St. Louis, MO
28 April – 1 May 2002

# $MgB_2$ and its application to electric power

*P. M. Grant, (Electric Power Research Institute)*
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AME4-E-o1-2002: 9:15 1 May 2002 (228)

# Nature, 1 March 2001

St. Louis, MO
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## Superconductivity at 39 K in magnesium diboride

**Jun Nagamatsu*, Norimasa Nakagawa*, Takahiro Muranaka*, Yuji Zenitani* & Jun Akimitsu*†**

** Department of Physics, Aoyama-Gakuin University, Chitosedai, Setagaya-ku, Tokyo 157-8572, Japan*
*† CREST, Japan Science and Technology Corporation, Kawaguchi, Saitama 332-0012, Japan*

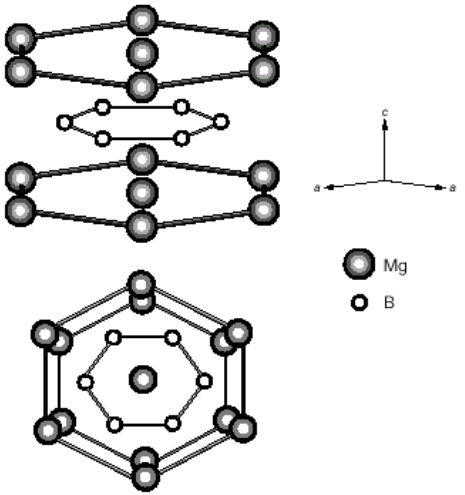


**Figure 2** Crystal structure of $MgB_2$.

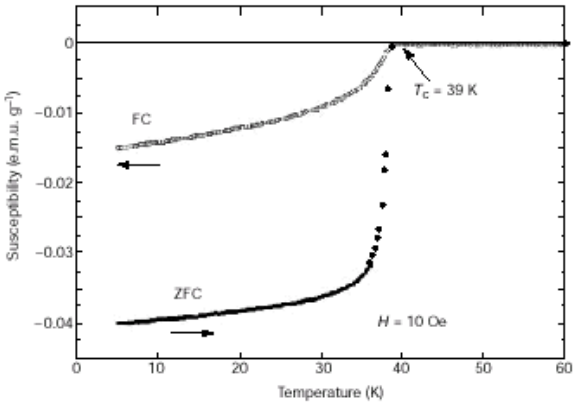


**Figure 3** Magnetic susceptibility $\chi$ of $MgB_2$ as a function of temperature. Data are shown for measurements under conditions of zero field cooling (ZFC) and field cooling (FC) at 10 Oe.

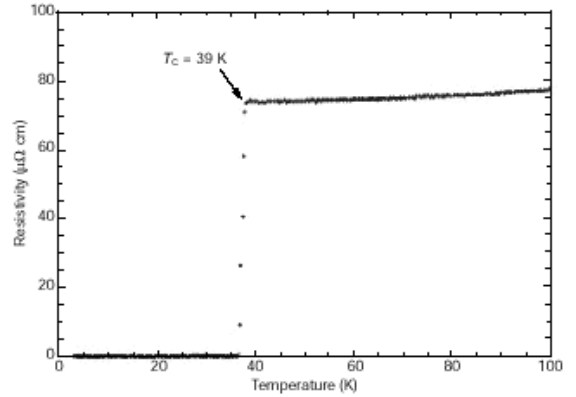


**Figure 4** Temperature dependence of the resistivity of $MgB_2$ under zero magnetic field.

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# Nature, 31 May 2001

Superconductivity

## Rehearsals for prime time

Paul Grant

Superconductivity seems to have been forever waiting in the wings. Although superconducting power cables are about to go live, will the newest material, magnesium diboride, become the class act of the future?

