National energy planning for the century: The Continental SuperGrid

BY CHAUNCEY STARR

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NATIONAL ENERGY PLANNING for the coming century is a concern for many reasons, and particularly because the future energy framework of the United States will be a major determinant of society's structure and lifestyle, as it is now. This was the stimulus for a paper of mine published last year[1] that recounted, and lamented, the obstacles to energy planning created by society's conflicting targets for energy supply, economic growth, and environment. These strategic conflicts are also the political root of the continuing competition among major programs for national financial support. This article proposes a solution to that challenge to century-long national strategy planning.

Energy technologists today are much too engaged in the short-term, fix-it policies of U.S. society's traditional policymakers. Unfortunately, these policymakers rarely show concern with long-range issues much beyond their administrative term in office. With the U.S. political process concerned with short-term conventional remedies, technologists have an opportunity to initiate programs specifically intended to shape the nation during this century.

If nothing is done, the conventional process shown in Fig. 1[2] will inevitably produce an "in-the-box" projection of today's known options, modified for the century by opinion-based guesstimates of their trends. Many persons (the author included) have published such projections, which differ mostly in their guesstimates rather than in their substance. They do provide a historical trend perspective for a few decades. Unfortunately, the present official efforts to develop specifics for a government energy plan will likely produce such a mundane mix—uninspiring but conventionally defensible. The recent U.S. Department of Energy and national laboratory programs to develop improvements for present energy systems may be helpful. I do not disparage such programs—they help to get the best from what we have. I'm grateful that the past political obsession with eradicating nuclear power seems to have been removed. None of these steps, however, are equivalent to long-range planning. Tweaking our present systems will not achieve the long-range environmental and performance goals that we are all seeking.

- Guidelines for selection of candidate technologies
- Promising generation technologies and their status
- Promising storage and delivery technologies
- Potential geographical locations for promising technologies
- Integration of promising technologies into potential national supply systems (scenarios)
- Ranking alternate scenarios using limited and uncertain knowledge
- Synthesizing top ranking scenarios into a single robust national planning scenario

Fig. 1. The process for conventional planning of electricity supply for the century (Source: EPRI)

Leadership on century-long planning cannot be expected from the government political process. If there is to be an effectively sophisticated direction of technical policy, it will have to come from the scientific and engineering community. Neither government nor the economy's market-based processes will do that. This was learned the hard way from the crippling of the early fast breeder and spent-fuel recycling initiatives. These programs were, and remain, fundamental parts of long-range planning for nuclear power systems.

An unplanned way

The 19th and 20th centuries have shown that unplanned radical innovations arise during a century period from science-stimulated R&D (e.g., electricity, telephone, petroleum-fueled engines, autos, airplanes, nuclear power, semiconductors, biotech, etc.). All these applied science products were initially "outside the box" of their period, but they became the powerful determinants of subsequent trends in technology, social structures, and lifestyles. In this respect, the U.S. military provides an example of preparing for the future, through its Defense Advanced Research Projects Agency (DARPA), by fostering a wide spectrum of "outside-the-box" R&D with the intent of yielding a few fresh military options for decades ahead. Recall that the Internet was a DARPA product.

Perhaps the same can be done with the U.S. peacetime energy strategy. We can seek "outside-the-box" embryonic innovations, and push those that may be potential portals to new energy systems—even if they are only marginally feasible now. As an example, this article presents such an embryonic proposal below. It could have a significant impact on the nation's national energy supply, and contains several technical components that are basic keys to a more imaginative energy future.

The Continental SuperGrid

The limitations of the national electricity grid have been recognized for some time. It is not feasible today to send electricity supplies back and forth between the coal-based East and the hydro-based West, and it is only partially feasible between regions. So, the great value of shifting supply through four time zones is lost. The power losses are too great over such large distances. At issue is hard-core security of supply and economics. The DOE has recently announced that it will initiate a study of the existing grid to disclose bottlenecks and remedies. This is a useful Band-Aid™ step. In contrast, my proposal is to establish an "outside-the-box," highly efficient energy corridor across the continent, a "Continen-

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tal SuperGrid," with local branches delivering both electricity and fuel (Fig. 2). This is an old vision, and new applied science makes it marginally feasible now.

