# Superconductivity: A Look Back and Forward

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One score and ten years ago, or 30 years and counting in less Linconesque units, Georg Bednorz first glimpsed evidence of granular superconductivity spanning the 10-20K range in a mixed-phase sample of the copper oxide perovskite $La_4BaCu_5O_{13}$ (or La-4-1-5-13, for short) while working at IBM's Rueschlikon Research Laboratory. [1] What followed next was 18 months of intrigue reminiscent of the "double helix" period associated with the Watson-Crick discovery of the structure of DNA in 1953.

By late January 1986, Bednorz had been working "off the clock" for more than a year under the guidance of his mentor, Alex Mueller, one of the pioneer IBM Fellows. Mueller had hired Bednorz at IBM after Bednorz completed his graduate studies at ETH Zurich. Mueller had become intrigued by speculations from B.K. Chakraverty (CNRS-Grenoble) [2] and K.H. Hoeck (TH-Darmstadt) [3] that Jahn-Teller derived bipolarons might form the bosonic glue mediating "higher temperature superconductors."

Mueller had by this time served many years as an advisor to the National Center for Scientific Research (CNRS) program at the University of Marseilles on its efforts focused on aluminum and transition metal oxides, principally nickelate compounds. He recognized the electronic structure contained elements of the Jahn-Teller bipolaron model speculations of Chakraverty and Hoeck, and suggested to Bednorz that he try preparing such systems to explore for potential "miracles." This new research, however, had to be performed by Bednorz on personal overtime and was not part of the official IBM Zurich research agenda.

Another CNRS group, led by Bernard Raveau at the University of Caen, published in mid-to-late 1985 its cumulative work on a series of related companion compounds to the nickelates, copper oxides perovskites, as possible high temperature oxygen sensors for cement kilns. [4] The research appeared in two relatively specialized and not widely read European journals on materials research, but Bednorz discovered these papers anyway, hidden amongst the recently shelved journals in the IBM Zurich library, and immediately recognized the work as the possible embodiment of the Mueller, Chakraverty and Hoeck vision.

Concentrating on La-4-1-5-13, which is very difficult to synthesize in single phase (try it yourself sometime!), he found trace amounts of, most likely, barium doped $La_2CuO_{4-y}$ and a resistive transition eventually nearing 30K. This finding ignited another fascinating historical episode in the annals of condensed matter physics…what I like to term "climbing perovskite pillars." It moves from the first measurements in Zurich, 30 years ago, through the quiet submission to ***Z. fur Phys. B*** in April 1986, and on to its publication [5] the following fall. Their findings were quickly replicated by groups at U. Tokyo (Tanaka team) [6], IBM Yorktown (Greene, et al.) [7], the University of Houston (Chu and Wu). By December 1986, a Houston/Alabama collaboration saw signs of transitions in excess of 90K. [8]

The Zurich team, however, was really the first to verify its own discovery. By early September 1986, the team observed the Meissner effect, using SQUID magnetometry, and thereafter published its results, again quietly, in ***Europhysics Letters*** [9] early the next year. By late February 1987, confirmation of high temperature superconductivity in various copper oxide compounds had been achieved by many groups worldwide, including our team at IBM Almaden Research, the first to correctly identify the positions of cations (positively charged ions) in $YBa_2Cu_3O_{7-y}$ (aka, Y-123 or YBCO). [10] This last work resulted in the fundamental international materials processing patent underlying all copper oxide perovskite superconductors with Tc greater than the atmospheric boiling point of liquid nitrogen. [11]

All these events exploded on the world scene at the APS March Meeting in mid-Manhattan, the "Woodstock of Physics," and again the following month during the April MRS Spring Meeting, held in Anaheim near Los Angeles, that I dubbed "the Altamont of Materials" to the press at the time (in honor of the infamous 1969 Rolling Stones concert in the hills east of San Francisco). A ***Time*** magazine cover soon followed, and the attention ultimately culminated

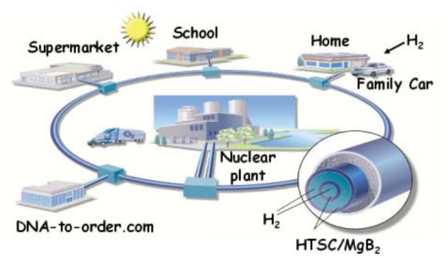


***Figure 1. The "SuperGrid Vision" proposed by Grant and his EPRI colleagues in 2002.22 Reproduced with permission from P. Grant, "Will MgB2 Work?" "The Industrial Physicist," October/November 2001, American Institute of Physics.***

in President Reagan hosting a White House Conference [12] in May that established the very successful (technically) 1987-2011 DOE Superconductivity Partnership Initiative. That era of hysteria was capped by a Spring 1988 PBS NOVA production, "Race for the Superconductor," [13] that won an Emmy for its producer (as well as the cast).

Next there were several years of various news journal publications and speculations predicting both novel paths to the Mecca of room temperature superconductors and anticipating the realization of the current discoveries as embodying the energy efficiency deliverance of mankind.

