

Development of Low-Cost 2G HTS Coated Conductors at STI

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EPRI 11th
Conference on Superconductivity

Tuesday, October 29, 2013



Leading Superconducting Innovation

Attacking large opportunity with Conductus[®] wire strategic initiative

1987



High Temperature Superconducting (HTS) Technology Development

Key competitive advantage



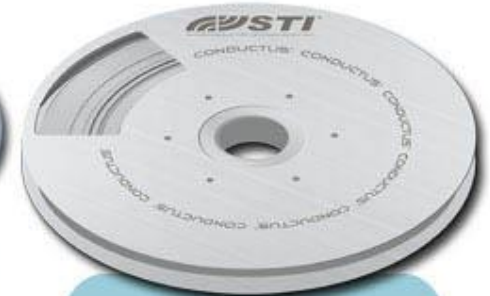
HTS Product Release

Only company to successfully commercialize HTS products for RF electronics. Established leadership with best-in-class HTS products



HTS Manufacturing High Volume

Advanced proprietary HTS deposition process in full scale manufacturing production. 6,000 systems deployed with Verizon Wireless and AT&T



Conductus[®] HTS Wire Production, New Manufacturing Facility in Austin, TX

Manufacturing of second generation (2G) HTS wire with industry leading performance

Technology Transfer and Partnerships

Wireless Product Business



Cryogenic Cooler Business

2012 and Beyond



Today





Delivering Superconducting Wire Innovation

- **What fiber optics is to telecom, superconducting wire is to power**
 - No other technology comes close
- **Addressing large Smart Grid market opportunity with a need for game changing technology**
- **Our technological superiority provides sustainable production advantages**
 - Proprietary expertise in superconducting production technology – Strong IP portfolio
 - History of IP development with over 100 patents issued and pending for various technologies
- **State of the art factory – 20 years of HTS manufacturing expertise focused on providing large volume of high-performance Conductus[®] wire**
 - Pilot production equipment in Advanced Manufacturing Center of Excellence (AMCE) in Austin, TX now operational
- **Strong customer demand - delivering our solution through existing channels**
 - Receiving multiple orders from large, multi-national industrial companies for certification testing
 - Committed to superconducting cable demonstration project with major producer of superconducting cables



Superconducting Wire

Changes the paradigm for the future design of electrical devices

Conventional Copper

Capacity	Low
Efficiency	Poor
Size, Weight	Large, heavy
Economics	Adequate for today
Design	Limited



100X more

Extremely high

Compact, light weight

Improved for future

Enabling new devices



Replacing legacy copper wire with ultra-high performance superconducting wire

Large Addressable *Smart Grid* Market

Innovative superconducting devices and industry participants

GENERATION

*Rotating Machines
Motors & Generators*



- Offers significant size reduction and increased performance over conventional technologies
- Motors and generators utilize 10's to 100's of kilometers of HTS wire per device

DISTRIBUTION

*High Power
Transmission &
Distribution Cable*



- 10X power capacity of conventional cable
- 100's of kilometer length HTS wire pieces used in a single cable

STORAGE

*Magnetic
Energy Storage*



- Enhances the capacity and reliability of stability-constrained utility grids

CONVERSION

*Fault Current Limiters
& Transformers*



- Superior protection; increases reliability, survivability, and minimizes power recovery time
- Short lengths of HTS wire are formed into 100's of coils stacked into a conductor bank