The engineering pieces have had enough scattered attention to provide a roadmap (Fig. 3). Conceive of the corridor as an assembly of bipolar coaxial loops using magnesium diboride (MgB_2) superconductor (Fig. 4). Its core coolant at 25 K is liquid hydrogen, with the hydrogen exiting as a fuel. The electricity and hydrogen are both generated by nuclear power plants spaced along the corridor—perhaps including some of the meltdown-proof small modular reactor concepts (Generation IV), recently assembled by the DOE.[3] Water vapor is the only gaseous effluent. It is a direct-current system, controlled by solid-state electronics. The end result is a system free of fossil fuel and greenhouse gas emissions, with a relatively small ecological footprint and mostly buried underground. The Continental SuperGrid would supplement (not replace) the extensive network of regional gas and electric grids that will clearly be stressed as the U.S. economy grows.

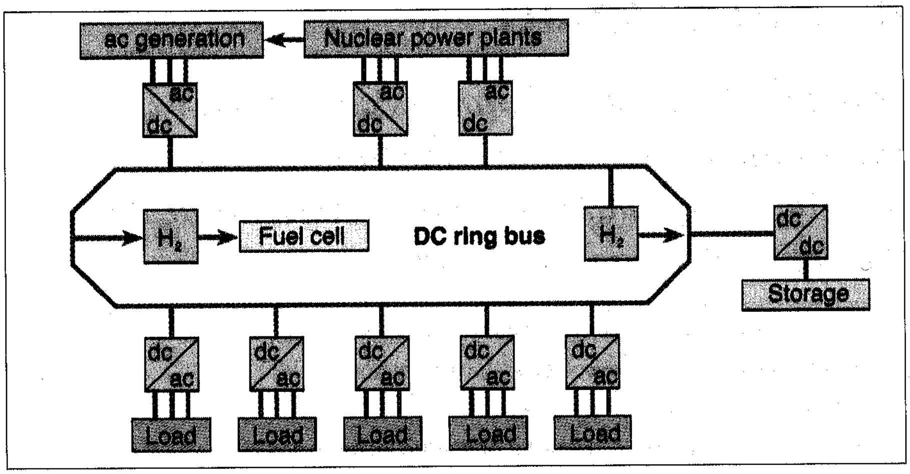

Fig. 2. The Continental SuperGrid (Source: EPRI)

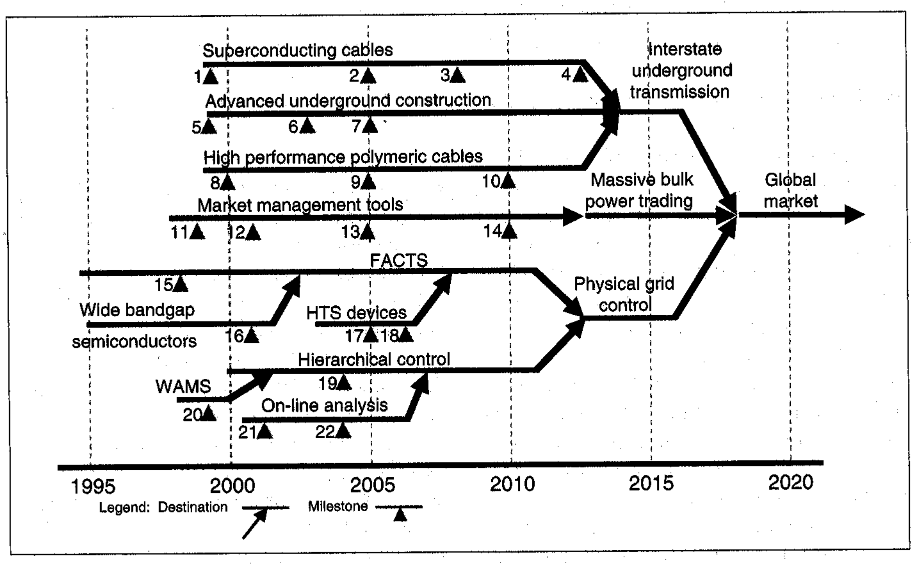

Fig. 3. Roadmap tree for power delivery technologies (Source: EPRI)

