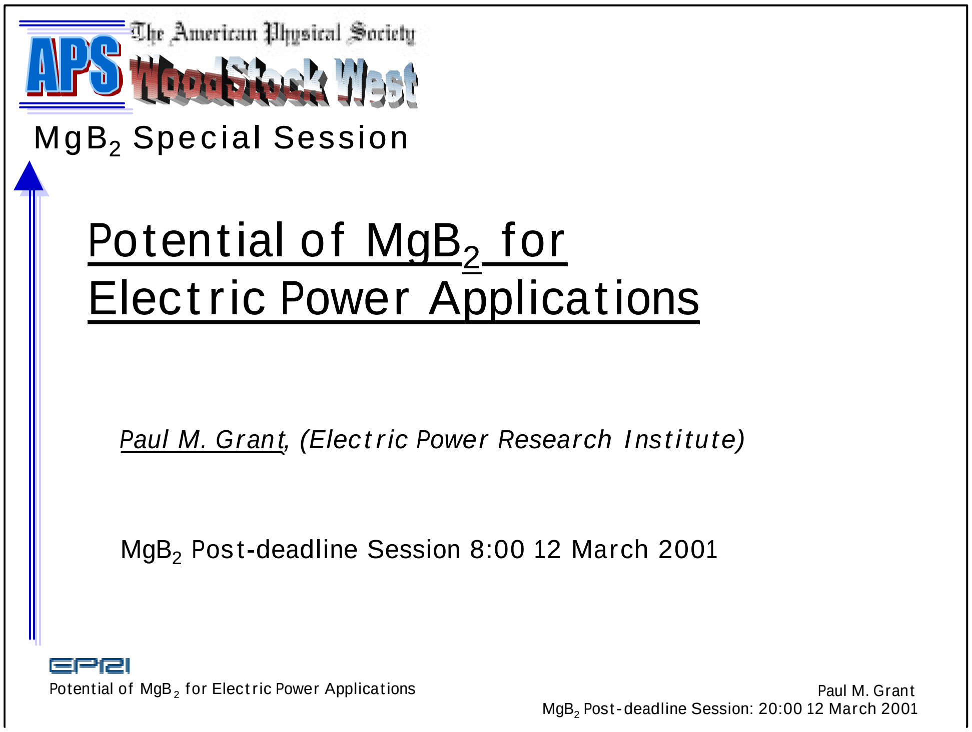


**Potential of $MgB_2$ for Electric Power Applications.** P. M. GRANT, *Electric Power Research Institute. Palo Alto, CA 94304.*

Notwithstanding the fact that the now-known existence of superconductivity below 40 K in the intermetallic compound $MgB_2$ is barely a few months old, sufficient data has already emerged to allow a preliminary assessment of its potential for electric power equipment and infrastructure application. Even at this early stage of investigation, present values of technical parameters such as critical current density, intergrain coupling and irreversibility field in a projected operation range of 25 – 30 K are already of encouraging magnitude and will only increase as vortex pinning mechanisms are understood and enhanced in what is now a relatively "clean" material. Moreover, there are signs that practical wire development is a distinct possibility at reasonable cost given the huge natural abundance of its constituent elements and widespread experience in commercial metallurgical manufacturing of similar materials. Thus superconductivity in $MgB_2$ opens a technical window to a range of electric power applications previously thought accessible only with copper oxide perovskites. These include superconducting rotating machinery, transformers, magnetic energy storage, and cables. In this talk, we will address the extent of this opportunity, and establish preliminary targets of performance and cost prospective $MgB_2$ wire would have to meet to fully capture its promise.

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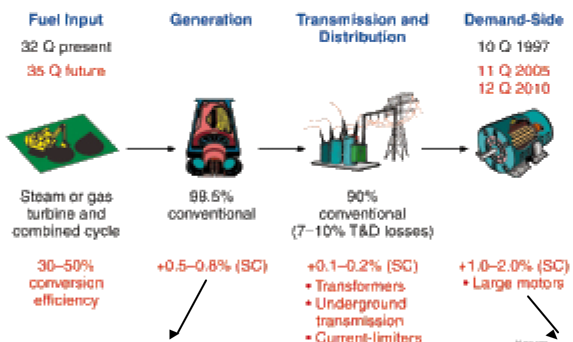
# Application Specs

