



## 2G HTS Pilot-scale Manufacturing at SuperPower

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*Providing HTS Solutions for a New Dimension in Power – TODAY!*

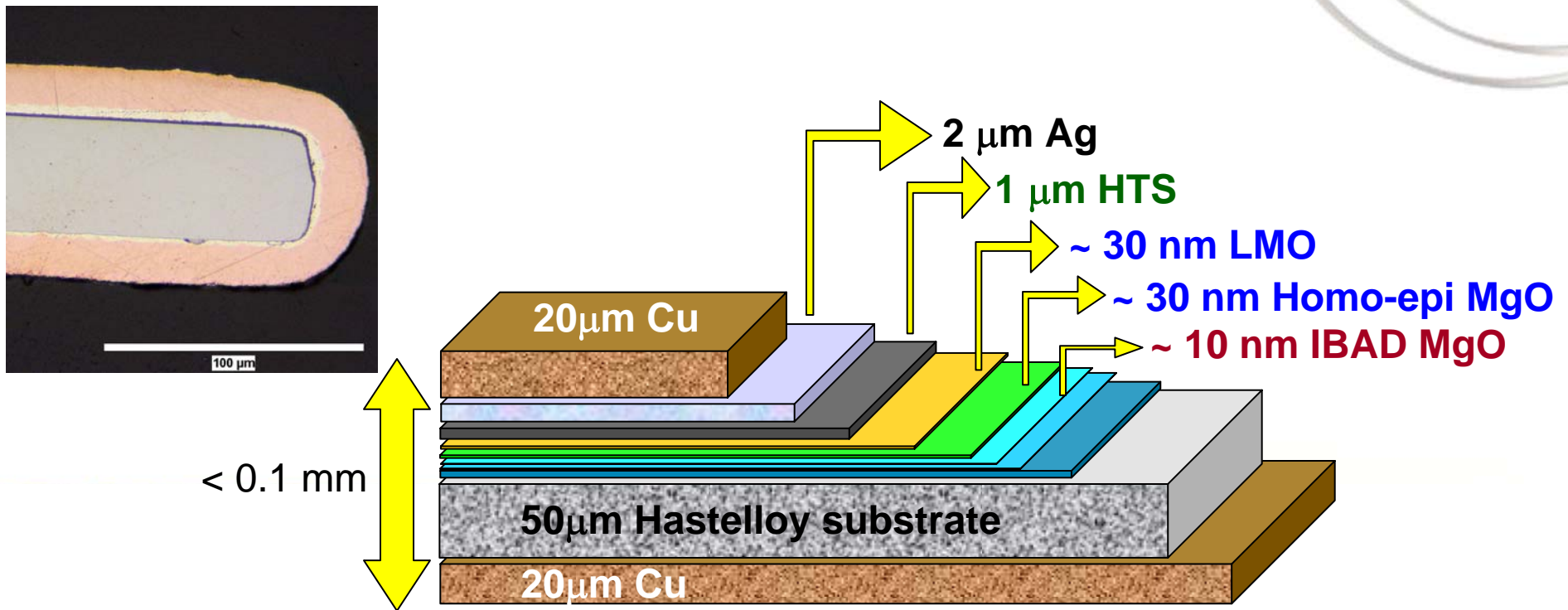
# SuperPower's 2G wire is based on high throughput processes & superior substrate

High throughput is critical for low cost 2G wire and to minimize capital investment.

SuperPower's 2G conductor is based on high throughput IBAD MgO and MOCVD processes.

Use of IBAD as buffer template provides us choice of any substrate.

- Advantages of IBAD are high strength, low ac loss (non-magnetic, high resistive substrates) and high engineering current density (ultra thin substrates)



