Accelerating the Energy Transition: **The Role that Direct Current (DC) Grids can Play**

8th December 2020

CurrENT
Enabling Network Technology throughout Europe

AGENDA

Welcome & Introduction by John Fitzgerald, Vice-Chair of currENT | CEO, SuperNode

Keynote Address from Joachim Balke, Head of Network and Regional Initiatives, DG ENER

- **Arnoldus Van Wingerde**, Chief Scientist, Fraunhofer Institute for Wind Energy Systems IWES
- **Jochen Kreusel**, Deputy President, T&D Europe
- **Cornelis Plet**, Principal Consultant Offshore Power Systems, DNV GL
- **Wolfgang Reiser,** Managing Director, VESC and President of ivSupra
- **Dirk Van Hertem**, Electrical Energy Systems and Applications (ELECTA), University of Leuven

Panel discussion and Q&A session, moderated by John Fitzgerald.

Introduction to currENT

Our vision is a European power network that is the recognised world leader in enabling decarbonisation through the efficient use of modern grid technology.

CurrENT

Enabling Network Technology throughout Europe

Previous WEBINARS

1 Accelerating the Energy Transition:

Optimised Power Grids for a Clean and Green Future
(October)

CURRENT
Enabling Network Technology throughout Europe

Who is SuperNode?

- SuperNode is developing superconducting electrical cable systems.
- Recently achieved statement of feasibility on its offshore offering.
- For more information, contact Rob at rob.oconnor@supernode.energy

https://renews.biz/64936/superconducting-cable-wins-feasibility-statement/

SUPERNODE

AGENDA

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Joachim Balke

Head of Unit,

Network & Regional Initiatives

An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future

Dec 8th 2020

Why an Offshore Renewable Strategy?

Context and objectives

- GHG Reduction*

2030
at least 55%

2050
Climate neutrality

Renewable Electricity*

2030
> 65%

2050
> 85%

The European Green Deal

Offshore Objective*

2030
> 60 GW wind
> 1 GW ocean energy

2050
300 GW wind
40 GW OE

Spatial planning

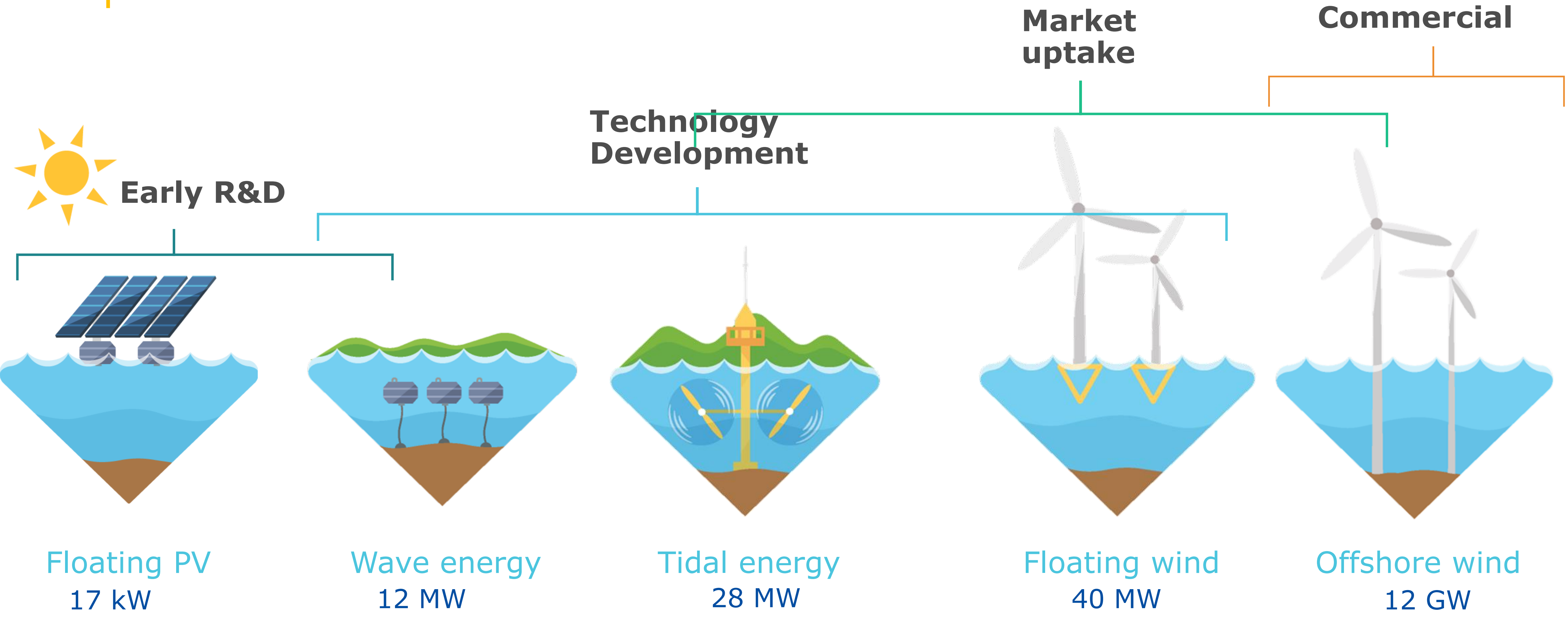
5 sea basins
Many activities
(Tourism, Fisheries, Transport, Defense)

Environment& biodiversity

European Commission

2030 Climate Target Plan Impact Assessment

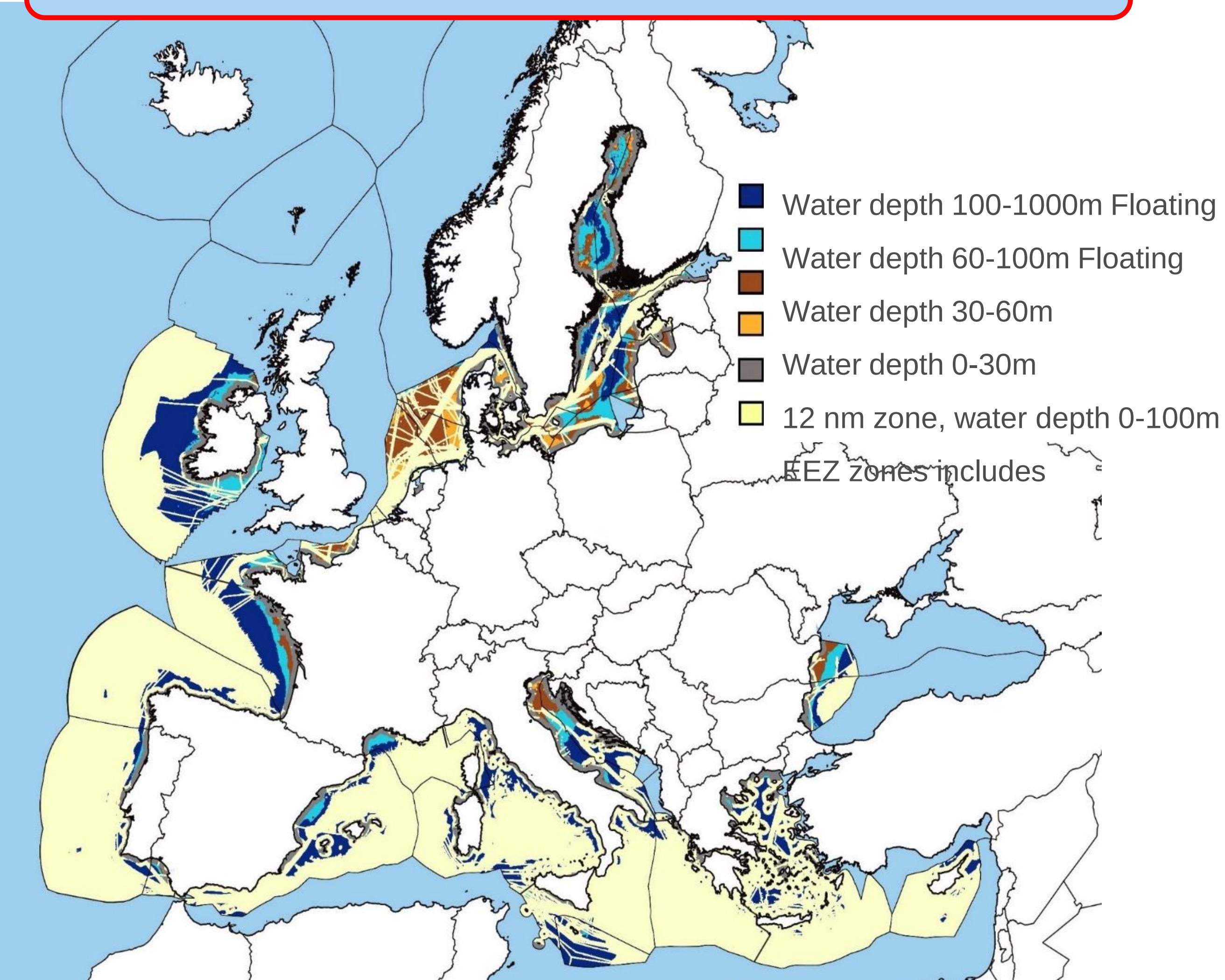
A technology neutral approach



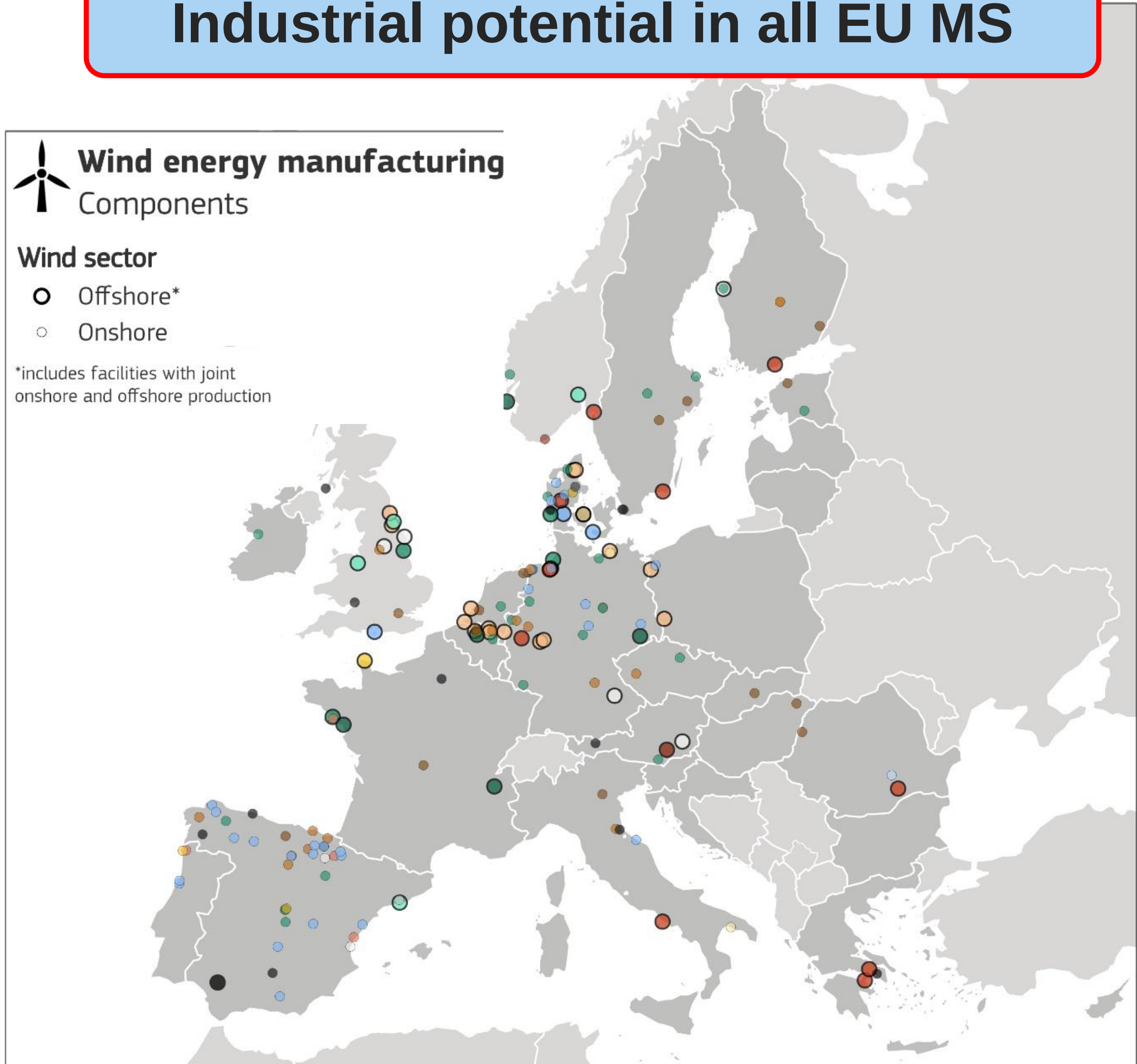
European Commission

A Strategy for the whole EU

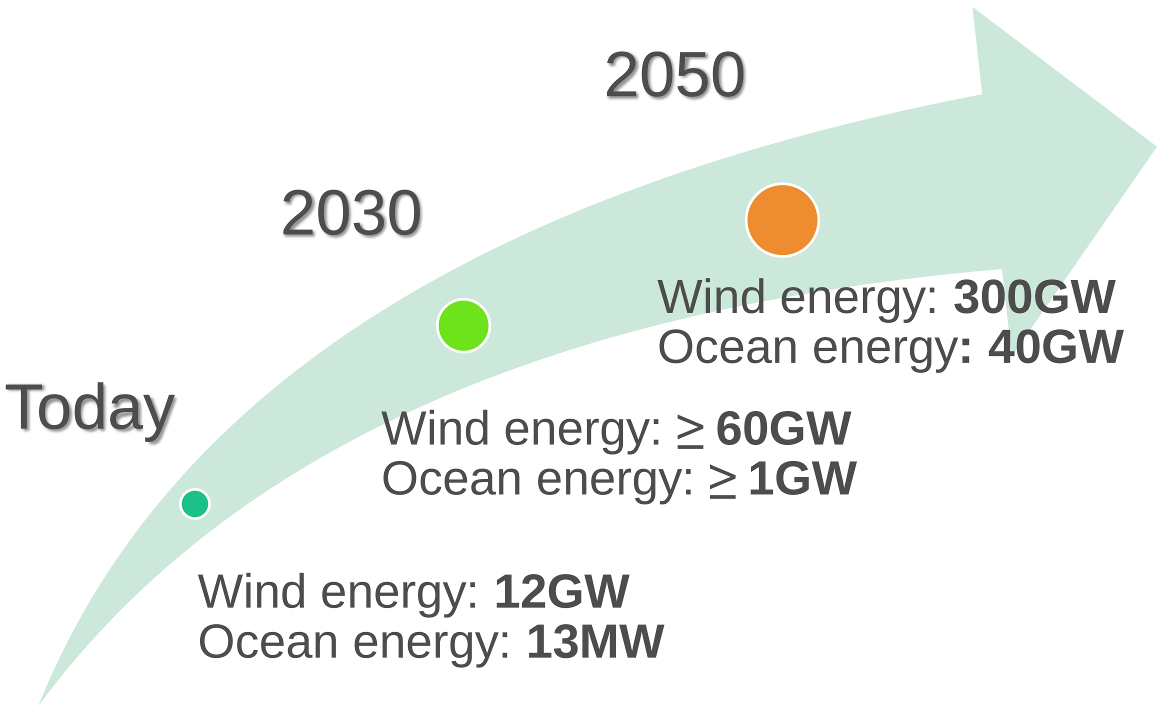
Energy potential in all EU sea basins



Industrial potential in all EU MS

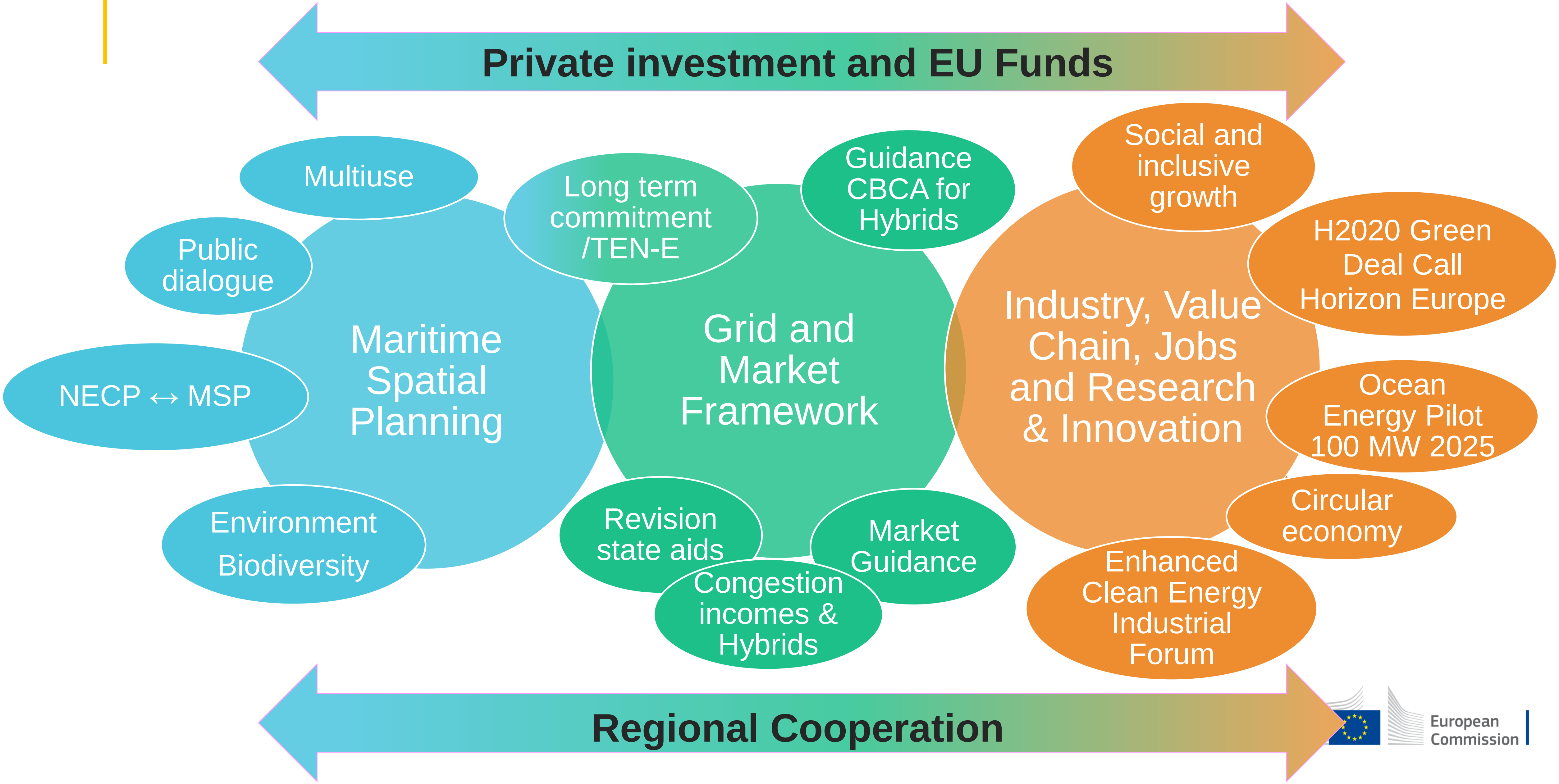


Global objectives



- Set ambitious targets for the growth of the offshore renewable energy sector
- Encourage public and private investment in new infrastructure and research
- Make it easier for different regions to work together more efficiently
- Provide a clear and stable legal framework

3 focus areas



European Commission

Upcoming key dates

TEN-E revision	December 2020
National Maritime Spatial Planning	March 2021
Renewable Directive Revision	June 2021

Thank you

European Commission

Dr. Arnoldus Van Wingerde

Chief Scientist

Fraunhofer Institute for Wind Energy Systems IWES

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Source: Conservative Energy future

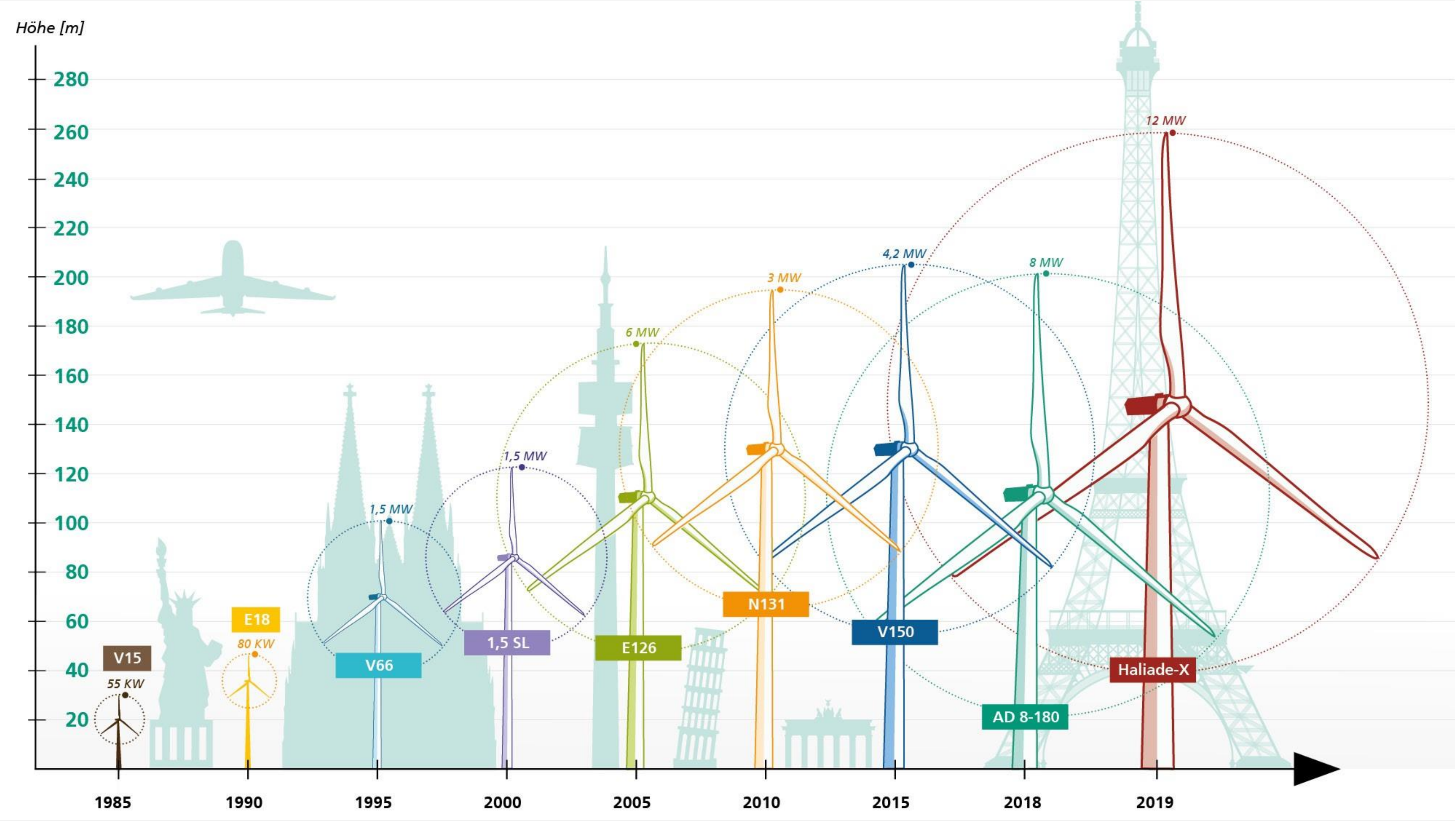
Source: Canva

Energy in 2050 – a retrospective view

Arno van Wingerde

December 8th 2020

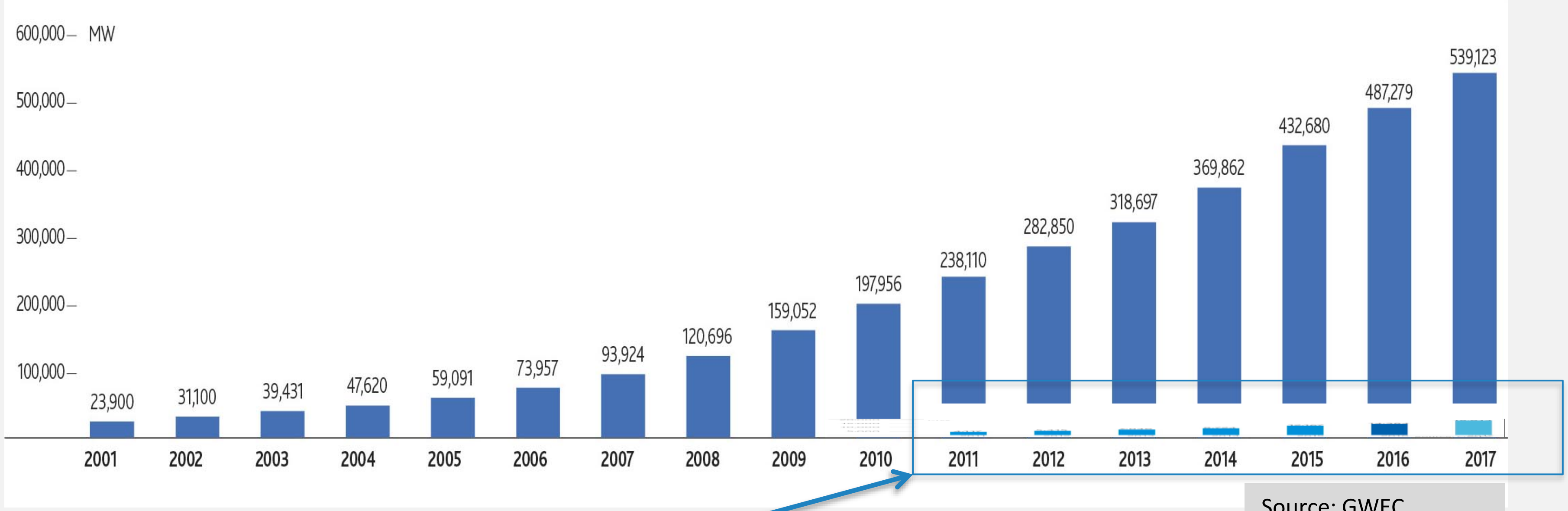
Wind energy – reaching new heights



Fraunhofer IWES

Global cumulative installed wind capacity

20 years difference between offshore and onshore?