MgB$_2$ Special Session

## Electric Power System




| | | | |
|---|---|---|---|
| T(K) = | 25 - 40 | 25 - 77 | 25 - 40 |
| H(T) = | 1 - 4 | 0.5 - 2 | 1 - 4 |
| Jc(A/cm$^2$) = | 154,000 – 192,000 | 7,000 – 231,000 | 154,000 – 192,000 |

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Potential of MgB$_2$ for Electric Power Applications

*R. D. Blaugher, NREL*

Paul M. Grant
MgB$_2$ Post-deadline Session: 20:00 12 March 2001

Figure taken from:

This article first appeared in *Research and Innovation* magazine, Issue 1/98, published by Siemens AG, March 1998.

*Research and Innovation* can be contacted at Postfach 3240-D-91050 Erlangen or via e-mail at 100034.14@compuserve.com

**Perspectives for Superconducting Electric Power Applications**

**Richard D. Blaugher**

T, H, Jc requirements roughly reflect those of current DOE Superconductivity Partnership Initiative Projects

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# Device Specs

| | T (K) | H (T) | $J_c$ ($A/cm^2$) |
|---|---|---|---|
| Motors/ Generators | 30 | 4 | 100,000 |
| Transformers | 30 | 2 | 80,000 |
| Current Limiters | 30 | 2 | 80,000 |
| Cables | 77 | 0.5 | 70,000 |

*\ For $MgB_2$, Assume Nominal Operating Point = 25 K, 1 T*

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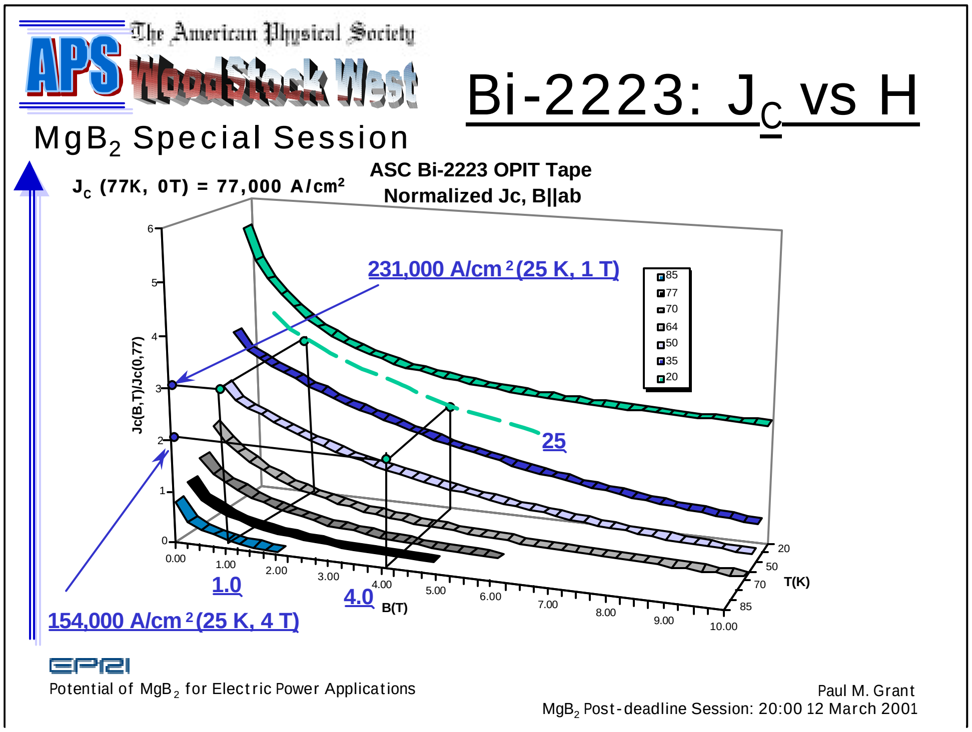
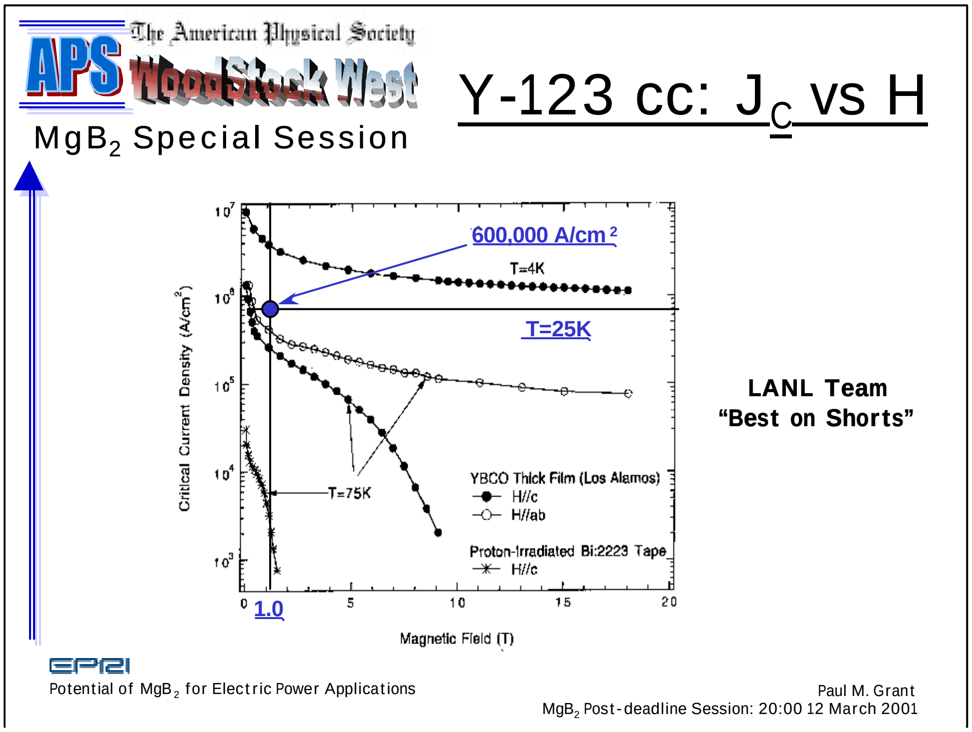
Specifications roughly reflect requirements of present DOE Superconductivity Partnership Initiative projects. See www.eren.doe.gov/superconductivity.

