



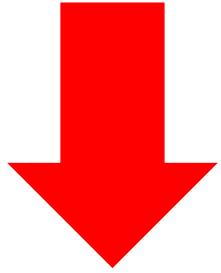
WHEN TRUST MATTERS

VSC-HVDC technology: European use cases, maturity, experiences and future plans

ERCOT HVDC Workshop
June 26, 2023

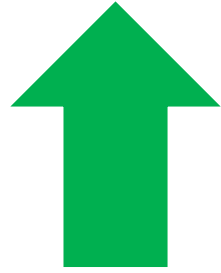
Cornelis Plet, Vice president – Power System Advisory
26 June 2023

EU 2030 climate & energy policy targets



40%

Cut in greenhouse gas emissions compared to 1990 levels



32%

Share of renewable energy consumption

600 GW solar

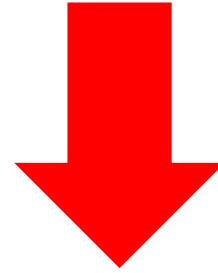
208.9 GW today

253 GW onshore wind

225 GW today

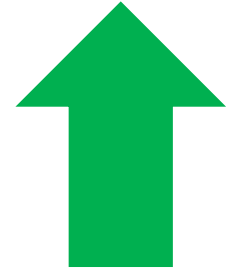
60 GW offshore wind

30 GW today



32.5%

Energy savings compared with the business-as-usual scenario



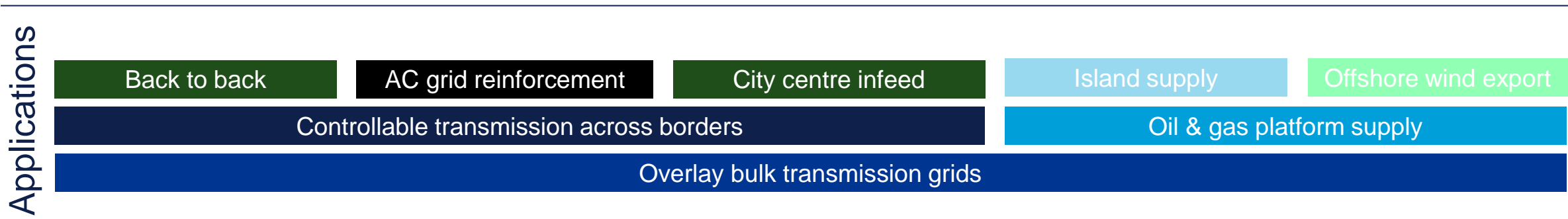
15%

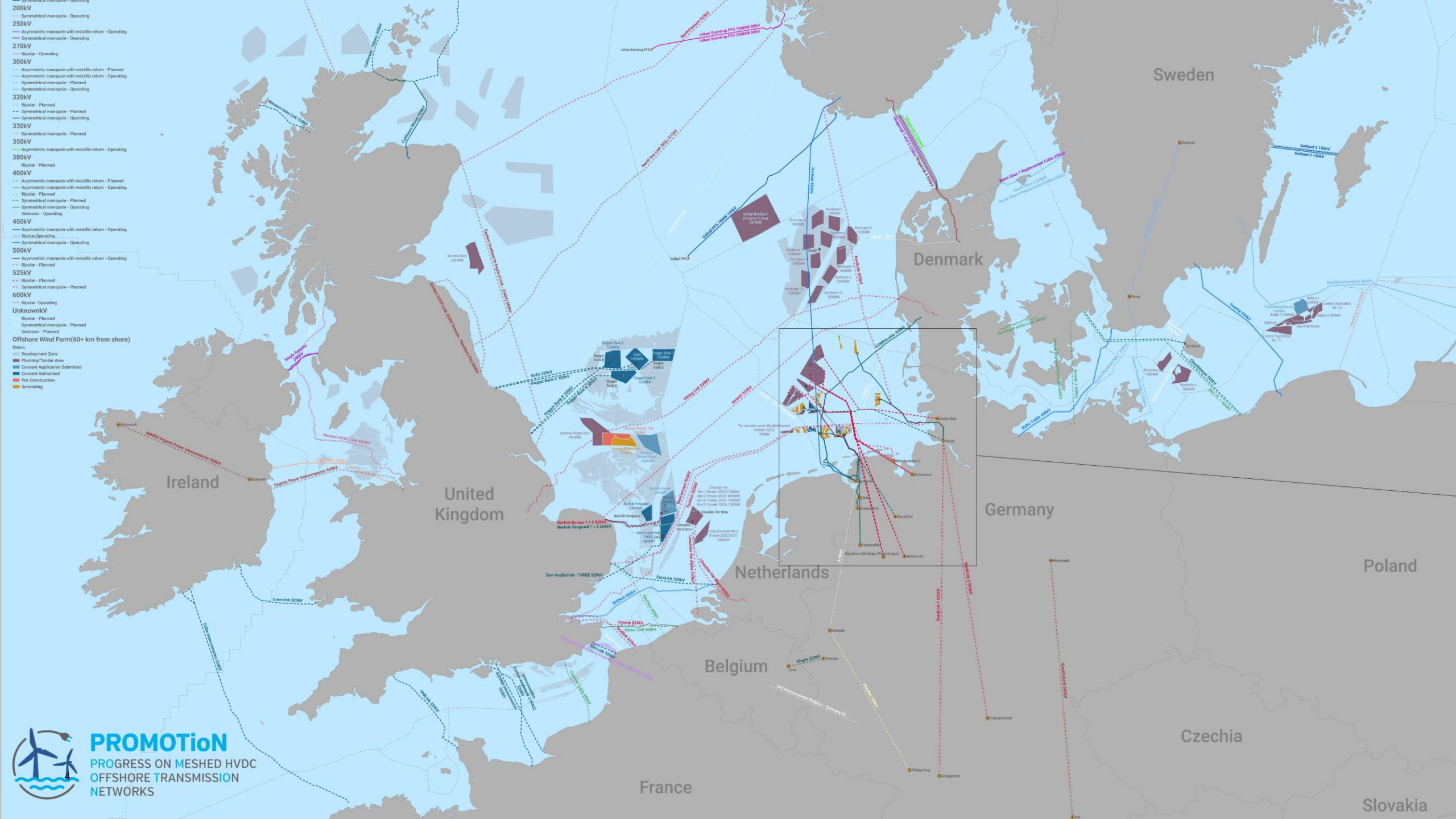
Electricity cross-border capacity target