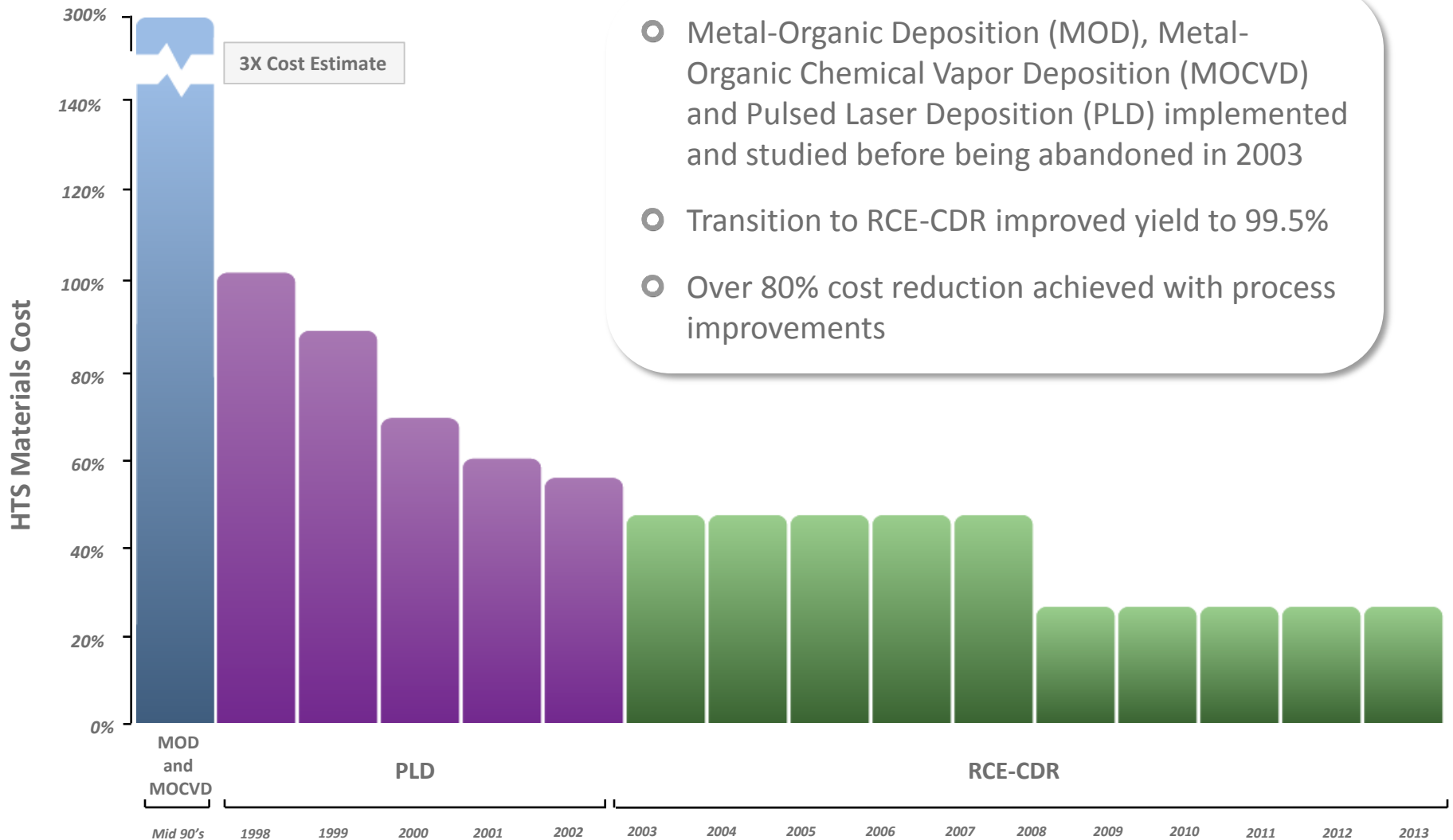
END USE

*High Field Magnets
Medical (MRI),
Lab (NMR) and
Research (Accelerator)*



- Enhances imaging performance for high field devices utilizing HTS wire

HTS Materials Cost Reduction Over Time





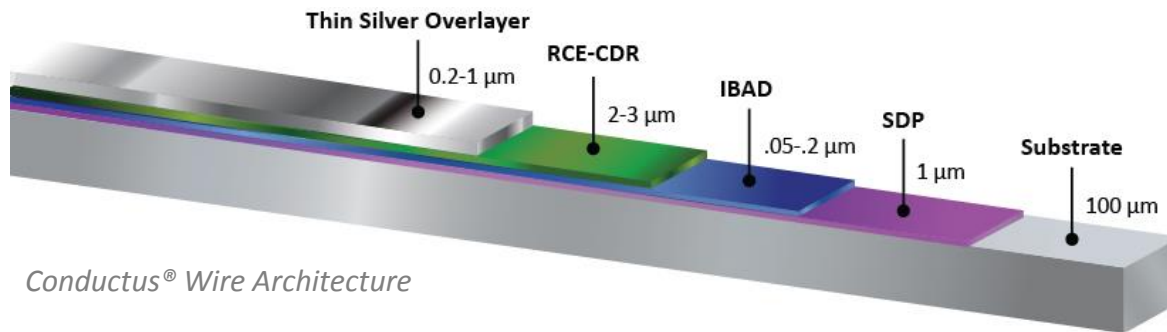
Our Wire

Superior deposition technology and a simplified, layered wire architecture provides sustainable production advantages:

- Significantly lower cost
- Ultra high performance
- Robust and flexible design
- Optimized HTS manufacturing processes reduce runtime and increase yield and throughput
- Validated performance for use in all major HTS applications underway currently
- Customizable for all power requirements



*Reel of 10mm
Conductus[®] wire*



Conductus[®] Wire Architecture



*100mm Conductus[®] wire
slit to 10mm*

