# *Hot Wires: Superconductivity R&D for Electric Power*

November 13, 2000
E-Source Members' Forum

**Bob Hawsey, Manager**
**ORNL Superconductivity Program**

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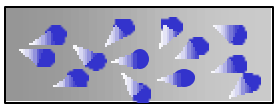
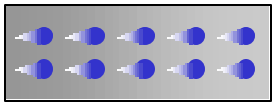
## Outline

- **What are superconductors?**
- **Today's "Hot Wires" Research**
- **Pre-commercial applications of high-temperature superconductors**
- **Opportunities for power companies**

# Superconductors: Electricity flows without loss of energy



Ordinary conductor: electrons moving at random lose energy in collisions, generating heat.



Superconductor: electrons moving in pairs don't collide, generating no heat and losing no energy!



# Superconductivity Is NOT New

- Superconductivity discovered in 1911 in mercury
- metallic superconductors: NbTi, $Nb_3Sn$
- operation in liquid helium, 4 K or -452 F
- medical imaging (MRI) & research magnets

## New Material Discovered in 1986: High-temperature Superconductors (HTS)

- **Ceramic**
- **$YBa_2Cu_3O_x$ --first superconductor with critical temperature above liquid nitrogen (77 K, -321 F)**
- **$Bi_2Sr_2Ca_2Cu_3O_x$ --**

**-superconducting at 110 K**

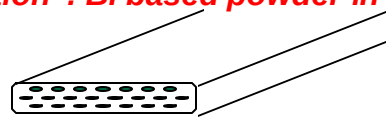
**-only HTS wire available in kilometer lengths today**

Courtesy of American Superconductor Corp.



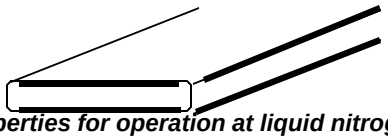
## HTS Wire Technologies

***"1st Generation": Bi-based powder-in-tube***



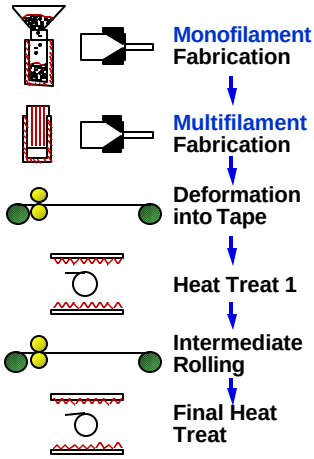
- *pre-commercial level of development (high cost)*
- *kilometer lengths with reproducible properties*
- *High field applications limited to low temperature (<30K)*

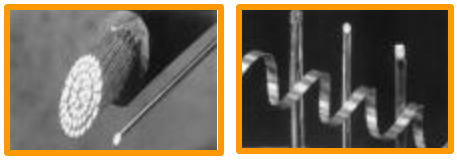
***"2nd Generation": YBCO on metal tapes***



- *Enabling properties for operation at liquid nitrogen temperatures*
- *Early development, only short lengths (~1 meter)*
- *Unproved economics, etc.*