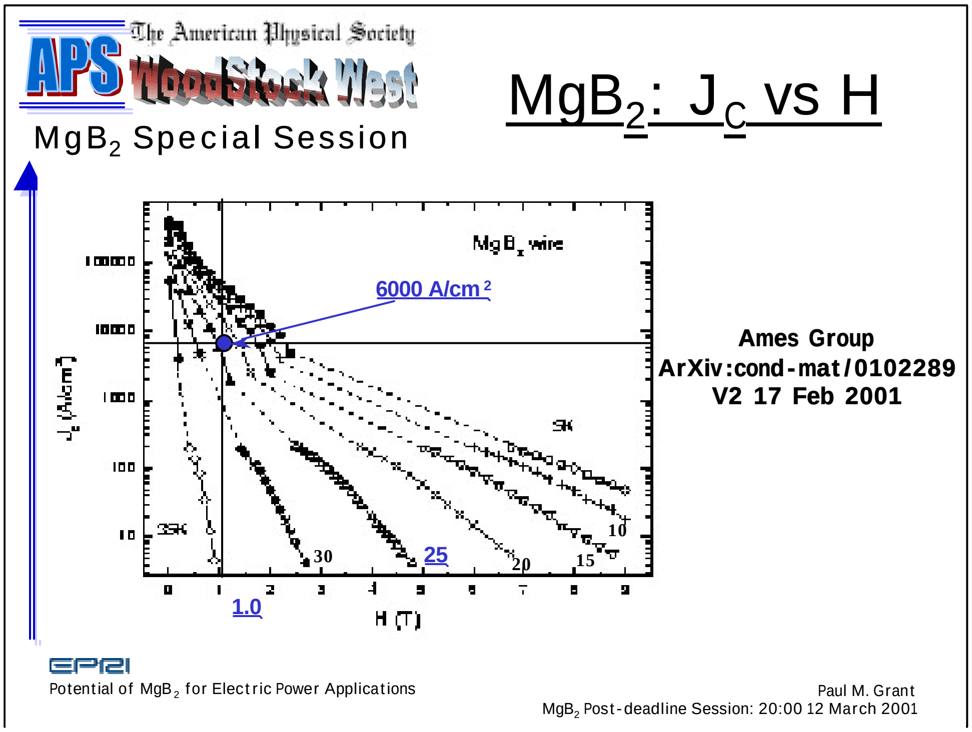



• Figure from data supplied by Greg Schnitzler, AMSC, at the 1996 HEP Snowmass conference. Normalized to then “championship” Jc.