Low-Cost HTS Coated Conductor Requirements



INPUTS

STI's process allows for low cost of raw materials

- Elemental source materials
- Inexpensive substrate material

3 STEP PROCESS

Low number of template buffer layers

- Simple and repeatable

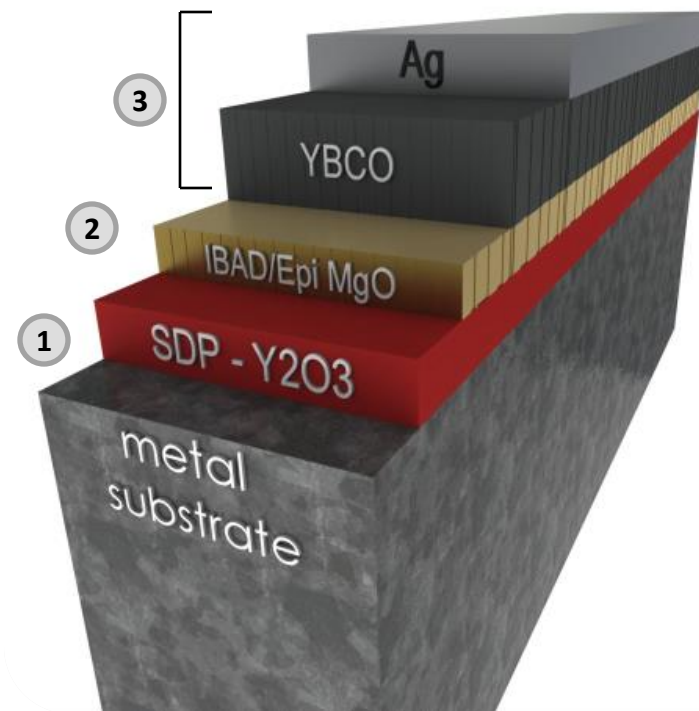
Low number of process steps per layer

- High yield in each process

High throughput and large HTS growth area

EQUIPMENT

Low production equipment cap-ex



Simplified structure inherently reduces cost and also increases yield



STI's Three Step Approach

SDP – Solution deposition planarization

- **Atmospheric wet coating which provides an amorphous ceramic overlayer**
- Low-cost solution process
- Diffusion barrier and planarization layer
- No need to polish metal substrate tape
- Compatible with many alloys