## Powder-in-Tube of Bi-1223 is the Preeminent Method Used in Fabrication of Long-Length HTS

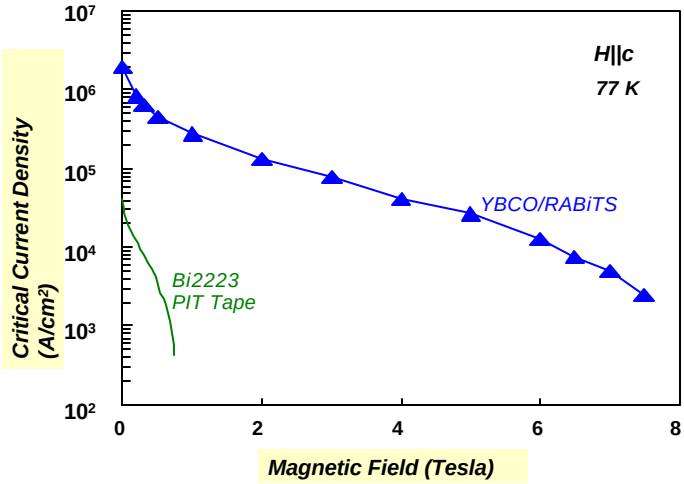


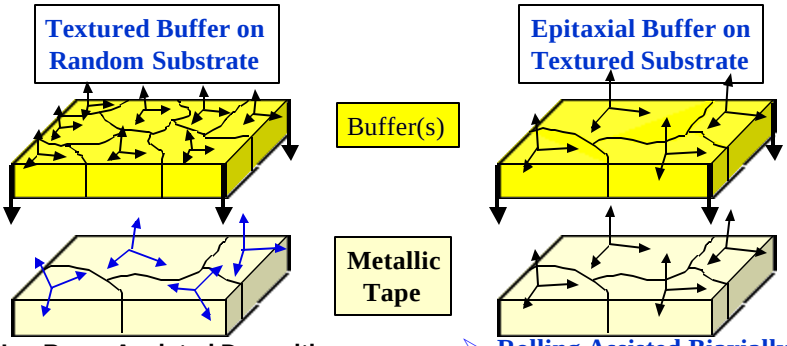
"First Generation" HTS Wires"



## "YBCO" Wire Technology Outperforms First-Generation HTS Wires in Strong Magnetic Fields



## Two Techniques that Result in Textured "Templates" are being Investigated for YBCO Wires




- Ion Beam Assisted Deposition (IBAD).
- Perfected by Los Alamos

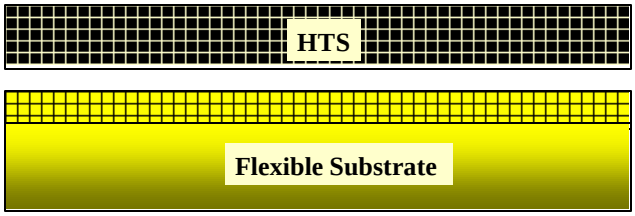
- Rolling Assisted Biaxially Textured Substrates (RABiTS).
- Invented by Oak Ridge



## What is Needed to Obtain High $J_c$ Flexible HTS Conductors for Magnets?

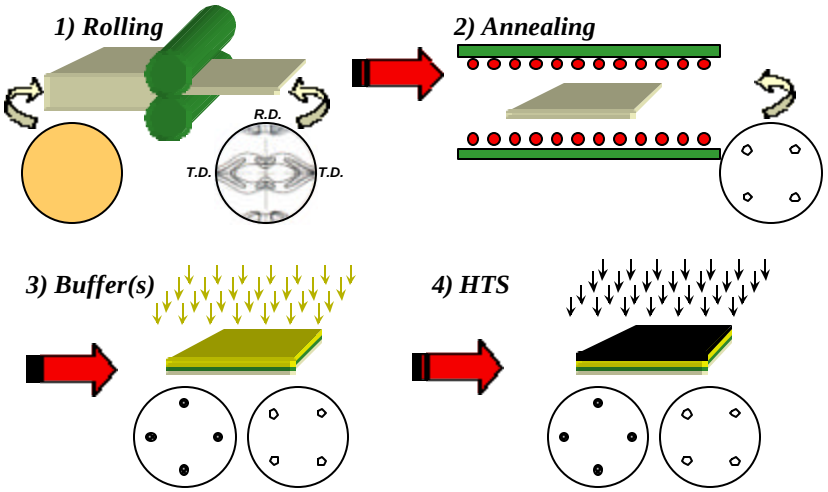
- HTS on flexible substrate.
- Out-of-plane AND in-plane texturing of HTS.

**Present Approach:**




- Deposition of HTS on Textured Templates.

# Rolling Assisted Biaxially Textured Substrates (RABiTS™)

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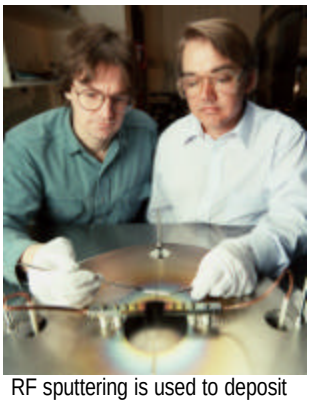
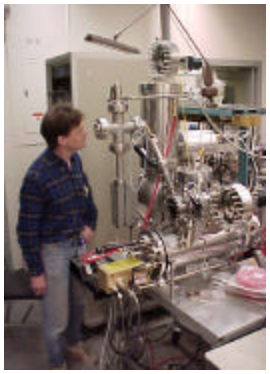
# High-temperature Superconducting Materials Research for Electric Power



RF sputtering is used to deposit oxide multilayers on biaxially textured nickel tapes

