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PI Solutions

Undersea Defence Technology
13-15 May 2019
Stockholmsmässan, Sweden

TECHNOLOGY TRENDS AND CHALLENGES FOR SUPERCONDUCTOR-BASED SHIP PROPULSION

PI INTEGRAL SOLUTIONS LIMITED - GERMANY

Manuel La Rosa Betancourt

Bartomeu Massuti Ballester

Ryan O' Regan

THEVA DÜNNSCHICHTTECHNIK GMBH - GERMANY

Dr. Markus Bauer

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Outline

- Global trends and drivers for electric ship propulsion
- State-of-the-art high-power electric propulsion systems
- 2G HTS materials, tape production and economies of scale
- Trends and challenges for HTS-based propulsion systems
- Disruptive approaches on all-electric ship propulsion
- Conclusions

Global trends & drivers for electric ship propulsion

Trends & drivers

- High power propulsion systems for travelling large distances
- Highly efficient subsystems for long mission duration
- Noise and electromagnetic signature reduction

State-of-the-art high-power electric propulsion systems

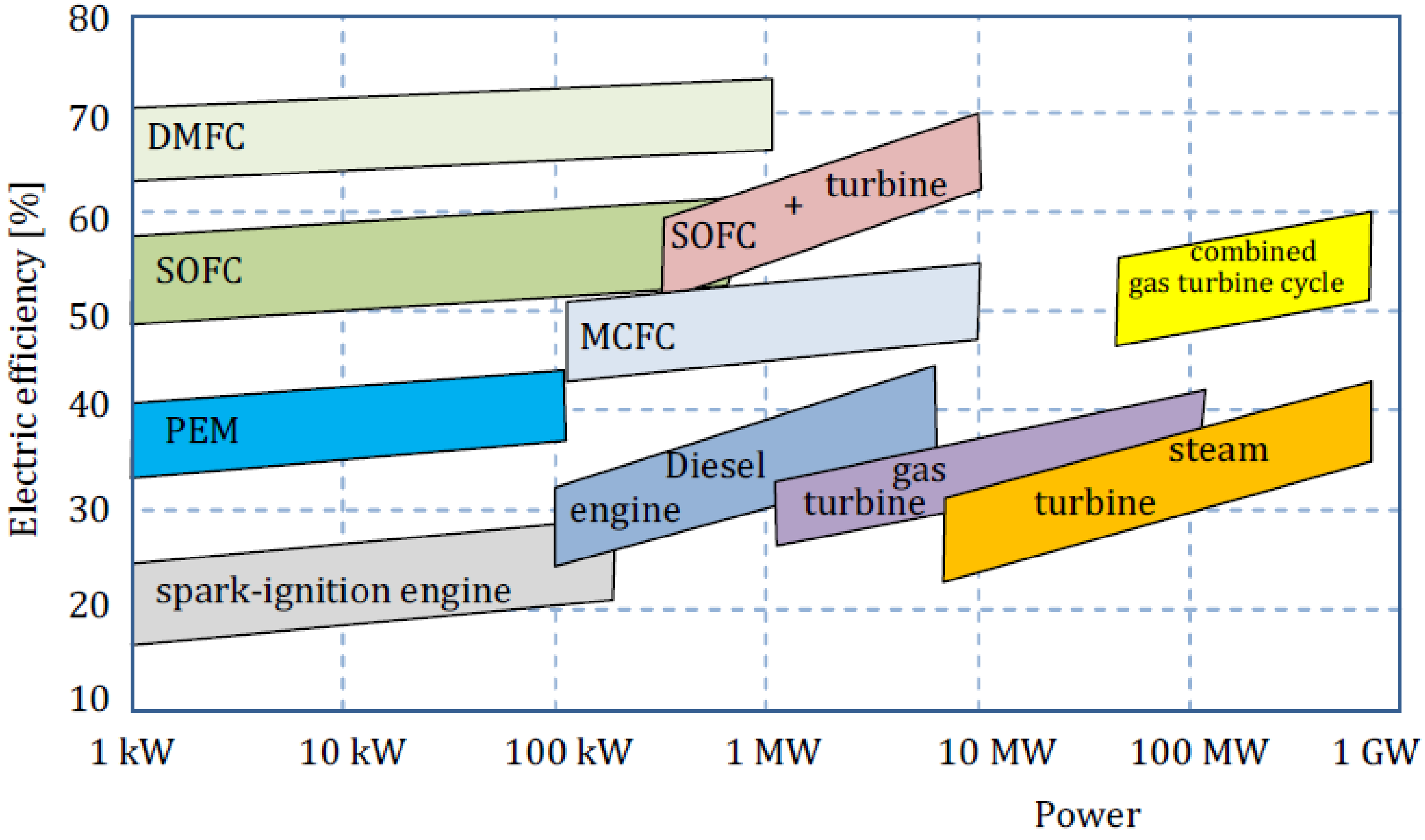
Electric Propulsion

- Higher efficiency in a wider range of rotational speeds
- No need of reduction gear
- Smaller mass and volume
- Quieter than conventional turbines or internal combustion devices

Electric Power Generation	Electric Power Distribution	Electric Power Consumption
Prime mover	Energy Transmission "SWITCHBOARDS"	Electric propulsion motors
Generators	Transformers, filters and power converters	Propulsion units
Energy Storage System		

