SUPERCONDUCTORS FOR RENEWABLES INTEGRATION

Marcos Byrne

SUPERNODE™

Introduction

1. Who are SuperNode?
2. What is happening with electricity?
3. What is superconductivity?
4. Do superconductors exist today?
5. What do superconductors offer?
6. What are the challenges of developing SuperNodes technology?

Who are SuperNode?

Mission

- To **Decarbonize** the Global Economy
- To harness the best **Renewables**
- To **Build and Grow** the **Renewable Industry**

People

Eddie O'Connor, Founder

(Executive Chairman, Mainstream Renewable Power)

Pat Cox, Chairman

(President of EU Parliament 2002-04)

John Fitzgerald, CEO

(Dir. Grid Development and Interconnection EirGrid 2013-18)

AKER Horizons
(50% ownership)

AKER HORIZONS

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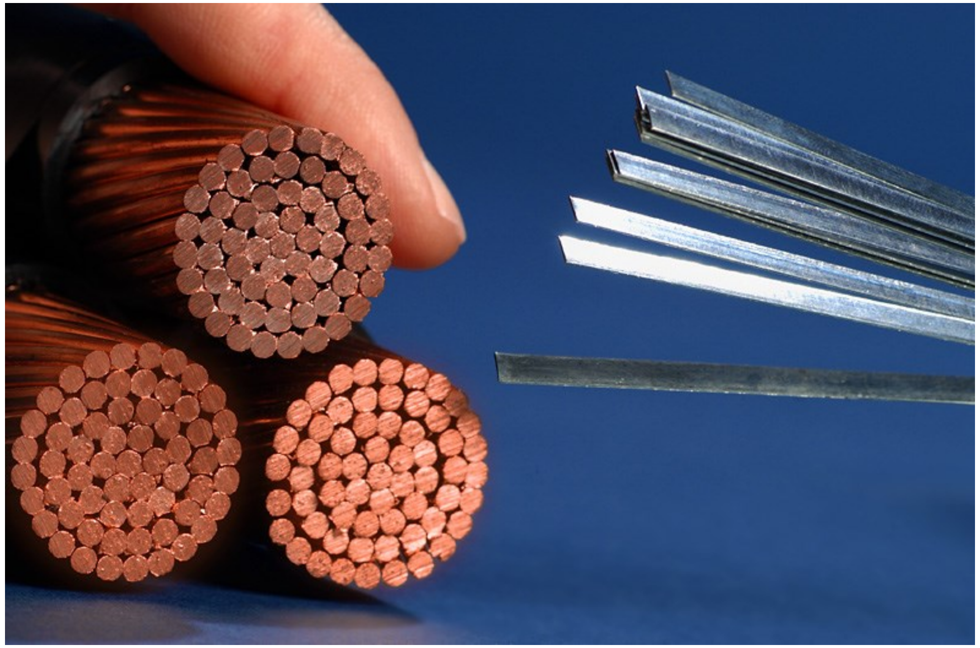
Why is new Transmission Technology Needed?

2050: Booming European Electricity Demand – decarbonisation, electric vehicles, heat pumps, data centres

Electrical energy demand will triple by 2050 compared to todays demand	More than 450 GW of offshore wind power will be needed	More than 800 GW of new solar power will be required
The best renewable resources are found at the peripheries of Europe	Transmission is a major constraint on the level of renewables required for deep decarbonisation	No clarity on transmission capacity for future past 2030

What is Superconductivity?

- Superconductivity is a phenomenon that occurs in some materials that, when cooled below a certain temperature, display unique characteristics:
  - Zero electrical resistance
  - High power density
  - Low electromagnetic field
- How to achieve superconductivity:
  - A material must be cooled to below its ‘*critical temperature*’
  - High temperature superconductors (HTS) are superconductive around -200◦c
- Superconductors are found in superconducting magnets, magnetic resonance imaging (MRI) scanners and the Large Hadron Collider.



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The Superpowers of Superconductivity

Zero Electrical Resistance - When a superconducting material is cooled below its critical temperature, its electrical resistance reduces to zero.

High Power Density – Superconductors can carry significantly higher levels of current and thus are capable of the transmission of higher power levels than copper.

Smaller Right of Way – Superconducting cables have a smaller cross-section and thus the right of way required for their installation is much smaller than comparable copper cables.

Lower Cost – The cost of the cables might be higher but the cost of a superconducting project can be significantly lower.

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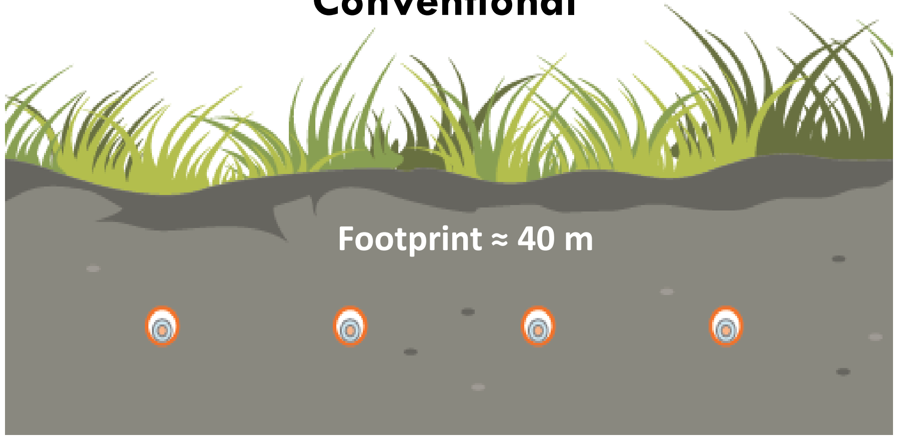
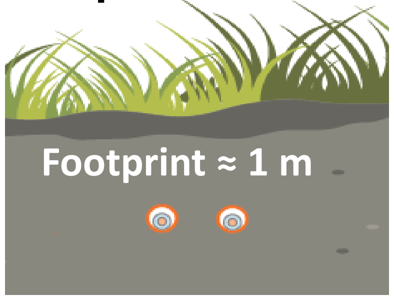
Greater Flexibility in Cable Placement

