, say, or talent for springboard diving, or for engineering---then the nations with the largest numbers of people should, if they choose to apply themselves in that particular area ought to enjoy the greatest success. It would seem that if not now then eventually China, all other things being equal, would come in first and India second. The medal would not be a lump of bronze worn around the neck but would be prosperity, maybe even economic hegemony over other nations.

Ah, you say, but things are not equal, and national cultural differences, and economic opportunities, are still quite varied around the globe. Chances in life are different for different places. Yes, but not as different as before. Internet technology, relatively cheap aviation, and growing educational flexibility have made the world smaller and larger at the same time.

So, here we are, riding the present moment through life as we always do, poised between past and future. The Chinese diver stands at the edge of the springboard preparing to take his turn in the competition. And behind him, mounting the ladder, are other people from other lands who wish also to move up in the standings.

The Grid in 1969

In the course of this book we have looked at the grid in a number of ways: as a chronology of great inventors and inventions (chapters 2-4); through the re-enactment of a particular blackout (chapters 5 and 6); as a kind of business report on the dismemberment and reconstruction of the power industry (chapter 7); by a series of visits to specific generation stations (chapter 8); and by observing a day in the life of a single utility (chapter 9). In this final chapter we are looking at how the grid has been brought to far-flung places, to localities where the grid is relatively new, or where the distribution of electricity is still on a shaky footing.

Concluding the history of a subject right up to the current moment is tricky since it involves hitting a moving target. New things come along. For instance, mentioning some piece of equipment as being the latest innovation in blackout prevention is problematic: in a few years that machine will be obsolete. Declaring a particular turbine design to be the most efficient is self-defeating: assuredly it would soon be overtaken by another model. Predicting future winning technology very far in advance is futile.

Life is lived forward but understood backwards. Consequently, to put a capstone on this history of the grid, we shall move forward into the past. "Forward" here means that although we will be going backwards by several decades, the narrative about, and appreciation for, the electrical grid will continue to progress.

Our retrospective destination is 1969. This is anything but an arbitrary choice, for in that year there occurred one of the greatest technological feats of all time, the Apollo 11 mission. Bringing electricity to the Moon did not directly affect the quality or quantity of electricity in Uganda or India or anywhere else, but it was an event that would have huge symbolic and practical repercussions, electrical and otherwise.

Why were men put on the surface of the Moon in 1969? The more prominent explanations were the following. (1) Exploration: it is in man's nature to explore, and the Moon's surface was the grandest destination within the technical means of current civilization. (2) War and Prestige: the Moon expedition was an extension of America's hot war being waged against the North Vietnamese and the Cold War against the Soviet Union; it underscored America's resolve to fulfill huge undertakings and America's prestige in being the first to do something so difficult. (3) Big Science: the Moon could be a place where scientific discoveries might be made and valuable mineral deposits located. (4) Big Business: the military-industrial complex of high-tech companies, not content with lucrative war work, desired still more contracts for their eager factories.

Bringing electricity to the Moon was *not* one of the stated reasons for the sequence of space flights known as the Apollo Program. Nevertheless, electricity was a major subsystem of the spacecraft itself, as indeed it must be for any substantial modern device of many parts, or one requiring subtle maneuvers at high speeds. A comparison between Apollo and that other epitome of 1960s advanced engineering, Con Edison's Big Allis dynamo, will illustrate the point. First of all, they're both about 400 feet tall: Allis with its stack and Apollo on its pad. They both burn immense amounts of fuel: Allis to make electricity and Apollo to reach the Moon. Both Allis and Apollo are bewilderingly complicated machines, each a small mountain of components linked to other components, many of which take part in sequences of actions leading to other actions.

One takes for granted that Allis is filled with metal conductors. So is Apollo, with 15 miles of electrical wiring (ref 10.32). You could say that this monumental feat of aeronautical engineering was built on a very steep slope. This doesn't mean that Apollo was necessarily badly designed or that an accident was destined to happen, but only that the tightly coupled complexity inherent in its architecture gave Apollo some of the tendencies of a sandpile or an inter-regional electrical grid. Even a tiny slip-up, a tiny perturbation to the system could lead to a large failure. Such it was with the first Apollo mission scheduled for flight, Apollo 1. The perturbation that set the avalanche in motion was slight, the sequence of events quick, and the results catastrophic.

Lying in their take-off prone position in the main capsule, the three astronauts were being fed pure oxygen, the better to keep cabin pressure low while supplying the men with the needed breathable substance. Somewhere else, in an equipment bay in the capsule, an electrical short (electricity trying to take a shortcut) is believed to have sent sparks onto some combustible material. A fire began, and in the rich oxygen environment the flames raced around; after all, you brighten a fire by blowing on it, by lending it more oxygen. The men were burned alive (ref 10.33).

The families, the corps of astronauts, and the nation were stunned. There had been fatalities before among the American astronauts and Russian cosmonauts. Whether test piloting new vehicles or riding a rocket into space, the men (and later women) faced many hazards. Still, the deaths of the Apollo 1 crew was the biggest blow yet to the manned spaceflight program. NASA's troubles could be seen as part of a culture-wide urease. There was at this time, the late

1960s, a vocal protest movement in America centered around disenchantment with the Vietnam War and with the campaign for civil rights. Many, and not just among the protestors, now regularly questioned whether billions of dollars should be spent on a new Lewis and Clark expedition to the Moon when Detroit and other US cities were ablaze, the result of racial unease.

The Moon mission went on. Apollo's wiring was redesigned, the oxygen was replaced with something more like normal air, and materials inside the crew compartment were made fireproof. A later spaceshot, Apollo 8, helped to rekindle enthusiasm for NASA's exploration extravaganza. On this flight, men had for the first time ventured all the way to the Moon. Although they did not descend to the surface, they did record those famous pictures of the Earth rising above the limb of the Moon. An astronaut could, and did, hold up his arm and with his thumbnail entirely cover up the entire view of his home planet, and along with it all the present inhabitants thereof, and all the oceans and landmasses, and all the strife and the achievements.

Back on terra firma, whether or not earthlings were preparing to stroll across the dusty plains of the Moon, the subways beneath the streets of New York still had to run. Elevators, stoplights, freezers for keeping ice cream firm, and network television broadcasts all needed regular electricity. Consolidated Edison, the company with monopoly right to sell power in the city, had the statutory duty to fill all requests for voltage, large or small, day or night. Still on the rebound from the 1965 blackout, constrained by new environmental regulations, and harried by citizen associations against locating any new generators in *their* neighborhoods, Con Ed was up against it.

As a responsible company, though, it was thinking ahead. Con Ed had a ten-year portfolio of building projects. It was obvious to all that the society's thirst for electricity would keep mounting. The laws that regulated the grid stipulated that the utility kept pace with that thirst. Thus the grid (the nation's and the world's first grid) that had begun with a few thousand watts of capacity on Pearl Street, now wanted to upgrade by six billion watts. The plan in 1969 called for several new nuclear plants, some to be built up the Hudson River, or on an island offshore from New Rochelle, and maybe one on Roosevelt Island in the East River ref (10.34). New York City would have plenty of power.

What about other grids? In 1969, China's grid is at a standstill. As they were fuelling Apollo 11, China is recovering from its "cultural revolution." The universities now churning out hundreds of thousands of engineers per year were, in 1969 still shut or just reopening. Although it was no longer necessarily a disgrace to be an educated person, and science and engineering studies were again being encouraged, technological progress was at a standstill.