## High critical currents in iron-clad superconducting $MgB_2$ wires

**S. Jin, H. Mavoori, C. Bower & R. B. van Dover**

*Agere Systems/Lucent Technologies, Murray Hill, New Jersey 07974, USA*

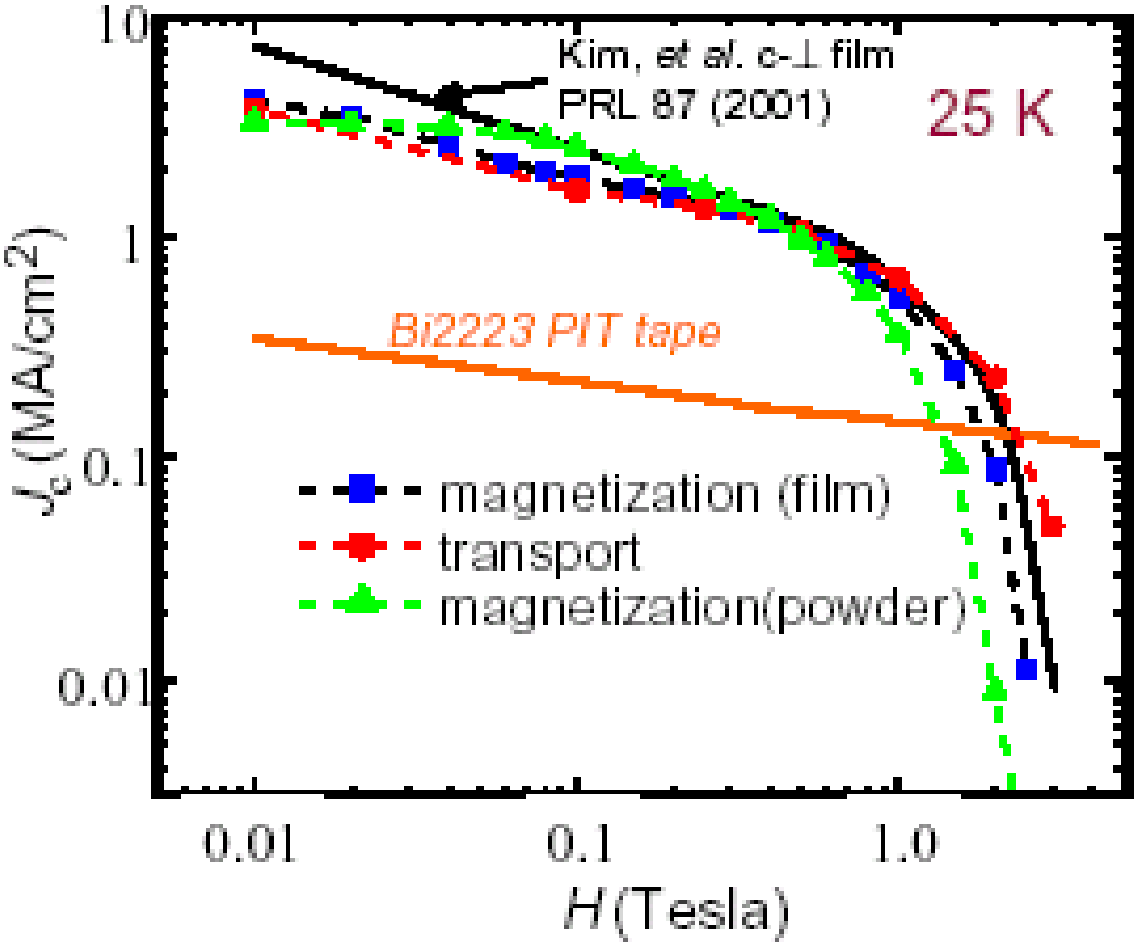
| | 4.2 K | 25 K |
|---|---|---|
| $J_c$ @ 1 T ($A/cm^2$) | 150,000 | 35,000 |