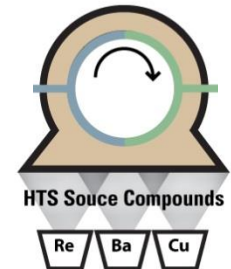


IBAD + Epi MgO – Ion beam assisted deposition

- **The thinnest, fastest template formation**
- Requires only 50 nm MgO layers for crystallinity
- Fast process
- In-situ process in a 2 chamber deposition system

RCE-CDR – Reactive coevaporation / cyclic deposition and reaction

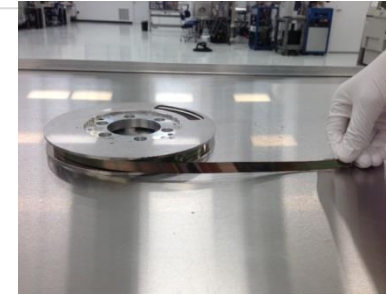
- STI has developed the RCE-CDR technique for >15 years in wireless filters and shown it to be a low-cost & high-yield production technique for HTS deposition
- Enables growth directly on MgO layer and can be used with optional buffer
- In-situ process in a single deposition system
- Elemental raw materials low costs
- Large-area deposition



Solution Deposition Planarization



10X 1cm with slitting



SDP Production System Operational

- High speed roll-to-roll process
- Up to 1000m length 10cm width capacity
- Manufacturing capacity >1000km/yr

Solution Deposition Chemistry Optimization

- Base-line Yttria based SDP process has been transferred from R&D stage to production scale
- Improvements made in film quality by chemistry improvements
 - Eliminate cracking
 - Minimize edge bead

