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Development of 2G HTS Wire for Demanding Electric Power Applications

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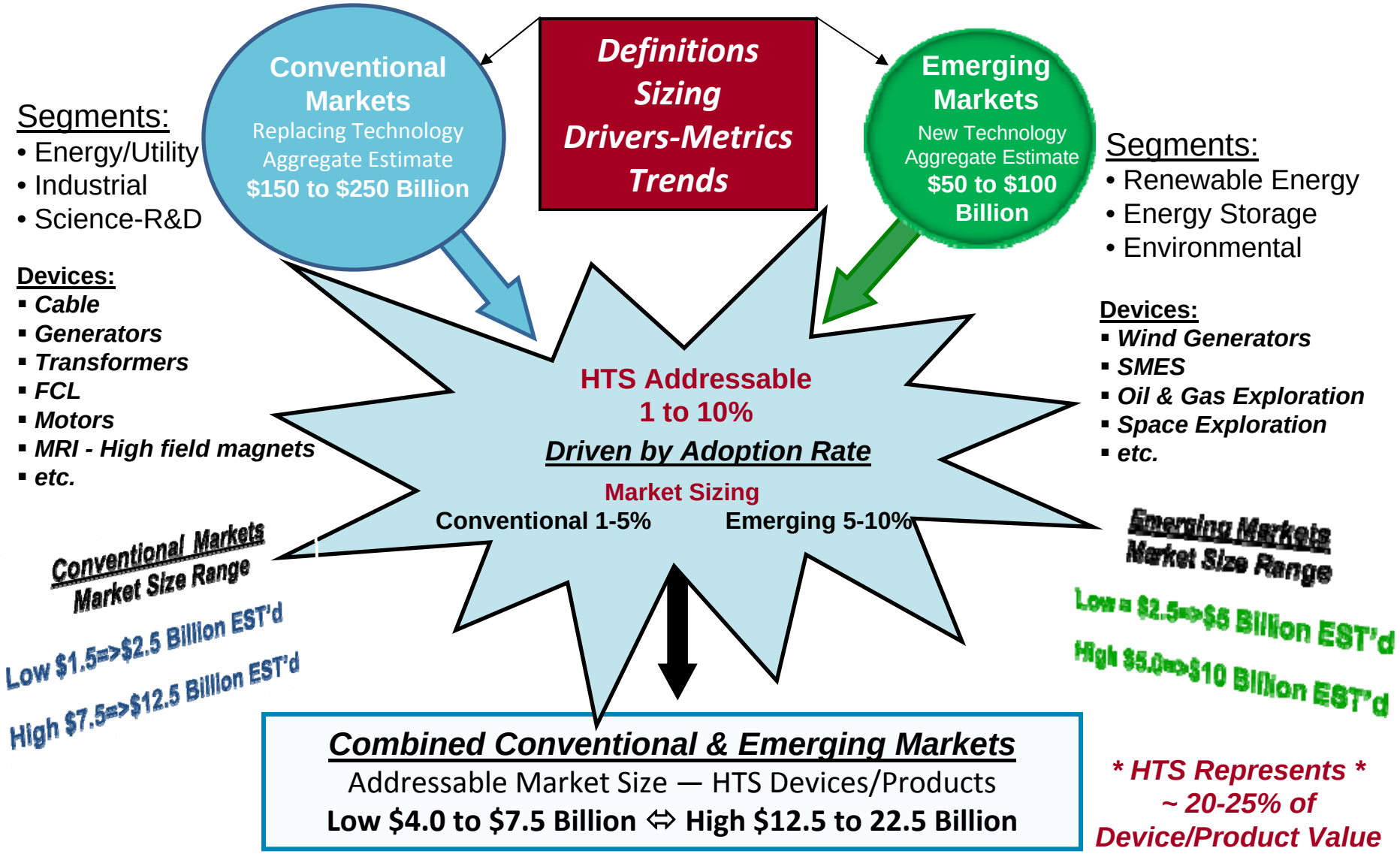
Topics

- The HTS market application and device opportunity
- Critical Success Factors to accelerating market adoption
- SuperPower's wire manufacturing program
- Continuing technology development
- Looking ahead

HTS Market Sizing Model & Analysis



HTS device portfolio - What are the winning devices?

Energy	Defense	Transportation	Industrial	Medical	Science/ Research
• **Cable (ac, dc)** • **FCL** • **Generators** – **Wind** – **Utility** – Hydro • **Transformers, incl. FCL** • **Storage** – **SMES** – Flywheels (Bearings)	• **Motors, propulsion** • **Cable, degaussing** • Directed energy weapons	• **Maglev** • Motors, Marine propulsion • Rail engines	• **Induction heaters** • **Motors, industrial** • **Generators** • Magnetic separation • Bearings	• **Current leads** • **MRI** • NMR	• **HF magnets** • **Space exploration** • SQUIDS • High energy physics • Electronics • Cell tower base station filters

Key:
- **Near-Term addressable by 2G HTS - 1-5 years**
- **Government interest/funding - Mid-Term 3-7 years**
- **Longer term/other - 5-10 years**

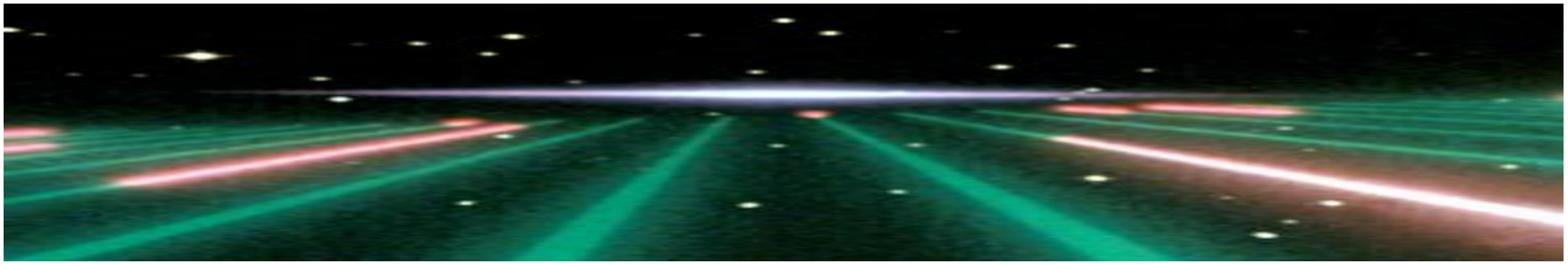
What does it take to accelerate the HTS adoption rate toward commercialization?