# Power Device Req'mts

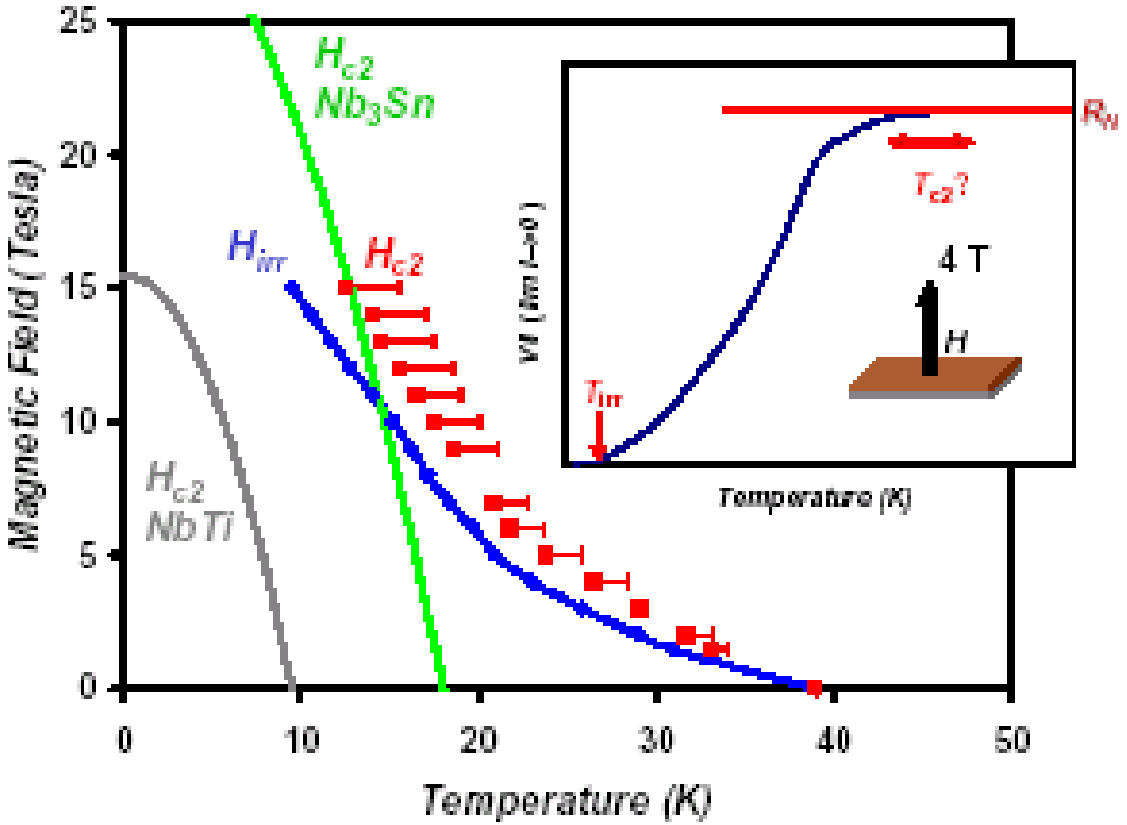
| Application | T(K) | Field (T) | $J_c$ (A/cm$^2$) |
|---|---|---|---|
| Fault-current controller | 20-77 | 0.1 – 3 | $10^4$ - $10^5$ |
| Large motor | 20-77 | 4 - 5 | $10^5$ |
| Generator | 20-50 | 4 - 5 | $10^5$ |
| SMES | 20-77 | 5 - 10 | $10^5$ |
| Power cable | 65-77 | < 0.2 | $10^4$ - $10^5$ |
| Transformer | 25-77 | 0.5 - 2 | $8\times10^4$ |

*R. D. Blaugher, et al., THERMEC*2000*

# ORNL: $J_c$ vs H


Kim, et al. c-⊥ film
PRL 87 (2001)
25 K
Bi2223 PIT tape
magnetization (film)
transport
magnetization(powder)
$J_c$ (MA/cm$^2$)
1.0
1
0.1
0.01
0.01
0.1
1.0
H (Tesla)

# ORNL: H vs T


25
20
15
10
5
0
0
10
20
30
40
50
Magnetic Field ( Tesla)
Temperature (K)
$H_{c2}$ $Nb_3Sn$
$H_{irr}$
$H_{c2}$
$H_{c2}$ NbTi
$R_N$
$T_{c2}$?
4 T
H
$T_{irr}$
Temperature (K)