- Smaller Right of Ways
  - Much smaller space needed compared to overhead wires or copper cables
  - Potential to use smaller or existing corridors
  - Less consents/permitting required
- Significantly less infrastructure required
  - Lower voltage so less need for large substations
  - Reduced impact on environment during construction
  - No oil leakage
- No excess heat:
  - Cables can be buried deep underground
  - Cables can be installed closer together
  - No heat leakage into surrounding soil
- Low electromagnetic field (EMF)
  - Copper cables can't be buried too close together
  - Public fears over EMFs
  - Can't install in metal dense areas i.e. bridges

Conventional



Superconductor



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Superconductors Today – EcoSwing, Horizon 2020

- The EcoSwing generator is the first full size direct drive superconductive generator for a wind turbine.
- Existing two-bladed turbine in Denmark retrofitted with a superconducting generator.
- The current density in a superconducting coil is up to 100 times greater than in a normally conducting material like copper - Result: a stronger field and lower energy losses.
- Key findings from project:
  - Generator reduced in volume by 25%.
  - Weight of Generator reduced by 40% - nacelle weight reduced by 25%.
  - Efficiency of generator improved by ~1%.

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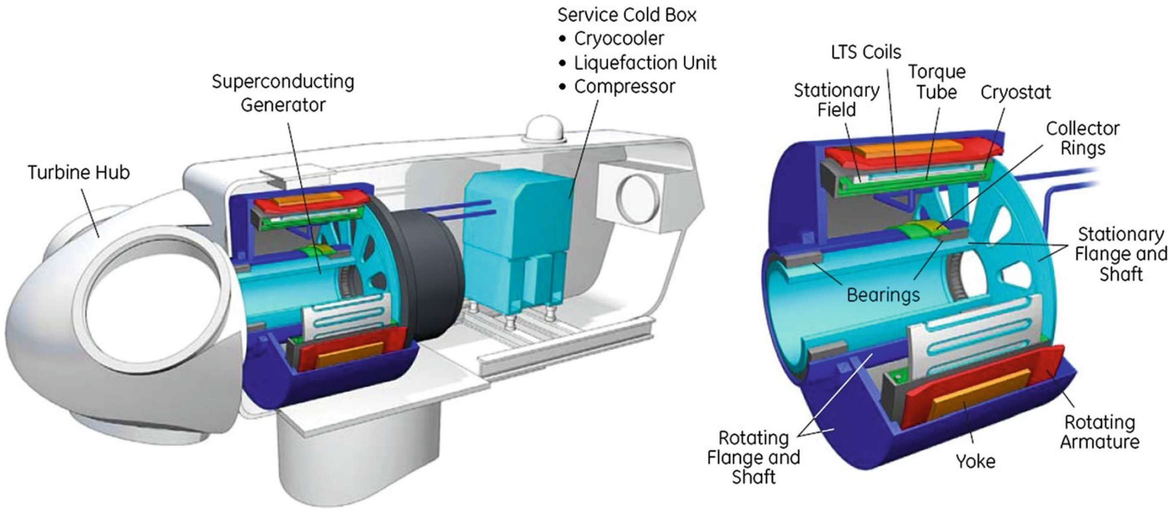
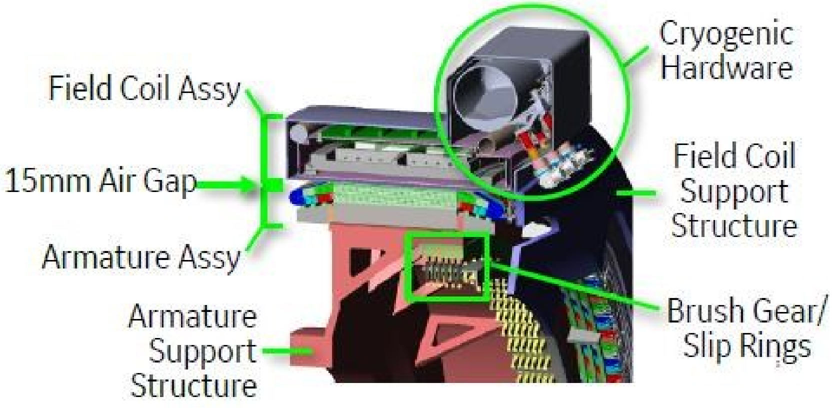
Superconductors Today – GE 15MW Future Turbines

- In 2019, the US Department of Energy provided $8 million of funding for two superconducting turbine designs (and one conventional) to American Superconductor and GE.
- In January 2021, GE received a $20.3 million contract from the US DoE.
- GE plan to produce a working prototype of a superconducting wind turbine generator by mid-2023.