Technology advancement

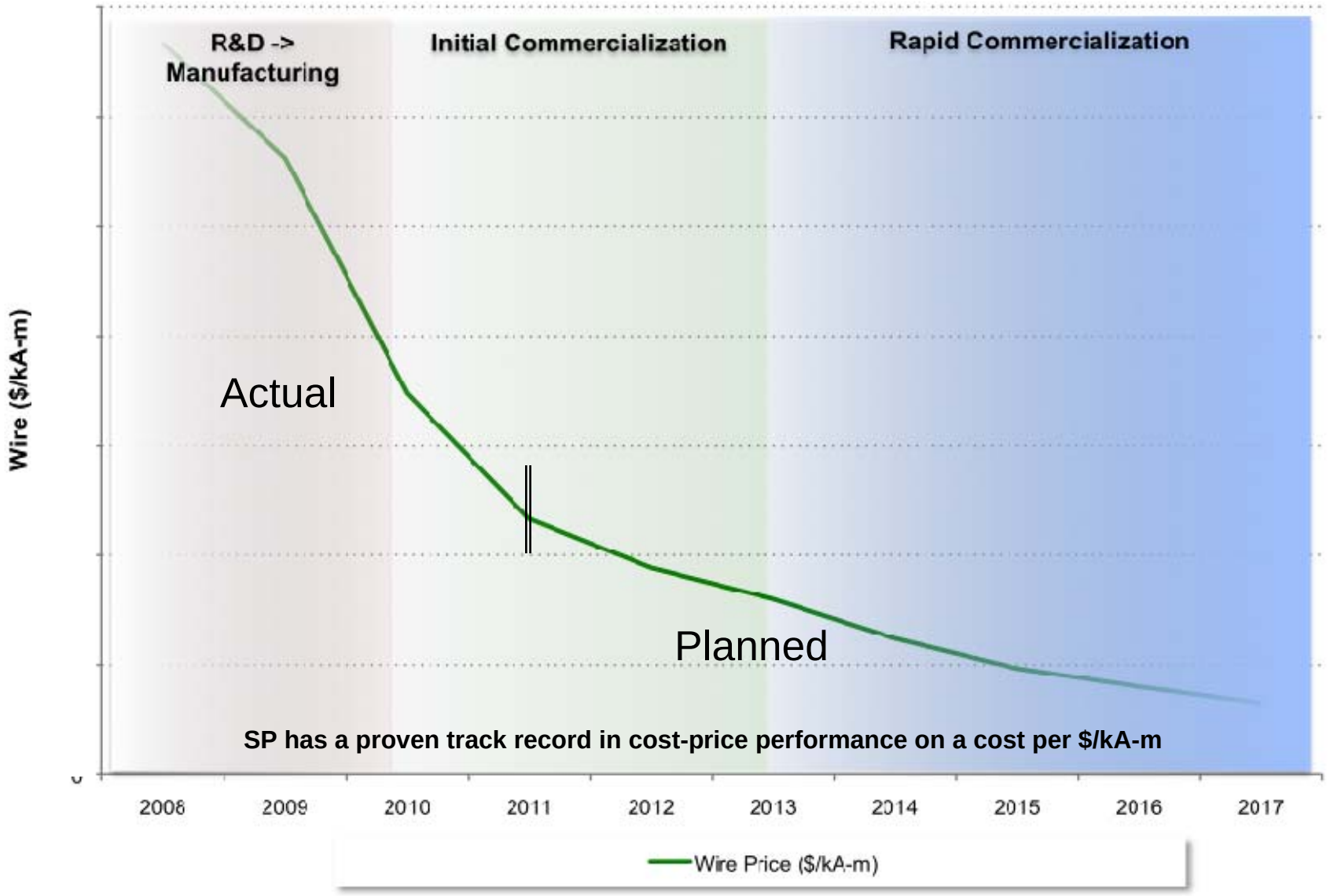
- Wire
  - Meet performance parameters
  - Achieve competitive price
  - Increase throughput / supply
- Providing a robust product portfolio
  - Market / device-driven
- Continuing device demonstrations
  - Government funding
  - Strategic partners

Reduced business risk

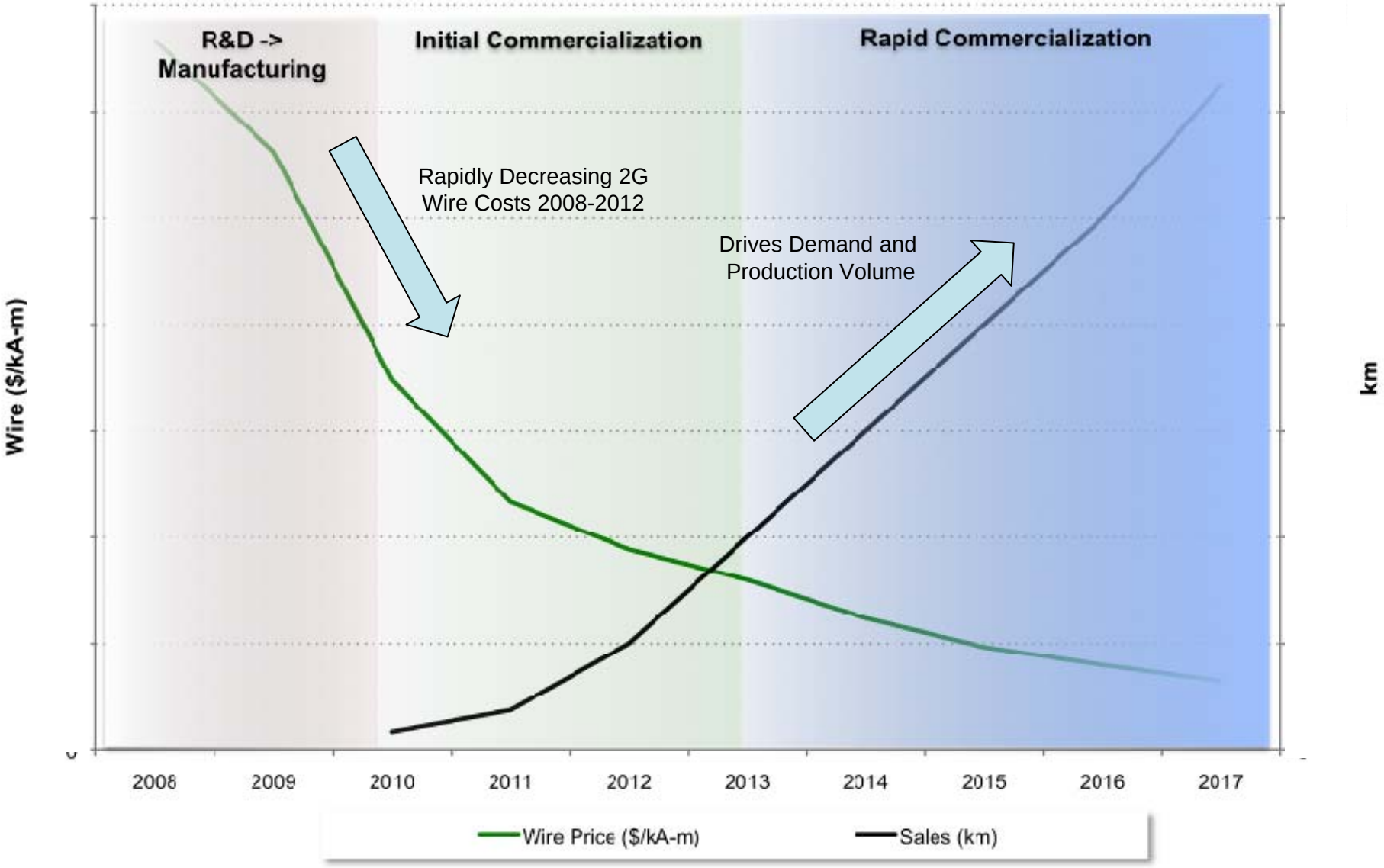
- Price must be competitive with alternative technologies
- Meet or exceed customer expectations
  - Supply
  - Quality
  - Performance
- Provide superior customer support