While Communist China is struggling with the consequences of its red revolution, India is undergoing its "green revolution," the effort to develop agriculture in a new way, especially with new irrigation. Electricity, most believe, is crucial to carrying forward the scheme. Many generators have been installed, per-capita consumption of electricity has improved dramatically---in some parts of Tamil Nadu State in the south, for example, by a factor of ten---but there is still a huge gap between need for and delivery of power (ref 10.35). Furthermore, there are disparities: some rich farmers, it is said, get essentially free electricity, while many others get none at all.

In South Vietnam in 1969, amid war, the grid is an easy military target. Generators must be defended as if they were forts. Nevertheless, US authorities officially maintain that the war can be won, and David Lilienthal is assigned the task of creating a postwar development plan for the delta region in the south. Lilienthal's proposal for what might have become a Mekong Valley Authority, including hydroelectric facilities, becomes irrelevant as the military situation deteriorates (ref 10.36).

In 1969, Amory Lovins is a graduate student at Oxford. For some time now he has been keenly interested in three topics---the environment, resource use, and international security---and sees them as crucial to future economic development. Where these three topics converge is energy; he wants to write a dissertation about energy. Oxford has a different view. Energy is not a proper academic subject, and Lovins is asked to leave.

In 1969, the Idaho Power Company is stymied in their effort to build more hydroelectric plants, or replace the dam at Swan Falls with a larger facility. They must, however, find ways to make power for all the new faces showing up in Boise. Accordingly, the utility decides solemnly to supplement water power with coal power. With another company, Pacific Power & Light, they decide to build a huge coal-fired plant in Wyoming (ref 10.37).

The Moon is also about to receive new electrical equipment. The "grid" that was being sent there would of course be only a tiny, expensive, provisional version of what cities and nations on Earth had. The delivery vehicle for the lunar grid, Apollo 11, roars off into space on July 16, the heaviest thing yet sent into space. The Saturn V rocket, the most powerful engine ever devised, making the loudest manmade sound (if you don't count the sound from a nuclear weapon), is discarded as soon as it finishes its job, which is to loft its payload into Earth orbit. Having left the station and been trimmed in size for its trip to the Moon, the composite Apollo craft now consists of the command module, where the men are, followed by a tool and supply shed called the service module, and in back a portable garage for the second family vehicle, the lunar module.

Apollo and Allis: the ship going to the Moon contains the most advanced electrical equipment money can buy. The command module, containing two million parts, is a movable electrical grid zipping away from Earth at an initial 23,000 miles per hour, as fast as humans have ever gone. Apollo's technology cousin, Big Allis, has just as many parts but doesn't travel anywhere. The view from where the astronauts sit in the crew compartment looks like what the dispatcher at a Allis' control room would see: a panel covered with indicators, sensor displays, digital readouts, control buttons and knobs, and nearly 600 switches. The available power amounts to about 2000 watts, about what a large house uses at the dinner hour.

The energy source for this extraterrestrial substation sits behind the astronauts in the service module and consists of fuel cells, devices in which oxygen and hydrogen are combined to make electricity; this same process might someday power hydrogen cars on Earth. (On the Apollo 13 mission, one of the oxygen cans will explode---possibly due to an electrical short---and the remaining onboard electrical capability will prove barely enough power to get the astronauts back home safely after a harrowing ride around the Moon.)

In July 1969, as the temporary lords of space hurtle toward the Moon, Prince Charles of Britain, humble on bent knee, is invested as Prince of Wales by his mother the Queen at Caernarvon Castle. Watched by millions, the Prince of Wales is soon eclipsed by Senator Edward Kennedy who, accompanied by a young female staffer, accidentally drives off a bridge, sending his car into the water. He struggles to the surface, swims to shore and dazedly walks away from the scene and does not notify authorities until later the next day. His companion drowns in her car seat and an investigation is launched.

A quarter million miles overhead, Apollo arrives on station and separates into its two component parts. The main craft, *Columbia*, remains parked in an orbit 69 miles above the Moon's surface, while the smaller craft, *Eagle*, sinks to an orbit of only ten miles. *Eagle* is but a subcontinent of Apollo but is fully self-contained. Its internal grid, the grid being brought to the Moon, is powered by batteries. In the lunar vehicle, the two astronauts, Neil Armstrong and Buzz Aldrin, are anxious but confident, eager but professional. Both have combat experience, but here they have no rivals, no enemies. No one is shooting at them. An unmanned Soviet probe is lurking in lunar orbit, but is not in the way. At this moment, American soldiers are fighting in

Vietnam, El Salvador troops are in Honduras, and Israeli fighter jets are over Egypt.

Grid Descending

Allis and Apollo: the giant generator in Queens was at that time the high-water mark of steam-electric technology, just as Apollo represented the peak performance of aeronautical and astronautical engineering. Allis was the most visible asset within the grid founded by Edison, just as Apollo was the prime accomplishment of the NASA system, founded on the work of people like Werner von Braun and Robert Goddard. Both projects---Allis plus all the electricity sent in all the grids of the world, and Apollo and all the ancillary craft and satellites put into orbit---were human feats on the scale of Egypt's Pyramids. But on July 20, all eyes are on Apollo.

Elevation of 50,000 feet. The landing phase of the mission begins when the descent rocket comes on. Electricity flows to an onboard gimbal, which starts to sense the craft's center of gravity so that the rocket firing can be adjusted to give just the right amount of counterthrust, a process that can be compared to trying to balance a broom handle in your palm (ref 10.38). Once the gimbal and computer have sorted out this balance business the rocket can be throttled up. The rocket is being used as a brake, slowing the craft and causing it to plummet further. The rest of the astronauts' ride down will extend 300 miles horizontally, 50,000 feet vertically, and take about 12 minutes. It's going to be the thrill of their lives.

In the vacuum of space there are, fortunately, no aerodynamic forces straining to rip *Eagle* apart. There will be, however, electrical and guidance problems lying in wait, and the pilots will need every last drop of agility built up in their thousands of hours of training. And helping the pilots will be the onboard computers.

43,000 feet above the Moon. Even as it falls, *Eagle* pitches up a bit so that the radar beams, shooting out of its lander legs, can better sense the onrushing lunar plain below. The craft shoots across the landscape in a shallow diagonal, with the bottom of the lander going first. The men just now start to feel their own weight again for the first time in four days. The return of muscle tone is a sensation that no terrestrial grid operator ever experienced.

Allis and Apollo: both have their own local control rooms---Allis at the Ravenswood plant in Queens and the astronauts' own crew cabin. Both also have a remote master control room---Allis' electricity is ruled by the Con Edison's energy center a mile west in Manhattan, while

Apollo commands come from 238,000 miles away in Houston.

In 1969, computers are not as great a factor as they would later be in running in operations on the grid or in space. That is not to say they weren't important. Truly, at this moment, *Eagle's* onboard computer is vital. It does a lot of the split-second calculations that the over-pressed astronauts cannot perform. It keeps track of the approaching surface, initiates appropriate rocket thrusts, and senses and actuates dozens of other subsystems. It does all this while staying within a tight budget of watts.

The computer, in summary, formulates a situational awareness of the mission at the local level, which it dutifully reports to its master in Houston and to the humans closer at hand. It tells them how things are through a variety of alarms and indicator lights. It might not have the aplomb of Hal, the computer running the mission in the movie *2001: A Space Odyssey* (released only the year before), but it does seem at times to have a personality of its own.

35,000 feet. Suddenly things change. Complexity intrudes. Small perturbations have occurred. Let's see if they turn into large disturbances. An alarm goes off and the data screen goes blank. The computer is not keeping up with events. It's been such a smooth ride till now. Why this? Rocket, gimbal, thrusters, radar data are all flooding in and decisions must be made. The craft seems to be proceeding on course, but the astronauts want to know the meaning of the alarm. Houston, what's going on?