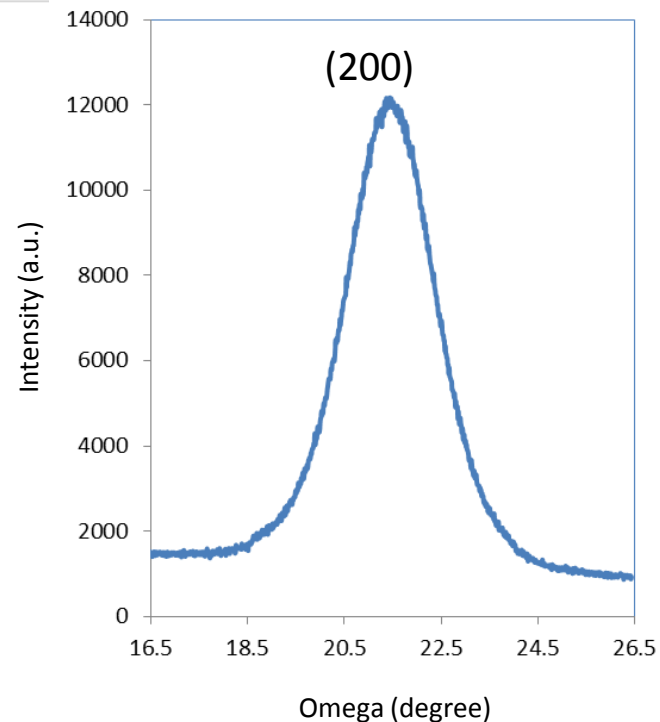
Ion Beam Assisted Deposition



CONDUCTUS®



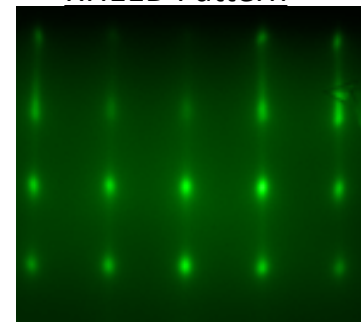
IBAO epi-MgO



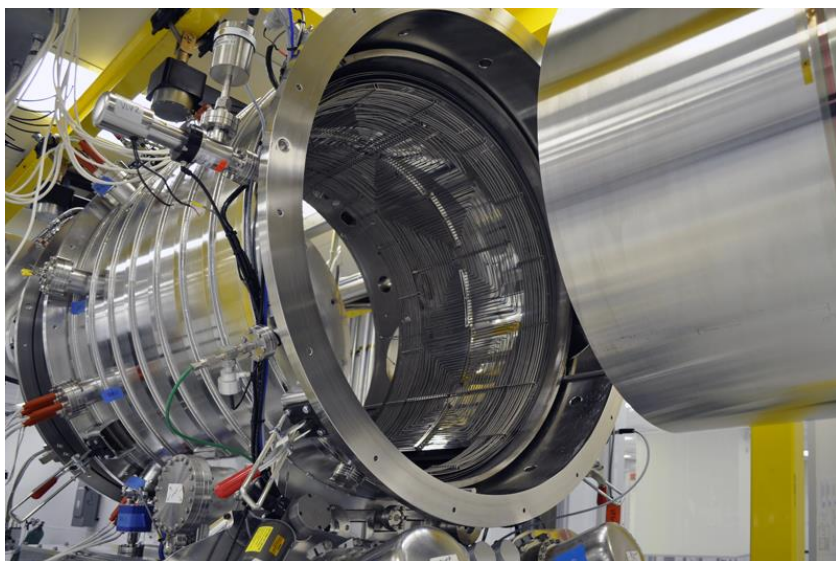
IBAD + EPI MgO Production System - Meeting specifications

- Capable of handling up to 1000m lengths – Capacity 1000km/yr
- Consistently getting $J_c > 2.5 \text{ MA/cm}^2$ - Out of plane orientation: 2.1°
- Performed DOE with hundreds of conditions to optimize IBAD & EPI
 - $J_c 3.8 \text{ MA/cm}^2$ reached as a result of DOE

RHEED Pattern



Reactive Coevaporation 100M System



RCE 100M System installed Q2 2013 and operational meeting customer specification

- Batch system capable of depositing ReBCO, optional buffer layer and silver
- Cyclic deposition and reaction on rotating drum
- Uses thermal evaporation sources for Rare earth, Barium, Copper, buffer material and silver
- Ability to optimize process for different superconducting applications: High I_c , High in-field



RCE 100M Results

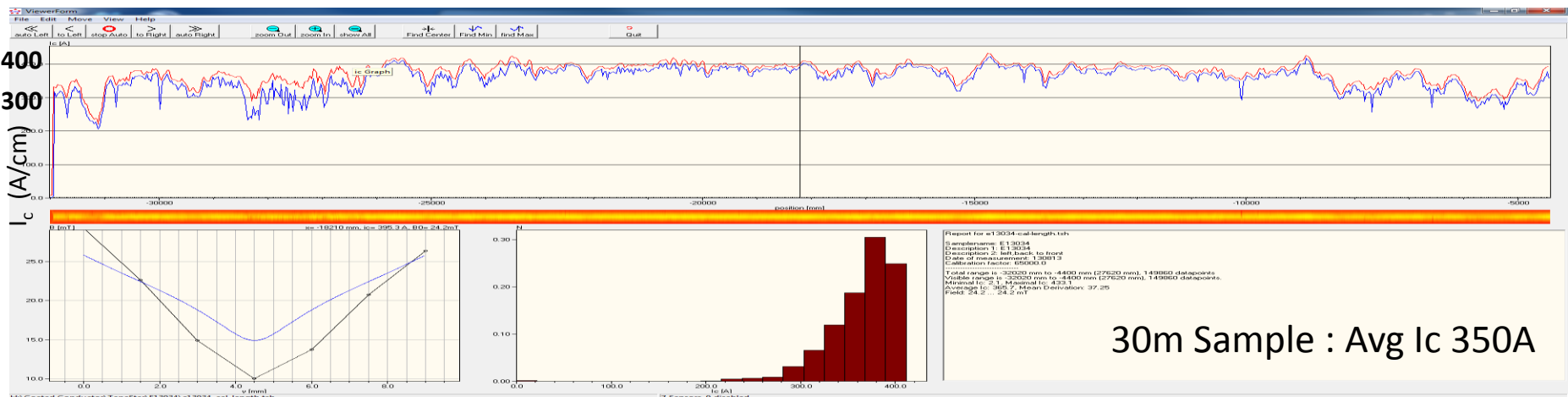
Successfully transferred RCE process from wafer machine to 100M system