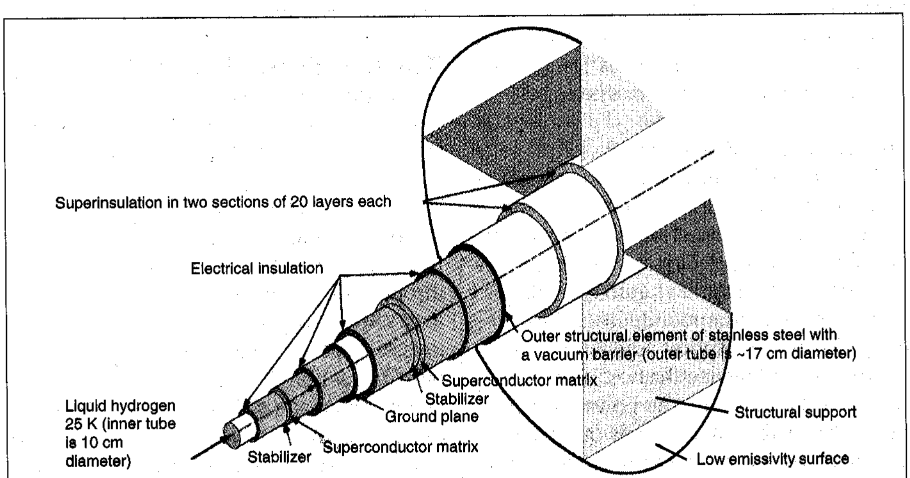

Fig. 4. Design of the MgB_2 DC superconducting transmission line in an evacuated pipe (Source: EPRI)

Technical background

Various aspects of this concept have been seriously considered in past studies—enough to provide reasonable confidence in its future feasibility. To start, there was the 1967 article of Garwin and Matisoo,[4] who tackled a continental-scale 100-GW, DC, 1000-kilometer line based on niobium-tin (Nb_3Sn) at 4 K. This was a sophisticated and detailed analysis of the technical design questions raised by a superconductor line as conceived 34 years ago. A more recent and modest study is the 1997 EPRI study of a 5-GW, 1000-mile DC line (50 kA, 100 kV) using a high-temperature superconductor (HTS) cooled with liquid nitrogen. That paper, authored by Grant, Schoenung, and Hassenzahl,[5] compared the detailed economics of an HTS line with that of a competitive high-voltage DC (HVDC) transmission line. A major finding was that the cost of the HTS wire made the concept noncompetitive. The new low-cost MgB_2 at about 25 K, cooled with pressurized liquid hydrogen, may bring the economics into a reasonably competitive range. Many of the results of these documents, and their long lists of references, provide a feasible framework for the Continental SuperGrid.

The local distribution and control systems for DC power have been addressed in EPRI's 1999 Technology Roadmap series, Power Delivery Module.[6] It suggests a milestone plan for superconducting cables (Fig. 5). In a July 2000 paper, Paul Grant outlined a stand-alone "Cryogenic-Based Energy/Communications Delivery Concept" for an isolated community.[7] It would contain a 1-GW nuclear power plant supplying electricity and hydrogen, in the manner discussed above, and a communication cable.

Most encouraging was the recent proposal of Black & Veatch Corp. and Siemens to construct a TransAmerica Grid (TAG), an 8-GW system pragmatically using coal-fired mine-mouth power plants connected to HVDC and extra-high-voltage AC (EHV AC) transmission lines.[8] This would utilize today's engineering practice for a long-distance electric power system. The TAG proponents maintain that competitive economic performance should be expected. If implemented, it would provide a valuable experience base for the more visionary concept described above, particularly regarding the social and political aspects of such a national project.

The production of hydrogen by electrolysis is an old art. Its combination with nuclear power for an efficient fuel system, particularly for vehicles, has been reviewed by Kruger.[9] It fits well with the hydrogen-cooled energy corridor concept, which might support the environmental objective of hydrogen end-use systems.

Continental SuperGrid scope

In summation, these concept scenarios have not disclosed any "showstoppers" for the Continental SuperGrid. If one adds the vision of magnetic levitation electrified transportation and fuel-cell electric autos, a picture of a futuristic all-electric energy system takes shape. If a hydrogen-fueled motor would gradually replace the internal combustion engine, the reduction of U.S. dependence on oil imports might radically change the nation's foreign policies and commitments. It would be a major contributor to national security by connecting geographically dispersed continental fuel resources. If terrorism remains a risk, all major parts of the system could be underground. Its long-term consequences might make the Continental SuperGrid a 21st century equivalent of the Panama Canal or the first transcontinental railroad.

The Continental SuperGrid would be a professional challenge to both engineers and scientists for the whole century. It would take time to complete, but energy system maturation is measured in decades. It would require a large national investment, perhaps $1 trillion at an average rate of $10 billion/year, including R&D, superconductor cables, and power plants. It would be built on mostly public rights-of-way, so industry, regulators, and politicians would be active negotiators. Funding could come from both the federal government and private consortia. To provide competition and save time, the Continental SuperGrid would be started at both coasts and at selected inland sites. Since it would take decades to complete, many U.S. presidents would share in its progress. I can picture the rhetoric and the symbolic switch-closings as we complete each milestone uniting the energy supplies of the eastern and western United States, and eventually the continent.