State-of-the-art high-power electric propulsion systems

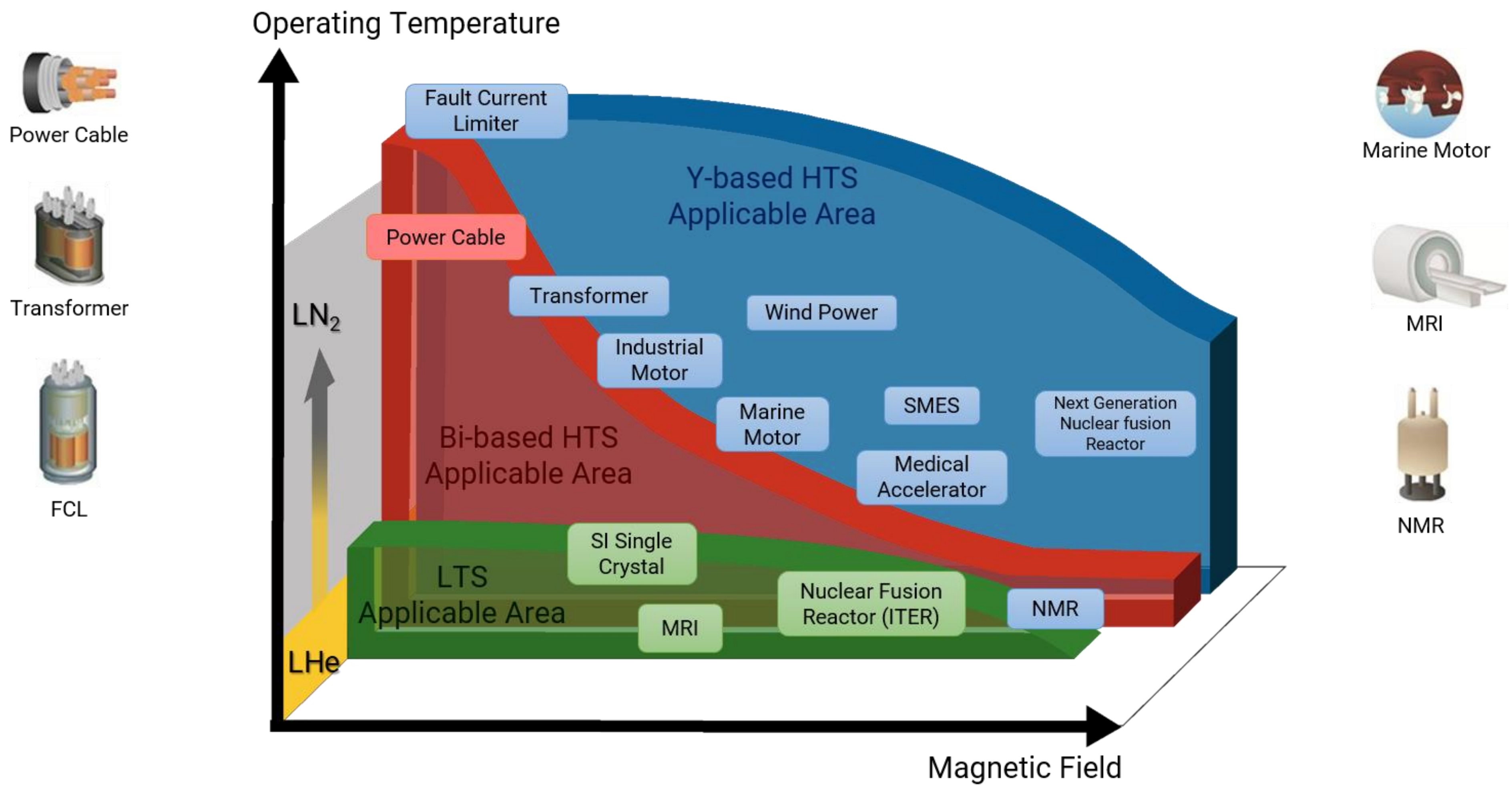
Electric Power Generation



[1] J. Markowski and I. Pielecha, "The potential of fuel cells as a drive source of maritime transport," *IOP Conf. Series: Earth and Environmental Science 214*, 2019.

2G HTS materials, tape production and economies of scale

Operating Temperature Range for HTS Applications



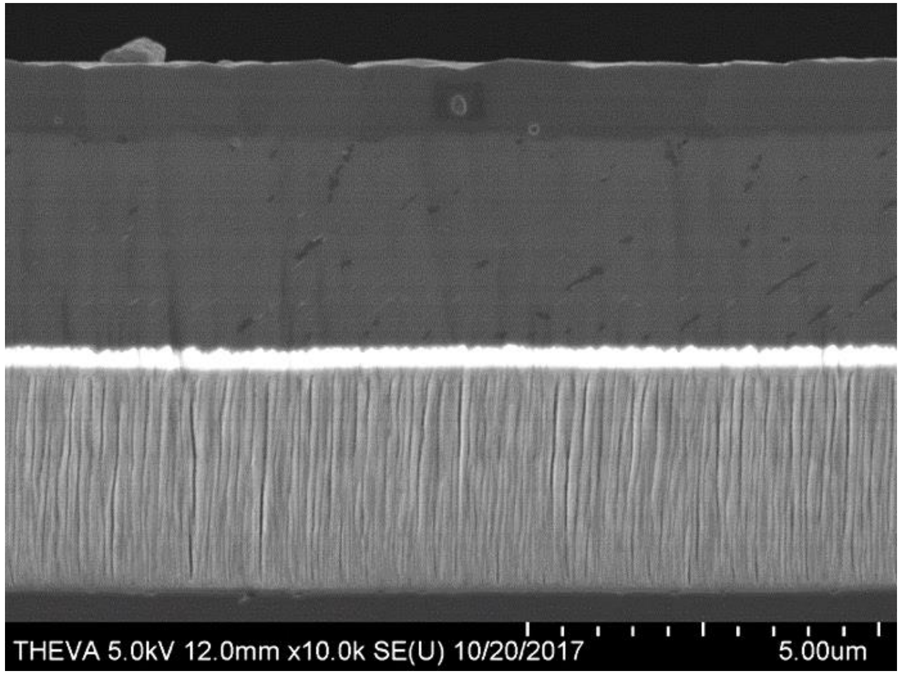
[3] Remastered by PI Integral Solutions. Based on superconductors and applications Fujikura Ltd

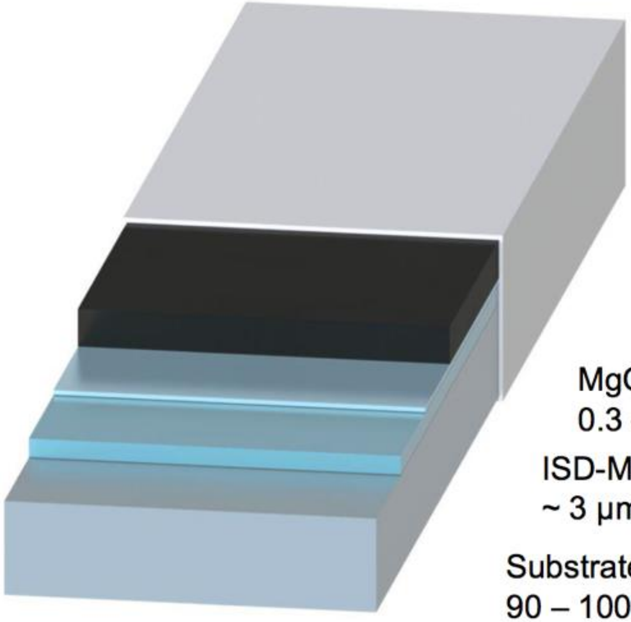
2G HTS materials, tape production and economies of scale

TYPE 2G HTS

THEVA

Materials





2G HTS materials, tape production and economies of scale

TYPE 2G HTS

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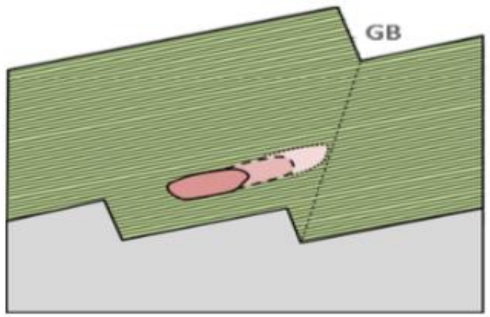
Main Properties