# SuperPower's 2G pilot manufacturing facilities have been operational since 2006

*Majority of investment already made for 1000 km/year capability*



**Pilot Substrate Electropolishing**



**Pilot Buffer**



**Pilot IBAD**

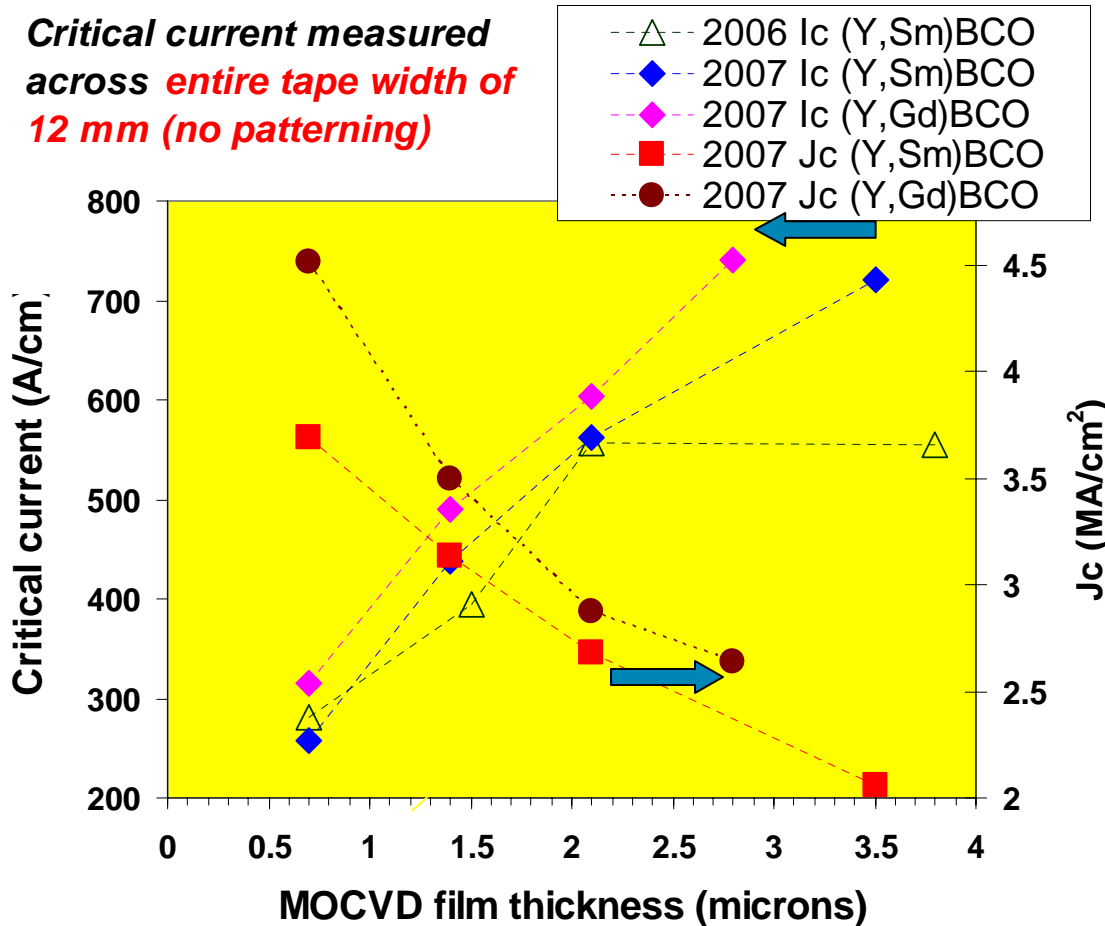


**Pilot HTS**

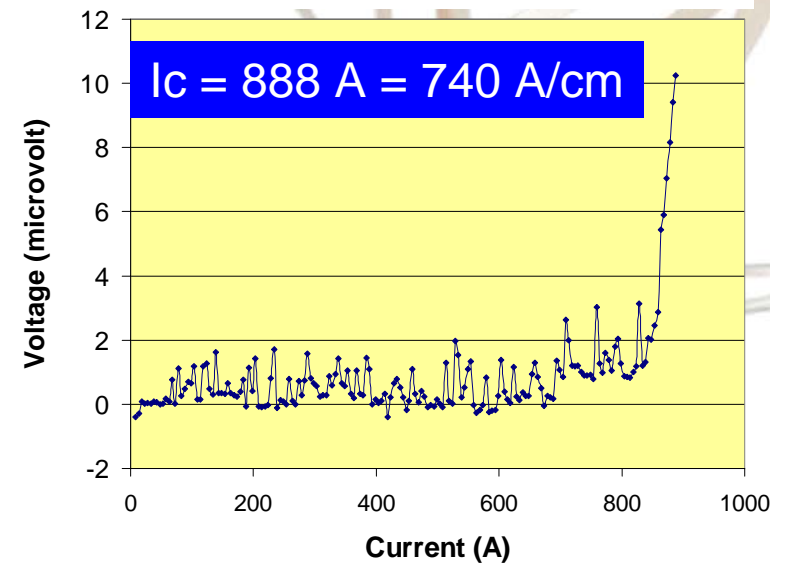
# Pathway to commercialization of 2G

## Metric 1: Higher Currents

Critical current measured across **entire tape width of 12 mm (no patterning)**



Achieved higher currents in thinner films using modified MOCVD precursor composition



Ic measurement using continuous dc current (no pulsed current) across entire tape width of 12 mm No patterning

In a 2.8 micron film made in 4 passes, achieved Ic of **740 A/cm (Jc = 2.64 MA/cm<sup>2</sup>)** over reel-to-reel processed 12 mm wide, 10 cm long tape.

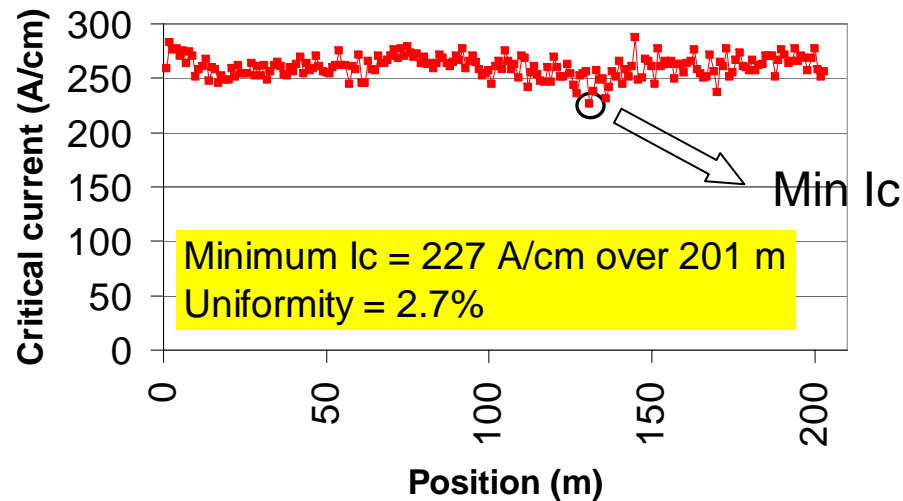
**This demonstration of 300 A wire performance in 4 mm width is 50% better than the best 1G available today**