- Significant progress made in last 5 months
 - Thermal stability of heaters
 - Reliability of evaporation sources
 - Differential pumping between the heater and source chamber improved
- Improved the deposition rate 4X without degrading HTS performance – higher throughput
- Direct current measurement gives $I_c > 450\text{A/cm}$ on meter length tapes
- Compositional uniformity is within 0.5% from along entire 100m length
- Currently improving scale up reliability, run-to-run composition control and differential pressure control



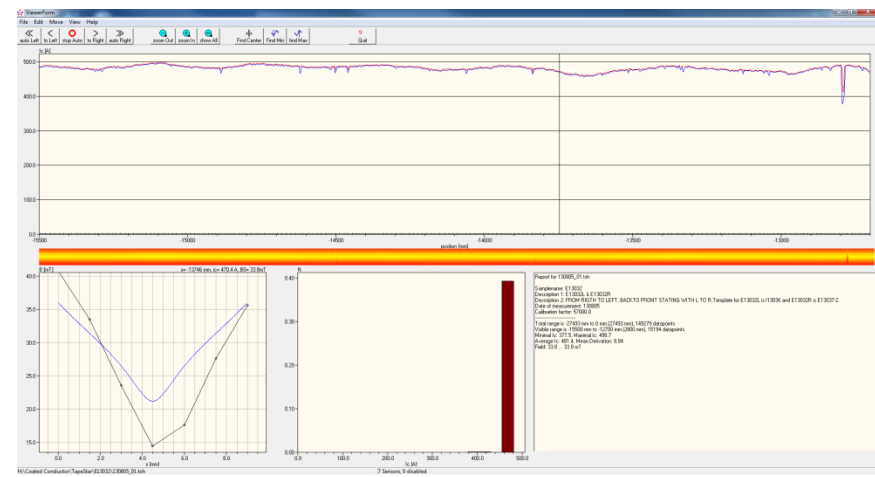
RCE 100M System Results

on TapeStar™



Successfully transferred RCE process from wafer machine to 100m system

- No significant dropouts for 30m long tape
- Avg I_c 350A
- Moving quickly to meet 500A/cm performance and lengths of 100m lengths / 4mm