• Normalized Jc “pickoffs” taken for T = 25 K and 1 and 4 T, then scaled to present “championship” Jc (77K, “0”T) as shown.




- Data supplied by Steve Foltyn, LANL, for use in Applied Superconductivity Conference 2000 Public Lecture.
- T = 25K data extrapolated between 4K and 75K and is believed to be a conservation estimate, i.e., Jc(25K, 1T) likely to be higher.
- Note for Bi-2223 tape, Jc(75K, 1T) is about 6000 A/cm$^2$.



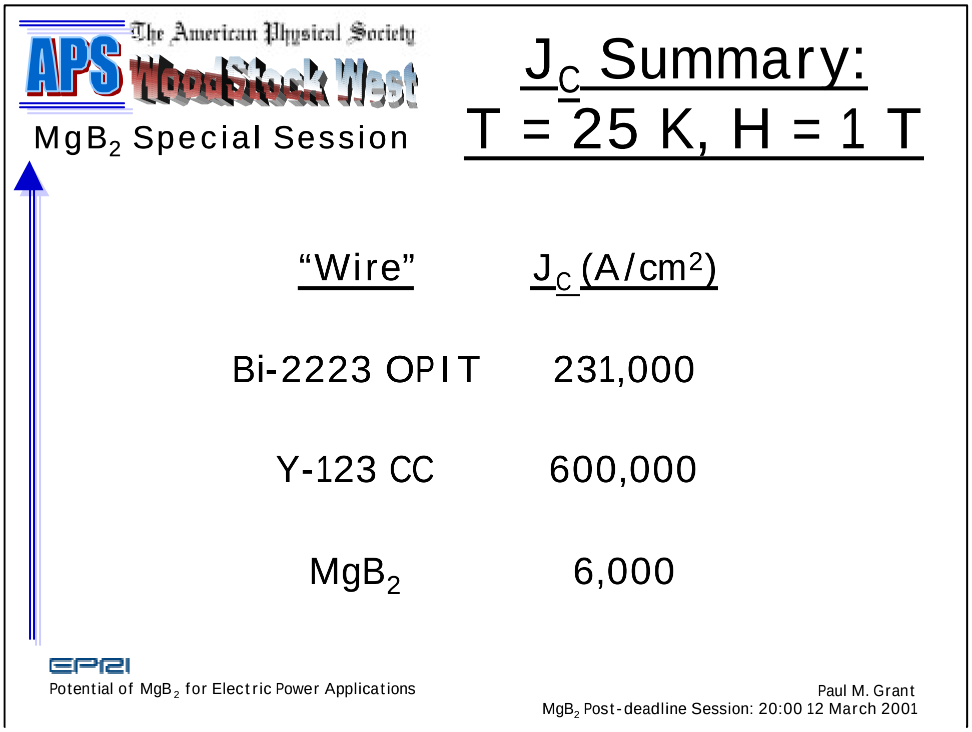

**Superconductivity in Dense $MgB_2$ Wires**

P. C. Canfield, D. K. Finnemore, S. L. Bud'ko, J. E. Ostenson, G. Lapertot,* C. E. Cunningham,[†] and C. Petrovic
*Ames Laboratory, U.S. Department of Energy and Department of Physics and Astronomy*
*Iowa State University, Ames, Iowa 50011*
(February 17, 2001)