Tunable performance

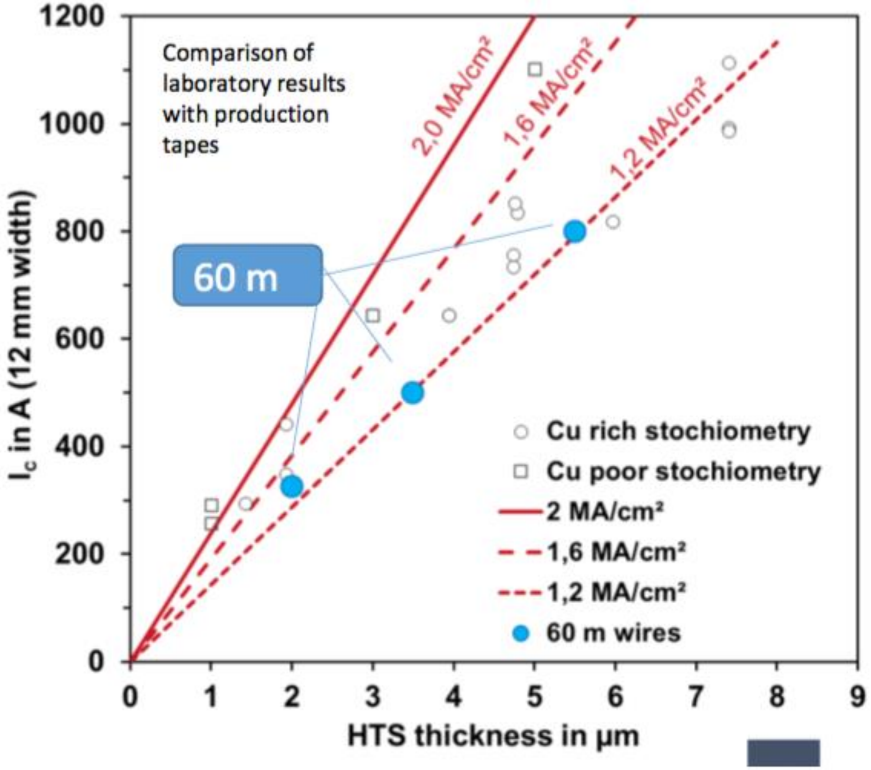
Positive effect of the tilt angle



Tilt leads to **textured** overgrowth of precipitates and misoriented regions

- J_c is thickness independent
- **Very high I_c possible**

Previous results from 2016



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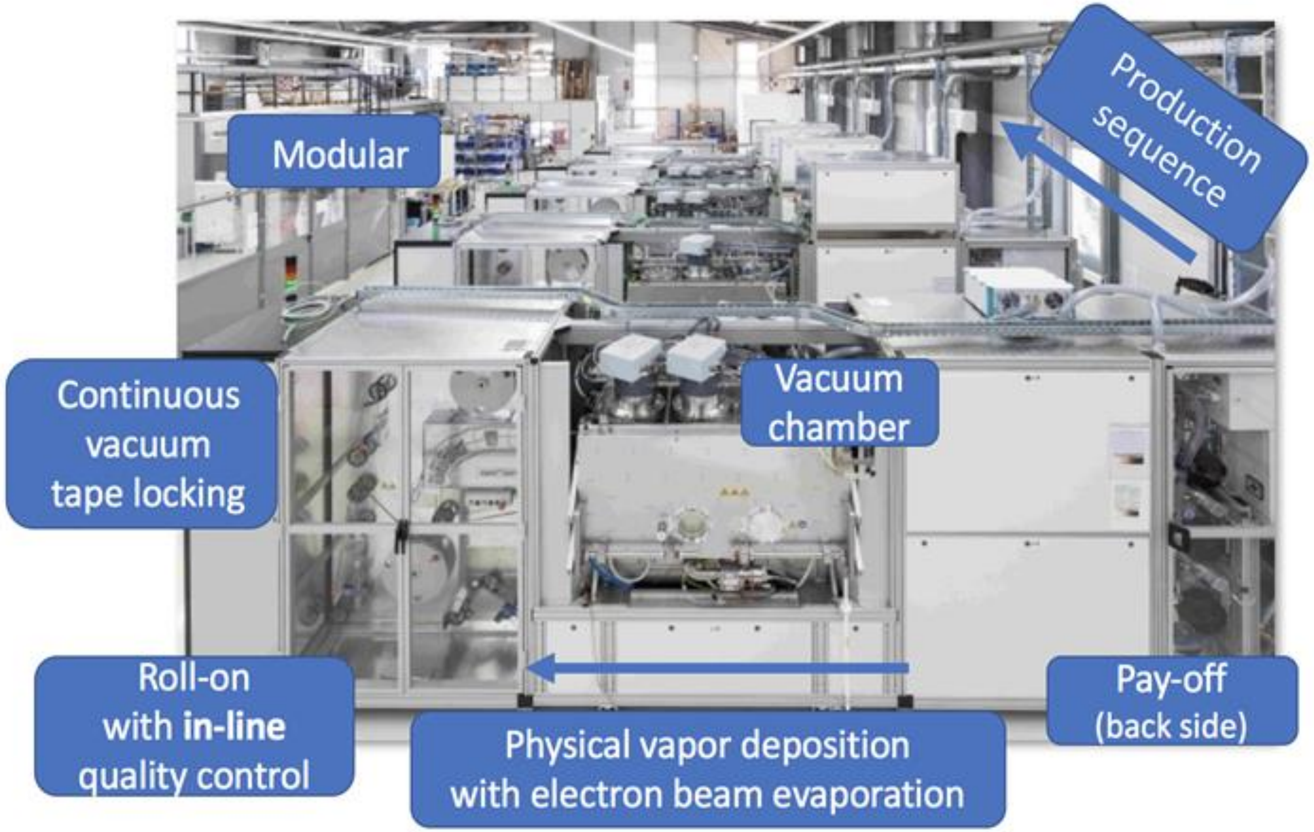
TAPE ARCHITECTURE