The word telemetry means metered information traveling far; in this case the data in front of Armstrong and Aldrin also goes to Houston, 238,000 miles away. It takes a second and a half to get there, so reality in Texas and at the Moon is three seconds apart. The data travels from *Eagle* by antenna to an antenna in Goldstone, California, and then over to Houston. Word then goes back in the opposite direction: "Go," meaning proceed. The astronauts listen to Mission Control, they accept this judgement from afar, but both men look over at the Abort button on their console.

Allis and Apollo: in 1965 Edwin Nellis, in the Con Edison control room, had only minutes to decipher perplexing electrical readout. Should he stick with the mission---keep the Eastern Interconnection going---or should he abort? His indecision helped to snatch the grid away from millions. Now in 1969 Neal Armstrong and Buzz Aldrin, essentially flying a compact, rocket-powered electrical grid dropping down out of the black, also must make sense of perplexing electrical readout.

Another warning light comes on and another ripple is sent through their nervous systems.

They loft another query toward Houston. Moments of silence shroud the hurricane of split-second thinking occurring at the far end. Encapsulated in radio waves and sent Moonwards, another Go comes back out of the vacuum. Ignore the computer, the men are being told. The astronauts obey orders. Both have been to war, both have fired at enemy craft. Neil Armstrong has been shot out of the sky. These men want to get to the Moon's surface but they also want to live. They could activate the Abort button, jettison the lower half of their own craft, and shoot back up toward *Columbia*. But no, they hang tough.

20,000 feet. Slower, lower, closer, more vertical. Engine, thrusters, all seemingly working properly. The horizon now climbs into view in their triangular windows. Another alarm, more tension, and another Go from Houston. They must perform a landing in the face of doubtful data.

500 feet. Here's where all that training proves itself. Here's where the bio-electricity flowing through the passengers made of flesh has to override, or at least supplement, the electrical judgements made in the onboard computer made of silicon. Software from 1969 has gotten them this far, but no further. Neil Armstrong takes over manual control of the craft. He does not like the view out the window. Damn, but they've overshot the landing field chosen for them. He slows the descent, stretches out the landing approach, and like a homebuyer looking for something better, fly the thing sideways like a helicopter, away from this rockpatch strewn with boulders. He wants a level surface, both for a safe landing and for a safe departure later on.

160 feet. Some of the electrical messages the astronauts receive are ignored, but others have to be taken very seriously: the low-fuel light comes on. The extended landing maneuvers are taking their toll. The voice from Houston breaks in to inform them that they have 60 seconds of fuel left. Armstrong is being picky. He wants to set down in just the right place.

30 feet. The silent rocket thrust is kicking up dust now. Houston: 30 seconds of fuel left. Buzz looks at the Abort button again. As far as we know, nothing living has ever visited this corner of the universe till now. Neil eases her down.

The merest mechanical touch is all it takes. The news naturally arrives electrically: a circuit is closed, a signal flows to the dashboard, where the blue contact light comes on. Houston, where the controllers are blue in the face, believes the ship has landed. That's what their monitors tell them, as they sit a quarter million miles away. But they're 1.5 seconds out of touch, and they ardently want confirmation from the guys themselves. After a moment or two by the clock and several heartbeats, the words Houston and the world long for, finally comes. "Houston, *Tranquility Base* here. The *Eagle* has landed." They weren't a moving vehicle anymore. They were a Moon base, a temporary colony, a fixed thing on a worldly body other than Earth.

Among the myriad plans and facts and expectations the astronauts had digested was the prediction that in the instant after touchdown and engine shut-down, the men would feel the sloshing of extra fuel in the tank as the craft settled into repose. But there was no slosh. When the voyageurs finally washed up on the shore of their new land, only 20 seconds of fuel remained. *Eagle* had been running practically on fumes (ref 10.39).

Tranquility Grid

In 1969, who had the grid? In China, where they took no notice of the Moon landing, some people in cities had it; outside the cities, far fewer. In India, it was the same. In India, Members of Parliament spontaneously stood and cheered Armstrong and Aldrin. In Uganda only a few had the grid. In Ohio everyone had the grid and everyone knew what had happened on the Moon.

How much did electricity cost in 1969? Depends on where you were and what you were doing. If you were camping and using a flashlight with AA batteries, electricity might cost a hundred dollars per kilowatt-hour. If your power supply were a special-made battery, such as the one in a hearing aid or lunar module, it could cost a thousand dollars or more per kWh.

Apollo's battery-powered electricity was expensive. Allis electricity was cheap. Consolidated Edison's newsletter, the one sent around while Aldrin and Armstrong were on the Moon, provides a detailed cost comparison between the price of everyday things in 1946 and 1969. For example, a one-pound grapefruit went from 6 cents to 14 cents. Cost of an airplane flight from New York to Detroit: up from $22 to $33. Simmons Innerspring Mattress: up 200%. New York subway fare: from 5 cents to 20 cents, a whopping 300% increase. The only thing that went down in Con Ed's study was (and this is supposed to be a pleasant surprise) the cost of electricity: *down* 17%, to about 4 cents per kilowatt-hour (ref 10.40).

Allis and Apollo: Allis electricity is at the cents/kWh level because the generator can take up all the space it wants, burn coal at its leisure, and amortize its expenses over a customer base of millions spread across the vast internal energy sea of the Eastern Interconnection. Apollo electricity is at the $1000/kWh level because it has no generator. Instead it depends on stored energy and has a customer base of two. Its grid is not an energy sea but an energy puddle nestled in the middle of the Sea of Tranquility.

Since that battery won't last forever---in fact, not much more than a day or two---the men on the Moon are anything but tranquil. Having rested some hours after their nailbiting descent, Neil Armstrong and Buzz Aldrin were now about to take a walk. The visit wouldn't be official until human footprints had been impressed into the gray carpet of dust outside, the debris of 4 billion years of meteor collisions. Armstrong is at the open hatch, trying not to knock things around in the cabin as he exits. He's wearing a special traveling suit, the most expensive garment in history, provisioned with its own electrical network, a home away from home away from home.

In Mexico City, the grid is converting from a frequency of 50 cycles per second to one of 60 seconds per second, just like the Yankee grid to the north.

In New York's Central Park and London's Trafalgar Square, giant video screens are set up and crowds are gathered around to watch that historic step. One fifth of all humans alive are watching TV or listening to radio at this moment---a very high degree of tuning-in, you might say. The Pope has used the Vatican telescope to look at the general lunar landing zone. The Emperor of Japan is watching from his private estate. President Nixon is by his telephone, waiting to make what he will call the most historic phone call of all time. Neil Armstrong climbs down his strutted gangplank into the Sea of Tranquility, sinking to the depth of less than an inch.

At this most watched event in history, electricity plays its part. Consolidated Edison notices that demand for television-consuming electricity is about 200 megawatts above normal. The surge in Tokyo goes up even more. In Iran, on a rickety black-and-white set, the young Massoud Amin watches the lunar steps. He is so impressed by the spectacle that he tells his parents he wants to become an engineer.