Superconducting Generator Details



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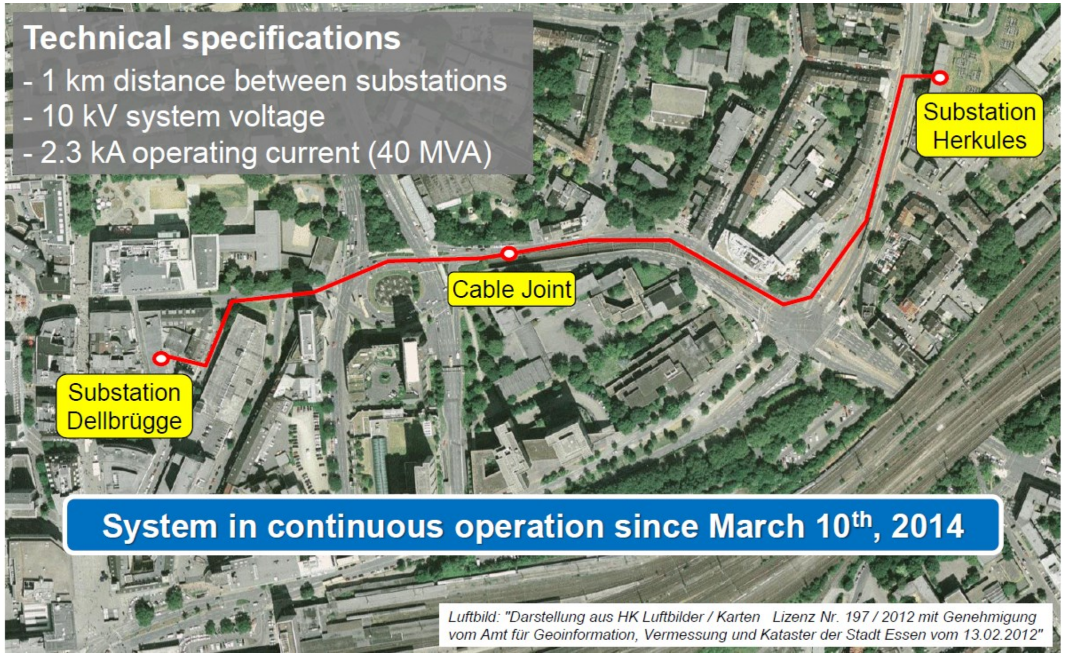
Superconductors in the Grid - Ampacity Project, Essen

- The Ampacity project was designed to solve an urban density problem.
- Essen is a typical European city with a busy pedestrianized city centre.
- Electricity demand was growing and the substation Dellbrugge required more power.
- Ideally, the city would build a new 110kV substation and a 110kV transmission line connecting it to a substation further out in the suburbs.
- However, there was no room to build such a large underground transformer.
- To solve this problem, a new transformer was built out in the suburbs where there was available space and a new HTS line was installed to connect them:
  - 1km long
  - 10 kV
  - Switchgear cubicle installed in Dellbrugge
  - Operational 6 year +
  - No corrective maintenance



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Superconductors in the Grid - Shingal Project, Seoul

- The Shingal project solves an urban density problem.
- Shingal substation needed a higher capacity but had no room for another transformer.
- HTS cables were installed to connect to Heungdeok substation:
  - 1km
  - 23kV
  - AC 23kV busbars
  - Shares supply capability between the stations
  - Provides emergency supply
- HTS was found to be 15% cheaper than the alternative method of building 154kV underground cables.

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SuperNode Cable System Development

SuperNode's R&D program is developing Superconducting cable technology focused on:

- MVDC, 2GW+, 100km offshore transmission
- Marine deployment
- Marine environment O&M
- Optimal loss management
- Cooling and pumping stations
- Reliability & robustness

- Recently achieved statement of feasibility on its offshore offering.