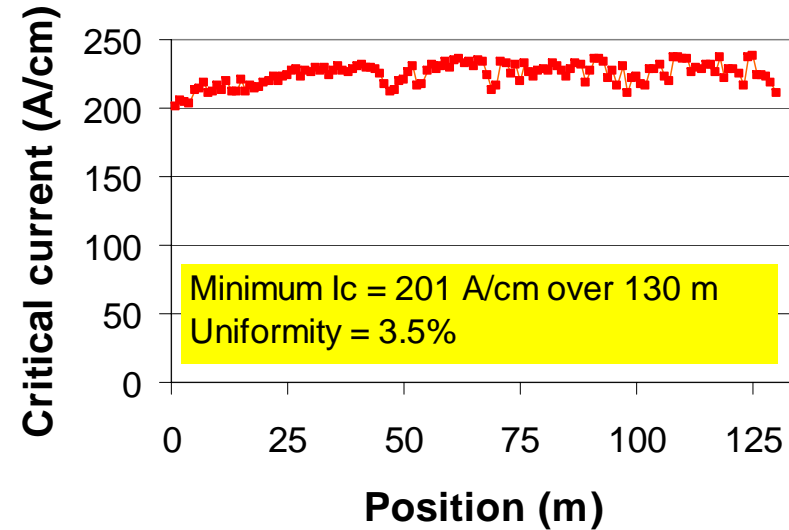
# Pathway to commercialization of 2G

## Metric 2: High Throughput

**Oct. 06:** High currents demonstrated over 200+m with **all processes at higher speeds**



**June 07:** High currents over 130+m with **all processes at even higher speeds**

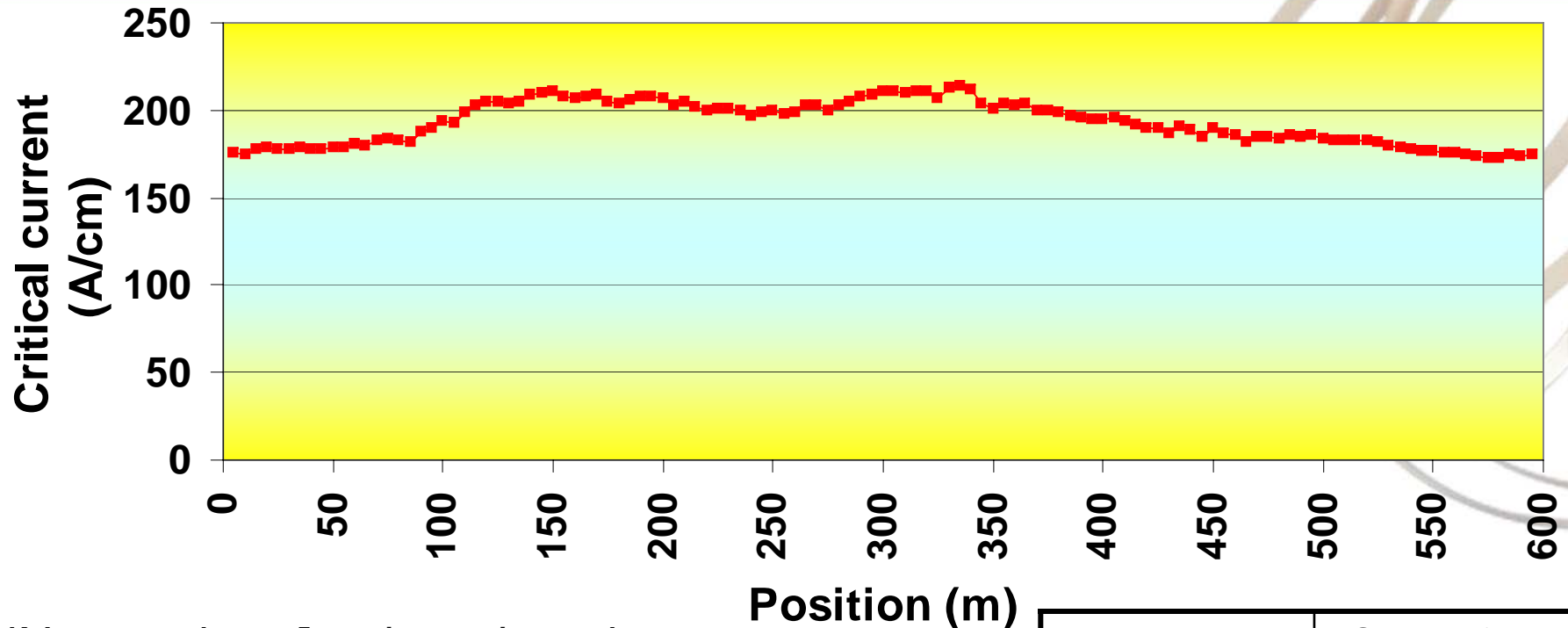


Process	Month	IBAD MgO	Homo-epi MgO	LMO	MOCVD YBCO
Speed of 4 mm wide tape (m/h)	Oct. 06	360	240	240	135
	June 07	360	345	345	180
Production capacity (km/yr) (if 45% of time/year is available for deposition)	June 07	1,440	1,380	1,380	720

**Production capacity goal of 1,000 km/year is already surpassed in IBAD MgO & Buffer processes and is close to being achieved with MOCVD**

# Pathway to commercialization of 2G

## Metric 3: Long Lengths



77 K,  $I_c$  measured every 5 m using continuous dc currents over entire tape width of 12 mm (not slit)

**Minimum  $I_c$  = 173 A/cm over 595 m**

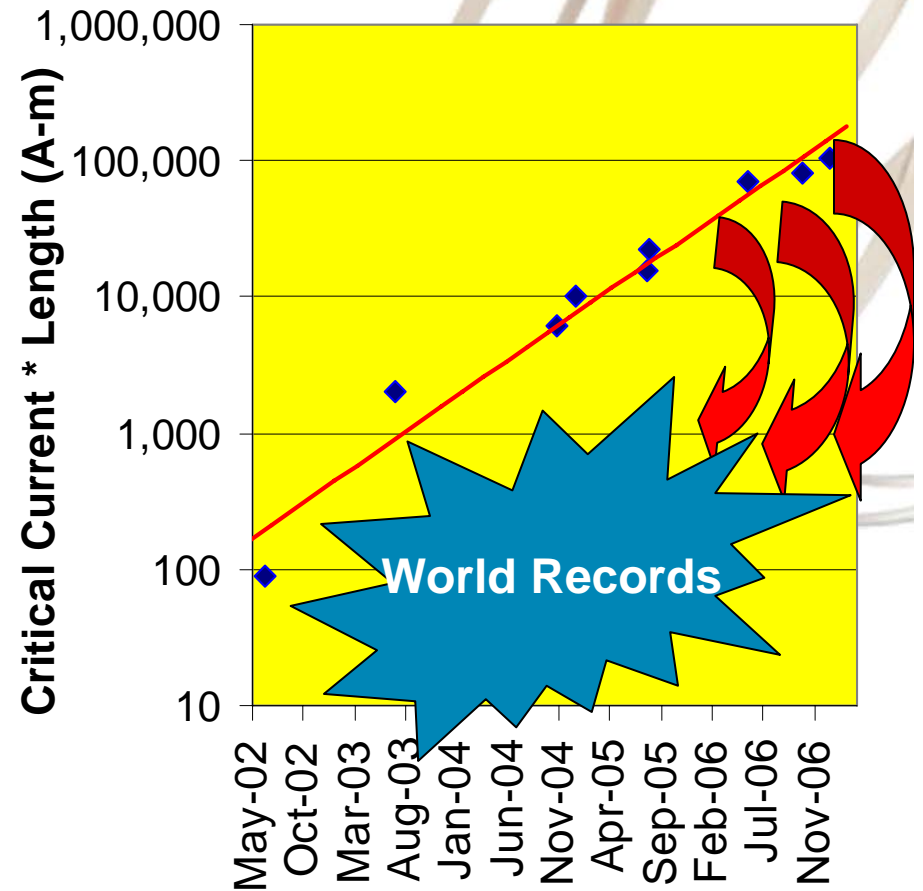
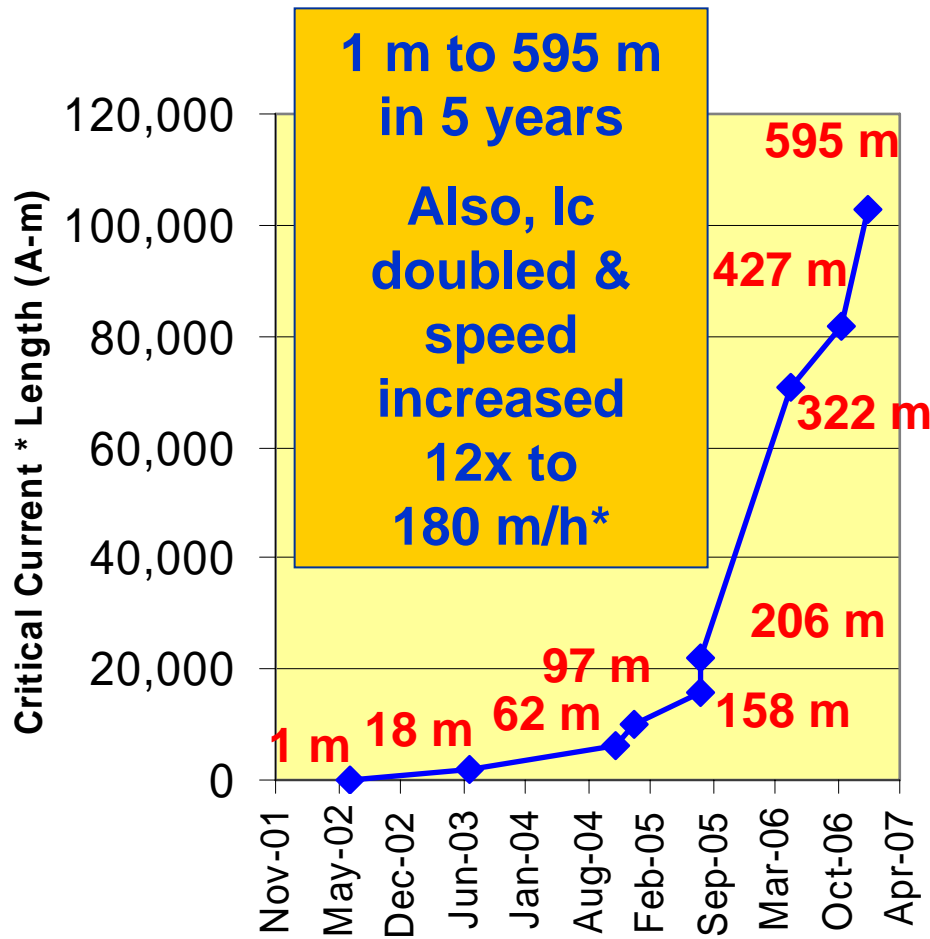
**$I_c \times \text{Length} = 102,935 \text{ A-m}$**