On this momentous occasion, *The New York Times* asks a number of prominent people, all known for their thought-provoking pronouncements, to add their perspective to the already swelling chorus of public sentiment. Most of the essays take the time to face the question of whether the whole exercise has been worth the tremendous expense. For Lewis Mumford the mission has been nothing more than a symbolic act of war:

> *In order to make this misappropriation of public funds and human energies acceptable, the Space Agency has turned the Moon landing program into a national sporting event whose excitement is augmented by the fact that as in speed racing, it provides a morbid thrill in the ever-present possibility of a*

> *spectacularly violent death (ref 10.41).*

Eric Hoffer, who has had an unusual career as longshoreman-turned-philosopher, argues that we would be wrong to spend money only on the necessities of life:

> *The necessary has never been man's top priority. The passionate pursuit of the nonessential and the extravagant is one of the chief traits of human uniqueness. Unlike other forms of life, man's greatest exertions are made in the pursuit not of necessities but of superfluidities. Man is the only creature that strives to surpass himself, and yearns for the impossible.*

Flying to the Moon is impossible. So says a 115-year-old woman in Japan. The woman is so old that she was alive when a ship came into Edo Bay, a type of armor-plated vessel that had never been seen before. The American commander, Admiral Perry, and his men in white suits, demanded that Japan open her port and her markets to commerce with the outside world. When asked for her venerable impression of the Apollo exploit, she says that it couldn't have happened. The Moon is a goddess to be worshipped, she says sincerely, not a place to be visited (ref 10.42).

Putting a man on the Moon? Pablo Picasso's attention, as always, is on his paints and pictures. Here is his entire essay on the subject: "It means nothing to me. I have no opinion about it. I don't care."

The Dalai Lama, asked for a response, cites the Buddhist belief that other civilizations, some of them more advanced than our own, existed in the universe. He hoped that we might someday open communications with these far-away cultures. In the meantime, it would be wonderful if the Moon experience led to more mental peace.

The men on the Moon harvest rocks and plant a seismometer on the surface. Then they hoist themselves back into their portable home, their "base," and it's all homeward bound from there. To reduce the weight, they've thrown those heavy packs out the hatch, those back-mounted water/oxygen/electricity supply chests that had sustained them during their hike in the dust. The first electrically-recorded scientific result from the Moon itself comes to Houston and is then relayed back to Tranquility: the plop of the discarded backpacks into the lunar dust was picked up by the seismometer.

Apollo and Allis: the part of the electrical grid that remains behind on the Sea of Tranquility, the seismometer, will shortly begin to overheat. Just about that time, back at the electrical grid attached permanently to Queens, New York, Big Allis will develop a short circuit, and be taken out of service.

It has been said that the Apollo program was the culmination of the Industrial Revolution (ref 10.43). Just think of where *Eagle* is: it's sitting on the Moon, with two living, expectant creatures inside. Watt and his engine, Edison and his energy-by-wire, Tesla and his motor, Goddard and von Braun and their rockets, would be proud. And let's not leave out the Chinese with their compasses and gunpowder, or the Indians and their numerals, or Arabs and their algebra.

It won't be a culmination, however, without a safe trip home. *Eagle* has many redundancies, and why not, since if you're on the Moon and a vital component doesn't work it's not as though you can order a replacement. So, for example, the electrical plant for the craft consists of two silver-zinc batteries, either one of which would get the mission done. The one big thing for which there is no redundancy is the ascent rocket that lifts *Eagle* back up for a rendezvous with the mothership *Columbia*. And the rocket doesn't fire without the enabling electric signal, and the signal doesn't flow forth unless that switch on the circuit breaker is closed, and the astronauts notice now dishearteningly that the switch has broken off, probably when one of the big backpacks swiped against it.

In an alternative universe, the switch is not found, the circuit stays open, electricity does not flow, the rocket goes unfired, the astronauts search frantically until their oxygen runs out, and millions of people back on the Moon's blue companion world would mourn. In the universe we know, however, things happen differently. The switch is not found but a felt tip pen does the job. The circuit is closed, the countdown proceeds, and the liftoff is perfect (ref 10.44). If you had been there it would have seemed absurd. The rocket's red glare would be evident but no roar. There would be no sound since the flame had no air to set vibrating.

Apollo and Allis: both represent terminal technology. Look at what happened over the next few years. A few steam-powered electric generators larger than Allis were built, but then the bigger-is-better approach ended. As for Apollo, five more ships would arrive on the Moon. A total of six lunar landers were left behind in the dust. A total of twelve men, a corps the size of a jury, strode the gray plains. No one since has paid a call.

The Grid in the Head

Where did the electrical grid come from? We've seen where it's been---Uganda, India, even the Moon. But where's the starting point? This narrative might have given the impression that the grid began in the 19th century with individuals like Edison and Tesla. To be more fundamental, though, one should go back a thousand years, and then a hundred thousand years before that.

An electrical grid did operate in those early times. In fact, it was, and still is, the most important of all the grids, the one inside your skull. Several times this book has referred to the human nervous system, usually in a metaphorical way, while making some point about the conventional, electrical utility grid. Now it is time to reverse the perspective and use the utility grid to help describe the neural grid.

The functioning brain, assisted by the rest of the central and peripheral nervous systems, constitutes a formidable electrical network. Like the utility grid, the neural grid has wires---an estimated one hundred billion neuron pathways---as many cells as there are stars in the Milky Way. Moreover, each neuron can form as many as a thousand linkages to other neurons. Like the utility grid, the neural grid carries enabling waves of electricity; signals are passed along the nerve cells as pulses of chemical activity. The speed of these pulses, up to about 300 feet per second, isn't close to the speed of light but fast enough to regulate the moment-by-moment functions of the body: breathing, seeing, heartbeat, sense of balance, and so forth.

An even more glamorous use of the bio-electrical grid is to energize the mental state we call consciousness. Without the neuro grid we wouldn't have the utility grid or the telephone grid or the Internet or any electrified network. All these grids are *made* things. They come late in the long stretch of historic and pre-historic time, during which men and women made many things: locomotives and steam engines; and before that aqueducts and looms; and before that pyramids and ovens; and before that clothing and bread and the wheel; and before that spears and stone hatchets.

One can say that man made tools and that, in a certain sense, tools made man. According to this line of reasoning, a large factor in the difference between humans and other animals is the much greater human use of tools. The very art of making and using tools might have spurred intellectual development over evolutionary time, leading to better tools, encouraging further mental development, and so on in a positive feedback loop of advancement. First the wheel, later high voltage.

Where did the electrical grid come from? Is it just one more of man's most recent and more elaborate tools? Did the use of early tools make man more human, more intelligent, less like the other animals? This kind of question frequently engaged Lewis Mumford. In locating the origins of our industrialized culture, he preferred to credit 13th century mechanical clocks as being more pivotal than 18th century steam engines, insofar as clocks began the centuries-long process of acclimating humans to a machine rhythms. Likewise, in pondering aspects of human nature which facilitated our species rising above mere animal status, Mumford preferred to credit out playful disposition---our desire to devise games and rituals and myths---more than our propensity to make tools.

In other words, Mumford says, before manual dexterity came mental dexterity. Before man the maker (Latin: *homo faber*) came playful man (*homo ludens*). The greatest human accomplishment was not the development of agriculture or the discovery of fire or the use of stone axes. It was the very act of becoming human, of coming into a state of self-regarding consciousness, a supreme process that probably took a million years.

> *The technological feat of escaping from the field of gravitation is trivial compared to man's escape from the brute unconsciousness of matter and the closed cycle of life (ref 10.45).*

Where did the electrical grid come from? First came tools, then agriculture, then cities, much later steam power, then the grid for sending telegraph and telephone messages; later still the Edison grid for supplying energy for light and power, then radio and computer and Internet. Now move in the other direction. What did we have before we had tools?

> *...ritual and mimesis, sports and games and dramas, released man from his insistent animal attachments; and nothing could demonstrate this better, I would add, than those primitive ceremonies in which he played at being another animal...Long before he achieved the power to transform the natural environment, man had created a miniature environment, the symbolic field of play, in which every function of life might be re-fashioned in a strictly human style, as in a game (ref 10.46)*

Where did the electrical grid come from? To see early attempts at a circuit diagram, a symbolic starting manifestation of the ingenuity that would later lead to Big Allis, Mumford might suggest you visit those 30,000-year-old caveman drawings in Spain and France. Our present electrical grid is certainly a handy tool, but it might serve, at some deep level, as part of a ritual or elaborate game.