184 GW transfer capacity

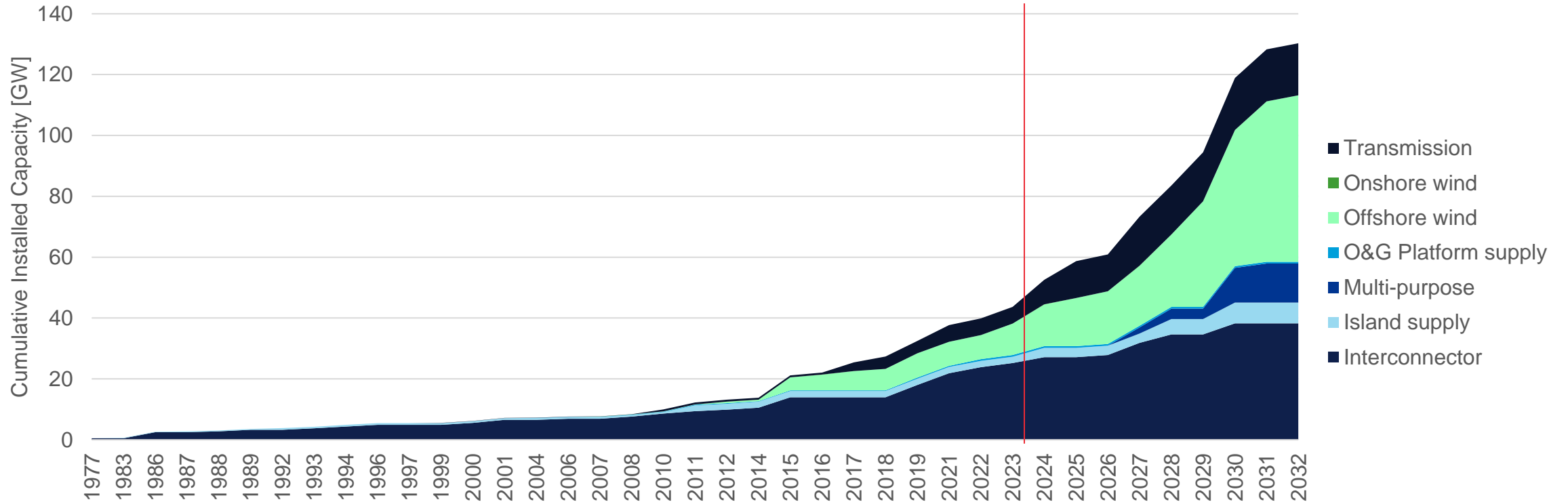
93 GW today

HVDC technology enables Europe achieve targets through:



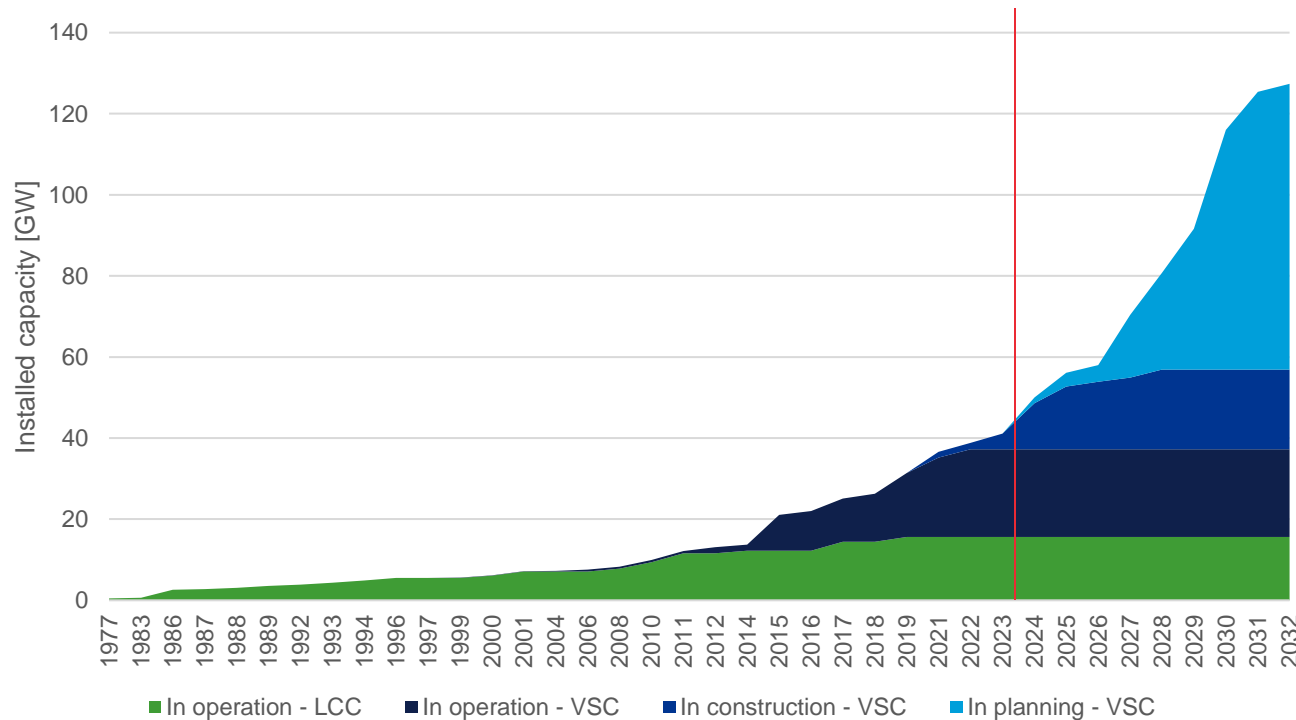


HVDC transmission is rapidly growing in Europe



- Total installed HVDC capacity will more than triple in the next decade.
- Over 60% of this will be used for reinforcing or interconnecting onshore transmission grids

The growth is enabled by a new HVDC converter technology



- The use of **Line Commutated Converter** technology enabled effective and low-loss long distance and high capacity (cable) transfer capacity
- The use of **Voltage Sourced Converter** technologies also realizes additional benefits
 - Compact & scalable
 - Grid support

Offshore wind export development has driven maturation of Voltage Sourced Converter technology to the point that is clearly the new HVDC industry work horse

HVDC transmission technology is mature



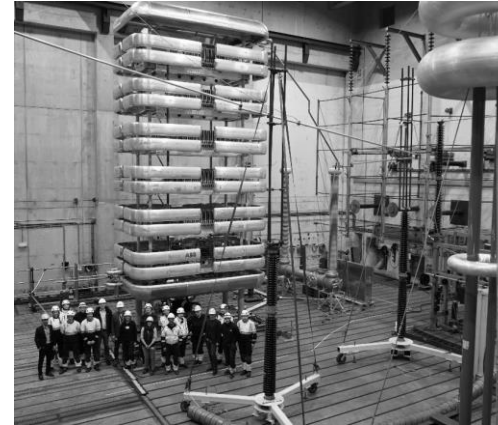
Credit: IMAGINECHINA/ALAMY



Credit: Prysmian



Credit: Siemens



Credit: Hitachi



Credit: PROMOTioN

Overhead line

- 1.100 kV, 12 GW in operation

Cables

- Mass-impregnated paper
 - 600 kV, 2.2 GW in operation
 - 800 kV announced
- Extruded polymer
 - 525 kV, 2.1 GW qualified
 - 640 kV, type tested