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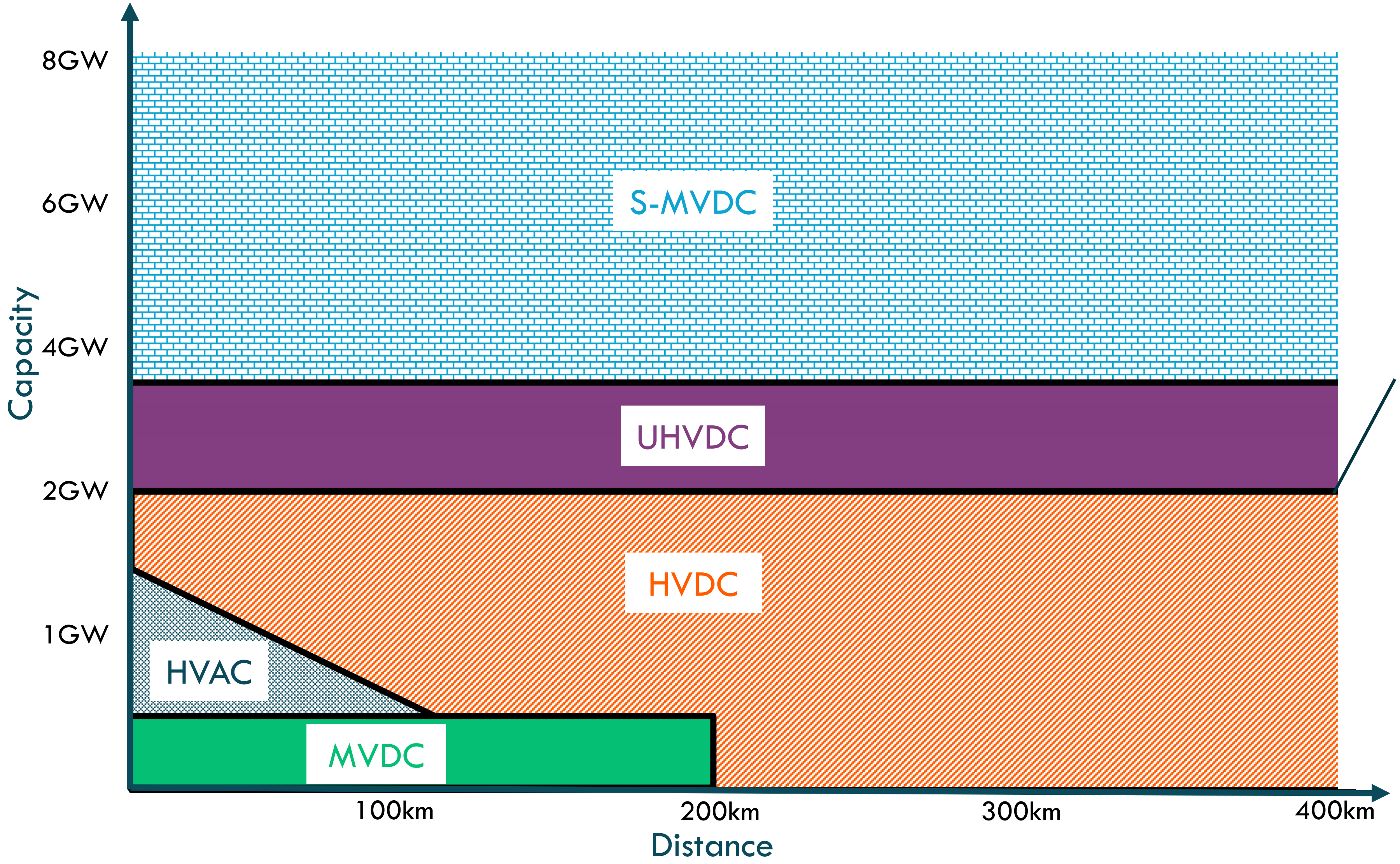
Marine Transmission Technologies