Some of the best curiosity-driven inquiry, the kind that leads to x-ray studies revealing the structure of DNA, or MRI scans mapping activity in the brain, or observations of distant galaxies implying that the universe as a whole is expanding, is performed, generally, by people---scientists and, in their realm, the great artists---who seem to be having *fun*. Much of this great scientific and artistic enterprise is supported by the electrical grid and by other grids. However, none of these grids, says Mumford, are as important as the neuro-electrical grid in the head:

> *But it is not by the light of burning wood that one must seek ancestral man's source of power: the illumination that specifically identifies him came from within. The ant was a more industrious worker than early man, with a more articulate social organization. But no other creature has man's capacity for creating in his own image a symbolic world that both cloudily mirrors and yet transcends his immediate environment. Through his first awareness of himself man began the long process of enlarging the boundaries of the universe and giving to the dumb cosmic show the one attribute it lacked: a knowledge of what for billions of years had been going on (ref 10.47).*

Where will the grid go next? We can't say. We can be confident, however, of the resourcefulness and resilience of that most valuable form of bottled lightning, human consciousness. Lewis Mumford said that man's greatest task was to become more human, by which he meant more aware of himself and of his surroundings. And maybe right now, in some corner of India or China, a new Faraday might be seeing something out of the corner of her eye. She might be having a remarkable flicker of recognition, the kind that leads to a new grid we hadn't thought of before.

28 September 2005

Chronology

100 Grid Developments Recounted

Antiquity---Rudimentary knowledge of electric and magnetic properties is gathered by the Chinese, Greeks, Romans, and others

1600s---William Gilbert's "De Magnete" (1600) describes static electricity and suggests that the Earth itself is a magnet. Otto Von Guericke (1660) develops machines for storing charge and for producing light from electricity

1700s---More experiments on conduction and charge storage. Ben Franklin (1752) and others demonstrate that lightning and electricity are related.

1800---Alessandro Volta develops a battery and demonstrates continuous current flow.

1820---Hans Christian Oersted shows that electricity can generate magnetism

1831---Michael Faraday and Joseph Henry independently show that magnetism can generate electricity. Thus are born the first primitive electric generator and transformer.

1844---A commercial telegraph system, including grids of wires, is promoted by Samuel Morse.

1865---James Clerk Maxwell develops the mathematical theory of electromagnetism.

1867---Zenobe Theophile Gramme develops a practical DC generator.

1870s---More electrical devices: Alexander Graham Bell and Elisha Gray separately invent the telephone (1876); Thomas Edison invents a "quadruplex" system (1874) of sending 4 telegraph signals on the same wire; Charles Brush pioneers networks of arc lights for street lighting (1877); Edison invents the phonograph (1877).

1876---Edison sets up his lab, his "invention factory," in Menlo Park, New Jersey. This will be the scene of many important electrical developments, including work on the phonograph, filament light bulbs, generators, and all the switching, control, and transmission gear needed for operating a full electrical network. He forms the Edison Electric Light Company (1878) to perform the needed research and development for creating the grid.

1879---A practical filament light bulb is invented separately by Edison and Joseph Swann.

1879---A 90%-efficient dynamo, referred to as "Long-Legged Maryann, is marketed by Edison.

1880---The Edison Electric Illuminating Company is formed to carry out the utility functions of supplying electricity to New York City.

1881---The Paris Exhibition is an important showcase for promoting grid schemes and components. Prominent displays show off the products of Swann, Siemens, Edison, and other others.

1879---Early (DC) electric grids operate in Menlo Park (NJ) in the US (1879), Godalming in the UK (1881), at Holborn Viaduct in London (1882), and Friedrickstrasse in Berlin (1884). A hydroelectric-powered grid operates in Appleton, Wisconsin (1882).

1882---The most important early grid is the one opened by Edison on September 4 on Pearl Street in lower Manhattan in New York. This is the first lasting, substantial city grid supplying electrical energy to a diverse customer base for a variety of uses, such as lighting, signaling, and torque.

1882---MIT offers a 4-year course of study in electrical engineering. A separate department for that purpose is established in 1902.

1882---Lucien Gaulard and John Gibbs develop transformers, making AC electricity practical.

early 1880s---Steam turbines are invented. Eventually they will replace the less efficient reciprocating-motion form of steam engine for producing electrical power.

early 1880s---Electric streetcars in Germany, US, and elsewhere.

1883---Edison observes that electricity can flow from one electrode to another across empty space. This "Edison effect" will later become the basis for electronic devices.

1886---George Westinghouse introduces the first AC grid in the US, in Great Barrington, Massachusetts.

1888---First practical AC electric motor and "polyphase" electricity system are patented by Nikola Tesla. With an effective AC motor in existence, there is little now that can prevent AC from taking over from DC as the principal form of electricity.

1888---Rotary converters are invented; they help to turn AC power into DC power, allowing utilities to employ AC technology even as they are phasing out their DC equipment.

1890---January 3, New York's first blackout occurs when the Pearl St. power station is gutted by fire.

1891---Long distance transmission of AC electricity: in Germany, 3 kilovolt power is sent 110 miles to an electrical exhibition in Frankfurt.

1891---The number of US central station systems that use Westinghouse's AC power surpasses the number that use Edison's DC approach.

1892---Edison's company is merged with the Thomson-Houston company to form General

Electric (GE), which controls three-fourths of the electrical market in the US. Edison is on the board of directors but no longer exercises essential control over events.

1893---Universal electric supply system, introduced by Westinghouse, allows one central generator to supply voltage to all kinds of loads, obviating the need for specialty generators.

1893---At the World's Columbian Exposition fair in Chicago, Westinghouse's AC electricity triumphs over Edison's DC electricity.

1893---Charles Steinmetz develops the mathematical methods for studying the behavior of AC currents in complex circuitry.

1896---The largest electrical project yet, the hydroelectric plant at Niagara Falls, sends high-voltage AC power to Buffalo, 26 miles away.

1898---Samuel Insull, speaking at the meeting of the National Electric Light Association (NELA), calls for lower electric rates and a more diverse customer base as ways of promoting a greater use of electricity. He extols the practicality of monopoly utility service operating under state regulation.

late 1890s---More precise metering provides better data on which to plan a utility's output.

1899--A national electrical code is established in the US, setting standards for electrical components and procedures.

1900---By now, most electrical grids have settled on 3-phase AC power as the standard type of electrical operation.

1900---Only about 5% of factories in the US are electrified, but already this accounts for half of all electricity consumed, indicative of the increasing use of electricity for powering machines rather than for lighting.

1901---Guglielmo Marconi transmits signals via radio waves from England to Newfoundland.

1903---Insull installs the first large turbogenerator, with an output of 5 megawatts, in Chicago, and this is a for a time the largest electrical generator in the world.

1904---John Fleming invents the electronic "valve," so called because it allows electricity to flow in one direction only. Also called a rectifier or diode, the valve employs two electrodes and exploits the Edison effect. Lee De Forest (1906) adds a third electrode to the diode to form a "triode." Placed in a device now called a radio tube, the triode design allows for the amplification of weak electric signals, and this becomes the foundation for the electronics industry.

1907---Public utility commissions, to regulate monopoly electrical operation, are set up in New York and Wisconsin.

