Meeting Divergent Expectations: Superconductors between Industrial Application & Cutting Edge Science

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Outline

1. About Bruker
   o An instruments & services company that also makes superconductors – because it is necessary...

2. BEST: Our Business, Our Customers
   o Superconductors are good for Healthcare & Big Science Research

3. Square Pegs & Round Holes (How to make it fit?)
   o “Citius, Altius, Fortius” (Faster, Higher, Stronger) - with fewer calories

4. The Road Ahead
   o How do we ensure that there is no future mismatch between expectations & capabilities?
About Bruker
Bruker at a Glance

Bruker is one of the world’s leading analytical instrumentation companies.

“Our high-performance scientific instruments and high-value analytical and diagnostic solutions enable scientists to explore life and materials at molecular, cellular and microscopic levels.”

2016 Revenue Distribution:

- BioSpin: 34%
- BEST 1): 8%
- CALID: 29%
- NANO: 29%

• Founded in 1960
• ~6,000 employees worldwide, with over 90 locations on all continents
• 2016 revenue: ~$1.6 billion
• R&D investment: ~10% of revenue
• ~75% of revenue from scientific and diagnostic instruments
• A public company (NASDAQ: BRKR) with Headquarters in Billerica, MA

1) Prior to Bruker OST acquisition. In 2017 BEST is expected to contribute approx. 11% of total revenue
“High-Performance Scientific Instruments Enable Our Customers to Explore Life and Materials”
BEST: The Superconductor Business of Bruker

“Superconducting Materials and Components are the most critical enabling technology for Bruker and our Customers”

- World leading magnet innovation requires world leading superconductor innovation
- Bruker continues to invest in world-class superconductor technologies
Our Business, Our Customers
Bruker Superconductors
The BEST Story in Numbers

- Bruker spent approx. $100,000,000 on BEST:
  - ~$50,000,000 on purchasing superconductor businesses & technologies
  - ~$50,000,000 investment in state-of-the-art technologies & manufacturing for superconducting materials (incl. HTS and RF-cavities)

- Over 600 people work at BEST:
  - Approximately 450 are directly engaged in manufacturing of superconducting materials & components
  - Some 90 engineers and 25 PhD’s in multiple disciplines support our research & innovation

- Over 330,000 sqft (~30,000m²) manufacturing footprint in three countries

- BEST generates close to $200,000,000 in annual revenue (2017FC)

- BEST spends on average > $7,000,000 on R&D each year (over 50% of spend on HTS)

- Close to 1,500,000 cubic feet (~40,000 m³) in warehouse space.
  - We receive and ship wares totaling > 15,000 metric tons each year
  - Our warehouses hold close to $100,000,000 in value at any given time

- BEST has yet to achieve “break-even” on the (continuing) Bruker investments in superconductor technology
Bruker Superconductors
The BEST Product Range

NbTi based

- NbTi (Niobium-Titanium)
- NbTi Wire in Channel (WIC)

NbSn based

- Nb3Sn Bronze route (Niobium-Tin)
- Nb3Sn RRP® / PIT (Niobium-Tin)

HTS based

- YBCO
- Bi-2212

B < 9.5 T

B > 10 T

B > 20 T or T >> 4.2K

NOT SHOWN: Superconducting RF-Cavities and accelerator components manufactured at RI Research Instruments
Performance & Application of Different Types of Superconducting Materials

- 
  - Clinical MRI
  - Industry
  - HEP, Accelerator, Fusion
  - Ultra-High-Field NMR

\[ j_{c}^{SC} \text{[A/mm}^2\text{]} \text{ @ 4.2K} \]

- NbTi
- Nb3Sn
- YBCO
Wire Economics

“What determines the Price of a Superconductor?”

- It is the Result of simple Multiplication & Division (sort of...)
  - Performance x Risk
  - Availability / Demand
    (A. Smith, *The Wealth of Nations*, 1776)

“What if markets are not in equilibrium and demand shifts above and below a stable supply?”

- It creates instability and consolidation, invariably impacting future performance and risk assessments
BEST Superconductor Revenues

Can we stay balanced?