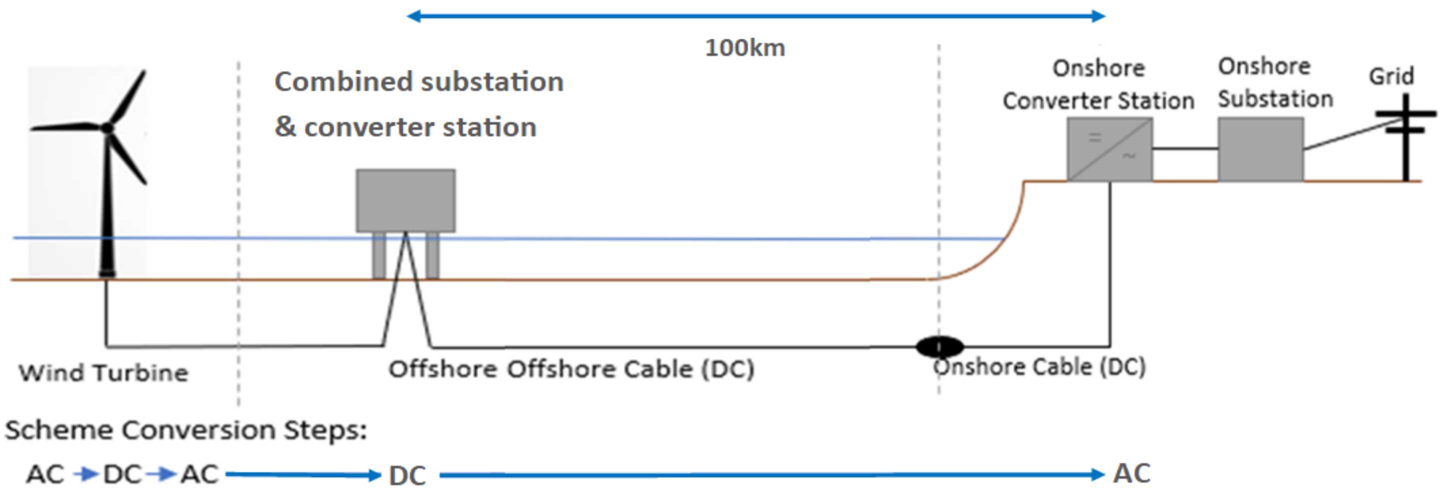


Superconducting Systems Competitive above 2GW

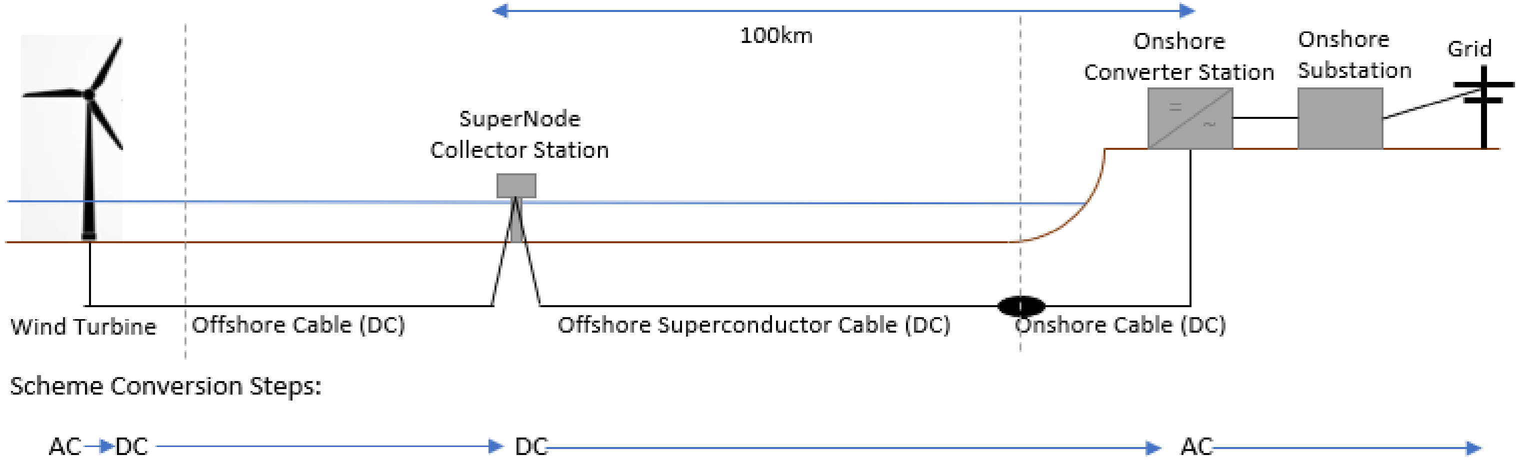
1 **Single pair of cables**
2 MVDC = 100kV
3 HVDC = <500kV
4 UHVDC = >500kV
5 S-MVDC = 100kV

SuperNode Connection Scheme

Conventional 2GW HVDC Scheme



Superconducting 2GW MVDC scheme



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Offshore Connections Alternatives

Offshore Wind Electrical Connection Competition

Huge Offshore Platforms

- Expensive
- Onshore equipment 'marinized'
- Slow supply chain
- **Upper limits on power capacity**

Man-Made Islands

- Onshore equipment 'on an island'
- State-level support required
- **Vast material source required**
- Shallow water only e.g. NSWPH

Lower Capacity MVDC/MVAC

- X 100s onshore connections
- Public resistance
- **Planning uncertainty**
- Limits on power capacity 300MW/link

Offshore Hydrogen

- Hydrogen/ammonia production
- Large offshore power platform required
- Use of existing gas networks unproven
- **Offshore production**

Dolwin 3 specifications

Capacity:	1 GW
Volume:	~ 120,000m^3
Weight:	~ 20,000 tons
Cost:	> €1bn

https://www.offshorewind.biz/2014/08/21/dolwin-beta-to-arrive-in-haugesund-tonight/