1908---Long distance high voltage transmission at 100 kilovolts is achieved. Later, even higher voltages were put into use: 240 kilovolts in 1930, 345 kilovolts in 1953, and 750 kilovolts in 1967.

early 1900s---Handy electrical appliances are developed: electric elevators (1889), fluorescent tubes (1896), vacuum cleaners (1907), washing machines (1907), air conditioners (1911), refrigerators (1913).

1910---Insull creates the Public Service Company of Northern Illinois, comprising five large utilities. Such holding companies come to control more and more of the power production in the US. He begins extending electrical service to rural towns outside Chicago.

1912---The Edison grid in New York City reaches every street in Manhattan and the Bronx.

1920---Vladimir Lenin announces plans to electrify the USSR. Within 20 years the Soviet Union moves from having a very primitive grid to being the second largest electrical producer in the world.

1920---First broadcasts of the first regular radio station, KDKA in Pittsburgh. Networks of stations come a few years later.

early 1920s---Confederations of utility companies, seeking to even out their load curves and to provide extra emergency production capacity, result in larger and larger regional grids. Examples: Bavaria in Germany (1924), UK (1926), and in the US, Carolinas/Georgia/Tennessee (1910), Connecticut (1922), Pennsylvania/New Jersey (1927).

1925---Chicago is the most electrified city in the world, with an average per capita electrical consumption approaching 1000 kilowatt-hours. Up to 90% of homes have electricity.

1926---In Great Britain Parliament creates a national grid scheme, overseen by a Central Electricity Board.

1929---The largest generators are now at the 200 megawatt level. Later milestones: 450 MW in 1960, 1000 MW in 1965, and 1500 MW in 1975.

1929---Scientists at GE and MIT devise a "network analyzer," a sort of rudimentary analog computer, for simulating the behavior of complex electrical grids.

1930---Electrification of US homes reaches the 70% level. In 1910 it had been only 14%.

1930s---The New Deal in the US confronts the effects of the economic depression and the stock market crash which brings down Insull's power trust (the largest bankruptcy in history up to that point). Legislation highlights: creation of Tennessee Valley Authority (1933), Public Utility Holding Company Act (1935), Federal Power Act (1935), Securities and Exchange Commission (1935), Rural Electrification Act (1936).

1933---A 138 kilovolt transmission link is complete between Niagara and New York City.

1935---Rural electrification generally lags behind that for cities. In Holland farm electrification is at the 95% level but only 11% in the US.

1936---Consolidated Edison is the new name for the reformed company distributing electricity, gas, and steam heat to residents in New York City and surrounding areas. Con Edison is for a long time the largest private utility in the US.

1939---The World's Fair in New York, visited by 45 million people, is typified by "The World of Tomorrow," a display extolling electricity. The Fair also features demonstrations of 10-million-volt artificial lightning and an early form of television.

1945---War production claims more and more electrical energy. The TVA, now the largest producer in the US, provides more than half its electricity to the military, much of this going toward the secret project to build an atomic weapon.

1946---Nationalization of the grid in France. UK in 1947, India in 1948, Italy in 1962.

1948---The transistor is invented. Later it becomes the basis for all electronic devices, such as integrated circuits (1958), microprocessors (1971), and personal computers (1980s).

1954---A 5-MW prototype in the USSR is the first nuclear reactor producing commercial power. Other reactors debut in Calder Hall, UK (1957) and Shippingport, PA (1958).

1957---Con Edison's peak electrical demand, for the first time, occurs during the daytime rather than at night.

1961---Power is passed between the British and French grids via a cable beneath the English Channel.

1962---Con Edison keeps expanding its facilities: it completes the first privately-funded nuclear reactor in the US; starts building the first underground 345-kilovolt transmission line; and completes its computer-controlled dispatch center.

1964---New air quality standards go into effect in the US, limiting the amount sulphur or particles that can be released from stacks.

1965---Con Edison's Big Allis, named after its manufacturer, Allis Chalmers, is the first steam-electric generator to exceed the 1000 kilowatt mark. The machine uses 537,000 gallons of water per minute and produces steam at 1000 F. Its boilers are 15 stories tall and it's stack about 500 feet tall. Fuel consumption is 1000 gallons of oil per minute or 2 million tons of coal per year.

1965---On November 9, an immense electrical failure, effecting some 30 million people, spreads across the northeast US and the southeast portions of Canada. In the aftermath the North American Electric Reliability Council (NERC) is created. Nevertheless, large blackouts continue, including another one in New York City (1977), notorious for the extensive looting which occurred, and one which crippled most of the grid in France (1978).

Late 1960s---Con Edison and other utilities have trouble providing sufficient power to meet a growing demand. On some hot summer days, utilties must lower voltage, leading to "brownouts" or rolling blackouts.

1972---High voltage DC (HVDC) long-distance transmission, with some advantages over AC transmission, reaches the 450-kV level. Power is sent 900 km in Canada.

1973---The war in the Mideast prompts an oil embargo against some western nations, which causes fuel prices to climb steeply. For the first time in decades, electric rates do not decline and electric consumption does not increase. Con Edison fails to pay a dividend to its shareholders (1974). Utility stocks perform poorly and analysts seek for a new business model for running power companies.

1976---Energy analyst Amory Lovins, writing in *Foreign Affairs*, calls for a "soft path" approach to energy usage, one emphasizing renewable sources rather than fossil fuels, more decentralized production, and a greater attention to energy efficiency and conservation.

1977---The Federal Energy Regulatory Commission (FERC) replaces the old Federal Power Commission. FERC's five commissioners rule on interstate electricity matters.

1978---The Public Utilities Regulatory Policies Act (PURPA) obliges utilities to buy power produced by qualified unregulated generation companies. The force of this legislation is much disputed in lawsuits, and at first the independent companies contribute only a small share of power, but eventually PURPA initiates a large revamping of the power industry in the US.

1979---An accident at the Three Mile Island nuclear plant in Pennsylvania, combined with an earlier accident at Brown's Ferry in 1975, increasing concerns over nuclear safety, and ballooning construction costs, cause a turnabout in orders for new nuclear reactors.

1986---The worst nuclear reactor accident cripples the plant at Chernobyl in the Ukraine.

1990---Great Britain begins to reform, or "liberalize," its power industry through denationalization and restructuring measures.

1992---The National Energy Policy Act enlarges the ability of independent companies to sell wholesale blocks of power to utilities and to gain access to the utilities' own transmission lines for "wheeling" power to distant markets.

1996---The California Public Utility Commission votes to deregulate retail electricity sales over a several-year period.

1997---Air conditioners now use half the power needed 30 years earlier. Greater energy efficiency is attained for many appliances.

2000---Carbon sequestration: a company in North Dakota (US) that converts coal into hydrogen-rich gas pipes thousands of tons of carbon dioxide per day to another company in Calgary (Canada) which injects it into underground reservoirs formerly occupied by oil.

2001---The Electric Power Research Institute (EPRI, founded in 1972), issues its "Electricity Technology Roadmap," which (in several editions) serves as a general overview of how the electrical industry might progress. Among its many goals, including a greater exploitation of energy efficient consumption and the production of electrical power with less pollution, the report suggests that by the year 2050 all persons in developing countries should have access to electricity at the level of 1000 kilowatt-hours per year per person. This is roughly the level attained by residents of Chicago in the year 1925.

2001---A crisis in electricity distribution in California, resulting in huge price fluctuations and rolling blackouts, causes the state government to suspend its power deregulation scheme.

2001---Enron, the company that pioneered the trading (as opposed to production of) wholesale power, goes bankrupt.

2001---The largest offshore wind farm, at Middelgrunden, Denmark, produces 85 GWh of electricity. Denmark gets 20% of its electrical power from wind turbines.