**Uniformity over 595 m = 6.4%**

Process (single pass)	Speed of 4 mm tape (m/h)
IBAD MgO	360
Homo-epi MgO	213
LMO	360
MOCVD	135



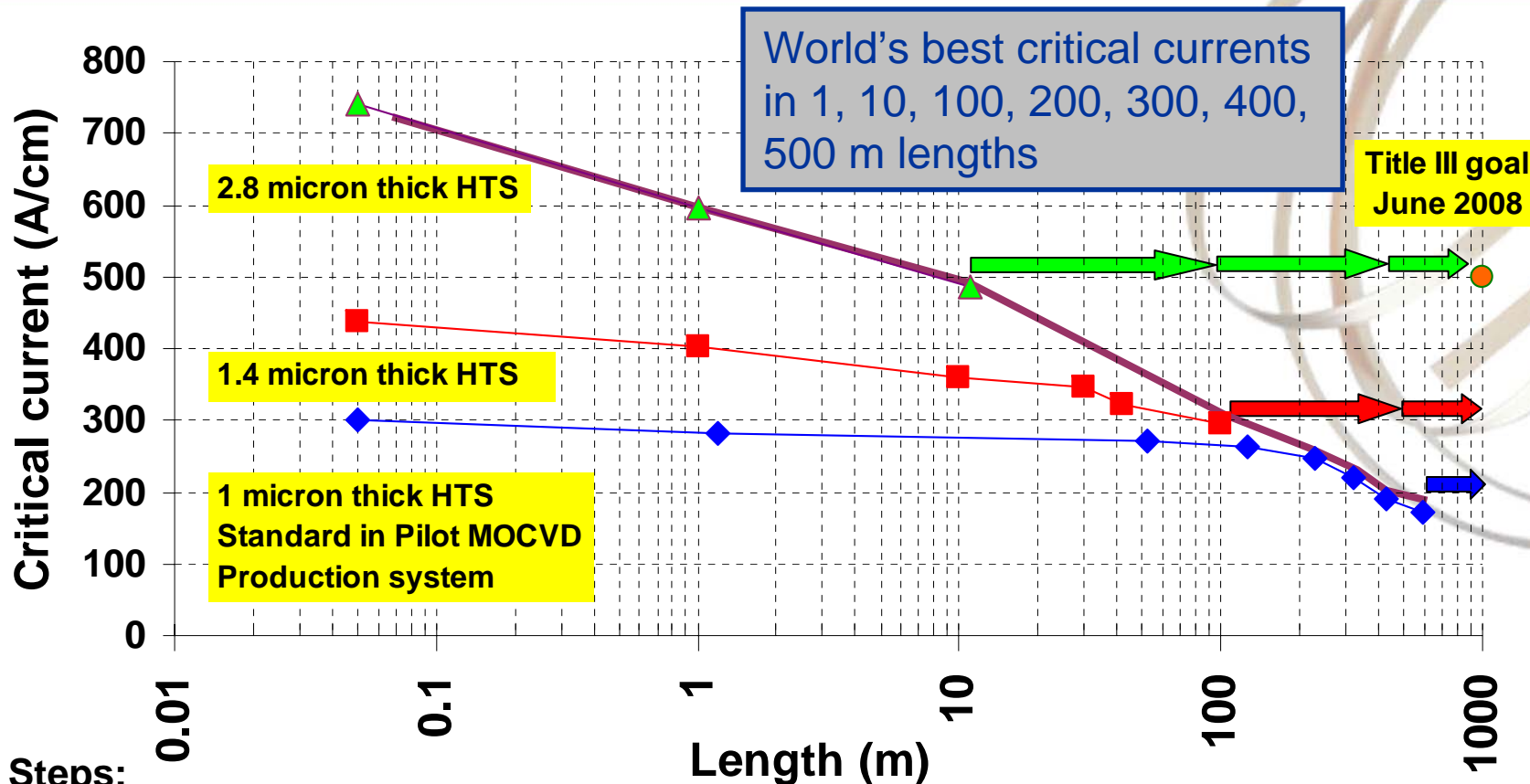
# Remarkable progress in 2G wire scale-up over the last 5 years