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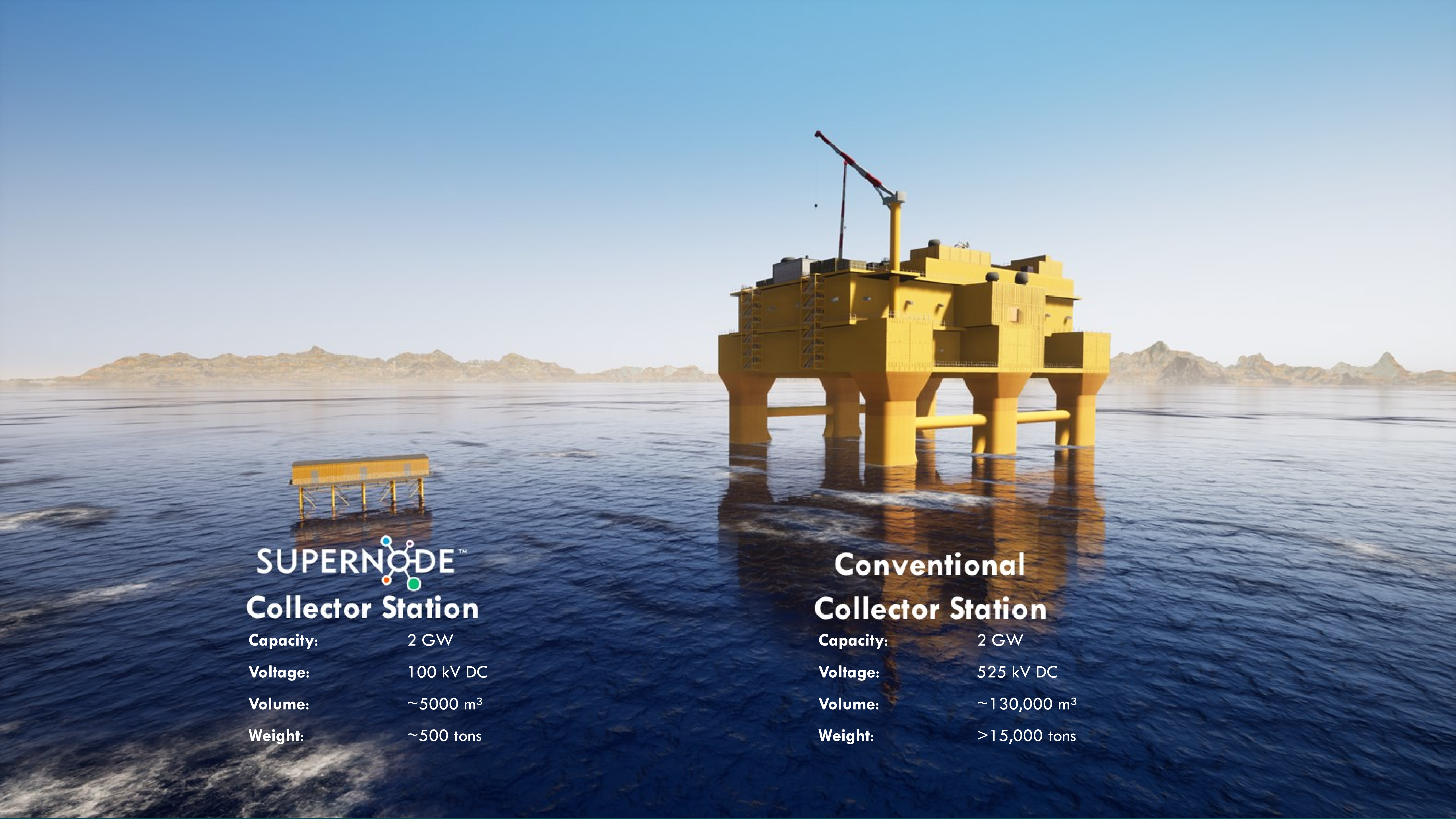
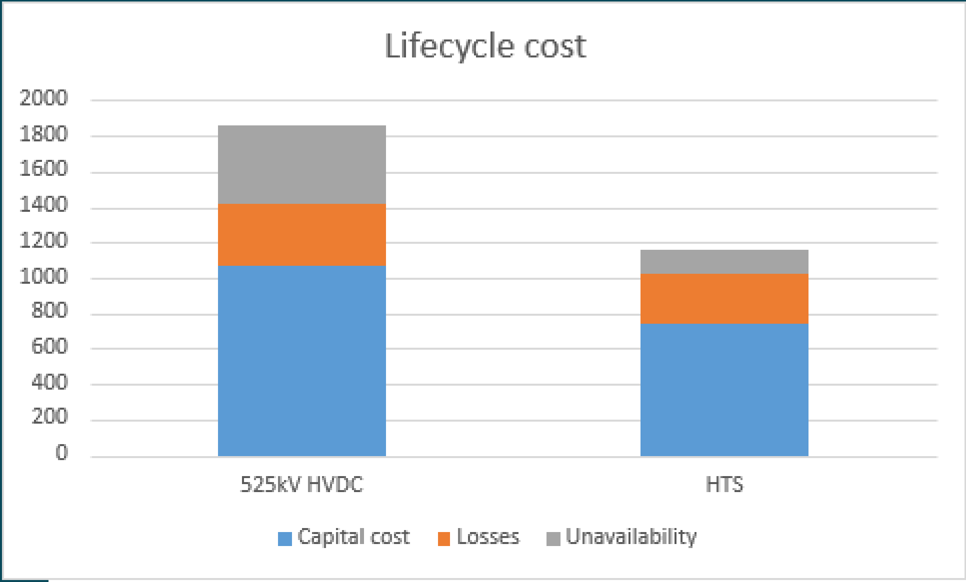
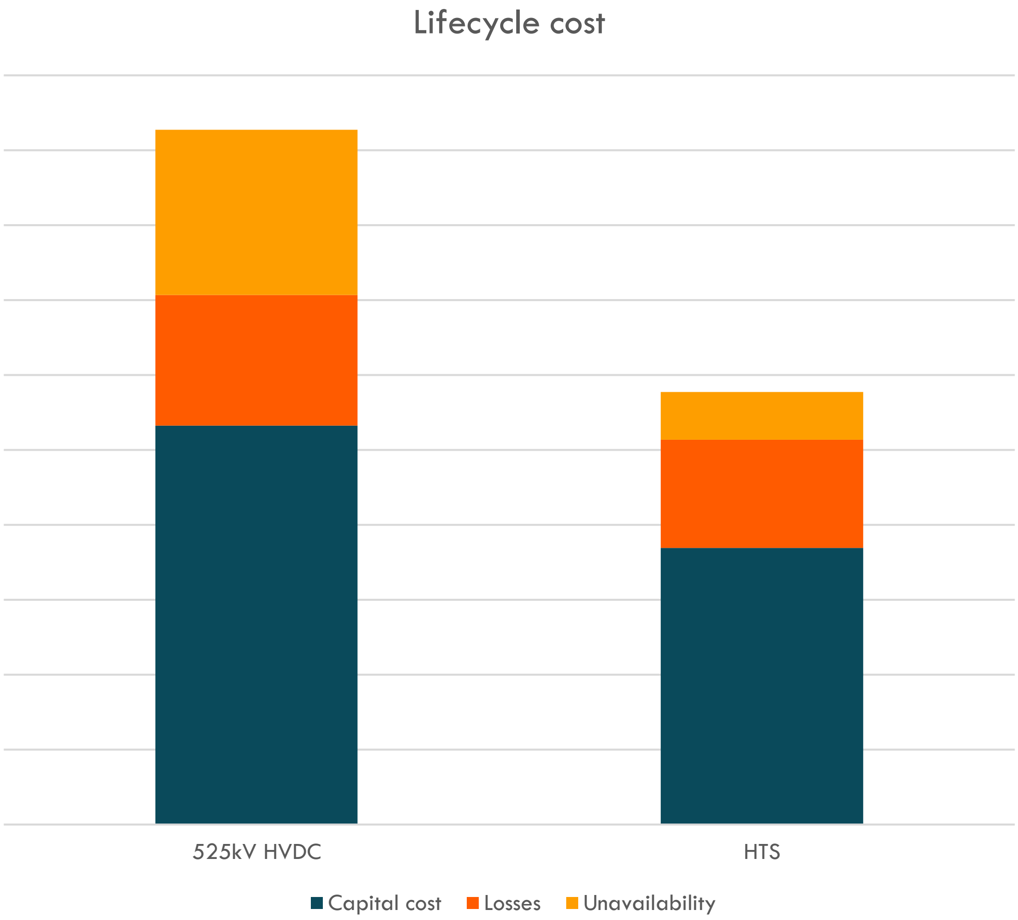