STI 2014 Plans

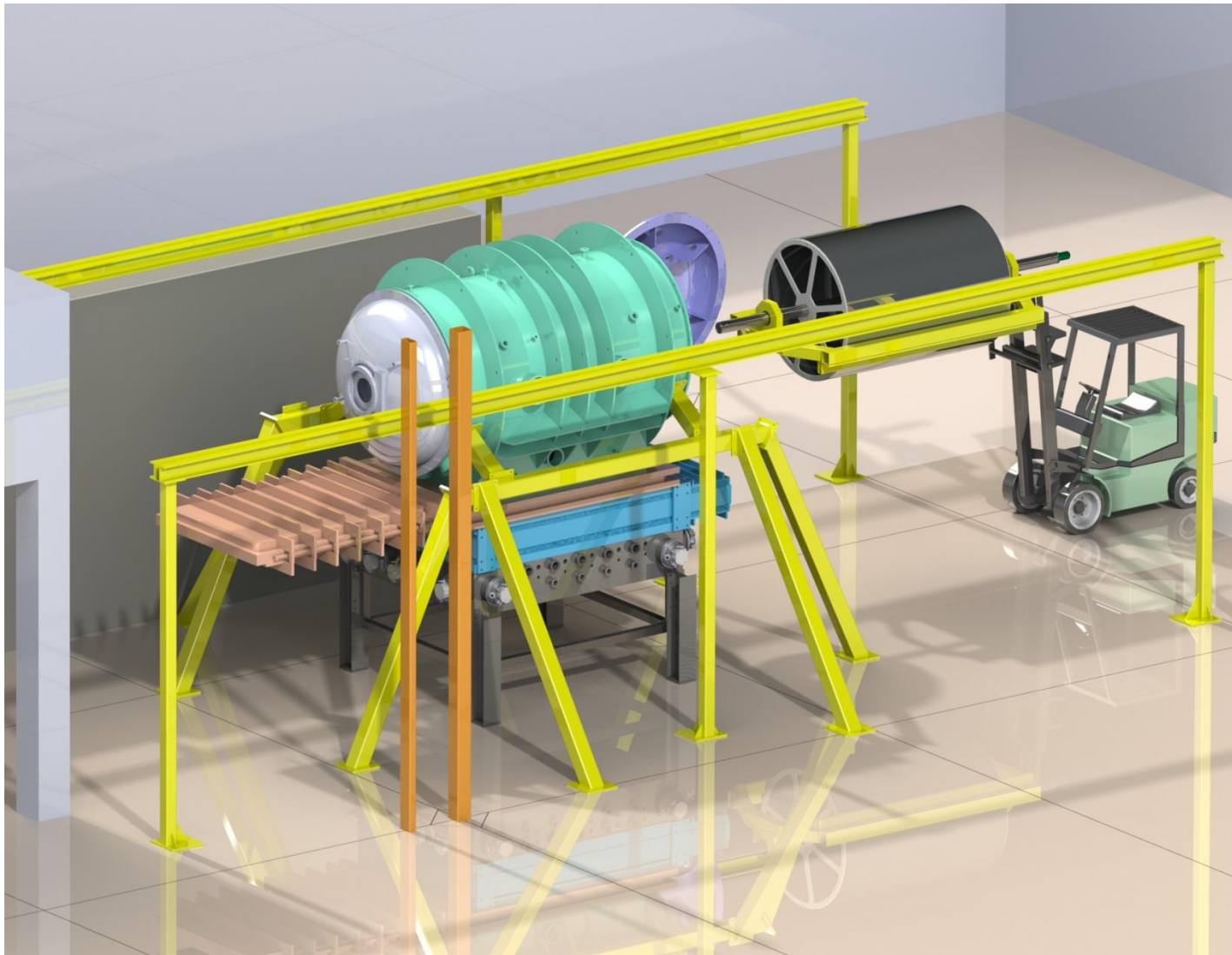
SDP and IBAD are production ready for 1km lengths

- Focused on ramping volume as production RCE 1000M comes on line

RCE 1000M System is being built

- Capital to build new system was secured in August 2013 – \$2.5M in CAPEX
- System Operational in 1H 2014
- RCE1000 System scale up from existing pilot 100M system with same process: Low risk
- Conductus production specifications: 1000m length (no splicing) of 500A-cm tape
- Projected annual capacity of 750 km of 2G HTS wire

RCE 1000M System





Summary

- **STI's Coated Conductor is inexpensive, high-yield, and scalable**
- **Our approach and HTS manufacturing experience can meet the demand for coated conductors and beat the industry cost targets**
- **Achieved results on a simplified template process requiring SDP and IBAD layers**
- **Successfully shipping Conductus wire to customers utilizing 100m RCE system**
 - 250A to 450A/cm
 - Piece lengths continue to increase from 10's of meters to 100m
 - Tape shows great compositional uniformity
- **Conductus wire production in 2014 – Project funded to capacity of 750,000m/yr**
 - SDP and IBAD production systems – Complete
 - 1000M RCE System is being built – 1H/2014



Thank You