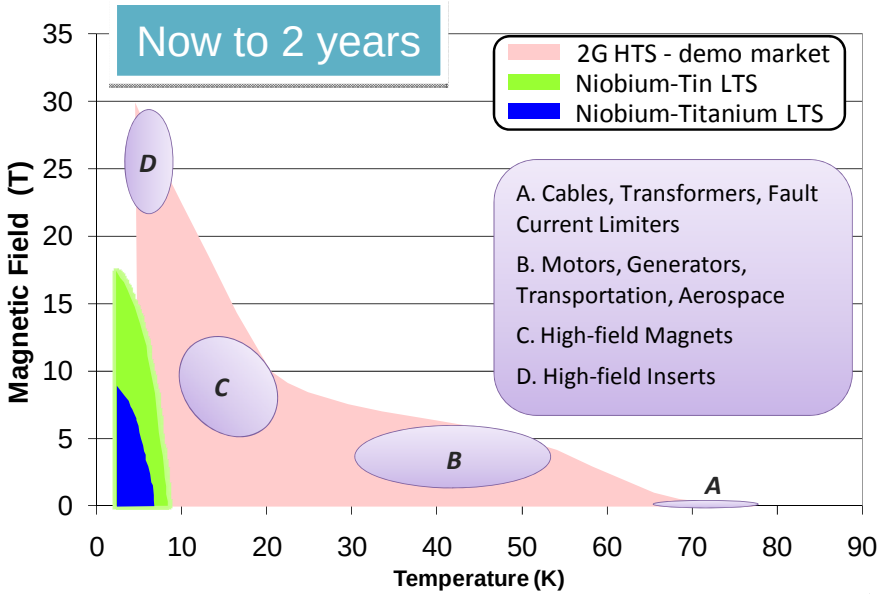
Driving Demand

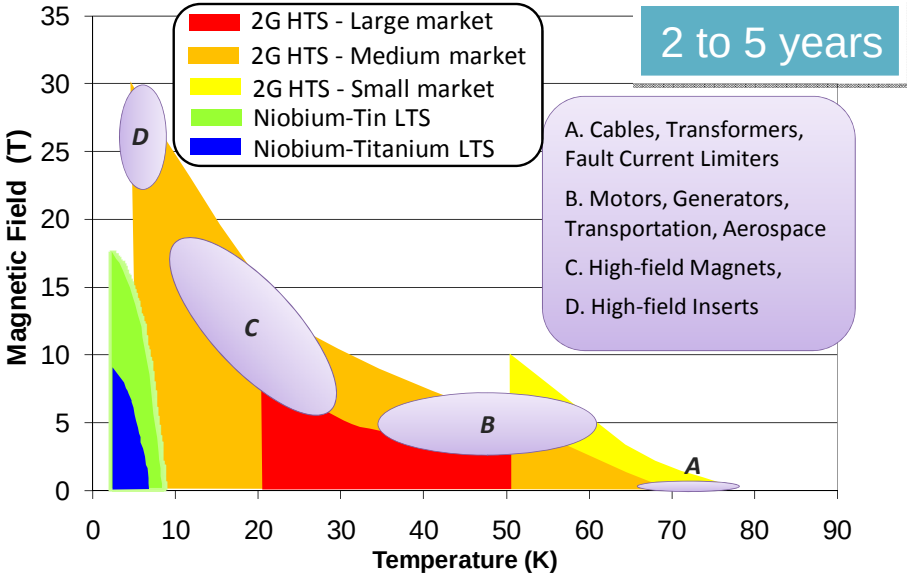


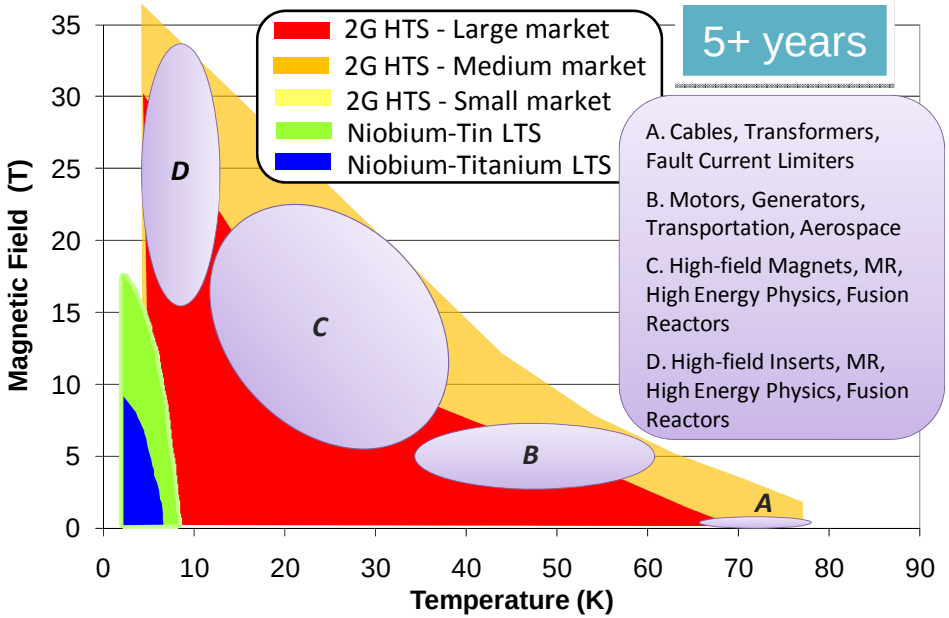
Driving Demand



Technology roadmap to realize large market potential







- Large market potential outside the capability of LTS wire
- Wide range of applications with broad operating conditions & unique requirements – need highly sophisticated & engineered wire
- Abundant opportunity to lead market capture through technology to improve wire performance and cost-profile

Application-specific requirements for HTS wire:

Superior performance in operating conditions

Application	Operating Field (Tesla)	Operating Temperature (K)	Additional requirement	Wire needed per device (kA-m)
Cables	0.01 - 0.1 (ac) 0.1 - 1 (dc)	70 - 77	Low ac losses	40,000 - 2,500,000
Wind/Off-shore oil platform generators	1 - 3	30 - 65	In-field Ic	2,000 - 10,000
Transformers	0.1	65 - 77	Low ac losses	2,000 - 3,000
Fault current limiters	0.1	65 - 77	Thermal recovery	500 - 10,000
SMES	20 - 30	4.2 - 10	In-field Ic	36,000 - 500,000
Automotive motors	2 - 5	30 - 65	Low ac losses	500 - 1,000
Aerospace	2 - 5	30 - 50	Light weight	1,000 - 2,000
Magnets/coils	5 – 30+	4.2 - 40	Long lengths, persist joints	200 - 2,000

SuperPower is well positioned to service these markets.

Collaborations are Key

Government

etc.

Research Institutes and National Laboratories

etc.

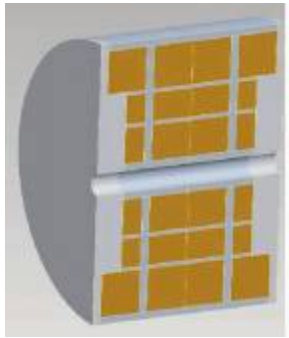
Industry - Utility

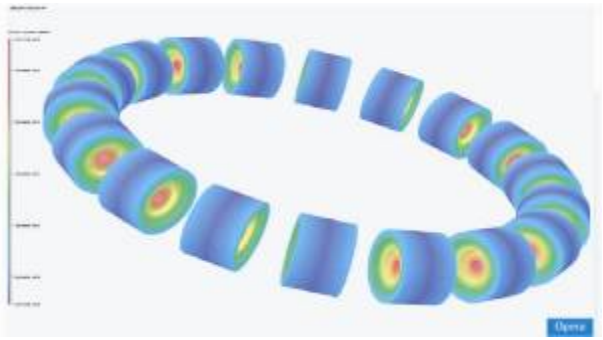
etc.

Academia

ARPA-E SMES development

- Funding: DoE ARPA-E $4.2 million (Total program = $5.25 million)
- Project timeline: 2011-2013
- Partners:
  - ABB, Inc.: project lead, power electronics
  - Brookhaven National Lab: SMES coil
  - SuperPower Inc.: 2G HTS wire, coil development
  - University of Houston, TcSUH: manufacturing improvements for wire cost reductions

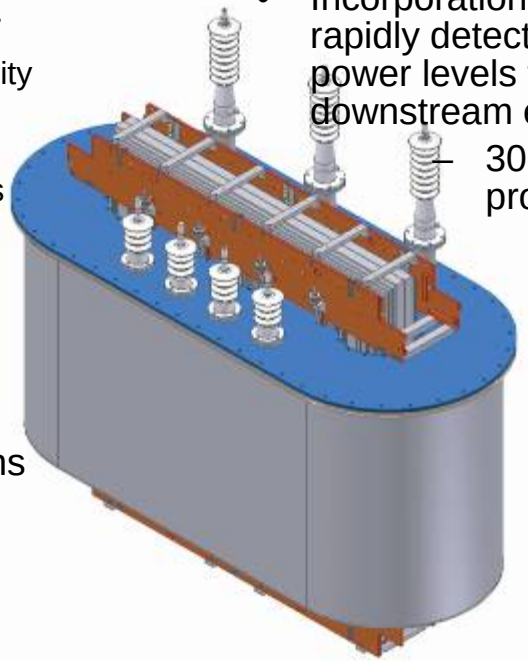




- Objective: proof-of-concept of modular, scalable SMES system by integrating an advanced power conversion concept with superconducting magnet coil
  - 20 kW UHF SMES device with capacity of up to 3.4 MJ
  - Field of up to 25 T at 4.2K
  - 2G HTS wire with high critical currents (~ 800 A) to drive down price/performance
  - Capable of flexible connection to medium voltage distribution networks at 15-36 kV
- Relevance:
  - High power and high energy storage in a compact device with cost advantages in material and system
  - Modular units for both long (hours) and short term (seconds) storage requirements to help load leveling on the grid being fed by variable renewable sources