2003---On August 14 another blackout in the northeast portion of the US and the southeast portion of Canada effects 50 million people and causes the disappearance of 70,000 megawatts of production. A month later nearly the entire Italian grid fails, effecting 57 million people. Earlier an electrical failure in India (January 2, 2001) effected an estimated 220 million people.

2003---At Baglan Bay in Wales a combined-cycle electric generator, employing both gas turbines and steam turbines, and operating at the level of hundreds of megawatts, attains an energy efficiency of 60%.

2005---A prototype zero-emission power plant, one in which waste carbon dioxide under high pressure is siphoned off, sends electricity into the local grid near Bakersfield, California.

September 27, 2005

Glossary

100 Grid Terms Defined

AC---Alternating current, the type of electricity in which the current flow, or movement of electricity through wires, rapidly reverses itself many times each second. In the US the rate is 60 times per second. In Europe and some other places the rate is 50 times per second.

Ampere---The unit of electric current, abbreviated as amp of just A.

Baseload---The minimum amount of power produced by a utility during the day.

Battery---A two-terminal device for storing energy in chemical form which can later be converted into electrical energy by attaching wires across the terminals.

Blackout---A widespread electrical failure in which many customers lose power.

Brownout---A milder form of blackout in which the voltage supplied to customers is reduced from the normal level, the better to conserve electrical power when generators cannot keep up with the demand.

Bus Bar---The main conductors, usually consisting of thick metal bars, conveying the electrical energy away from a generator and toward a switchyard, where the power can be divided and transformed to a suitable voltage for transmission.

Capacitor---An electrical component for storing electrical charge.

Capacity---The rated maximum amount of power that a generator or utility can deliver. Usually specified in terms of megawatts.

Central Station---A powerhouse where electric power is produced in a generator and sent out to a variety of customers.

Circuit---A complete conducting loop in which electric current can flow.

Circuit Breaker---A device which allows a circuit to be interrupted. When the breaker is in the "open" position current cannot flow. Flow resumes when the breaker is in the "closed" position.

Cogeneration---A process in which both heat and electrical power are produced and used effectively. Sometimes called "combined heat and power" (CHP) operation.

Combined Cycle---A type of electrical generation in which the heat produced in a gas turbine is used to run a steam turbine, thus converting a much greater fraction of the fuel's energy into usable electricity.

Complexity---A property of some physical systems, such as electrical grids, in which the interaction of many coupled subcomponents can allow a small perturbation to the system to escalate into a major disruption.

Conductor---A material which allows current to flow easily.

Current---The flow of electrical charge through a conductor.

DC---Direct current electricity, in which the current flows continuously in one direction at a fixed voltage.

Demand---The aggregate load on a circuit or the power consumed by customers at a particular time or averaged over a certain period.

Demand Side Management---Actively taking into account the usage needs and habits of the consumer when planning electrical output by a utility. Examples: encouraging the customer to use more power at off-peak hours or to employ energy-saving appliances or methods.

Deregulation---The removal or decrease of regulations governing the making, sending, or sale of electricity.

Diode---A component that allows current to flow in one direction only.

Distributed Generation---The generation of electric power in a widespread array of decentralized and often small machines, such as fuel cells, microturbines, solar cells, or wind turbines.

Distribution---That part of the power business in which electricity is divided up into subsidiary circuits or delivered to individual retail customers.

Dynamo---Another name for an electrical generator.

Electric---Anything relating to electricity or to the static and dynamic properties of electrons and charged objects in general.

Electric Intensity---The ratio of a country's per capita electric consumption to its gross domestic product. As such it is an indicator of how efficiently electricity is being used in producing goods.

Electricity---The flow of electrical charge, whether in the natural form of lightning or in the form of a current moving through a conductor---or even through vacuum from one electrode to another---under the action of an electric force.

Electrification---The process of bringing electrical service to customers, whether a home, a city, or an entire nation.

Electromagnetic---Pertaining to the combined effect of electric and magnetic forces acting together. Examples include an electromagnet, in which electricity flowing through wires wrapped around an iron yoke produces a magnetic effect; or the transmission of light, which consists of mutually reinforcing waves of electric and magnetic fields.

Electronics---The application of the "Edison effect"---in which an electric current can move across a vacuum from one electrode to another under the action of high voltage---for a variety of applications, such as the broadcast or detection of radio waves or, in general, the switching or amplifying of electrical signals. Also the name for the industry which produces fast-acting electric devices exploiting electronic principles.

Electrostatic---Pertaining to the properties of stationary electric charge.

Energy---The capacity for doing work or for carrying out a variety of physical actions, such as lighting or heating. Energy can be converted from one type to another and can exist in a variety of forms, such as chemical (energy stored in a battery or in a lump of coal), electrical (energy flowing as a current moving through wires), heat, light, or nuclear fuel.

Energy Efficiency---The fraction of energy stored in a fuel or inserted into a machine which actually results in a practical effect, such as the generation of electricity.

Feeder---A conductor for carrying electricity at an intermediate voltage from the higher voltage of a substation to the lower voltage used in individual households.

Field---The manifestation of electric or magnetic force at any point in space. The value of an electric field at a particular place, for example, specifies the strength and direction of the electric force at that place.

Fossil Fuel---A fuel, such as coal or oil, deriving from the fossilized remains of a living organism. When burned to produce electricity such a fuel will release undesirable gases such as carbon dioxide and a variety of sulphur and nitrous compounds.

Fuel Cell---A device in which a chemical fuel is combined with an oxidizing agent to produce electricity. A fuel cell is not so much a battery---containing its own fuel which is converted into electricity---as it is the vessel in which fuel and an oxidant are combined.

Fuse---A safety component designed to melt, and thus create an open circuit, if a current becomes too high.

Gas Turbine---An engine in which compressed streams of oxygen and gaseous fuel are combusted, with the hot product forcing the blades of a turbine to spin in order (at a powerhouse) to produce electrical energy or (in a jet engine) to produce thrust.

Generation---The amount of electrical power produced by a generator or utility, often specified in terms of kilowatt-hours.

Generator---A machine for converting one type of energy---such as fossil fuel, nuclear fuel, running water, sunlight, or wind---into electricity.

Geothermal---A type of conversion process in which useful energy, even electrical energy, can be derived from the temperature differential between two places inside the Earth, say, at a hot spring.

Gigawatt---A unit of power equal to one billion watts.

Grid---the network or conductors---whether local or regional---over which commercial electric power flows. Sometimes the name applied to the whole infrastructure for generating, transmitting, and distributing electricity.

Ground---The voltage level of the Earth itself, or any universal voltage reference.

Hertz---The unit of frequency equal to one cycle per second. Named for Gustav Hertz, who discovered radio waves.

Horsepower---A unit of power, derived originally from the ability of a horse to produce useful work by turning a mill wheel or pulling a cart. Not much applied anymore to electric products or processes, one horsepower (1 HP) is equivalent to about 746 watts.

Hydroelectric---Pertaining to the conversion of water power at a dam into electrical power.

Impedance---A measure of the complex resistance offered by an AC electric circuit.

Independent System Operator (ISO)---A independent company which oversees the flow of power over a state or regional grid.

Induction---The process in which a changing magnetic field can produce, or induce, an electric current in a nearby conductor.

Insulator---A material which does not conduct electricity well.

Integrated Circuit---An array of electrical circuits, often involving millions of transistors and other circuit elements wired up together on a microchip.

Kilovolt---A unit of voltage equal to 1000 volts.

Kilowatt-Hour---A unit of power used to typify consumption of electricity, abbreviated as kWh.

Kirchoff's Laws---The physics laws that specify how currents will flow in a circuit for certain conditions of voltage and loading.