THEVA

Production Technologies



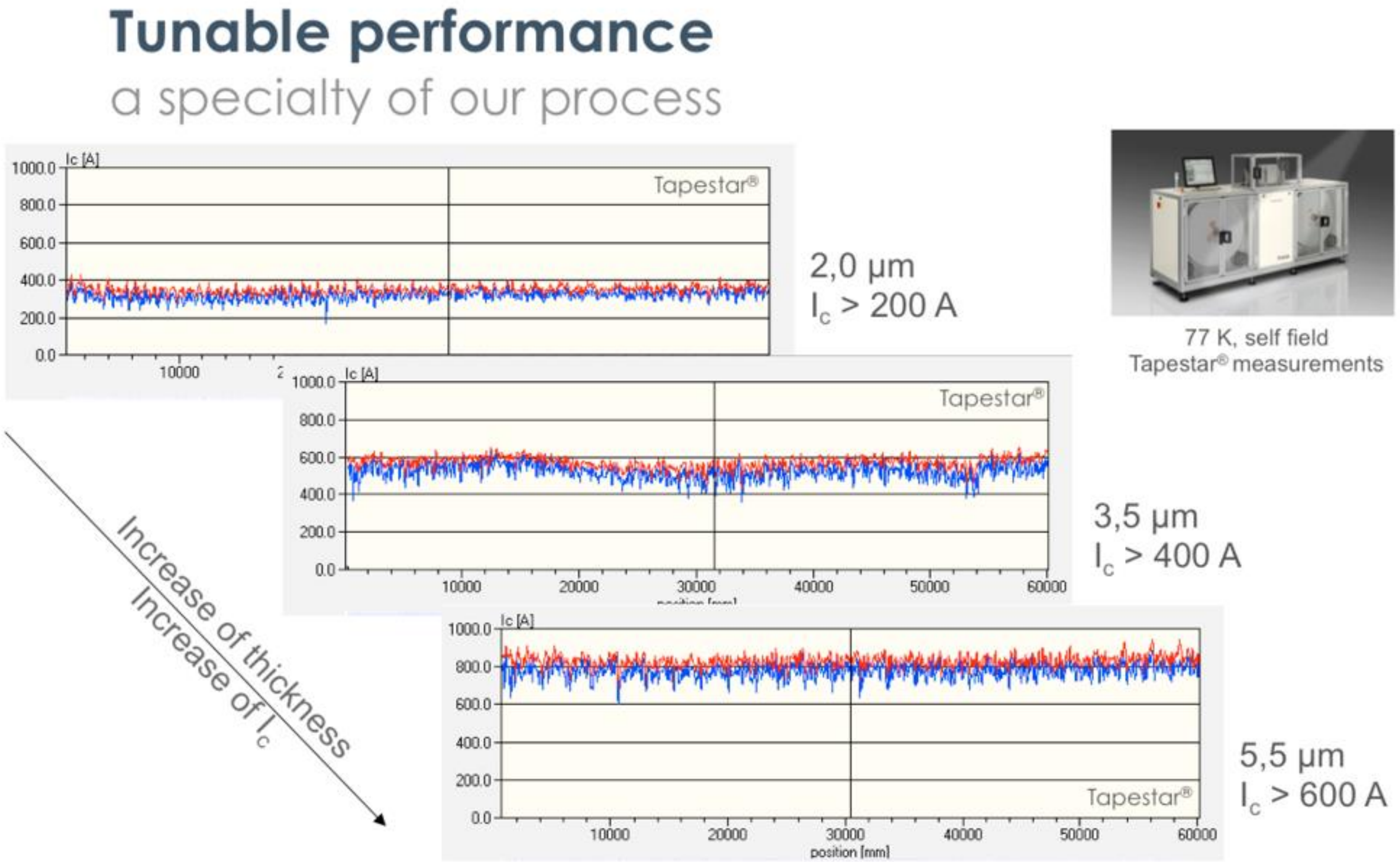
- Cost efficient production
- Robust process allowing high yield
- Implementation of industrial standards
- Proof of production: high quality tape

2G HTS materials, tape production and economies of scale

TAPE ARCHITECTURE

THEVA

Performance



[3] Superconductivity Centennial Conference Working around HTS Thickness Limitations – towards 1000+ A/cm – Class Coated Conductors

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TAPE ARCHITECTURE

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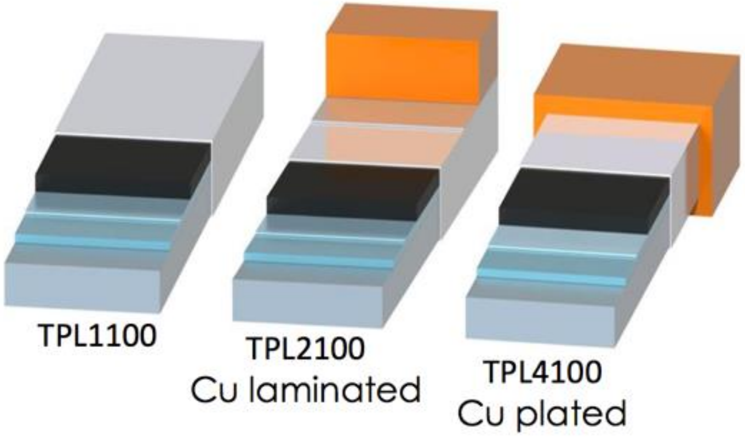
Typologies



- Cu stabilization according to application
- Standard width 12 mm
- Smaller width samples availabe