DoE Smart Grid SFCL Transformer Demonstration

- Funding: DoE Smart Grid Demo $10.7M (Total Program = $21.5M)
- Partners:
  - Waukesha Electric Systems
  - SuperPower
  - University of Houston
- Project objective:
  - Design, develop, manufacture and test SmartGrid-compatible SFCL Transformer
    - 28 MVA 3-phase FCL Medium Power Utility Transformer (69 kV / 12.47 kV class)
    - Testing on So. California Edison Smart Grid site in Irvine, CA – expecting 2 years of grid operation
  - First transformer to use significant amounts of 2G HTS wire
- Relevance:
  - Smaller footprint than conventional transformers, enabling existing substations to increase distribution capability without expanding into limited or expensive real estate
- Benefits
  - Greater efficiency
  - Smaller, lighter, potentially quieter
  - Safety: no oil for cooling
  - Can run indefinitely above rated power without affecting device life
- Add FCL feature …
  - Compatibility with Smart Grid requirements
    - Incorporation of FCL feature to rapidly detect and limit surges at high power levels that can be handled by downstream equipment
      - 30-50% reduction of prospective fault current



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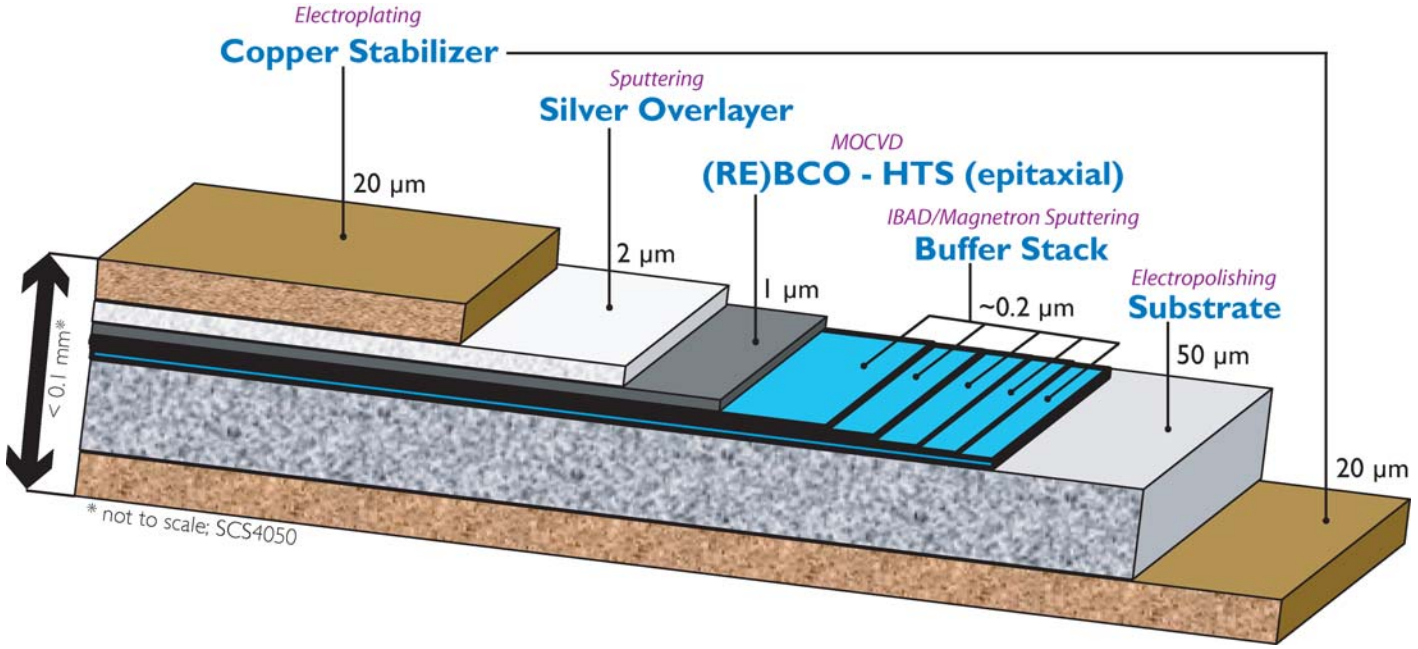
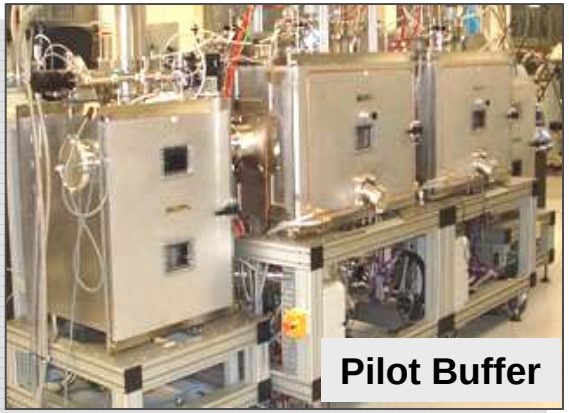
SuperPower's Wire Architecture and Production Methods

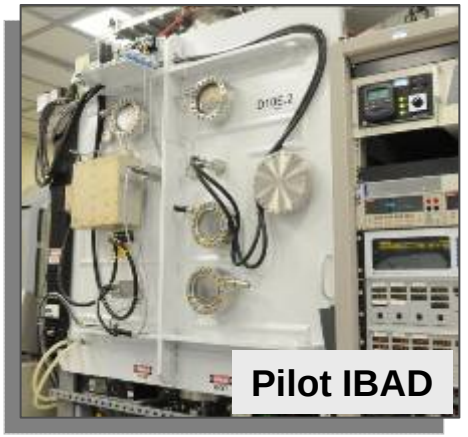
Thin film-based 2G HTS

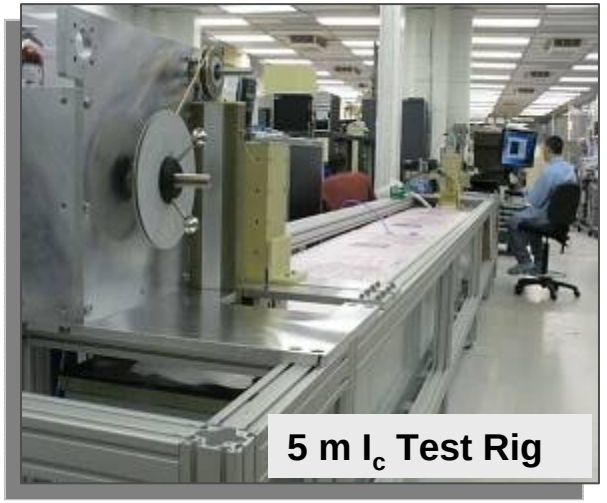


- 2G HTS wire is produced in an automated, continuous process
- Cost-effective materials architecture:
  - 95% of the structure of 2G is comprised of inexpensive nickel alloy substrate and copper
  - Only 3% of 2G is made of silver, compared to 70% in 1G
  - About 40 times less HTS in 2G than in 1G

SuperPower manufacturing approach

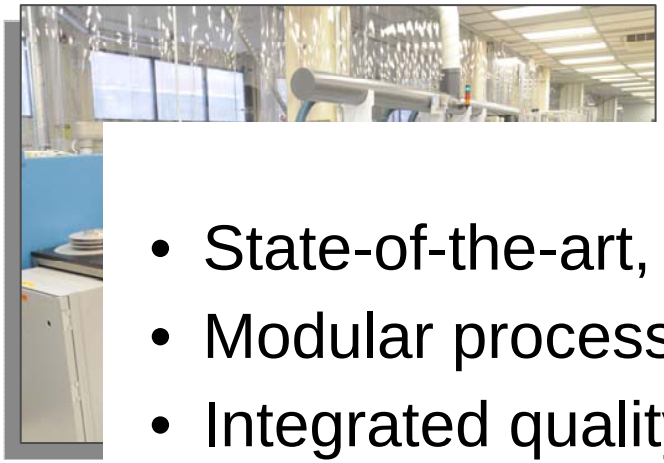


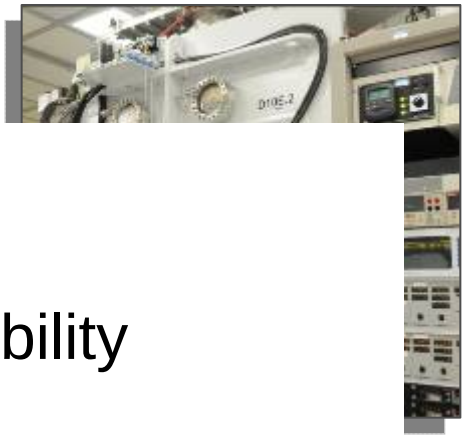




Strong, concentrated emphasis on manufacture of high quality, long length 2G HTS wire to satisfy market demand