Healthcare: 85%

Big Science: 15%
Square Pegs & Round Holes
Business Comparison: BEST LTS for Big Science

- Dominated by few large international projects in fusion & high energy physics
- Revenue has evolved from high-end NbTi to latest generation Nb₃Sn conductors
- Difficult to plan because of high risks, long time lines and multitude of delays
- Supply chain insecurity: Highly specialized recipes make for limited supply chains
- Risky Business: Long development cycles and price targets set at early stages make for high risk during execution. Limited ability to correct course in mid flight...
- Wild Ride: Historically the Big Science business for BEST has expanded and contracted between ~ $2m and >$30m per year - a factor of 15 change within very few years

Forecast

The Large Hadron Collider (LHC) ...as seen by a Superconductor Manufacturer

11 Years of Development

- Up-front cost and risk for over a decade
- Material supply selection by customer – added risk
- Numerous technical challenges and changes
- “All-new” processes needed to be developed (< 7µm filament stack-and-draw, very thin SnAg₅ coating, cabling)
- Several years of delay from original time line with uncertainty
- Final award (volume) lower than expected and prices too low

5 Years of Production:

- Numerous technical challenges, additional work and measurements
- Up to 25% of total B-EAS business and ~ 35% of work load in production at peak
- High financial loss and massive restructuring with a large number of layoffs at the end...

...and others got a Nobel Prize....
The International Thermonuclear Experimental Reactor (ITER) ... as seen by a Superconductor Manufacturer

1990

Development – Model Production – Development

- Two decades of iterative specifications and research on two different Nb3Sn conductors with diverse and narrow performance windows: low performance for CS model coil, advanced performance for TF ITER
- Again: Risk carried by companies involved in R&D
- Uncertain time line with 6 years downtime and many years of delays, impacting cost and supply chain availability
- Final ITER conductor design fixed due to variable T_{CS} measurements on EFDA prototype strand e.g. advanced layouts are precluded for production (=increased risk)
- Additional measures and efforts needed to be implemented to minimize loss of material

2010

Production

- 5 years of production
- Up to 25% of total business (B-OST) at peak load
- Workforce reductions and machine idling at end of project
**Business Comparison: BEST LTS for Healthcare**

- Approx. 95% of LTS revenue in Healthcare is high-volume, highly standardized NbTi wire.
- Healthcare LTS is used primarily for clinical imaging in diagnostics and treatment. Other applications include cancer therapy, guided intervention and a wide array of research & development.
- The overall addressable market for our Healthcare customers is >> $20 billion.
- The LTS market for Healthcare grows relatively consistently despite effects of wild currency fluctuations, US-legislation, China anti-corruption efforts and European recession in the last decade.
- The Healthcare market is dominated by a small number of very large industrial players that exert extreme price pressure on the supply chain – that is us!
- **Cost leadership vs. technology leadership.** Emerging industrial attitude: “Good is good enough”. What does this mean for innovation?
- **Precarious balance:** Need to continue with lowering cost while delivering 100% quality at maximum flexibility and high volume.
The ongoing "industrialization" of Healthcare creates a set of problems for the superconductor industry.

Superconductors have a highly complex supply chain and production route. Few companies around the globe have the specialized know-how and equipment. Even fewer companies in the LTS supply chain depend on it for their broader business interests.

- In recent years the cost of pre-material and services has risen (Cu, NbTi, extrusion etc.) while prices for superconductors have come down.

- Customers adopted “Just in Time” and increasingly pushed the requirement for (their own) planning down to the suppliers, thereby increasing short term demand fluctuations: A problem with lead times for NbTi superconductors (from scratch) between 6 and ~ 12 months.