Liberalization---A term, often used in Britain and elsewhere, to describe the restructuring of the electrical industry by encouraging greater competition.

Linear---A process in which the output is proportional to the input.

Load---The amount of electrical work done by a device in a circuit or the power consumed by a customer or by a whole variety of customers on a grid. At all times the power produced by a generator supplying a grid must balance the aggregate load on the grid.

Load Curve---The graph of power demand on a grid around the clock. Often demand is greatly reduced in the middle of the night and consequently generators will go underused. A utility tries to even out the load curve across the day, the better to efficiently utilize their equipment.

Load Shedding---The process, usually performed only in an emergency, in which parts of a load on a grid are dropped (denied electric service) in order to bring load and generation capacity into balance.

Megavolt---A unit of voltage equal to one million volts, abbreviated MV.

Megawatt---A unit of power equal to one million watts, abbreviated MW.

Microgrid---A grid consisting of a one or a small number of consumers, often powered by a distributed array of generators. Such a grid might contribute power to, or draw some extra power from, a larger external grid.

Nationalization---The appropriation of privately-owned utilties into a government-owned or controlled grid.

Nonlinear---A process in which the output is not proportional to the input.

Nuclear Reactor---A generator in which the energy locked up in the heart of fissile nuclei such as uranium-235 is used to heat steam and produce electrical power.

Ohm---The unit of resistance in a circuit, designated by the Greek letter omega.

Ohm's Law---The physics law which states that the voltage across two points in a circuit equals the resistance of the circuit between the points times the current flowing through that segment of circuit.

Peak Load---The maximum load needing electricity from a utility during the day. Extra generators, some operating only a few hours a day (peaking power plants) might be required to satisfy this high load.

Photovoltaic---Pertaining to the generation of electricity from light, especially in "solar cells."

Polyphase---A type of generation in which electricity is generated in sinusoidally (AC) shaped waves in two or three or even more wires in succession, in such a way that the different waves, or "phases," are offset from each other uniformly. For example, in two-phase electricity, the two currents are 180 degrees out of phase with each other; in three-phase electricity, the three currents are each 120 degrees out of phase with the others.

Power---The ratio of energy transmitted per unit of time. The standard unit of power is the watt, defined as one joule of energy per second. Electrical power is consequently specified in terms of watts or some larger unit, such as kilowatts (1000 watts) or megawatts (1 million watts). Power, used as a verb, loosely refers to energizing a machine or grid with electrical energy.

Power Electronics---That branch of electronics which deals with devices operating at very high voltages or frequencies or power levels.

Power Pool---A confederation of power companies which are wired together in such a way that they can deliver power to each other.

Public Utility Commissions---State agencies that rule over utilities operating in a monopoly mode by setting prices or other guidelines for the pricing and delivery of electricity.

Pumped Storage---The process by which electricity is used to pump water uphill into a storage reservoir at times of low demand, only to be redeemed later at times of peak demand when the energy of falling water is turned back into electricity through hydroelectric action.

Reactor---A device in which certain atomic nuclei, such as uranium-235, are allowed to break apart through nuclear fission, to generate heat, which can then be used to generate electricity.

Reactive Power---A type of power contained in circuits which, owing to the slight lag between the instantaneous voltage and the current flow at any point, is not usable by a load.

Rectifier---A circuit component which turns AC electricity into DC electricity

Relay---A protective circuit element which senses a current or voltage level and, when a fixed limit is exceeded, will activate a circuit breaker in order to protect equipment from harm.

Regional Transmission Operator (RTO)---A neutral and independent company which oversees the wholesale power flow in a regional grid.

Renewable---A type of energy which can be replenished in the normal course of events, examples being solar energy or hydroelectric energy.

Resistance---The load on an electrical circuit offered by an object or machine that consumes or dissipates some of the electricity that passes through it.

Restructuring---The general name for the process of reforming the electrical industry through reducing the amount of governmental regulation pertaining to utilities or through a revision in the way utilities, or independent power companies, carry out the functions of generating, transmitting, and distributing electricity.

Rotor---The set of wire coils which rotate with the central shaft at the heart of an electrical generator.

Semiconductor---A material whose conducting properties lie somewhere between those of conductors and insulators. Semiconductors, because their conducting properties can often be altered quickly by an applied voltage, are invaluable in electronic devices where fast switching or amplification is needed.

Short Circuit---An action or condition in which a closed circuit is interrupted, such as with a break in a wire or the melting of a fuse.

Solar Cell---A device for converting sunlight into electrical energy.

Spinning Reserves---Reserve power generating equipment in the form of generators which are actively spinning but not carrying high power. A utility will maintain such a reserve so that it can be put into use within a few minutes during emergencies when another generator fails.

Steam-Electric---That type of electrical generator in which steam is used to turn a turbine.

Stator---That part of an electrical generator which remains stationary.

Substation---The part of a utility's electrical network where power, made elsewhere in a generator, is divided for distribution into several different circuits and where the voltage can be made higher or lower.

Thermal-Electric---The kind of electrical generation requiring steam made by burning fossil fuel or by fissioning nuclear fuel.

Tidal Generation---The use of ocean or river tides to turn turbines and generate electricity.

Three Phase---A type of generation---the one most often used in generators---in which three waves of AC electricity, staggered by 120 degrees, are sent out into three separate wires.

Transformer---A passive device, consisting of two wire coils wound around a central metal yoke, in which the voltage of electrical power can be altered.

Transmission Line---A line for carrying high-voltage power, often over long distances, from one utility to another or from a generator to some distant load.

Turbine---A spinning bladed shaft set in motion by steam or hot gases which turns a shaft attached to an electric generator.

Uninterruptable Power Supply---A power source which, through backup capability using such things as batteries or flywheels, will always supply steady electricity even if the main grid should fail.

Utility---A company supplying steady electricity to a variety of customers.

Volt---The unit of voltage.

Watt---The unit of power.

Wheeling---The movement of wholesale power from one company to another, sometimes over the transmission lines of some third party company.

Wind Power---The generation of electricity by the wind turning a turbine.

Zero-Emission Power Plant---A power plant scheme in which undesirable byproducts of combustion, such as carbon dioxide, are carefully removed (perhaps under high pressure) rather then vented to the open air.

July 1, 2005

Proposal for a Book Provisionally called GRID
by Phillip F. Schewe

About the Author

A popular book on a subject as complex as the electrical grid should entail all of the following traits: readable technical descriptions, down-to-earth explanations of scientific principles, colorful cultural perspective, a broad understanding of history, and literary flare. How does the author's experience answer to these needs?

---As a scientist (PhD in particle physics) he participated in landmark research, conducted at Fermi National Accelerator Lab, leading to a better understanding of the internal structure of the atomic nucleus.
---As a journalist (writing monthly for *Physics Today*, circulation 120,000, and in *Physics News Update*, a weekly news alert on the web at www.aip.org/physnews/update) he regularly provides fresh analysis of the very latest and hottest research findings coming from the physical sciences.
---As a playwright (his plays have been performed in theaters in New York, Washington, DC, and Dallas) he has gained experience in telling a dramatic story and in looking for telling details.
---As a science popularizer (he has written for the Washington Post and is regularly quoted in newspapers as an expert on physics) he knows how to transform technical subjects into understandable terms. He is often called upon at physics meetings to officiate at press conferences, where he acts as a bridge between the scientific and journalistic worlds.
---He is probably the only person who is simultaneously a member of the American Physical Society, The Dramatists Guild, and the National Association of Science Writers.
---He lives in Takoma Park, Maryland with his wife and two sons. He works at the American Institute of Physics, the largest physics journal publisher in the world. At AIP his job title is chief science writer.

February 1, 2004