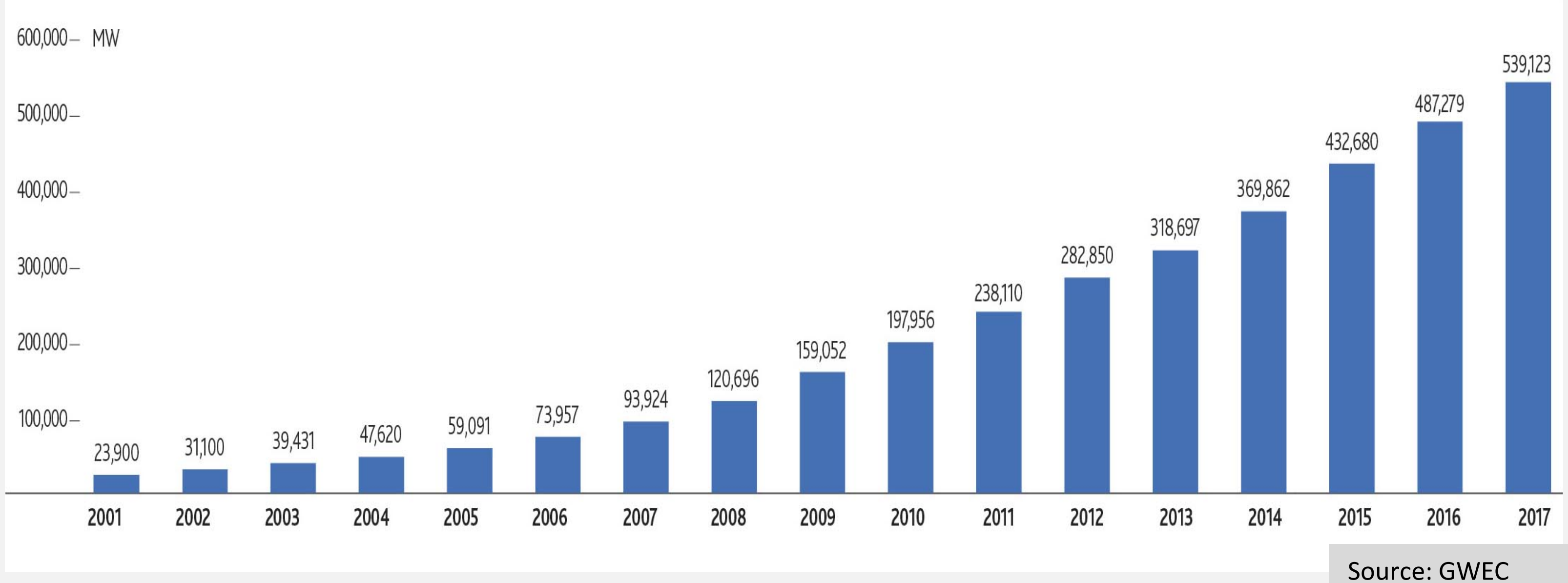
Source: GWEC

Offshore wind

Fraunhofer IWES

But… just where do we need to go?

500 GW done 18 TW to be done



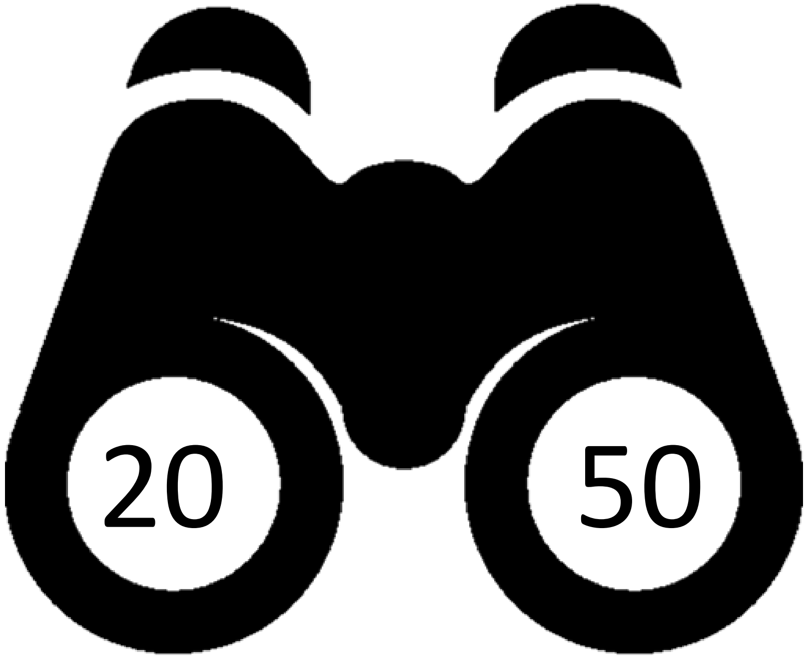
Source: GWEC

Fraunhofer IWES

2050: Strategy

Most strategies work like this…

- GWEC: global current energy use: 18 TW
- Population will increase, energy efficiency too…: 18 TW
- Say wind energy 1/3, and 1/3 capacity: 18 TW wind installed in 2050
- Same for solar energy
- Electricity grid to transfer current electricity use + transport + heating: 18 TW + spare capacity
- OK so we need to add this transmission line here and that transmission line there… Growing the national grids together into a more European grid and connect the European grid to the rest of the world…



Example: German politics

Markus Söder
Bavarian prime minister

Source: Idowa, Michele Tantussi /Reuters/Pool/dpa

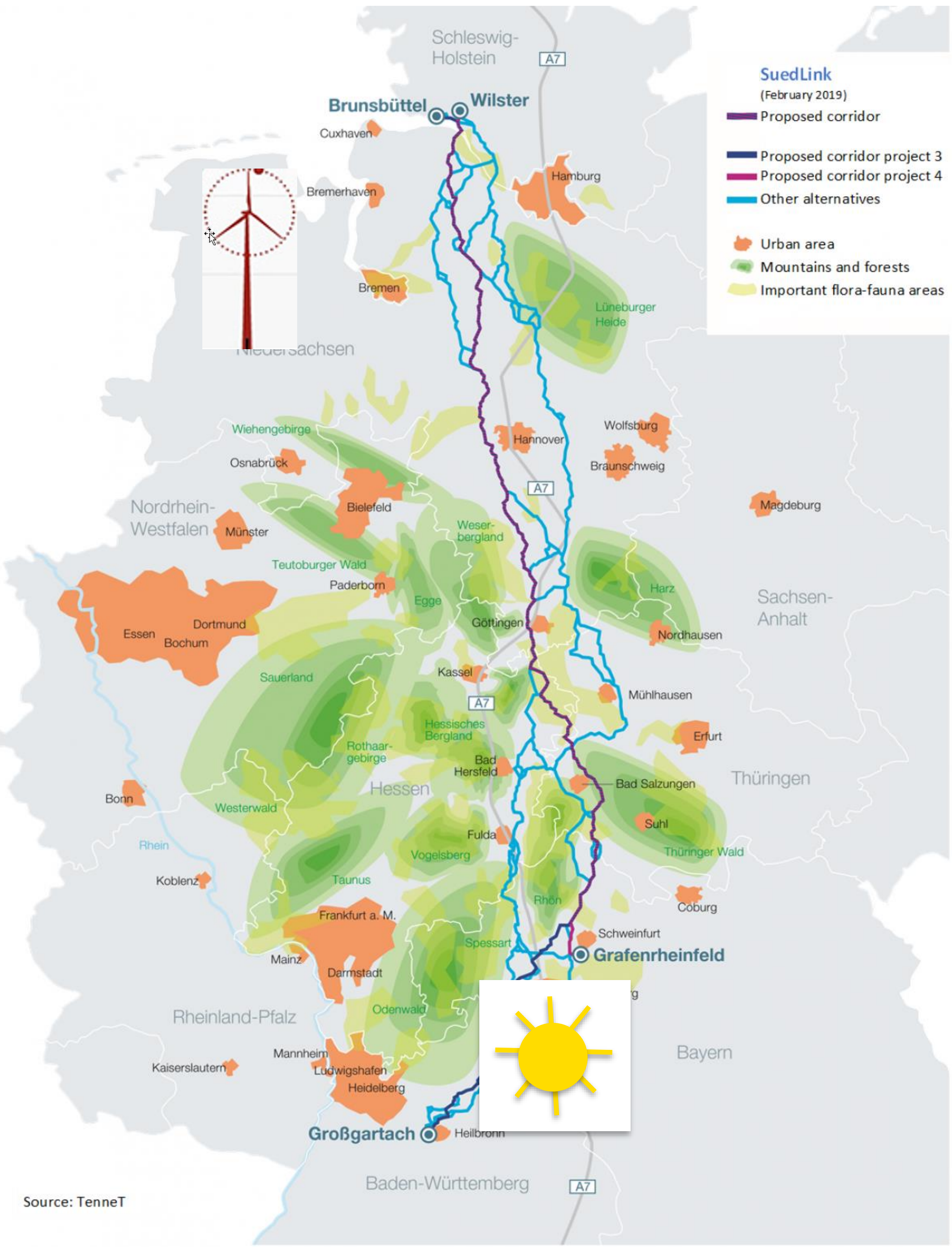
Source: the Guardian

Fraunhofer IWES

North South Transmission Line

“Now that the legislator has specified a general underground cable priority for direct current projects, the SuedLink power line is currently being re-planned. For this purpose it is necessary that the statutory requirements are specified as a planning method by the Federal Network Agency as the responsible authority. We will be working out new power line corridors and presenting them to the public on this basis.”

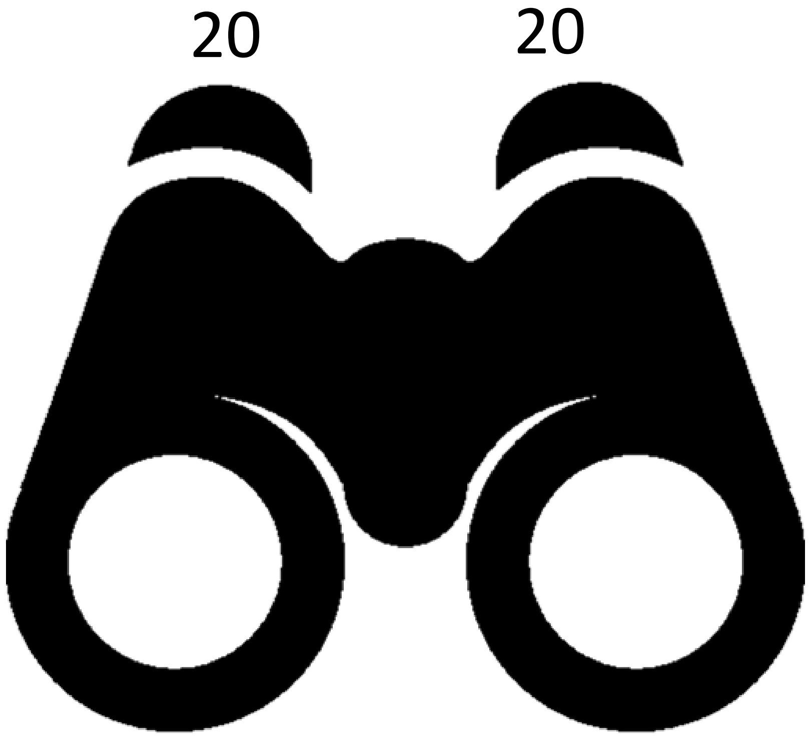
Source: TenneT



2050: Strategy

Clean slate: how about looking at it from the other side?
Welcome to 2050!

- Clean slate: we have 100% CO_2 free energy
- What does a grid that can handle the 18 TW electricity, couples major population centers across the world look like?
- Which technologies, standards, regulations do we use?
- How did we get there – what is necessary and in which order?



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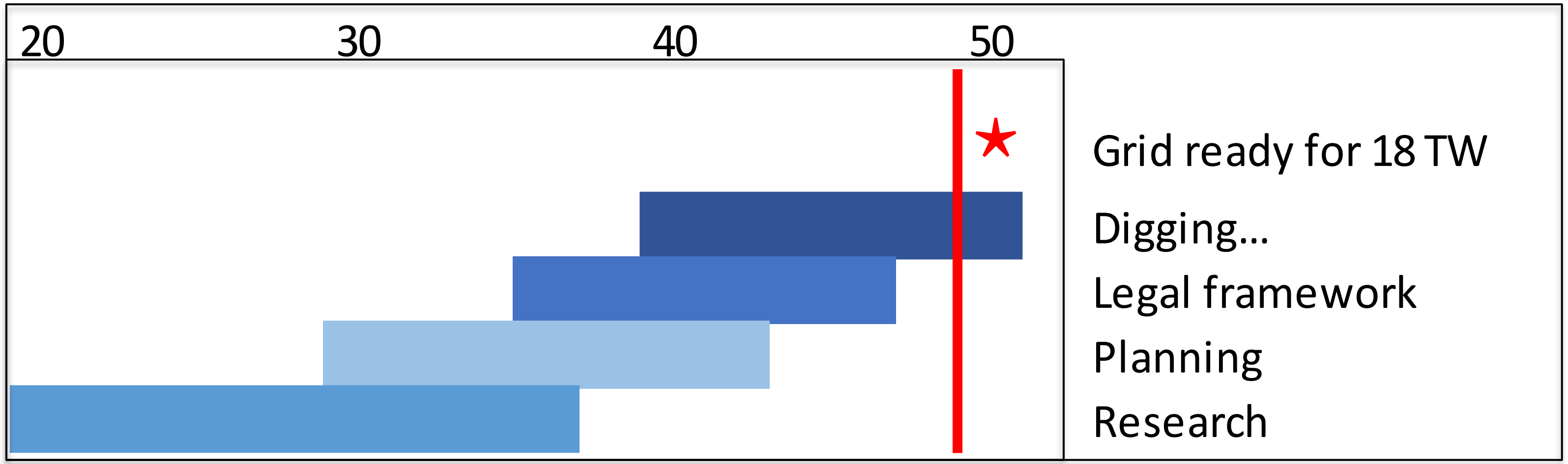
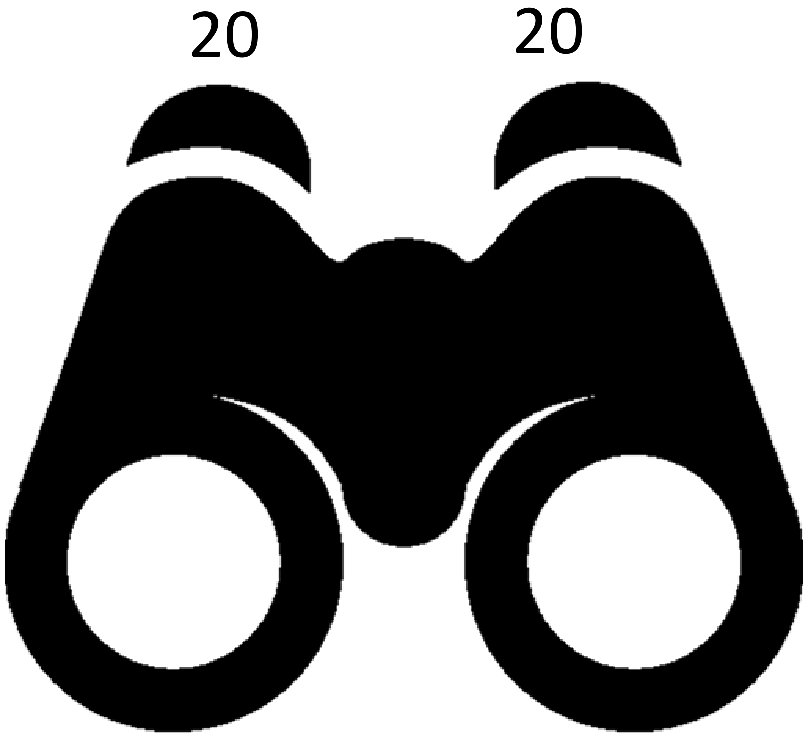
2050: Strategy

Timeframe: the reversed Gantt chart





Cost development

- Materials may run out … or more likely experience major rises => € ↑
- OTOH: technologies which enable automated production => € ↓

Supranational grids

Stringing the continents together…

Electricity from $20bn farm on 10,000 sq km property in Newcastle Waters also planned to feed Northern Territory's power grid

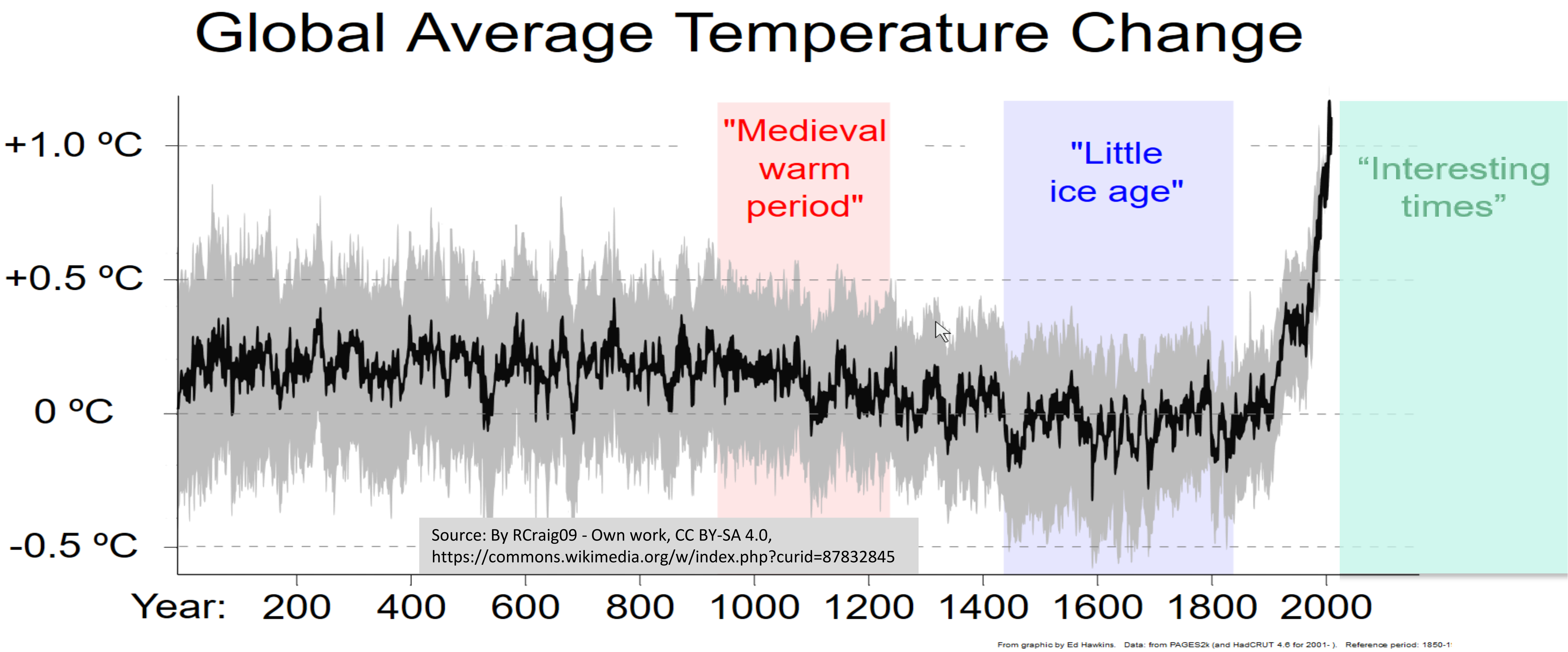
▲ Solar farm panels. A $20bn solar farm, to be the world's biggest, is planned for Newcastle Waters in the Northern Territory and has the backing of billionaires including Andrew 'Twiggy' Forrest and Mike Cannon-Brookes. Photograph: Lisa Maree Williams/Getty Images

Source: the Guardian

Fraunhofer IWES

Currently global temperatures have risen by 1°C

But heh, what is 1°C amongst friends? …well… Let’s look at the last 2000 years



Conclusions

1) It is suggested to consider the needs for a global 2050 grid capable of handling the challenges of a CO_2 free energy system.
2) The main barrier towards creating a grid capable of handling the 2050 challenges is often a lack of political will to think more than 2 elections ahead.
3) In order to be successful a wide ranging grid is necessary, capable of transferring vast loads between countries and even continents.
4) In order to achieve this in a timely manner, a reversed Gantt chart is a useful tool, also to make politicians clear that just talking about 2050 does not absolve them from implementing the first steps today, as it can be shown that time is already running out to achieve our goals. Waiting for action in 2049 is not going to work…

Fraunhofer IWES

Thanks a lot for your attention!