- **Strategic research** conducted in 3 ORNL divisions has led to "rolling-assisted, biaxially textured substrates" (RABiTS) invention
- **Partnership** with DOE-SC and DOE-EERE
- **Substrates** require near single-crystal-like performance in kilometer lengths
- Five patent licenses; ten issued patents
- American Superconductor announced RABiTS scale-up initiative May 30
- 4 other companies scaling up



Reel-to-Reel annealing and buffer layer deposition for scale-up research and development

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R&D 100 Awards

Recognizing the 100 Most Technologically Significant New Products & Processes of 1999

"The Most Prestigious Honor in Applied Research"

"RABiTS™ :
Single Crystal-Like, Flexible Substrates for Energy/Electronic Applications"

Invented by: Oak Ridge National Laboratory



## What's the Federal Role? Government/Industry Cooperation

- Requires long-length *wiremaking* using *semiconductor* technology
- Partnership enables FASTER rate of change
- Requires resolving issues of timing, commitment
- Main idea: "elevated intent" among the team members to
  - work better together
  - work faster

… in a process called **collaboration**

## Wire Research Formal Partnerships: YBCO on Rolling-Assisted, Biaxially Textured Substrates (RABiTSª)

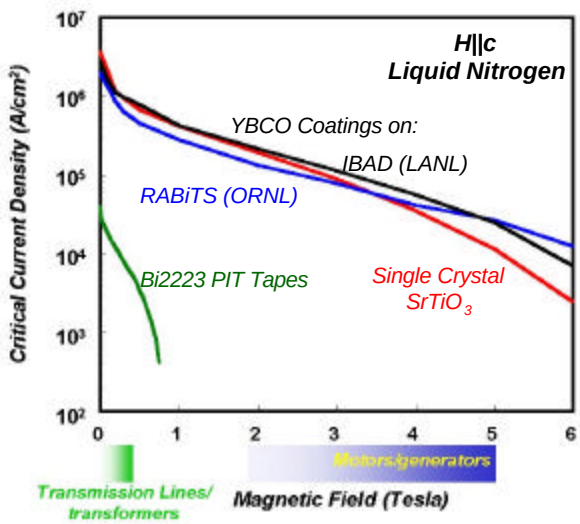
**Four Teams are Led By:**

- **3M Company**
- **American Superconductor Corporation**
- **EURUS Technologies**
- **MicroCoating Technologies & Oxford Superconducting Technology**

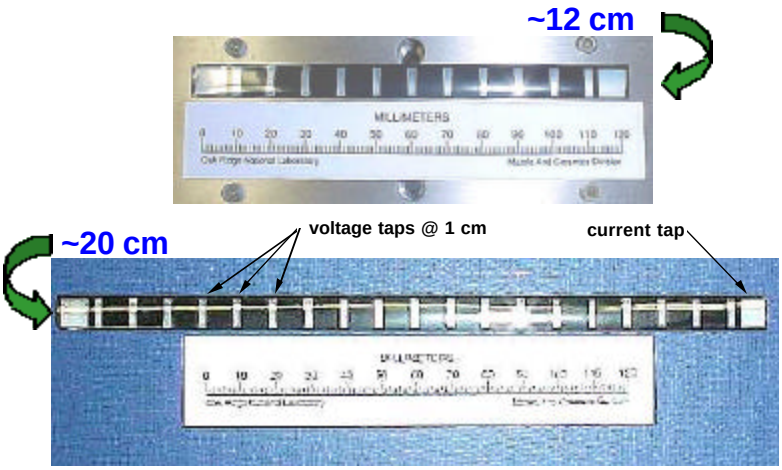
***** CRADA Partners Choose the HTS Deposition Method (National Laboratories will conduct continuous processing research at < 10 m lengths in 2001)**



## The Opportunity Offered by YBCO Wires



# YBCO Conductor Status 1999

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# Projected Timeline for Coated Conductor Scale-up in USA

| Pre-commercial Scale-up<br>Phase- US Industry | Year | Estimated Budget ($M) per year for each Phase | | |
|---|---|---|---|---|
| | 99 00 01 02 03 04 05 06 07 08 | Commercial | Federal | Total |
| I Continuous Processing Feasibility & 1-m lengths | | 8.0 | 8.0 | 16.0 |
| II 10-m piece lengths with lab-scale demonstration | | 12.0 | 12.0 | 24.0 |
| III 100-m piece lengths and field tests using YBCO conductor in SPI | | TBD | TBD | TBD |
| IV Pre-commercial production | | TBD | 0 | TBD |