\*4 mm speed equivalent



# Progress being made both in Pilot Manufacturing of long lengths & technology development with shorter lengths



## Next Steps:

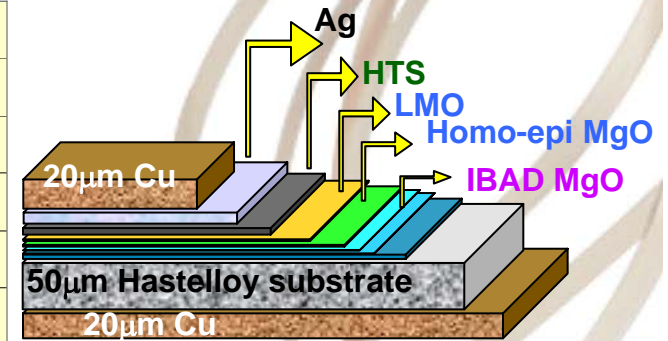
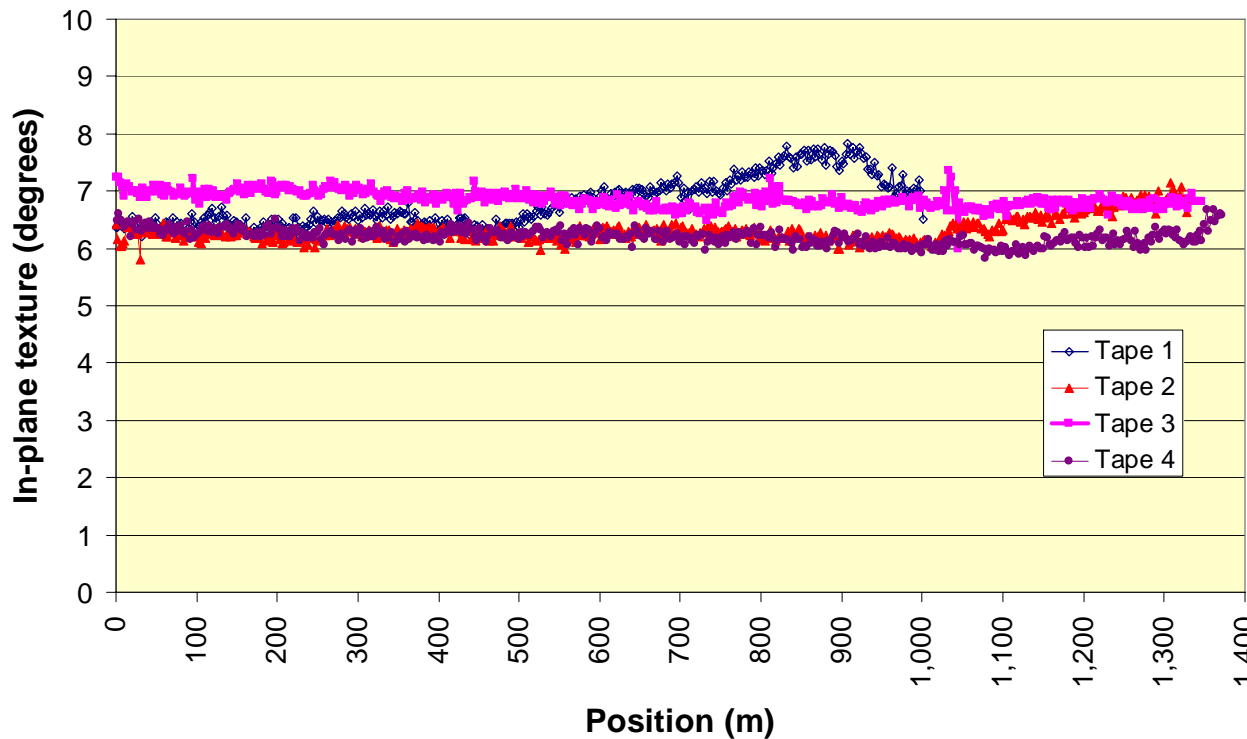
Manufacturing scale-up to reach 1000 m with  $I_c > 200$  A/cm

Manufacturing improvements to raise  $I_c$  level of 500+m Production lengths to that of short lengths of same film thickness i.e. 500 m and then 1000 m with  $I_c > 300$  A/cm

Technology transition of higher-current conductors to Pilot manufacturing i.e. 100 m, then 500 m and then 1000 m with  $I_c$  of 500 A/cm



# Kilometer lengths of fully buffered tape produced with excellent & uniform in-plane texture



*Several wires with complete 5-layer buffer stack produced in lengths of 1,350 m with in-plane texture of 6 – 7 degrees and excellent uniformity of ~ 2%.*

*This achievement brings us one step closer to producing kilometer long 2G wires!*

Tape	Length (m)	In-plane texture (°)			Uniformity
		Average	Min	Max	
1	1,001	6.79	6.20	7.84	6.2%
2	1,343	6.33	5.80	7.16	3.3%
3	1,346	6.85	6.00	7.35	2.1%
4	1,372	6.20	5.83	6.68	2.2%



## Substantial improvements made in the last year in all key metrics: $I_c$ , speed, and piece lengths of 2G wire

Metric	2005	2006	2007	Improvement in 2007
$I_c$ (A/cm) – short, reel-to-reel processed	407	557	<b>740</b>	30%
$I_c$ (A/cm) over 1 m	236	470	<b>595</b>	27%
$I_c$ (A/cm) over 10 m	215	276	<b>484</b>	75%
IBAD speed* (m/h)	3	195	<b>360</b>	85%
Buffer speed* (m/h)	n/a	120	<b>345 to 360</b>	185 to 200%
MOCVD speed* (m/h)	15	90	<b>180</b>	100%
$I_c$ over 200 m at stated speed	106	246	<b>227</b>	Same $I_c$ level with much higher speeds in all processes
Buffered tape piece length (m)	210	550	<b>1,375</b>	150%
Completed 2G wire Piece Length (m)	207	322	<b>595</b>	85%
$I_c \times L$ (A-m)	22,000	70,520	<b>102,935</b>	46%

*Rapid progress with higher currents, higher speeds, and longer lengths are all leading the way to a lower-cost 2G wire*