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- Senator of Economy, Labor and Ports
- Senator of Science, Health and Consumer Protection
- Bremerhavener Gesellschaft für Investitionsförderung und Stadtentwicklung mbH

Federal State of Lower Saxony

Free and Hanseatic City of Hamburg

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Market Innovation Manager Power Grids Division
Hitachi ABB

T&D europe

The European Association of the Electricity Transmission and Distribution Equipment and Services Industry

CurrENT webinar “Accelerating the energy transition” – 2020-12-08

The role of DC grids in the energy transition

Jochen Kreusel

Deputy President, Chairman of TF Large Power Systems

EUROPE'S GRID TECHNOLOGY PROVIDERS

T&D europe

- T&D Europe's members enable the **energy transition** to a **climate-neutral Europe** by 2050.
- Over 200,000 people in our industry manufacture, innovate and supply smart systems for the efficient **transmission and distribution of electricity**.
- Our technologies and services **future-proof** the grid and make **clean electricity** accessible to all Europeans.
- We put our collective expertise to work to craft **a brighter, electric future**.
- **Ready for the Green Deal**
- www.tdeurope.eu

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AFBEL AGORIA ANIE FEDERAZIONE CONFINDUSTRIA

ANIMEE beama EMSAD fedet sectie T&D

FEEI FACHVERBAND DER ELEKTRO- UND ELEKTRONIKINDUSTRIE GIMELEC Norsk Industri Federation of Norwegian Industries

SWISSMEM ZVEI: Die Elektroindustrie

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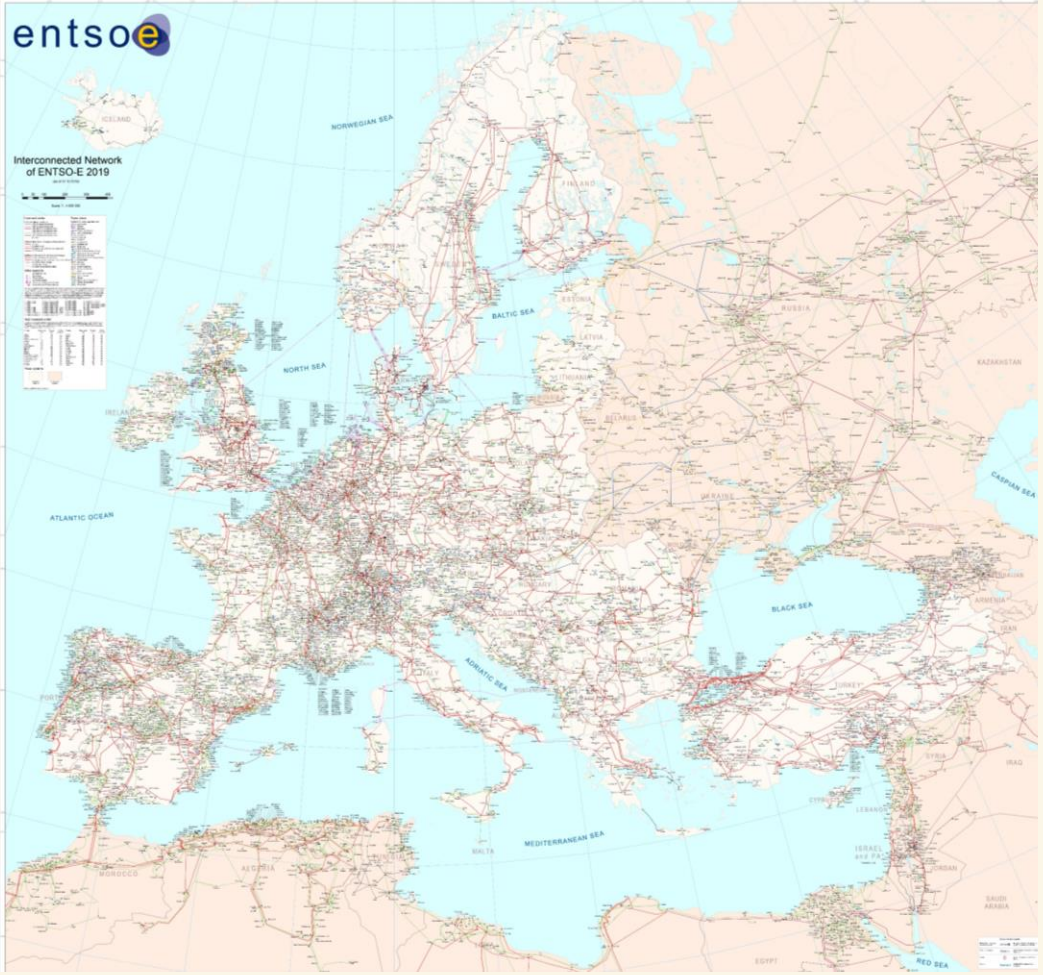
3M INVENTEC PERFORMANCE CHEMICALS SOLVAY WIKA

STRENGTHS AND LIMITATIONS OF AC NETWORKS

T&D europe



Source: ENTSO-E

Advantages

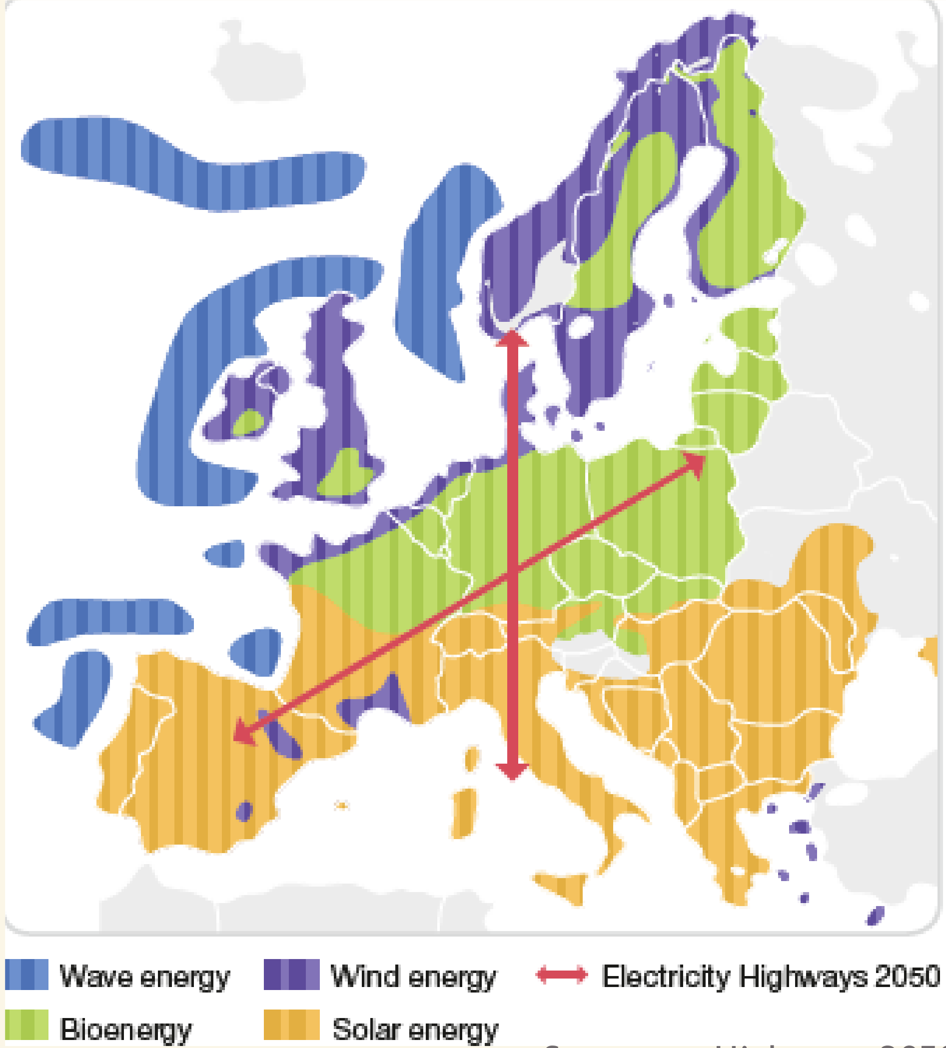
- Voltage transformation
- Current interruption
- Easy conversion into mechanical energy and vice versa
- Frequency as system-wide signal
- Meshed networks

Limitations

- Long distance transmission
- No long cables with high voltages

A very good fit for interconnecting regionally balanced sub-systems.

INCREASING RELEVANCE OF HVDC IN EUROPE



Source: e-Highways 2050

Geographical reasons

- RES are geographically constrained
- Local concentration of generation
- Even highly distributed resources may feed in locally concentrated peaks
- Need for long-distance transmission
- Offshore installations require cables

Operational reasons

- Much stronger variation of load-flow situations due to low utilization of RES
- Active network control beneficial

HVDC is the solution addressing the new challenges.

NEW CHALLENGES REQUIRE A NEW HVDC APPROACH

T&D europe

Traditional HVDC approach

- Few point-to-point projects
- Limited / no operational interference
- Complete lines (at least both converters) usually built by one technology provider
- No need of cooperation or coordination between technology providers

Hybrid AC/DC transmission networks

- Converters become either nodes in a network or are interfering because of proximity in an AC network
- Entire HVDC network will not be ordered in one go
- Systems need to be expandable by others than the original manufacturer
- Network operators need to be enabled to analyse interaction of HVDC elements in their simulation tools

RECENT ACHIEVEMENTS AND NEXT STEPS

Recent achievements

Best Paths (FP7, 2014-2018)

- Simulation of VSC HVDC multi-terminal systems
- Recommendations for development

PROMOTioN (H2020, 2016-2020)

- Agreeing on requirements for meshed offshore HVDC grids
- Development towards DC protection and breakers

What needs to done next?

- Converters also need to be described by standards, network codes and standardized models
(work in progress, CENELEC TC 8X/WG 06, ENTSO-E with T&D Europe)
- We need to get practical experience in a real-life environment – next step should be a multi-vendor, multi-terminal project in Europe

A lot of solid groundwork has been done in the past – it’s to go live now.

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www.tdeurope.eu

@BetterGrids

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DNV GL

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ENERGY

Hybrid & Meshed DC Grids

State of the Art | Challenges

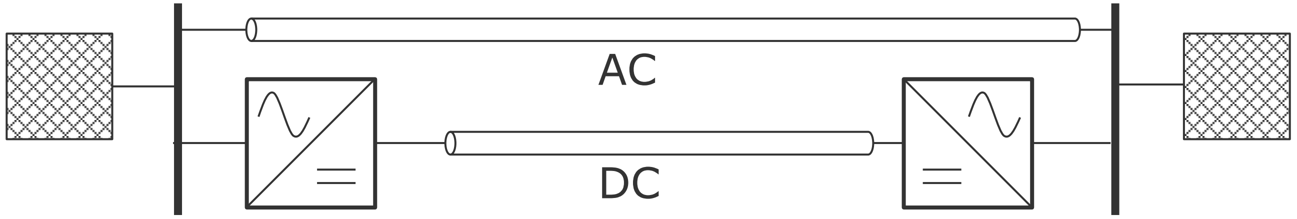
Dr. Cornelis A. Plet

08 December 2020

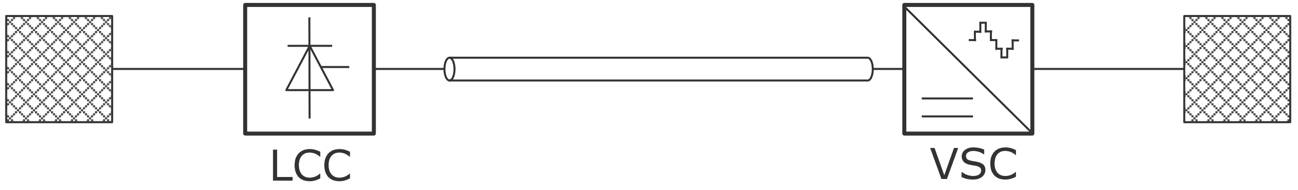
What does hybrid mean in the context of DC grids?

What are hybrid systems?

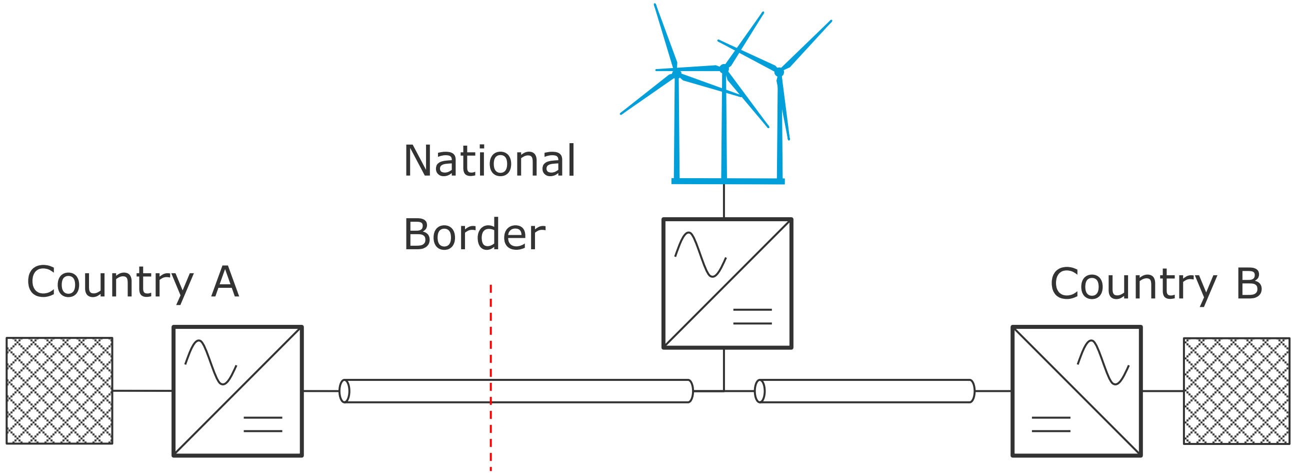
- Hybrid transmission system: Combine different transmission technologies
  – E.g. AC & DC



- Hybrid DC system: Combine different converter technologies
  – E.g. LCC & VSC

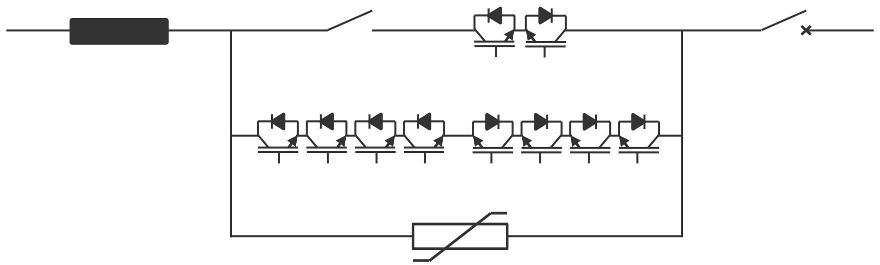


- Hybrid interconnector: Combine different transmission purposes
  – E.g. interconnection & offshore wind export

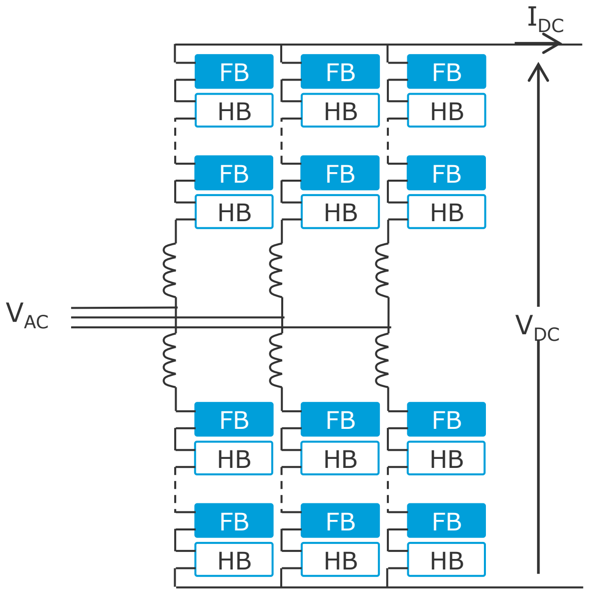


What are hybrid components?

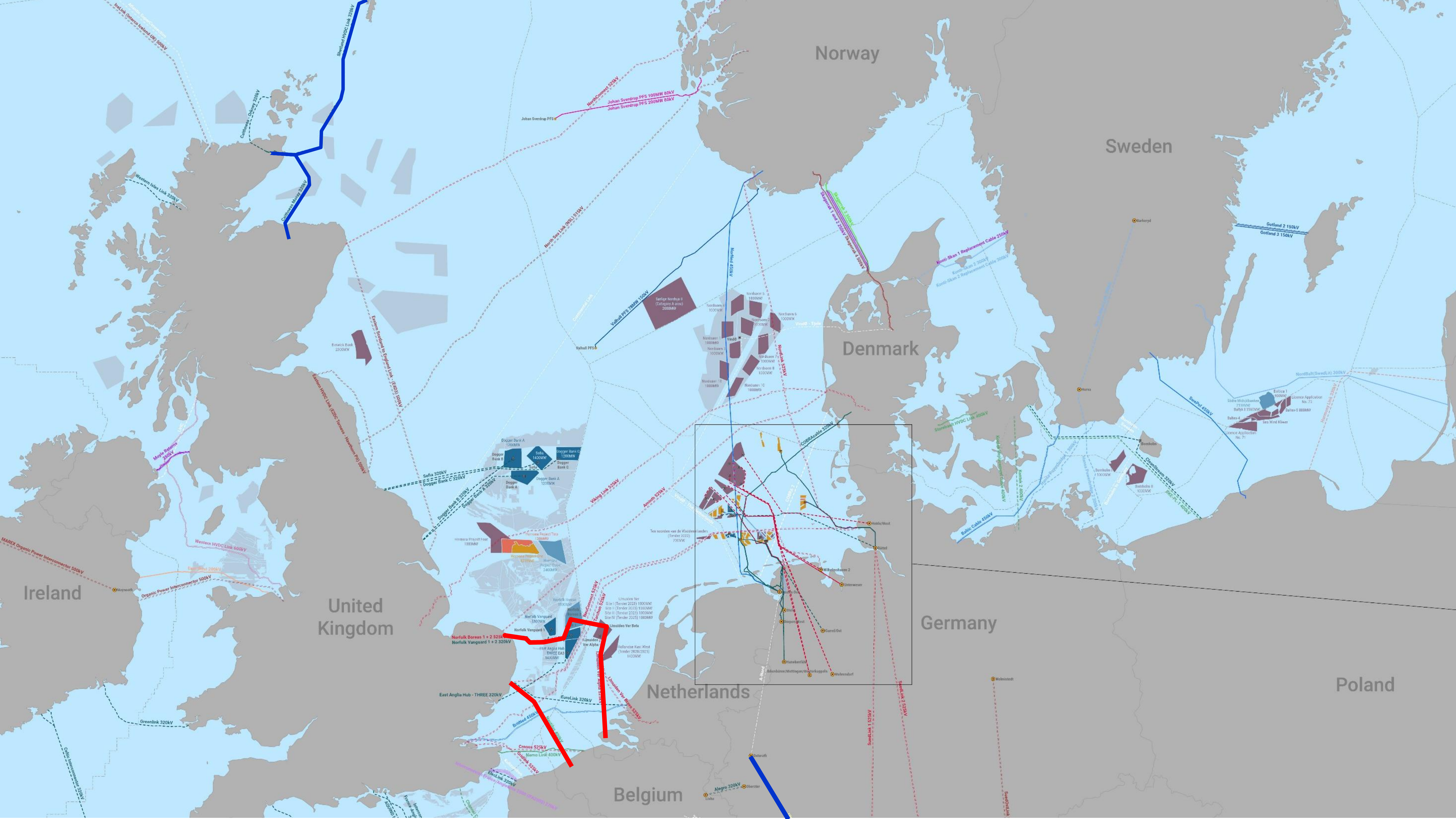
- Hybrid HVDC circuit breaker: Combine different switching technologies
  - E.g. Mechanical & power electronic switches



- Hybrid MMC-VSC converter: Combine different submodule topologies
  - E.g. Mixed half bridge & full bridge submodules

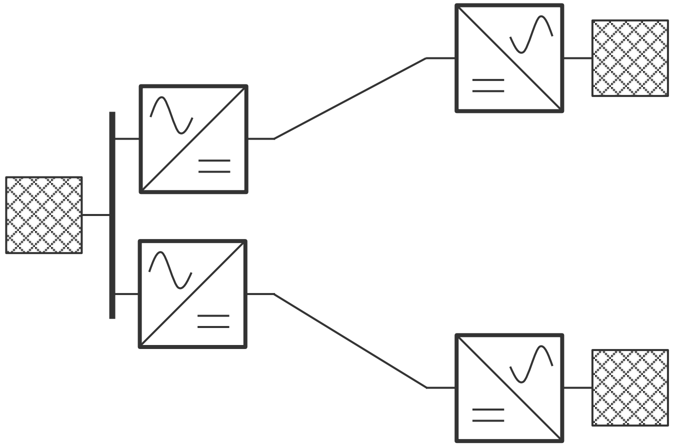


What are meshed DC grids and what can they do for us?



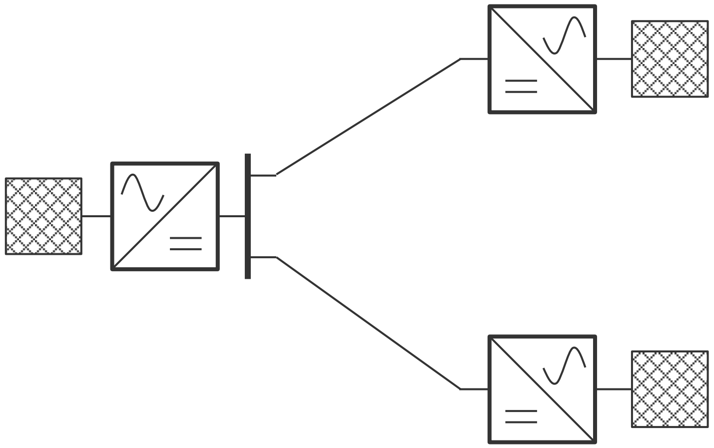
Norway
Sweden
Denmark
Ireland
United Kingdom
Netherlands
Germany
Belgium
Poland
Norfolk Boreas 1 + 2 525kV
Norfolk Vanguard 1 + 2 320kV
East Anglia Hub - THREE 320kV
EuroLink 320kV
Greenlink 320kV
Nemo Link 400kV
Cronos 525kV
Alegro 320kV
Gotland 2 150kV
Gotland 3 150kV
Western Isles Link 320kV

Multi-terminal & meshed DC systems



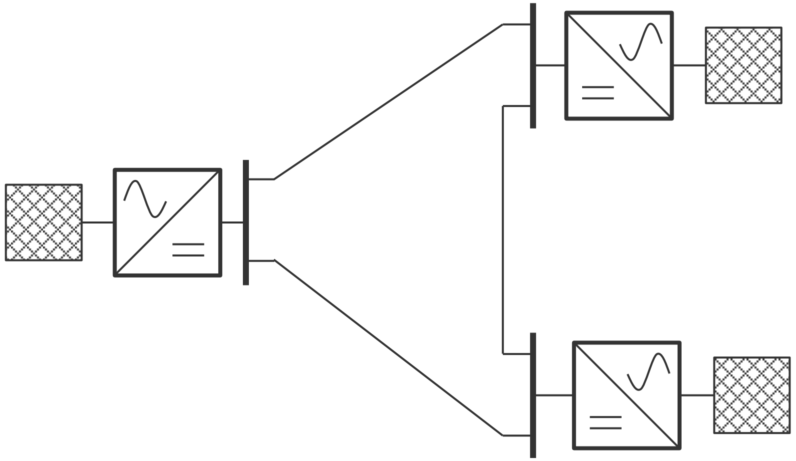
Point-point systems

- Easier project development
  - Single vendor procurement
  - Single purpose
- Mature and widely applied



Radial multi-terminal system

- Fewer converters
  - Lower cost
  - Lower footprint
  - Lower losses
- A few projects in operation



Meshed multi-terminal system

- Reduced impact on AC grids
- Requires DC protection system
- One full-scale demo project in commissioning

Two challenges

Number of cables

- Design grid to minimize amount of cable to minimise cost and environmental & societal impact
- EU offshore wind target in North Sea is 300 GW
- State-of-the-art HVDC cable (pair) rating is 2,6 GW
- Challenge to accommodate 100s of cable corridors, and associated onshore substation space
- Need higher capacity cables and smaller converters!