Converters

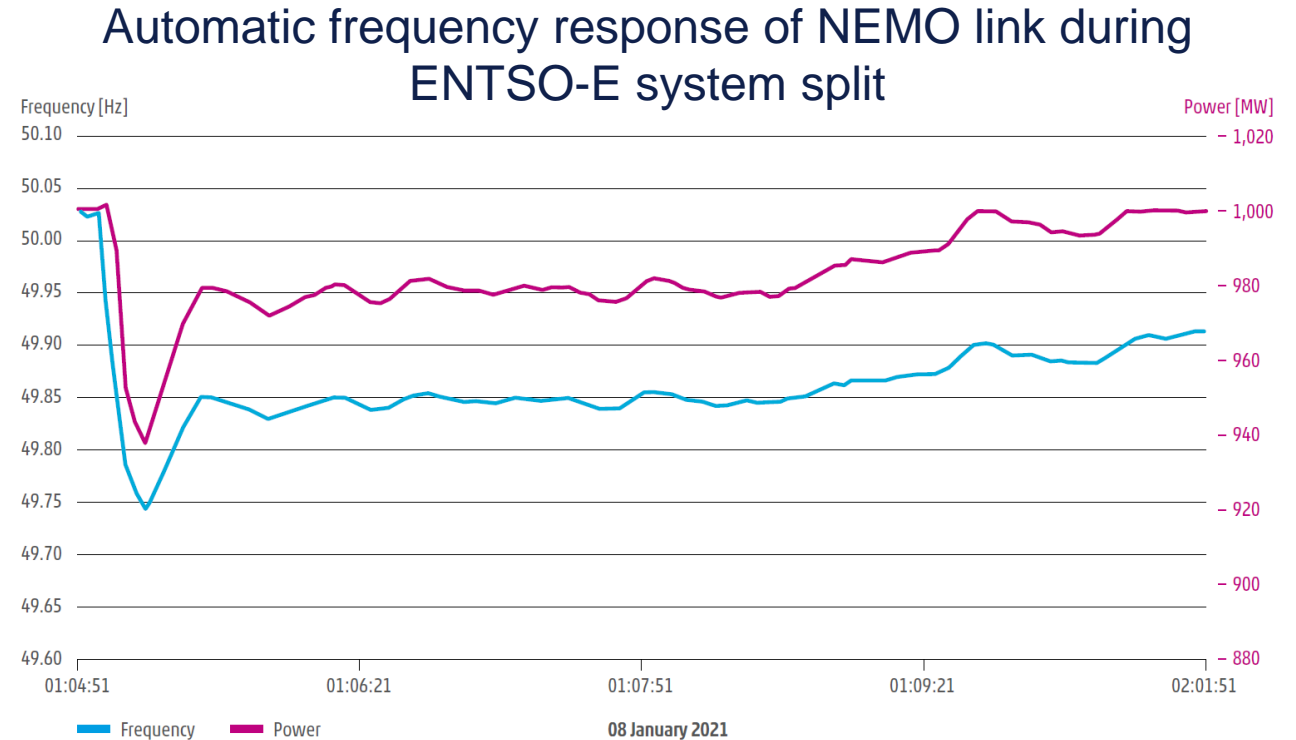
- Voltage sourced converters
 - 800 kV, 5 GW in operation
- Line commutated converters
 - 1,100 kV, 12 GW in operation

Switchgear

- HVDC circuit breakers
 - 500 kV, 25 kA in operation
- HVDC gas insulated switchgear
 - 250 kV in operation
 - 525 kV qualified

Voltage sourced converters offer valuable grid support capabilities

- VSC-HVDC superior control capabilities
 - Independent and near-instantaneous control of real and reactive power
 - Grid-forming or grid-following
 - Grid-supporting
- VSC-HVDC systems have:
 - Provided reactive power support
 - Provided emergency frequency support
 - Increased security of supply
 - Demonstrated black start capability
 - Emulated AC transmission line for easy integration
 - Damped power oscillations



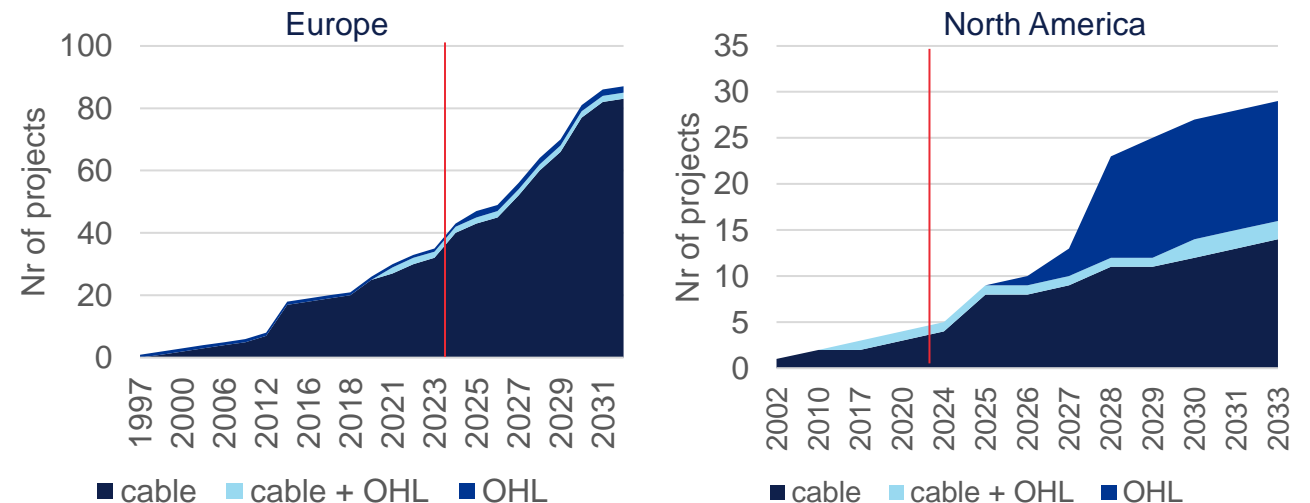
Operators in Europe opt for HVDC over AC due to VSC's grid support capabilities