- **Superconductors**
  1. Demonstration of HTS cable—1999
  2. Demonstration of second generation HTS cable—2002
  3. Commercial demonstration of coaxial AC HTS cable—2004
  4. Commercial demonstration of coaxial DC HTS cable—2006
- **Advanced underground construction**
  5. SafeNav drilling system commercialized—1999
  6. Surface trenching achieves 2 miles-per-day—2003
  7. Micro-tunneling achieves 500 feet-per-day—2005
- **High-performance polymeric cables**
  8. Demonstration of cable prototype—2000
  9. Commercialization of the cables—2005
  10. High-performance polymeric cables achieve widespread use—2010

Fig. 5. Cable milestones. This figure is taken from EPRI's Road Map for superconductor engineering development, and refers to the demonstration experience with HTS (High Temperature Superconductors—costly oxide compounds cooled with liquid nitrogen). This ongoing experience provides engineering development directly applicable to the proposed use of liquid hydrogen with the inexpensive magnesium diboride. (Source: EPRI)

- Existing technologies that are compatible and/or adaptable with incremental R&D
- Identification of fall-back positions for highly uncertain future promising technologies
- Plausible paths for bridging existing regional systems with the Continental SuperGrid
- Identification of technologies for bridging, such as Cryo-silicon power electronics
- Detailed planning and implementation of R&D to assure availability of these necessary technologies

Fig. 6. Bridging near-term systems with the proposed Continental SuperGrid (Source: EPRI)

Can we make it a living vision in our energy planning?

Let us now return to the constraints on multigenerational programs described in my earlier paper,[1] and consider their influence on the proposed Continental SuperGrid. Assume that the project is started with a detailed plan that gives reasonable assurance that it utilizes the best available information and experience (Fig. 6). During the initial decade, progress may proceed as planned, but eventually new technical issues are sure to appear, requiring more R&D support. Also, during the extended period of construction, there will be new contributions from the cryogenic and tunneling techniques now being explored for physics research facilities, so construction techniques may improve with each leg of the grid, reducing unit costs.

More important, as discussed in my earlier paper, there are social and political interventions that harass any long-term energy project, including the continuous competition for available funds (private, public, national, and local). It is these interventions that make multigenerational projects so uncertain. The Continental SuperGrid will require annual federal financing for decades. The issue will not be feasibility or eventual value, but rather how to keep the project from being derailed. For example, even NASA's space program faces the problem today of competing with the siren song of untried fresh ideas and new targets, such as this one.

Figure 7 lists some of the issues that are likely to arise during the construction of the Continental SuperGrid. They are summaries of my earlier paper collected by my colleague Simcha Golan.[2] This is a formidable list of obstacles, and their combined probability of appearing could discourage all but the most dedicated dreamers. Yet, long-range projects of great difficulty do get accomplished—e.g., NASA's International Space Station. What do they teach us?

A deep and pervasive national commitment needs to be created. Political support needs to cross party lines. A major campaign is required to sell the vision to the public. The selling points for the proposed Continental SuperGrid are:

■ Its hard-core east-west connection to secure electricity supply.

■ The replacement of imported oil as autos move to the electric/hydrogen cycle.

■ The vision of an energy nirvana—inexhaustible electricity and energy fuel.

■ The stimulation given to a multicentury total electricity/hydrogen energy system, a major environmental goal.

■ Developing the technology for a continental system.

■ The reaffirmation of national pride in the United States' technical capability and leadership—like the moon landing of Project Apollo. The Continental SuperGrid is a similar promised dream.

While costs will obviously be debated, it is within the scope of large national projects. The direct costs, however, are secondary to the indirect benefits. Those benefits would include the economic worth of (1) the value of a storable hydrogen-based fuel supply, so important for intermittent renewables; (2) the load flattening arising from the three-hour time difference; (3) the higher capacity factor of each power plant; (4) the intangible but large savings from the foreign policy benefits of continuous reduction in imported oil.

The Continental SuperGrid would be a public good, like the interstate highway system or the Internet. Its value is in the costs and shortages avoided nationally and internationally. The year-to-year financing would likely shift from an initial, mostly federal support to a mix with private funding, as the R&D and system uncertainties are gradually reduced, and the commercial benefit/risk ratio increases enough to attract the free market.