Source: NKT

Impact on AC grids

- In point-point and radial grids, cable size is limited to maximum loss of infeed
- Central Europe loss of infeed is 3 GW, lower elsewhere in Europe
- Maximum cable size is approaching loss of infeed limits
- Meshed grids could alleviate this, but require strong international coordination

Source: New York Post

PROMOTioN conclusions

- **Technology ready** for multi-terminal HVDC grid development
- Further **standardisation** work needed on multi-vendor HVDC grid integration
  - Functional compatibility
  - Procurement & contractual compatibility
  - Multi-vendor interoperability
- International **collaboration & coordination** key to establish:
  - Regulatory & legal compatibility
  - Project & planning compatibility
  - Topological compatibility

  } Political agreement
- **Full-scale pilot project** best to demonstrate feasibility and realize benefits

- For more information visit: www.promotion-offshore.net

Concluding remarks

- Many uses of the word ‘Hybrid’ in the context of DC grids, be careful!
- We already have a hybrid AC & DC transmission system
- Hybrid interconnector & offshore wind farm export links are in development
- They are building blocks offshore DC grids
- Technology is ready, but more international coordination, harmonisation and standardisation necessary
- Power density of cables and converters must be further increased to ease planning and permitting issues
  - Clearance distances due to high voltage air insulation in converters are main volumetric driver
  - Can super-conducting high current ‘low’ voltage technology provide respite?
- Maximum loss of infeed is main restriction on cable capacity, meshed grid topologies can overcome this

Thank you for your attention!

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SAFER, SMARTER, GREENER

Dr. Wolfgang Reiser

Managing Director, VESC and
President of ivSupra

Superconductor DC Grid Applications

CurrENT webinar Dec 8, 2020

Dr. Wolfgang Reiser

CEO of Vision Electric Super Conductors GmbH → www.vesc-superbar.de

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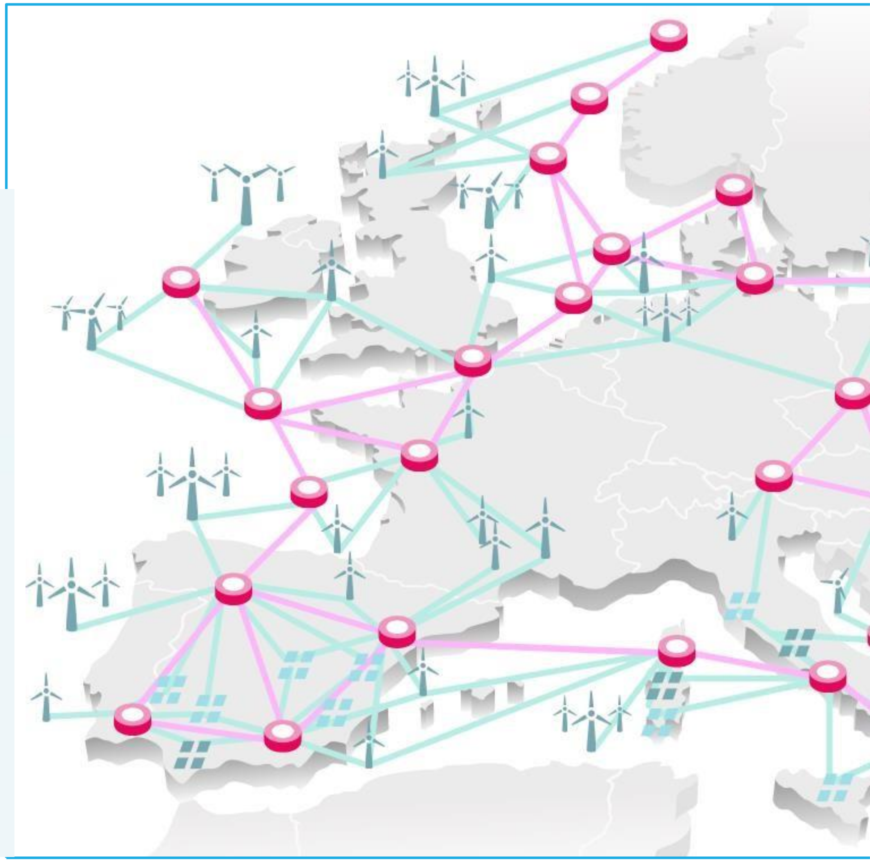
ADVANCING SUPERCONDUCTING LINKS FOR VERY HIGH POWER TRANSMISSION

POLICY RECOMMENDATIONS

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. **The partners of the demonstration project are now calling on European policymakers to financially incentivise the deployment of this technology in the electricity grid.**

In the long term, superconducting links are expected to transport large amounts of electricity over long distances. In the short term, the most suitable applications are areas where civil work is expensive, but also urban areas where space is limited. Here, a short superconducting cable could serve as a 'bridge' connected to resistive cables or overhead lines. **The partners of the demonstration project recommend the consideration of superconducting links in feasibility studies and public tenders for new transmission projects.**

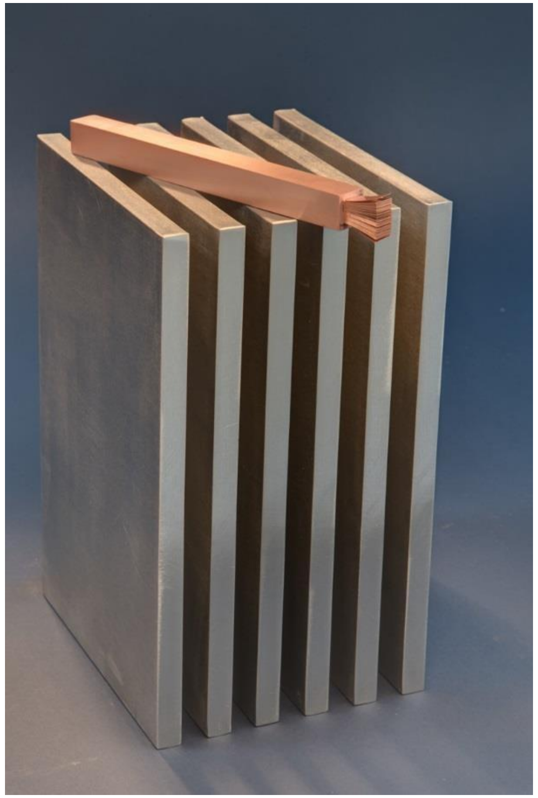
www.supernode.energy

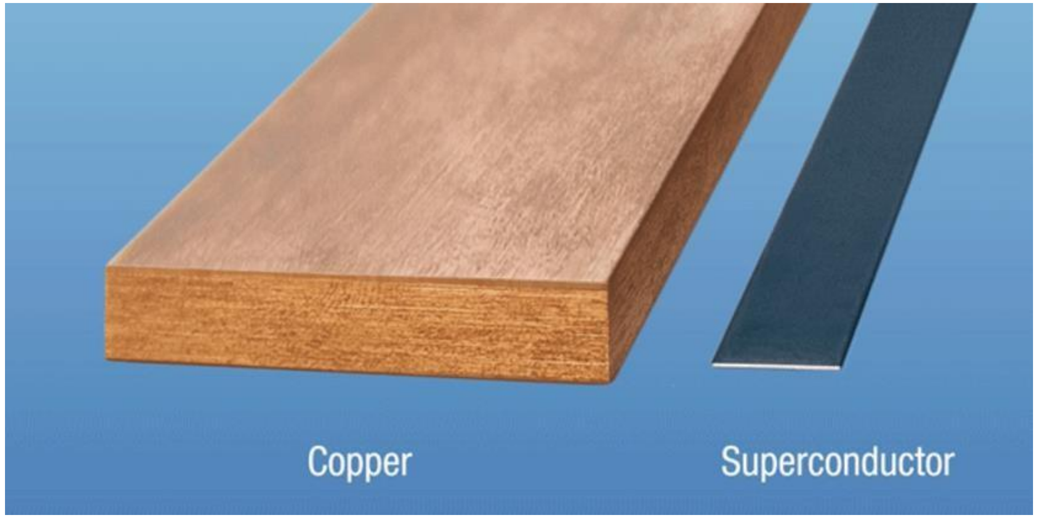


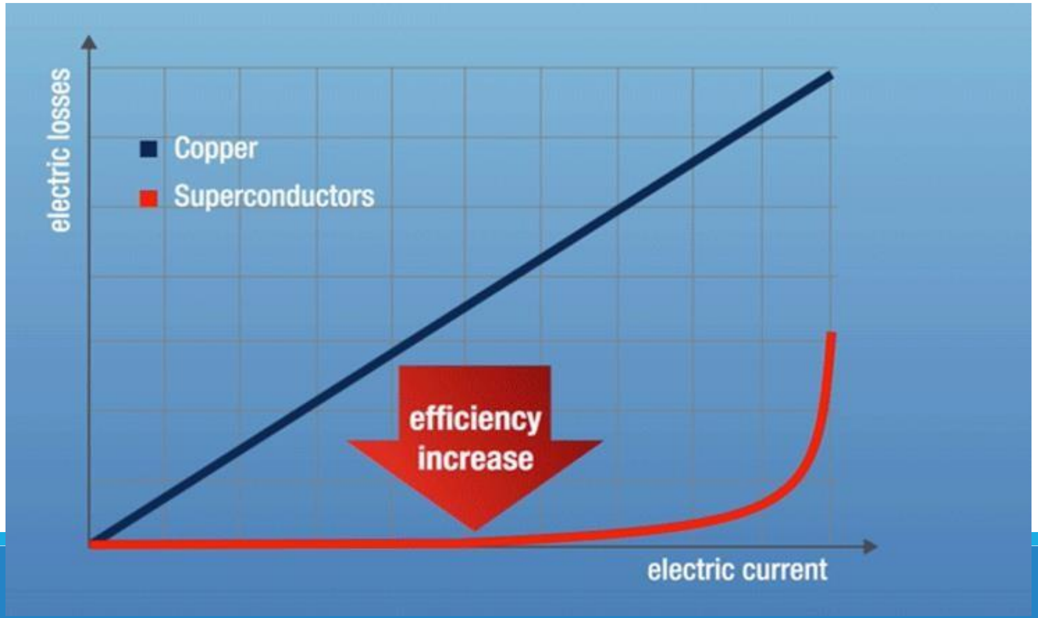
Superconductor Cable / Busbar Systems

- Very high DC currents
- Ultra compact
- Zero losses
- Highest material efficiency
- Zero thermal emissions
- Low OPEX
- Low electro-magnetic fields
- Environmental friendly
- Sustainable, etc.

- Relative high CAPEX
- ROI: 1 – 12 years





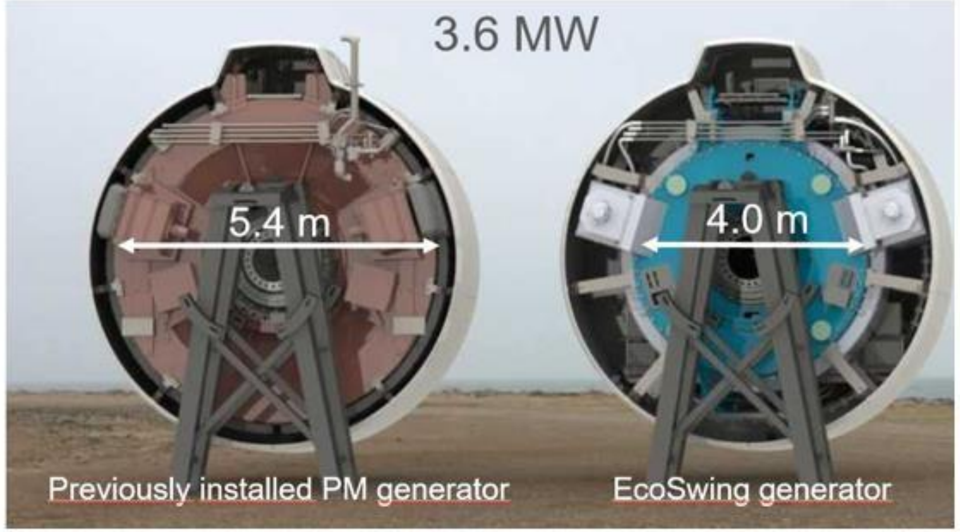


Projekt EcoSwing II, EU Horizon 2020

- Windgenerator project ecoswing
- 3.6 MW direct drive generator

15 rpm, 128 m rotor

PM generator exchanged 2018



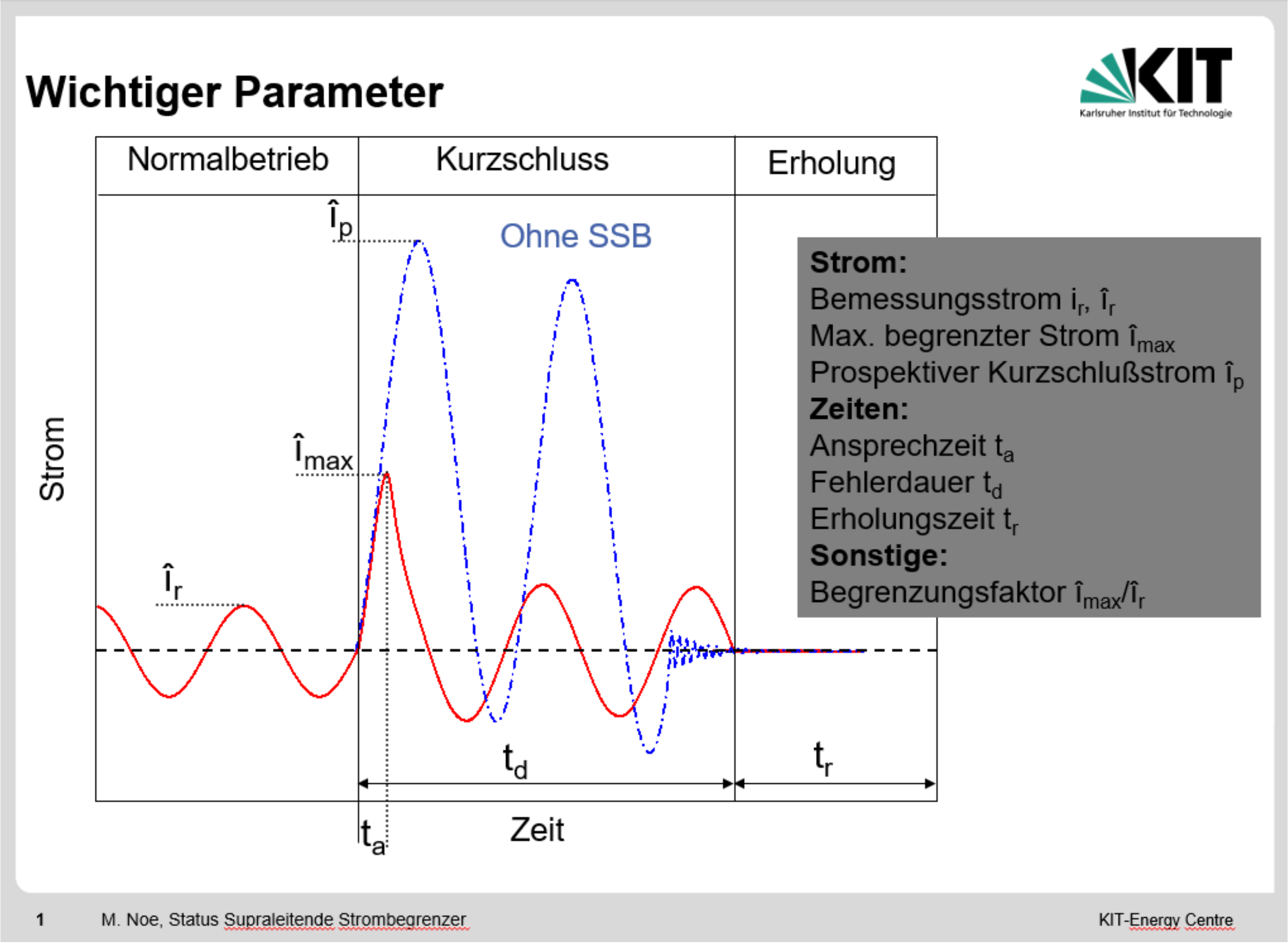
Diameter PM → SC
100% → 75%

Mass PM → SC
100% → <65%

Horizon 2020
European Union Funding
for Research & Innovation

"EcoSwing has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 656024." "Herein we reflect only the author's view. The Commission is not responsible for any use that may be made of the information it contains."

Superconducting Fault Current Limiter



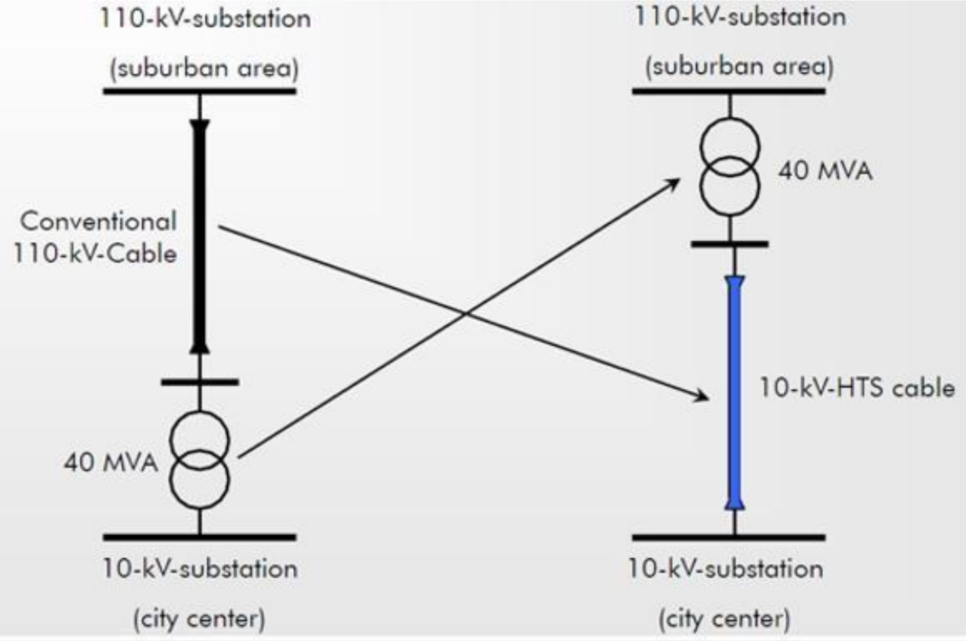
Reduction of short circuit currents in AC and DC grids

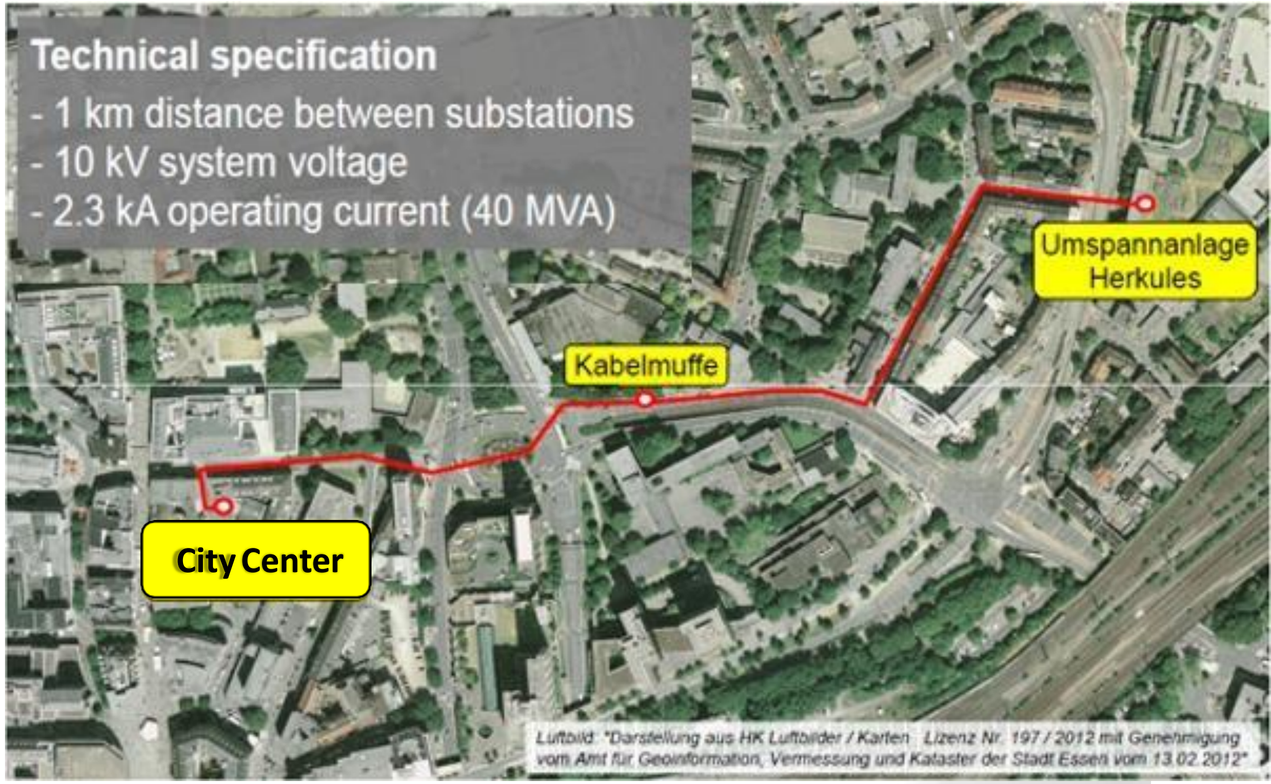
- Technical Advantages
  - Fast current limiting at first rise
  - Almost zero impedance under normal operation
  - Automatic reuse disposition
- Reduction of investment at power upgrate of grids and short circuit fault level
- Reduction of operating costs

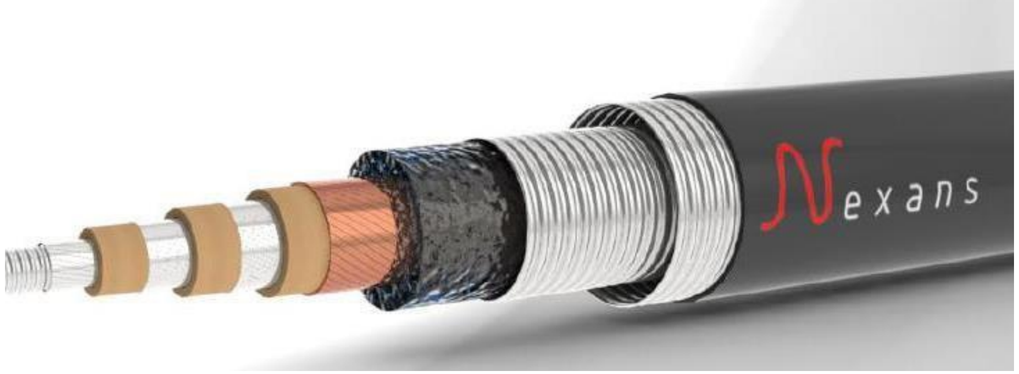
Super Conductors in Grids

Ampacity, Essen

- ✓ Integrated S-FCL
- ✓ Continous Operation since 2013
- ✓ Substitute of 110 kV cable to the city center pedestrian zone
- ✓ Reduction of 110 kV transformer station

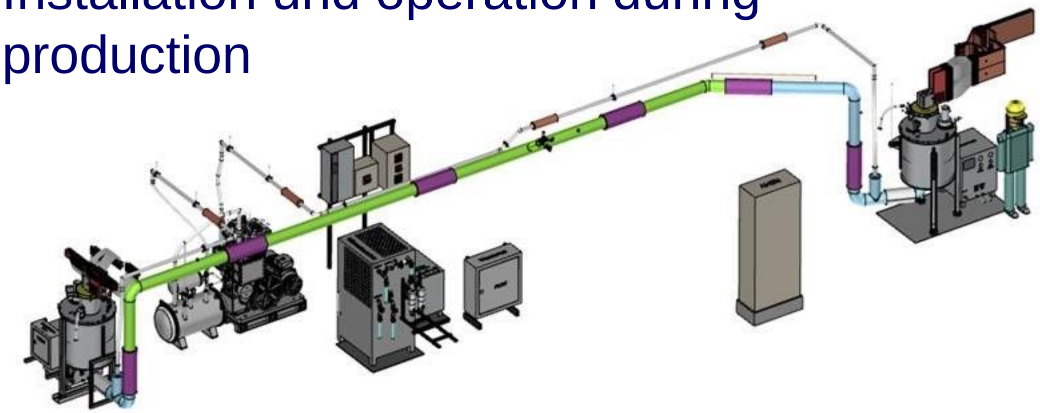






Project 3S, BASF Ludwigshafen

Industry qualification for 20 kA DC:
Installation und operation during production