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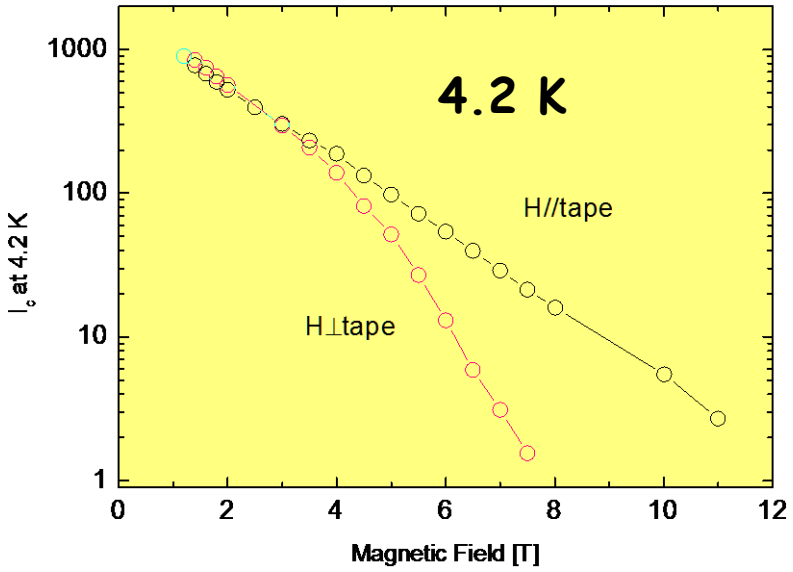
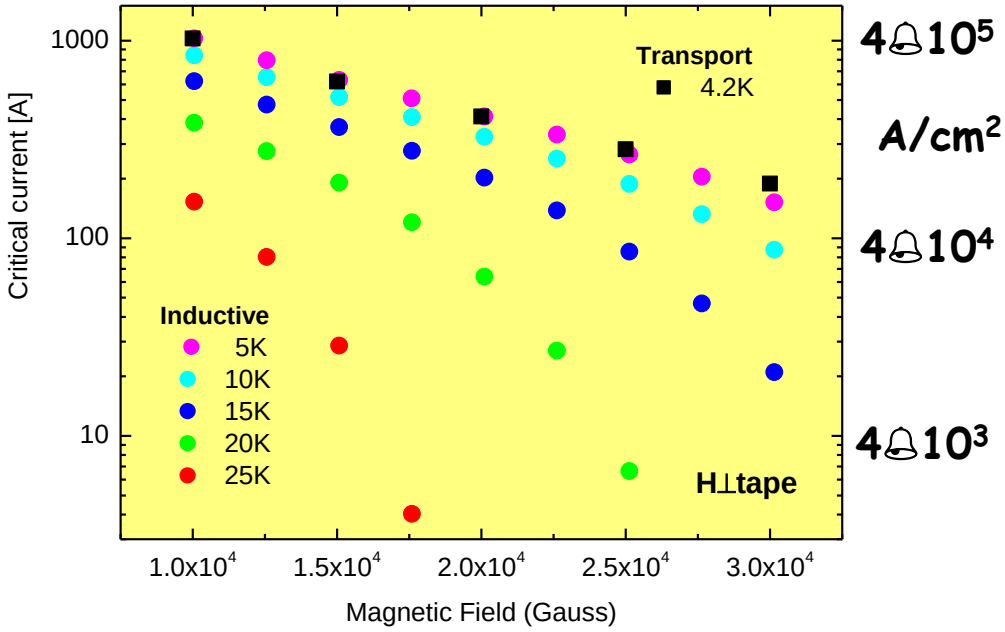
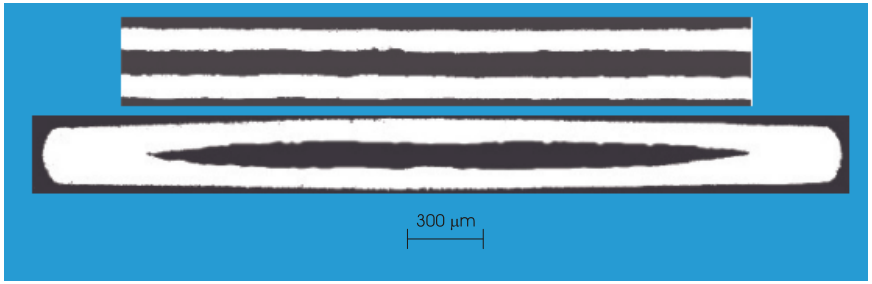
# INFM-Genova
# Ni-Sheathed $MgB_2$ Tape