VSC with overhead line

- VSC-HVDC with overhead line is technically feasible
- Majority of VSC-HVDC projects in Europe are completely cable based, in US more OHL
- VSC-HVDC projects using overhead line are in operation today
 - 2 in Europe
 - 9 worldwide
- Several demonstrated technical solutions for dealing with transient faults exist
 - Re-closing of converter breakers (1-2 sec)
 - HVDC circuit breakers (10 msec)
 - Full-bridge converters (us)



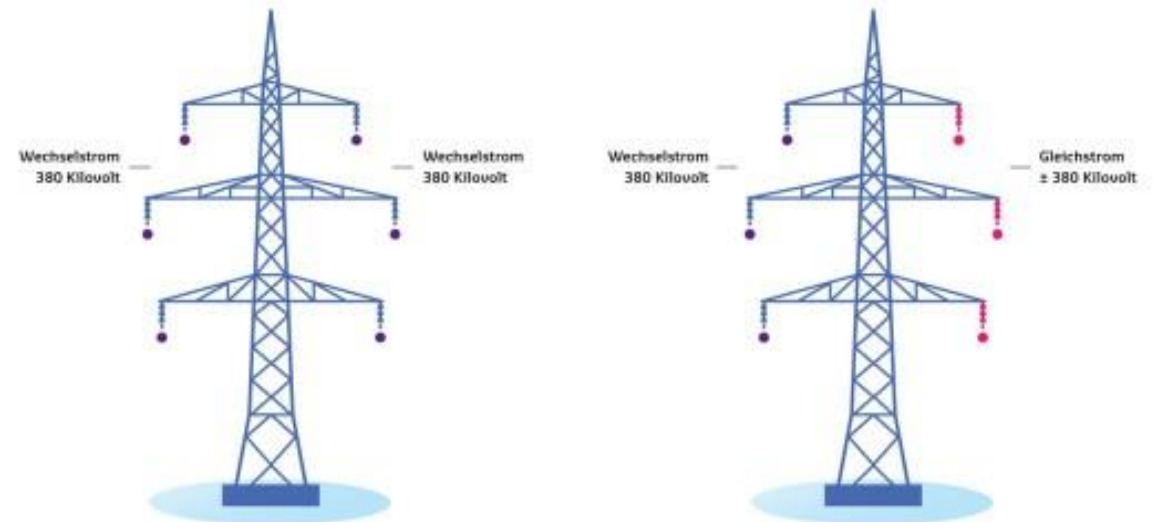
NordLink, 515 kV, 1.4 GW, Source: [ELNOS](#)



Converting existing AC overhead lines to DC

- Conversion:
 - Add converter stations
 - Replacement of insulator assemblies
 - Potential enhancement of conductors
 - Tower and foundation reinforcements
- In same right-of-way:
 - triple power transmission rating
 - reducing transmission losses
 - avoid AC instability issues
 - gain VSC enabled grid support functions
 - at third to half the cost of building a new DC line
- Combining AC + DC circuits on single tower