SuperPower manufacturing approach





- State-of-the-art, novel equipment
- Modular processing for maximum flexibility
- Integrated quality systems
- Designed to scale for high throughput to meet market demand
- Skilled and dedicated workforce

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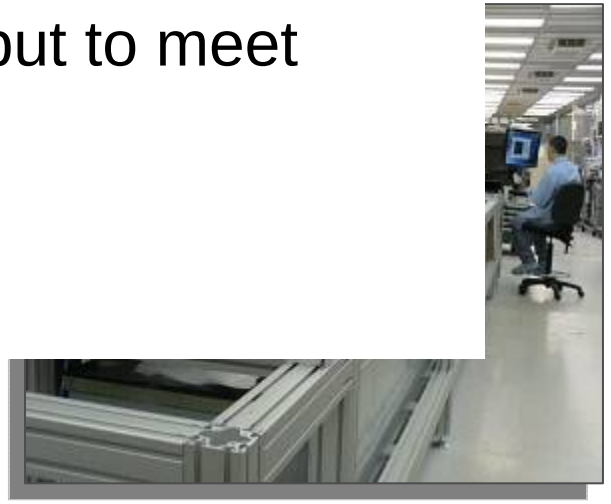
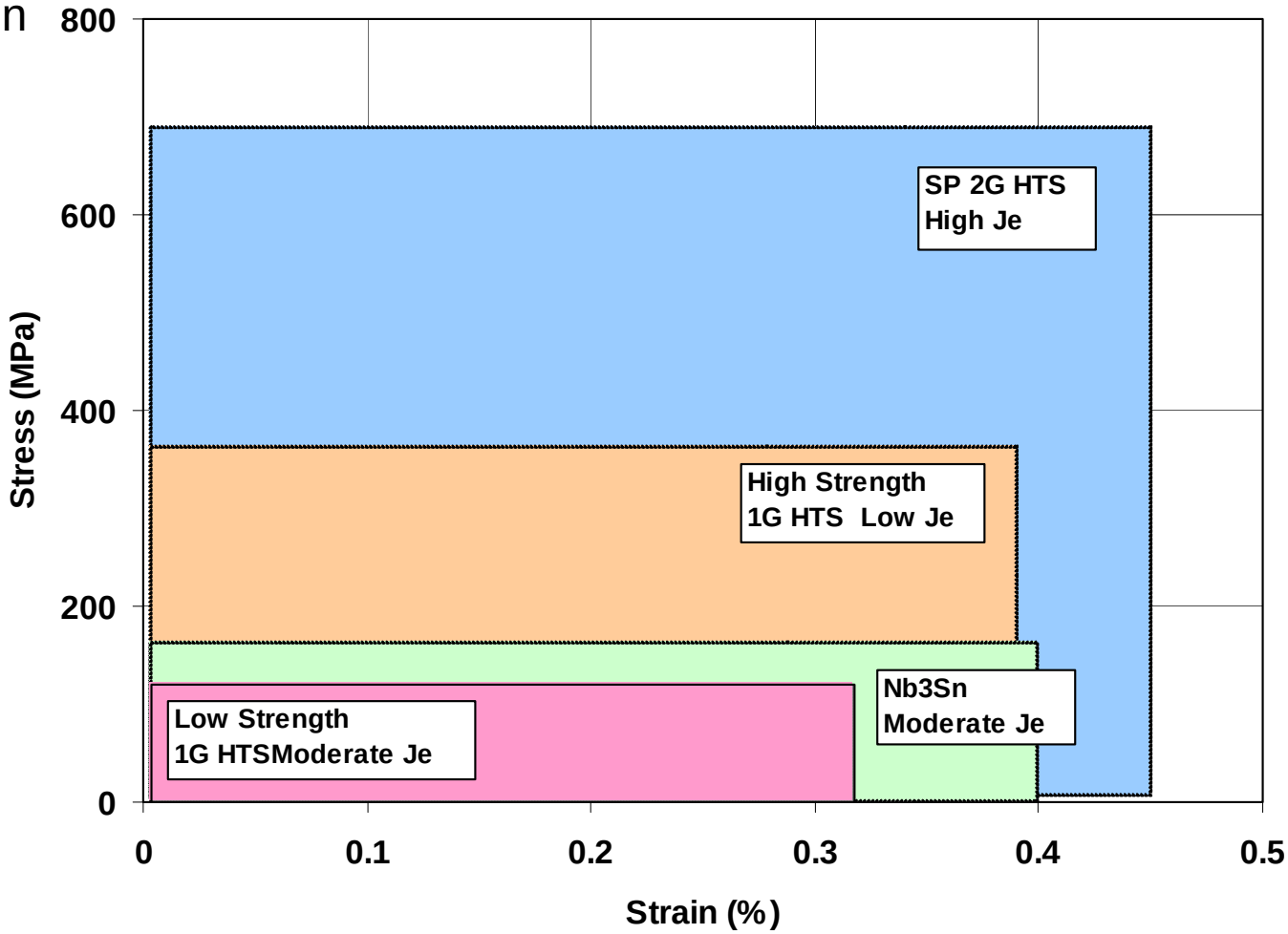
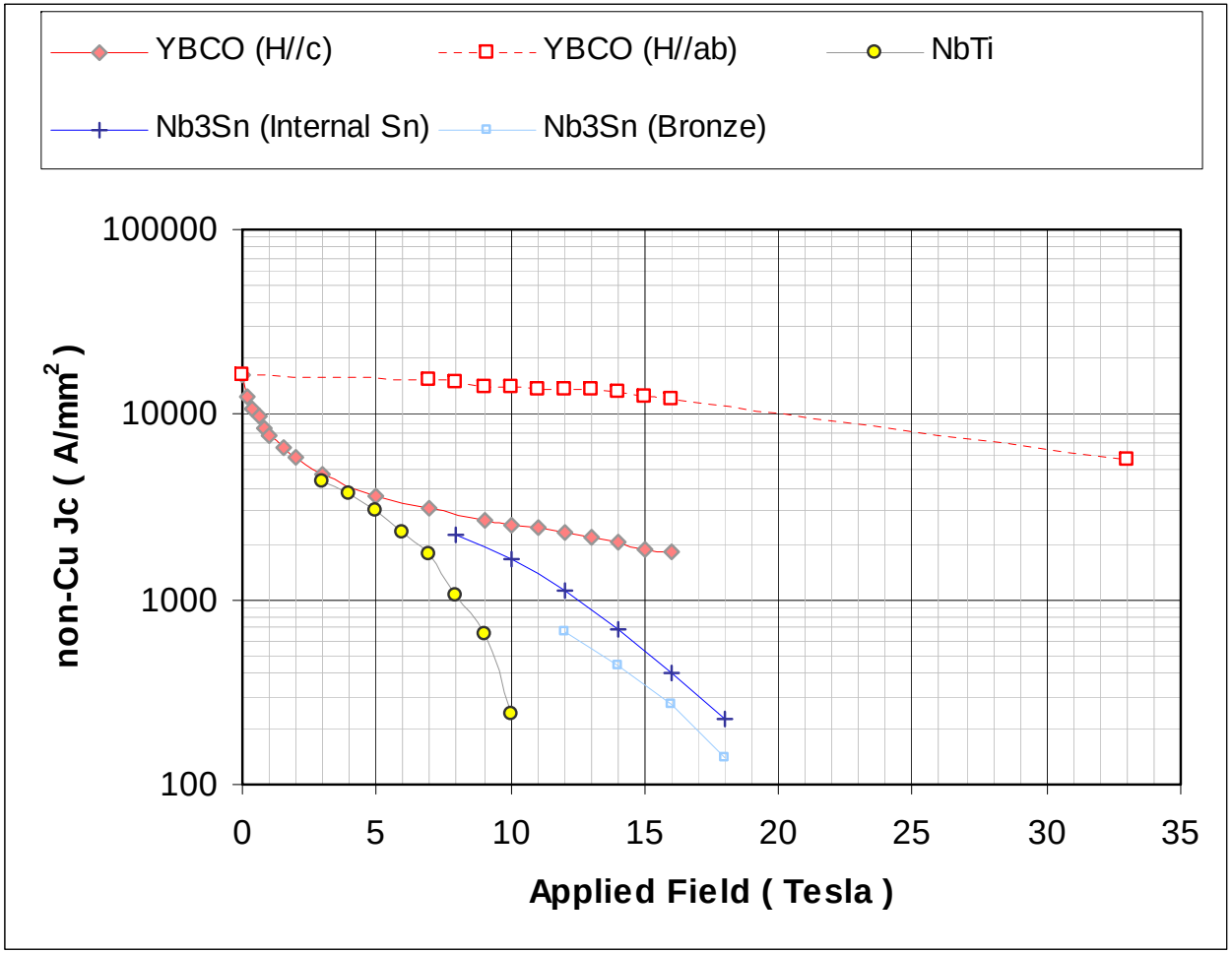