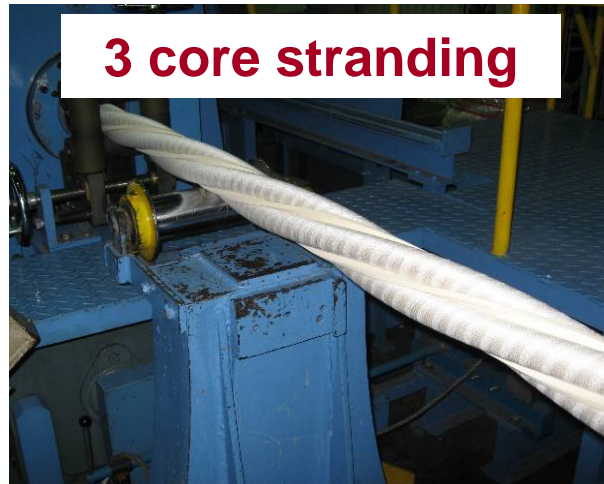
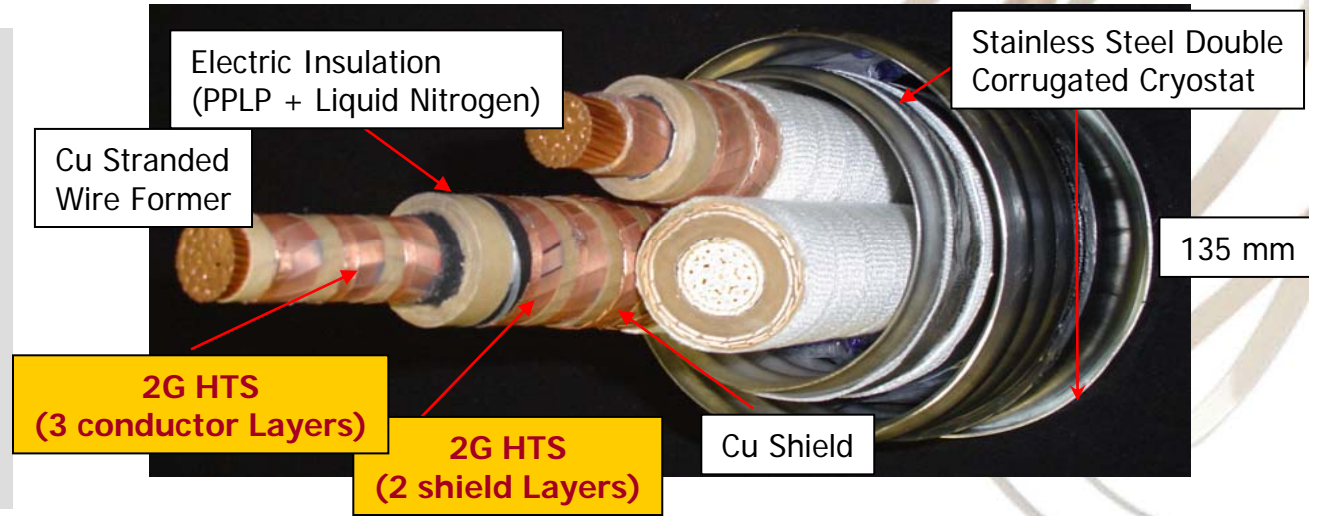


**SuperPower** Inc.

\*4 mm wide tape equivalent, single pass

# 30m 2G Cable has been manufactured & tested by Sumitomo with ~ 10,000 m of our 2G wire

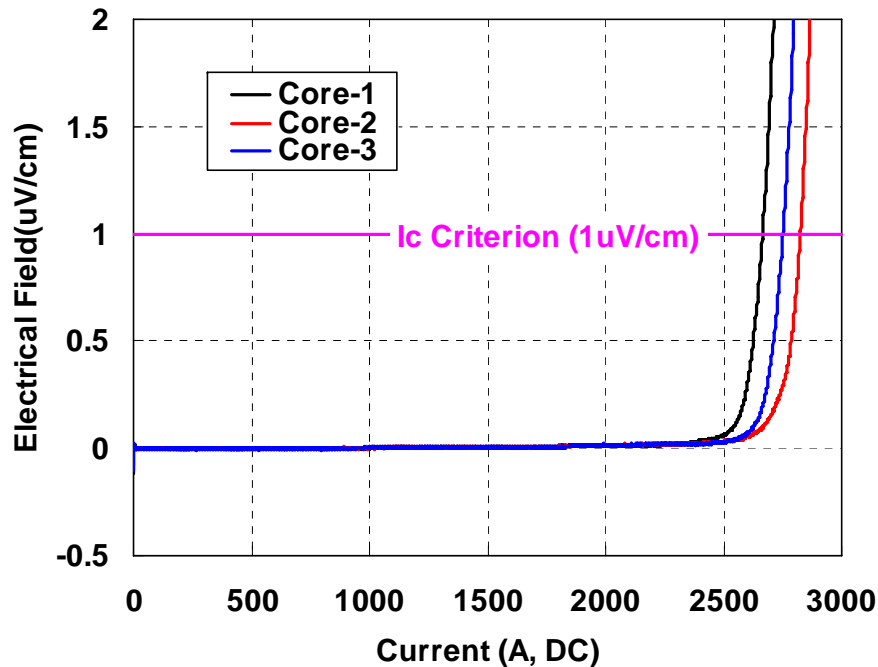
*Nearly 10,000 m of 2G wire in 43 m piece lengths and minimum  $I_c$  over 70 A was delivered by SuperPower in Dec. 2006, marking the single largest delivery of 2G wire*