## Ex-Situ Sintered

Tape dimensions: 3.5 mm x 0.35 mm

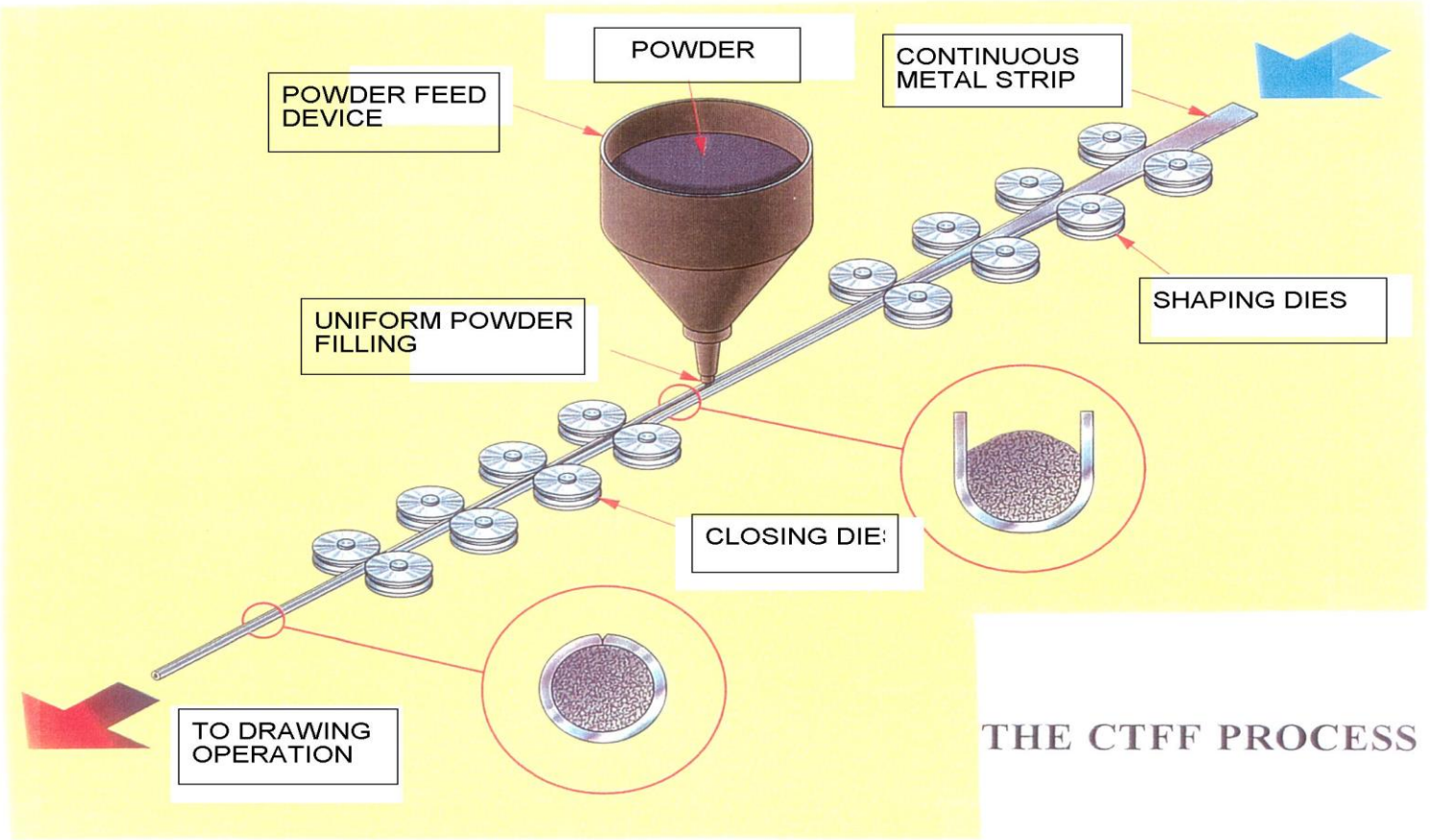
Filling factor 20% $A_{sc} = 2.5 \times 10^{-3}$ cm$^2$

Treated at 900°C for 2 hours in Ar

INFM-Genova, G. Grasso, A. Malagoli, V. Braccini, S. Roncallo, and A.S. Siri, Italy

# HyperTech CTFF for $MgB_2$

## CONTINUOUS TUBE FORMING AND FILLING (CTFF)



# HyperTech Representative $J_c$'s

| | | | |
|---|---|---|---|
| Temperature, K | 4K | 4K | 4K |
| Field, T | 0-0.2 | 1 | 3 |
| Jc -kA/mm$^2$ | 7.5* | 3* | 0.2 |
| **A/cm$^2$** | **750,000** | **300,000** | **20,000** |
| Temperature, K | 30K | 30K | |
| Field, T | 0-0.2 | 1 | |
| Jc -kA/mm$^2$ | 0.32 | 0.1 | |
| | (over 300 amps) | (over 100 amps) | |
| **A/cm$^2$** | **32,000** | **10,000** | |