**US Government and Industry Research is Expected to cost $20 million in 2001.**

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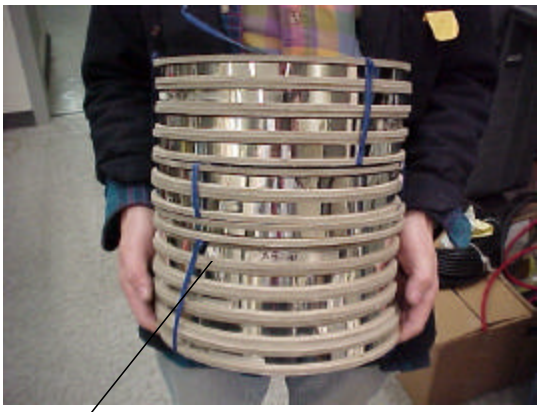
*In 2000, ORNL specified rolling conditions and obtained homogeneous, well-textured Ni from an outside commercial source*

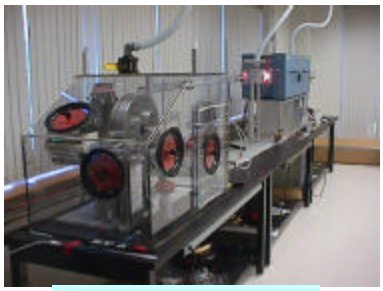


**~2 kilometers of rolled Ni, 1 cm wide and 2 mils thick**



## Industry scaling up laboratory discovery for longer lengths in 2000

- **Reel-to-reel pilot web coating line developed at ASC**
  - **process based on ORNL buffer layer technology**
- **World Record YBCO Wire Performance using ORNL's RABiTS technology: 1.9 MA/cm$^2$ current density**



**Pilot coating line at ASC**

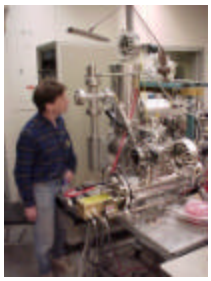
## HTS Coated Conductors Are an Opportunity and a Challenge for the Nation's National Laboratories and Industry

- **Requires applying technologies from the** *semiconductor industry* **to make new electric wires with 100 times the capacity of copper wires**
- **Unique coated conductor features, however, mean new facilities and expertise are required in support of industry scale-up of HTS wires**
  - **large areas and "web coating" technology**
  - **continuous processing equipment (reel-to-reel)**
  - **real-time quality control and measurement**
- The Labs and Industry do not have these capabilities today

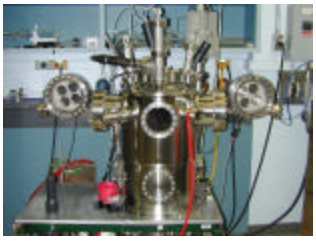


## Building the Foundation Through ORNL's Unique Research Facilities

- **Reel-to-Reel (1-3 m) Tape Handling for Coatings Via Scalable Processes**



Buffer Layers



Precursor

YBCO Conversion

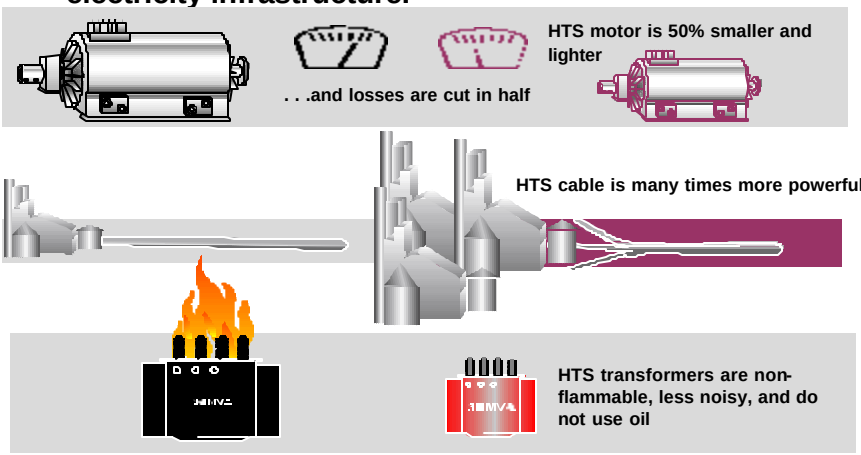
## University Collaborations are important to understanding key aspects of the technology