2G HTS wire offers superior mechanical properties

- 5 times higher yield stress than RABiTS-based wire
- Higher critical tensile stress
- Higher tensile strain
- Higher bend strain



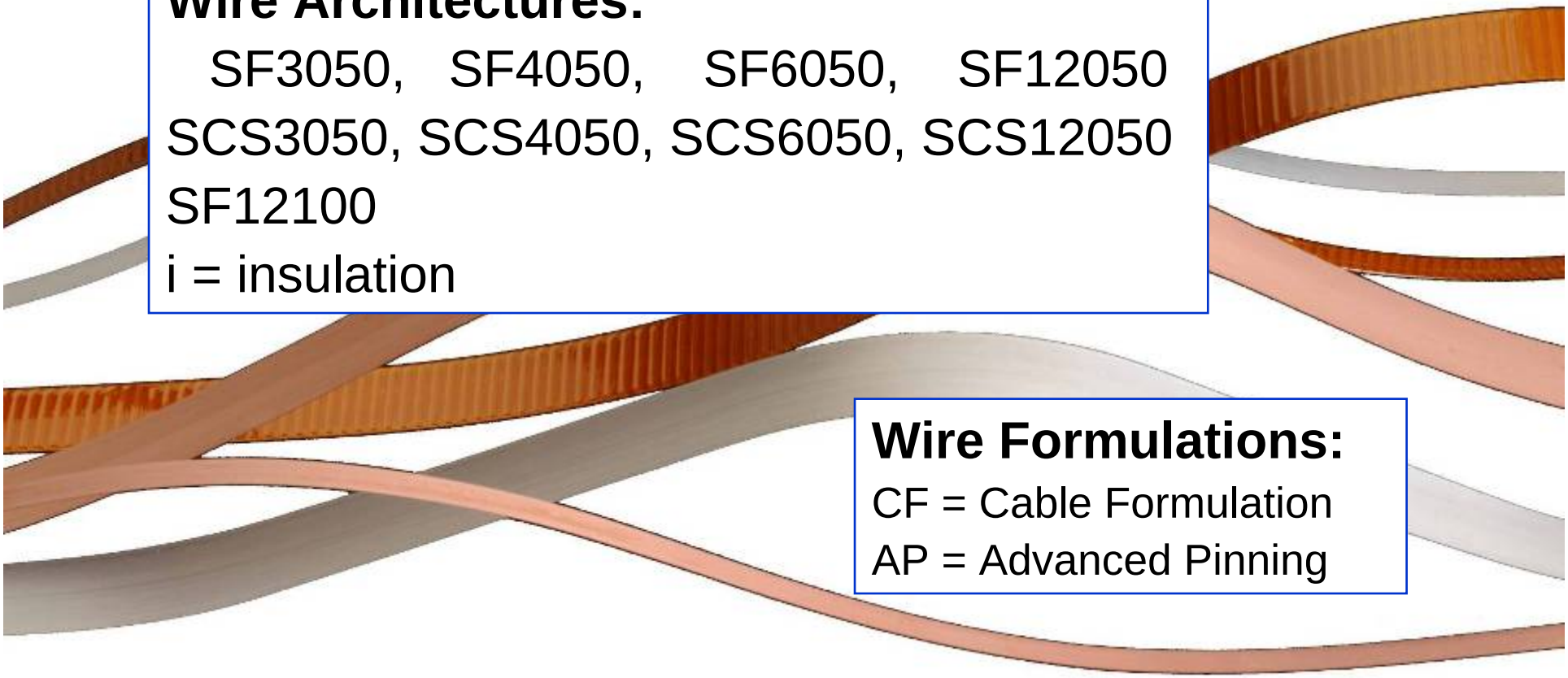
2G HTS wire allows operation at higher temperatures and in higher magnetic fields



Product offerings

Wire Architectures:

SF3050, SF4050, SF6050, SF12050
SCS3050, SCS4050, SCS6050, SCS12050
SF12100
i = insulation



Wire Formulations:

CF = Cable Formulation
AP = Advanced Pinning

Expanding manufacturing operations to meet customer demand

Increasing annual capacity:
Improving manufacturing efficiency & effectiveness:
Yield
Throughput
Quality assurance
On-time delivery
Cost improvement
Product engineering/application support
Quality certification
New product development
Technical support
Coil design, engineering and fabrication

SuperPower Wire: Competitive Assessment

	SuperPower	Others	Advantage for		
			Coil	FCL	Cable
Performance at 77 K, zero field (4 mm wide)	100 to 150 A	80 to 100 A	SP	SP	SP
'Lift Factor' in magnetic field (at 30 K, 2 T)	2.6	1.2	SP	---	---
ac losses	Medium	High	SP	SP	SP
Engineering current density	2x	1x	SP	---	---
Strength	700 MPa	250 MPa	SP	---	---
Resistivity	High	Medium	---	SP	---
"Stiffness"	Medium	High	---	---	Others
Production volume	~ 300 km/yr	10 to >300 km/yr ?	---	---	Others

We continue to widen our advantage in performance, lift factor and ac losses through our continuing technology development program

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Technology Update and Outlook

SuperPower R&D operations at U of Houston

- SuperPower scientists at U of Houston fully focused on R&D
- Research-scale deposition systems in place for trial runs
- SuperPower staff work with research students and university staff
- Enables clear focus on next generation of technology advancements

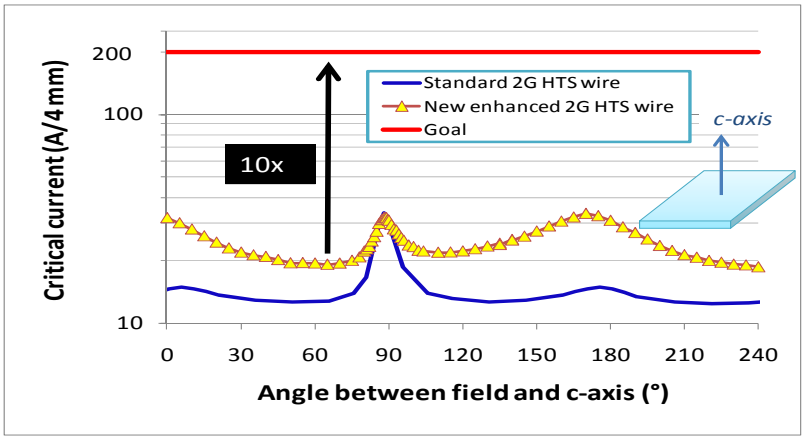
Technology development goals

Achieve higher amperage

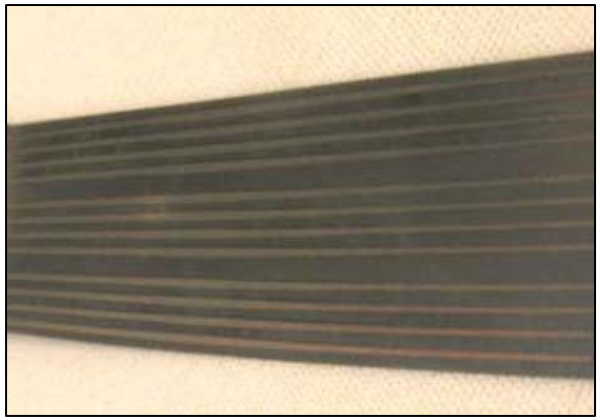
	Today	2 yrs	5 yrs
Ic at 77 K *	100-130 A	200A	300 A