 **SUMITOMO ELECTRIC**

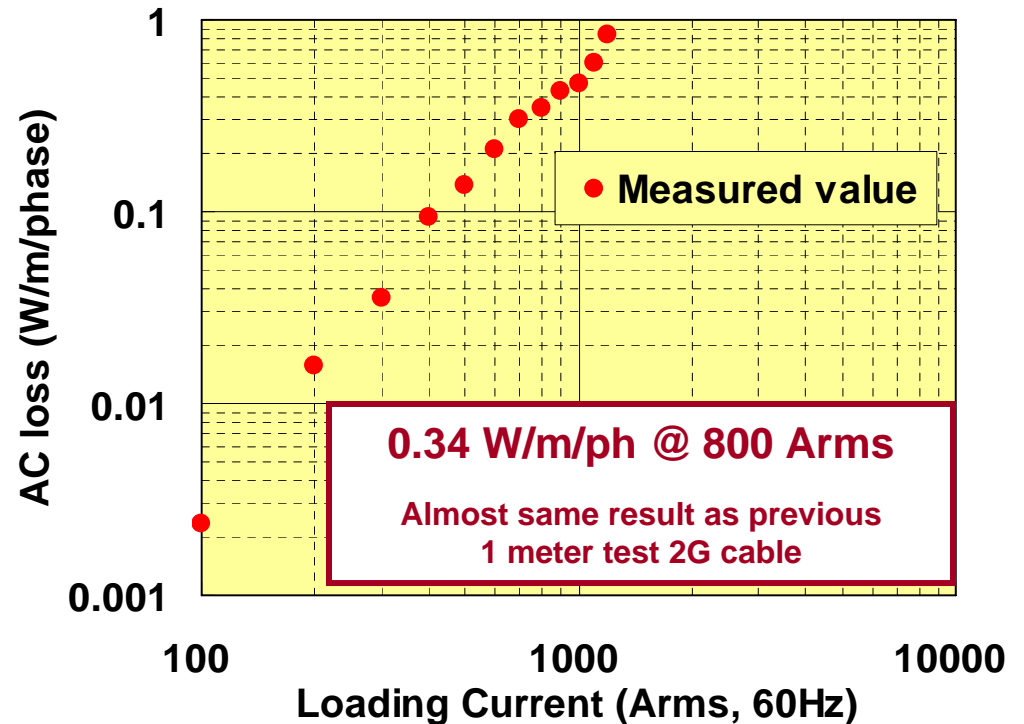
**Ingenious Dynamics**

# Excellent overall performance obtained in 2G cable



Ic of conductor layers ~ 2660 – 2820A  
(DC, 77K, 1 $\mu$ V/cm)

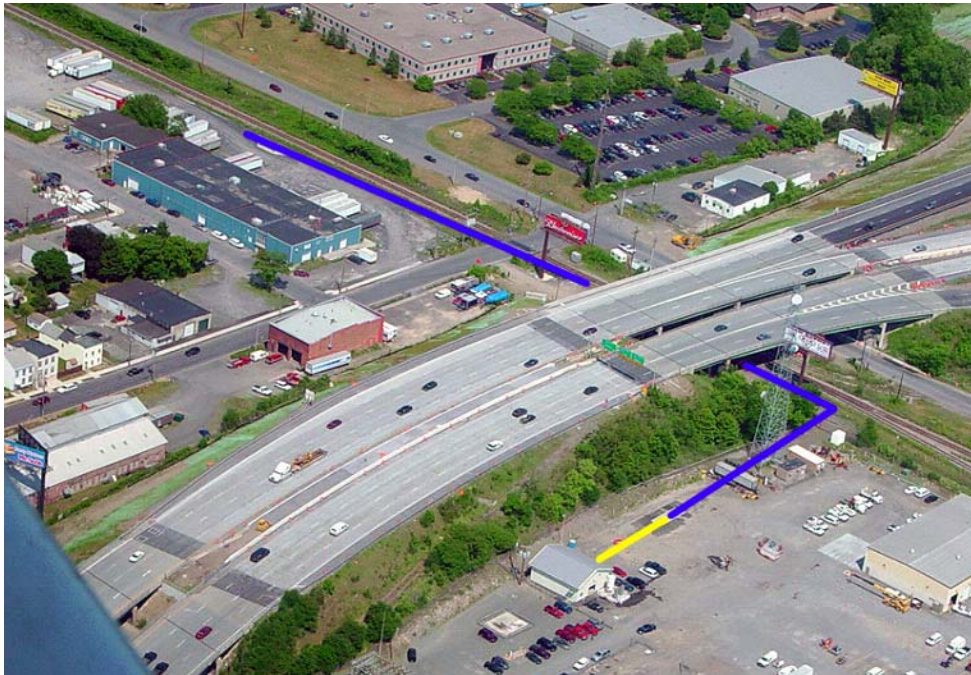
Ic of shield layers ~ 2400 – 2500A  
(DC, 77K, 1 $\mu$ V/cm)



No Ic degradation and No defect was found at dismantling inspection when bend to a diameter of 2.4 m

Cable withstood AC 69kV for 10 minutes and Impulse  $\pm$ 200kV, 10 times

# 2G cable has been installed in the National Grid system at the Albany Cable site



Installation at Albany Cable site  
(Aug. 5, 2007)



- World's first in-grid cable, first underground HTS cable, first cable-to-cable joint, 350 m long
- On-grid operations began July 20, 2006
- 30m segment of 1G cable replaced by 2G cable: the world's first 2G device

*2G cable will be energized in the grid by November 2007*



 SUMITOMO ELECTRIC

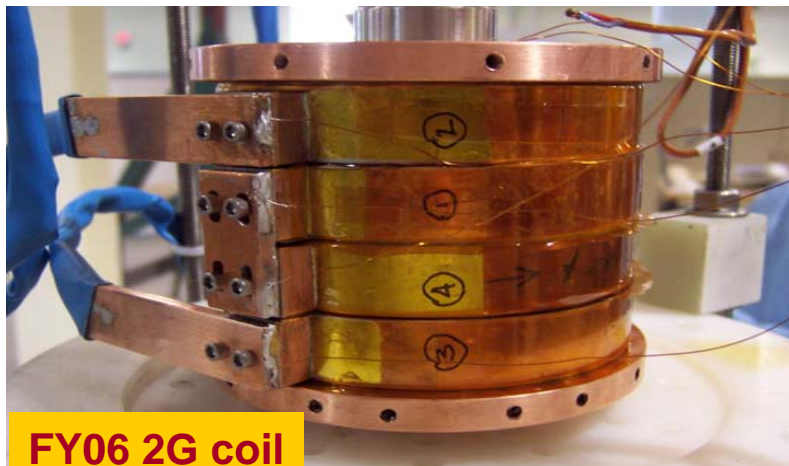
Ingenious Dynamics

 Power Inc.

# New high field coil constructed with 2G wire

*Total thickness of our 2G wire including copper stabilizer is only 0.095 mm which is half the thickness of 1G and other 2G wires.* This is very useful for coil applications where higher number of amp-turns can be obtained.