As has been pointed out in several recent articles in ***Cold Facts*** by yours truly ("Cold Power," [14] October 2015; and "Superconductivity: Will it be coming in from the cold," [15] 2014), we're still waiting, despite two decades of successful demonstrations of HTSC power applications in cables, transformers, SMES and fault current limiters. [16] Perhaps the most successful commercial application to date has been the levitation kit first built by my daughter Heidi as her 8th grade science project in April 1987. [17] It brings to mind the wisdom expressed in the closing paragraph of the Foner-Orlando 1988 February MIT progress report, "Superconductors: The Long Road Ahead": "…a great deal remains to be done."[18] And still does. Incidentally, a component of the pavement of that road to be laid involves greater insight into the pairing mechanism of HTSC, still an open question, although most would agree that phonons, charge density and spin waves all play a role. We also await the development of a density functional tool that would allow the computational design of new "perovskite pillars." [19]

So what could be the eventual practical blessings bestowed by the Rueschlikon revelation? My crystal ball reveals two possible scenarios:

## Exploring the Theory of Everything

Most of my high energy physics colleagues point to the need for a next generation of atom smashers to explore the treasure trove of supersymmetry (hierarchy) beyond the Higgs boson. This is a tall order and would require large hadron colliders with center-of-mass energies greater than 100TeV. Right now, the CERN LHC upgrade will top out at 14 TeV. Given the extremely high critical currents and fields of the copper oxide perovskites at low temperatures ($H_{C2}$ at 4K has yet to be measured in YBCO), extremely powerful and compact deflection electromagnets are now possible to construct and deploy. However, the vision I prefer is this:

At the turn of the last century, a team at Fermilab (CSA CSM) led by Peter Limon, Ernie Malamud and Bill Foster (Foster now serves in the US House of Representatives) envisioned a Very Large Hadron Collider (VLHC) buried in a 200+ km circumference tunnel, wherein oppositely charged hadrons would be confined by the magnetic field emanating from a superconducting cable. [20] The design of the VLHC (alternatively called the "pipetron" or—quietly behind closed doors in Batavia—the "American Big-Bang-a-Tron") was recently re-engineered by Fermilab researchers, employing an HTSC cable situated in the middle of a "c-pole" ferrite magnet pair whose gaps would constrain counter-rotating beams of such particles before eventual collision and subsequent "whatever-on" emission. [21].

## A Global Energy SuperGrid

At the end of the next "one score and ten years," after we have finally oxidized the last remaining loosely bound carbon atom on the planet, a resurgence of nuclear fission power accompanying solar will inevitably occur, engendering a Global Energy SuperGrid [22] supplying electrons and protons, the former over a SuperCable refrigerated by the latter in the form of cryogenic hydrogen, either as liquid or in supercritical singlet/triplet state at 77K and above 1000 psi. The citation in reference 22 explores two concepts: "SuperUrban" embodiment as the template for a global energy generation, delivery and end use infrastructure (Figure 1), and the design of a general purpose SuperCable (Figure 2).

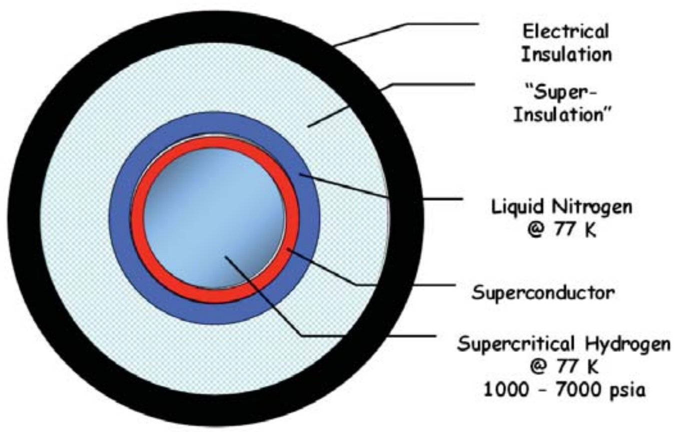


***Figure 2. Cross-section of a possible "SuperCable" design to enable a Global Energy SuperGrid.22 Reproduced with permission from P. Grant, "Cryo-delivery Systems for the Co-transmission of Chemical and Electrical Power," AIP Conference Proceedings 823, 291 (2006), American Institute of Physics.***

Commencing construction of the next "Big-Bang-a-Tron" and the Global SuperGrid is indeed technically feasible right now. So let's encourage the US Department of Energy, in collaboration with similar agencies worldwide, to undertake a modest engineering economy study to determine the societal cost benefits of each.

Their mutual realization would significantly advance understanding the boundaries of our cosmic existence and help preserve the quality of life on Carl Sagan's "Pale Blue Dot"[23] captured therein. The ultimate "Power to the People," if you will. John Lennon, are you out there listening? [24]

## References


1. This commentary contains a number of anecdotal and informal references to the discovery period of high temperature superconductivity and beyond. Other sources and background can be found by linking to the author's website page http://w2agz.com/SuperWiki.htm#Superconductivity%20Today or by contacting the author via e-mail at w2agz@w2agz.com. This resource is offered as "fair use only," with scholars and students as the target audience.
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