2G HTS materials, tape production and economies of scale

ECONOMIES OF SCALE

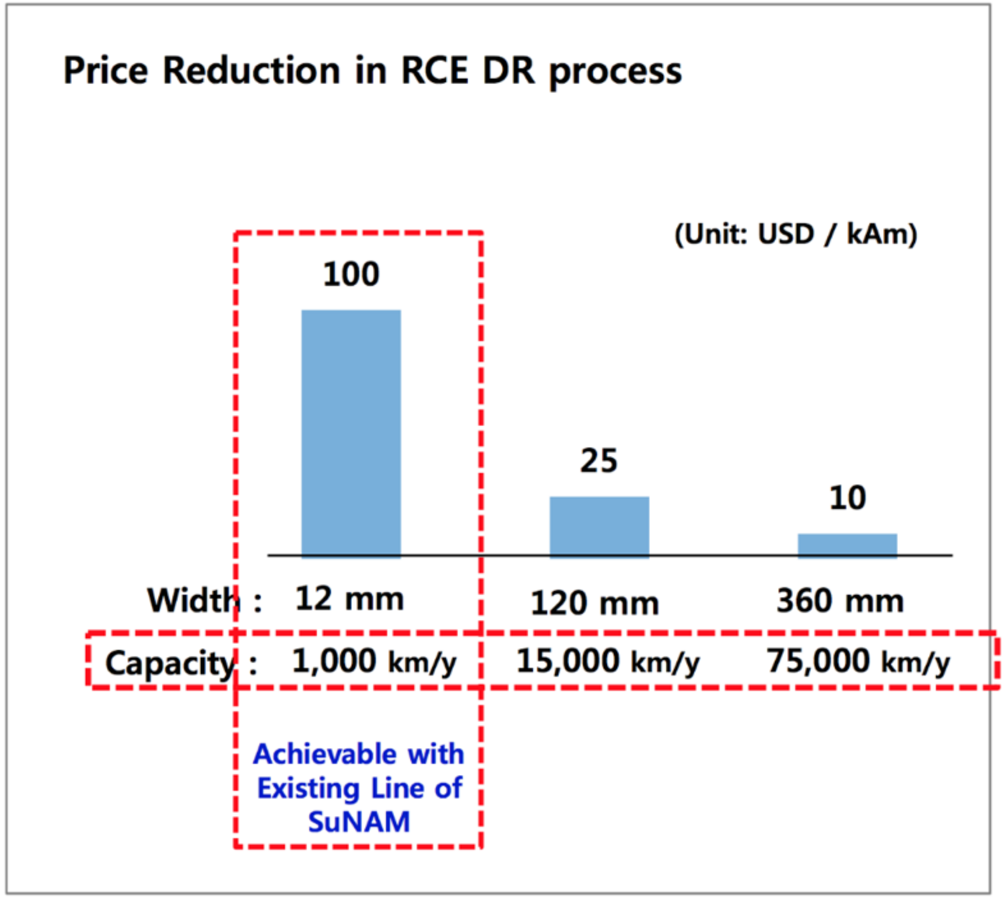
Production Capabilities

"Increasing Demand for HTS 2G wire has surpassed the supply"

"For market entrance $ 50 / kAm is the threshold "

"Price Reduction will ignite an exponential growth of demand for HTS 2G wire"

"High throughput, low material cost, High yield is 3 Critical Success Factor"



[4] Venkat Selvamanickam, University of Houston, Recent Advances in High Temperature Superconductors and Potential Applications (2014)

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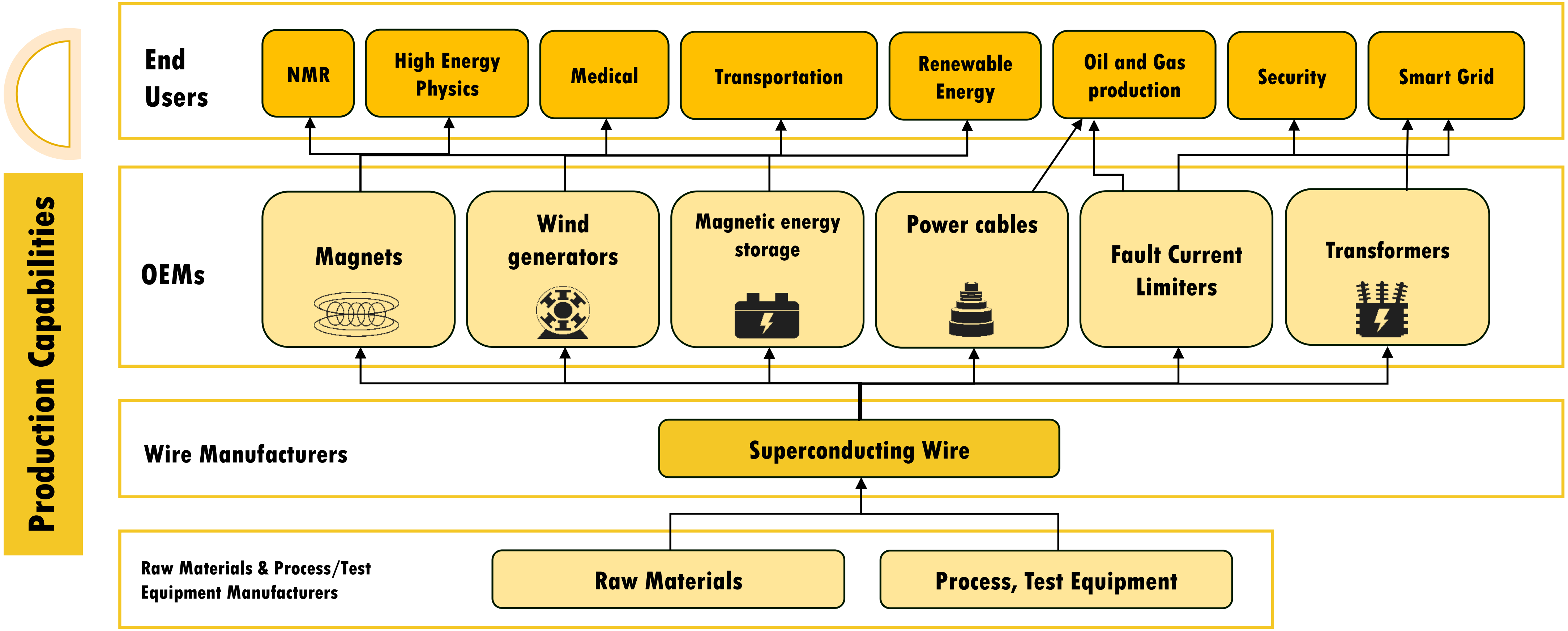
ECONOMIES OF SCALE



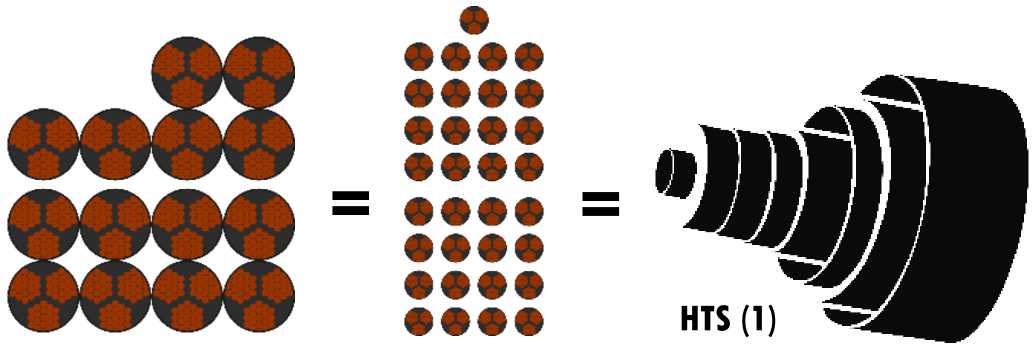
[5] © 2017 Copyright PI Integral Solutions based on
Venkat Selvamanickam, (2014): Recent Advances in High Temperature Superconductors and Potential Applications, University of Houston

Trends and challenges for HTS-based propulsion systems

Main DC Bus Data from S3D Baseline Design

Benefits of HTS based in front of Copperbased

- **Lower material costs**
  Fewer cables to install
- **Lower volume and weight**
- **Higher power density**