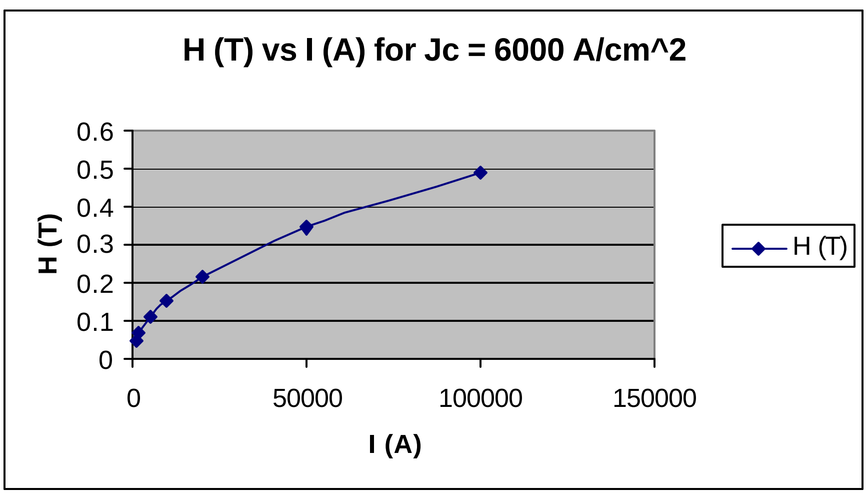
FIG. 4. Superconducting critical current density, $J_c$, as a function of applied field every 5 K in 5 - 35 K range. Open symbols were taken via direct measurement of current dependent voltage of the wire. Filled symbols were determined via a Bean model analysis of magnetization data from wire samples with the applied field parallel to the wire length. The dashed lines simply connect data sets taken at the same temperature.

• Data taken from Ames Group work published on cond-mat on “wires” made from Mg infusion of B fibers

• Note that Jc, H line for 25 K line is likely below Caplin’s Imperial Group’s “creep” limit for “pure” $MgB_2$.




Note that this is not the usual standard for reporting Jc in HTSC wire which is at 77 K and self field. The following chart shows the self field vs current of an $MgB_2$ wire capable of 6000 A/cm$^2$ (max diameter = 10 cm at I = 100,000 A).



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# Cost Issues

**Merit Factor for Superconducting Wire:**
**C/P = $/kAmp × meters**

| Wire | C/P | Cost Driver |
|---|---|---|
| NbTi (4.2 K, 2 T) | 0.90 | Materials (Nb) |
| $Nb_3Sn$ (4.2 K, 10 T) | 10 | Materials (Nb) |
| Bi-2223 (25 K, 1 T) | 20 | Materials (Ag) |
| Y-123 (25 K, 1 T) | 4 | Capital Plant |

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Above data drawn from the following paper presented at the 1998 Applied Superconductivity Conference held in Palm Desert, CA. C/P adjusted from projected $50/kA×m for Bi-2223 and $10/kA×m for Y-123 wire at 77 K, self fie

## Cost Projections for High Temperature Superconductors

Paul M. Grant and Thomas P. Sheahen
EPRI, Palo Alto, CA 94304 and SAIC, Gaithersburg, MD 20878

*Abstract* --- It is generally argued that for high-temperature superconductors (HTS) to be cost-competitive in power applications, the wire will have to sell for about $10 per kiloamperexmeter ($10/kA×m) for operation at 77 K (e.g., NbTi costs around $1/kA×m and $Nb_3Sn$ around $8, each at 4.2 K). Given what is already known about the critical current performance of Pb-stabilized Bi-2223 (BSCCO), this cost target may be extremely difficult to realistically achieve for silver-sheathed BSCCO produced by the oxide-powder-in-tube (OPIT) technique. In this paper, we examine the cost of component materials, add reasonable estimates for labor and related costs, and arrive at a likely cost/performance (C/P) figure. We also estimate the capital cost of a factory to produce HTS conductor by a particular coated conductor method, and calculate the necessary production-output and performance parameters necessary to manufacture 10 km/yr of wire and its associated C/P. Our results indicate that the real C/P seen by the customer will remain substantially above this $10/kA×m target for some time to come.