* 4 mm width

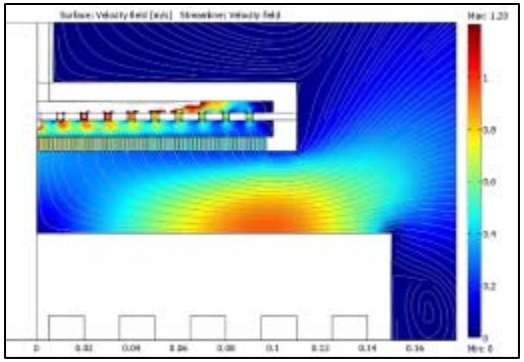
Increase in-field performance



Develop low ac loss wire



Improve throughput and reduce cost



New MOCVD Reactor Design

Silver Electrodeposition

SuperPower 2G wire program strategy

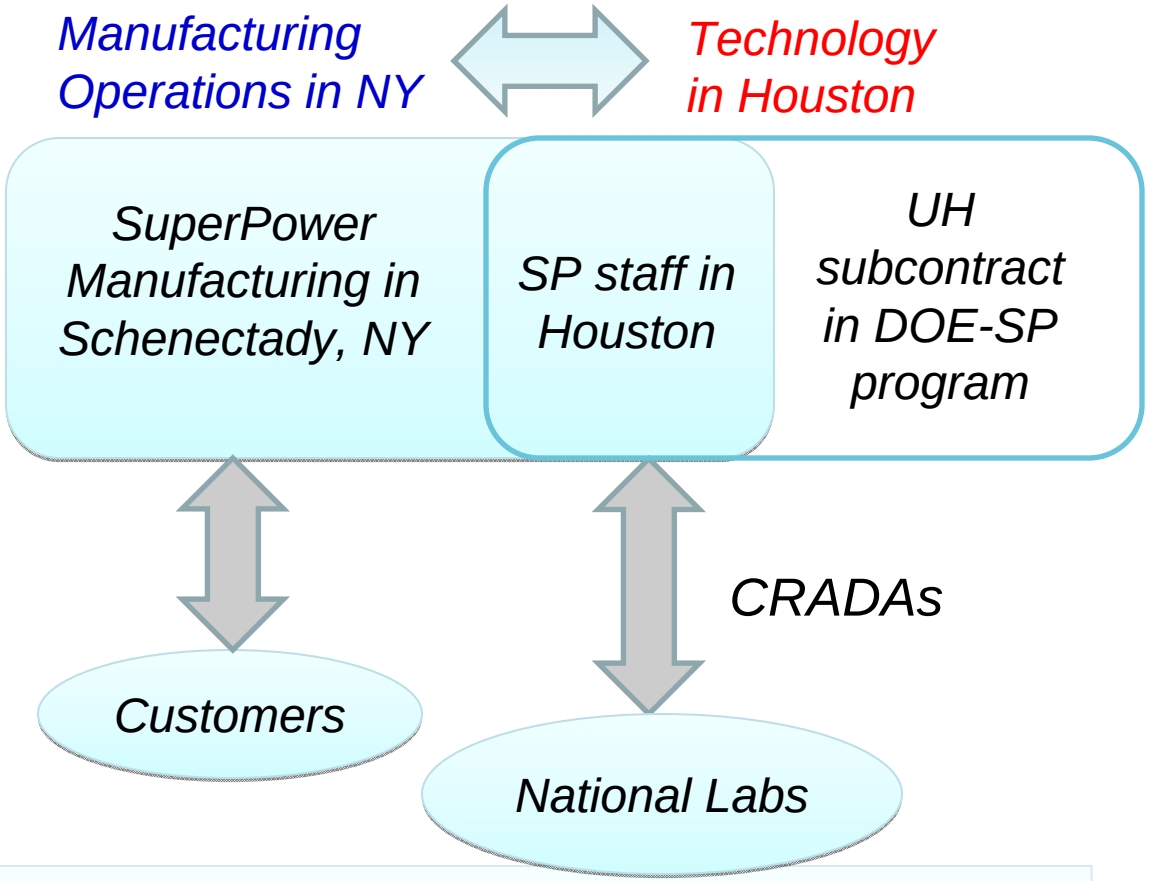
- SuperPower's technology operations consolidated in Houston, allowing total focus on manufacturing in Schenectady.

Manufacturing objectives

- High yield, high volume operation
- On-time delivery of high-quality wire
- Incorporate new technology advancements

Technology objectives

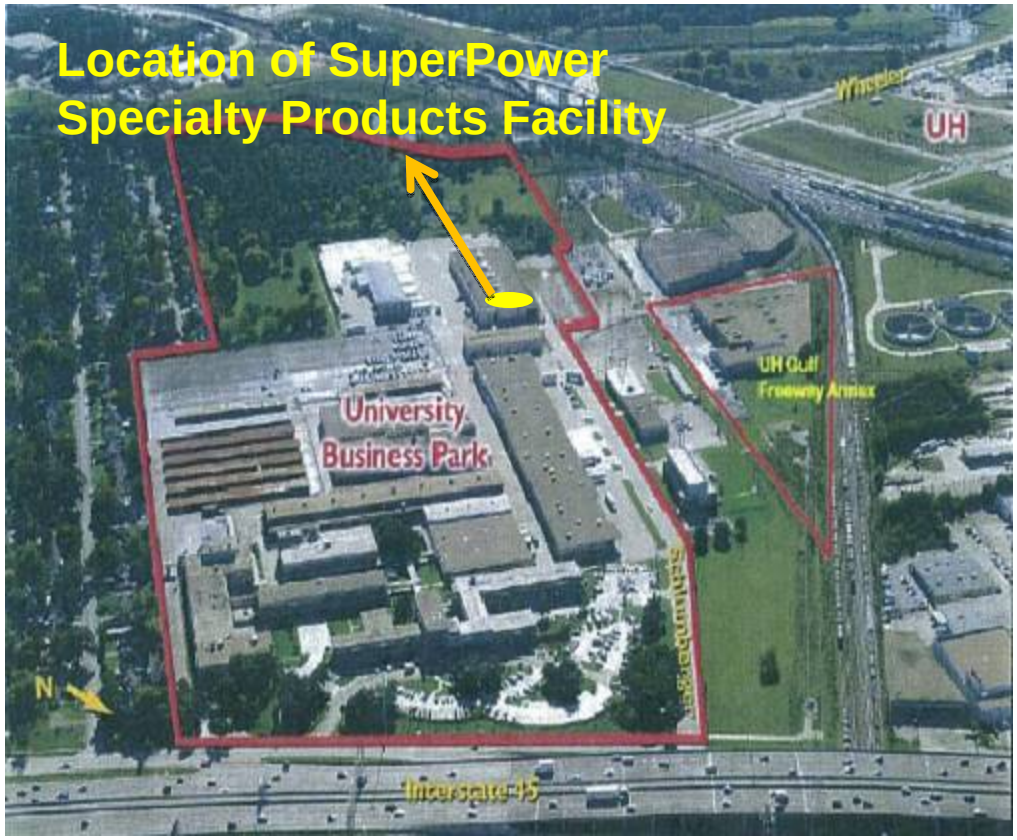
- High performance wires
- Highly efficient, lower cost processes
- Advanced wire architectures
- Successful transition to manufacturing