* by extrapolation due to flux jump and lack of stabilization

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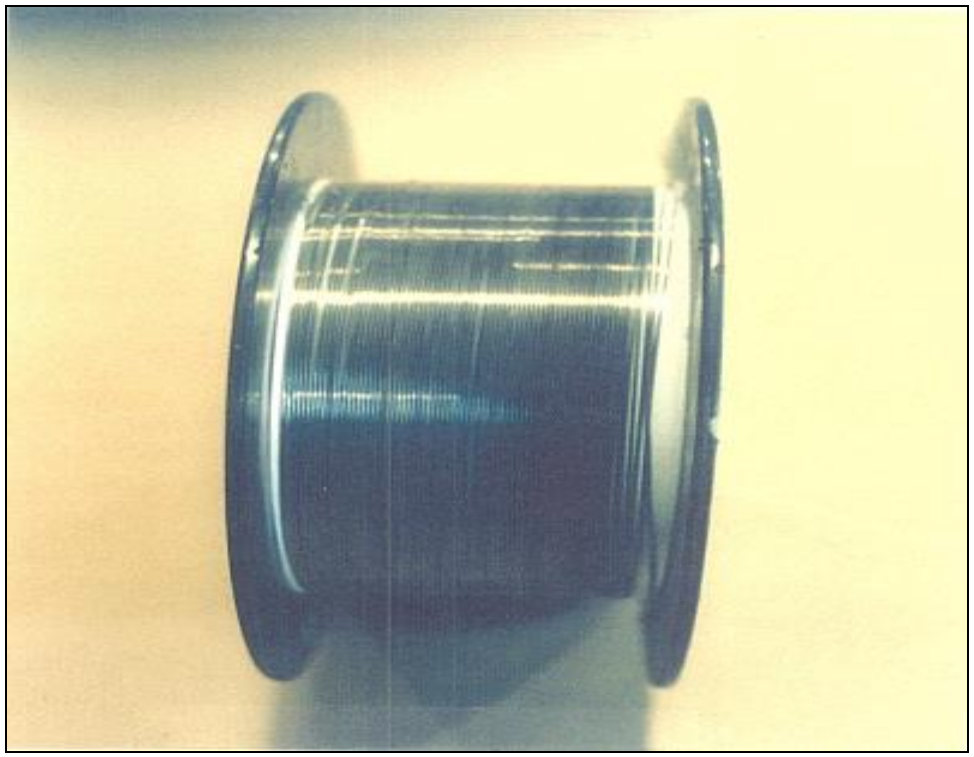
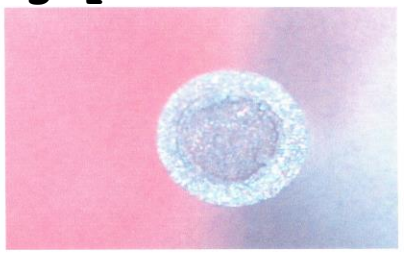
# HyperTech $MgB_2$ Wire

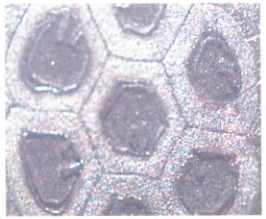
## 60 meters, 1.2 mm Mono



## $MgB_2$ CTFF Iron in Monel



## Multi-filament



# $MgB_2$ Wire C/P

## Assumptions/Givens:

- $J_C$ = 100,000 A/cm$^2$
- $I_C$ = 2000 A/wire (Area = 2 mm$^2$)
- Non-Materials C/P = 0.11 $/kA•m (NbTi)

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

- 750 $/kg (0.75 $/gm)

## $MgB_2$ Wire C/P

- 2.03 $/kA•m @ 25 K, 1 T

# $MgB_2$ Opportunities

## 20 – 30 K, 0 – 3 T

- Transformers
- Rotating Machinery
- Cables (?)

# Transformer Cost of Ownership

| Item | Units | Cu | BSCCO | BSCCO | YBCO CC | $MgB_2$ |
|---|---|---|---|---|---|---|
| Operating Temperature | K | 300 | 77 | 77 | 68 | 25 |
| Operating Field | T | 2 | 0 | 2 | 2 | 2 |
| Electrical Losses | W/kA×m | 60 | 0.25 | 0.25 | 0.25 | 0.125 |
| "Effective" Carnot Factor | $W_t/W_e$ | 1 | 20 | 20 | 23.6 | 76 |
| Cryo-unit Electrical Load | W/kA×m | 0 | 5 | 5 | 5.9 | 9.5 |
| Total Cost of Losses @ 1 $/W | $/kA×m | 60 | 5 | 5 | 5.9 | 9.5 |
| Cryo-unit Cost @ 5 $/W Rating | $/kA×m | 0 | 25 | 25 | 29.5 | 47.5 |
| Wire Cost (T, H) | $/kA×m | 5 | 50 | 150 | 50 | 2 |
| **Total Cost of Ownership** | **$/kA×m** | **65** | **80** | **180** | **85** | **59** |

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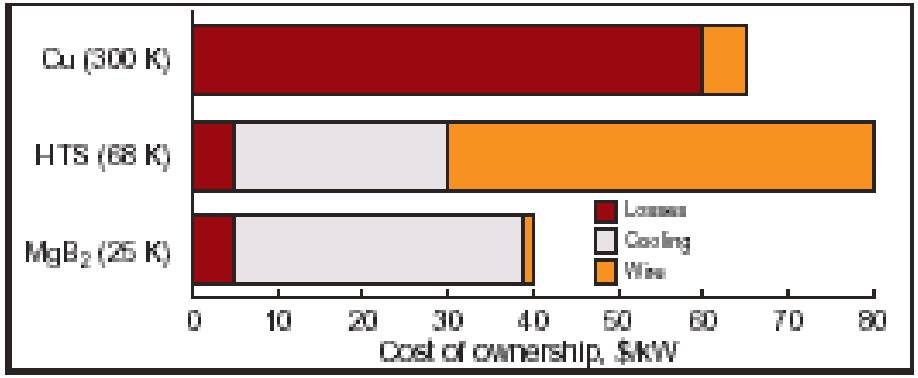
# Science

## Bob Service, 1 Feb 2002

NEWS FOCUS

Magnesium diboride can't match the properties of high-temperature superconductors. But it is far easier to work with, which may prove even more valuable in the end

# $MgB_2$ Trades Performance for A Shot at the Real World




Cheap shot. Transformers made with $MgB_2$ wire should cost less than those based on copper or high-temperature superconductors.