20 kA → 200 kA

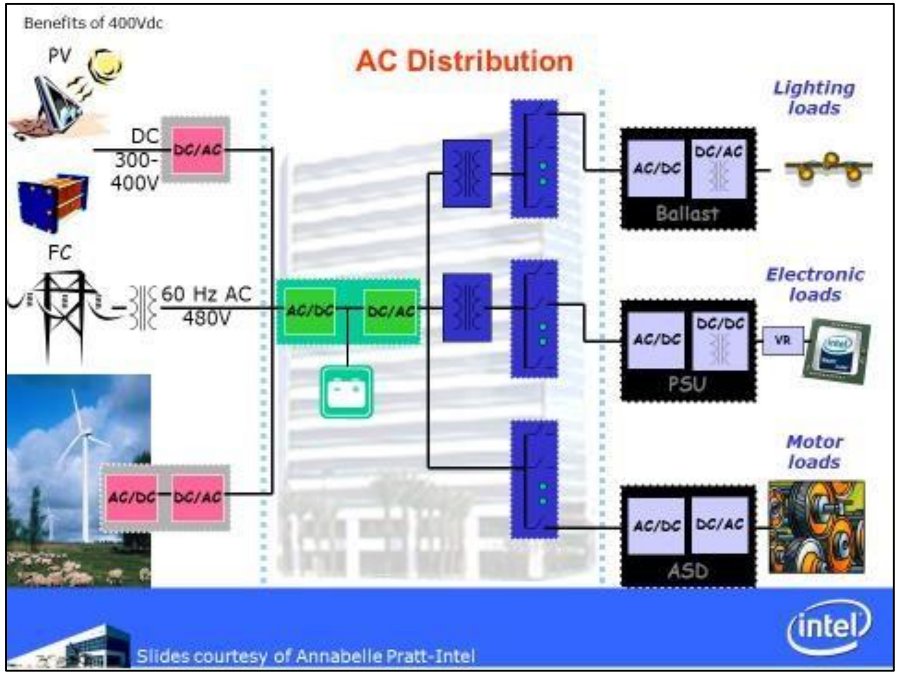
Project DEMO200, Trimet

Installation of a 200 kA demonstrator in 2021 → www.demo200.de

Next step: Operation at aluminium smelter

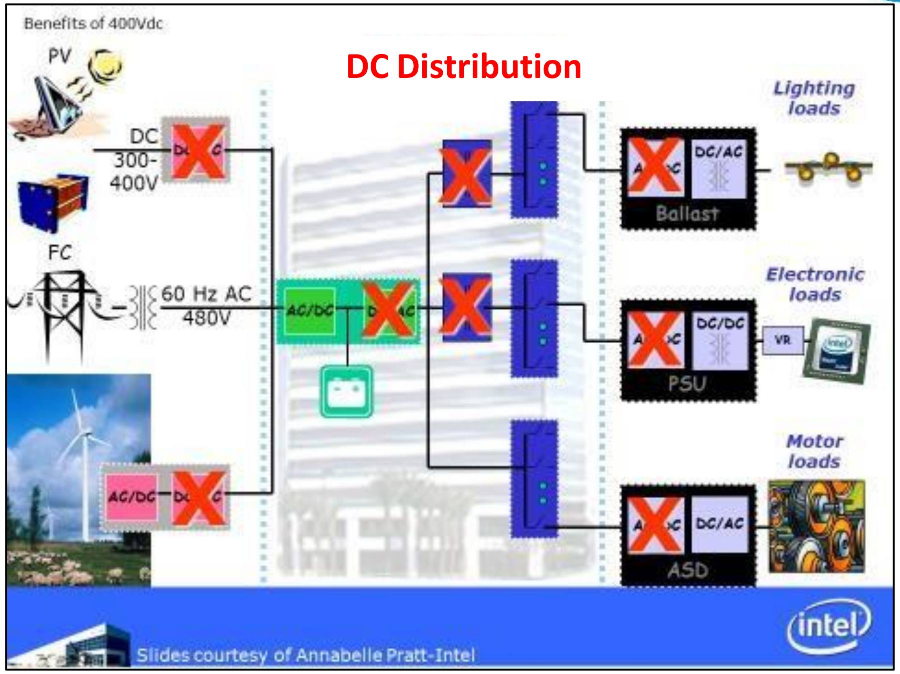
DC Datacenters – Superconductors are the Missing Link

VISION® ELECTRIC Super Conductors



Technology driver

- **Carbon Footprint Reduction**
- **Energy Efficiency**
- **On-site Energy Generation**

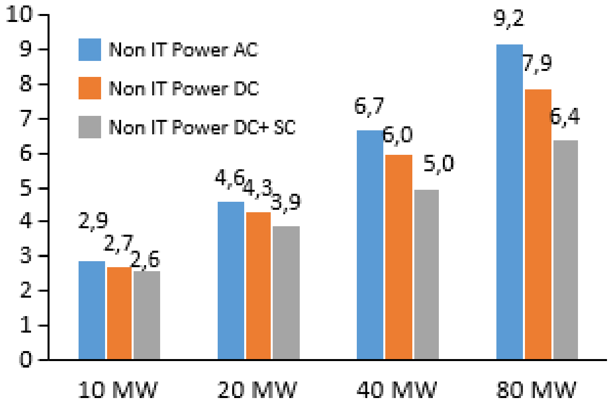


- The Graphic above demonstrates simplification of DC vs. AC data center designs. Reduction of conversions leads to simplified data center designs resulting in CAPEX as well as OPEX reduction
- Besides all advantages of DC based data centers against AC based technology a key issue remains, reducing the benefits of DC technology
- Concepts so far considering power transmission based on **conventional aluminum or copper busbar** systems resulting in significant power losses and compensatory power generation, **eating up the advantages of DC based solutions**
- **Near loss free power transmission based on superconductor technology is the missing link to fully capture the advantage of DC technology in data center environments**

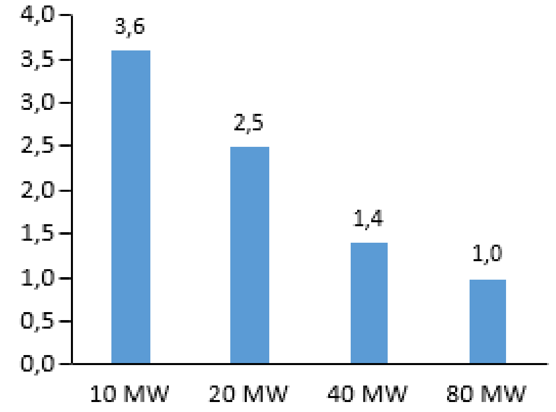
Superconductors enable DC-Datacenters

VISION® ELECTRIC Super Conductors

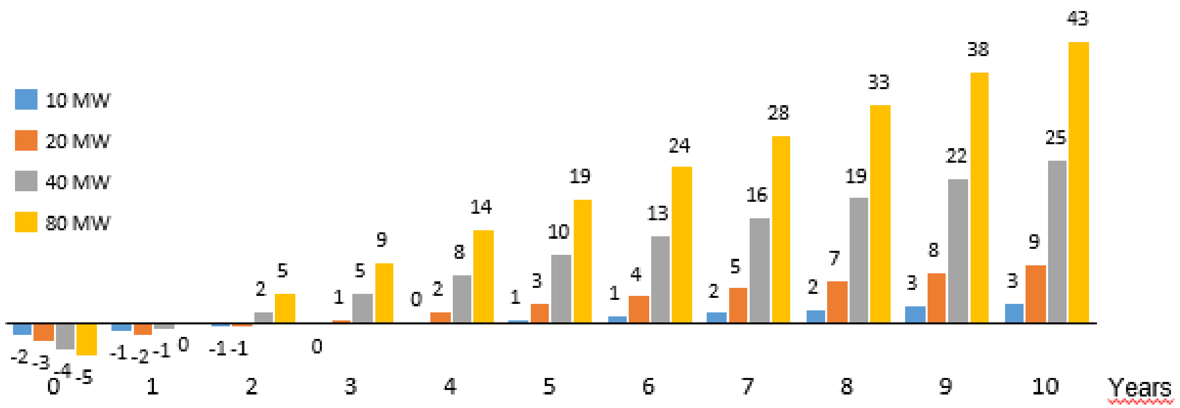
Non-IT Power Usage in MW



DC+SC payback period in years



Cummulative net savings of DC+SC against AC Data Center in Mio. €



Analysis performed on ROM* cost based estimates

- Total DC-Power above 10 MW ➔ Hyperscale Datacenters
- Lower total Power Losses
- Reduced Air Condition → Lower CAPEX & OPEX for Air Cond.
- Reduction of Carbon Footprint
- Zero Fireload
- Minimum or Zero electromagnetic fields
- Simplified Structure → reuse of superconductor elements → conserve investment at usage changes
- Huge Reduction of Space Requirement
- Easy integration of renewables (e.g. PV-Power) and storage systems (e.g. batteries, LH2 + Fuel cells)

*Rough Order of Magnitude

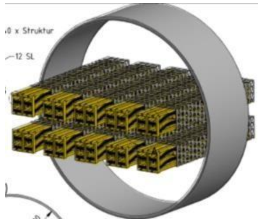
Superconductor Systems offer significant advantages

VESC busbar systems support hyperscaler design and requirements…

- Smallest Conductor and System Dimensions - Minimum space required (e.g. for microgrids)
  - lower building volume - lower civil costs
  - less underground work – smaller cable trench, lower construction costs
  - small weights – easy to ship, store and handle on site – low erection costs
  - minimum weight, reduced fixing loads – existing fixing structures can be used
- Modularity
  - Modular system design
  - Highest flexibility combining functional modules like angle, tap-off, etc.
  - Easy module exchange, re-design and additions in case of outside damage or data center expansion / re-design
  - Factory tested modules – reduce site risk, increase safety

Minimal space requirements…

Modular & standardized..



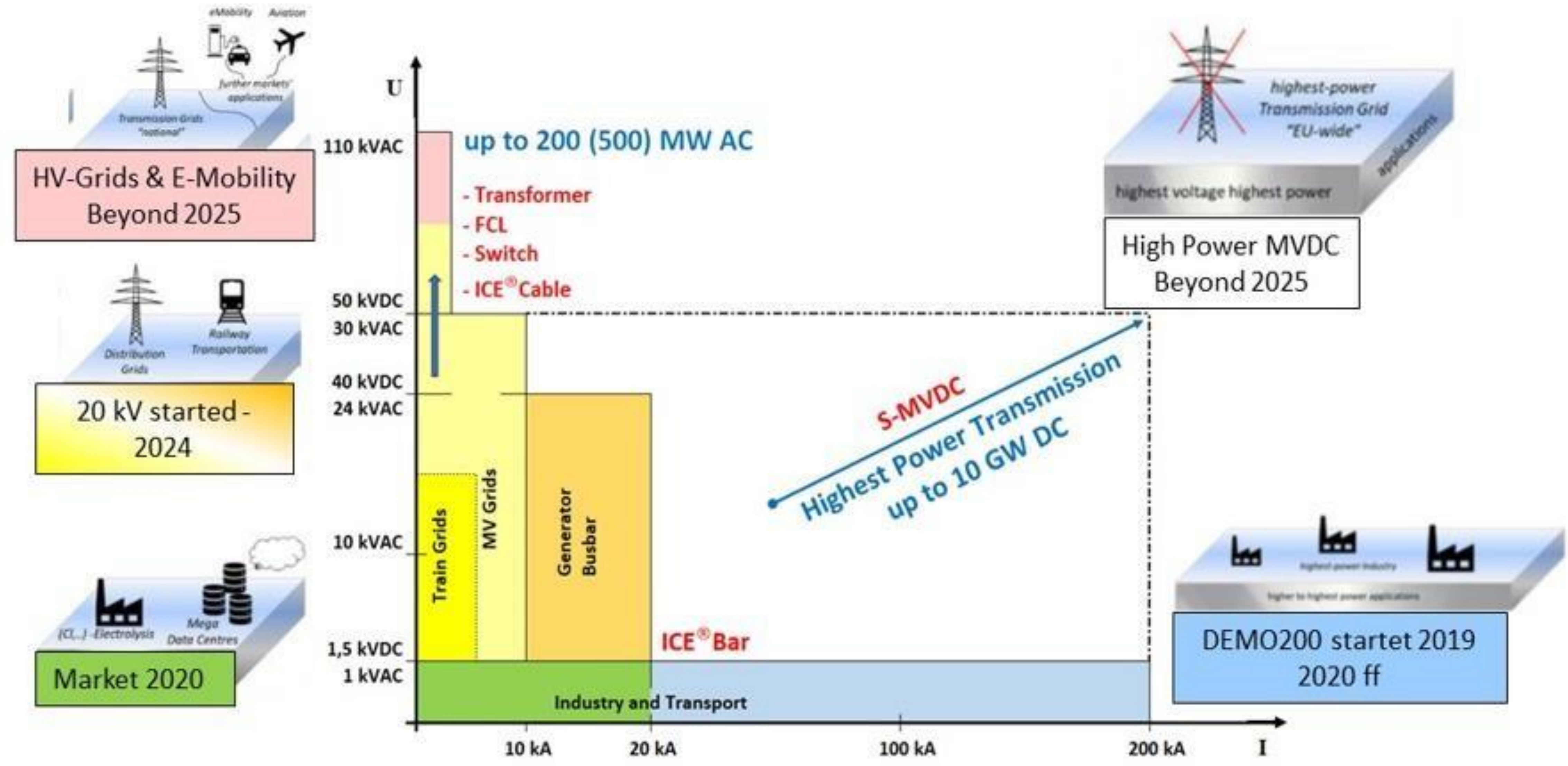
Easy and speedy installation

… as well as trends regarding energy and sustainability goals

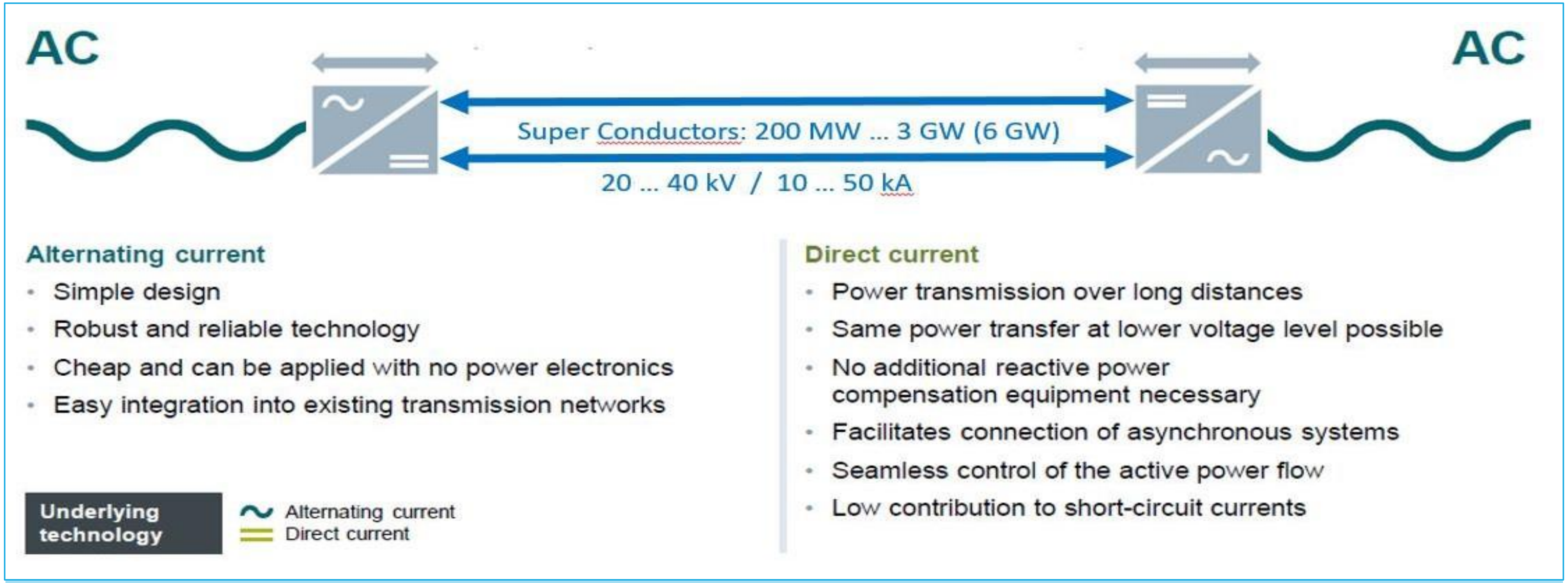
- Energy efficiency and carbon footprint reduction
  - Zero DC losses, zero voltage drop – reduced operating costs
  - Reduction of CO2 emissions comp. to copper and aluminum conductors
- Environment
  - No thermal emissions
  - Minimum to zero electromagnetic emissions
  - Zero fire load – cannot burn and cannot emit dangerous smoke
  - Easy separation of material and recycling after end of live
- Health
  - High protection degree IP 68 – highest class of human protection
  - Minimum electromagnetic fields – no electro smog
  - Intrinsically safe

Superconductors for High Power DC Grids

VISION® ELECTRIC
Super Conductors



Cable Trench Width: Copper > 20 m / SC < 2m → „Autobahn“ compared to „Field Path“

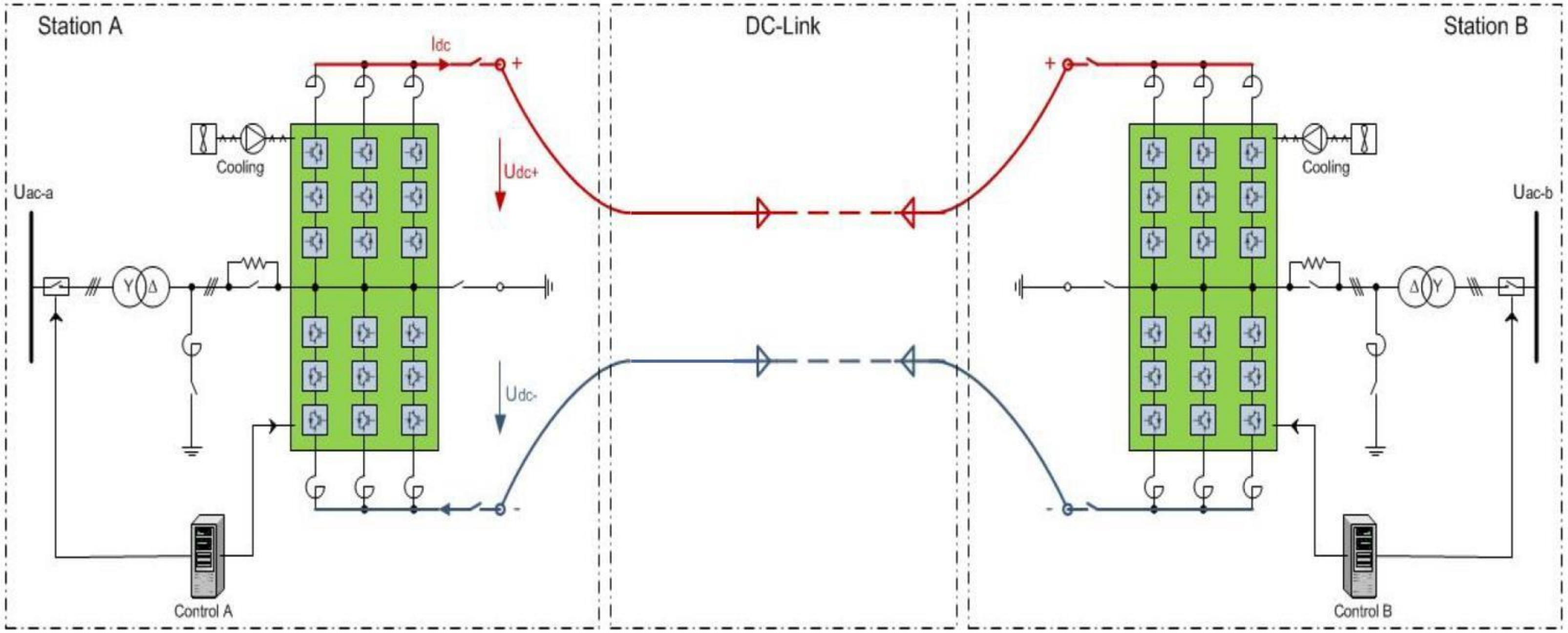


Superconductor ICE®Cable

zero voltage drop, zero losses, compact design, unlimited distance, smallest environmental impact, zero thermal emissions, zero electric field, very low or zero (on design) magnetic field, short approval period, reduced society resistance, invisible, short realisation time, etc.