In FY06, we demonstrated a 2G coil that generated 1.1 T at 77 K and 2.4 T at 64 K



**FY06 2G coil**

**FY07 2G coil**

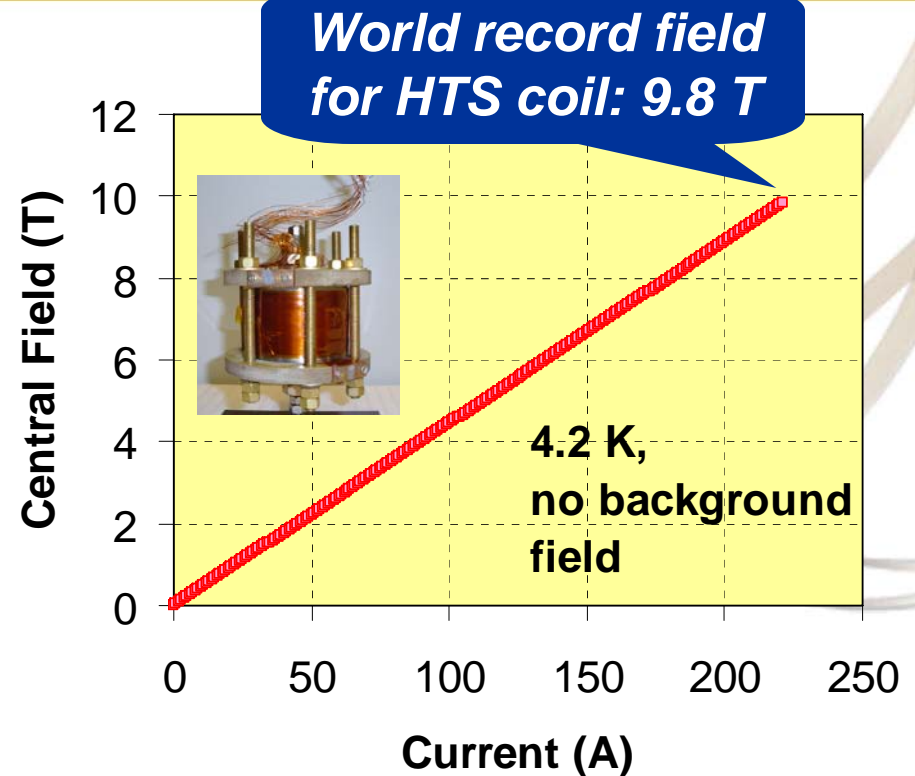


- In FY07, we constructed a coil with 6 double pancakes using 462 m of 2G wire.
- The coil was tested in the National High Magnetic Field Lab at FSU

**SuperPower** Inc.

# World record performance achieved with 2G coil

Coil ID	9.5 mm (clear)
Winding ID	19.1 mm
Winding OD	~ 87 mm
Coil Height	~ 51.6 mm
# of Pancakes	12 (6 x double)
2G tape used	~ 462 m
Average $I_c$ of tapes in coil	78 A in 4 mm width (77 K, self field)
# of turns	~ 2772
Coil $J_e$	~1.569 A/mm <sup>2</sup> per A
Coil constant	~ 44.46 mT/A



4.2 K Coil $I_c$ - self field	221 A
4.2 K Amp Turns @ $I_c$ - self field	612,612
4.2 K Central field – self field	9.81 T

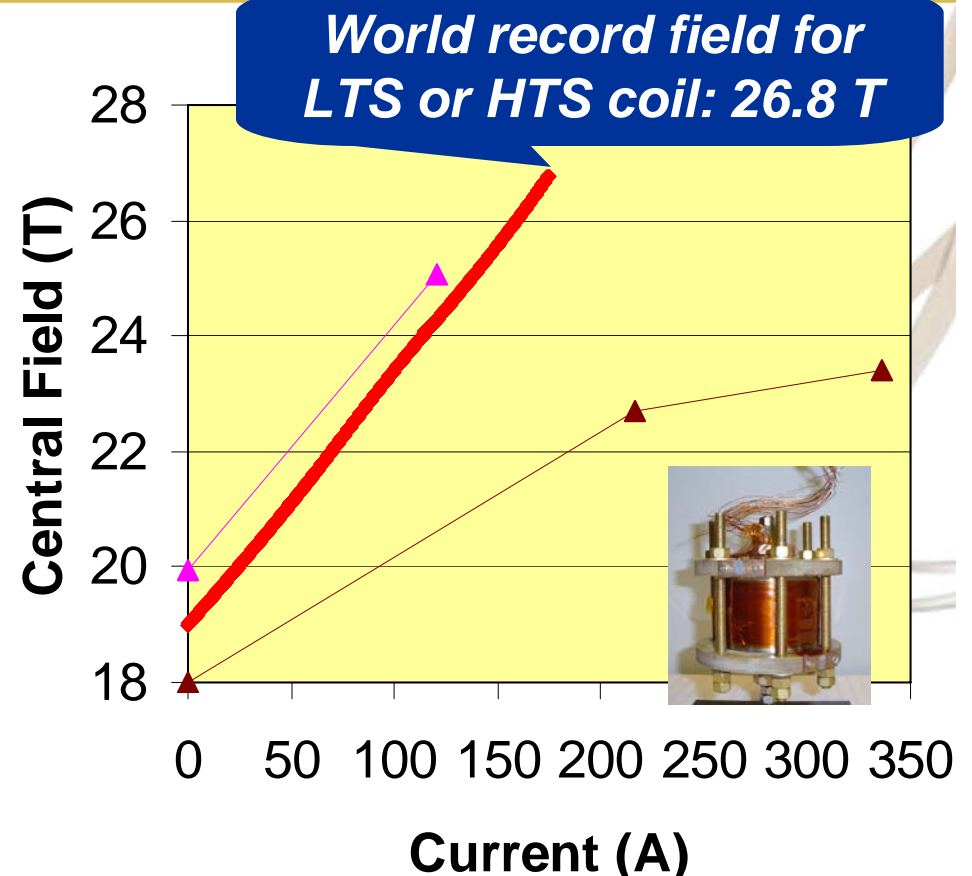
# World record performance achieved with 2G coil

4.2 K Coil $I_c$ – 19 T background (axial)	175 A
4.2 K Amp Turns @ $I_c$ – 19 T background (axial)	485,100
4.2K Central Field – 19 T background (axial)	26.8 T

	2007 SP	2003 OST	1999 Hitachi 2- insert
Conductor length (km)	0.46	2.1	1.0
Winding $J_e$ (A/mm <sup>2</sup> )	275	86	125/112
Additional field generated (T)	7.8	5.1	5.4
Total field achieved (T)	26.8	25.1	23.4

*This demonstration extends the potential of 2G over a wider application range*

Coil tested by H. Weijers, D. Markewicz, & D. Larbalestier, NHMFL, FSU



- ◆ SuperPower 2G
- ▲ OST Bi-2212 tape
- ▲ Two concentric Hitachi Bi-2212 inserts

**SuperPower**