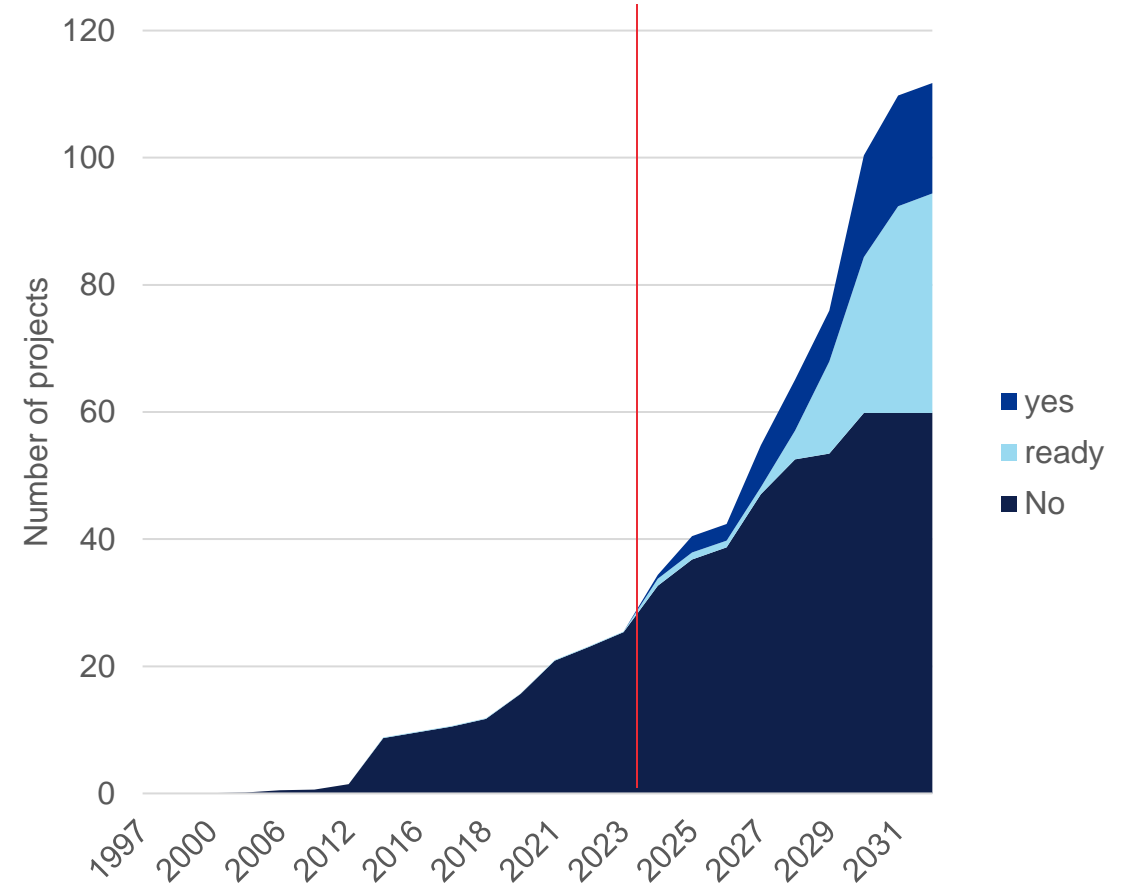
- [Converting AC power lines to DC for higher transmission ratings, ABB Review 3 / 1997](#)
- [Feasibility study for converting 380 kV AC lines to hybrid AC / DC lines, ABB, 2009](#)
- [AC-to-DC Power Transmission Line Conversion, EPRI, November 2010](#)
- [Guide to the conversion of existing AC lines to DC operation, CIGRE TB583, 2014](#)



ULTRAnet, 380 kV, 2 GW, Source: [Amprion](#)

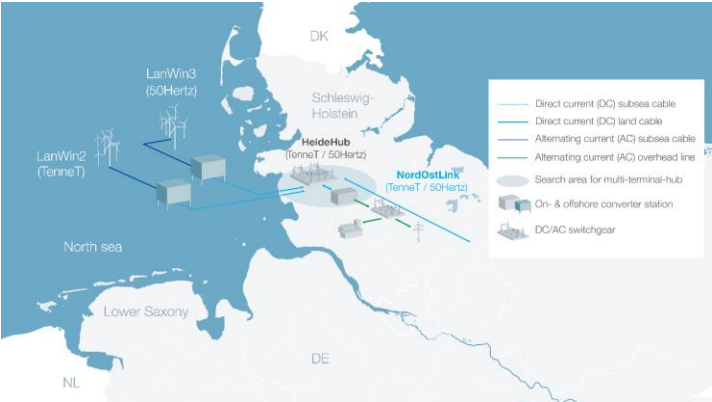
Multi-terminal HVDC grids are on the rise

- The first multi-terminal grids are appearing
 - For now single vendor
- Many future HVDC projects are being specified to be 'multi-terminal ready'
 - Compatible physical characteristics
 - Spare DC disconnector bays
- Several European grid planners have announced plans for multi-terminal HVDC grids
- Initiatives to solve multi-vendor interoperability underway