SUPERNODE™
Collector Station
Capacity: 2 GW
Voltage: 100 kV DC
Volume: ~5000 m³
Weight: ~500 tons
Conventional
Collector Station
Capacity: 2 GW
Voltage: 525 kV DC
Volume: ~130,000 m³
Weight: >15,000 tons



ore Connection

MVDC systems compared at 100km cable length.

- HTS System comes in over 35% cheaper than HVDC System cost.
- Competitiveness of superconductors improves further as capacity increases



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Superconducting Material Choice

- **Low Temperature Superconductors (LTS)**
  - Materials whose critical temperature is below 30K. Most robustly operated at temperatures below 5K in high-field magnet and MRI applications and cooled using liquid helium coolant.

- **High Temperature Superconductors (HTS)**
  - Materials whose critical temperature is above 30K. Typically, these are ceramics including copper oxides, iron-based superconductors and Magnesium Diboride. Often 77K is used as the upper temperature band for this class of material as this is the liquid nitrogen boiling point at atmospheric pressure, above which convenient mass cooling solutions do not exist.

- Typically, Gen2 tapes are:
  - Cheaper and of less volatile pricing than Gen1
  - More easily manufactured than Gen1
  - On shorter lead-times than Gen1
  - More mechanically stable than Gen1
  - More readily available – larger supply chain
  - Have similar critical current, critical magnetic field and critical temperatures to Gen1

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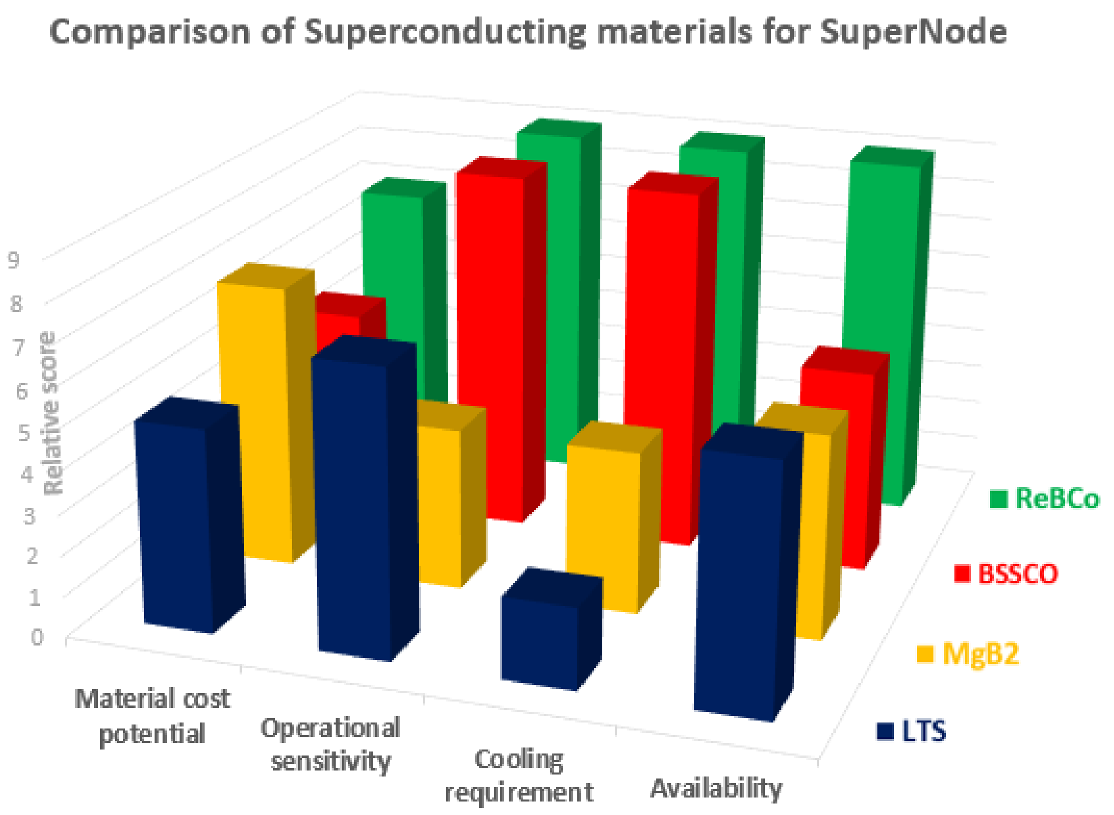
Superconductive Materials