## YBCO Confronts Life in the Slow Lane

Power coil. Los Alamos physicists Steve Foltyn and Paul Arendt show off a meter-long strip of YBCO tape.

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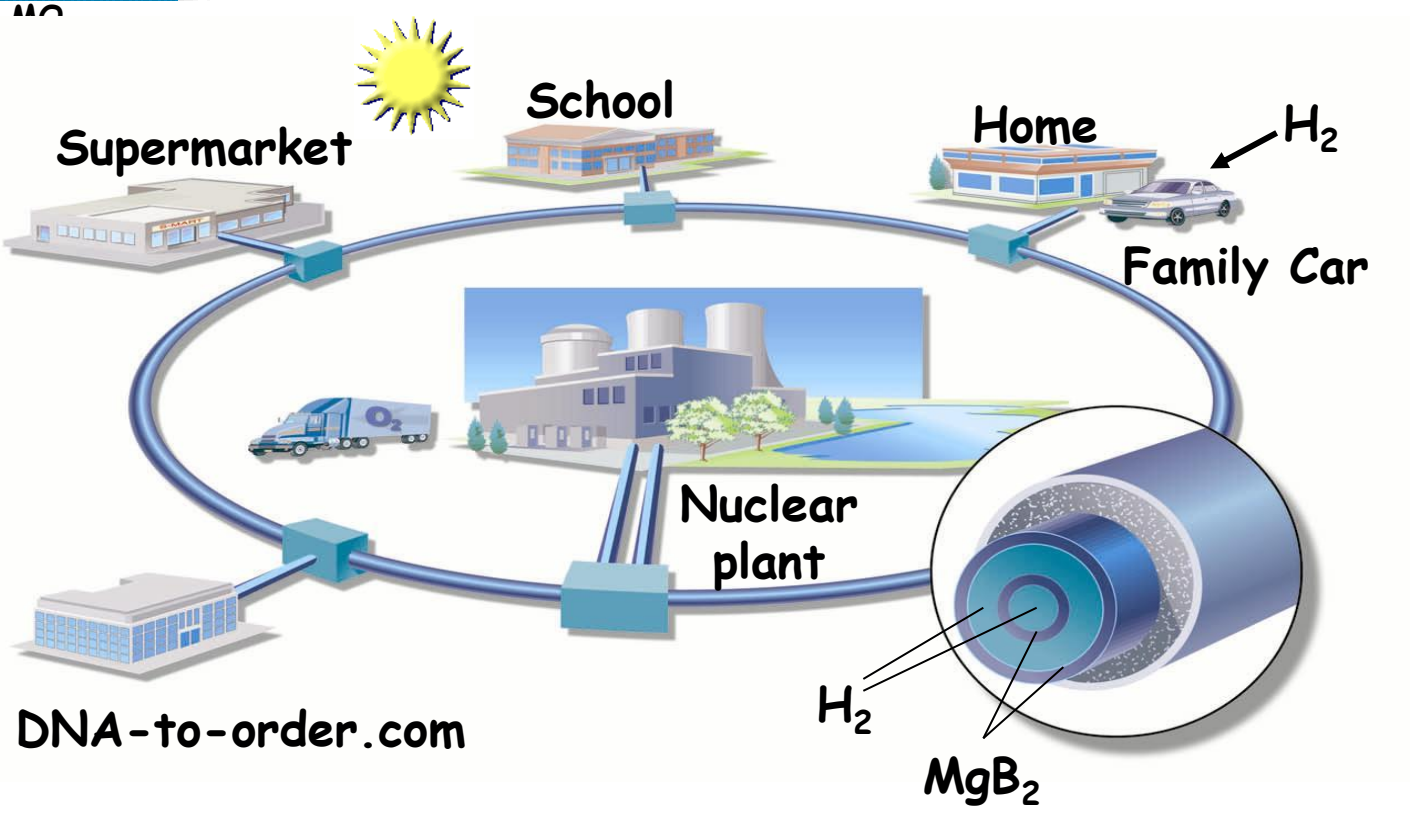
# "SuperCity"