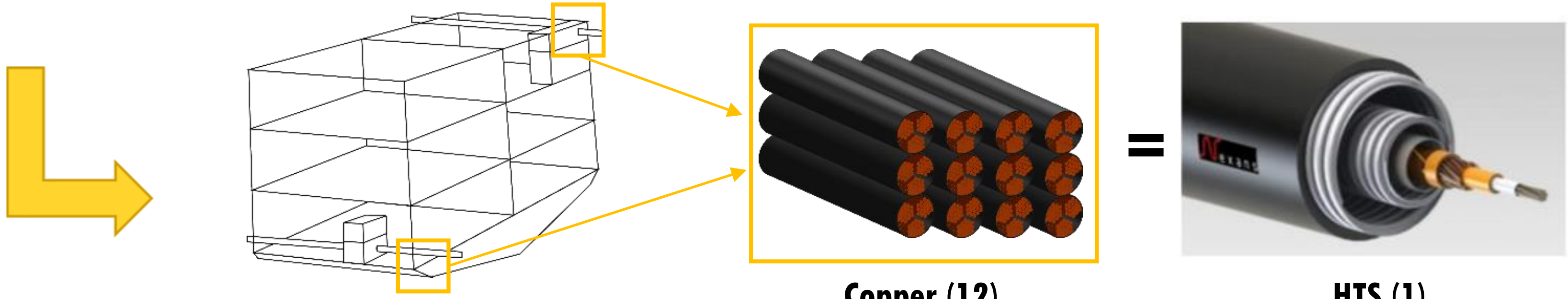


Copper (14)
1,75" OD

Copper (33)
0,6" OD

HTS (1)
1,75" OD

Degaussing Cable



Copper (12)
2,3" OD

HTS (1)
2,75" OD

Power Distribution Cable

[7] © 2018 Copyright PI Integral Solutions based on C. E. Bruzek, N. Lallouet, E. Marzahn, and K. Allweins,"Superconducting cables on board a ship A fiction or a reality?", Seminar on ship building, The Netherlands, 2nd October 2012

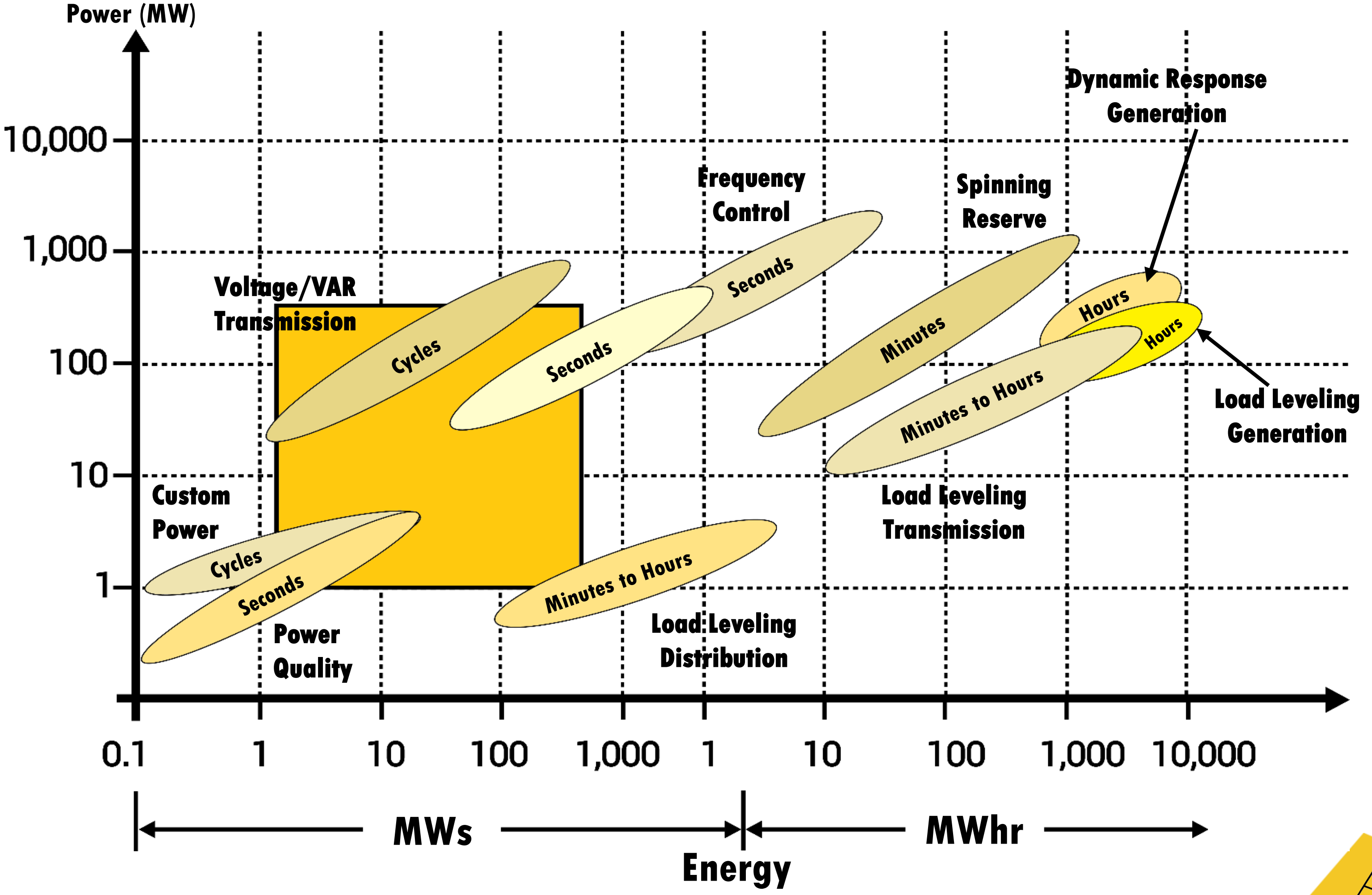
Trends and challenges for HTS-based propulsion systems

SUPERCONDUCTING MAGNETIC ENERGY STORAGE

Superconducting Magnetic Energy Storage

Magnets based on 2G HTS technology has reached a level of maturity that are able to generate magnetic fields as high as the ones produced by low temperature superconductors.

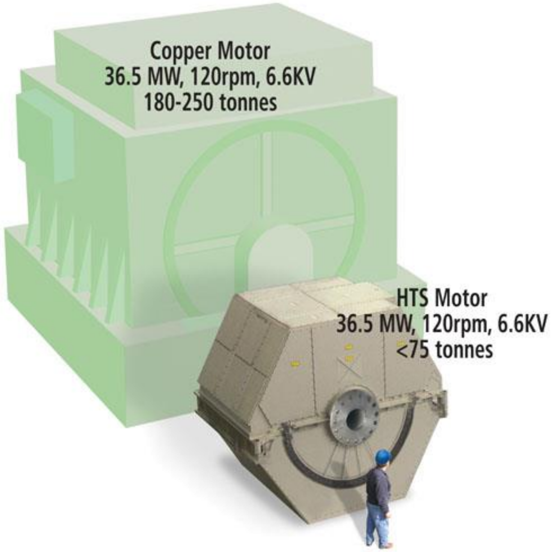
SMES systems exhibit an outstanding performance in power transmission control and stabilization in front of other energy storage solutions