- *HTS ReBCO materials rank highest in terms of potential for cost reduction, operational robustness, lowest cooling needs and highest availability*



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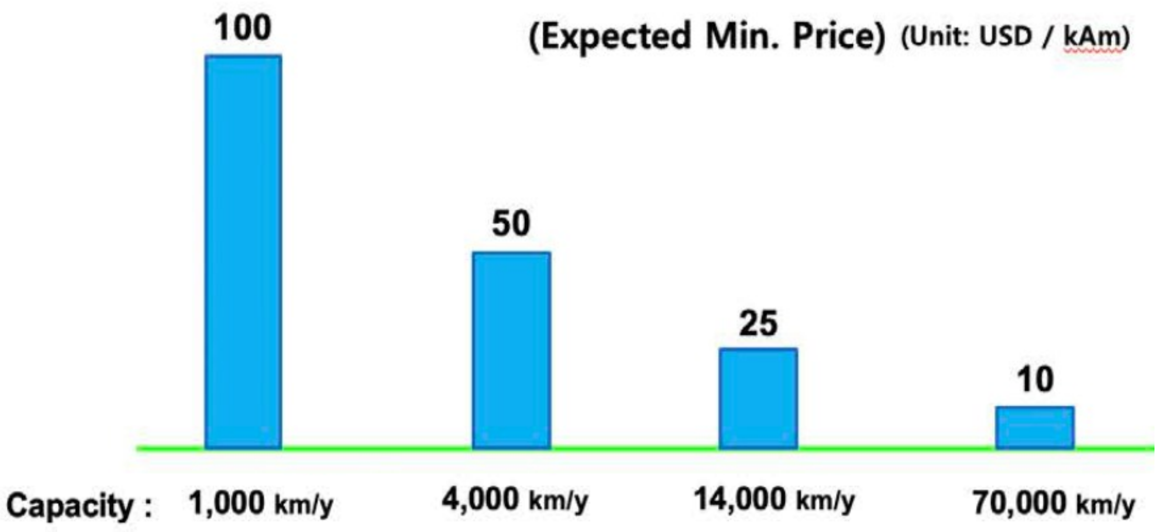
Cost of Superconducting Materials

- Increasing uses for HTS tape has led to demand surpassing supply.
- Current prices for tape are too high, halting mass adoption.
- Cost of superconducting materials is dictated by limited demand today.
- Increasing production scale of superconductors should realise economies of scale benefits and drive the cost of tape down significantly.

Future Tape Costs (2030+)



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Superconducting Cable Challenges

Superconducting cable system development & qualification program

Deployment / Demonstration projects

DC connection system to supply Superconducting cable

Industry collaboration

Establishing a secure and reliable supply chain

“It would be beneficial to develop HTC technologies for Superconducting Transmission Lines (STL) to explore its potential in situations where very high amounts of power need to be transmitted”

European Commission, “*Clean Energy Transition – technologies and innovations. (CET-TIR)*” 2020

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An expert perspective on superconductors

"By its very nature, renewable electricity will be cheaper than zero-carbon hydrogen (which is a vector that stores renewable electricity). In the view of the authors, this gives rise to possibly the most important conclusion from this study. Aside from energy efficiency, the most important and immediate priority for the EU in ensuring a cost-effective decarbonisation of its energy system must therefore be to identify and eliminate infrastructure and other bottlenecks that are likely to constrain the cost-effective production and use of renewable electricity moving forwards"

Florence School of Regulation: A. Piebalgs, fmr. European Commissioner for Energy, C. Jones, fmr. Head of Cabinet, DG Energy, European Commission, "*Cost-Effective Decarbonisation Study*" 2020

"Regarding HVDC cables, recurring to superconductivity technologies and namely High Temperature Cables (HTC) may be technically and economically convenient when the increase of transmission capacity need over a corridor requests the addition of more cables in parallel - It would be beneficial to develop HTC technologies for Superconducting Transmission Lines (STL) to explore its potential in situations where very high amounts of power need to be transmitted"

(…)

"to build the offshore energy production, and its connection to onshore consumption, an interconnected grid is needed"

European Commission, "*Clean Energy Transition – technologies and innovations. (CET-TIR)*" 2020

"In Best Paths, gigawatt-scale superconducting cables were investigated and shown to be technologically mature and cost-competitive for the transmission of large amounts of electricity. Thanks to their high efficiency, compact size, and reduced environmental impact, superconducting cables are likely to find higher public acceptance than overhead lines and conventional cables"

Best Paths, "*Advancing Superconducting links for very high-power transmission*" 2018

"Superconductors will do for electricity what fibre optic cables did for telecoms by replacing the twisted pair"

Pat Cox, SuperNode Chairman and former President of the European Parliament

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