Although such focus on marketing may seem too cynical for pragmatic scientists and engineers, it should be emphasized that multigenerational programs cannot survive without a continuing promotional campaign. The Continental SuperGrid will always be attacked by those who feel their programs are more deserving or threatened. The best start would be for the President to anoint this project as a national priority, as was done with the moon landing project. To quote President Kennedy from his 1961 Special Message to Congress: "... this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space, and none will be so difficult or expensive to accomplish." It is interesting that the Apollo Project's political history showed that the public allure of "impressive to mankind" made secondary the "difficult and expensive" aspect. The lesson is clear.

How might the Continental SuperGrid be born? First, a professional group of believers needs to flesh out the concept with a layperson's description of its basic feasibility and national benefits. This would provide the basis for seeking seed funding for a preliminary engineering analysis. The seed funding might come from a consortium of engineering companies or from private foundations, perhaps as the result of a competition among several consortia. A consortium might be composed of the necessary complementary engineering companies, a national laboratory or two, perhaps a major railroad company interested in offering its right-of-way, and a major financial house interested in future investment opportunities.

Technological:
- Unexpected go–no-go technical issues
- R&D scope greatly underestimated
- Unexpected siting requirements
- Low-level effluent public risk perception
- Unsettled effluent management criteria
- Major earthquake functional survival
- Sabotage/terrorist attack resistance
- National security implications

Economic:
- Cost of money
- Much delayed financing
- Delay of critical support technology
- Imposition of CO_2 sequestration
- Cooling restrictions: air vs. water
- Unexpected regulatory requirements
- Unexpected critical resource restrictions
- Unexpected alternative competition

Environmental health:
- Unexpected air/water/land pollution limitations
- Uncertain global climate-related restrictions
- Vague land and sea use restrictions
- Public radiation exposure perceptions
- Unexpected ecological concerns

Social/public acceptance:
- Unexpected changes in social value priorities
- Unexpected changes in living patterns such as rapid increases in longevity
- Unexpected changes in demographics
- Unexpected public transportation shifts
- Major shifts in city planning
- Public phobias/fear of technology
- Weapons proliferation concerns
- Energy-related national security issues

Fig. 7. Major long-term energy planning uncertainties (Source: EPRI)

The resulting prospectus would become the sales document for an experienced Washington representative (a lobbyist) to push for Congressional hearings. Advisory support for this prospectus might be provided by a private foundation in collaboration with EPRI and other public stakeholders in the nation's energy future. The Congressional hearings might result in a line item in a committee budget to fund a detailed technical study of the first stages of the program. Then the project would either grow with federal funding to underwrite it, or fade away. The Washington political sequence is now well known.

In view of the difficulties listed in Fig. 7, is it reasonable to assume that a substantial multigenerational Continental SuperGrid program could ever be completed? Yes, but it is a close call. It needs a persistent constituency of believers maintaining official attention. The enthusiasm of professional societies would help to keep the pot boiling. Refer again to the history of NASA's space program. For the Continental SuperGrid, it is assumed that R&D could deliver what is proposed. That is the least risk in the proposal.

The Continental SuperGrid is ready today for initiation. So, who is prepared to think big, be persistent, articulate a proactive stance on the feasibility of the dream, and work to get it started?

The big picture

As mentioned earlier, it is not feasible to lay out the specifics of a meaningful energy plan for a century, although it may be done for a few decades. Therefore, the pragmatic policy should be to keep all energy options open, allowing each one to seek its role in a competitive energy mix. This would permit the best of what is available at any time to develop and grow, even when burdened with society's temporary interventions.

An important companion policy would be to seek and accelerate "outside the box" embryonic energy technologies, some of which might substantially alter end-use lifestyle for the public. The EPRI Roadmap provides a start.[6] The Continental SuperGrid is a large-scale example. An even more visionary target would be a low-cost, high-energy-density electricity storage device, equivalent to a gasoline tank. Its availability would radically alter the structure of almost all electrification systems. Other and more imaginative targets can be envisioned.

This type of exploratory R&D program, starting from the applied sciences, should be a major part of the annual federal energy budget. The National Institutes of Health is such a program for public health. DARPA is such a program for the military. Why not create a similar and independent Energy System Advanced Research Project Agency (ESARPA)? It would bring a "be-fruitful-and-multiply" vitality to creation of future options.

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