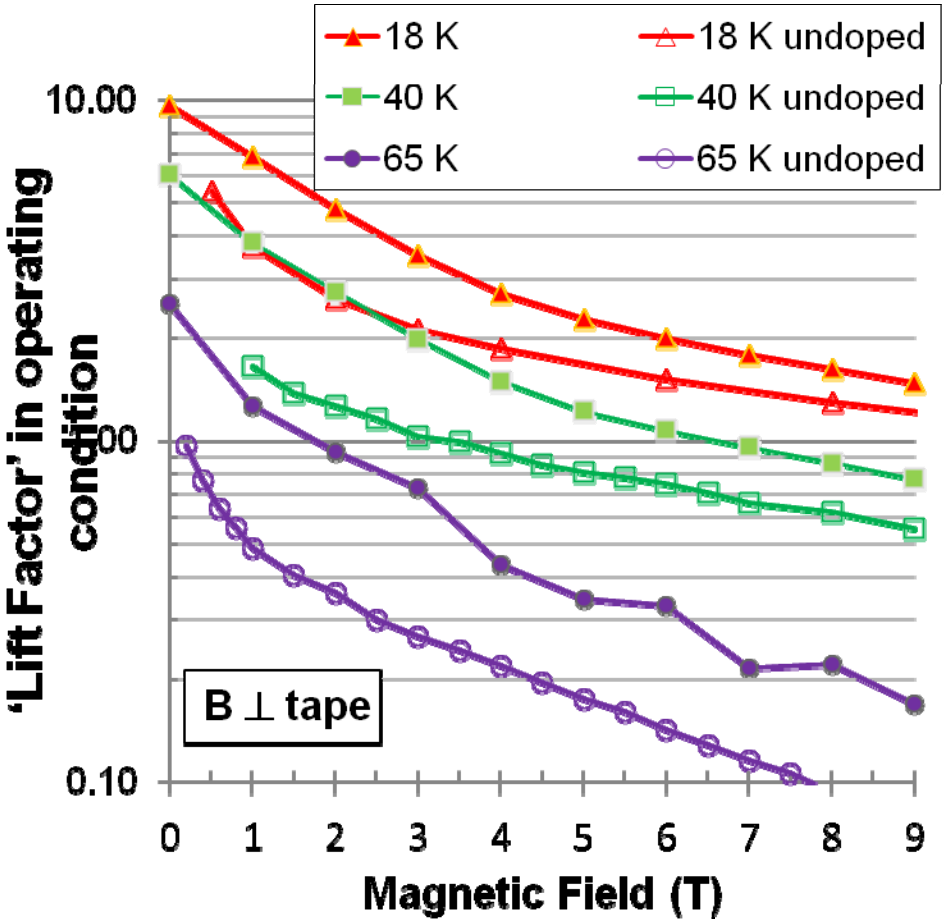
Best of both worlds:
Strong, concentrated emphasis on manufacturing AND technology development

Planning ahead: Specialty Products Facility in Houston

- New SuperPower facility at UH Energy Research Park – opening August 2011
- Bridge between R&D and Manufacturing
- 5th MOCVD system procured by UH being installed at SPF
- Post-HTS processing and test equipment to also be installed



Huge progress in wire performance in 2010



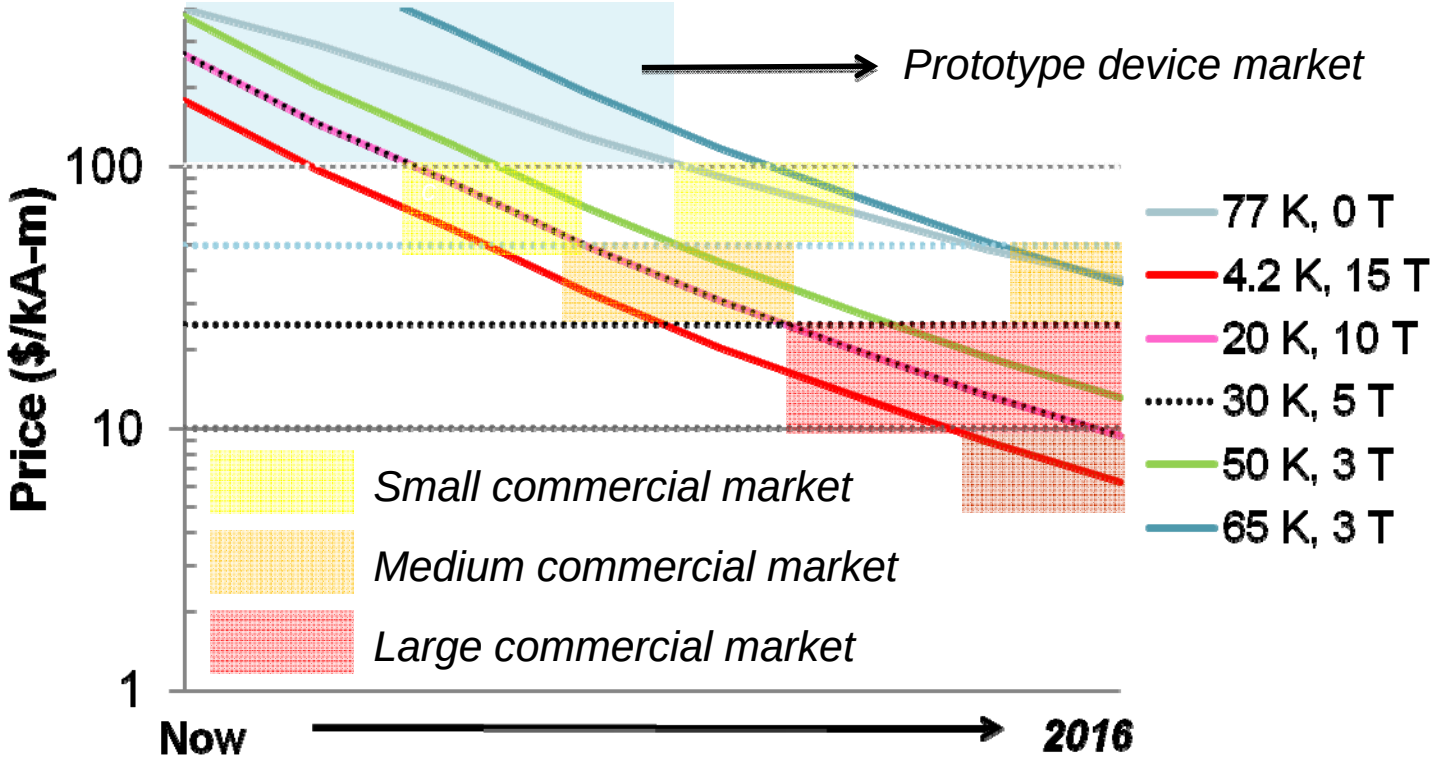
Lift factor from 77 K, zero field I_c	65 K 3 T	40 K 3 T	18 K 3 T
Our standard (undoped) wire	0.27	1.02	2.13
Advanced pinning (AP) wire	0.73	1.99	3.50
Lift factor of AP wire is higher by	2.7	1.9	1.6
77 K zero-field I_c of 2009 wire = 100 A			
77 K zero-field I_c of 2010 AP wire = 130 A			
Lift factor of AP wire (including higher zero field Ic) is higher by	3.5	2.5	2.1

Lower cost to customer ($/kA-m) while maintaining wire price ($/m) - our approach for increasing sales

Time	Performance at 77 K, zero field (4 mm width)	Lift Factor at device operating condition	Performance at device operating condition	Wire price ($/m)	Wire price ($/kA-m) at device operating condition
Now	**100-130 A**	**2**	**260 A**	**$40**	**$150 +**
2 years	**160 A**	**4**	**640 A**	**$35**	**$ 55**
4 years	**200 A**	**6**	**1200 A**	**$35**	**$ 30**

Improving wire performance is the key to the success of our approach

Significant price improvements projected through technological advancements



- Price reduction due to improvements in zero-field critical current, retention of in-field critical current, and cost reduction ($/m)
- Applications that involve magnetic field benefit from the additional improvement factor of in-field Ic retention
- Increasing market opportunities with decreasing price at operating condition

Looking ahead:
SuperPower's primary areas of focus

- Scaling up manufacturing operations to ensure supply
- Further advancing the technology
- Working with customers to understand and meet their needs
- Collaborating to ensure success
- Participating in device demonstrations
- Meeting the price / performance challenge
- Working closely with all of our stakeholders

Thank You!

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