S-MVDC = Superconducting Medium Voltage DC

VISION® ELECTRIC Super Conductors

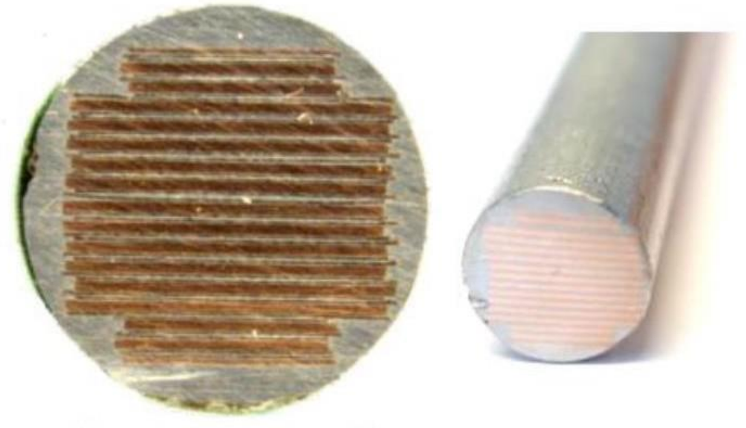


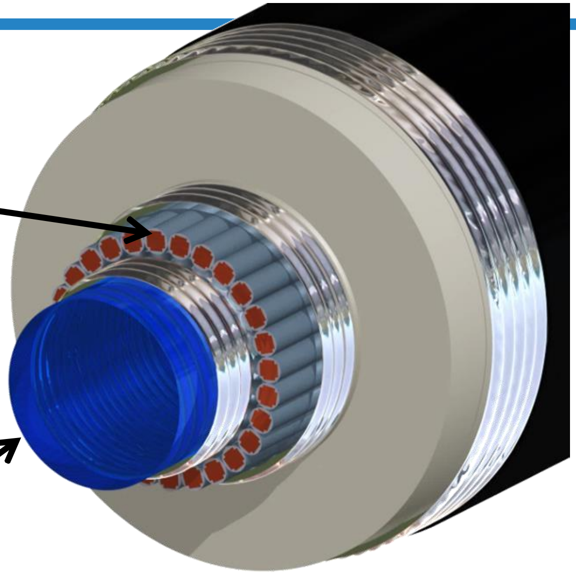
- Multilevel Voltage Sourced Converters
- Superconductor cable → large distances, zero losses
- Same Power as HVDC on MV
- Same or lower CAPEX & lower OPEX compared to cable systems

Power / Voltage	250 MW	500 MW	1 GW	2 GW	3 GW	5 GW
± 25 kV	5 kA	10 kA	20 kA	40 kA		

ICE®Cable

- Cross Conductor CroCo
- Multiple layers of HTS to form a round conductor
- High mechanical stability
- Developed by KIT
- Licensed to VESC on
  - Commercial production
  - Marketing & Sales





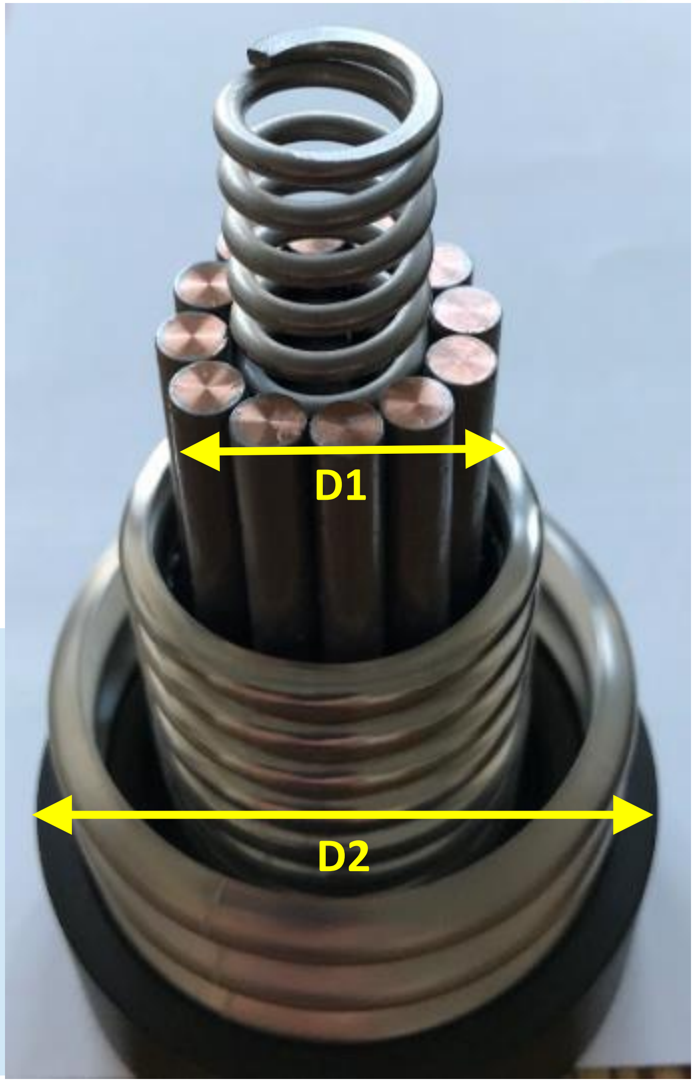
- ICE®Cable 40 kA @ 70K (LN2)

  eq. 100 kA @ 20K (LH2)

  12 CroCos around former

  D1 = 40 mm

  D2 = 100 mm



Suedlink – Comparison HVDC vs. S-MVDC

VISION® ELECTRIC Super Conductors

Capacity: 2 x 2 GW, 700 km Length

- Costs HVDC

  ±500 kV / 2 systems 2 kA

  - Converterstations: approx. 250 mio € / GW → 1.000 mio €
  - Copper cables incl. installation: → 7.000 – 9.000 mio €
  - Problems on rivers, railways, motor ways, etc.
  - **Total CAPEX: → 8.000 – 10.000 mio €**
  - **OPEX (power losses): → 6 – 8 %**
    4 GW in → 3,7 GW out

- Costs Superconductors

  ± 25 kV / 2 systems 40 kA

  - Converterstations: approx. 200 mio € / GW → 800 mio €
  - Superconductors: → 3.700 mio €
  - Cryotechnology: → 1.600 mio €
  - Engineering & Installation: → 2.900 mio €
  - **Total CAPEX: → 9.000 mio €**
  - **Opex (therm. Losses): → < 1 %**
    4 GW in → 4 GW out

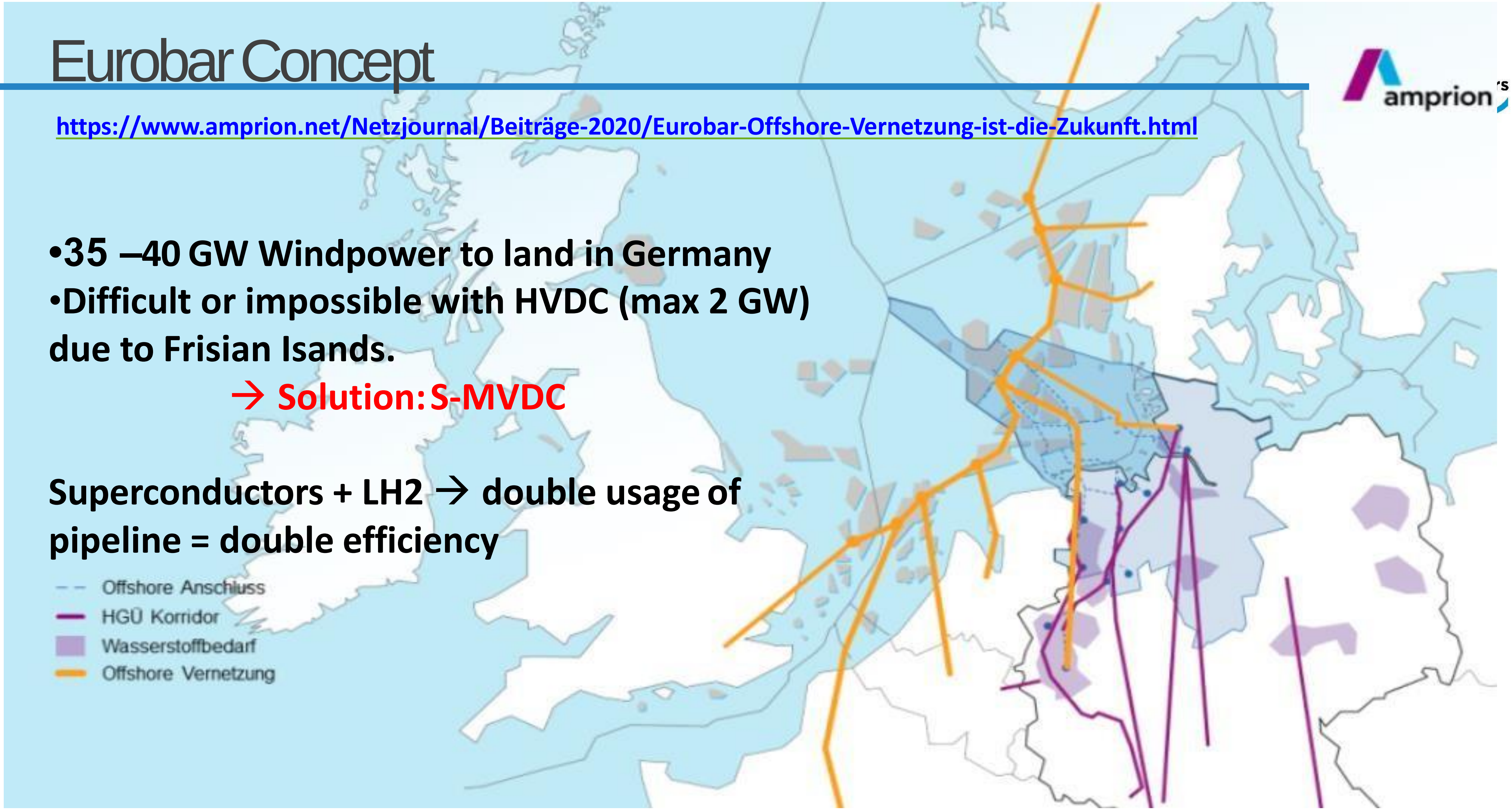
Eurobar Concept

https://www.amprion.net/Netzjournal/Beiträge-2020/Eurobar-Offshore-Vernetzung-ist-die-Zukunft.html

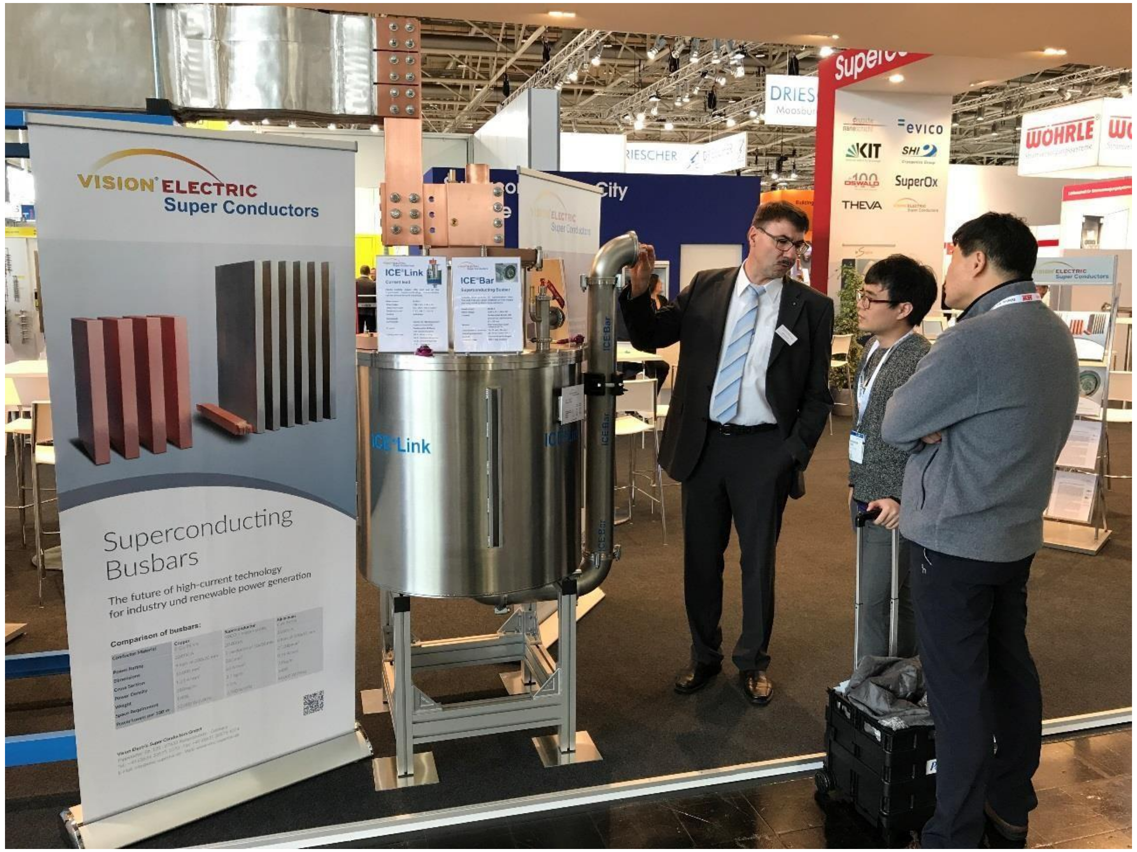
•35 –40 GW Windpower to land in Germany
•Difficult or impossible with HVDC (max 2 GW) due to Frisian Isands.

→ Solution: S-MVDC

Superconductors + LH2 → double usage of pipeline = double efficiency

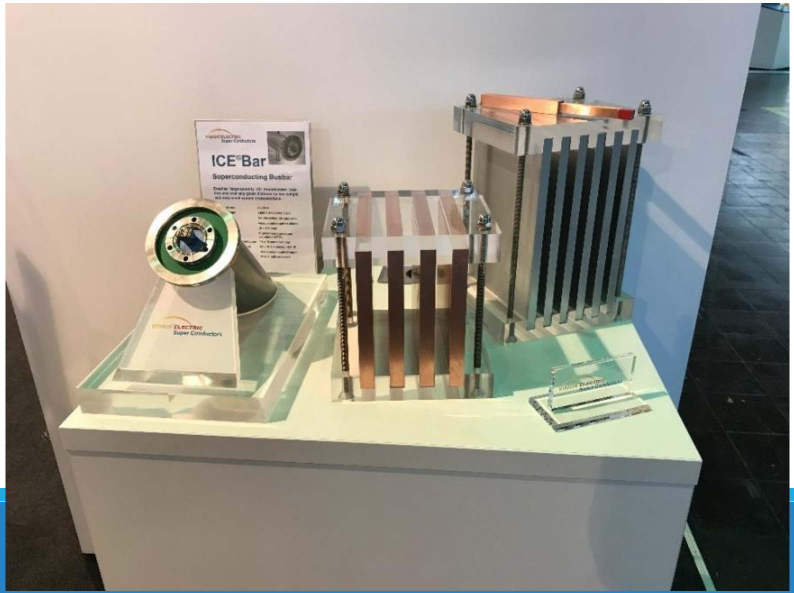


Thank you for your attention!



Wolfgang Reiser with Nobel prize winner Dr. Bednorz

Hanover exhibition



See Video: https://www.youtube.com/watch?v=sPZ8x7dCLvg

Dr. Wolfgang Reiser

Interessenverband Supraleitung e.V.

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c/o

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www.vesc-superbar.de

Prof. Dirk Van Hertem

Electrical Energy Systems and Applications (ELECTA)

University of Leuven

Where DC grids can take us in the future and how DC grids integrate with AC grids

Prof. Dirk Van Hertem
KU Leuven & EnergyVille

Where do we need to go?

We need to connect 200 GW from the north sea
➔ Assume 5 GW links

Ambitious goals

- +/- 22 GW of wind offshore installed to date
  - Expected increases up to ±100 GW by 2030, 200 GW in the North Sea by 2050, 450 GW in total
  - (EC: 300 GW)
- Connections are increasingly further from shore:
  - HVDC is only realistic option
  - Meshing is needed
  - Needs to be integrated in the existing system (hybrid AC/DC)
- + onshore
- Solar developments are equally fast:
  - South to north flows

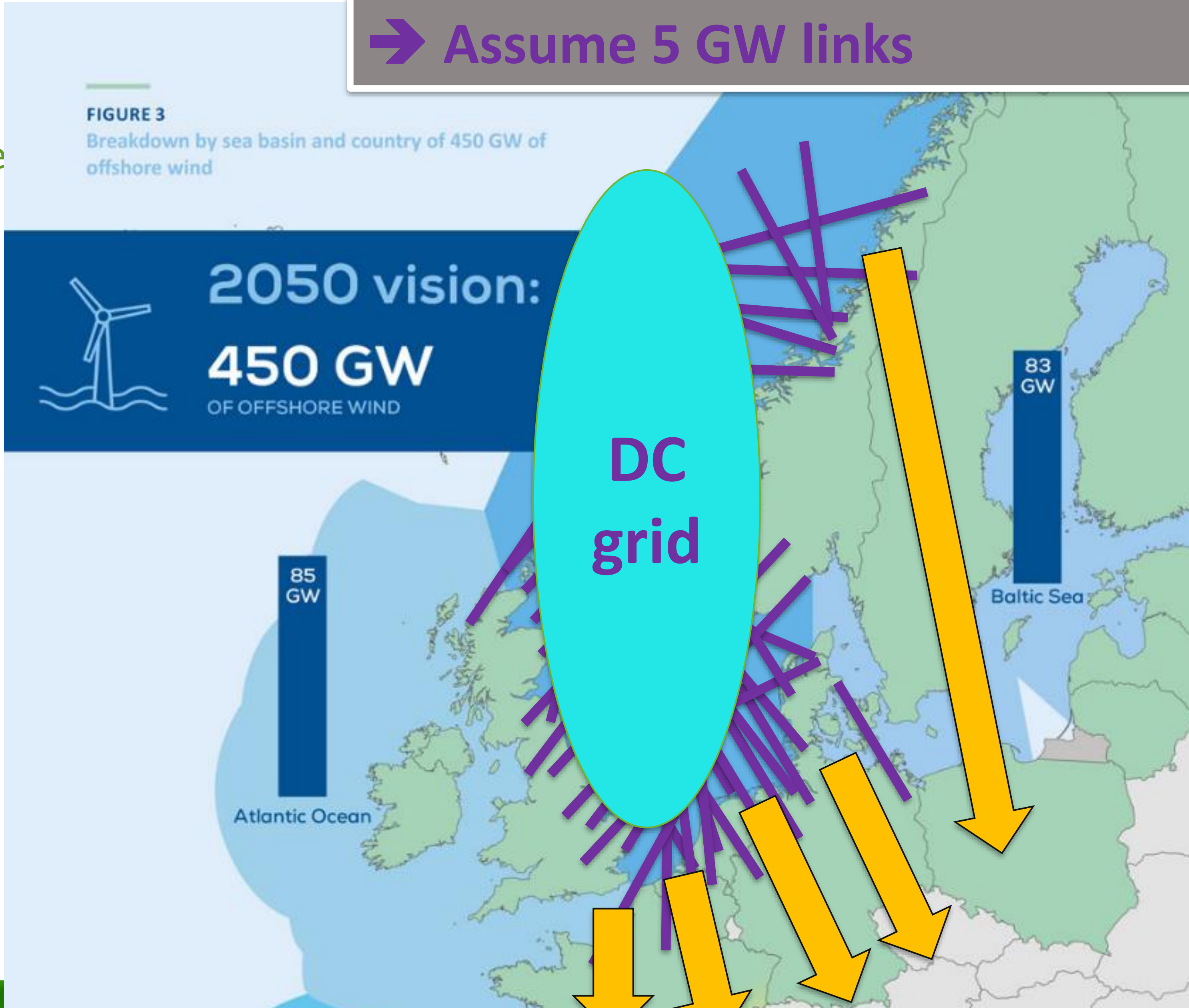


Figure: WindEurope

So we are going to build this DC grid

What's the status?

- HVDC is a known technology
- "Experts" have been advocating for DC grids for over a decade
- EU (was) in the lead for HVDC technology
- Demonstrated in China

- …and yet, DC grids do not seem to happen in Europe
- ➔ Policy makers ask us why not?

So why don't we have DC grid

Technical hurdles?

- Suitable rating for VSC HVDC systems (in particular cable) only recently became available
  - Ideal voltage: 500/525 – 640 – 800 kV?
- Large and expensive converters stations (in particular offshore)
- Control and protection is more difficult
  - Complex interactions between AC and DC systems
  - Interoperability of power electronics, in part due to black-boxed converter models
  - Protection and DC breakers were missing
- Technology does not seem to fit well with existing systems (no experience)
- No existing installation (in Europe)

So why don’t we have DC grid (today)

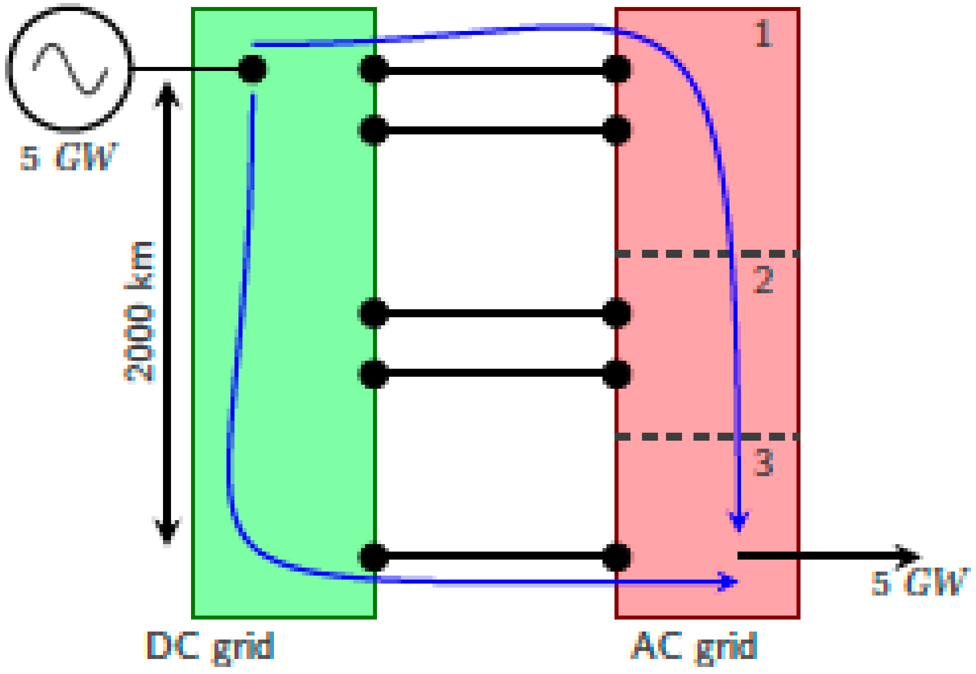
Organizational/legal/financial hurdles?

- Current legal framework is not designed to support optimal grid investments and operations
  - National regulators, national objectives
  - Complex offshore rules
- Who will invest, who will develop, who will operate?
- Significant uncertainty in costs, benefits,…
- The standard investor (TSO) is (by nature) risk averse and AC oriented ➔ why push risky investment?
- One does not invest in a grid, one invests in a line
- How to correctly reward the investor and those influenced by the investment
- Each investment needs to be cost-effective to all involved stakeholders
- A level-playing field is needed for all stakeholders and technologies (not simple)

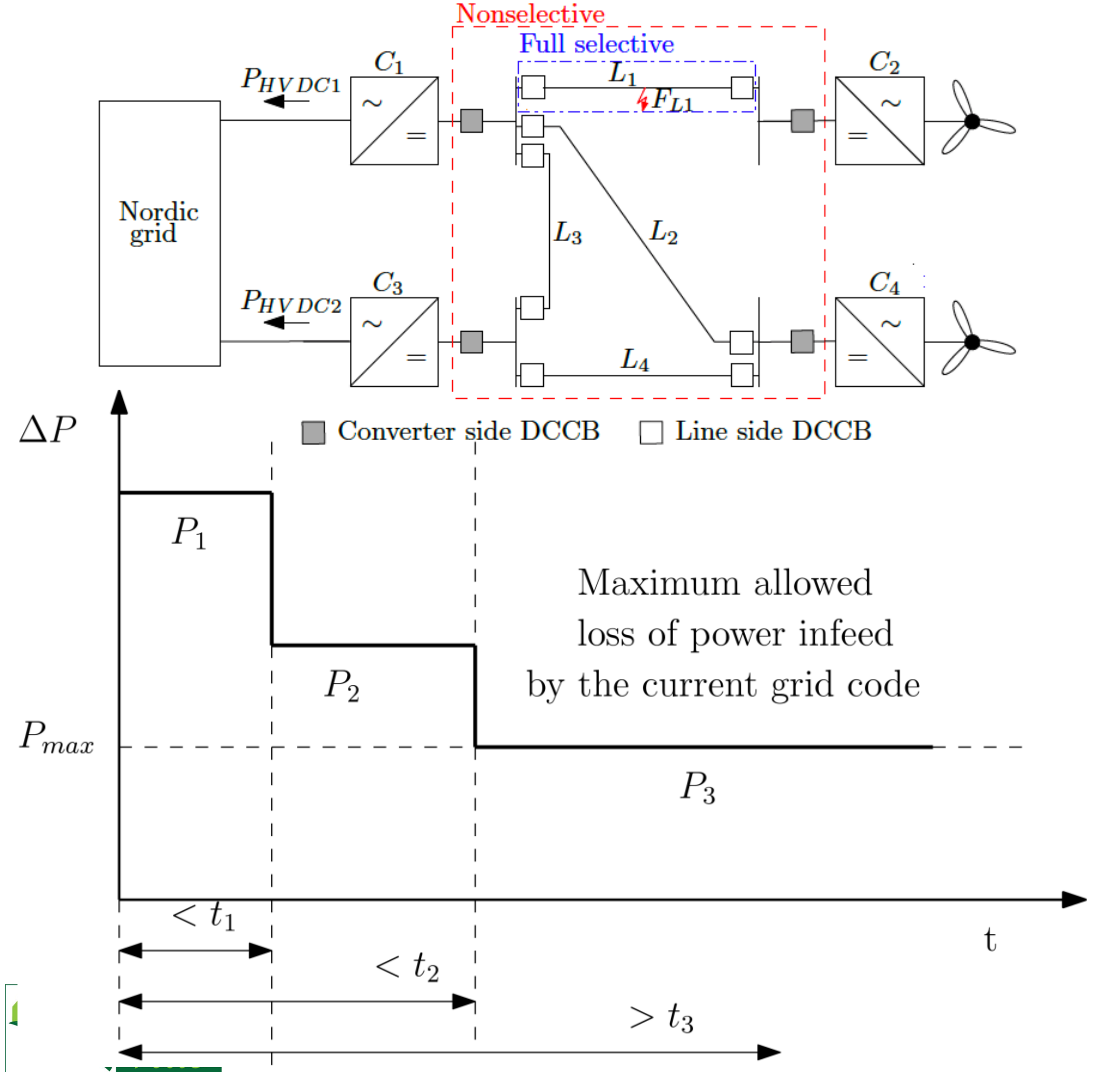
How to integrate it into the AC system?