Trends and challenges for HTS-based propulsion systems

High power electric propulsion

- Higher flexibility on the location of the electric motors
- More compact designs saving weight and volume
- 4.7 MW HTS machine from Siemens (25 % weight reduction)
- 36 MW HTS motor from Northrop Grumman (50 % weight reduction)



Main Characteristics

Characteristics	Kawasaki	Siemens	US Navy
Max. power	3 MW	4.7 MW	36.5 MW
Nominal voltage	6.6 kV	3.1 kV	6.6 kV
Nominal rotational speed	160 rpm	120 – 190 rpm	120 rpm
Total weight	-	-	75 tonnes
Volume	D 1.4 m x L 2.8 m	-	D 2.1 m x L3.0m

T. Yanamoto, M. Izumi, K. Umemoto, T. Oryu, Y. Murase y M. Kawamura, «Load test of 3-MW HTS Motor for Ship Propulsion,» IEEE Transactions on Applied Superconductivity, vol. 27, nº 8, 2017.
B. Gamble, G. Snitchler y T. McDonald, «Full power test of a 36.5 MW HTS propulsion motor,» IEEE transactions on applied superconductivity, vol. 21, nº 3, 2011.

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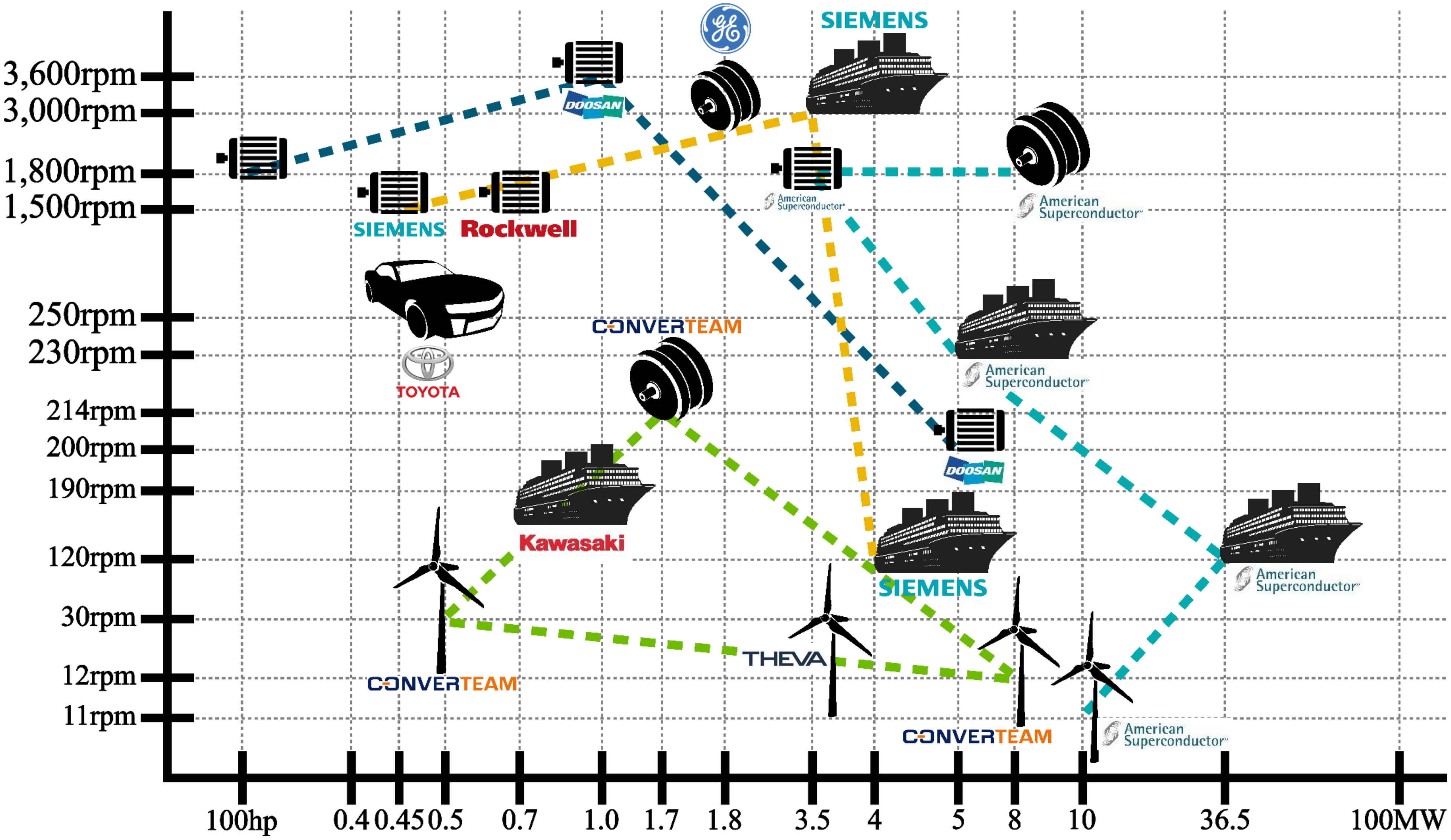
Trends and challenges for HTS-based propulsion systems



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Trends and challenges for HTS-based propulsion systems

Full superconducting synchronous motor

- Double-Helix (DH) coils
- Flux Pump System (FPS)
- Higher power density
- Lower heat dissipation

Table. Synchronous motor performance.

Output power	35	MW
Phase voltage	3000	V
Power factor	0.87	
Power angle	60	
Phase current (RMS)	4520	A
Synchronous reactance	0.468	
Motor line frequency	2	Hz
Motor rated torque	2.84E+06	N-m
Air gap shear stress	1550	kN/m2
Cold mass diameter	0.81	m
Cold mass length	3.4	m
Estimated motor mass with cryostat	15	tonnes
Estimated power density	2.3	kW/kg

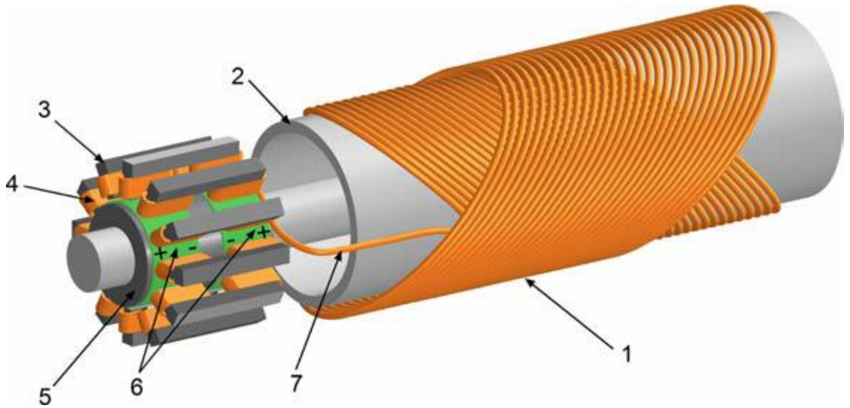

Fig. 10. 24-element drum type HTS flux pump connected to a double helix rotor (1). (2) Torque tube support for coils. (3) Stationary core for flux pump excitation magnet. (4) Externally controlled excitation coil (Permanent magnets are an option also.) (5) Rotating iron core of flux pump assembly. (6) Rotating HTS flux gates (thin cylinders, shown in green). Polarity of induced voltage shown and the elements are connected in parallel (not shown). (7) Coil lead (+) connected to flux gate. Other lead (-) is connected to the parallel connection (-) between flux gates (not shown) [15].

