The National HVDC Centre

Operators Forum

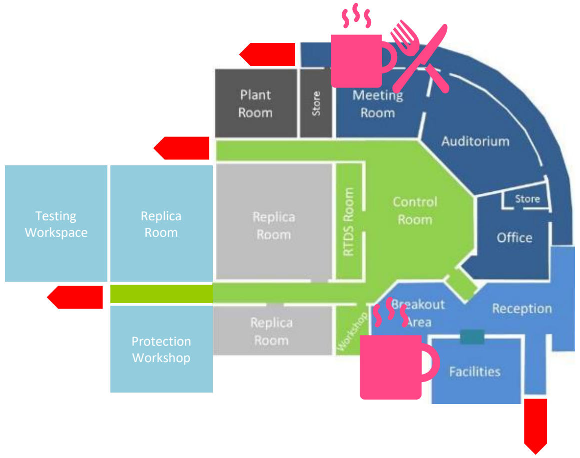
Welcome and Overview of Event

10/11 June 2026

Ben Marshall, Technology Manager

The National HVDC Centre *part of* Scottish & Southern Electricity Networks *together with* nationalgrid SP Energy Networks NESO National Energy System Operator

Housekeeping – Site Safety



Fire Safety

- **Exits:** Familiarise yourself with the nearest exits.
- **Assembly Point:** The fire assembly point is on the pavement outside the main gate.
- **Call points, extinguishers & blanket.**



Note: Weekly Fire Alarm Test is every Thursday at 9:00am cancelled

Caution: Hot Water

Please take care with our:

- Boiling water tap; and
- Kitchen sink tap is also very hot.

First Aid

- There are first-aid kits, burns kits and a defibrillator on site.
- Simon, Fabian, Asif and Yaxing are trained first-aiders, please contact them for assistance.




Safety Rules

- Reverse Park
- Sign-In & Out
- Assess Risks
- Report All Incidents/Hazards
- Accept Challenges

The National HVDC Centre

Scottish & Southern Electricity Networks

Housekeeping – Operators Forum meeting etiquette

The National HVDC Centre

There's a lot of people here today, so-

- Please keep mobile phones on silent and feel free to pop in and out of the Auditorium as you need to, as discreetly as you can.
- Please be courteous to speakers. For questions, don't shout over or interject; we have allocated time for Q&A and panel interactions across the event.
- Please be conscious of keeping to time when presenting and similarly during coffee breaks.
- Please use flipcharts / room white board to record any further questions, observation/discussion points, expectations. We will come back to these across the event where we can.

HVDC Centre – end of an era – and beginning of a new one…

The National HVDC Centre

2013-2017 "living the dream"	2017-2021 "building the dream"	2021-2026 "consolidating the reality"	2026-2031 "reality bites busy and big"
• NIC project start • Implement Centre building • Implement RT & replica simulation environment • Develop partnerships • "Finding our feet" derisking	• NIC project ends • Occupy building & use capabilities • De-risk HVDC projects in replica and modelling • TAB, Operators forum, stakeholder projects • Offshore co-ordination, grid forming, international projects, R&D in UK &EU	• BAU activity • Extend the building, new capabilities • New industry tools, methods, patents, models. • + collaboration across industry & research • Range of project and strategic de-risking inputs	• + Supporting NZ delivery • New building & further new capabilities • GB scale RT simulation (LENS) • Increasing international partnerships • Enhanced operational support at scale

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ectricity Networks

Another adventure about to start for Simon Marshall who got us here…

- Next month, Simon will start a 1-year sabbatical after leading The National HVDC Centre from its beginnings
- Please wish Simon a great break over the next year!

Welcome to Operators Forum 2026 – Delivery at pace and scale...

The National HVDC Centre

Morning Session

09:00 Teas, Coffees, Cakes and Registration

09:30 **Welcome and Overview of the Event**
Ben Marshall, The National HVDC Centre

09:45 **Opening**
Dave McKay, SSEN-T

Session 1 "Big Picture Strategic Planning": What are the game changers for 2030 and beyond?

10:05 **Introduction**
Ben Gomersall, The National HVDC Centre

10:15 **Clean Power 2030 and Beyond**
Laura Schade, *DESNZ*

10:35 **Big Picture Resilience**
Robert Keast, Carbon Trust

10:55 Coffee Break

11:15 **HVDC Technology- International Trends and Opportunities**
Ben Marshall, The National HVDC Centre

11:35 **VSC HVDC Controls - Gaps and Possible Ways Forward - Results from the 'Evolution of VSC HVDC Controls Project'**
Mike Barnes, University of Manchester

11:55 **Panel Q&A**

12:15 LUNCH

Tours, Exhibition & Networking

Afternoon Session

Session 2 "Technology Developments": How should HVDC product design change in response to strategic needs?

14:15 **Introduction**
Adam Scott, The National HVDC Centre

14:25 **Regulatory and Policy Aspects of the Meshed DC Grid**
Biljana Stojkovska, Hitachi Energy

14:45 **Control & Protection Developments to Facilitate Future Multi-Terminal HVDC systems**
Carl Barker, GE Vernova

15:05 Coffee Break

15:25 **Multi-vendor HVDC: Trends, Experiences, and Ongoing Development**
Fred Page, Mitsubishi Electric

15:45 **Superconducting Fault Current Limiters for HVDC Grids**
Alberto Bertinato, SuperGrid Institute

16.05 **Panel Q&A**

16.45 Close

Event Dinner
10th June 2026
Westerwood Hotel – The Conservatory
Starting at 18:30

Morning Session

08:30 Teas and Coffees

09:00 **Welcome to Day Two**
Simon Marshall, The National HVDC Centre

09:10 **HVDC Centre Achievements**
Ben Marshall, The National HVDC Centre

Session 3 "Lessons from Owners and Operators": What are the key challenges in delivery, operation, and asset management?

09:30 **Introduction**
Colin Foote, The National HVDC Centre

09:35 **Preparing for Day One: Building Operational Readiness During Construction**
Ian Reed, NeuConnect

09:55 **Recent Developments from the Moyle Interconnector**
Vahid Sabzpoosh, Mutual Energy

10:15 **Lessons from operating the CMS link**
Cameron McHardy, SSEN Transmission

10:35 Coffee Break

10:55 **FIFA – extending the life of the UK's first HVDC interconnector**
David Monkhouse, National Grid Ventures

11:15 **Lessons from operating Greenlink**
Matthew Gibson, Greenlink

11:35 **Learnings from Sofia windfarm**
Chris Smith, RWE

11:55 **Panel Q&A**

12:15 LUNCH & NETWORKING

Afternoon Session

Session 4 "De-risking Integration": How do we de-risk HVDC integration at scale?

13:15 **Introduction**
Dong Chen, The National HVDC Centre

13:25 **EMT Model Requirements for Plant Connections in EirGrid and SONI Systems**
Sebastien Dennetiere, RTE international & Treisa Sahaya, EirGrid

13:45 **Network Reduction Techniques for Interaction Analysis**
Diptargha Chakravorty, Siemens Energy

14:05 **TO experiences of de-risking HVDC integration**
Afshin Pashei, NGET

14:25 Coffee Break

14:40 **System Operator Perspectives on the Future use and Operation of HVDC Technology**
Ankur Majumdar, NESO

15:00 **HVDC Supervisory Control Technology from the System Operator's Perspective**
Gumin Kwon, KEPCO

15:20 **Wrap-up**
Ben Marshall, The National HVDC Centre

15:30 Close

Scottish & Southern Electricity Networks

Next

Keynote Speech – Dave McKay (SSEN Transmission)

The Benefits of Growth in The Transmission System

Dave McKay

Network Director

10 June 2026

Scottish & Southern Electricity Networks
TRANSMISSION

MAIN NORTH OF SCOTLAND ELECTRICITY TRANSMISSION NETWORK IN 2030

Scottish & Southern Electricity Networks
TRANSMISSION

In-flight Investments

1. Argyll 275kV strategy
2. Fort Augustus to Skye 132kV upgrade
3. Orkney 220kV AC subsea link

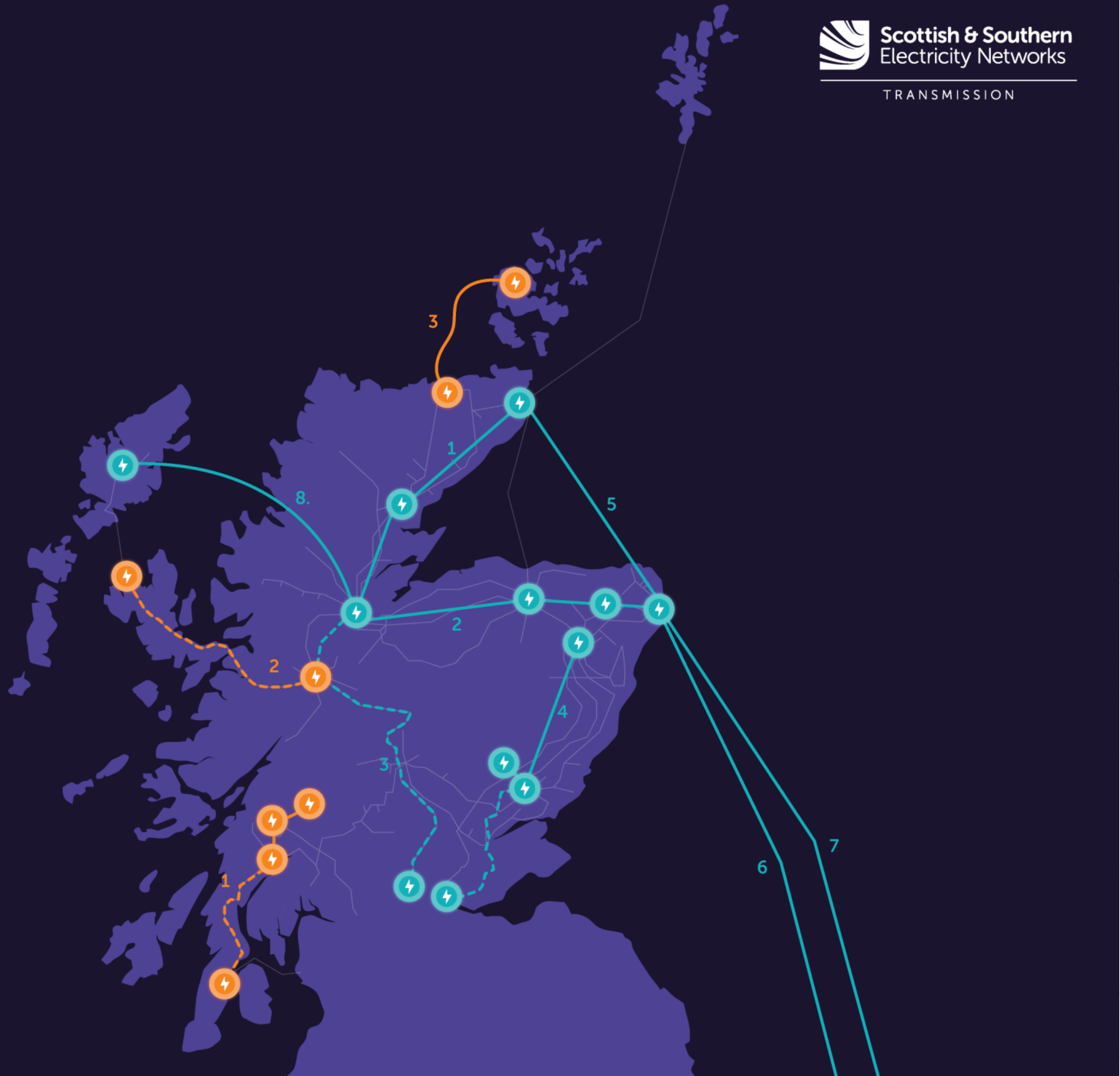
Pathway to 2030 Investments

1. Beauly to Loch Buidhe to Spittal 400kV
2. Beauly to Blackhillock to New Deer to Peterhead 400kV
3. Beauly to Denny 400kV uprating (with SPT)
4. Kintore to Tealing (with connection to Alyth) to Westfield 400kV (with SPT)
5. Spittal to Peterhead 2GW HVDC subsea Link
6. Peterhead to Drax 2GW HVDC subsea link – Eastern Green Link 2 (with NGET)
7. Peterhead to South Humber 2GW HVDC link – Eastern Green Link 4 (with NGET)
8. Western Isles 1.8GW HVDC link

Public Consultation to Inform Project Development

All new reinforcements remain subject to detailed consultation and environmental assessments to help inform route and technology options

More detail on these projects, including how to sign up for updates, will be made available on SSEN Transmission's website, www.ssen-transmission.co.uk



New Infrastructure (Routes shown here are for illustrative purposes)
Upgrade/Replacement of Existing Infrastructure
Existing Network

Big Picture Strategic Planning: What are the game changers for 2030 and beyond

Ben Gomersall,
The National HVDC Centre

The National HVDC Centre

Scottish & Southern Electricity Networks
TRANSMISSION

What are the game changers for 2030 and beyond?

Session aims

- Share industry perspectives on where the field is heading toward 2030 and beyond.
- Step back from day-to-day project delivery and assess whether we are moving in the right direction.
- Set the context for today and tomorrow.

Let's see what Copilot can do.

National
C Centre

Themes:

Generally good but generic

7/10

Details:

Overly optimistic and not fully correct

4/10

Aesthetic:

Good at first glance but worse the longer you look

5/10

Conclusion:

Not going to replace our excellent presenters…yet.

*This is AI generated and not checked

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city Networks
MISSION

Agenda

Session 1 **"Big Picture Strategic Planning": What are the game changers for 2030 and beyond?**

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Ben Gomersall, The National HVDC Centre

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11:55 **Panel Q&A**

12:15 **Group Photo & Lunch**

Thanks for listening.

Any questions, please?

For further information, please visit **www.hvdccentre.com** or email **info@hvdccentre.com**

www.hvdccentre.com/technical-films/

The National HVDC Centre

Follow our Linkedin page **The National HVDC Centre** for regular updates.

Department for Energy Security & Net Zero

Clean Power 2030 and Beyond

HVDC Operations Forum 2026

June 10, 2026

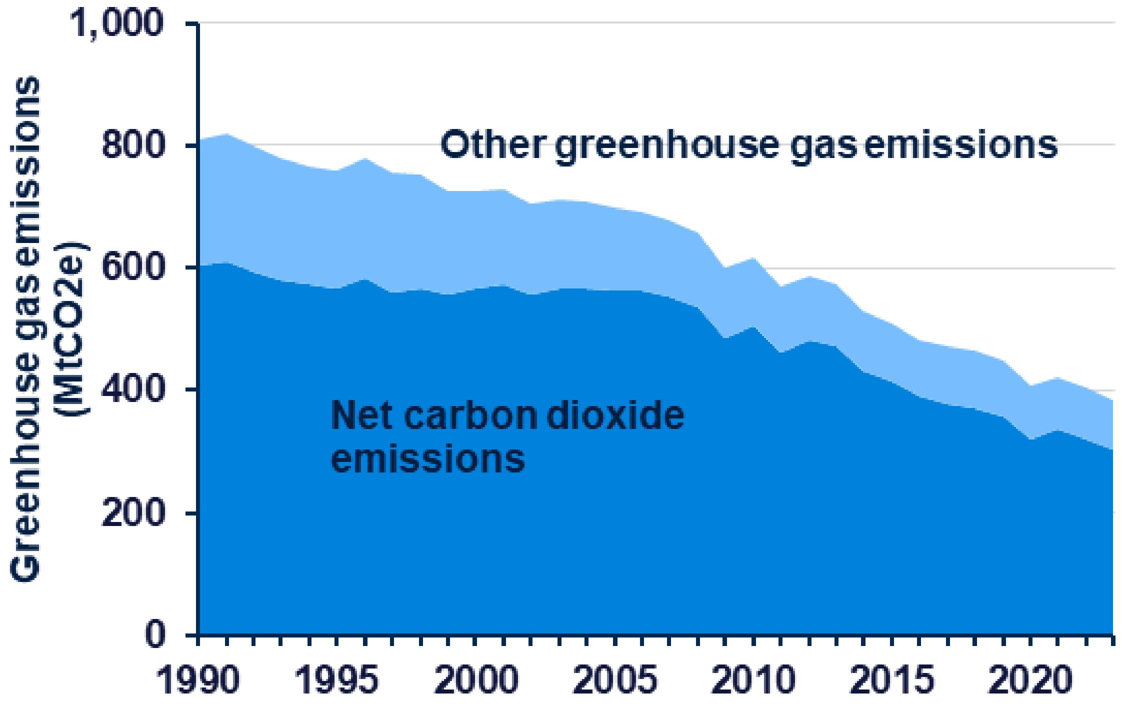
Dr. Laura Schade

Agenda

- Clean Energy Superpower Mission
- Role of HVDC in GB
- Interconnector next steps
- Electricity Network Sector Growth and Supply Chains
- Research and Development

UK is committed to net zero carbon emissions

- The UK is legally committed to Net Zero by 2050
- The UK is the first G20 country to halve its emissions, achieving this milestone in 2022



DESNZ Figures

UK Energy Priorities

Clean Energy Superpower Mission

Clean Power by 2030

Increasing the deployment of renewables, investing in CCUS and hydrogen, removing barriers in the planning process, grid and supply chains.

Policy

- Clean Power 2030 Action Plan
- Industrial Strategy
- CESM Areas of Research Interest
- Clean Tech Challenges

Accelerating to Net Zero

Net zero is a significant economic opportunity and our domestic performance is crucial for re-establishing UK global leadership on climate.

Government support for research, development & innovation

to support the Clean Energy Superpower Mission significantly increases the likelihood of delivering and sustaining the Clean Power by 2030 target and accelerating to net zero.

R&D for evidence ↔ **R&D for delivery** ↔ **R&D for innovation**

Clean Power 2030

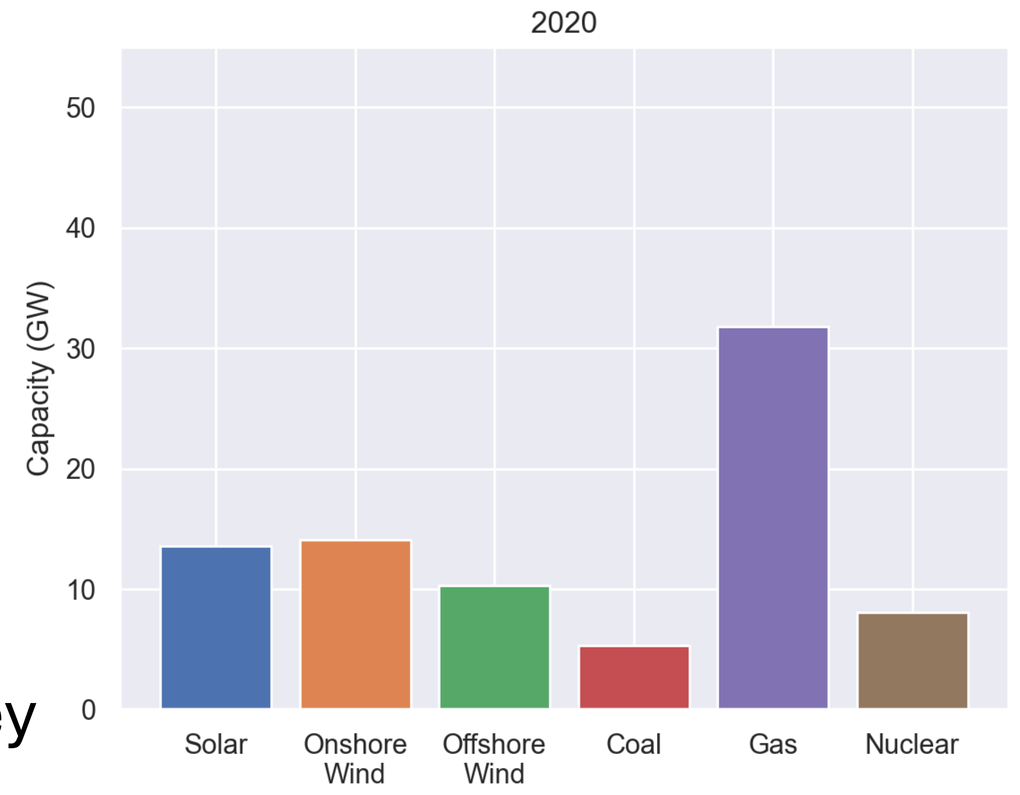
- The UK Government has set the ambitious goal of achieving a clean power system by 2030. This means:

Clean sources produce at least as much power as Great Britain consumes in total

Clean sources produce at least 95% of Great Britain’s generation

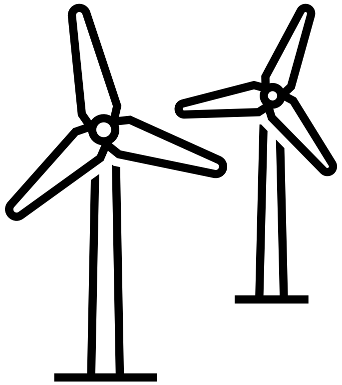
Clean power requires electricity generation shifts

	2024		2030
Onshore wind	14.2 GW	→	27-29 GW
Offshore wind	14.8 GW	→	43-50 GW
Solar	16.6 GW	→	45-47 GW

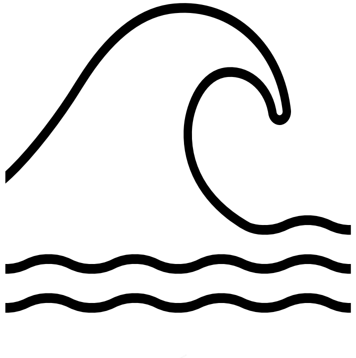


Beyond 2030, electrification of demand is key for decarbonisation, requiring further investment in generation and network capacity.

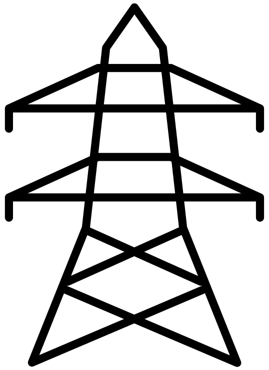
HVDC techs have a key role especially in:



Offshore wind



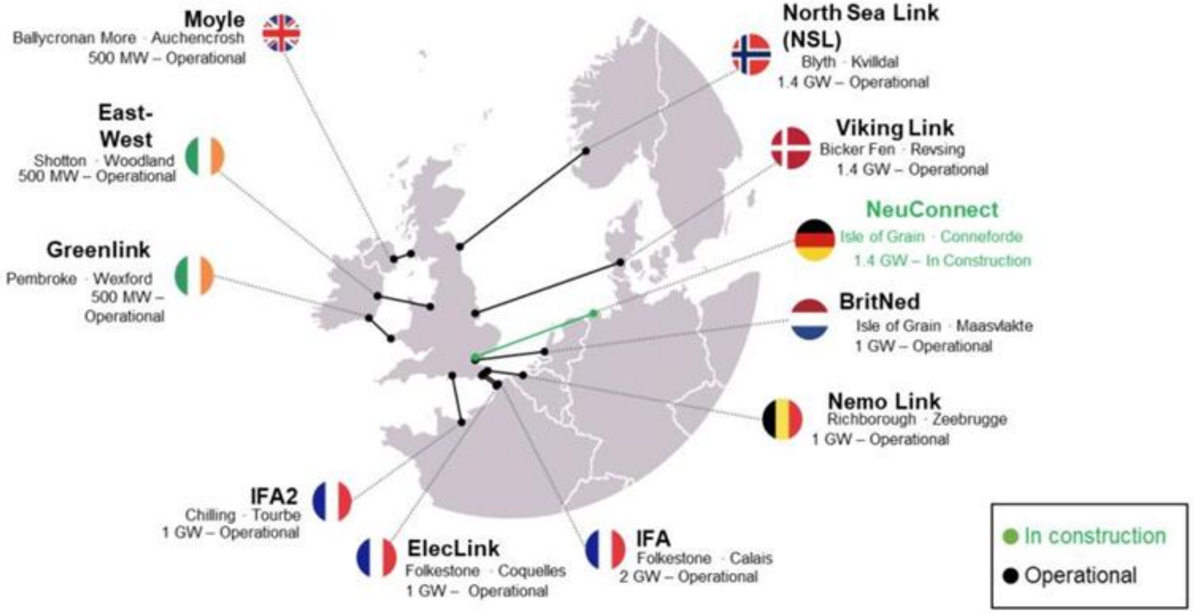
International interconnection



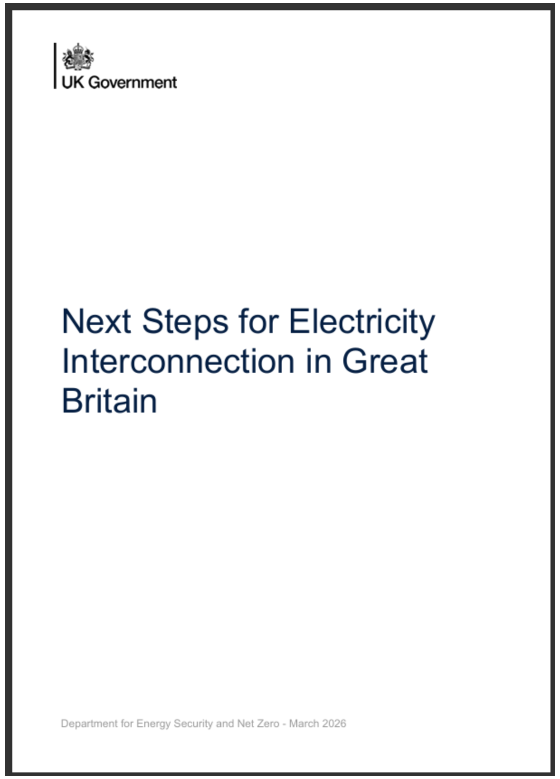
Domestic GB networks

Next Steps for Electricity Interconnection in Great Britain

- In March 2026, DESNZ released *Next Steps for Electricity Interconnection in Great Britain*



Source: Internal DESNZ representation


UK Government

Next Steps for Electricity Interconnection in Great Britain

Department for Energy Security and Net Zero - March 2026

[Next steps for electricity interconnection in Great Britain]

Next Steps for Electricity Interconnection in Great Britain

New strategic approach

- Interconnector deployment will move to a strategically planned, whole-system approach guided by NESO's new strategic planning
- Great Britain's renewables-based system is changing the drivers for interconnection, increasing the need for flexibility and coordinated offshore planning

Government objectives for electricity interconnection

1. Delivering new interconnectors and Offshore Hybrid Assets that are strategically aligned with a Net Zero energy system
2. Strengthening cooperation with international partners to support the timely delivery of projects on the right terms
3. Ensuring the efficient operation of the interconnector fleet and supporting delivery of pipeline projects to ensure they provide the most value

Our next steps

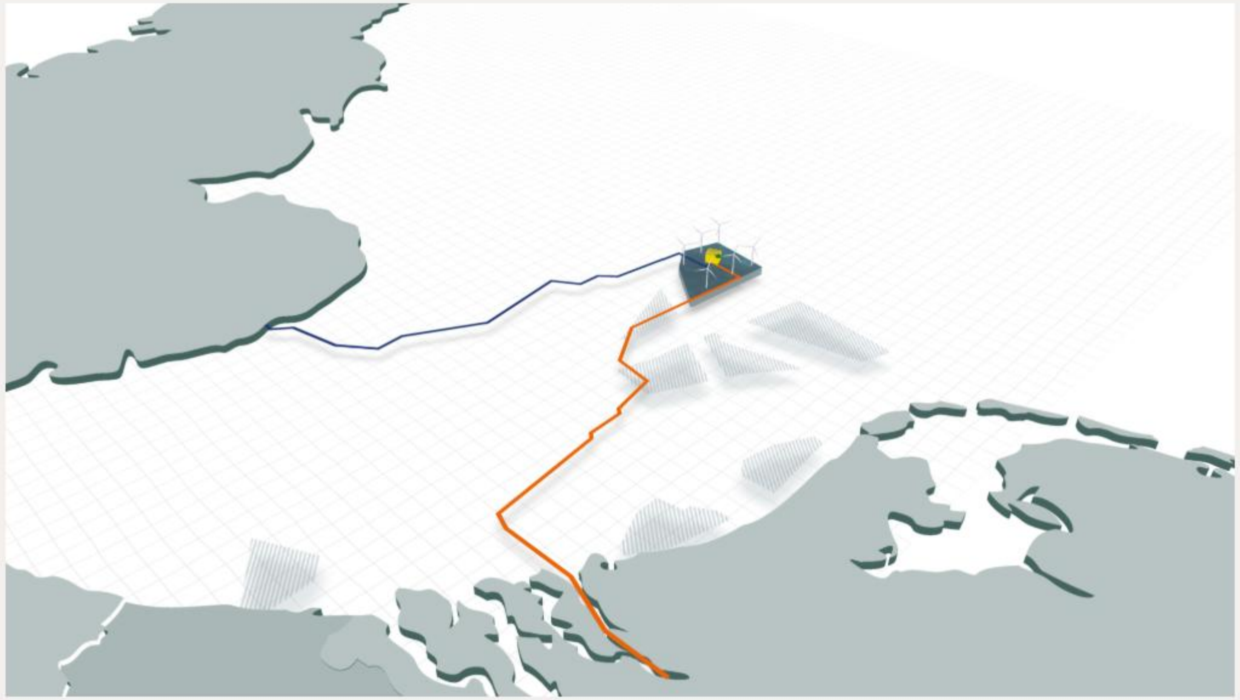
- Improving the efficiency and system value of the existing interconnector fleet, ensuring current assets and pipeline projects continue to deliver maximum benefits for consumers
- Designing the future delivery & financing frameworks alongside Ofgem, including exploring the commercial viability of Offshore Hybrid Assets (OHA)
- Aligning these with NESO's strategic planning in the SSEP (2027) and CSNP (2028)
- Deepening cooperation with European partners to enable GB to continue to play a leading role in the delivery of OHAs and realise the benefits of coordination

Engagement timeline

- Ofgem Call for Input on the regulatory model for interconnectors 25/03/2026
- DESNZ strategic publication and Ofgem consultation in Autumn 2026

Offshore hybrid asset in development: Lion Link

- This would be a first-of-a-kind electricity link between the UK and the Netherlands
- This would be a vital step toward an integrated North Sea grid
- On the GB side, National Grid consultation was January to March 2026, with responses currently under review



The blue line represents the LionLink connection

Source: https://www.tennet.eu/nl-en/projects/lionlink

Supply Chains

Electricity Networks Sector Growth Plan

- An **industry-led plan** which will drive collective action across the sector to **drive growth:** boost domestic supply chain and skills capabilities.
- **Interim publication** in Dec 25, setting out early evidence and actions to drive delivery. Full plan publication expected **~September**.

Supply Chains

Regulation, Legislation & Investment

- ❑ **Ofgem** have developed interventions to support procurement: the Accelerated Strategic Transmission Investment **(ASTI)** framework has **enabled early and programmatic procurement** for key HND projects, while the Advanced Procurement Mechanism **(APM)** will continue to enable a similar approach more generally across projects to improve access to equipment and accelerate build.
- ❑ **DESNZ / Ofgem / CO** reviewing regulations, legislation, and network owner procurement to consider how to **improve growth of domestic supply chains** to enable ambitions of Industrial Strategy.
- ❑ **GBE** have **launched £300m** OFW & networks manufacturing **fund**.

Data & Evidence

- ❑ Tracking **supply-demand gaps** in electricity network components to 2035+
- ❑ Map & boost current/future. manufacturing capabilities.
- ❑ Working with the sector to identify supply chain bottlenecks and boost exports.
- ❑ Assessing critical minerals demand with DBT.

Supply Chains

Summary: Key objectives to improving supply chains

- ❑ A **sector growth plan** which quantifies/tracks equipment + skills demand and increases investment opportunities to grow domestic capabilities.
- ❑ A regularly updated quantifiable **Supply chain health risk assessment** to CP30, NZ and industrial strategy objectives.
- ❑ **Regulatory and procurement environment**: Ofgem support and incentivises, and network owner procurement behaviour, which appropriately enables growth of domestic supply chains and addresses order certainty.

Great British Energy Supply Chain Fund

To construct new, or extend existing, manufacturing facilities in the UK

Offshore wind sector	Related electricity networks sector
Mooring and Anchoring	High Voltage Direct Current (HVDC) Cables
Blades	High Voltage Alternating Current (HVAC) Cables (including Dynamic)
Nacelles	Power Transformers (AC & DC)
Towers	HVDC Converter Stations
Transition Pieces	Switchgear
Monopiles	Reactive Power Management & Control systems

Contracts for Difference Clean Industry Bonus

- The CfD Clean Industry Bonus (CIB) means fixed and floating offshore wind applicants can obtain extra CfD revenue support if they choose to invest in more sustainable supply chains
- CIB is our key demand signal policy on offshore wind which is in its infancy through AR7
- DESNZ will be continuing to review its effectiveness over AR8 to establish how it should be taken forward and any changes required
- DESNZ concluded a consultation on contract amendments to implement Clean Industry Bonus reforms in May 2026
- We expect CfD Allocation Round 8 to open this **July**

Clean Power 2030 Action Plan

Technologies to deliver Clean Power by 2030, and to support increasing electrification of the economy out to 2050.

2030 Priority | Offshore/Onshore Wind I Solar I Bioenergy I Heat Pumps I CCUS I Energy Storage

2050 Priority | Floating Offshore Wind I Tidal Stream I Decarbonising Industry and Buildings I EVs

Industrial Strategy

Technologies to deliver the Mission in a way that utilises UK strengths and resources:

- Attract over £30 billion annual investment
- Grow exports to create jobs
- Drive domestic commercialisation
- Secure resilient and robust supply chains.

10 Year Strategy: Frontier Industries | Onshore Wind I Offshore Wind I Floating Offshore Wind I Heat Pumps I CCUS I Hydrogen I Fusion Energy I Nuclear Fission

R&D for evidence

Research and Development are the building blocks for robust, evidence-based policies; ensuring we make the right decisions at the right time.

For the Clean Power Action Plan and Industrial Strategy, analysis of UK R&D helped to identify what technologies:

1. *can deliver a Clean Power System*?*
2. *will achieve our goals by 2030 and 2050?*
3. *will bring the greatest economic opportunities?*
4. *and the benefits of innovation?*

*A Clean Power System is one where clean sources produce at least as much power as Great Britain consumes in total and at least 95% of Great Britain's generation. A Clean power system will see a deduction in the carbon intensity of electricity generation to well below 50gCO_2e /kWh in 2030.

CESM Areas of Research Interest

Clean Tech Challenges

CESM Areas of Research Interest

To align research proposals, **support** dialogue, **inform** funding decisions, and **guide** cross-sector collaboration

9 Priority R&D Challenges

For Clean Power 2030:
Energy Storage I Flexible Demand I Supply-side Flexibility I Offshore Wind

For Net Zero 2050:
Circular economy and electrification I Putting the 'Net' in Net Zero I Low carbon fuels I Food system I Society as a catalyst

Clean Tech Challenges

Overcoming mission-critical innovation challenges through financial and non-financial levers:

- drawing on Government's **£86 billion** for S&T.
- engaging innovators and investors **to mobilise investment** – public and private.
- focus efforts on creating **market pull to accelerate deployment.**

R&D for innovation

DESNZ conducts analysis on the innovations needed to meet UK Carbon Budgets, and the policies needed to support this:

1. *How to overcome obstacles to deployment?*
2. *How to bring down costs?*
3. *How to transition to a net-zero economy, including grid innovation?*

R&D for delivery

R&D is essential to deliver key Mission outcomes for the British people:

Economic Growth & Protecting Billpayers I Domestic deployment to *support jobs, drive investment across the country and deliver cost savings.*

Energy Security & Reducing Emissions I *Accelerating the transition away from fossil fuels, reducing reliance on volatile fossil fuel markets.*

Clean Power 2030 Action Plan

Industrial Strategy

Department for Energy Security & Net Zero

Thank you!

CARBON TRUST

Offshore electrical infrastructure security and resilience: The need for cross-industry collaboration

22 June 2026

Our mission is to accelerate the move to a decarbonised future.

5

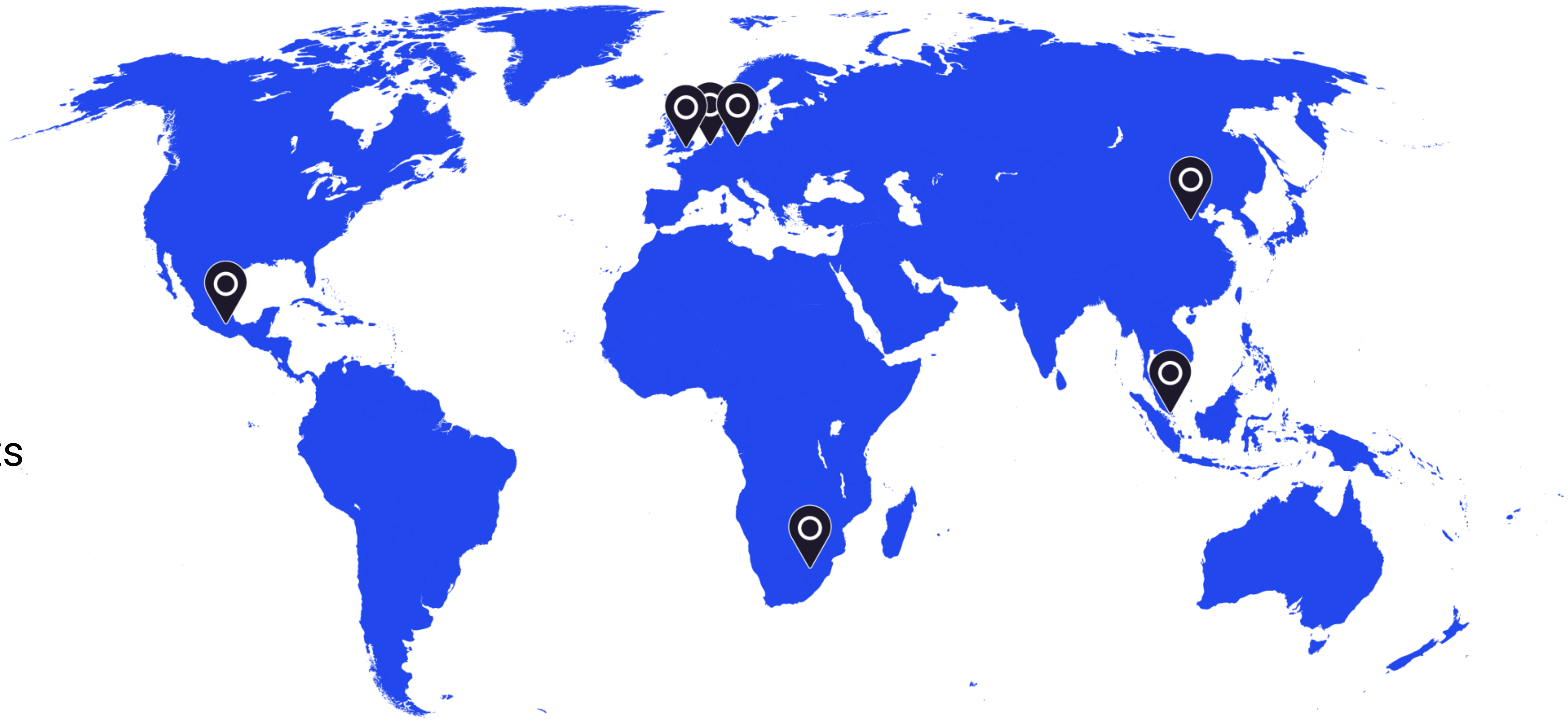
supporting clients across 5 continents

350+

experts and consultants

25

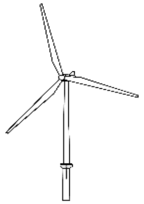
years of experience



Carbon Trust's Offshore Wind Innovation Platform

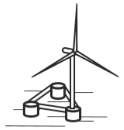
CARBON TRUST

World-leading offshore wind programmes



The Offshore Wind Accelerator (OWA) — 2008

The Carbon Trust's flagship collaborative RD&D programme for bottom-fixed offshore wind.



Floating Wind JIP — 2016

The Floating Wind Joint Industry Programme (JIP) overcomes challenges and advances opportunities for commercial scale floating wind.

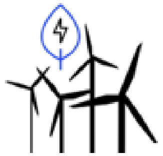
orjip
working to accelerate offshore consenting

The Offshore Renewables JIP (ORJIP) — 2011

Offshore Renewables JIP aims to reduce consenting and environmental risks for offshore projects.

The Integrator — 2020

The Integrator is designed to examine the interplay between offshore wind, existing infrastructure, and other technologies to highlight opportunities for innovation investment.



Sustainability JIP — 2023

The Sustainability JIP aims to decarbonise offshore wind farm developments and support developers to achieve Net Zero targets.

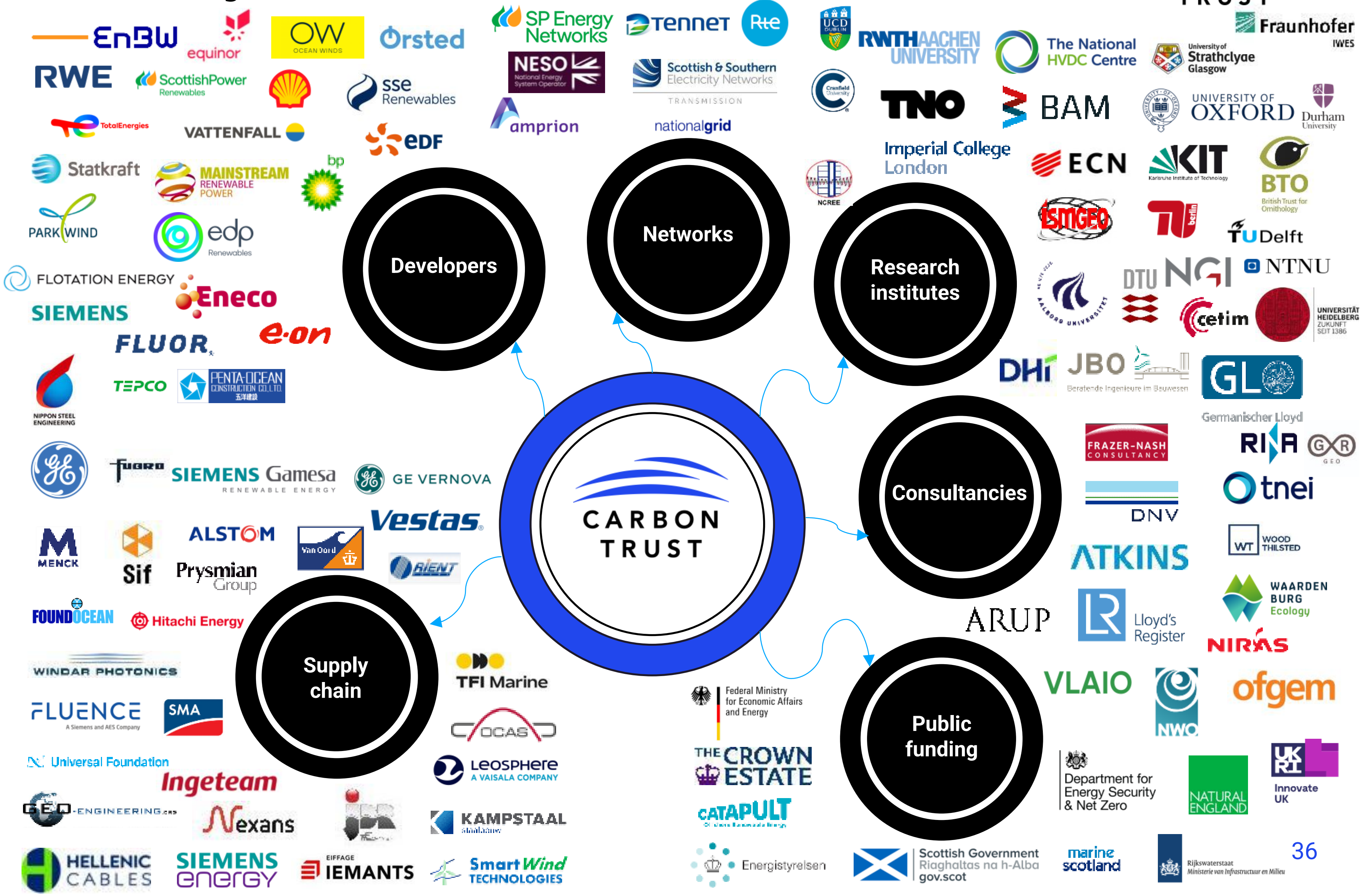
EDF renouvelables
EnBW
equinor
JERA NEX BP
Kyuden Mirai Energy
OW Ocean Winds
Ørsted
RWE
ScottishPower Renewables
Shell
skyborn
sse Renewables
TotalEnergies
TEPCO
Tohoku Electric Power Co., Inc.
VATTENFALL
The Crown Estate
Crown Estate Scotland — Oighreachd a' Chrùin Alba
Scottish Government — Riaghaltas na h-Alba

Our Joint Industry R&D Project Track Record

Our programmes create a **trusted environment for collaboration.** This provides a platform for Joint Industry R&D Projects.

The Carbon Trust is **skilled and experienced** in setting up and running Joint Industry Projects:

- Set up and run **32 JIPs**
- Total budget: **>£95 million**
- Public funding: **>£27 million**



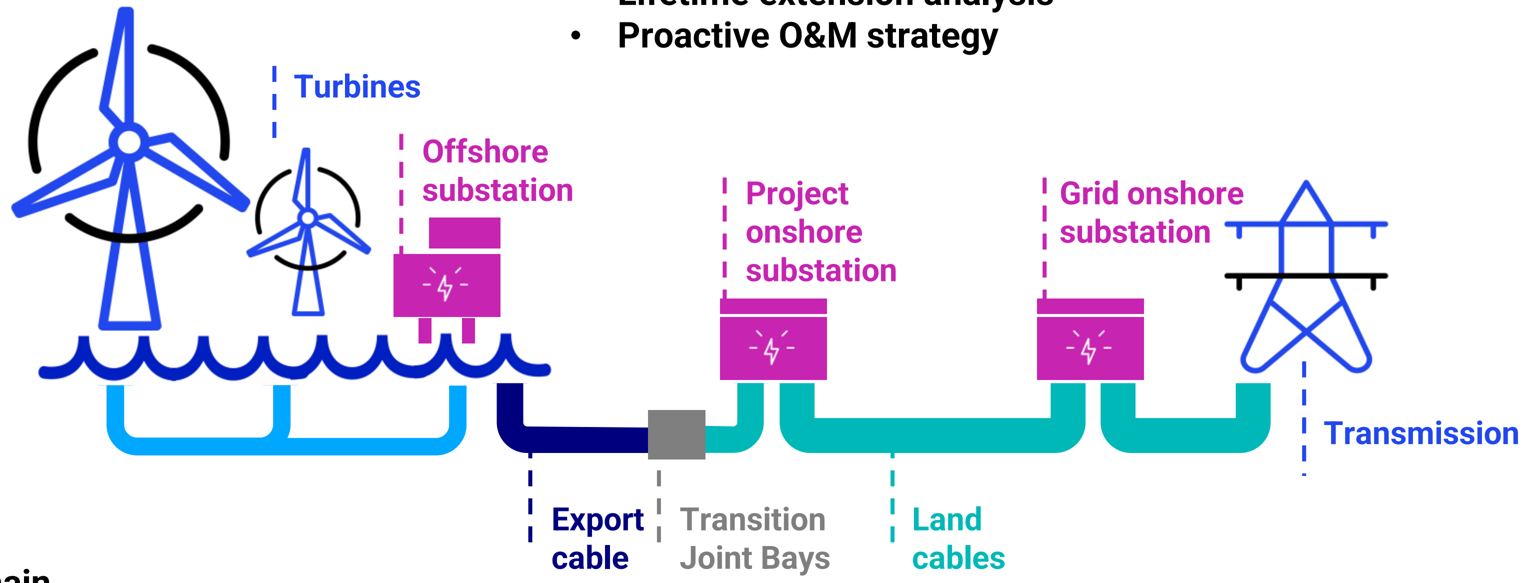
Security and resilience concepts

Security is driven by **failure prevention**

Resiliency is driven by **ability to recover**

Operation
- Condition monitoring
- Lifetime extension analysis
- Proactive O&M strategy

Construction
- Cable burial risk protection
- Cable protection systems
- Cable termination testing



Supply chain
- Spares & vessel readiness
- Universal joints and spares

Systematic issues with security and resilience offshore

CARBON TRUST

Onshore

- Transmission
  - 20,000km
  - 3 companies
- Distribution
  - 800,000km
  - 6 companies
- Average
  - ~90,000km per operator

Offshore

- In operation
  - 20,000km
  - 20 lead developers + 60 other investing companies
- Coming soon
  - 40,000km
  - 20 additional lead developers + 30 additional investing companies
- Average
  - <2,000km per operator

→ **Challenge for system-level security and resilience**

Carbon Trust track record in offshore wind

CARBON TRUST

Carbon Trust programmatic approach has developed several concepts addressing **different layers of security and resilience**

Physical design & protection

Mitigating external threats (anchors, fishing, seabed, impact)

- Cable Burial Risk Assessment (CBRA)
- Cable protection systems guideline (CPS)

Repair & intervention (inc. logistics)

Reducing repair time, cost and complexity

- Universal repair joints (UniCat)
- Termination quality & workforce capability (QQQTs)
- Equipment distribution optimisation (EDO) and spare parts clubs (SPARROW)

Monitoring & diagnostics

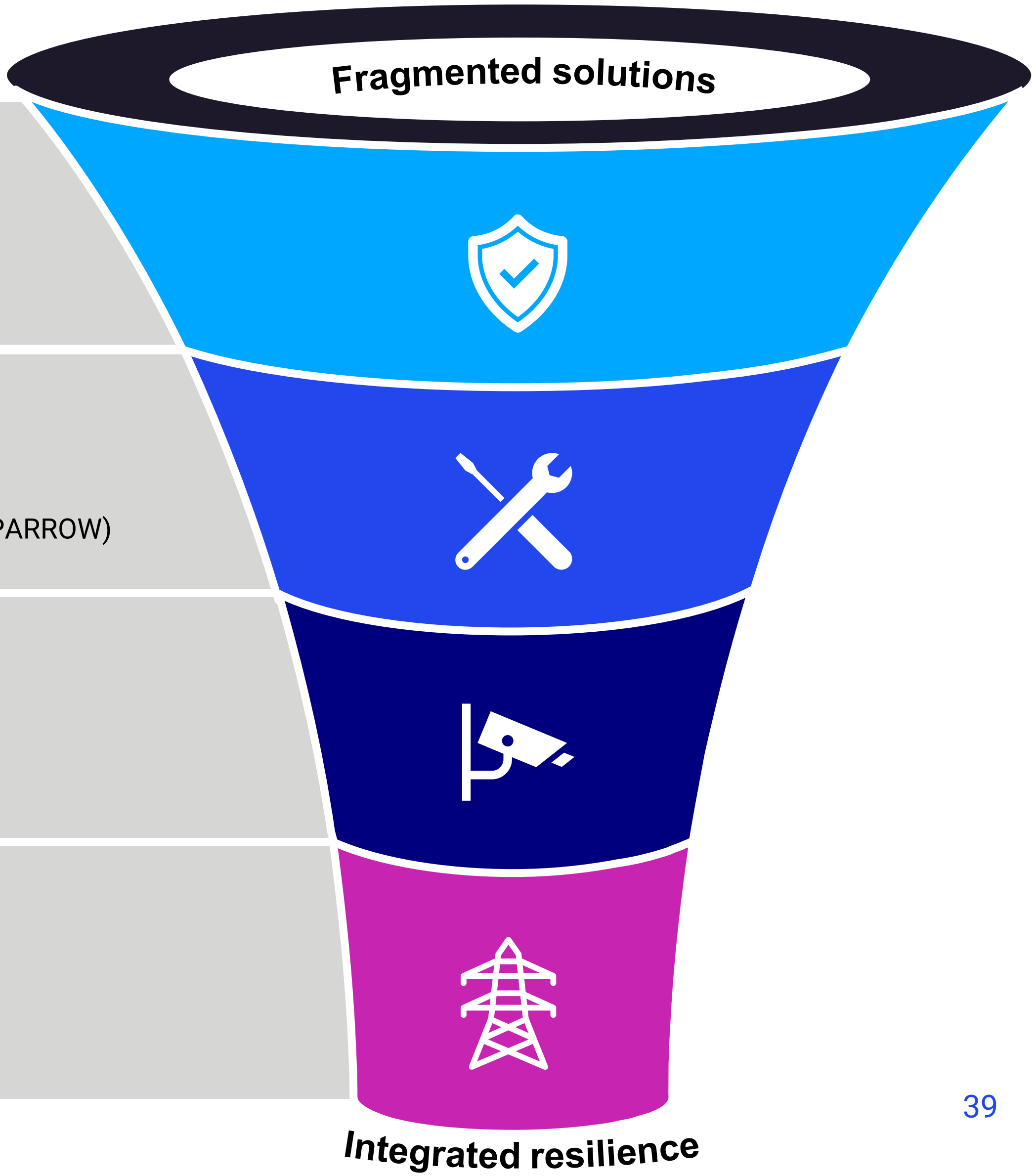
Improving visibility of asset condition

- Lifecycle / degradation assessment (CLEF)
- Cable termination testing (ToAC, FACT)
- Termination condition monitoring (TERM)

Grid stability & recovery

Ensuring system stability and restoration

- Offshore electricity system stability (INCENTIVE)
- Offshore electricity system restoration (BLADE)



Current initiative: Cable Burial Risk Assessment (CBRA) 2.0

CARBON TRUST

Helps specify the optimal depth for cable burial, considering soil conditions and general activity in the area.

More flexible than prescriptive methods as it uses a probabilistic methodology to evaluate risks to cables based on site-specific conditions

Aims to reduce the frequency and severity of cable-related incidents.

CBRA

A standardised approach for assessing cable burial risks

Published 2015

Cable routing → Geological data collection and review → Assessment of seabed conditions focusing on *seabed mobility* → Risk assessment focusing on *natural hazards, commercial fishing, and shipping* → Probability risk assessment

GAP

CBRA continues to be widely used and relied upon, but it was developed more than a decade ago, at a time when offshore wind projects were smaller, less standardised, and operating under different technical and commercial conditions.

There is need to refresh this to reflect current industry practices and risks, across a broader range of stakeholders (not just OSW developers).

Carbon Trust's Offshore Wind Accelerator is going to refresh this in CBRA 2.0 in 2026.

We want this to involve not just OSW developers but also offshore transmission companies with long term ownership and operational exposure to cable assets.

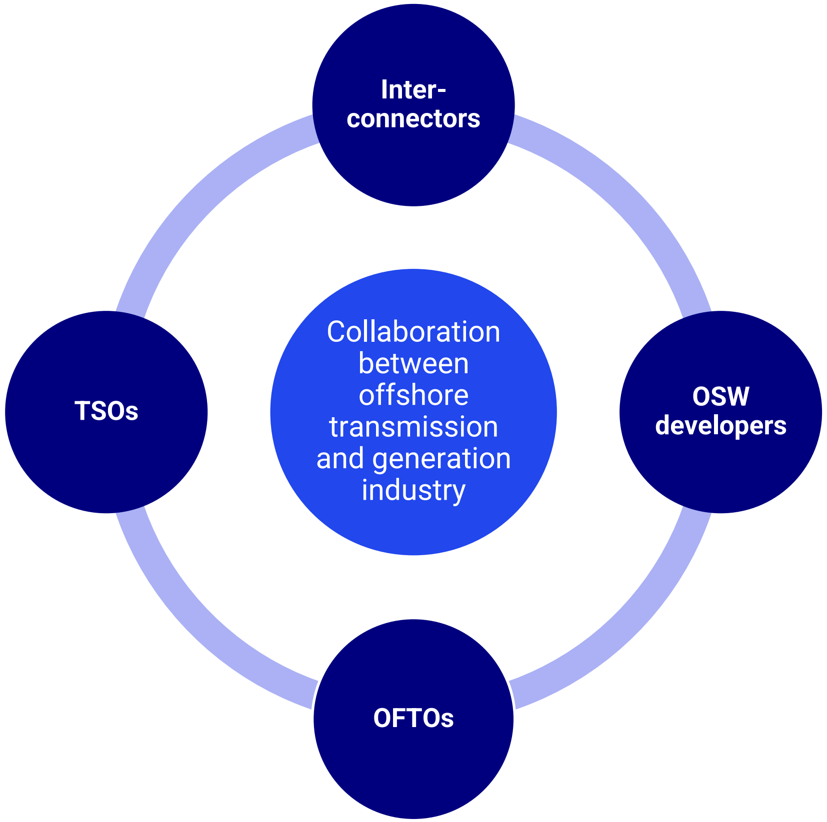
If you are interested to participate, please let me know.

Future initiative: system-level prioritisation and implementation

CARBON TRUST

Aims

1. How do we move from project-level solutions→ to system-level optimisation?
2. What are the must-have concepts not making it to market and how can collaborative de-risking accelerate this?
3. What needs to be coordinated across transmission & generation? E.g. repair frameworks; spare parts & logistics sharing; standardised universal spare parts and repair process; decision-making tools and data



Approach

Proposed project

Discovery Phase

- **Knowledge sharing**
- **Review** of physical security and resilience in other related industries.
- **Gap analysis** to identify opportunities for development in Alpha Phase and to rule out the need for further work

Alpha Phase

- **Technical and economic feasibility study** of the key concepts selected in Discovery Phase.
- **Selection** of biggest impact and most achievable concepts for Beta Phase.

Beta Phase

- **Detailed development** of the key concepts selected in Alpha Phase.
- Drive the key concepts into **commercial implementation** through all necessary development and de-risking, including where necessary:
  - Working with supply chain to develop novel capabilities
  - Physical demonstration of new technical approaches
  - Development of novel legal entities and contracts for novel collaboration arrangements.

CARBON TRUST

Conclusions

Onshore

- Transmission
  - 20,000km
  - 3 companies
- Distribution
  - 800,000km
  - 6 companies
- Average
  - ~90,000km per operator

Offshore

- In operation
  - 20,000km
  - 20 lead developers + 60 other investing companies
- Coming soon
  - 40,000km
  - 20 additional lead developers + 30 additional investing companies
- Average
  - <2,000km per operator

Challenge for system-level security and resilience

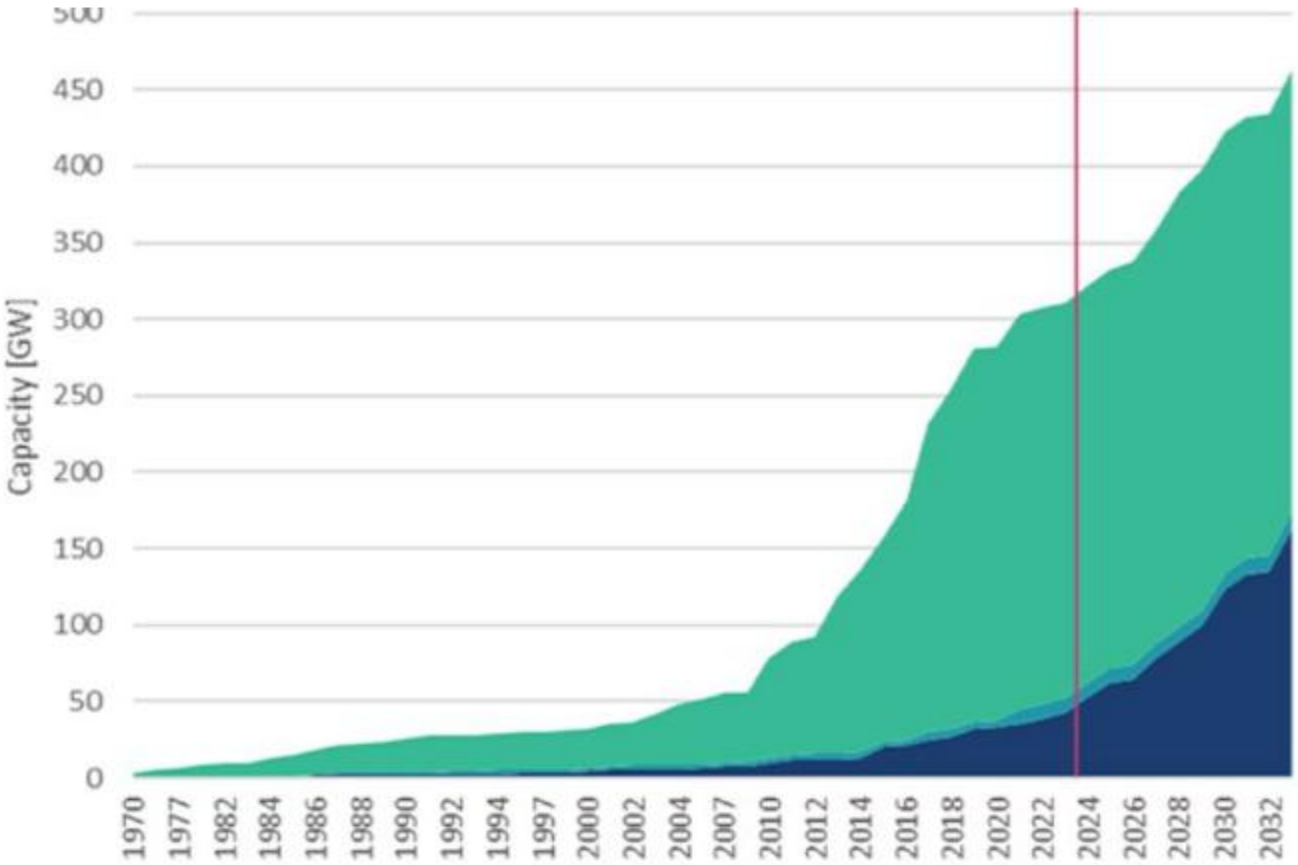
It is now or never to design in system-level security and resilience to individual projects

We must work together to identify specific, achievable, top priority concepts, and make them happen

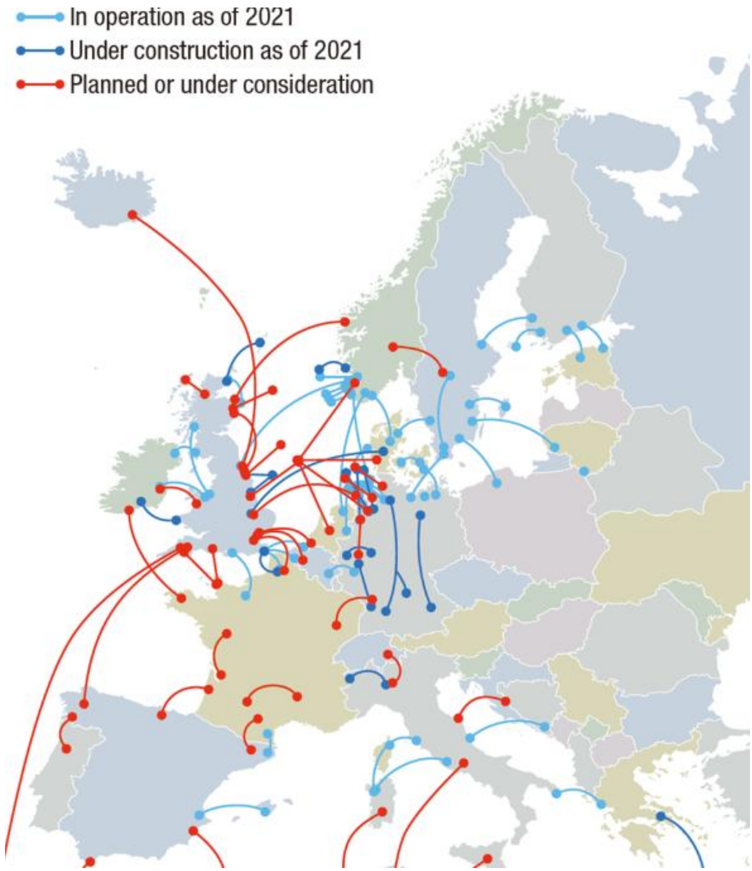
2025-2026: HVDC Technology-International Trends and Opportunities

Ben Marshall, The National HVDC Centre

Growth of HVDC Technology use continues…



World-wide



Europe- ahead of post 2021 commitments

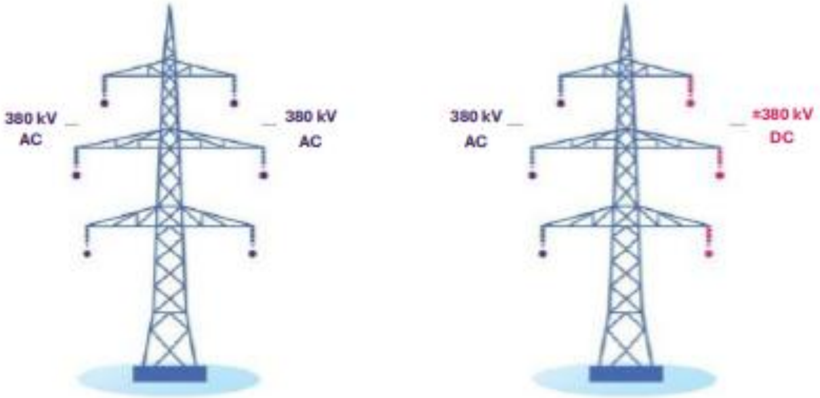
Major HVDC Projects Underway-

Commissioning of Indias first VSC-HVDC to Mumbai city centre

A-Nord 2GW VSC HVDC construction

Installation in China of first 2GW VSC HVDC platform for offshore wind

Cable installation on Suedlink



Ultranet re-use of AC OHL for HVDC

India's Sassaram BtB upgrades LCC->VSC, 0.5->1GW.

Major HVDC Projects Underway (continued)

The National HVDC Centre

Dolwin Epsilon commissioning

Champlain - Hudson (CHPE) project early commissioning

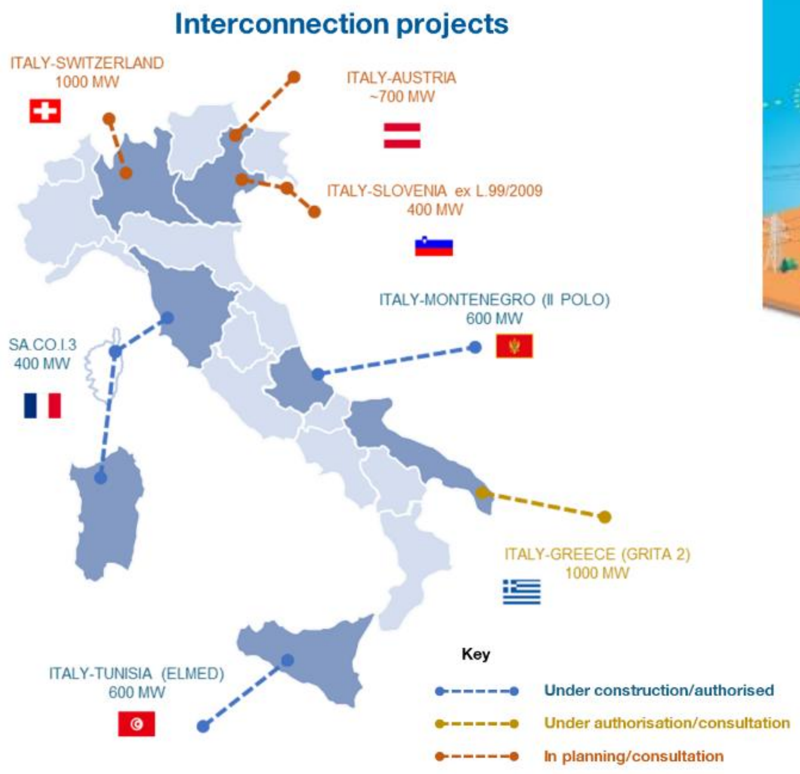
Construction of 10GW 800KV route Tibet- Hong Kong;
VSC or Hybrid converter (TBD)

Marinus (Australia) link FID complete, moves to build

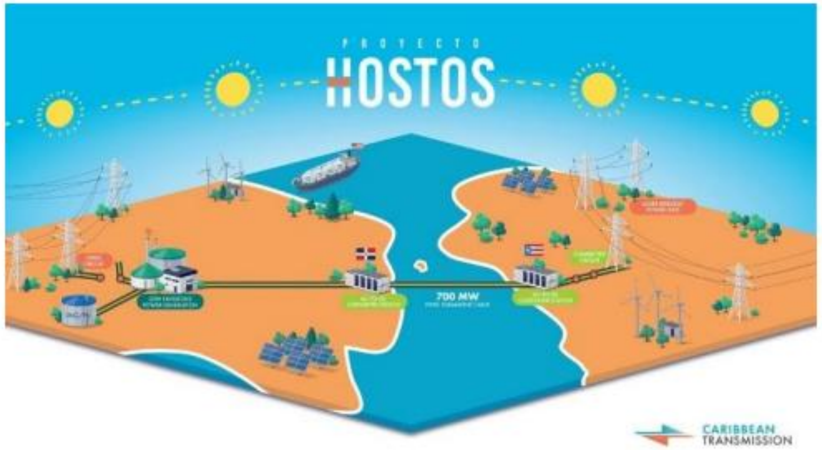
Major HVDC Projects Underway (continued)

The National HVDC Centre

Sun Xia- commissioned with onshore wind



Terna- projects in delivery



Caribbean HVDC project initiated (any takers?)

Multi terminal Projects in delivery

Lion Link- consenting an offshore NSI

Griffon Link MPI project announced & in early development

Hansa Link MPI in development, approaching detailed design phase.

Heide Hub 2032, together with 2 further hubs 2033-35 and DC4x 2035 onwards in CEED stages with German TSOs

Block-work for Prince Elizabeth island installed by end 2025 –Nautilus NSI in development

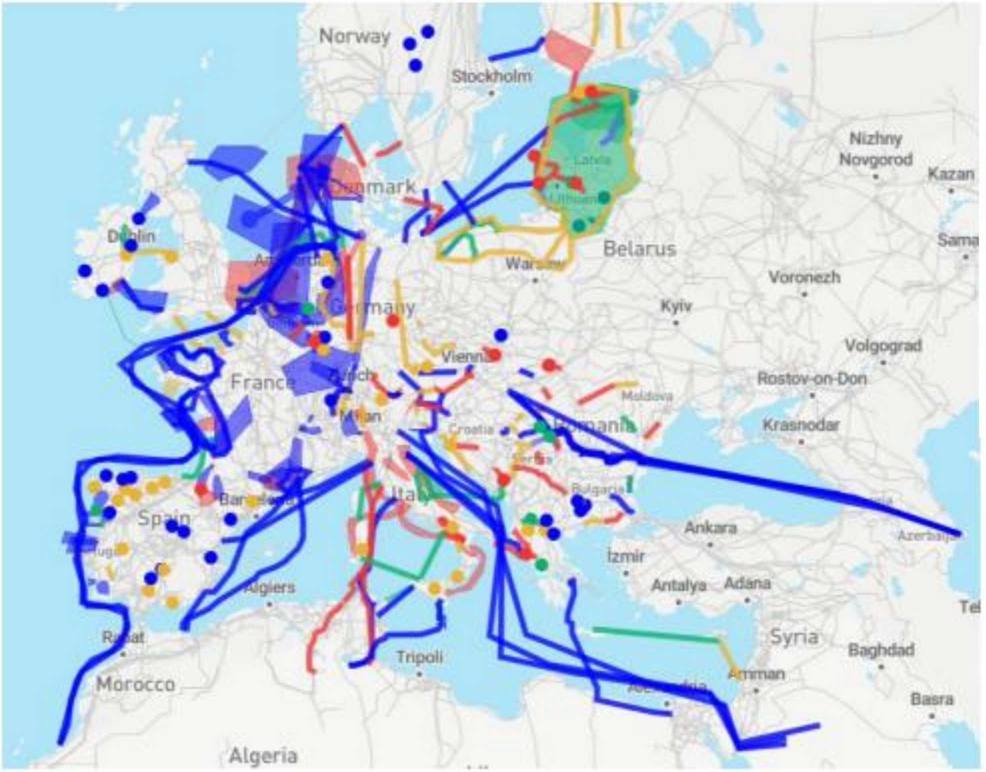
Wudongde–Kunliulong HVDC China transmission project commissions Hybrid converter elements.

HVDC Policy developments

The National HVDC Centre

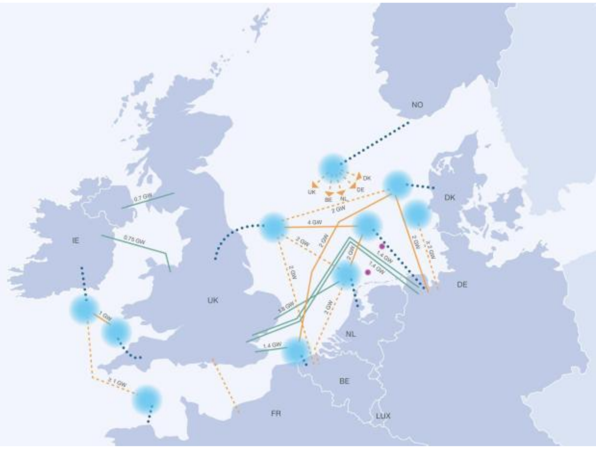
MoU for Irish- Spain interconnection

Hamburg agreement- HVDC grid cooperation for 100GW of North Sea offshore wind



EU TYNP vision for further HVDC developments

Bornholm island HVDC-delivery agreement as EU project of common interest.



North Sea interconnections 2040

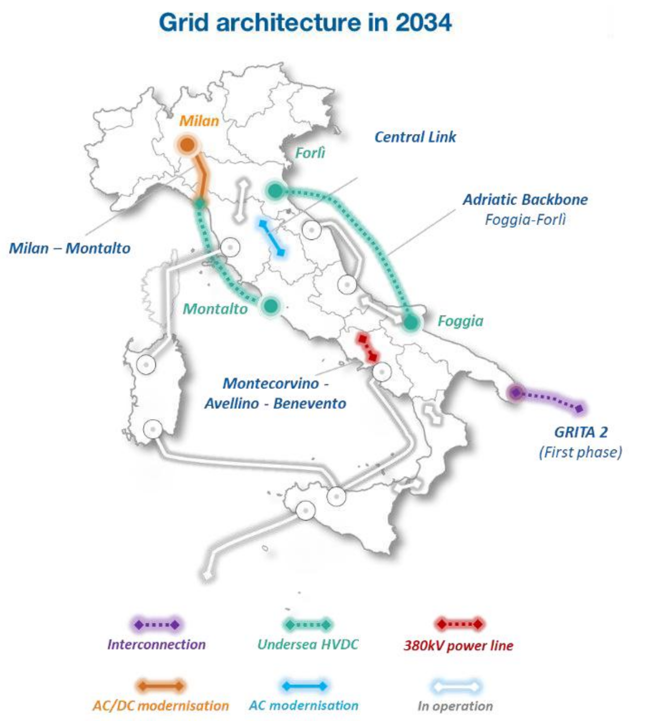
Scottish & Southern Electricity Networks

HVDC Policy developments (continued)

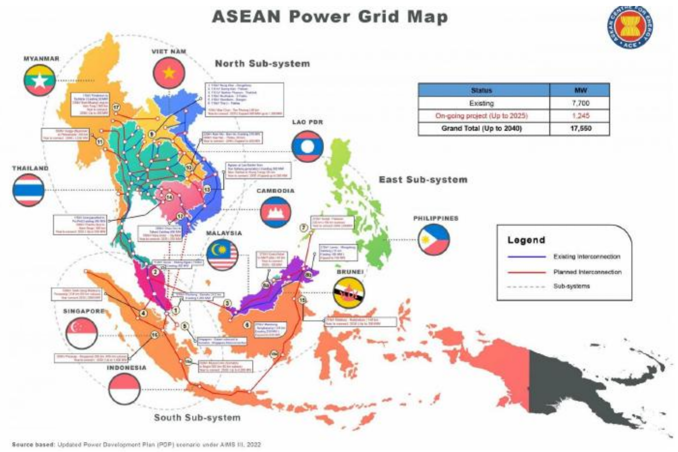
The National HVDC Centre

SOO green onshore 2GW VSC-HVDC bootstrap approvals

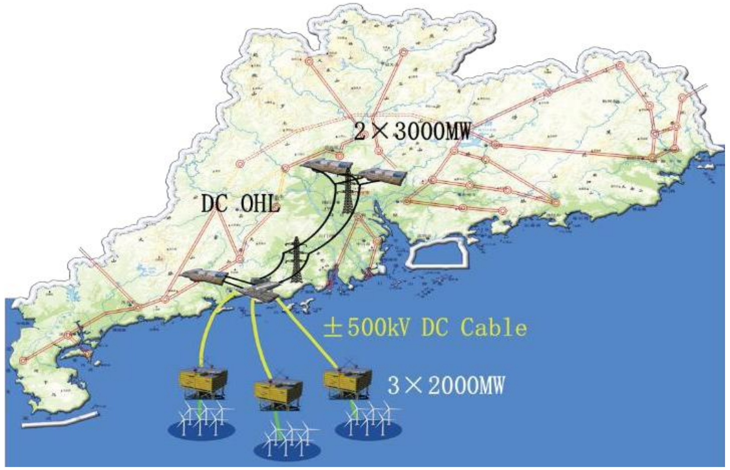
Hitachi & KEPCO MoU; one of a number of arrangements being developed in South Korea



Remaining TERNA HVDC projects



ASEAN Powergrid MoU, supporting HVDC interconnection development



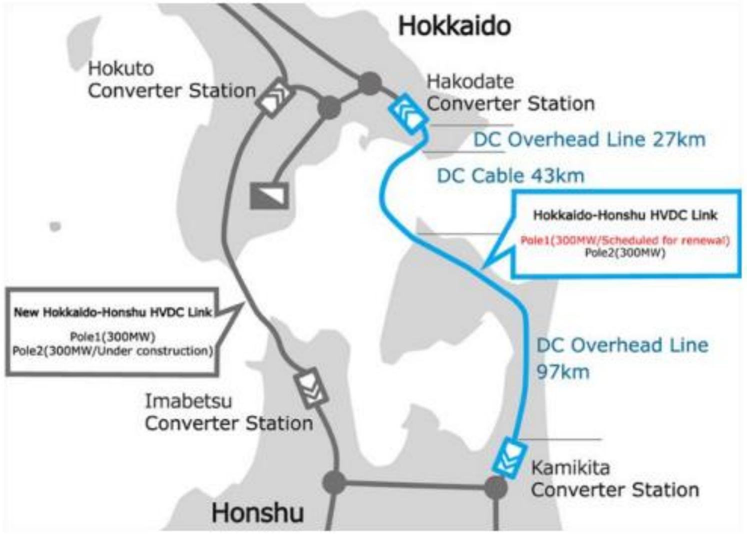
China HVDC connected Offshore wind plans.

Consolidation, new entrants, upscaling

Nexans Electra – constructs 4 drum vessel

Sumitomo entering German 2GW cable delivery

New South Korean vendor Taihan acquires smaller vessel



Toshiba entering VSC-HVDC with refurb project

GE Vernova HVDC transformer manufacturing in Vietnam

Consolidation, new entrants, upscaling (continued)

5 German TSO MoU on HVDC cable maintenance

RHODES project to deliver optimised offshore floating platforms for HVDC

RXHK manufacturing of valves on 8GW onshore VSC converter project in China

New Hyosung HVDC transformer factory breaks ground

Hyosung collaboration with South Korean academia to advance a 2GW HVDC capability for west coast project

Scottish & Southern Electricity Networks

Conclusions/ Reflections.

The National HVDC Centre

- Theres a lot going on. And that's not nearly all of it
- Some common themes- upscaling, consolidation, policy movement- trends towards collaboration
- Much of these themes reflected In GB
- We may have a head start, but the rest of the world are catching us up.
- As John Tudd (Jeremy Irons) in the film Margin Call said-
  - "It is sure a lot easier to be first.."

Thanks for listening.

Any questions, please?

- For further information, please visit **www.hvdccentre.com** ; OR email: info@hvdccentre.com
- **https://www.hvdccentre.com/technical-films/**

The National HVDC Centre

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MANCHESTER 1824
The University of Manchester

Review of Evolving VSC HVDC Control Developments

Presenter: Prof M Barnes
10th/11th June 2026

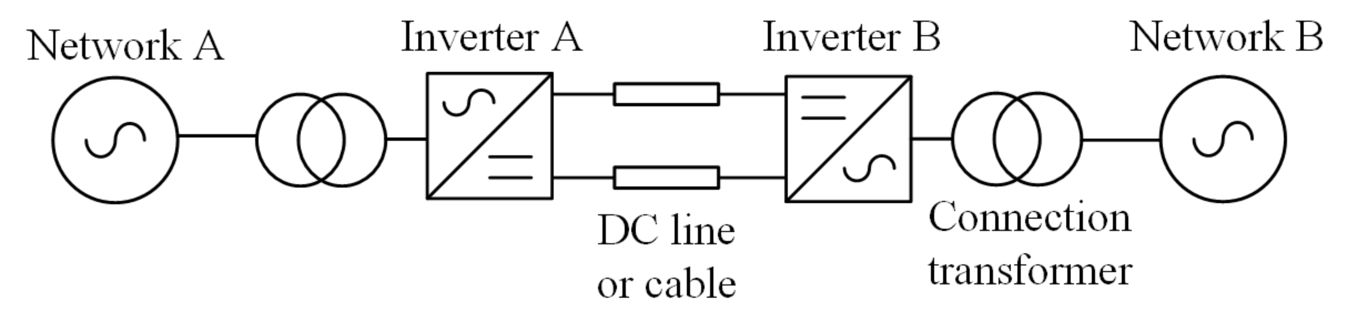
A. Korompili, M. Barnes, R. Preece, A. Pashei, J. Fradley, R. Tumilty, C. Brozio, X. Wang, J. Hunte, X. Ding, M. Sadabadi, J. Milanovic

Outlook

- Introduction: VSC HVDC Systems to Date
- GFM Capabilities for VSC HVDC Systems
- GFM Control Models for VSC HVDC Systems
- Control Interactions in VSC HVDC Systems
- Grid Codes
- Conclusions of Highlighted Gaps

Introduction: VSC HVDC Systems to Date
HVDC Systems Technologies

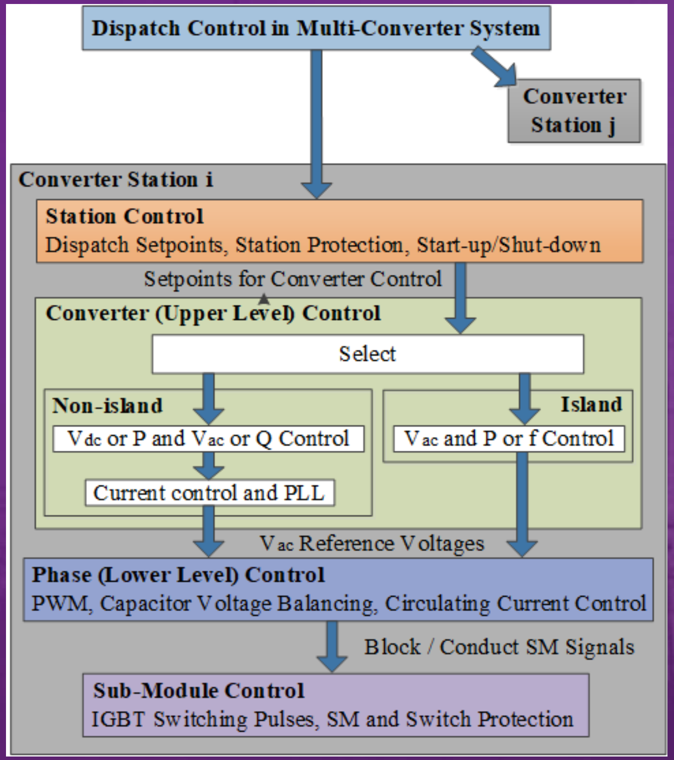
- Increasing integration of HVDC systems
  - Integration of remote RES
  - Interconnection of asynchronous AC power systems
- Point-to-point HVDC links in monopolar layout
- Bipolar system layout and multi-terminal networks present advantages
  - Fewer applications and limited research
- VSC starting to dominate over LCC (certainly in UK)
- Modular multi-level converter (MMC)



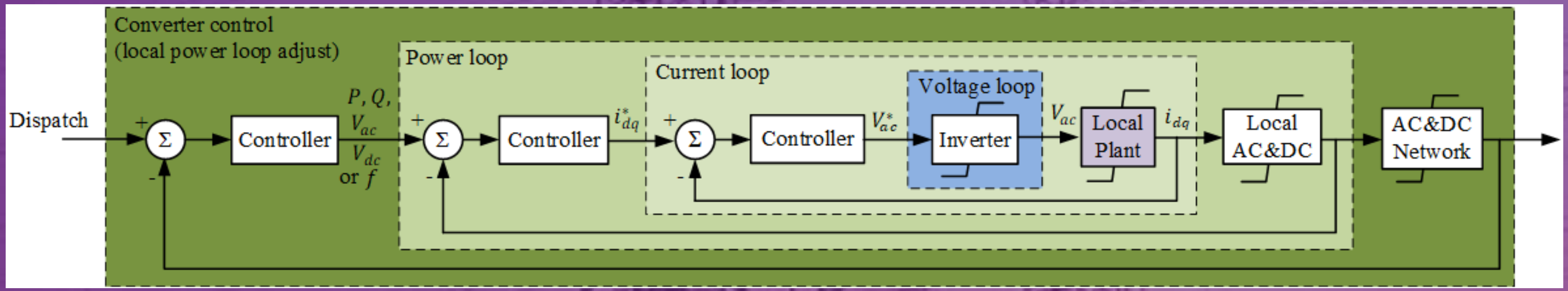
Symmetrical monopolar HVDC point-to-point link

Introduction: VSC HVDC Systems to Date
VSC Models

- VSC control hierarchy
- CIGRE: Categorisation of modelling fidelity according to studied phenomena
- Cascaded control structure



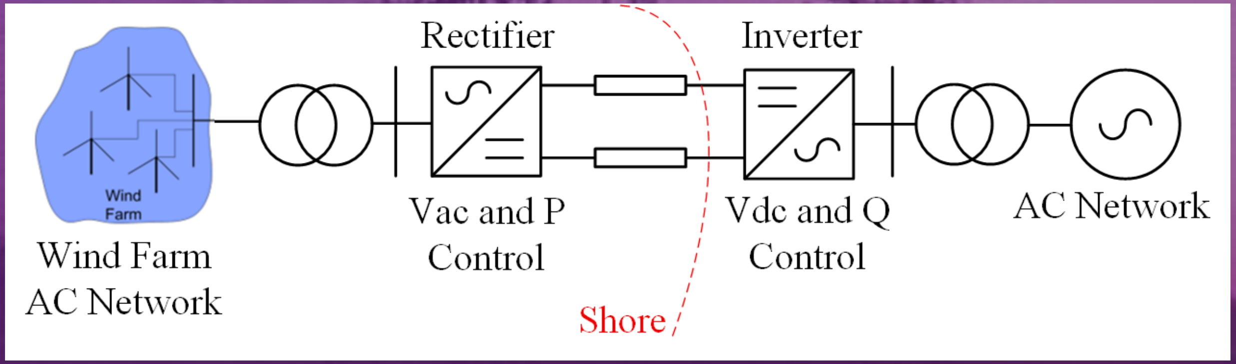
MMC control hierarchy



VSC cascaded control structure

Introduction: VSC HVDC Systems to Date
VSC in HVDC Link

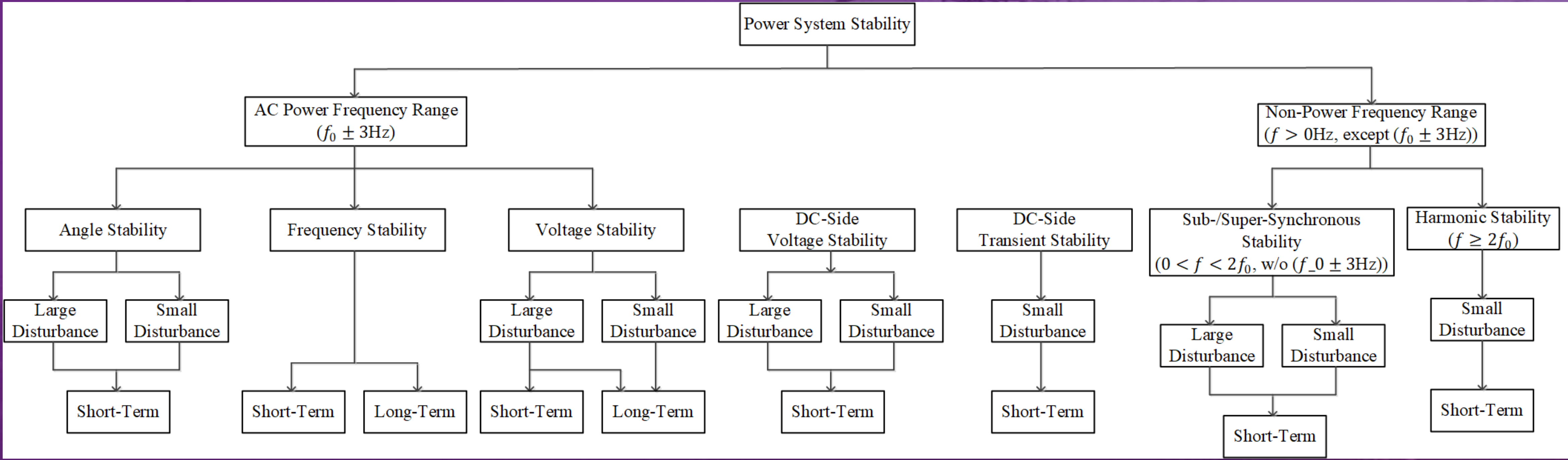
- Control strategy of VSCs at two ends of HVDC link
  - Q or Vac control at both converters
  - P or f control at one converter, Vdc control at other converter to keep power balance
- Grid-following (GFL) converter: power control and PLL to track voltage
- Grid-forming (GFM) converter: to form AC voltage magnitude, phase and frequency
  - Synchronous GFM (SGFM) converter: GFM converter operating in parallel with other frequency regulating equipment
  - Constrained GFM (CGFM) – both end in GFM, with rules if any capability exceeded
- GFM capabilities still evolving



VSC control strategy in HVDC link for wind farm connection

Introduction: VSC HVDC Systems to Date
Stability Classification

- Two new stability classes (IEEE): “Resonance Stability” and “Converter-Driven Stability”
- CIGRE stability classification
  - “Sub-/Super-Synchronous Stability” and “Harmonic Stability”
  - DC stability classes: “DC-Side Voltage Stability” and “DC-Side Transient Stability”



CIGRE stability classification

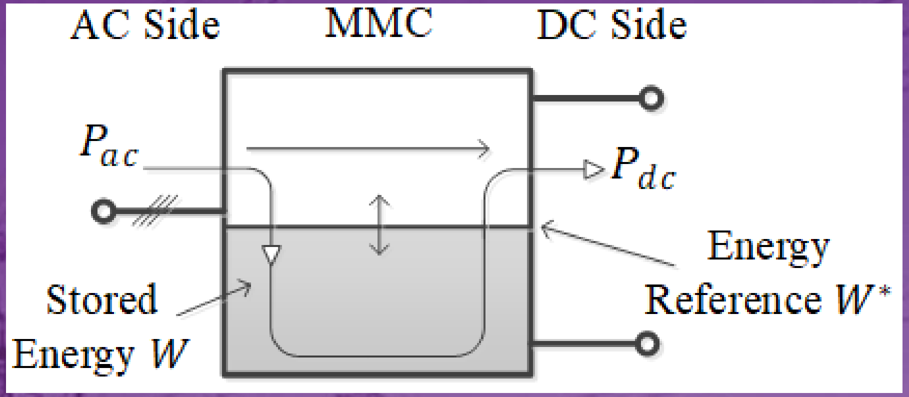
GFM Capabilities for VSC HVDC Systems
Control Objectives of GFM Capabilities

- Main control objective: control AC voltage, ensuring synchronisation with grid
- Additional control objectives
- Different control objectives required by different TSOs
- Contradictory GFM capabilities
  - Inertial response vs. speed of active power response

GFM Capabilities – Additional Control Objectives	
Frequency stability support	Operation in weak grids
Voltage stability support	System restoration and black start
Damping of small-signal stability phenomena	Seamless transition GFM/GFL control
Fault-Ride-Through (FRT)	Seamless transition isolated/grid-connected mode

GFM Capabilities for VSC HVDC Systems
GFM Capabilities and Device Limits

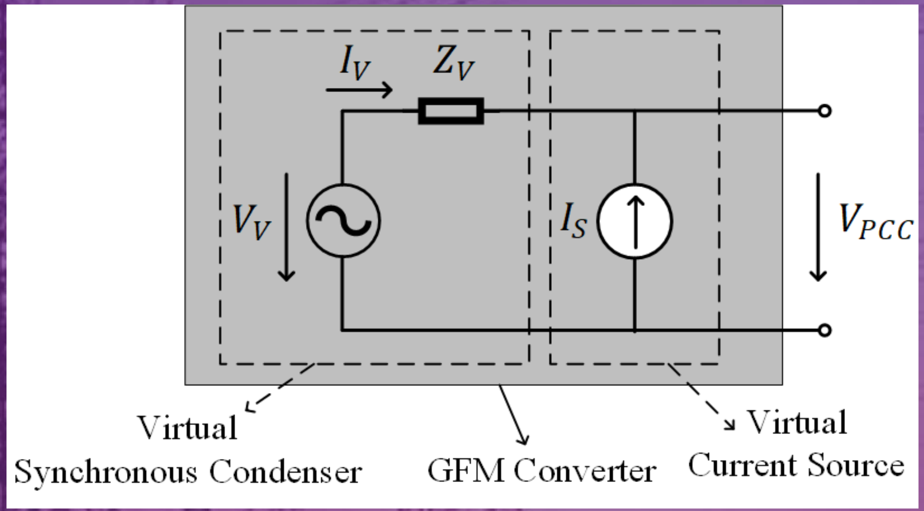
- Device limits should be considered
  - Limits of inherent energy of MMC
    - Sufficient for transient stability support and power oscillation damping
    - Insufficient for frequency stability support
  - Needed energy balancing in MMC
    - Interactions with requirement for fault current injection
  - Current limits
    - Prioritisation between positive and negative sequence currents
- Needed oversizing or additional components should be considered
  - Requirement for additional storage or source for black start



MMC inherent energy

GFM Capabilities for VSC HVDC Systems
GFM Converter in HVDC Link

- GFM converter at one end, GFL converter at other end
  - GFM capability dependent on GFL capability
- (C)GFM converters at both ends for supporting weak AC grids
  - Limited/Constrained GFM capability
    - Coordinated control between GFM converters
    - GFM as virtual condenser
      or virtual current source
    - DC voltage-dependent GFM
      and frequency-controlling GFL
- No clear, universal GFM definition yet



GFM emulating virtual synchronous condenser and virtual current source

GFM Control Models for VSC HVDC Systems
Research Gaps in GFM Control Models

- Limited work on rigid bipolar HVDC systems (i.e. no neutral return)
  - Challenges on energy/power balancing due to absence of metallic return path

- Limited work on multi-terminal HVDC networks
  - Combination of GFM control and power flow in DC network

- Limited work on black start and system energisation/restoration

- Application of advanced control methods to inner voltage and current control loops
  - Limited work on applications in GFM control loops

Control Interactions in VSC HVDC Systems
Oscillations in VSC HVDC Systems

- Oscillations in sub-synchronous and high-frequency range
- Cause of high-frequency oscillations: matching between converter and line impedances
- Key cause of oscillations: time delay in control loops
- Damping control (filtering) for oscillations mitigation

Conventional modelling for analysis of oscillations			**Emerging modelling requirements**
Model	Core assumptions	Limitations	
Single-machine infinite bus	Ignoring inter-machine dynamic interactions and network structure impacts	Overlooks different components in AC networks	Multi-machine detailed modelling
Single-frequency analysis	Focusing on dominant modal frequency	Fails to capture multi-modal characteristics	Multi-frequency co-analysis
Full-parameter white-box modelling	Based on fully-known physical models	Overlooks confidential converter models in multi-vendor systems	Grey- or black-box modelling

Control Interactions in VSC HVDC Systems
Research Gaps in Control Interactions

- Limited work on control interactions between converters in proximity in bipolar systems

- Limited work on interactions of control loops for GFM capabilities

- Limited work on interactions in multi-terminal multi-vendor HVDC systems
  - Interoperability issues

- Limited work on inclusion of time delay in control loops modelling

(note this is non-exhaustive)

Grid Codes

- Needed services in systems with high penetration of inverter-based resources (IBRs)
  - Desired IBR technologies at concept level
- Different definition of GFM capabilities at different grid codes
  - Need for harmonisation
- Need for GFM requirements specifically in HVDC systems
  - Avoid contradictory GFM requirements
  - Interoperability requirements

GFM capabilities	**System operators and regulatory bodies**						
	AEMO	ACER	Fingrid	German TSOs	HECO	NGESO	NERC
Maintain synchronisation	x				x		x
Provide frequency regulation	x	x	x	x	x	x	x
Provide voltage regulation	x	x	x	x	x	x	x
Provide damping	x		x	x		x	x
Coordinate protection	x		x			x	x
Maintain power quality	x		x	x			x
Support black start	x			x	x		x
Support islanded operation	x		x		x		x

Conclusions of Highlighted Gaps

- VSC control and GFM control in HVDC systems: gradually evolving research areas
- Further work needed:
  - Clarification on GFM capabilities and harmonisation of grid codes
  - Bipolar systems and multi-terminal multi-vendor networks
  - Interactions analysis of control loops for GFM capabilities and considering time delays
  - Advanced control methods for GFM control loops
  - Black start and system restoration – for highly inverter dominated systems

Thank You!

Acknowledgement

This work was supported by the project ‘Evolution of VSC HVDC Control’, funded by National Grid Electricity Transmission through the UK Network Innovation Allowance (NIA2_NGET0072).

Panel Q&A

Robert Keast, Carbon Trust
Ben Marshall, The National HVDC Centre
Mike Barnes, University of Manchester

LUNCH
Tour & Exhibition
Networking
12:15-14:15

Visitor WiFi

The National HVDC Centre

1. Open **NetZero Sponsored Guest** from the Wi-Fi options.
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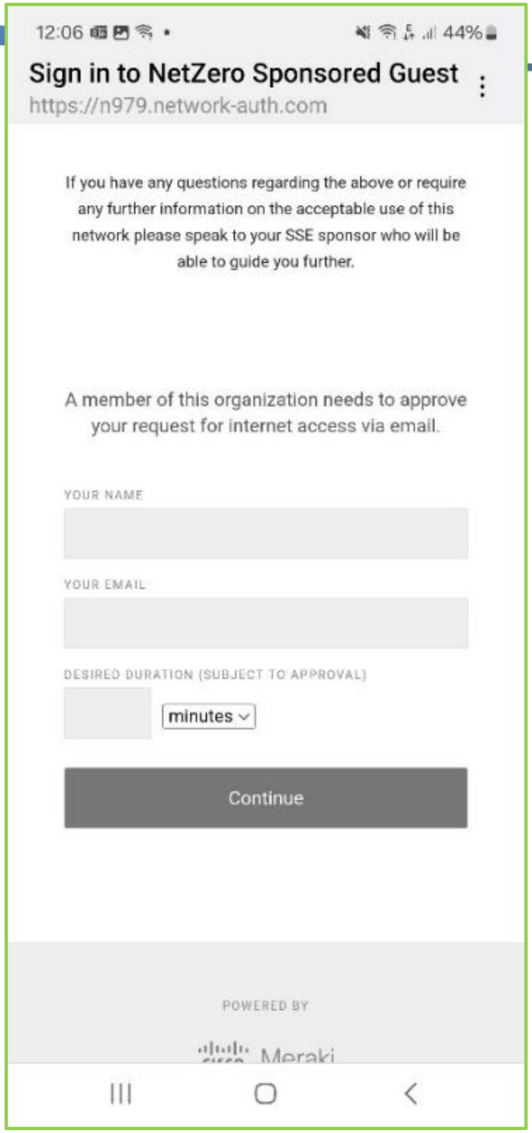
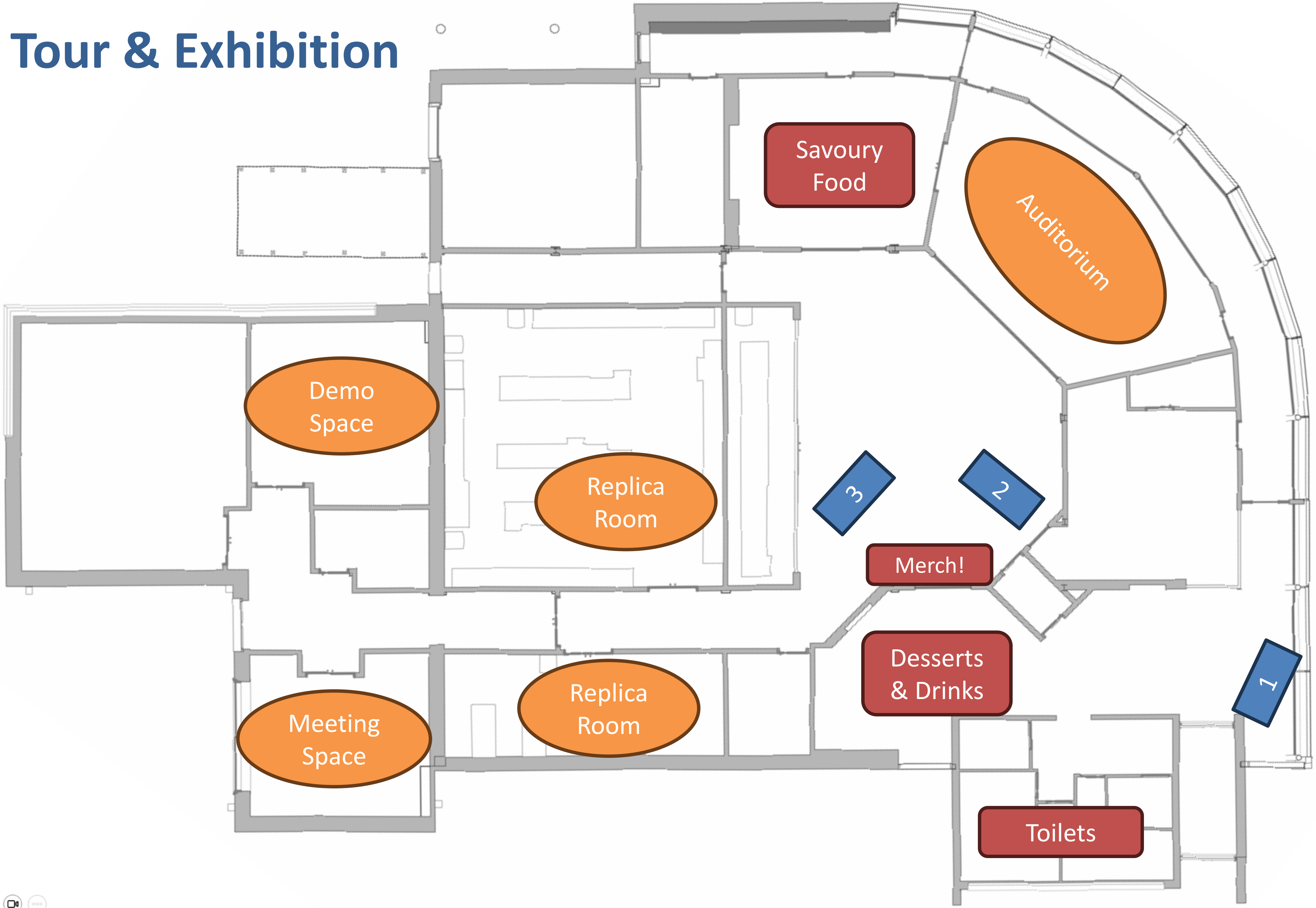


Tour & Exhibition



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2. OPAL-RT
3. RTDS

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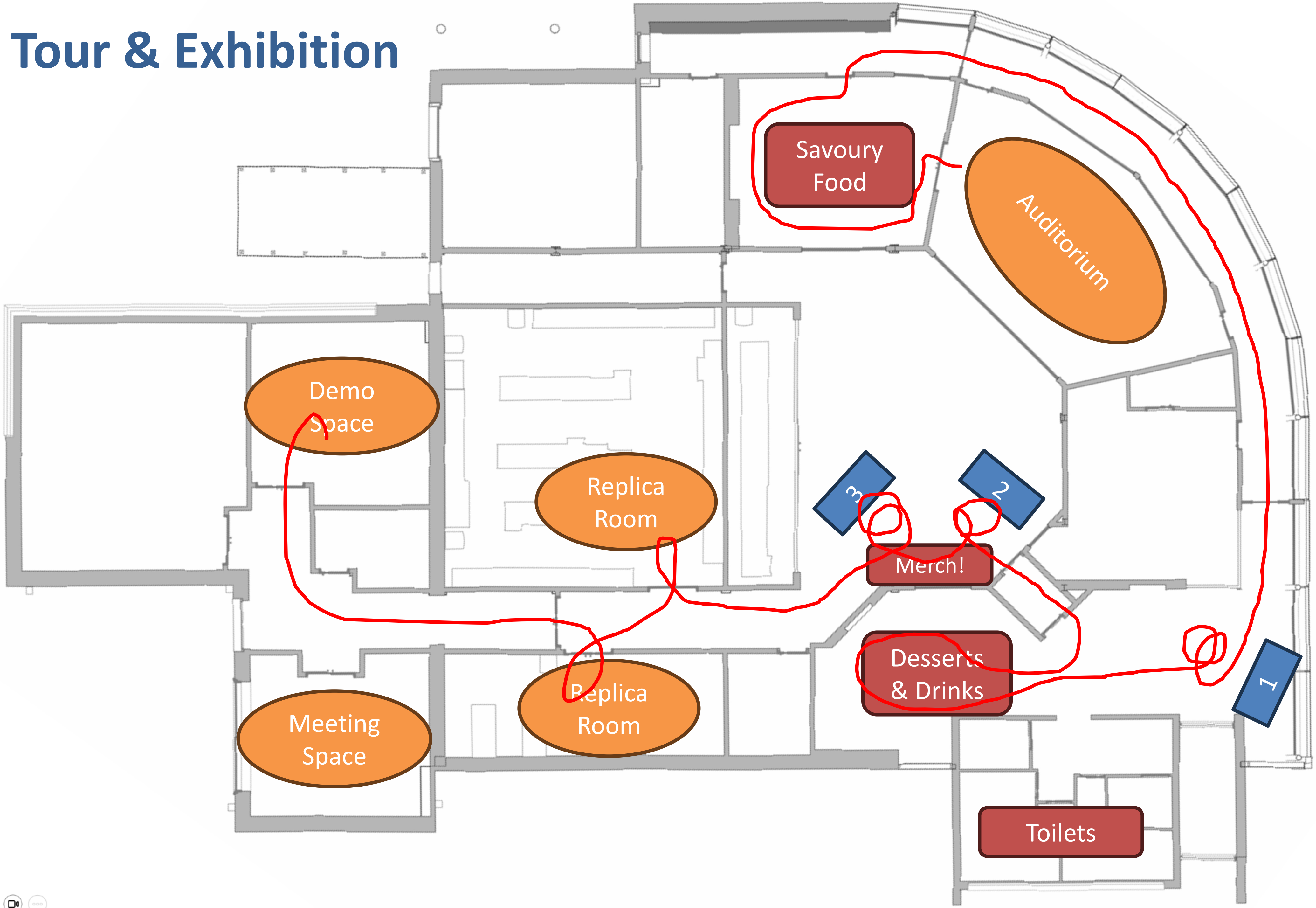

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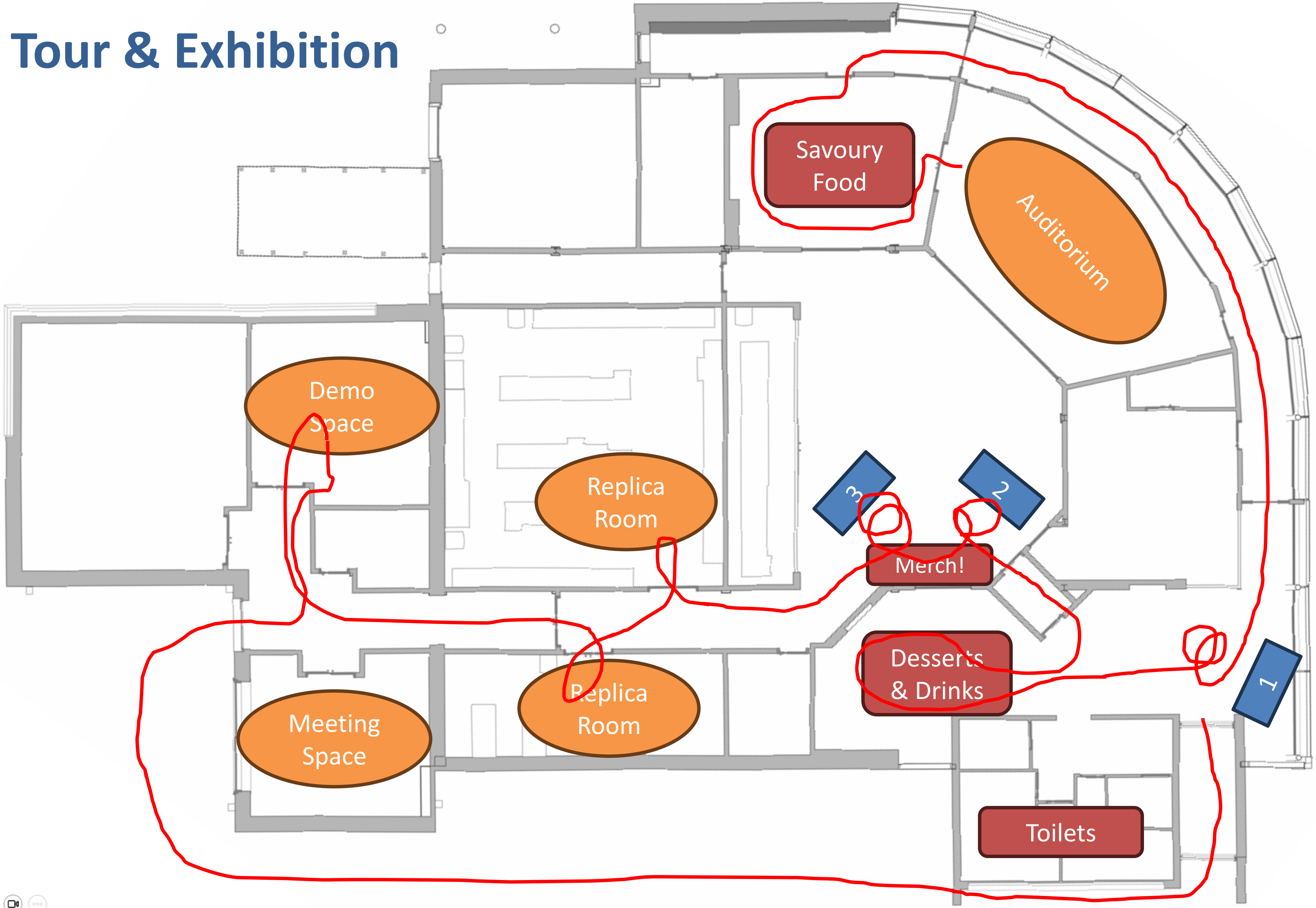

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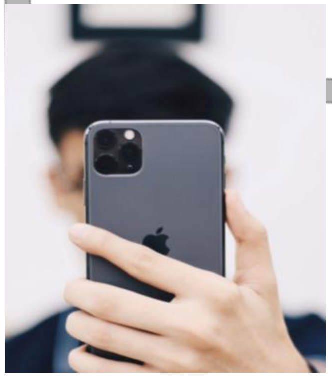
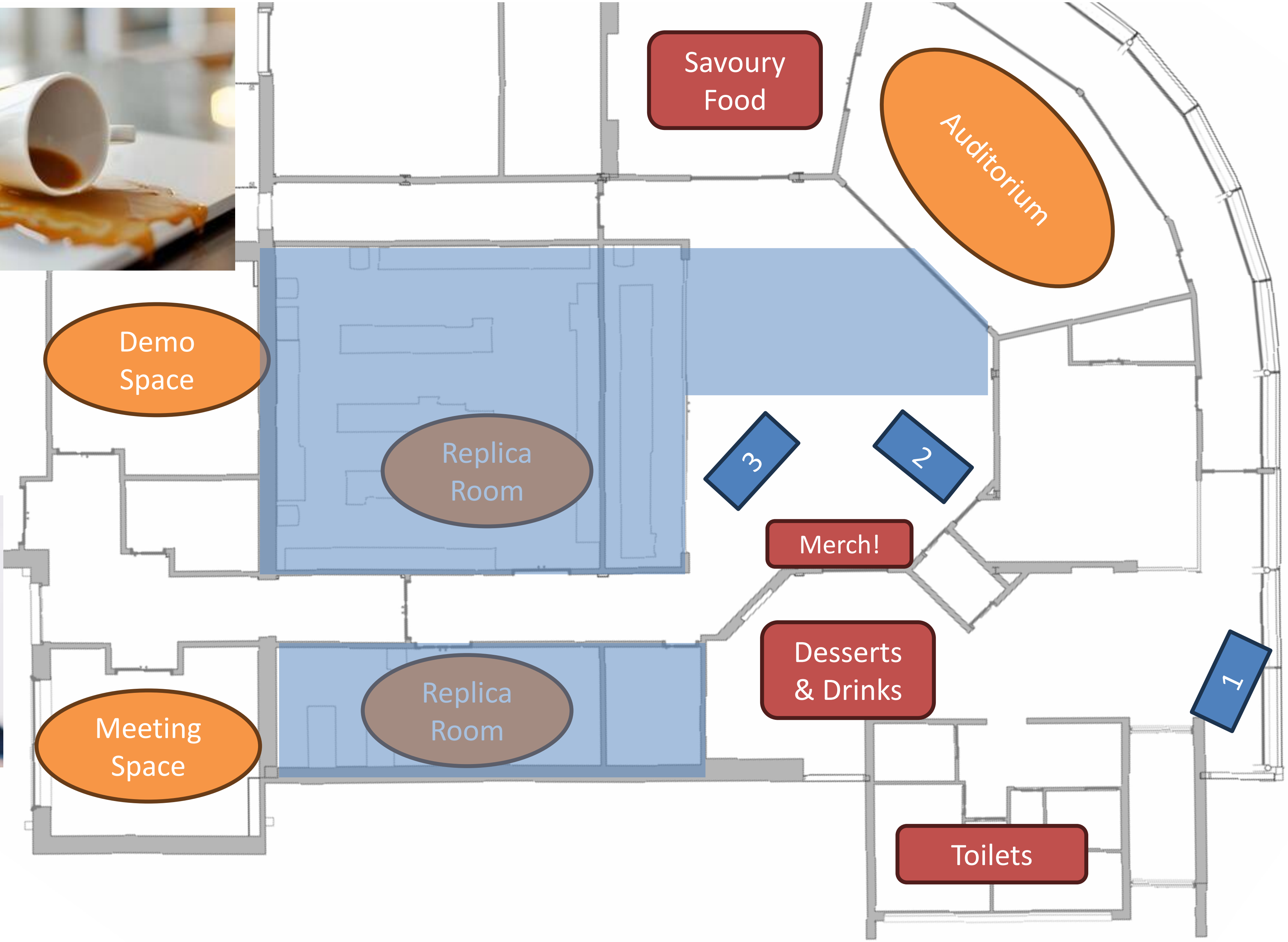
Restrictions in the Replica Rooms or behind the Exhibitors





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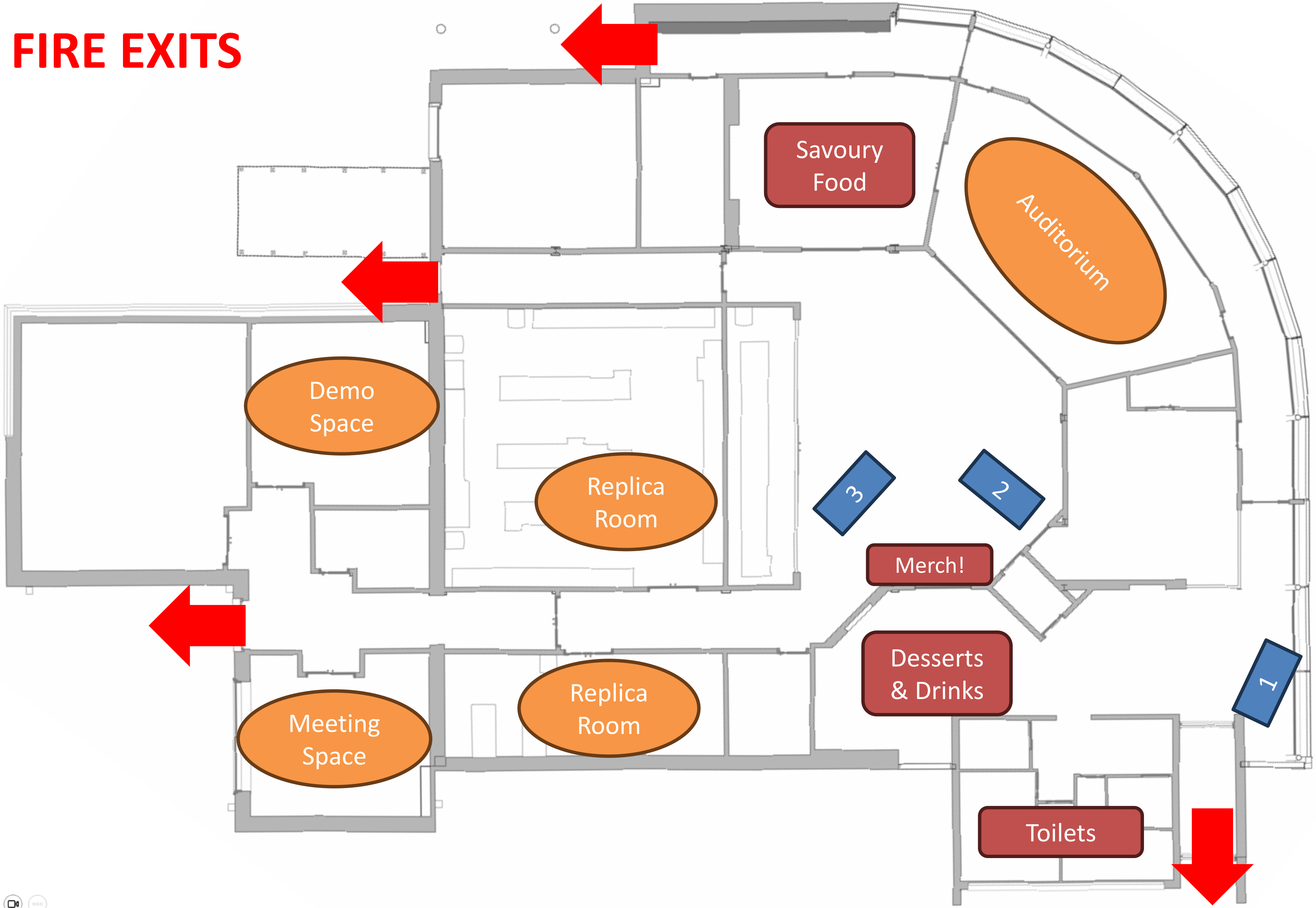
- No photos

FIRE EXITS



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Session 2 starts 2:15pm

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