Massive offshore integration through a DC grid requires changes:

- Feeding to shore is not enough
- Multi-GW overhead lines in Europe?
- Which connection point to connect to?
- N-1?
- Grid operations in normal operation and contingency?
- Integration in the different markets needed
- Who will invest in/own DC grids?
  - TSOs, but also offshore developers & investors
- Who will operate?
  - TSOs??? ➔ RSC like solution seems most realistic

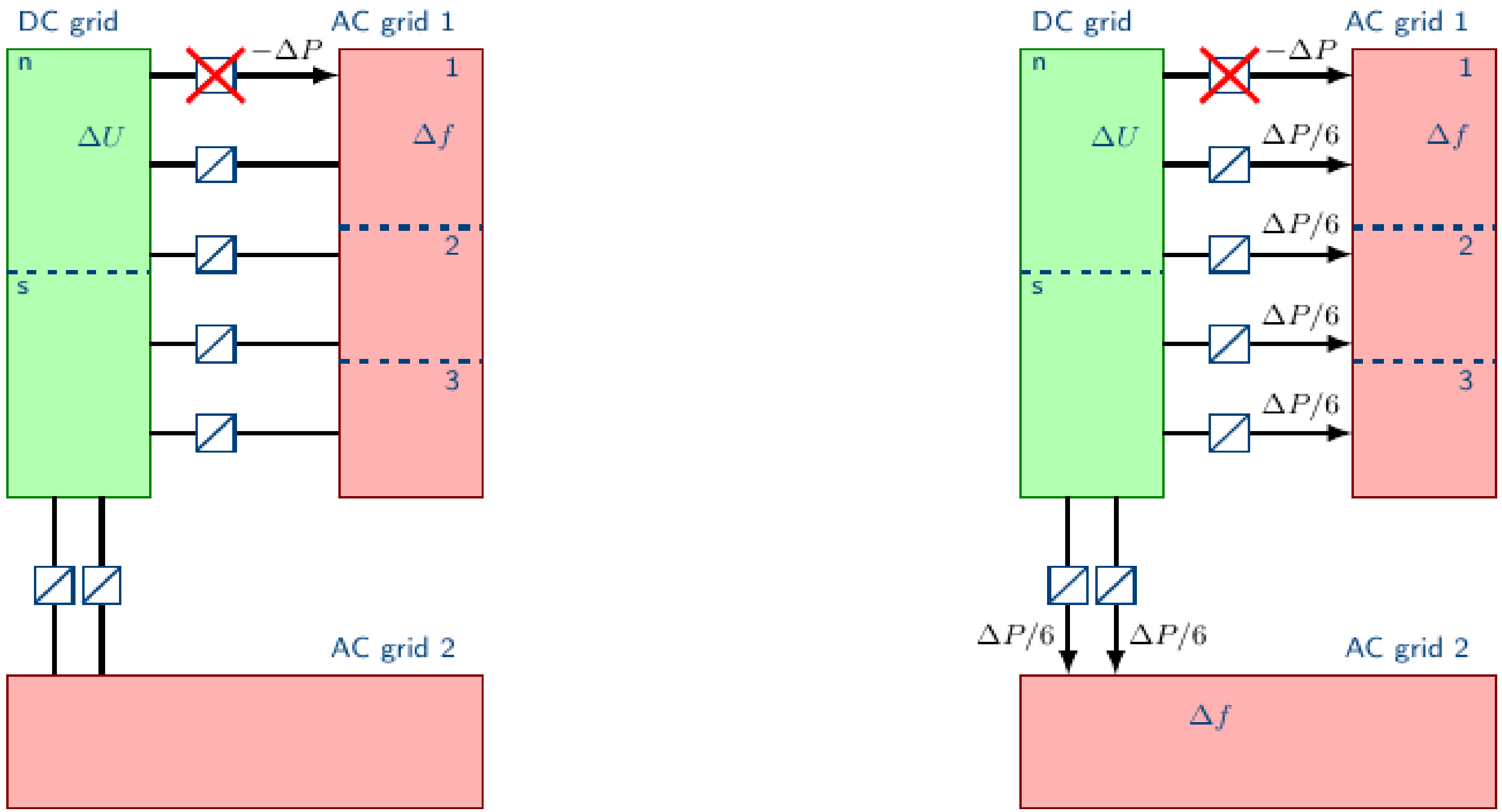


DC protection & AC impact



- Different approaches to DC grid protection exist:
  - Selective, non-selective and partially selective
- DC fault may cause transient interruption (loss of power)
- Current loss of infeed limited (e.g. 3 GW for continental Europe, 1,8 GW UK) ➔ continuous loss
- Depending on the protection strategy, a transient interruption beyond the steady state limits may be acceptable ➔ faster = higher limits ➔ adjustment grid code needed
- Balance between reserve requirements, max single loss of infeed (speed of protection) and EENS

Hybrid AC/DC interactions: Frequency/voltage management

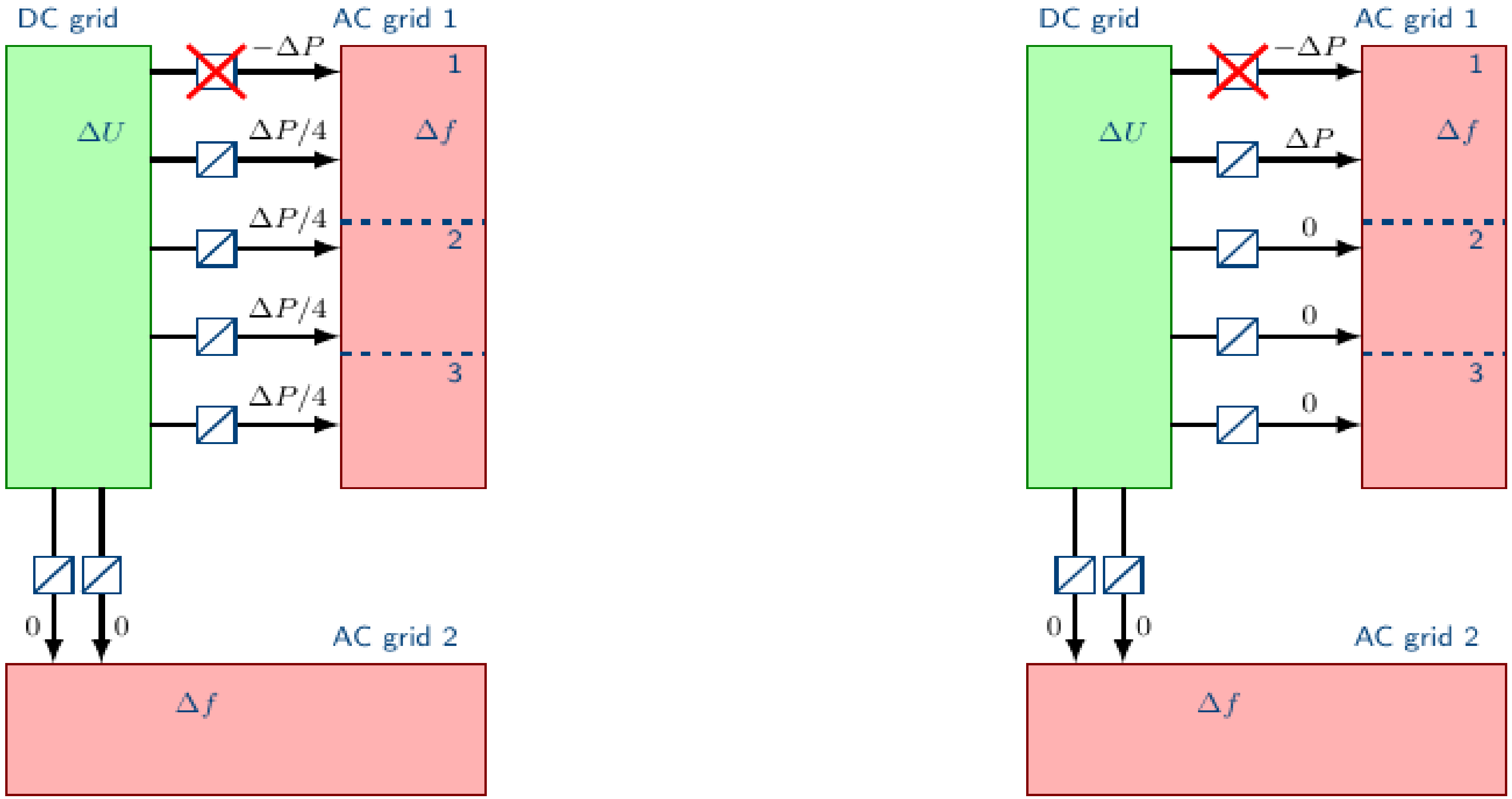


(a) Outage of a converter station connecting the HVDC grid with AC grid 1, zone 1

(b) Equal droop reaction causes all converters connected to the HVDC grid to contribute

Figure: Solving unbalances through power injection adjustment (simplified)

Hybrid AC/DC interactions: Frequency/voltage management

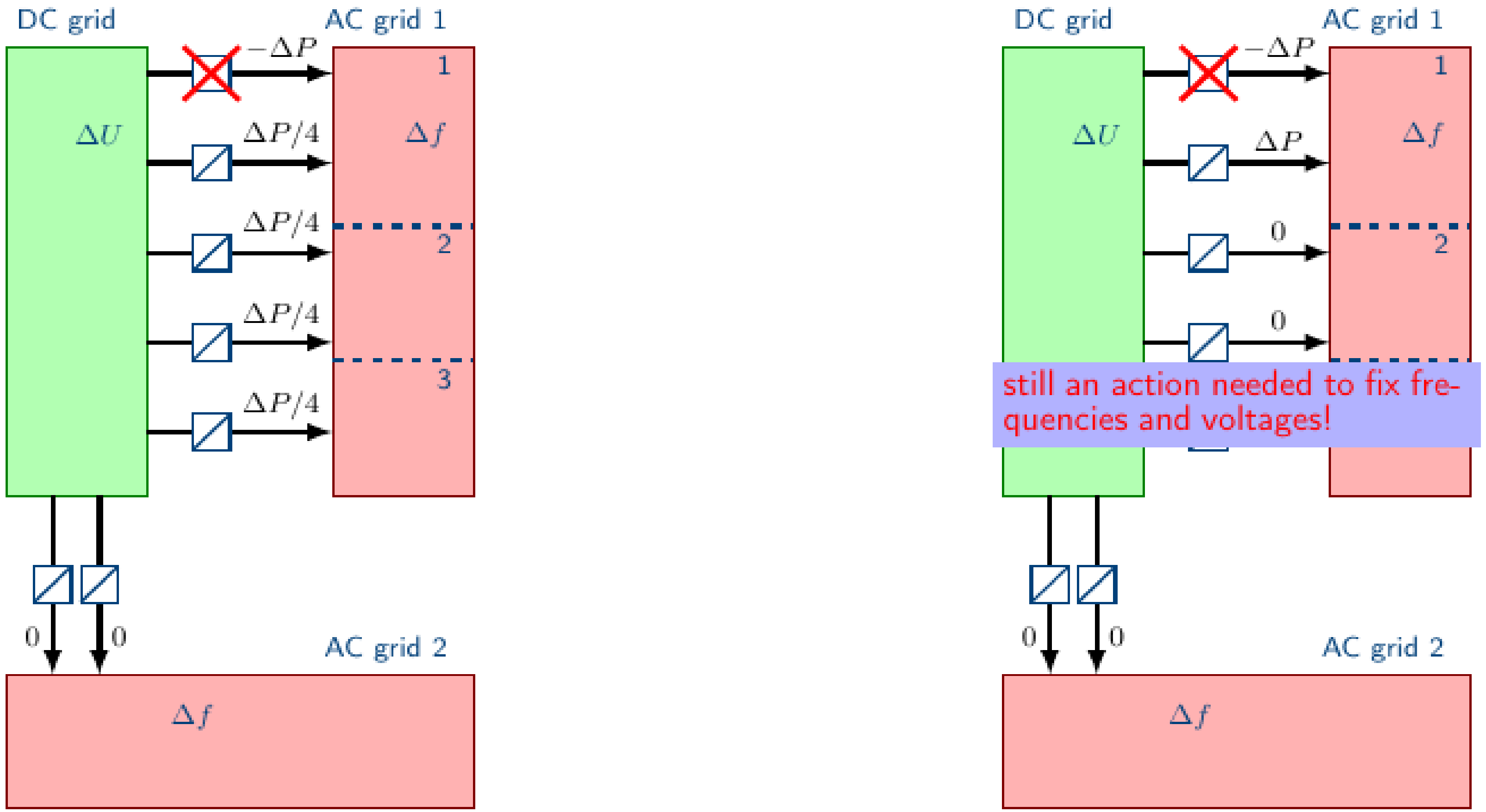


(a) The schedule with AC grid 2 is corrected, resulting in only a contribution from AC grid 1

(b) Control zone 1 of AC grid 1 takes the full unbalance over from the other systems

Figure: Solving unbalances through power injection adjustment (simplified)

Hybrid AC/DC interactions: Frequency/voltage management



(a) The schedule with AC grid 2 is corrected, resulting in only a contribution from AC grid 1

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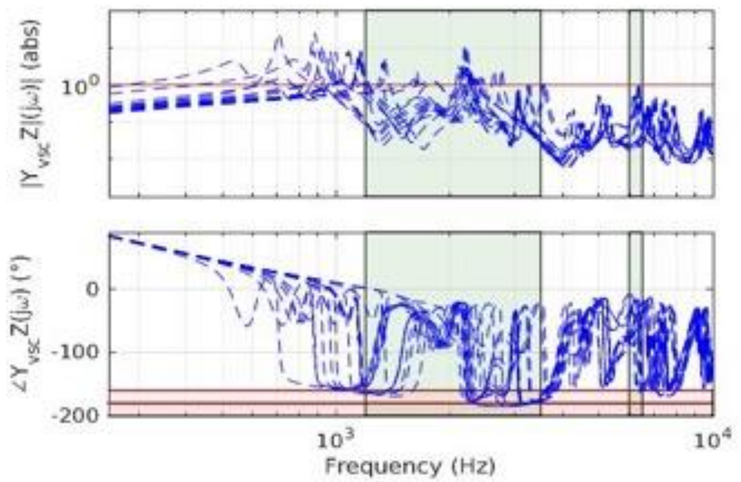
Figure: Solving unbalances through power injection adjustment (simplified)

Beerten J., Gomis-Bellmunt O., Guillaud X., Rimez J., van der Meer A., Van Hertem D. 2014. Modeling and control of HVDC grids: a key challenge for the future power system. In Proc. PSCC 2014 Power Systems Computation Conference, Wroclaw, Poland, 18-24 August 2014. , pp. 1-21

An interoperable (multi-vendor) HVDC grid

- Guaranteeing multi-vendor interoperability for converter controls …
  - HVDC systems dynamics determined fully by converters
  - AC system dynamics influenced significantly by converters
- … in a changing power system stability landscape
  - New types of interactions do not always fit traditional classification paradigms
- Converters are controllable over a wide bandwidth
  - Room for new types of converter control to completely steer system response
- Current understanding of converter and grid models is lagging
  - ➔ unintended interactions
- Current day practice of using full replica’s as standard for testing all interactions cannot be maintained



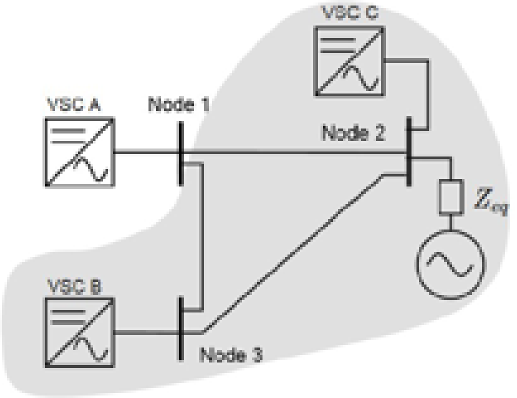


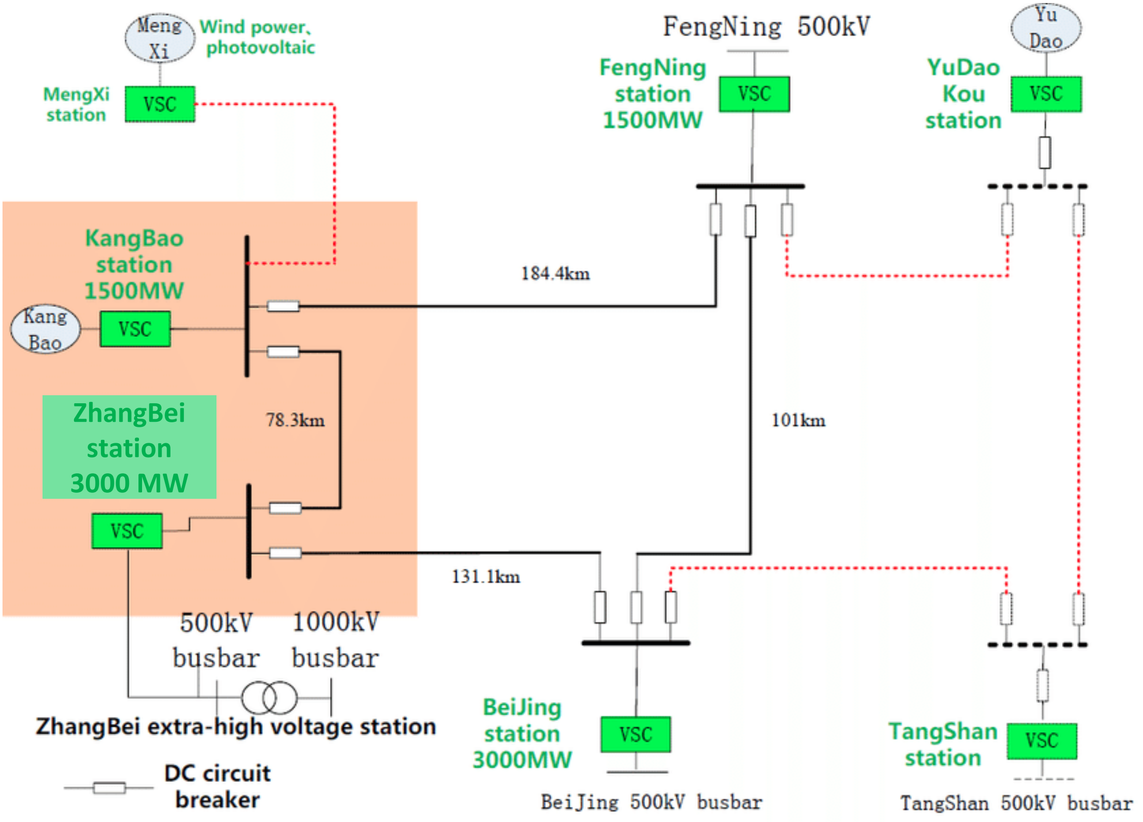
Image source: A. Bayo Salas, “Control interactions in power systems with multiple VSC HVDC converters – Analysis, modelling and mitigation of electromagnetic stability problems,” PhD thesis, KU Leuven, 24. Aug. 2018

In the meantime in China… they built a real-size demo

Phase I (4-terminal system)	Key dates
Construction commenced	Feb. 2018
First energization the four-terminal ring grid	June 2020
Commercial operation	June 29, 2020
Phase II (extend to 7-terminal system)	
To be commissioned	2021

Parameters	Values
Rated DC voltage	±500 kV
Rated power	2*3000 MW/ 2*1500 MW
Configuration	Bipolar with dedicated return path
Route	Overhead lines
Demonstration of key equipment	500 kV MMC (multiple vendors for converter valves)
	500 kV DC circuit breakers (16 units, rated 535 kV/3 kA/25 kA/3 ms, multiple vendors)
	Ultra-fast DC protection relays (< 3ms)
	Overall HVDC grid control and protection system, supplied by NR. Electric.

Zhangbei ±500 kV HVDC grid

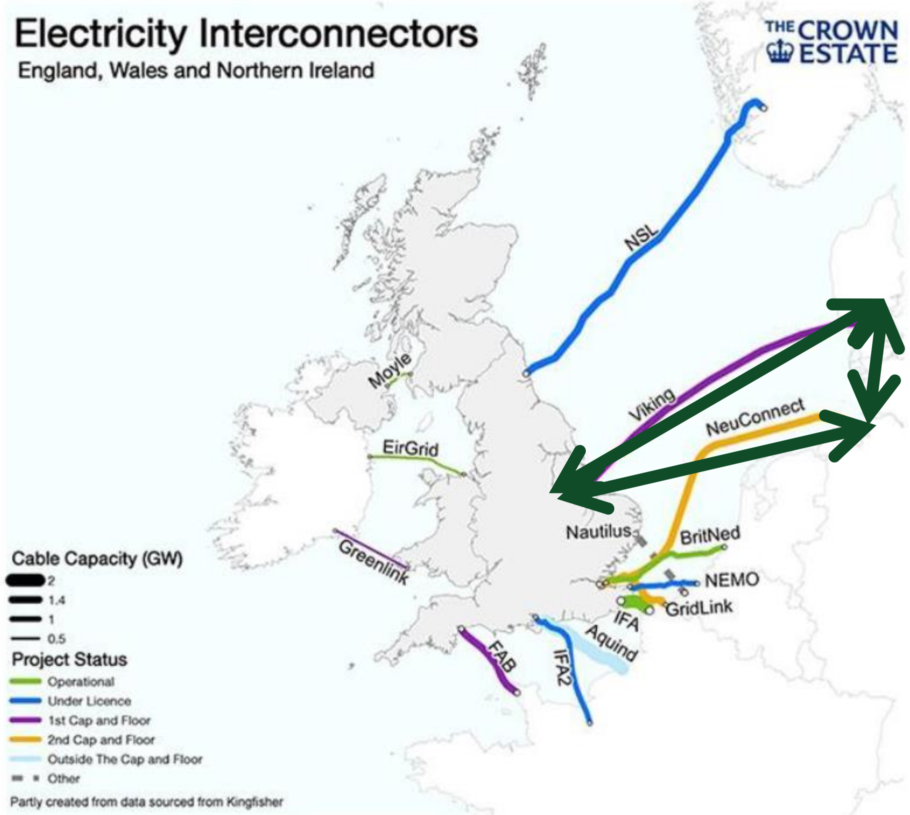


Schematic diagram of the Zhangbei HVDC grid
(source: Buigues, et al, Present and future multiterminal HVDC systems: current status and forthcoming, Renewable energy & power quality journal, 2017, DOI:10.24084/REPQJ15.223)

Suggestion: why don't we build a DC grid as a European experiment/demonstrator?

- Connecting locations with different energy prices
- 525 kV, 2 GW lines (cables)
- 4 GW converters
- De-risking technology

Figure 8: Map of electricity interconnectors in the UK



Source: Extracted from the Crown Estate (2018)

What does a demo grid cost?