- **University of Wisconsin-Madison**
- **Stanford University**
- **Boston College**
- **University of Houston**
- **University of Kansas**
- **Massachusetts Institute of Technology**
- **Florida State University/NHMFL**
- **University of South Carolina**
- **Oak Ridge Associated Universities (post-doctoral research fellowships)**



## Potential to Impact Existing Technologies and Opportunities for Novel Applications

- **Significant efficiency benefits to the national electricity infrastructure.**



## Collaborations in HTS Applications Development

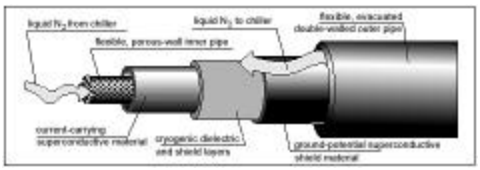
- **The Superconductivity Partnership Initiative(SPI)**
  - **cost-shared cooperative agreements with the DOE**
  - **Vertically integrated teams required**
- **Two examples**
  - **Southwire Company - HTS Cable**
  - **Waukesha Electric Systems- HTS Transformer**
- **Utility Partners in the SPI**
  - **Southern Company, Rochester Gas and Electric, Southern California Edison, Georgia Transmission**



## Superconductivity Partnership Initiative: Southwire Company & ORNL Develop HTS Cable

- **$12 million cost-shared project resulted in a 3-phase cable installed 12/99 in Carrollton, Georgia**
  - **real-world load equivalent to city of 25,000**
  - **cable powers two manufacturing plants and corporate headquarters**
  - **5x power through urban rights-of-way**
  - **more efficient transmission and distribution**
  - **eliminates oil cooling in conv. underground**
- **ORNL and Southwire have constructed 5-meter single-phase HTS cable test bed**
  - **1300 amperes exceeds design goal**
  - **all cable subsystems qualified at ORNL**

## Cable Cross Sectional View




- **Features**
  - **Magnetic field shielded.**
  - **Both conductor and dielectric are wrapped from tapes.**
  - **Cryogenic dielectric reduces size and increases current carrying capacity.**
  - **Flexible cable to allow reeling**

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## ORNL assisted Southwire with the assembly of 30-m HTS cable terminations in Sept. 1999

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# Southwire/ORNL Research: Test and Evaluate 5-meter HTS Cable System

- **A comprehensive testing program:**
  - **Cable critical current**
  - **Background thermal losses**
  - **Ac loss**
  - **Continuous/cycling ac current loading**
  - **Long- and short-term overload capability**
  - **Partial discharge measurements**
  - **Ac voltage withstand**
  - **Impulse withstand**
  - **Cable bending & splice**
- **First 5-m cable testing and evaluation was completed in 1998.**

Partial Discharge Testing of Cable Termination

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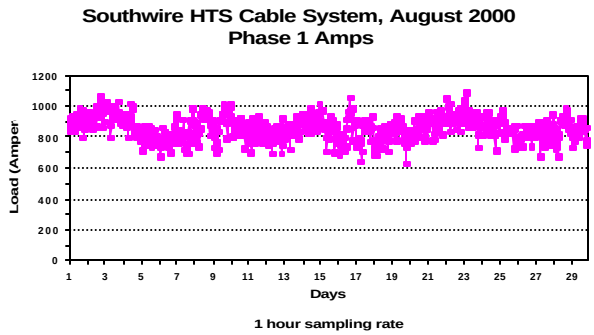
# First Industrial Application On-Line for > 3,300 Hours

**Run 100% loading….**

- **3,300 hrs (and counting) as of 10/17/2000.**




Max Current ~ 1115 Amps



# Splice Development and Testing Critical to Utility Acceptance

- A cable splice design has been developed.
- A model cable has successfully tested the dielectric splice design.
- A 5-m splice cable has been manufactured by Southwire and is undergoing testing at ORNL.
- Future plans include a 2nd 5-m prototype and testing a splice on the 30-m cable at Southwire.