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<thead>
<tr>
<th>Material Sourcing</th>
<th>Wire Production</th>
<th>Shipping</th>
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<td>2 – 6 months</td>
<td>3 – 4 months</td>
<td>1 – 8 weeks</td>
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The Healthcare Challenge
...as seen by a Superconductor Manufacturer

- Investments (machines, automation) improve unit cost by improving shop floor productivity
  - Problem: Shiny new machines cost money over time and need to amortize by being used as much as possible. Therefore a factory needs to have a crystal ball to predict future business
- Processes, personnel, focus on sustainable core competences – trim the fat without cutting into the flesh...
  - Reduce shop floor times (Value Stream Optimization/Lean etc.)
  - Engage supply chain
  - But: Someone will always carry additional (inventory) risk for flexibility and reduced lead times
  - And: Shop Floor Yields now at ≥ 98% - no meaningful improvements left
- We are at or near the end of meaningful process innovation and cost reduction. Future changes will need to be more complex and (technologically) risky
- This will need closer collaboration or partnership along the value chain, including – especially – the Healthcare industry itself
The Road Ahead
The Road We Are On
...what does this all mean?

Healthcare:
- **Healthcare sees superconductors as a commodity.** Availability is assumed, innovation is free, performance is always the same (and perfect). Only price matters.
- Prices in the healthcare industry will no longer allow support of sustained in-house development or even maintaining availability of capacities (machines) or capabilities (persons) outside the current endeavor to deliver the cheapest possible wire to healthcare customers.
- **The Verdict: This is not a sustainable cycle.** The industry has seen a high level of consolidation (i.e. business closures) within the supply chain in the last decade. Where do we go from here?

Big Science:
- **Research is increasingly focused on ultra-high performance** \(\text{(Nb}_3\text{Sn, HTS)}\). The long-term development of superconductors is decoupled from major market in healthcare.
- Development of superconductors that push way beyond established performance is increasingly risky. New and more complex materials and processes are needed. Machines, materials and suppliers become more specialized, and overall the risk of technology dead ends and failures increases.
- **The Verdict: Someone needs to pay for innovation** and carry the risk of delays and failures. How are risks and rewards distributed fairly?
The BEST Way to the Future
Stewardship & Sustainability

“Stewardship & Sustainability are the Dual Focal Points of BEST’s Long Term Strategy”

1. Stewardship

Stewardship recognizes that improved technologies & capabilities need long term vision, planning & financing. This cannot be done by the wire manufacturers alone.

- Bruker will continue to develop superconductors for its own portfolio. This means superconductors required for ultra-stable, ultra-homogeneous and ultra-high performance magnets (1.200Mhz or 28T and beyond..) to be produced in reasonably small quantities

- The Big Science HEP and Fusion communities must seek ways to establish long term funded Stewardship to attain their own long term goals: How to secure the development of related but technically very different high performance superconductors that can be produced at affordable cost in the large quantities required? Long gaps in funding or reduced competences through attrition will delay meeting of targets and increase cost later...

- The Healthcare Industry must guard its own needs: Innovation Partnerships will be needed to address and implement the technology changes that will allow us to continue with cost improvements, but also to reignite innovation. Otherwise this industry is headed for stagnation.
The BEST Way to the Future
Stewardship & Sustainability

“The Stewardship & Sustainability are the Dual Focal Points of BEST’s long term Strategy”

2. Sustainability

Sustainability recognizes that availability and affordability must go hand-in-hand, in order to secure our entire value chain, suppliers, wire manufacturers, magnet builders and end users alike.

- Bruker will continue to uphold and invest in superconductor manufacturing for its own portfolio. This includes limited quantities of NbTi, high performance Nb$_3$Sn and – for now – HTS. However, Bruker will only maintain industrial size capabilities as long as the business approaches self-financing.

- Big Science HEP and Fusion communities face the biggest challenge. How to estimate production needs and required investments for possibly the biggest projects yet - but in twenty years time? This conundrum overlaps with Stewardship: maintain innovation & capabilities + monitor and continuously assess future cost and production requirements to find the right time to scale up.

- The Healthcare Industry has the clearest path, and also the lowest chance of following it. Superconductors are strategic to a huge part of healthcare. Disruptions would jeopardize billions in revenue and hundreds of millions in profits. Long term partnerships along the value chain, reliable business outlooks and cooperation on cost should replace outdated “supplier management” practices from the last millennium. We should not hold our breath...
Innovation with Integrity