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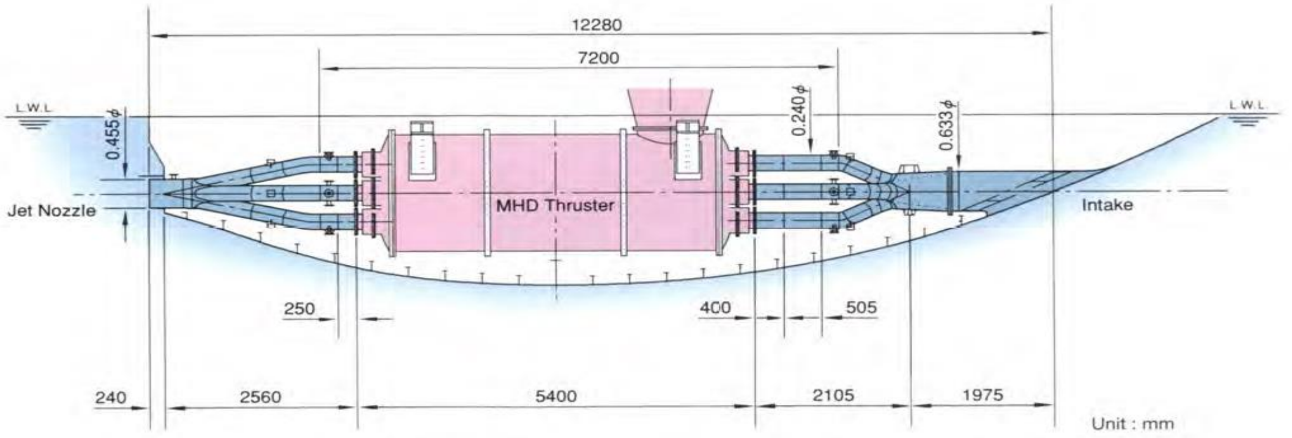
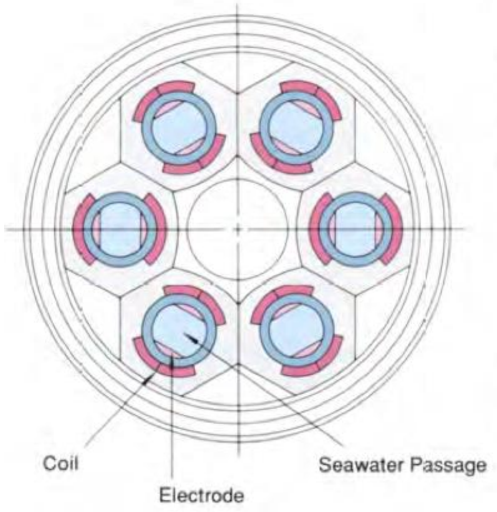
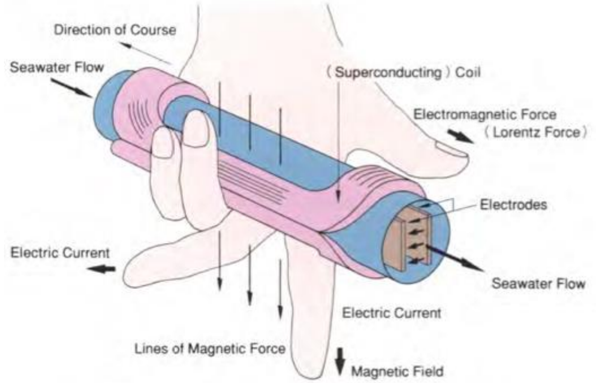
Disruptive approaches on all-electric ship propulsion

Type	Superconducting magnets of internal magnetic field type containing 6 coils arranged on a circle
➔ Coil	
Quantity	6 pairs
Magnetic field at bore center	4.0 teslas
Effective magnetic field length	3.000 mm
Cooling method	Cooling by immersion in liquid helium
➔ Cryostat (14)	
Diameter	1.850 mm
Overall length	5.400 mm
Bore diameter at normal temperature (15)	260 mm
Weight	15 tons or less
Heat invasion	7 watts or less

These were the performance figures provided to the manufacturers by the committee for the superconducting magnet design.







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CONCLUSIONS

1 PROBLEM AND CHALLENGES FOR FUTURE NAVY

- Efficiency of high power propulsion systems
- Mass and volume reduction of power generation and distribution systems
- Noise and electromagnetic signature of vessels

2 STATUS QUO OF 2G HTS TECHNOLOGY

- Constant increase in the production of basic elements
- Growing number of applications for HTS

3 2G HTS AS KEY ENABLING TECHNOLOGY FOR ELECTRIC NAVAL PROPULSION

- Power generation
- Power distribution
- Electric propulsion

4 DISRUPTIVE APPROACHES ON ALL-ELECTRIC SHIP PROPULSION

- MHD propulsion
- No rotating parts
- Reduction of noise and vibrations

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Thanks for your attention

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3. Remastered by PI Integral Solutions Based on superconductors and applications Fujikura Ltd
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8. © 2018 Copyright PI Integral Solutions based on C. E. Bruzek, N. Lallouet, E. Marzahn, and K. Allweins,"Superconducting cables on board a ship A fiction or a reality?", Seminar on ship building, The Netherlands, 2nd October 2012
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CONTACT

PI INTEGRAL SOLUTIONS LIMITED, Moltkestr. 127, 50674 Köln, Germany

Manuel La Rosa Betancourt

manuel.la-rosa@pintegralsolutions.de

THEVA DÜNNSCHICHTTECHNIK GMBH, Rote-Kreuz Str. 8, 85737 Ismaning, Germany

Dr. Markus Bauer

bauer@theva.com

THEVA

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Manuel La Rosa Betancourt
Founder & Director
PI INTEGRAL SOLUTIONS LIMITED
Zweigniederlassung Köln

Moltkestr. 127, 50674 Köln, Deutschland

+49 221 5795674
+49 171 5231978
manuel.la-rosa@pintegralsolutions.de
www.pintegralsolutions.de