P.M. Grant, The Industrial Physicist, Feb/March Issue, 2002

http://www.aip.org/tip/INPHFA/vol-8/iss-1/p22.pdf

# Energy Intensity Factoids

## Grant Household Power Requirements

| Watts | Avg | Peak |
|---|---|---|
| Elect | 2000 | 4000 |
| Therm | 4000 | 8000 |

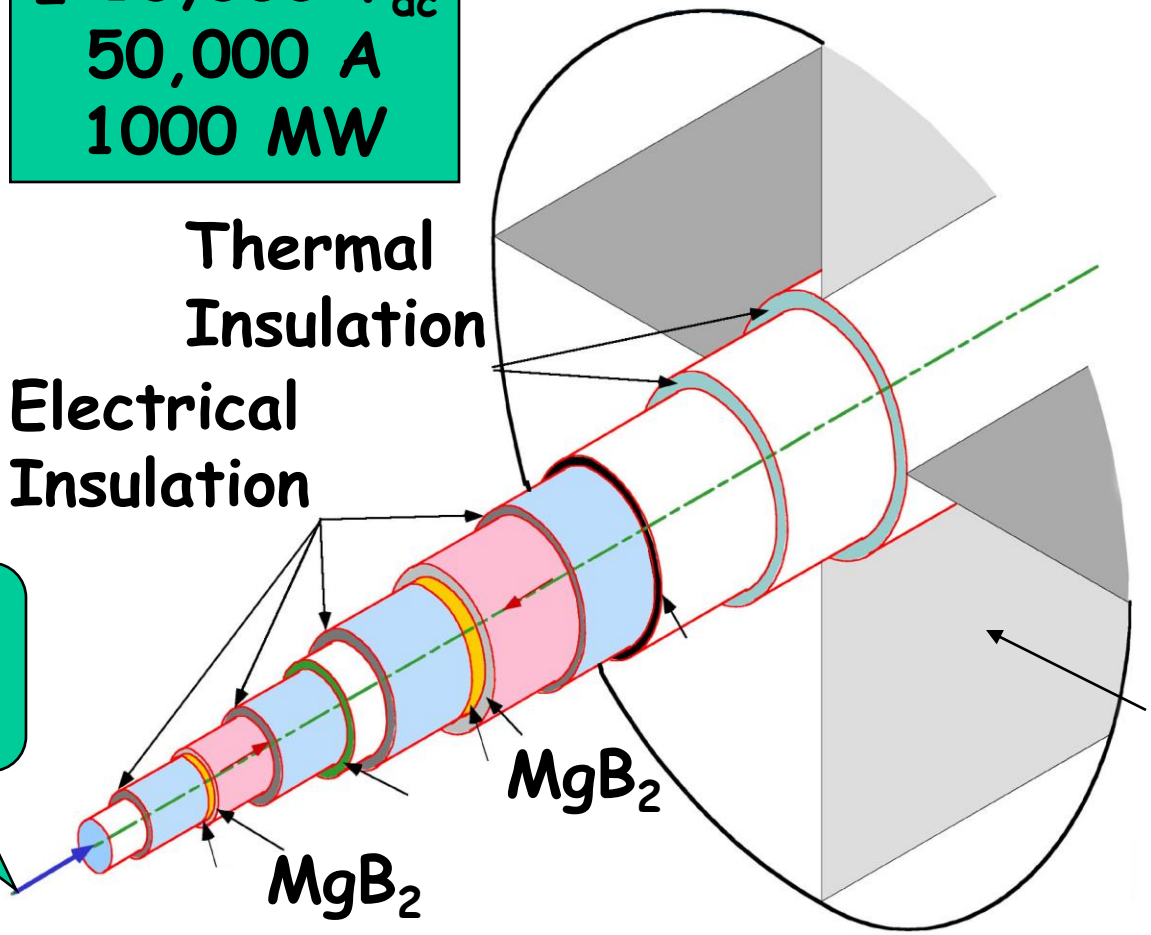
*Does not include 3 automobiles!*

## Peak Power for 250,000 GHE's

Electrical: 1000 MW
Thermal: 2000 MW

# "The Energy Pipeline"

± 10,000 $V_{dc}$
50,000 *A*
1000 MW



# Hydrogen Factoids

- 0.025 $/kWh Electricity -> 0.22 $/kWh Hydrogen
- Hydrogen flowing @ 1 m/s -> 0.6 MW/cm$^2$
- Delivering 2000 MW Hydrogen -> 67 cm dia pipe

  *Electricity via superconductivity is essentially free!*
- To power all cars in the US with hydrogen would require appropriating all present electric power generated in the US
- German studies show water emissions from powering all cars with hydrogen could cause changes in microclimate.

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# Hindenburg Hysteria


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