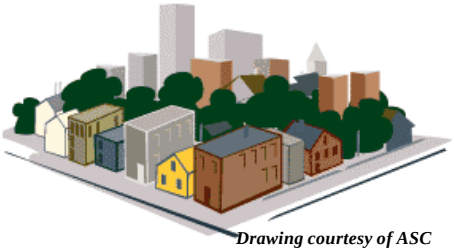
**Future location of splice at 30-m test site.**

## HTS Transformers will be Oil-Free

**Today**

***Bank of 3 transformers on fire***
***May 1999, USA***
***Est. repair cost: $3 million***

**Tomorrow**



*Drawing courtesy of ASC*

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## Superconductivity Partnership Initiative: Waukesha, IGC, RG&E, and ORNL Develop HTS Power Transformer

**HTS Transformers** offer economic, operational, and environmental advantages.

- Higher Efficiency
- Better Overload Capability
- Lower Environmental Hazard
- Lighter & More Compact

•1-MVA Test Transformer Completed June 1998
•5-MVA unit to power Waukesha manufacturing plant mid-2002.

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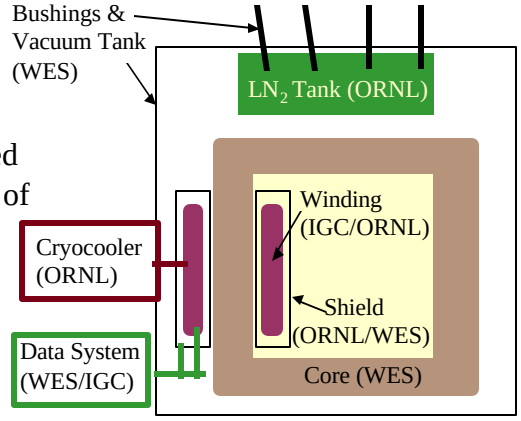
## Waukesha 1-MVA Demo HTS Transformer Using ORNL Research

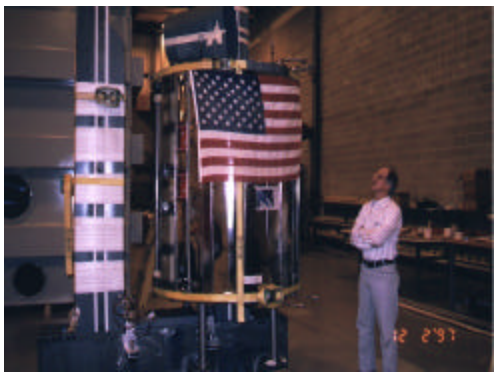
- 1-MVA, 1 phase
- HV=13.8kV, 72.5A
  LV=6.9kV, 145A
- Transformer is a test bed with core cross-section of a 30-MVA transformer
- HTS winding is cryocooled to ~25K
- Core at near room temperature

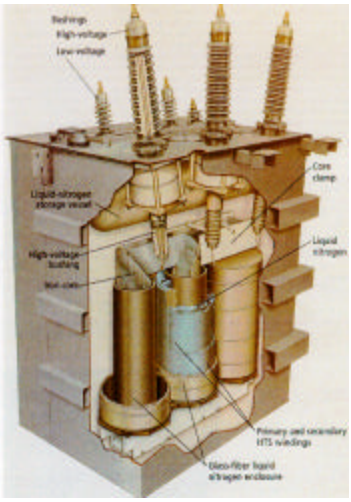





## Pre-Commercial HTS Prototypes are Being Tested

Waukesha's Single-phase Demonstration HTS Transformer





3-phase HTS Transformer

## New Superconductivity Partnership Initiative Call for Proposals

- **Call for new projects expected December 2000**
- **DOE anticipates making up to $9 million per year available for cost-shared projects**
- **50% cost share required from non-federal sources**
- **Emphasis on power applications**
- **Suggested task using "second generation" wires**



## Superconductivity is the right technology for tomorrow's energy delivery systems

- **SPI demonstration prototypes are important --- power companies taking notice**
  - **Southwire's cable transmits 30-MW at just 12 kilovolts! Enough to power a city of 20,000 people**
  - **Pirelli's cable in Detroit will handle 100-MW at just 23 kilovolts**

**Enabling a completely new option: High-Power Distribution**

- **Waukesha's transformer will handle 5-MVA (10-MVA overload) without oil cooling and loss of transformer life during overload events.**

## SUMMARY

- **A new superconducting wire technology, invented at a national laboratory, is being commercialized by 5 U.S. companies**
- **Superconducting power equipment is being field-tested today**
- **Potential benefits to the consumer include:**
  - **More efficient T&D; oil-free transformers, "overloadable" transformers; smaller and more efficient motors and generators; and new power quality equipment**
- **DOE's SPI Program available for power companies**