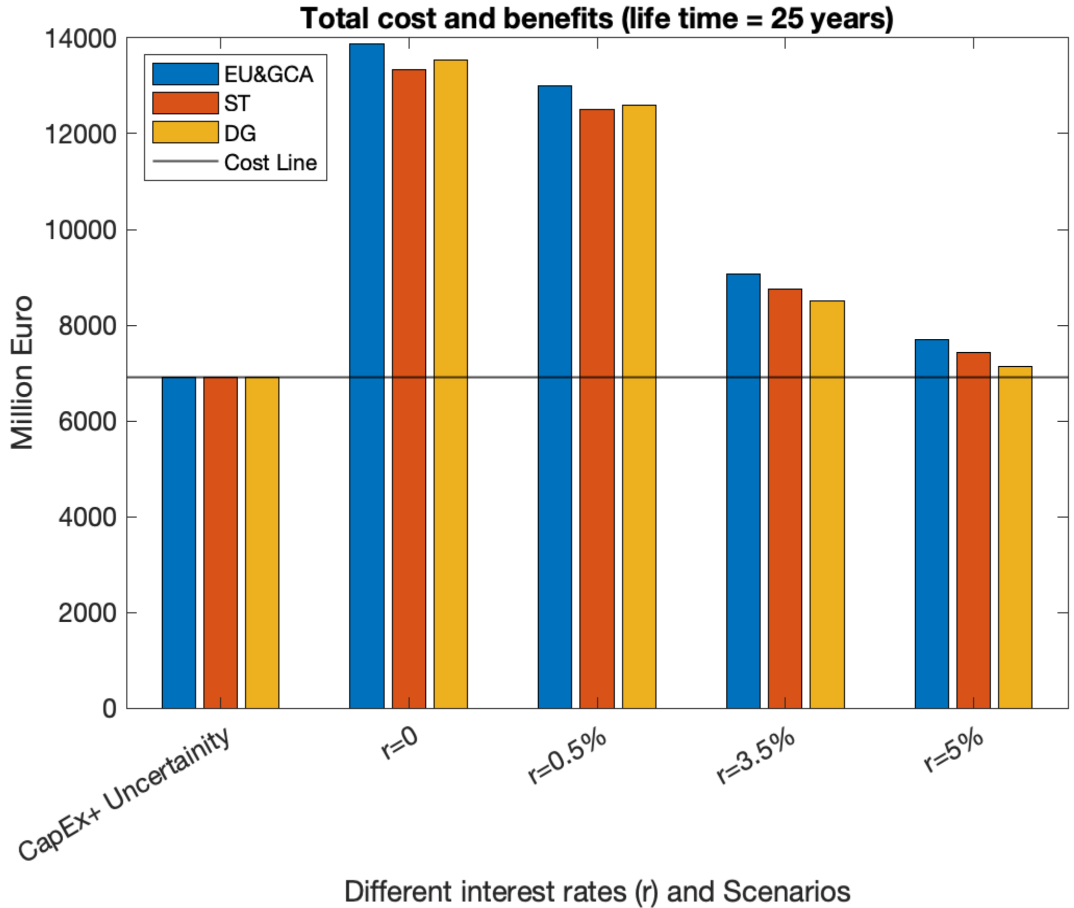
- 5 converters: 5* 200 M€. 1000 M€
- 3 GW lines (bipolar, 2 M€/km/pole) 1500 km? 6000 M€
- 20 % for protection, lawyers and things I forgot. 1400 M€
- Total

- Western Europe (Fr, D,
- 10 years paying (with C
- Per year per person

ITER is expected to cost > 20 Billion Euro, 45 % EU

Suggestion: why don't we build a DC grid as a European experiment/demonstrator?

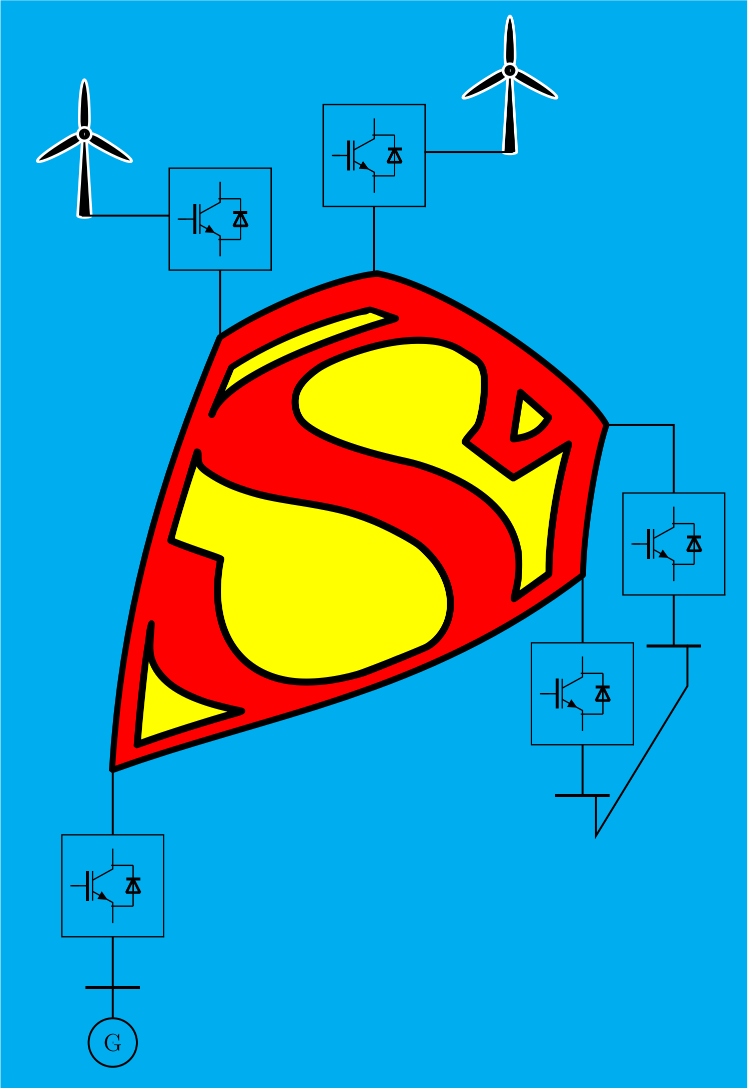
- Connecting locations with different energy prices
- 525 kV, 2 GW lines (cables)
- 4 GW converters
- De-risking technology
- CBA based on ENTSO-E scenarios
- Returns calculated with day-ahead prices (2018)
- EU as investor?



Conclusions

- DC grids are the (near) future of transmission
- Perceived risks/uncertainties have delayed developments ➔ recent change
- The required upgrade of the grid is fundamental
  - Providing patchwork solutions will not suffice
  - “This is not how we do it today” is not relevant
- Regulation should never be the blocking issue
- AC and DC systems interact
  - More control
  - Adverse interactions possible => new tools needed
  - The operation of the hybrid AC/DC grid shall be different from the existing grid

- Lets start to build a DC grid today!
  - Significant social benefits (It’s a profitable investment).
  - Reduces risks
  - High payback period (around 10 years or more) ➔ (partially) public investment?



Energy Ville

Dirk Van Hertem

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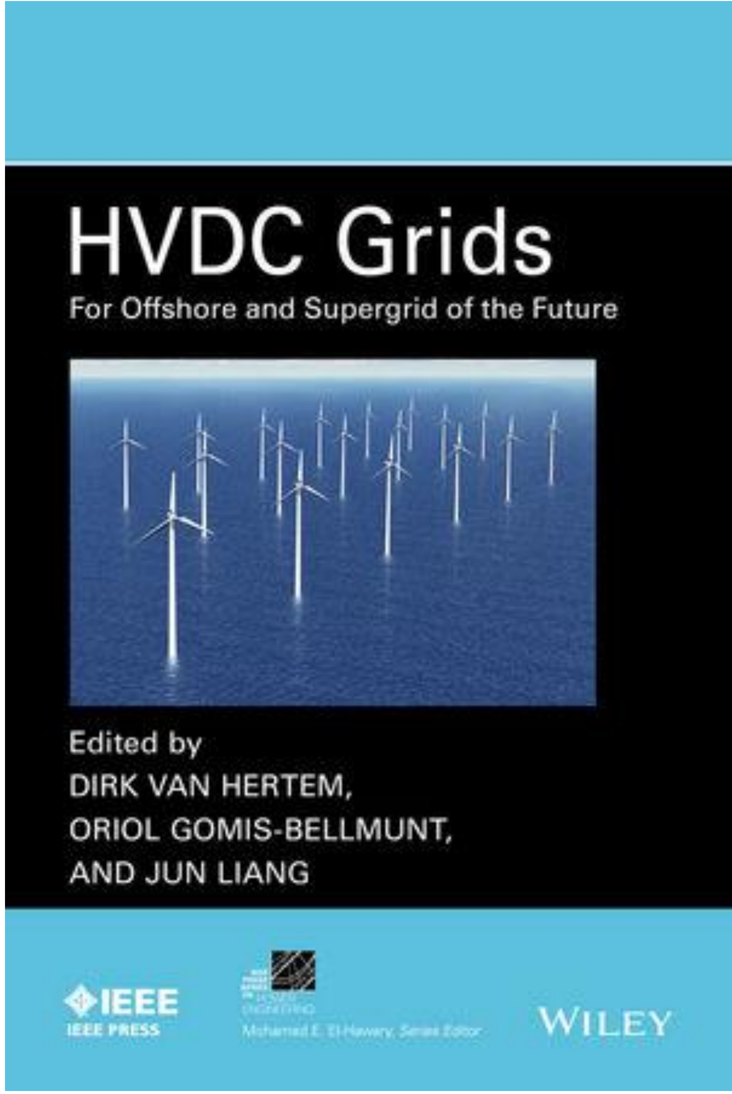

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

KU LEUVEN

vito

imec

UHASSELT

Panel Discussion

Including questions from the audience

CurrENT
Enabling Network Technology throughout Europe

UPCOMING WEBINARS

3

Accelerating the Energy Transition:

How Dynamic Line Ratings optimise the grid (14th January)

Register here:

4

Accelerating the Energy Transition:

Cyber security (February/March)

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Thank you for your attendance

To keep up to date with our activities:

info@currenteurope.eu

https://www.linkedin.com/company/current-europe/

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Back up slides

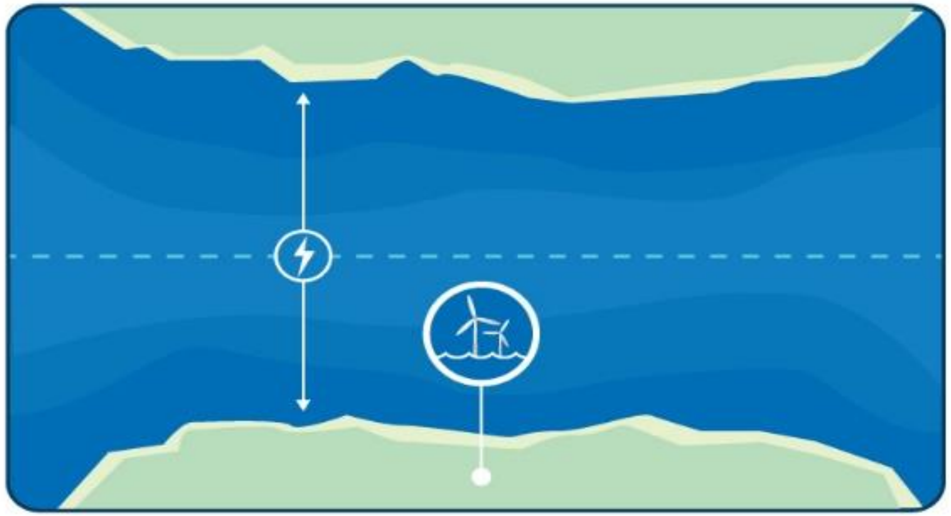
Hybrid projects

- Historically, national projects connected directly to the shore via radial links
- To step up deployment in a cost effective and sustainable way a more rational grid planning and the development of a meshed grid is key.

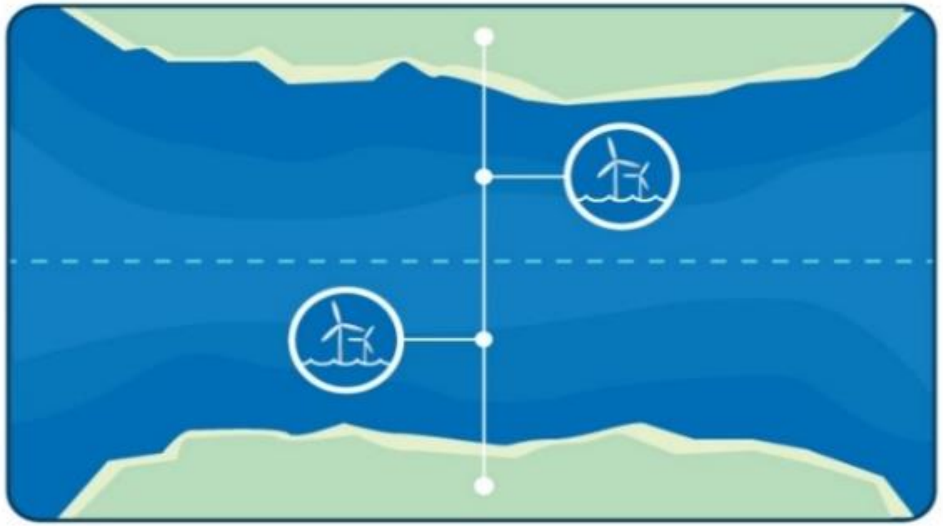
A share of the future offshore grid will ideally be built around hybrid projects to reduce costs and use of maritime space.

<u>Hybrid projects</u>

They combines electricity interconnection between 2 or more MS, and transportation of offshore renewable energy, to its sites of consumption

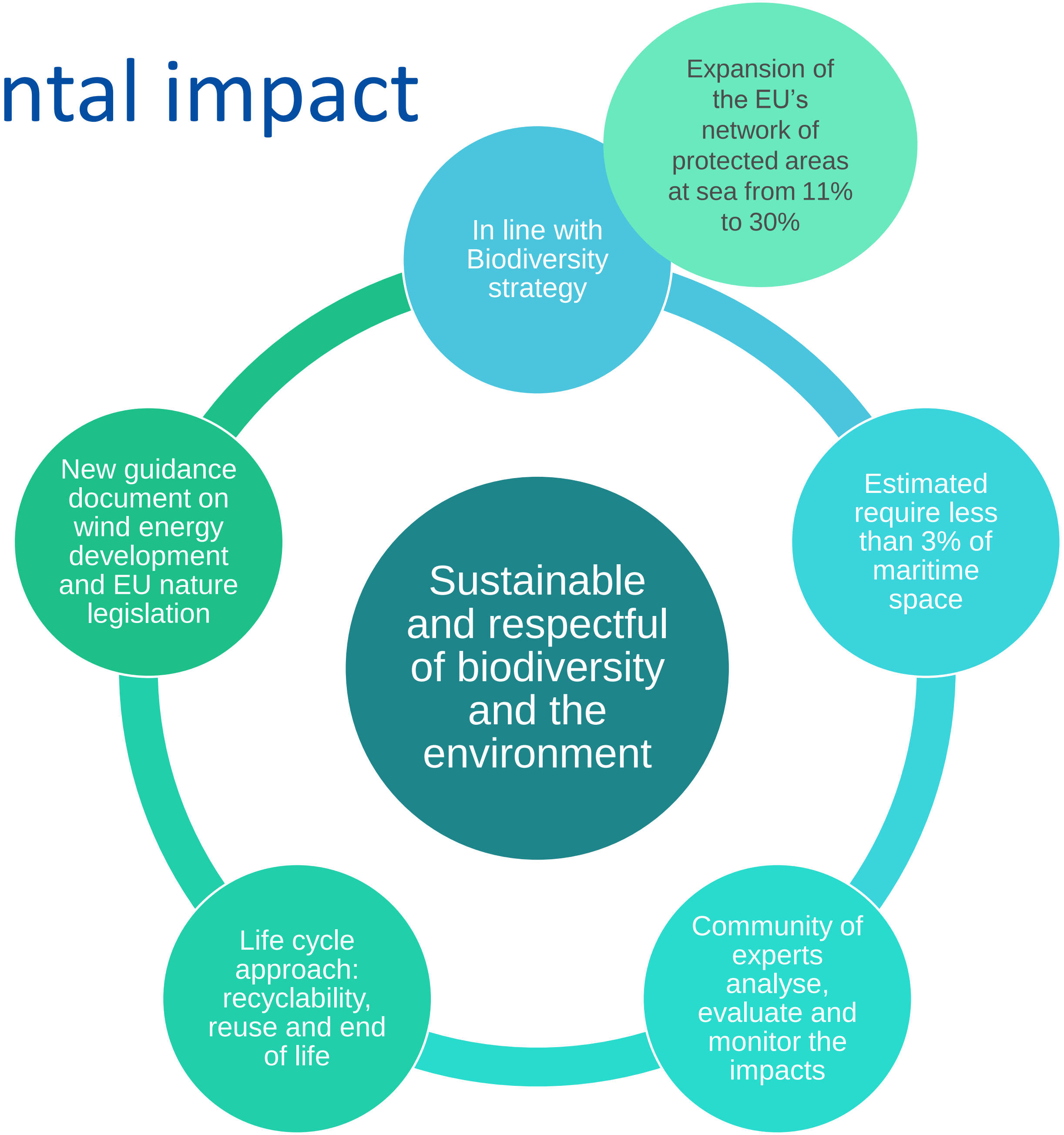


Radial connection and separate interconnector



Example of a hybrid project, the tie-in model

Environmental impact



European Commission

Relevant funds

- **The Cohesion Policy Funds**
- **InvestEU programme**
- **The Connecting Europe Facility**
- **The Renewable Energy Financing Mechanism**
- **Horizon Europe**
- The **Innovation Fund** under the EU Emission Trading System (EU ETS)
- **The Modernisation Fund** under the EU ETS

European Commission

Challenges

<u>Sustainable management of maritime space and resources</u>

Co-existence with other sea space uses / Multiuse approach

Respectful of marine biodiversity and environment

Lead A

- Aligning NECPs and national MSP
- Reinforce Sea-basin cross-border cooperation in MSP
- Support multiuse pilot projects
- Guidance wind / nature legislation
- Engagement with Community of practice

Challenges

<u>Deployment and integration of Offshore Renewable Energy in the future European energy system (1/2)</u>

Grid technologies, permitting, planning and development

Lead

Long-term commitment deployment per sea basin

TEN-E Framework for long term offshore grid planning

Hybrid projects

Framework for TSO – grid investments

Guidance sharing costs and benefits accross borders

Allowing anticipatory investments

Challenges

<u>Deployment and integration of Offshore Renewable Energy in the future European energy system (2/2)</u>

Market framework / Investment-support

Lead
A

- Market guidance to clarify the offshore bidding zones for hybrid
- Amendment to legislation: flexibility allocation of congestion income for hybrid
- Amendment to Grid Connection Network codes for HVDC grids
- Revision State Aid Guidelines
- RRF and Power up Flagship
- CEF and Renewable Energy Ficancing Mechanism

Challenges

Mobilizing investments

Nearly €800bn needed / Mostly private investments / Catalytic role of EU funds

Lead Actions

Encourage MS to include offshore in their national recovery and resilience plans

Facilitate the development of cross-border cooperation projects (CEF, Renewable Energy Financing Mechanism, InvestEU)

Support strategic investment in offshore energy

InvestEU

Challenges

Supporting Research & Innovation in Offshore Renewable Energy

Strengthening Europe's technological leadership

Lead Actions

Support cooperation for large-scale HVDC-grid demonstration project

Improve industrial efficiency across the whole value chain

Create additional SET Plan group on HDVC

H2020 Green Deal Call Horizon Europe

Develop new wind/ocean energy and solar floating technology designs

Review SET Plan targets on ocean energy and offshore wind

Use of available funds for ocean energy technologies

Challenges

Strengthening European industrial leadership in offshore renewable energy

Industrial development and competitiveness / Industrial capacity / Circular economy approach

Lead A

Promote standardization and interoperability of converters

Enhanced Clean Energy Industrial Forum on renewables dedicated to offshore

Value Chain

Develop/Strengthen export markets

Facilitate access to third country markets

Challenges

Build a social and inclusive growth through offshore renewable energy takeoff

Lead Actions

Cohesion Policy Funds

Just Transition Fund

Support to the development of technical and academic educational programmes

Staff Working Document

European Commission

SWD on Market Rules

Clarity

- Market integration and cross-border trading has worked well for years
  => market coupling saves consumers ca. €1billion annually.
- However, relevant legislation is complex and focuses on the onshore system
  => clarity is needed regarding how it applies to a future offshore grid.

Acknowledgement

- The CEP and secondary legislation covers key elements regarding rules for renewables integration, cross-border trading and regional cooperation that are relevant for the development of offshore renewables.
- Until now, RES projects have largely been shielded from market dynamics
  => Market participation is new.

The SWD supports the sector with a clear explanation of the rules and by checking that they are fit for purpose.

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Explanation of the Rules

1

Market Dispatch & Balance responsibility

- Electricity legislation has been updated in the CEP to make the market fit for renewables and renewables fit for the market
- Explanation provided on how it applies to offshore.

2

Unbundling

- Separation of ownership of generation & transmission to ensure third party access: key principle for well-functioning markets
- Explanation of models that still allow non-TSOs to build transmission

Explanation of the Rules

3

Cross-border trading

- Free movement of goods principle applies to electricity. Cross-border trade should be maximised => min. 70% target for trade seeks to address historical problems of closing borders & overall EU welfare loss.
- Explanation of how to ensure 70% for offshore projects connected to several markets: **offshore bidding zones**

4

Governance of Offshore Bidding Zones

- Explanation of how to establish & manage an OBZ (incl. TSO & NRA responsibilities):
  - At national level (e.g. Nordics, Italy)
  - Multinational OBZs: e.g. DE-AT-LU & iSEM
- Longer-term, due to increasing complexity in some sea basins, a model for regional cooperation with one ISO could be beneficial.

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Check if legislation is fit-for-purpose

Modelling results show that **Offshore Bidding Zones for hybrid projects** are better for overall efficiency: they lower costs, support system operation and are well-suited for a large upscale of offshore projects.

But

OBZs might entail more risk for project developers

What risk?

- For over half the projects modelled, the impact on revenues was less than 1%. However for some projects, this was up to 11%.
- For those projects that had a bigger revenue impact, the congestion income was proportionately higher.

Project topology is key!

Grid planning

Congestion Income

Check if legislation is Fit-for-Purpose

5 Congestion Income

- Income received by TSOs from the price difference between zones. Rules govern its use.
- If structural congestion exists, it could mean high CI for TSOs & low prices for developers.
- The Commission will investigate granting NRAs flexibility to allow developers of hybrid projects to receive CI.

6 Connection Rules

- The Grid Connection NCs set standards for generators, demand and transmission cables to connect to the grid.
- Lots of flexibility allowed at national level.
- Study for the Commission proposes some best practice requirements for offshore HVDC
- Experts from GC ESC will follow up this study as part of amendment process.

Summary

- Explain how the following rules apply to offshore electricity systems:
  - Market dispatch and balance responsibility
  - Unbundling
  - Cross-Border Trading
  - Governance of offshore bidding zones
- Fit-for-purpose check with a view to amending the following:
  - Rules on the use of congestion income
  - Technical Codes for connection

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Backup Slides

ivSupra - Interessenverband Supraleitung

German speaking organisation of SMEs and Institutes to stipulate and support superconductor technology

Vision Electric Super Conductors GmbH

VISION® ELECTRIC Super Conductors

- Development, Sales and Production of superconducting systems
- 10 highly motivated pioneers
- Close cooperation with
  - KIT Karlsruhe
  - TU Kaiserslautern
  - University of Applied Science
  - Etc.
- System integrator for turnkey solutions

Superconducting Systems - Advantages

VISION® ELECTRIC Super Conductors

- Smallest Conductor and System Dimensions - Minimum space required
  - lower building volume - lower civil costs
  - less underground work – smaller cable trench, lower construction costs
  - small weights – easy to ship, store and handle on site – low erection costs
  - minimum weight, reduced fixing loads – existing fixing structures can be used
- Modularity
  - Factory tested modules – reduce site risk, increase safety
  - Highest flexibility combining functional modules like angle, tap-off, etc.
  - Exchange of one module in case of usage change, outside damage, etc.
  - Standardized procedures for engineering, production and site work
- Energy efficient
  - Zero DC losses, zero voltage drop – reduced operating costs
  - Reduction of CO_2 emissions comp. to copper and aluminium conductors
- Environment
  - No losses – no thermal emissions
  - Minimum or zero electromagnetic emissions
  - Zero fire load – cannot burn and cannot emit dangerous smoke
  - Easy separation of material and recycling after end of life
- Health
  - High protection degree IP68 – highest class for human protection
  - Minimum electromagnetic fields – no electrosmog
  - Intrinsically safe
- System
  - High structural stability (3mm SS-tube) for extreme industry environment
  - In case of damage: Leakage of non-combustable nitrogen
  - Operating data independent of location (altitude, ambient temperature, humidity, etc.)