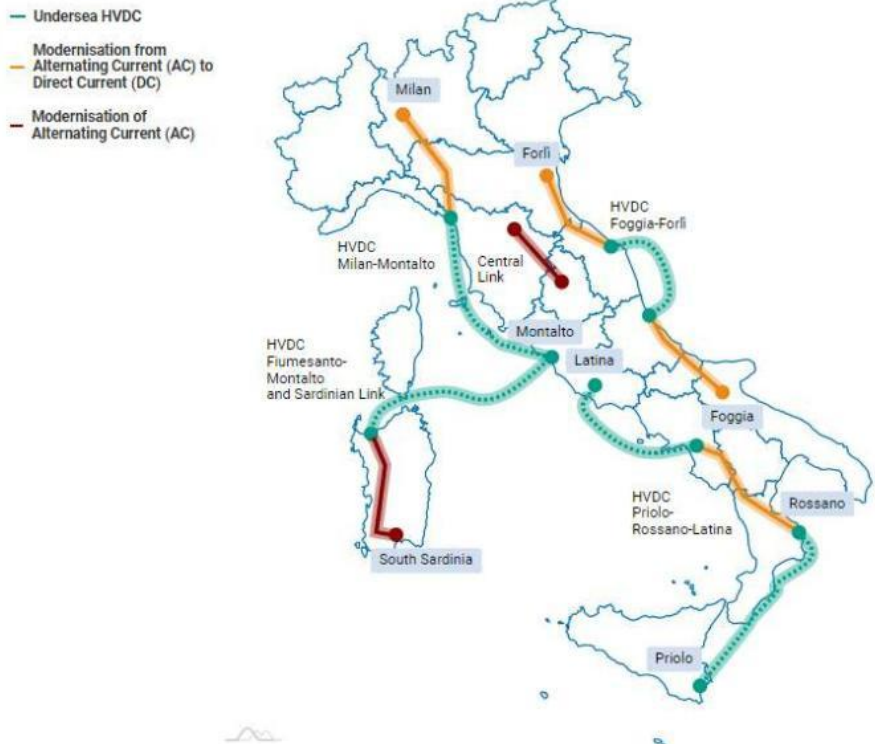


HVDC overlay grids now long term strategy in Europe!

Heide & Rastede HVDC onshore hubs



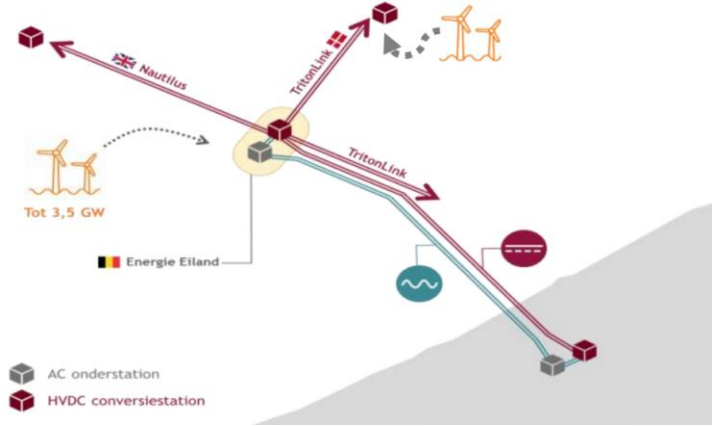
Italian 'hypergrid' - Terna



Dutch-German 'target grid' - TenneT



Belgian & Danish energy islands



National and EU wide policy and coordination frameworks support uptake of HVDC

Policy frameworks

- Common EU [HVDC AC interface grid code](#)
- [Multi-lateral agreements](#) between [countries](#) for transmission and wind farm planning
- Market models for interconnectors
- TSO cooperation mechanisms
 - Cross-border grid planning: [ENTSO-E](#), [NSWPH](#), [EUROBAR](#)
 - Reserve sharing [platforms](#)
 - [Monitoring](#) of HVDC performance

Technology coordination

- EU demonstration projects to de-risk HVDC technology: [PROMOTioN](#), [Interopera](#)
- [TenneT 2 GW, 525 kV program](#)
 - Technology qualification
 - [Mega tenders](#)
 - [Standardisation](#)
- Multi-terminal technology pilots
 - [HVDC circuit breakers](#)
 - [Vendor interoperability](#)

Take aways

- HVDC technology can be a **key enabler of energy policy targets** with lowest impact
- HVDC transmission is **rapidly growing** and **significant operational experience** exists
- The growth is enabled by **valuable grid support capability of Voltage Sourced Converters**
- VSC-HVDC transmission is **mature technology**
- VSC-HVDC can **combine with overhead lines** to increase utilization of existing right of ways
- **Convert existing AC overhead lines to DC** for improved performance
- **HVDC overlay grids** now long-term strategy in Europe!
- National and EU wide **policy and coordination frameworks** support uptake of HVDC