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## Cost Issues: MgB2

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### Assumptions/Givens:

- $J_C$ = 6000 A/cm$^2$
- $I_C$ = 120 A/wire (Area = 2 mm$^2$)
- Non-Materials C/P = 1.13 $/kA•m (NbTi)

### Alfa Aesar $MgB_2$ Price Quote (10 kg)

- 750 $/kg (0.75 $/gm)

### $MgB_2$ Wire C/P

- 33.75 $/kA•m @ 25 K, 1 T (~1.5´ Bi-2223)

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Potential of $MgB_2$ for Electric Power Applications

Paul M. Grant

$MgB_2$ Post-deadline Session: 20:00 12 March 2001

The following calculation assumes an eventual non-materials basic manufacturing cost (BMC) similar (in this case equal) to that of present commercially available NbTi wire. 10 kg batch quote from Alfa Aesar on 8 March 2001.

| MgB2 Cost Scenarios | | | NbTi Numbers | |
|---|---|---|---|---|
| Jc | 6000 | A/cm^2 @ 25 K, 1 T | Total length cost | 0.9 $/m |
| Ic | 120 | Amps per wire | Non-materials cost | 0.225 $/m |
| Area | 0.02 | cm^2 | | |
| Diameter | 1.59577 | mm | | |
| Volume/meter | 2 | cm^3 | | |
| MgB2 Density | 2.55 | gm/cm^3 | | |
| Mass/meter | 5.1 | gm | | |
| Materials Costs | 0.75 | of basic manufacturing cost (BMC) based on NbTi | | |
| Non-Materials Cost | 0.225 | $/m based on NbTi | | |
| Non-Materials C/P | 1.875 | $/kA*m based on NbTi but Ic of MgB2 | | |
| Costs: Alfa Aesar Supplier | | | | |
| Quote !0 kg batch | 750 | $/kg | | |
| | 0.75 | $/gm | | |
| | 3.825 | $/m | | |
| MgB2 C/P | 33.75 | $/kA*m @ 25 K, 1 T | 31.875 | |

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# Cost Issues: MgB2 as a Commodity

Assumptions/Givens (Previous $J_C$, $I_C$, %BMC):

- Mg Spot = 0.003 $/gm (e.g., Ag = 0.14 $/gm)
- Boron Spot = 0.004 $/gm
- Boron Extraction = 0.10 $/gm
- $MgB_2$ Reaction = 0.10 $/gm

$MgB_2$ Wire C/P

- 2.64 $/kA•m @ 25 K, 1 T !!!

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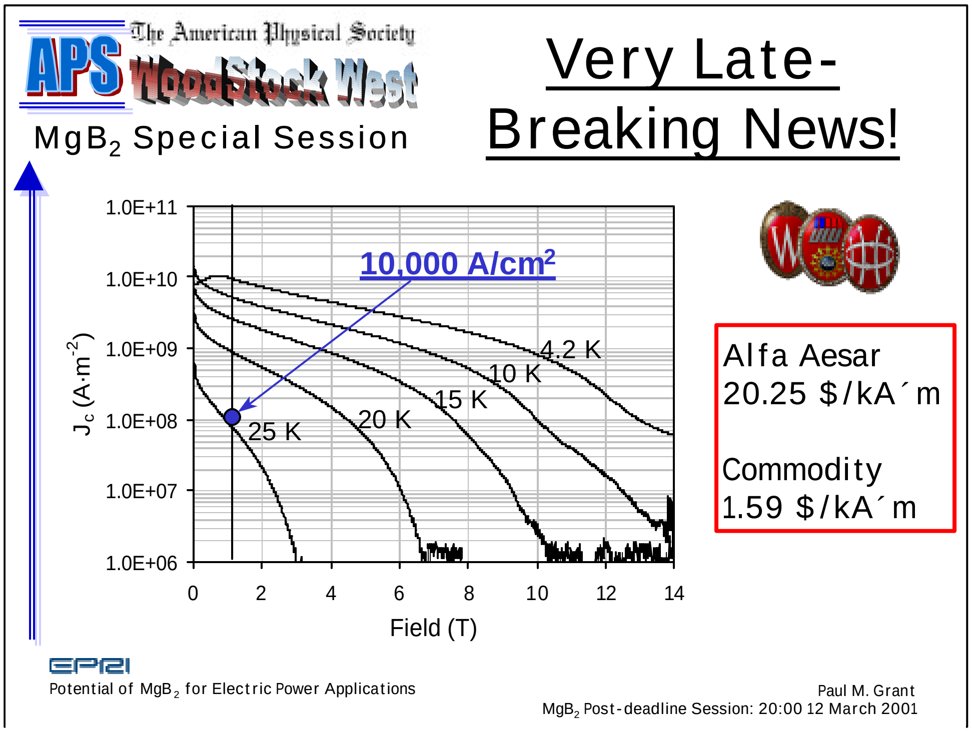
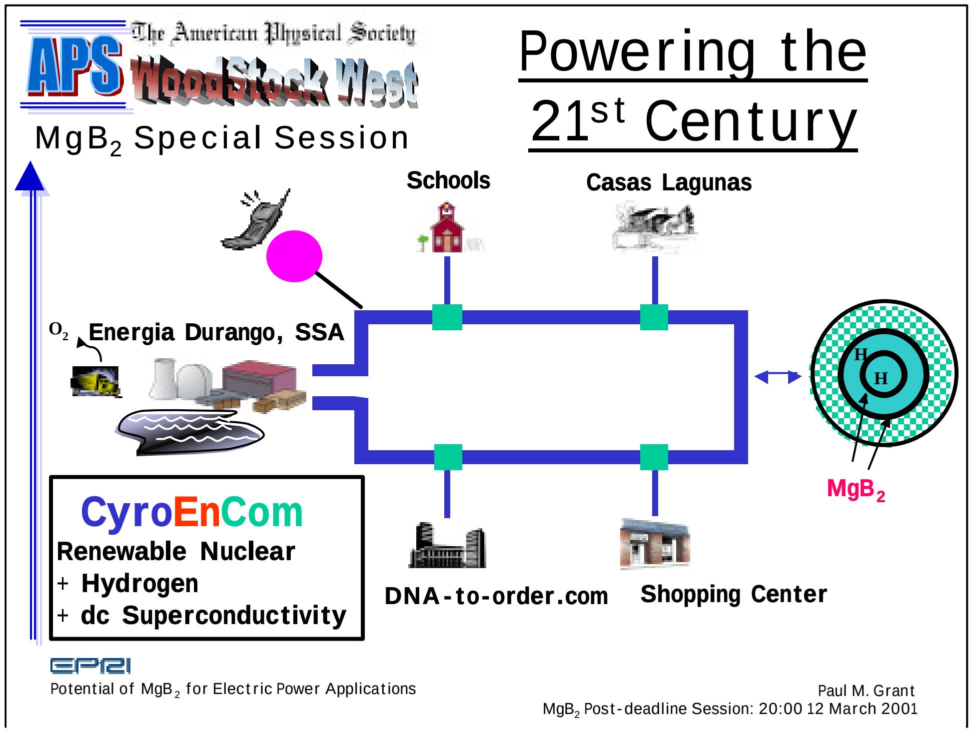
| | | |
|---|---|---|
| Costs: Raw Materials Based | | |
| Magnesium: | | |
| Molar Weight | 24.312 | gm |
| YE 2000 U.S. Spot | 1.35 | $/lb |
| | 2.97 | $/kg |
| | 0.00297 | $/gm |
| | 0.072207 | $/mole |
| Boron: | | |
| Molar Weight | 10.811 | gm |
| YE 2000 U.S. | | |
| Boron Pentahydrate | 376 | $/US ton |
| Molar Weight (BPH) | 100.811 | gm |
| B/BPH | 11% | |
| Boron Cost | 3506.145 | $/US ton |
| | 1.753073 | $/lb |
| | 3.85676 | $/kg |
| | 0.003857 | $/gm |
| Boron extraction: | 10 | $/kg |
| Total | 13.85676 | $/kg |
| | 0.013857 | $/gm |
| | 0.149805 | $/mole |
| MgB2: | | |
| Molar Weight | 45.934 | gm |
| Raw Mg + B | 0.371817 | $/mole |
| | 0.008095 | $/gm |
| | 8.094603 | $/kg |
| Processing Cost | 10 | $/kg |
| Total | 18.0946 | $/kg |
| | 0.018095 | $/gm |
| | 0.092282 | $/m |
| MgB2 C/P | 2.644021 | $/kA*m @ 25 K, 1 T |




Data from UW/ASC, Chang-Boem, received 11 March 2001




Challenges…

• Get $J_C$ up higher…

• Develop low cost manufacturing method…

Should these be met, then…

**$MgB_2$ holds great promise**

**as an enabling technology for the**

**Hydrogen/Superconductivity Energy Economy**

**of the 21$^{st}$ Century**