Thank you

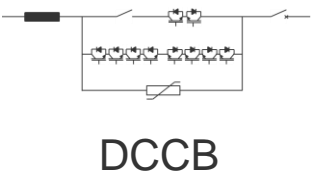
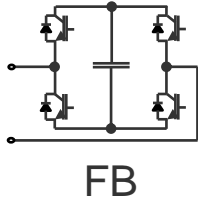
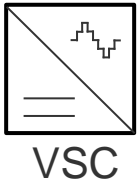
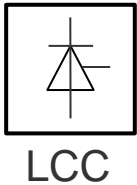
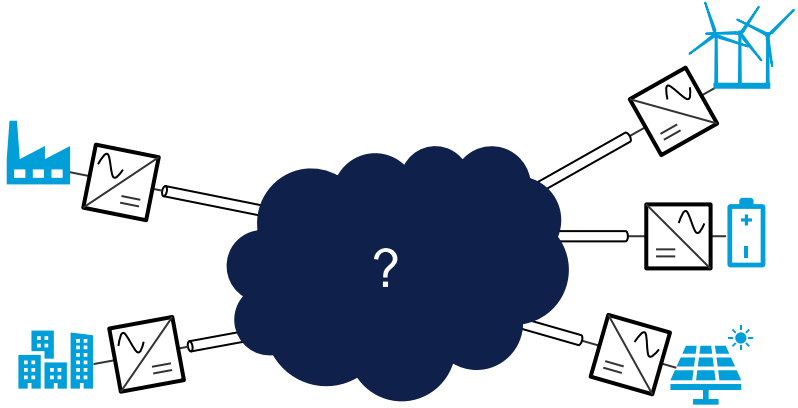
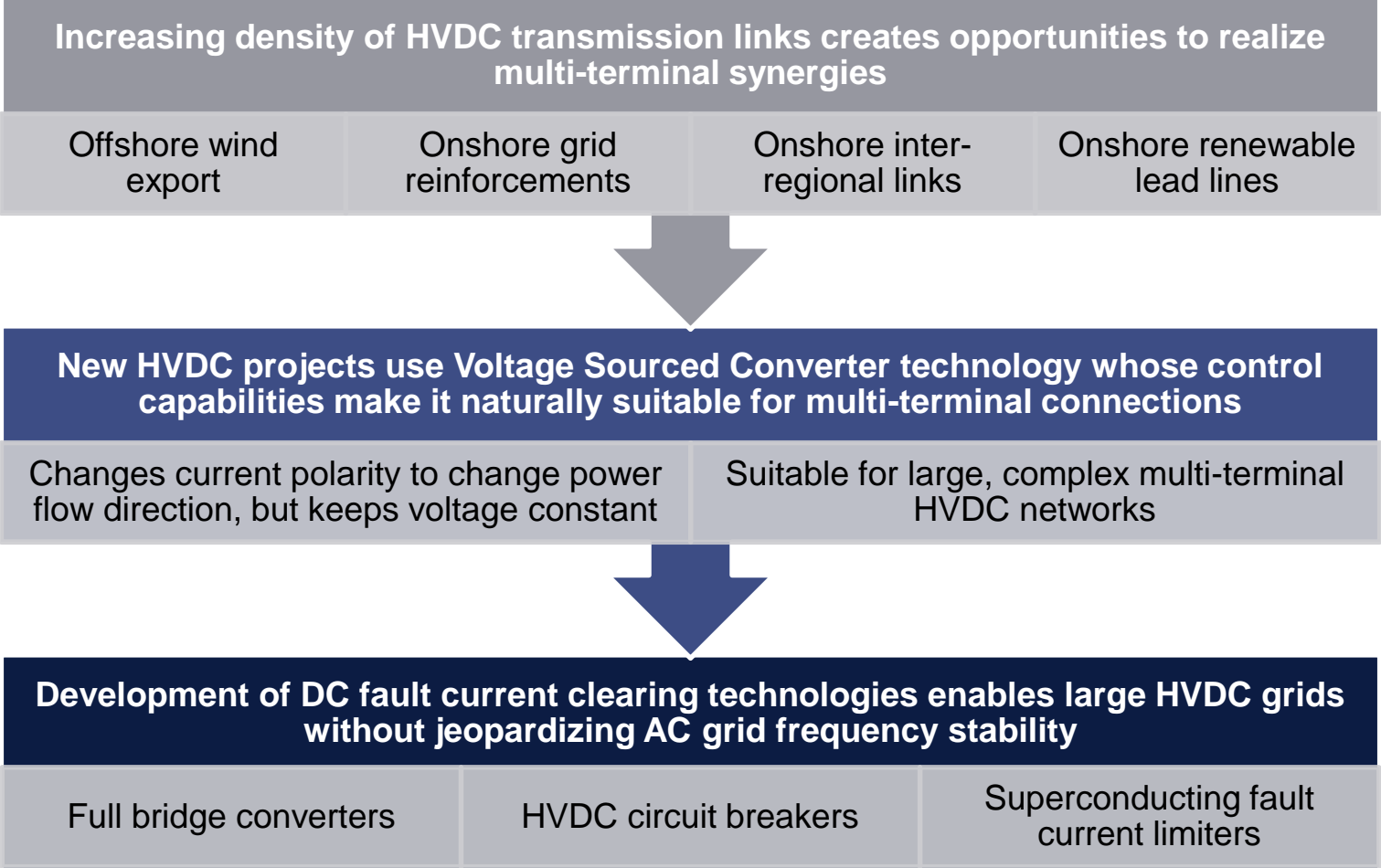
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Gradual shift from point-point links to multi-terminal



HVDC technology enables Europe achieve its climate & energy policy targets through:

