...giving Hydrogen the green light?

16th April 2021

FUTURE OF TECHNOLOGY SERIES

SHARING IDEAS
UNLOCKING OPPORTUNITIES

ADVANCED PROPULSION CENTRE UK

Technology Driving Transition OGTC

APC Future of Tech

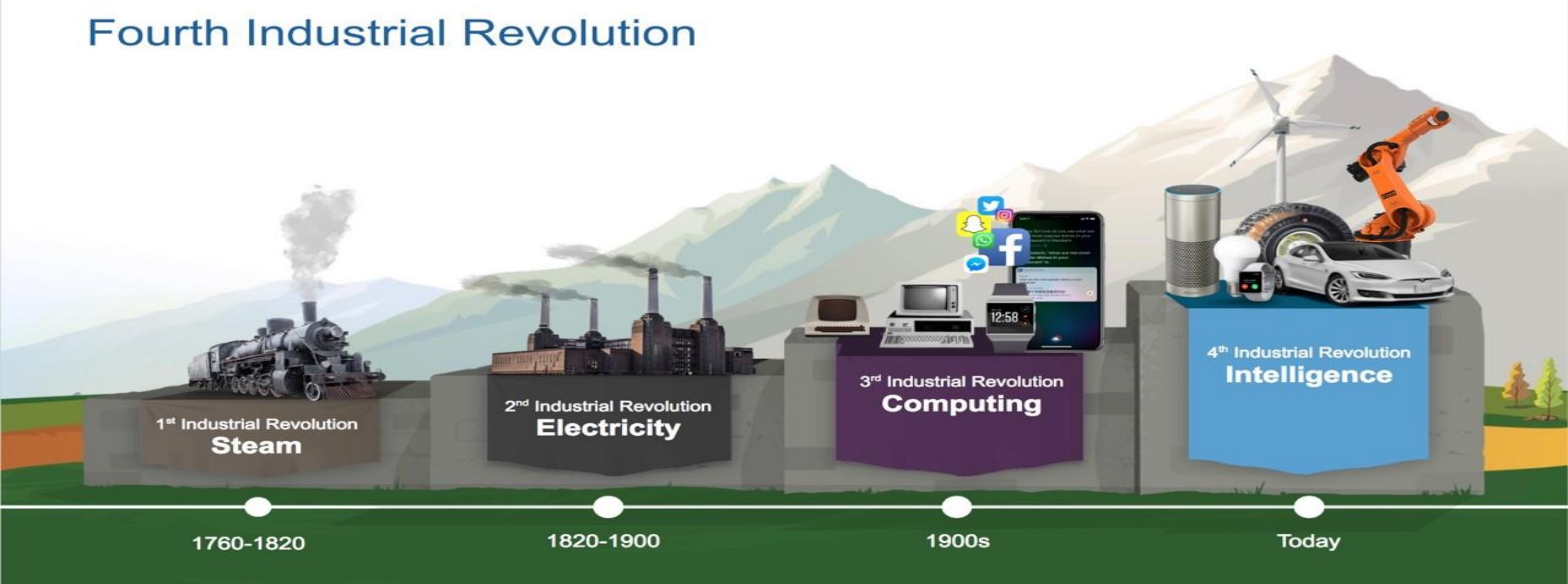
Giving Hydrogen a Green Light??

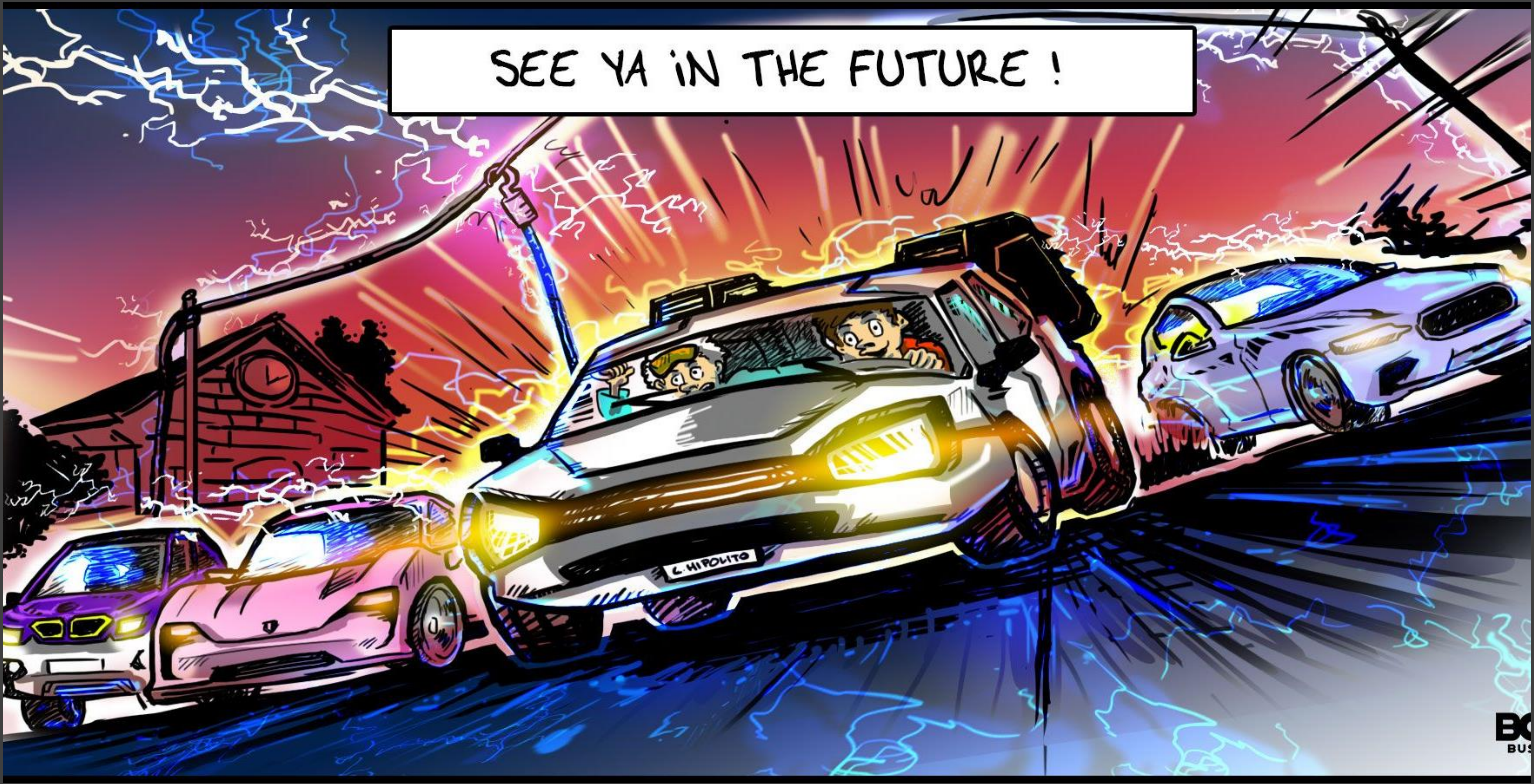
Colette Cohen

CEO OGTC

10th March 2021

Pace of Change

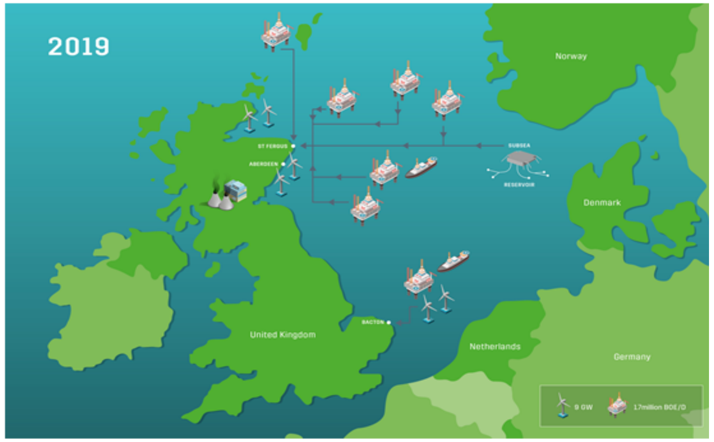


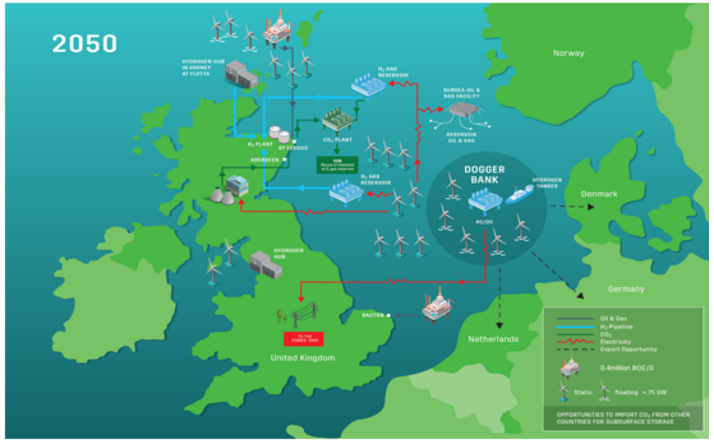

SEE YA IN THE FUTURE !

The Energy Transition in Numbers

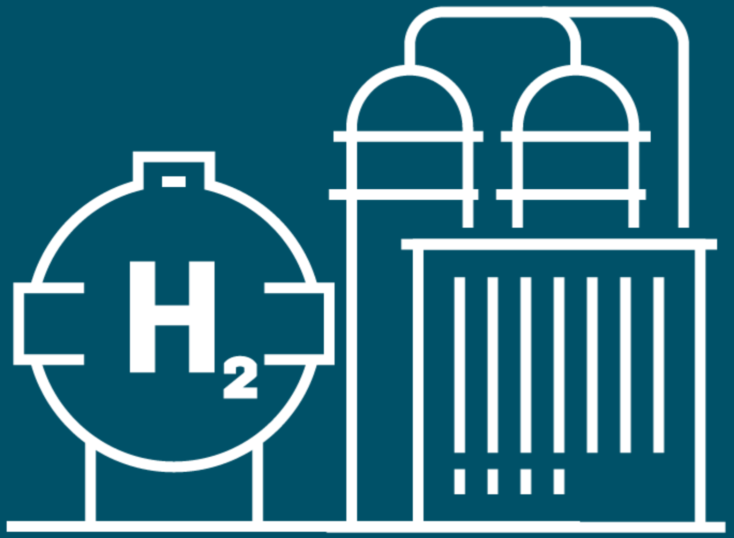
	Net zero Emissions O&G Offshore Operations	Offshore Renewables Integration	Hydrogen production leveraging the O&G industry	CCUS from industrial clusters and blue hydrogen production	
	Vision 2035 production x today's oil & gas prices	CCC wind x £40/MWH	CCC H_2 x £2/kg	CCC CCS x £50/t	
2020	£24 Bn	£2Bn			£26Bn
2030	£20 Bn	£5Bn	£1Bn	£2Bn	£28Bn
2040	£16 Bn	£11 Bn	£5 Bn	£4Bn	£36Bn
2050	£11 Bn	£16 Bn	£13 Bn	£9 Bn	£49Bn

Enabling





EVs Not the Only Option



Hydrogen 2050

0TWh GREY HYDROGEN

17-270TWh BLUE HYDROGEN

270TWh+ GREEN HYDROGEN

WIND

WAVE & TIDAL

SOLAR

OIL & GAS

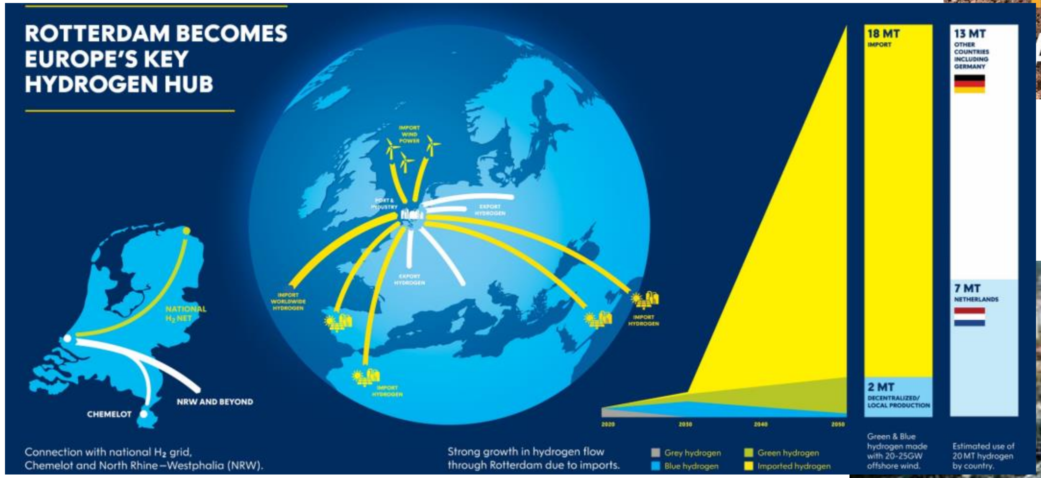
HYDROGEN

CATAPULT Offshore Renewable Energy

Technology Driving Transition OGTC

Hydrogen will have a role in mobility

Hydrogen will have a role in heavy industry



UK rich in hydrogen generation potential

Northern Scotland and Islands

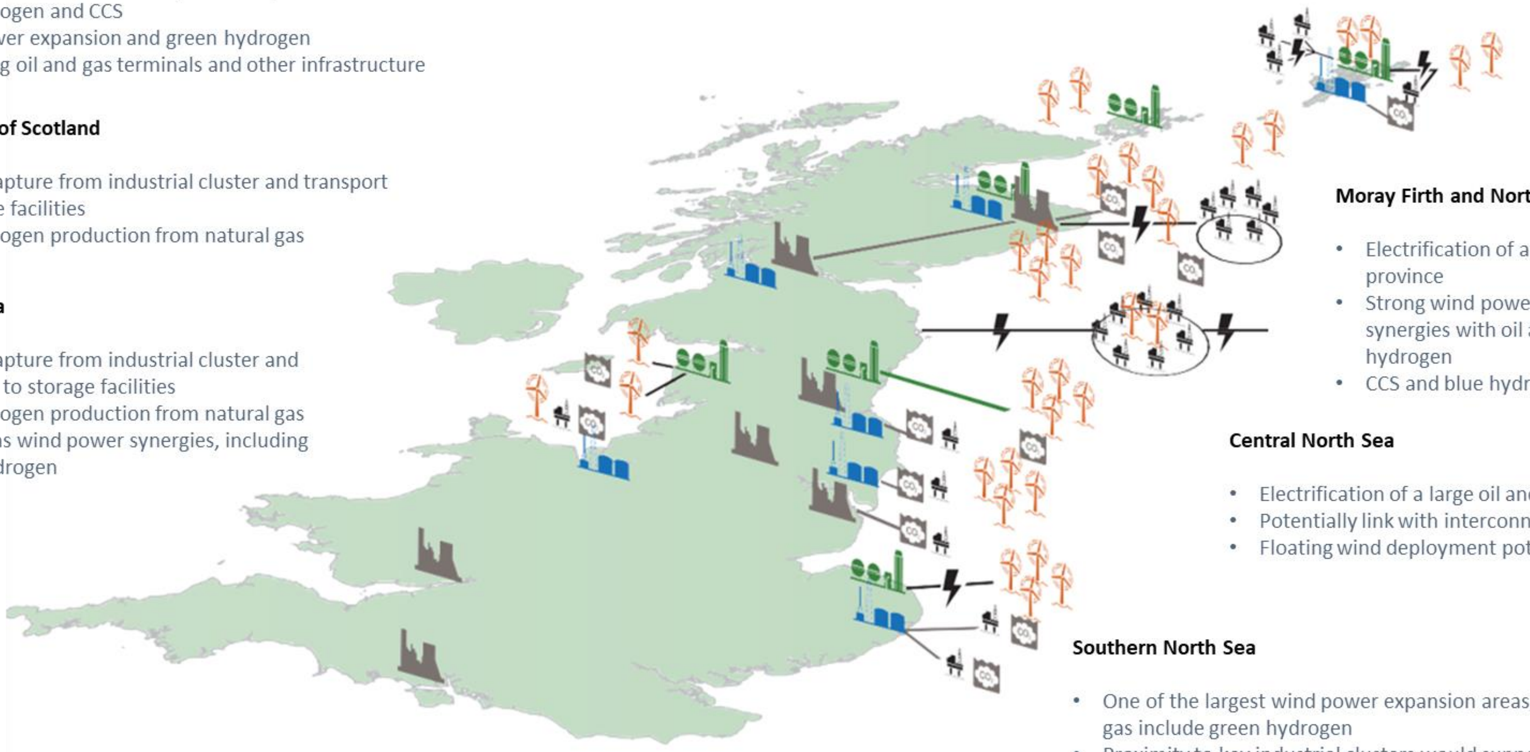
- Electrification of new oil and gas developments
- Blue hydrogen and CCS
- Wind power expansion and green hydrogen
- Leveraging oil and gas terminals and other infrastructure

Central Belt of Scotland

- Carbon capture from industrial cluster and transport to storage facilities
- Blue hydrogen production from natural gas

East Irish Sea

- Carbon capture from industrial cluster and transport to storage facilities
- Blue hydrogen production from natural gas
- Oil and gas wind power synergies, including green hydrogen



Moray Firth and North East Scotland

- Electrification of a large oil and gas province
- Strong wind power expansion driving synergies with oil and gas and green hydrogen
- CCS and blue hydrogen at St Fergus

Central North Sea

- Electrification of a large oil and gas province
- Potentially link with interconnector opportunities
- Floating wind deployment potential

Southern North Sea

- One of the largest wind power expansion areas, synergies with oil and gas include green hydrogen
- Proximity to key industrial clusters would support CCS deployment
- UK natural gas production and imports would support blue hydrogen

It is an End to End Challenge

The UK H2 value chain

Advantage

n Gap

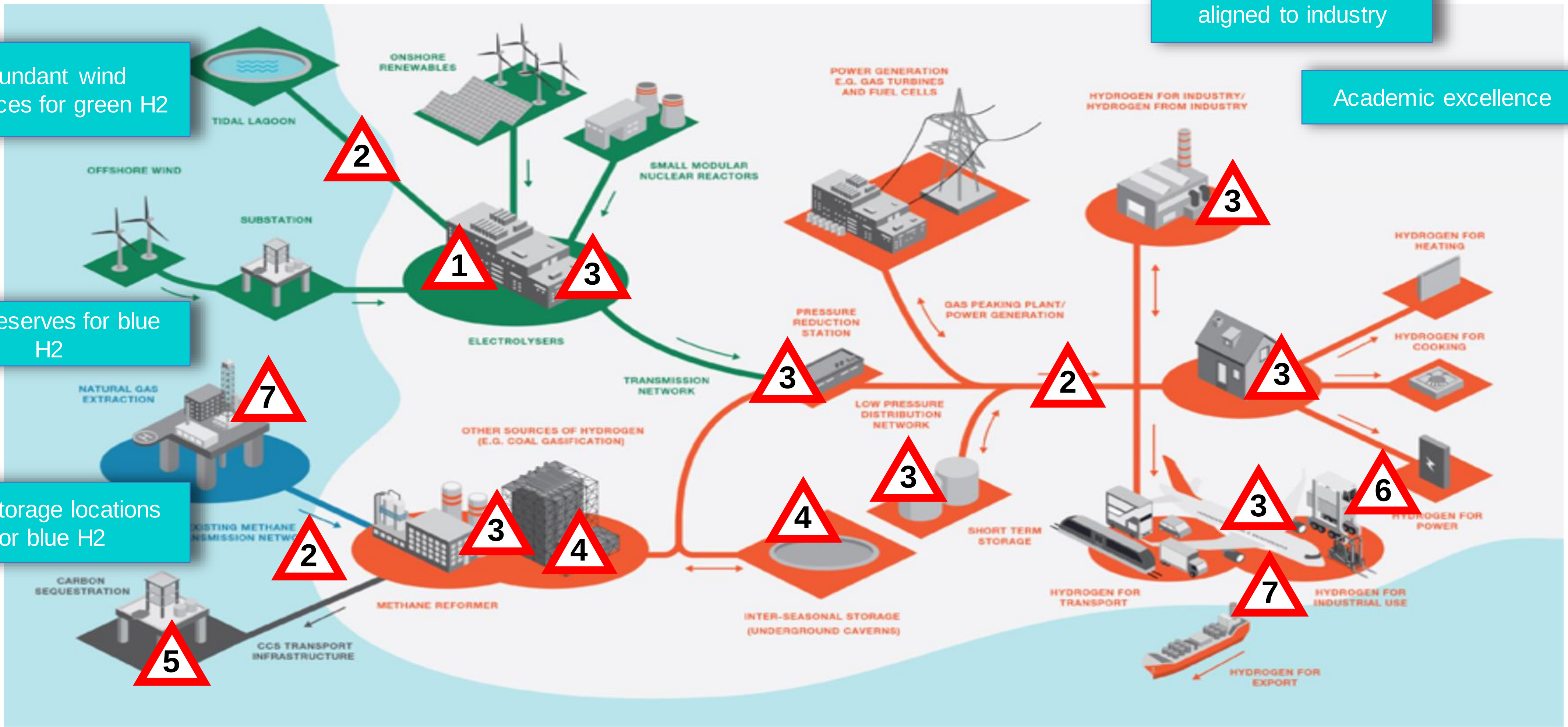
Technology centres aligned to industry

Academic excellence

Abundant wind resources for green H2

Gas reserves for blue H2

C02 storage locations for blue H2



1 Electrolysers

2 Pipes

3 Pressure vessels

4 Hydrogen conversion

5 Carbon capture

6 Fuel cell manufacture

7 Hydrogen turbine technology

Realising the energy transition *opportunity* requires coordinated investment at PACE

Emerging commitment to CCUS & Hydrogen:

Industry level

Govt & Local level

Cross-sector collaboration

The North Sea Has:

Highly skilled workforce

Strong entrepreneurial ecosystem

Rich depth of technical companies

Diverse supply chain

Technical innovation

Bamford Bus Company

Trading as **Wrightbus**

Brian Maybin – Head of Advanced Technology

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201 Galgorm Road, Ballymena
N. Ireland. BT42 1SA
www.wrightbus.com

Bamford Bus Company

- Wrightbus was founded in 1946
- Based in Ballymena, Northern Ireland
- Manufacturer of iconic New Bus for London (New Routemaster)
- Launched first BEV in 1999 and first FCEV in 2008
- New ownership in 2019 via Jo Bamford
- Updated factory facility with significant capacity for growth
- Very focused on Zero Emission Buses – both BEV and FCEV

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Iconic Projects

1,000 New Routemaster
hybrid-electric vehicles for London

StreetCar hybrid-electric 18 metre
Bus Rapid Transit Vehicles for Las Vegas

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Zero Emission Product Roadmap

[redacted]

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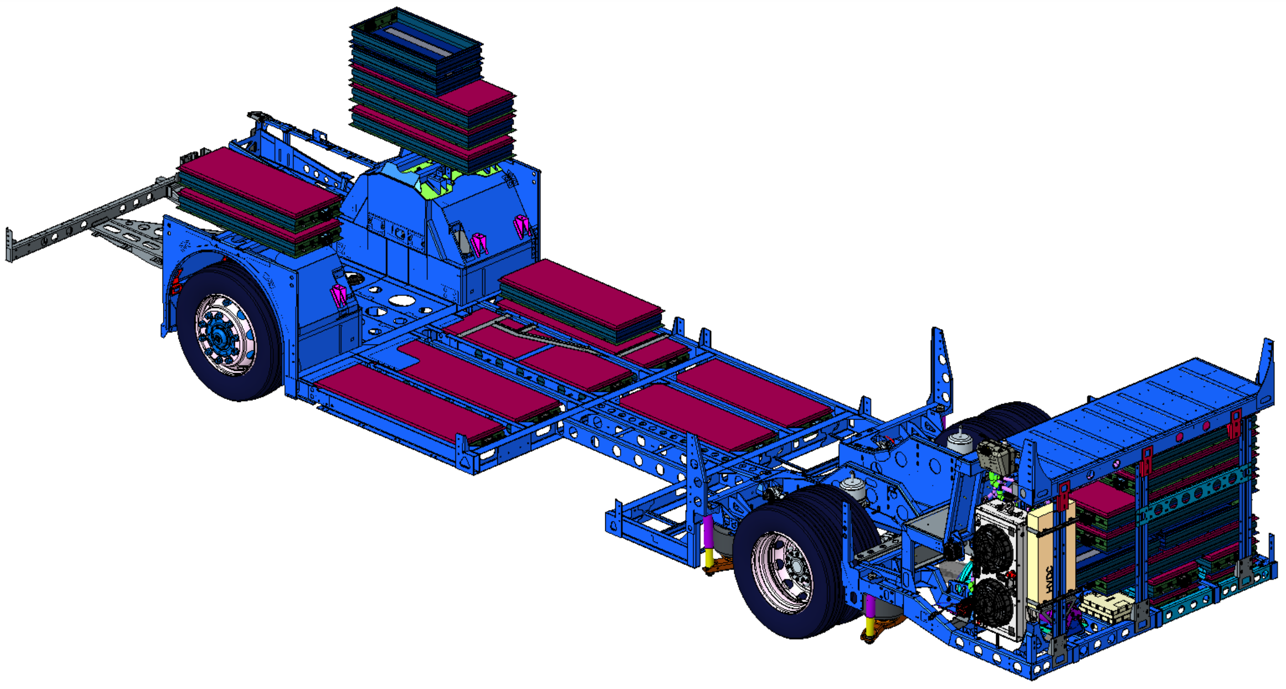
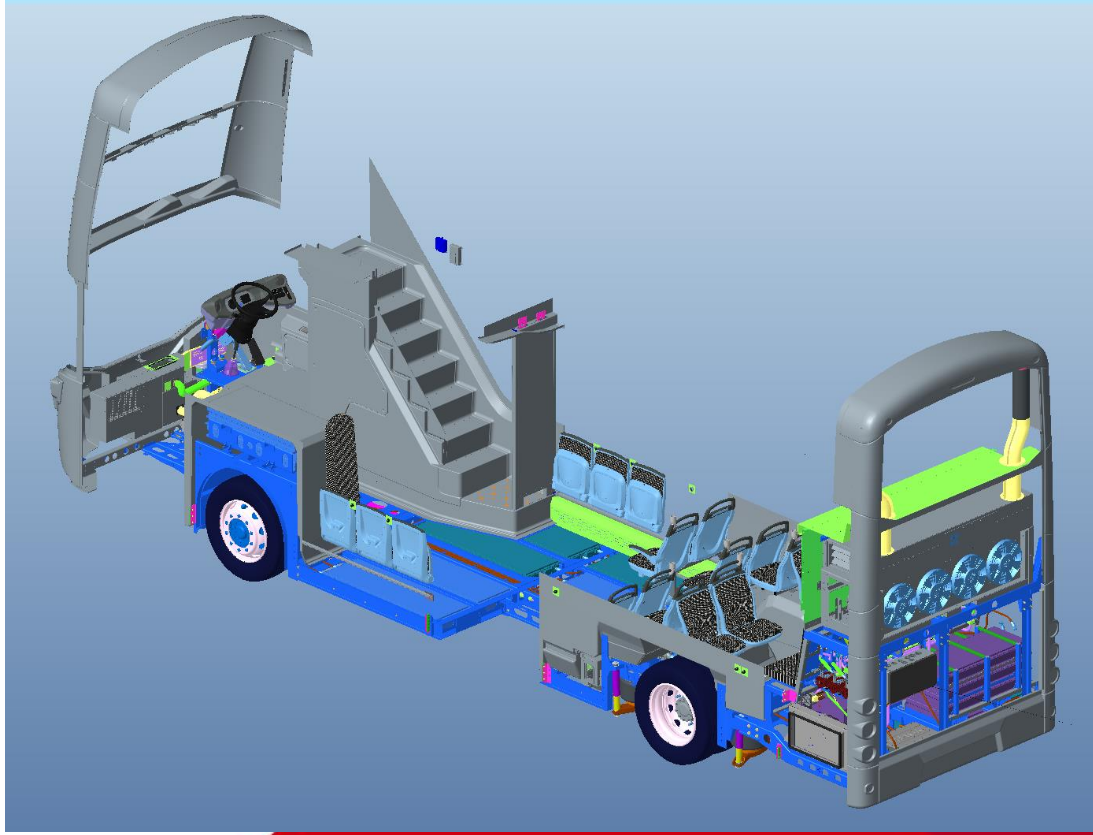
Gen1 FCEV Double Deck

On sale from 2020, around 50 buses delivered and around 100 further buses are on order

Gen2 BEV Double Deck





New BEV double deck being launched in June 2021

Available with largest battery capacity / longest EV range

80 of these have been ordered by Translink in NI

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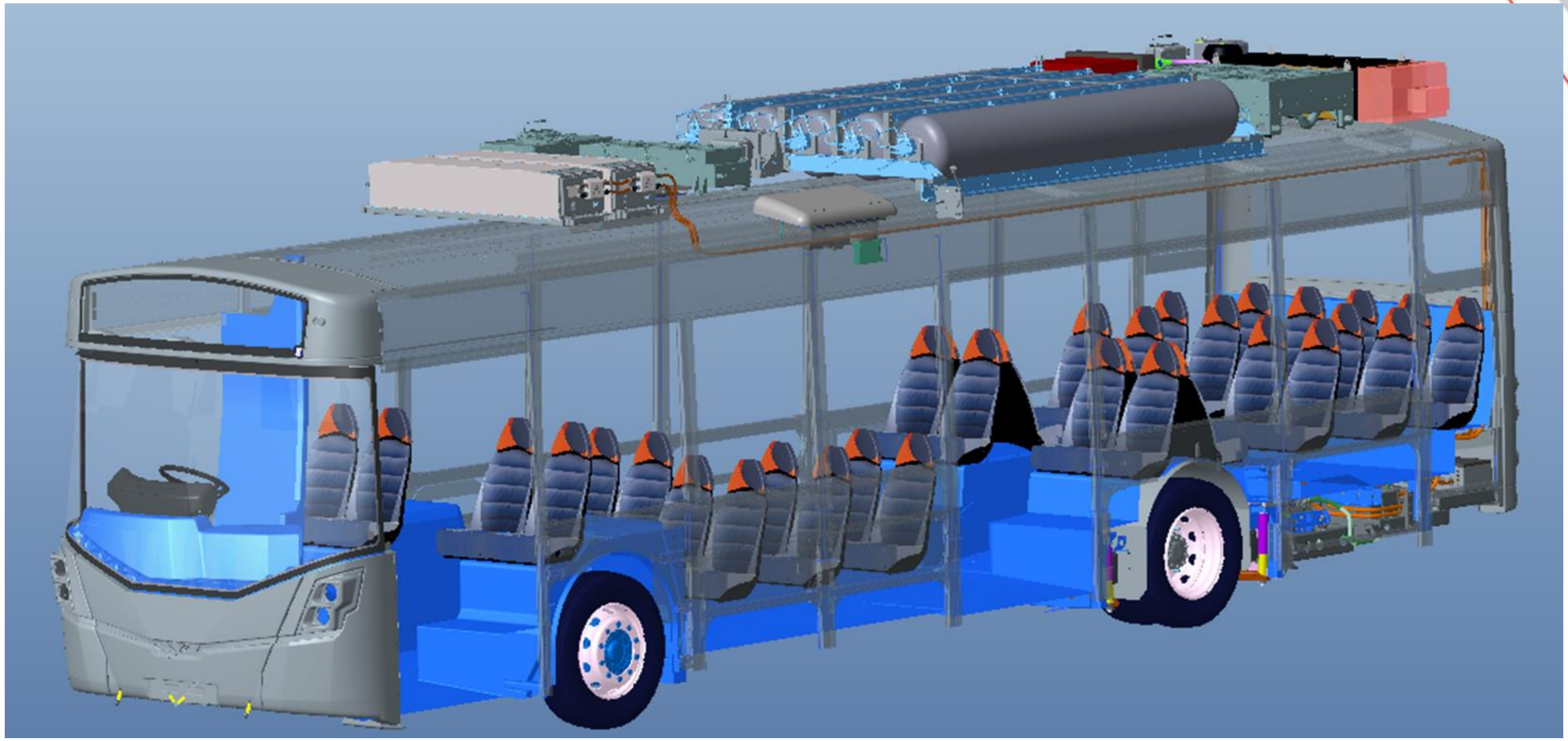
Gen2 FCEV Single Deck



A driveline test mule for new FCEV technology is being developed under the APC Advanced Road to Market Demonstrator programme

This test bus will be displayed at the Cenex Low Carbon Vehicle Exhibition in September 2021

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What is a FCEV?

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Advantages of FCEV over BEV

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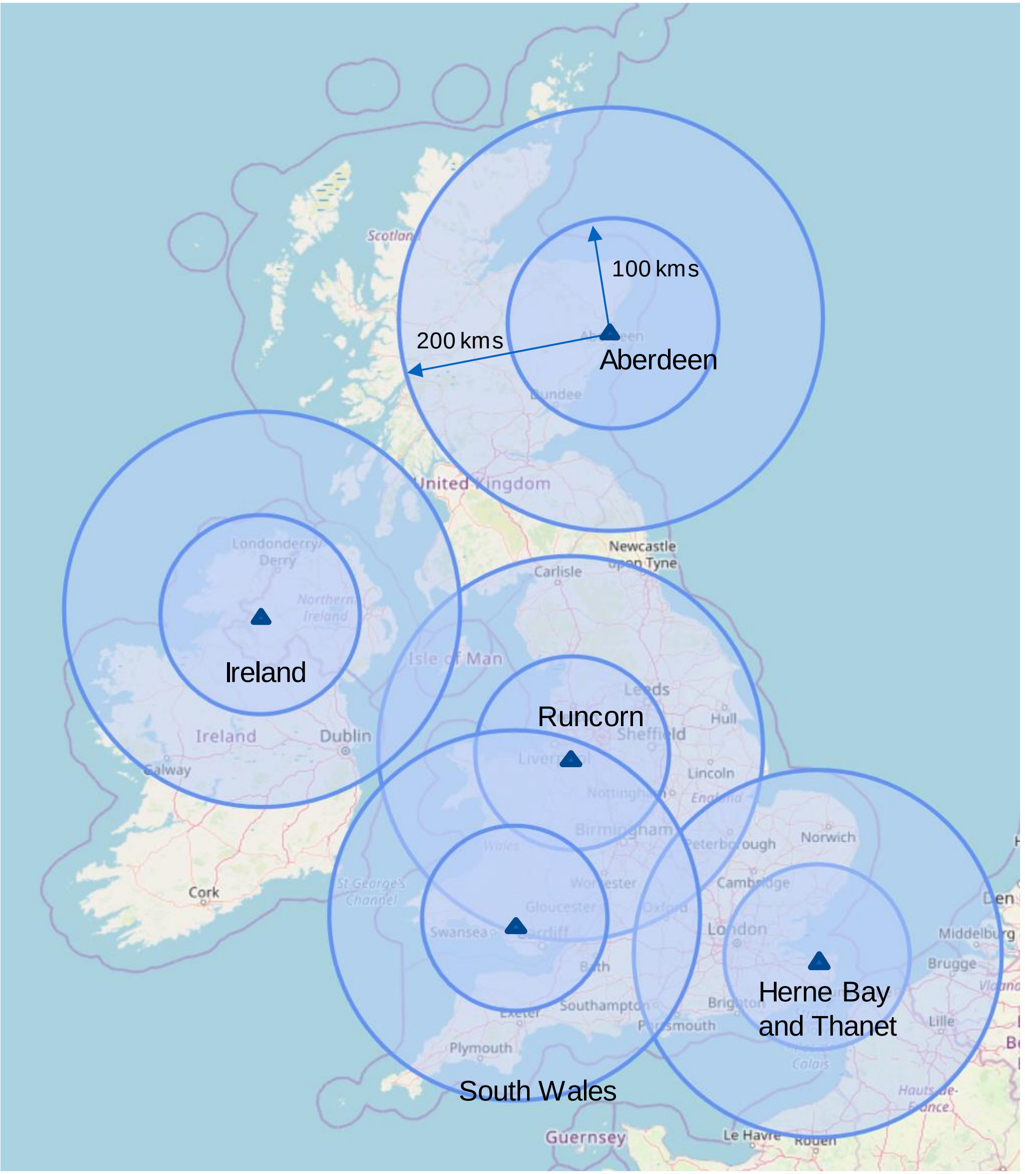


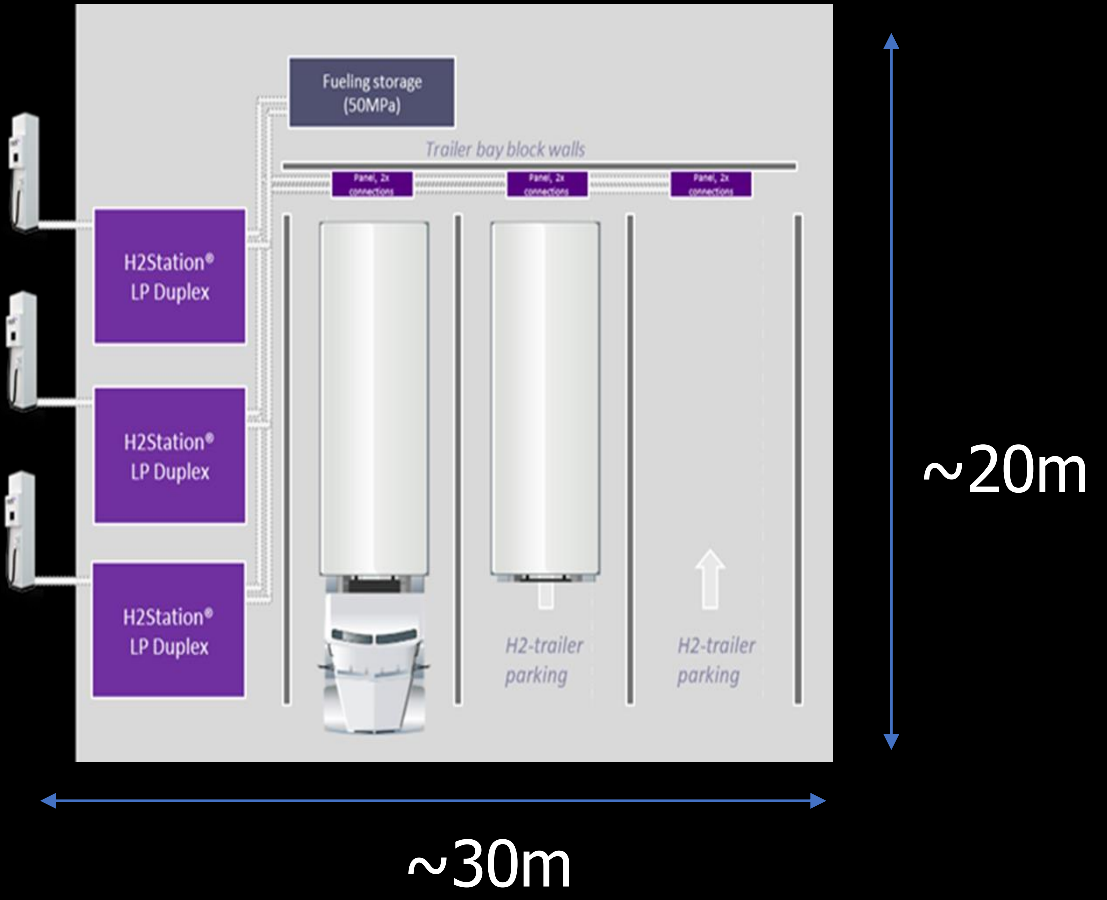
Planned hydrogen production sites

Long term plan is to harness surplus wind power to produce Green Hydrogen

However, much more investment is needed in UK green hydrogen production and distribution

Easier to scale up a FCEV bus garage due to the small footprint and the very quick refuelling times

Solution for fuelling >100 buses per day



FCEV Components & Layout

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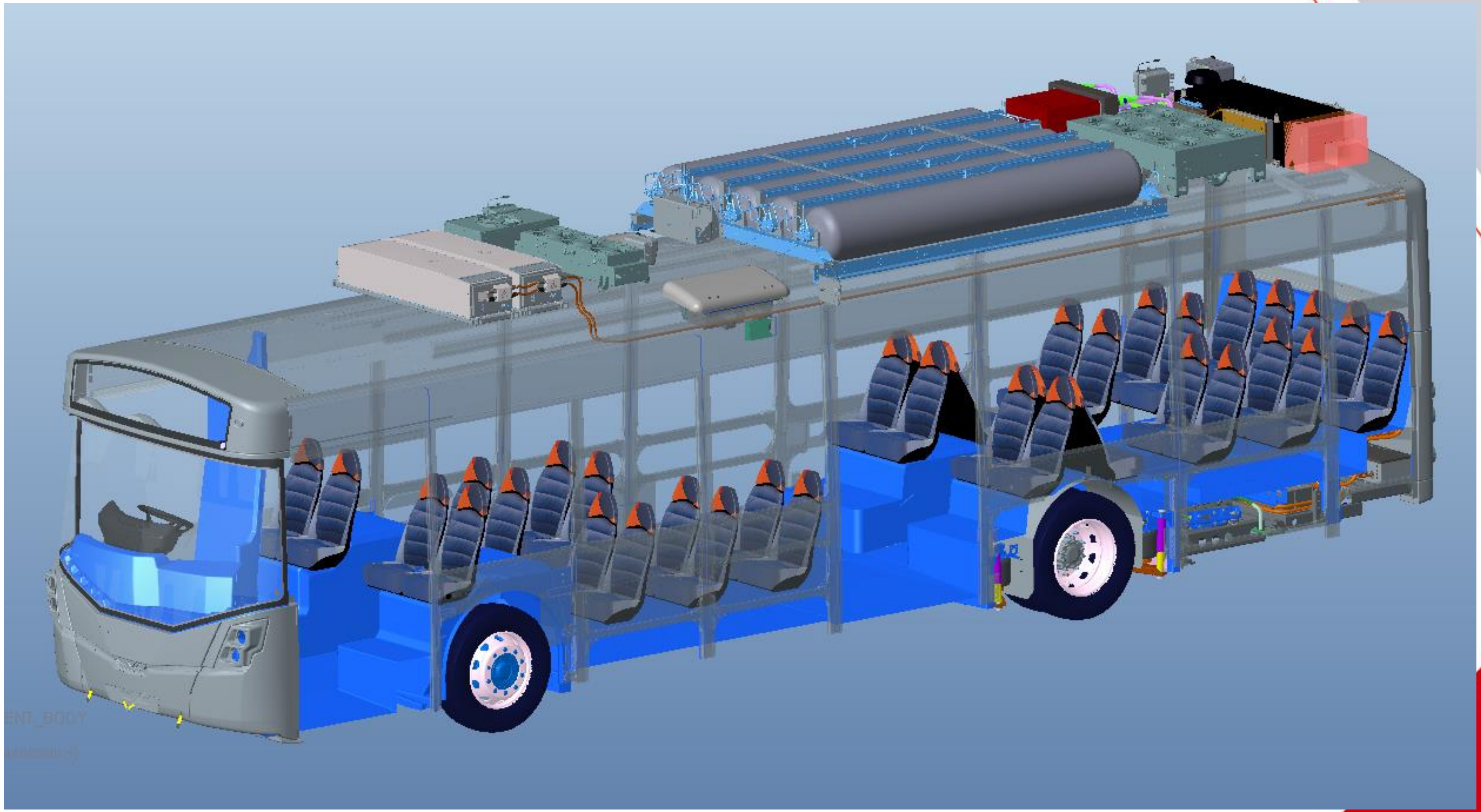
Component layout on single deck



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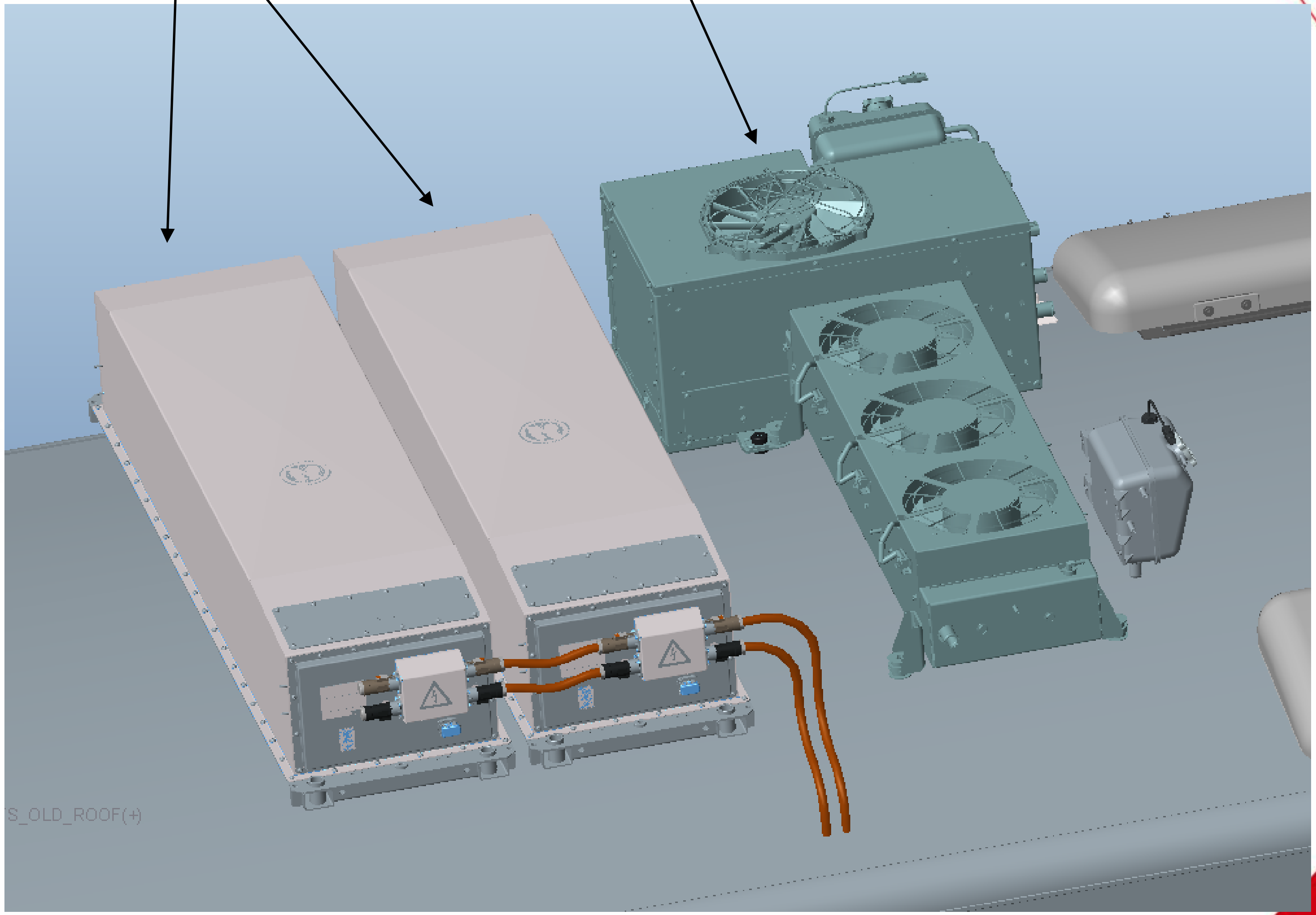
Lithium Battery

Small Lithium Battery

Battery Thermal Management System



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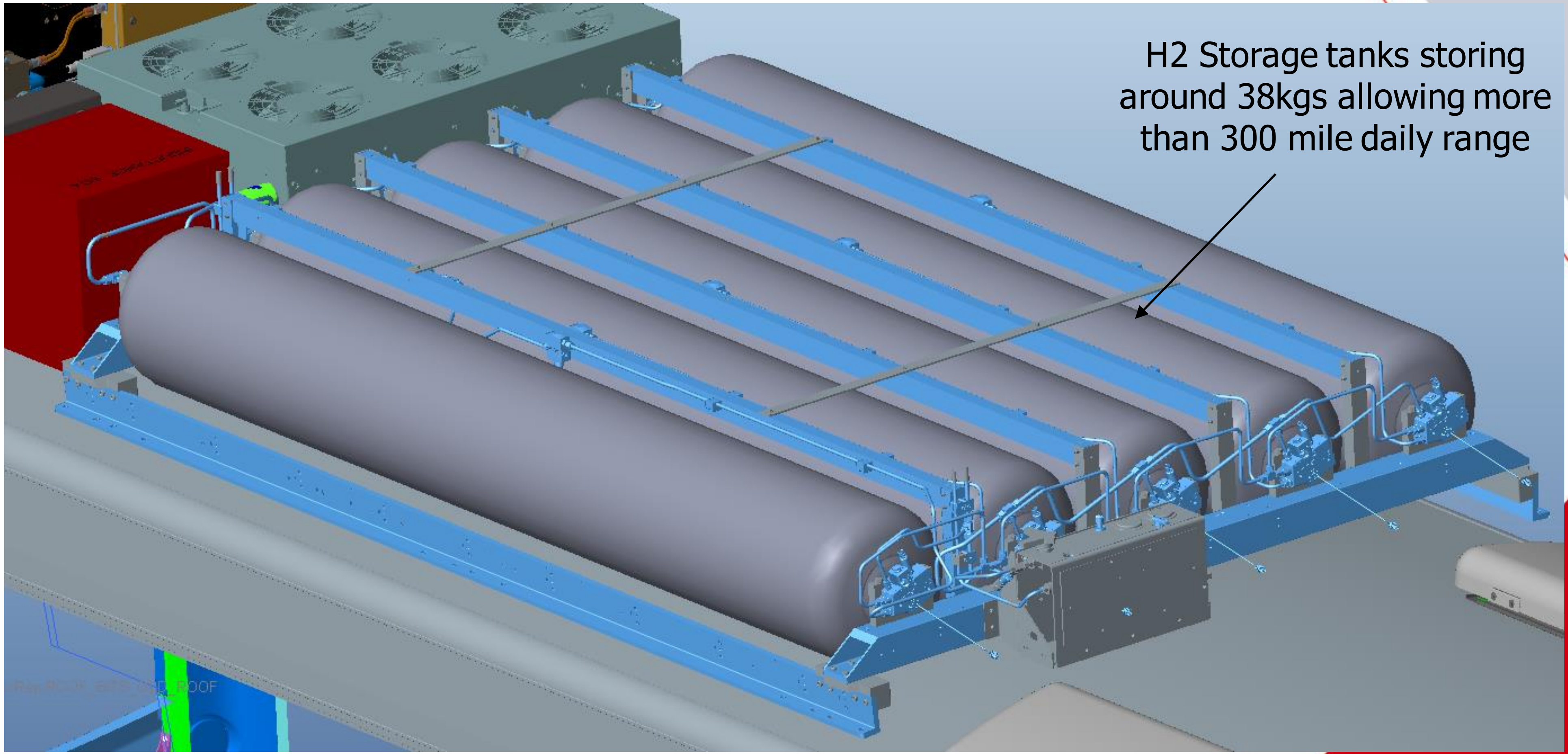
Hydrogen storage tanks



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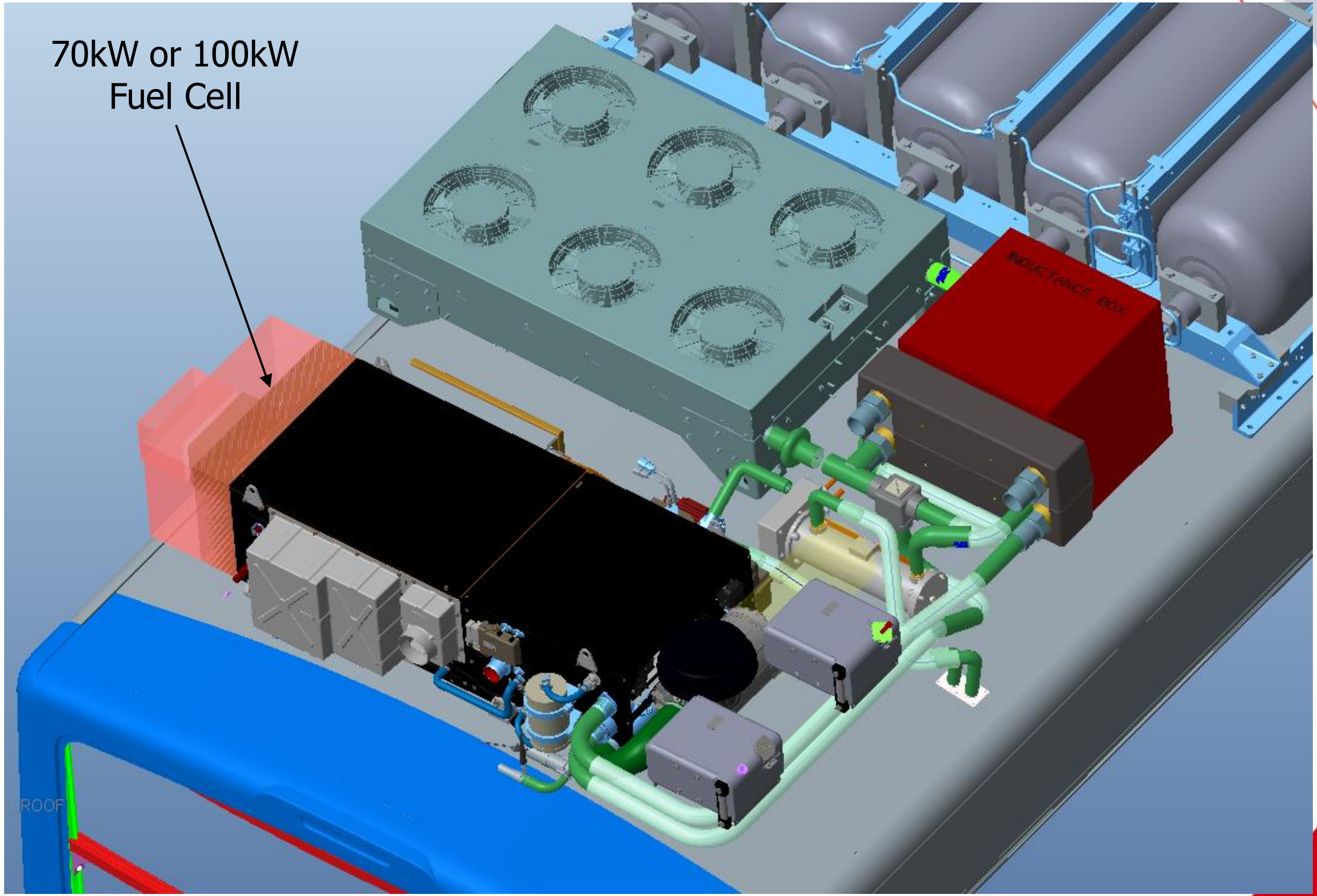
Fuel Cell



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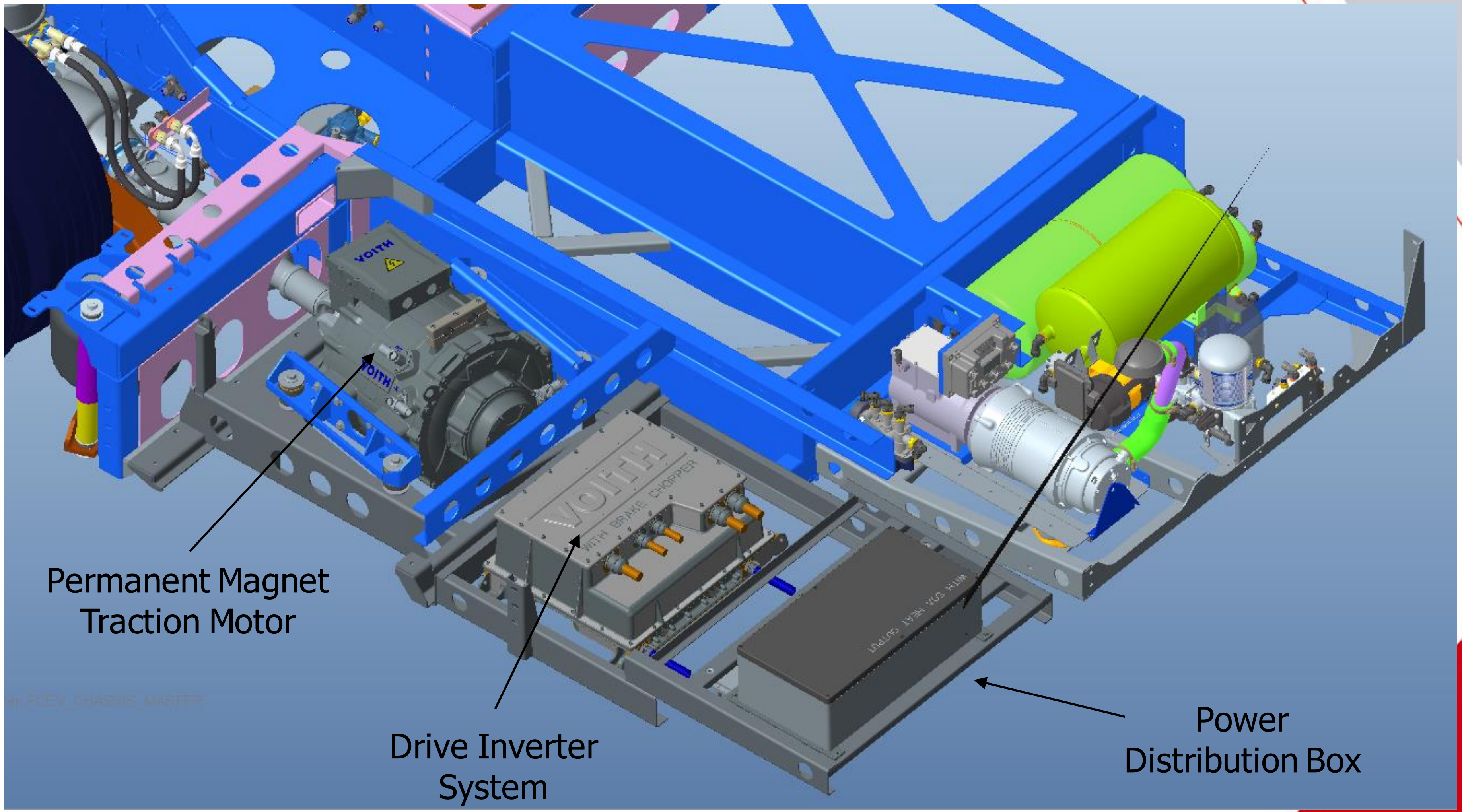
Electric Traction System



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Thank You

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Hydrogen supply and the path to net zero

Jo Howes

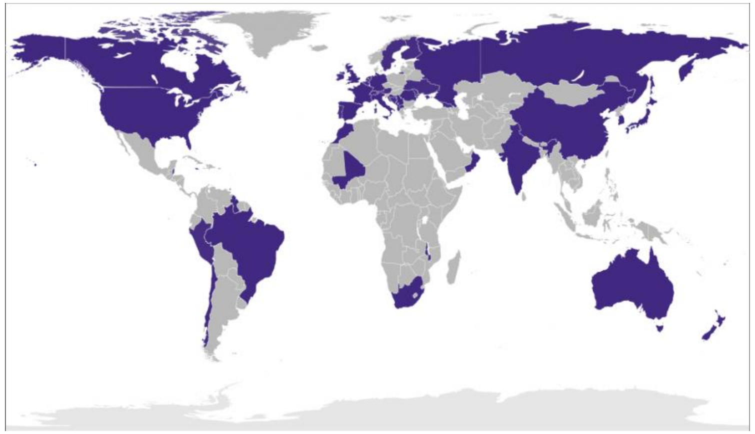
Are supply developments… giving hydrogen the green light?

Future of Technology Series

14th April 2021

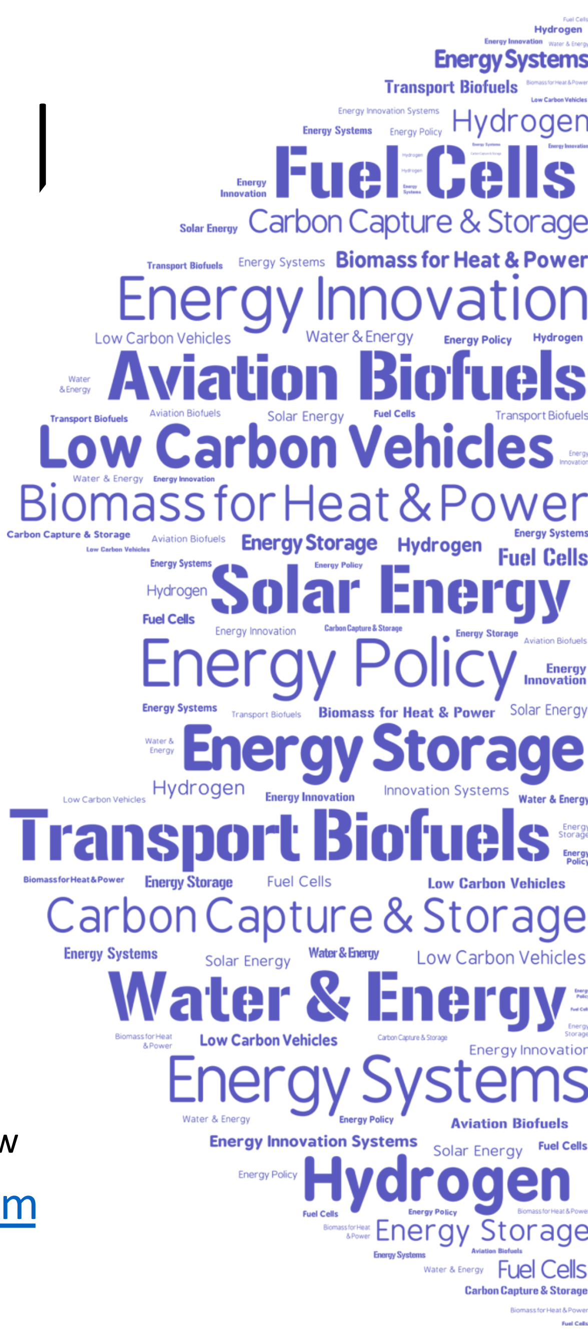
E4tech perspective: Strategy | Energy | Sustainability

- International consulting firm, offices in UK and Switzerland
- Focus on sustainable energy, including electrified vehicles
- 21 years old this year, always independent
- Deep expertise in technology, business and strategy, market assessment, techno-economic modelling, policy support…
- A spectrum of clients from start-ups to global corporations



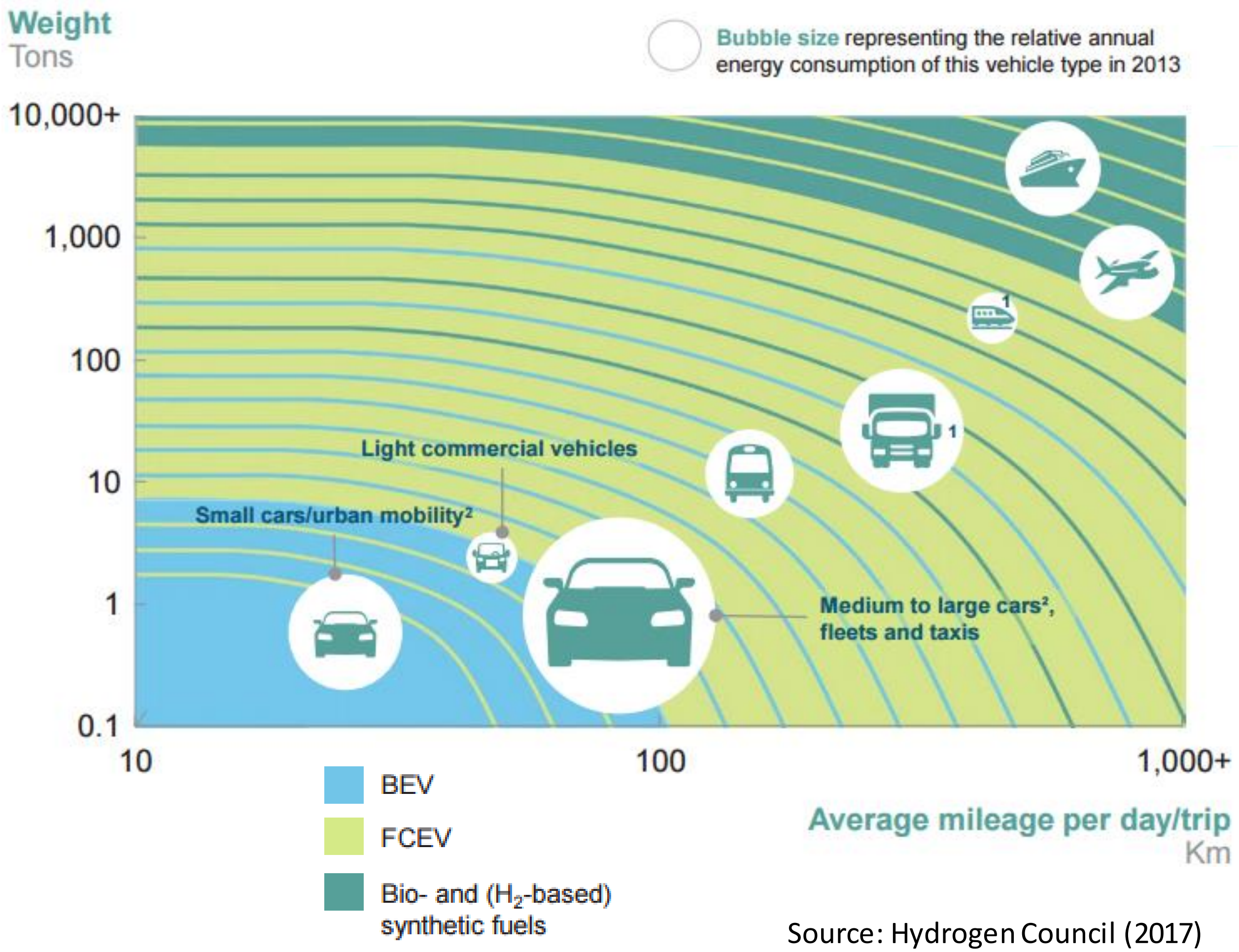
E4tech's annual Fuel Cell Industry Review

www.FuelCellIndustryReview.com



Hydrogen fuel cell vehicles offer the benefits of BEVs with fewer drawbacks than batteries, particularly for heavy veh

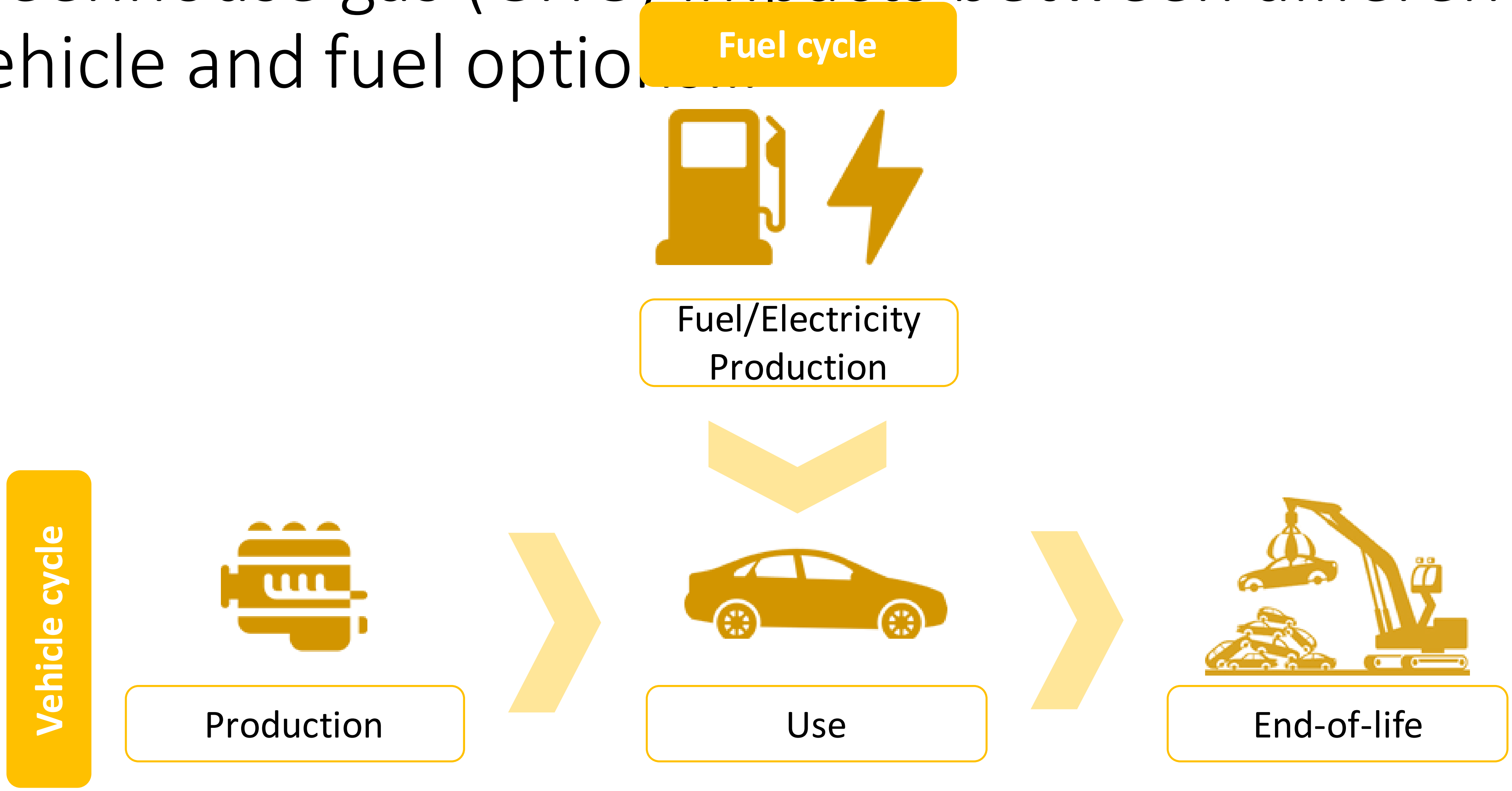
- Fuel cell *power* is decoupled from hydrogen *energy* – unlike batteries
- Neither very hot nor cold conditions strongly affect performance
- Range and gradient climb are close to conventional vehicles
- Hydrogen fuelling is fast; the model is familiar to oil companies and service station providers
- The business model and supply chain works for vehicle companies too



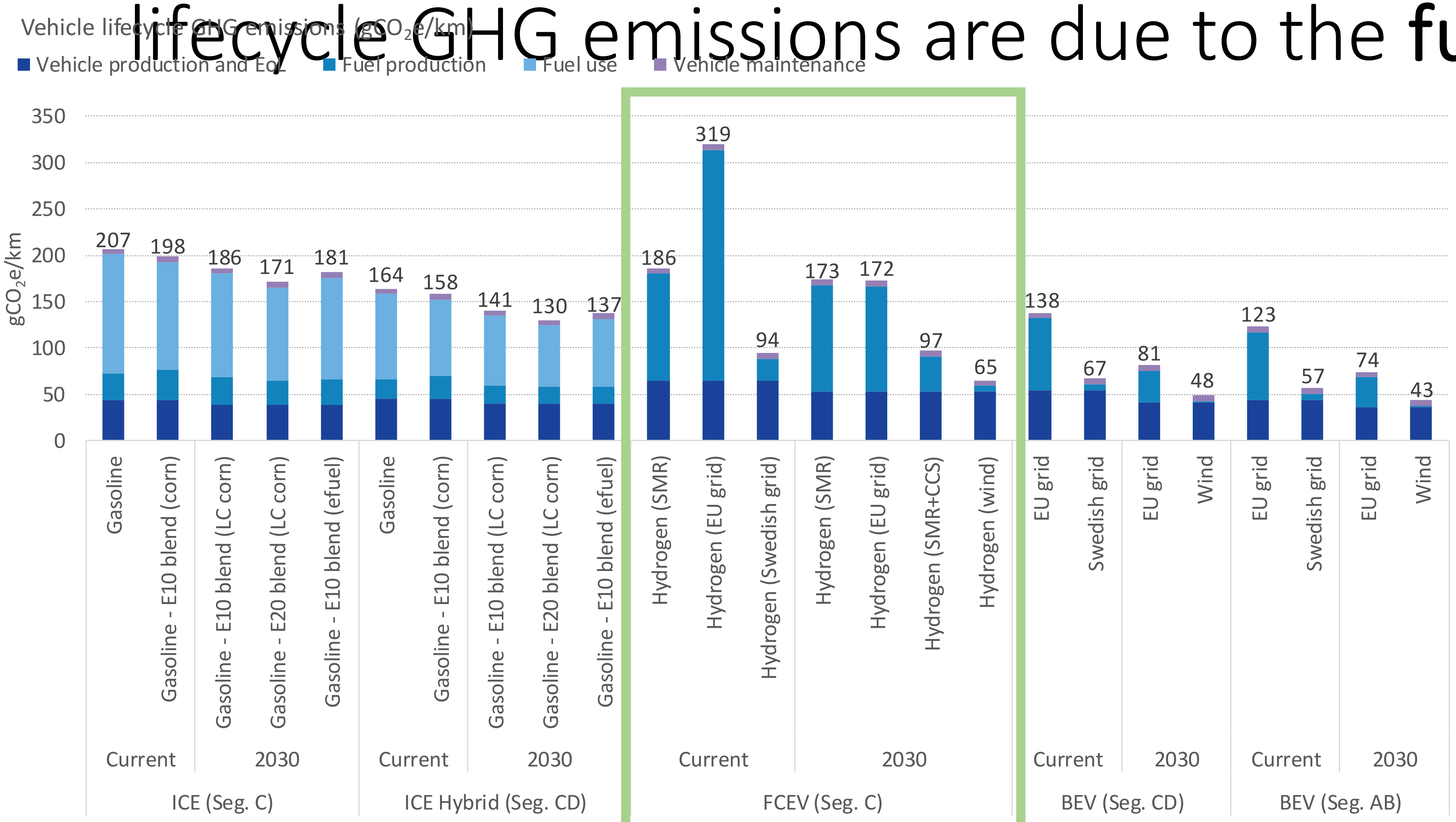
Source: Hydrogen Council (2017)

[1] Battery-hydrogen hybrid to ensure sufficient power
[2] Split in A- and B-segment LDVs (small cars) and C+-segment LDVs (medium to large cars) based on a 30% market share of A/B-segment cars and a 50% less energy demand

Life cycle analysis (LCA) is needed to compare greenhouse gas (GHG) impacts between different vehicle and fuel optio



… and for most powertrains, the majority of lifecycle GHG emissions are due to the **fuel cycle**



- For hydrogen vehicles, the emissions depend heavily on how the hydrogen is produced

Source: E4tech analysis (2018)

Hydrogen can be produced in several ways, with very different GHG emissions

Some of the many routes to hydrogen…

SMR / ATR plus CCS
Natural gas + steam →
hydrogen + CO_2

Source: Air Products

Electrolysis
Water + electricity →
hydrogen + oxygen

Source: NEL Hydrogen

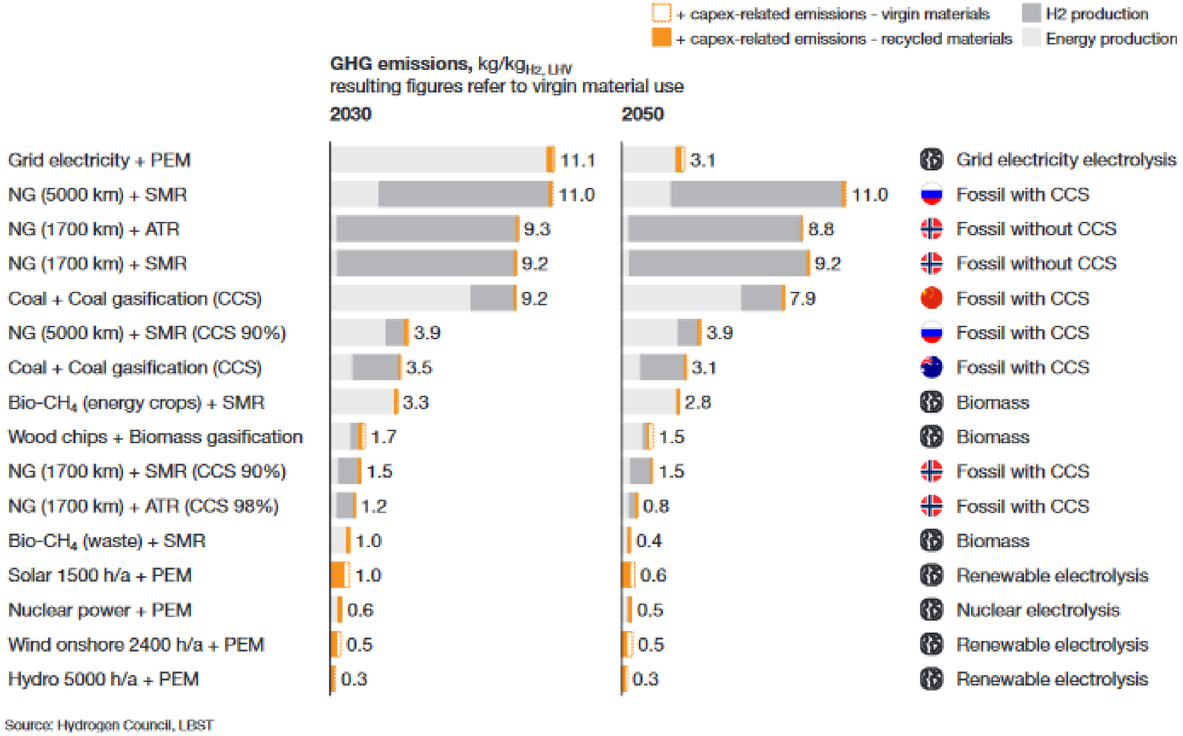
Biomass gasification (+CCS)
Biomass or waste →
Syngas → H_2

Gasification (not for H_2) Source: Enerkem

By-product hydrogen
e.g. Chlor alkali plants,
Ethylene plants

Chlor-Alkali Plant in Portugal. Source: Krebs Swiss

GHG emissions of hydrogen production pathways 2030 and 2050



Source: Hydrogen Council and LBST, Hydrogen decarbonization pathways: A life-cycle assessment January 2021

E4tech and LBST have recently completed a study on low carbon hydrogen production standards for BEIS, including hydrogen LCA results for the UK, to be published this year

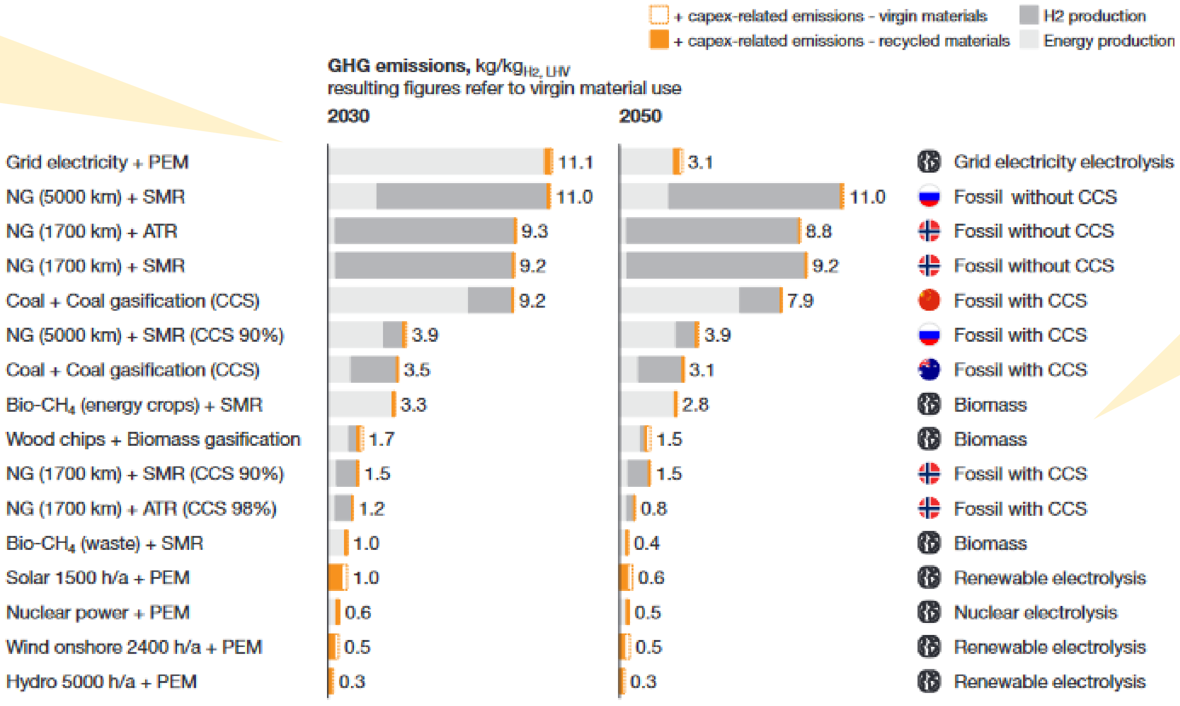
Emissions results are specific to the exact supply chain, place and time, not just the choice of n technology

Grid electricity
Significant decarbonisation over time brings down emissions from electrolyser and chlor-alkali routes

CCS
Is needed to enable low carbon fossil routes ('blue' hydrogen)

Renewables and nuclear
Give very low GHG hydrogen

GHG emissions of hydrogen production pathways, 2030 and 2050



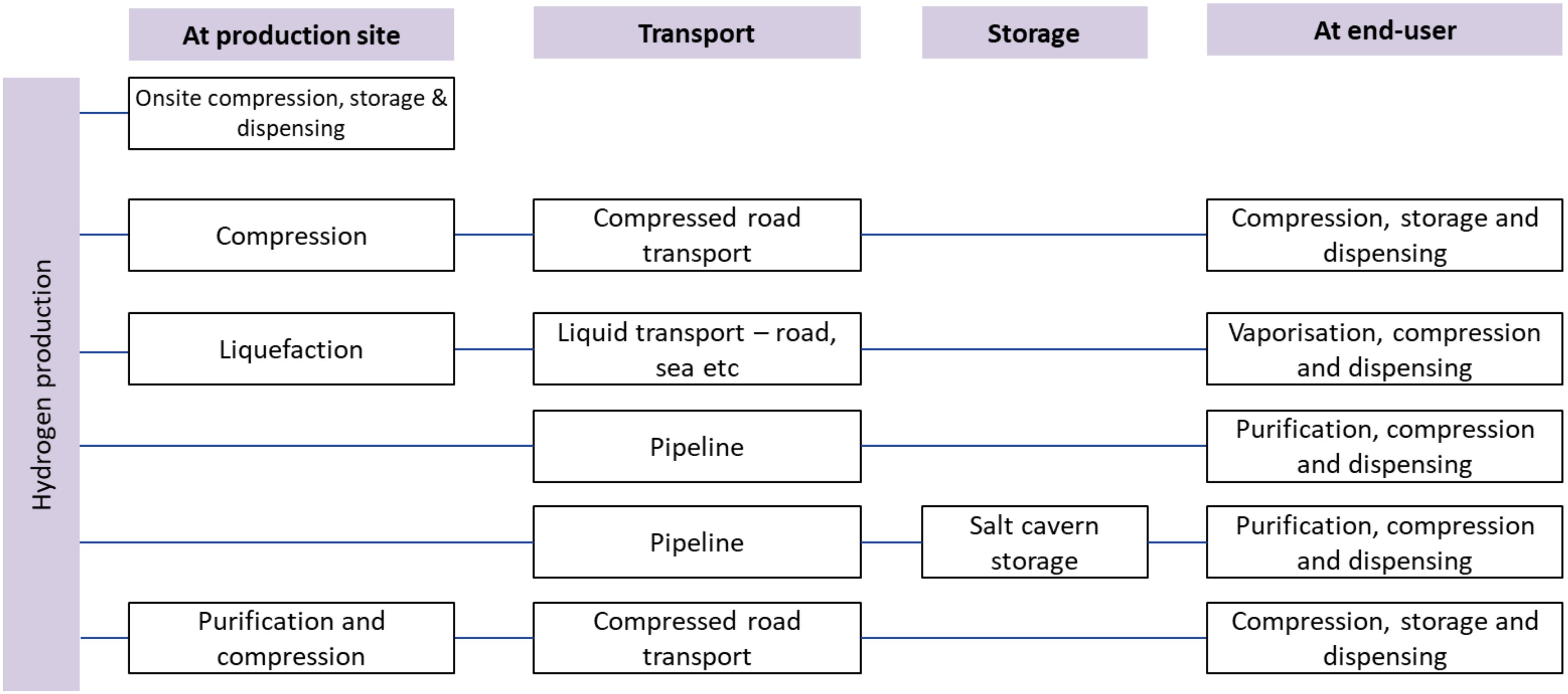
Source: Hydrogen Council, LBST

Biomass feedstocks
Have widely varying emissions depending on their source and production method

Negative emissions
Biomass routes with CCS (not shown here) can have negative emissions – i.e act as a carbon sink

The emissions of the supply chain downstream of hydrogen production can also be important

- Many downstream options are possible
- Emissions from some of these can be larger than those from production itself
- Several uncertainties remain



Standards and policy will be important in demonstrating and driving low GHG emission hydrogen pathways

- Comparing pathways with LCA relies on common methodologies, typically defined in standards, which can underpin…

Voluntary standards

CertifHy

Voluntary hydrogen Guarantee of Origin scheme within the EU, EEA and Switzerland

Transport fuel policies

Department for Transport

RTFO

The UK Renewable Transport Fuel Obligation incentivises use of renewable hydrogen meeting sustainability criteria, including 60% GHG savings

Future hydrogen policy

?

Other policies may be developed to support low carbon hydrogen use across all sectors of the economy

E4tech – strategic thinking in sustainability

For more information please visit our website:

www.e4tech.com

Or contact us in London or Lausanne:

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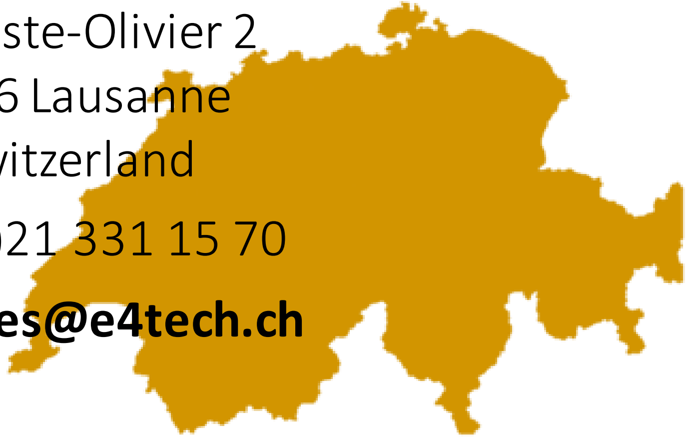

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Hydrogen Innovation Initiative

14/04/21

E2E Hydro-GEN

Driving Connected Innovation to accelerate the Hydrogen economy

Dr Gareth Williams, Strategy Director, National Composites Centre, HVMC

CATAPULT High Value Manufacturing
CATAPULT Energy Systems
CATAPULT Offshore Renewable Energy
CATAPULT Connected Places
CATAPULT Digital
CATAPULT Compound Semiconductor Applications
CATAPULT

Current Collaborators

CATAPULT Compound Semiconductor Applications

Driving exploitation of advances in compound semiconductor technologies

CATAPULT Digital

4 locations, driving innovation in advanced digital technology innovation

CATAPULT High Value Manufacturing

7 centres, 2.5k design & manufacturing engineers, £800m digital & manufacturing assets

CATAPULT Connected Places

4 locations, Innovation accelerator for cities, transport and places

CATAPULT Offshore Renewable Energy

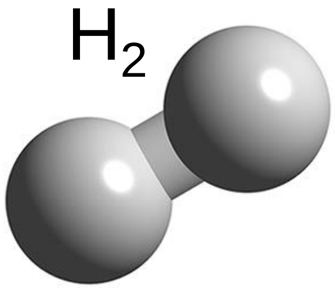
7 regional hubs, 200 Energy professionals, £250m large scale testing

CATAPULT Energy Systems

2 hubs, 200 Energy Innovation experts, Digital and systems engineering

Technology Driving Transition OGTC

£180m innovation funding, 130 members, £140m co-invested in 230 industry led projects



NPL National Physical Laboratory

440 world class laboratories, 1000 people, part of National Measurement System (NMS)

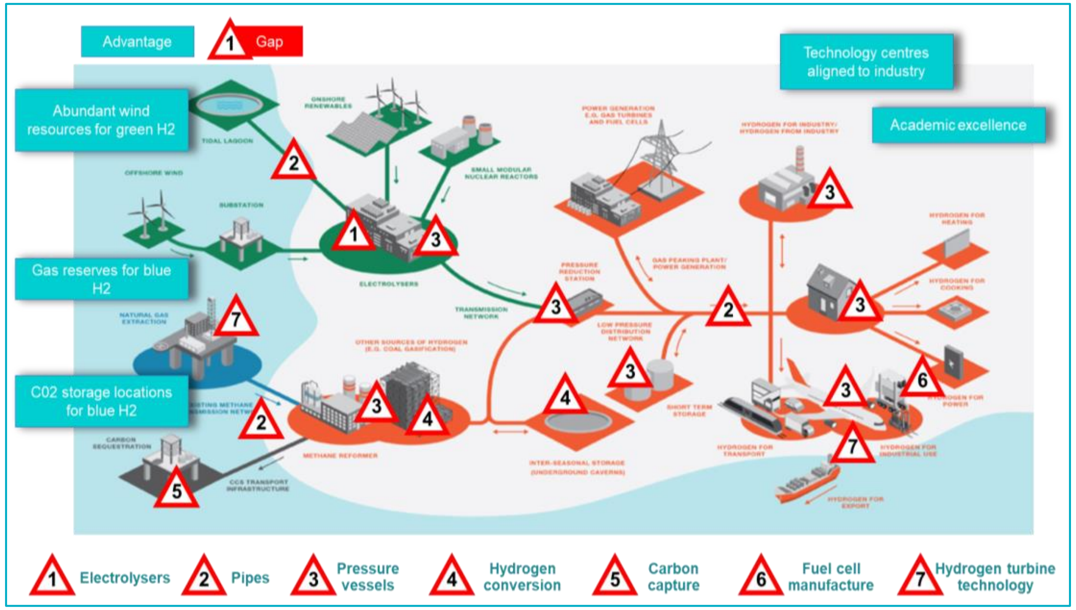
Aerospace Technology Institute

£1.4bn grant funding awarded, 182 live projects, 339 organisations supported

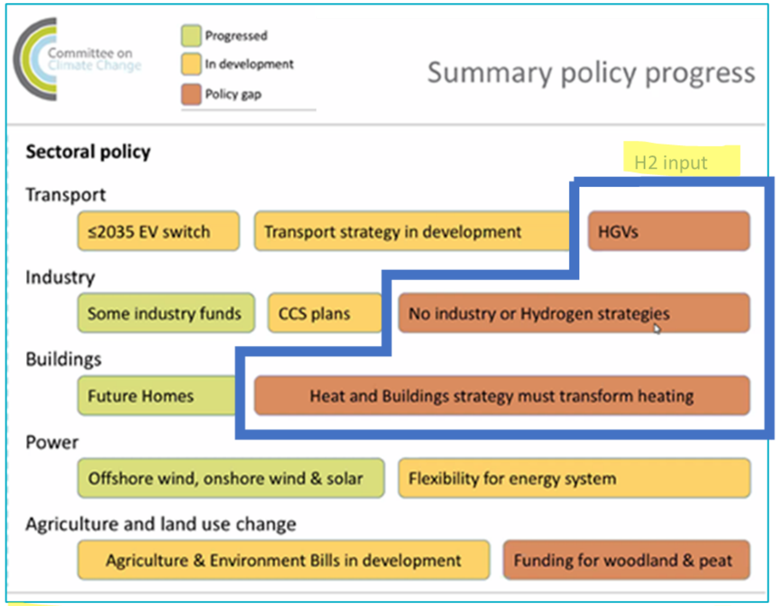
Advanced Propulsion Centre

£1bn+ investment committed, 150 low carbon projects, 375 project partners

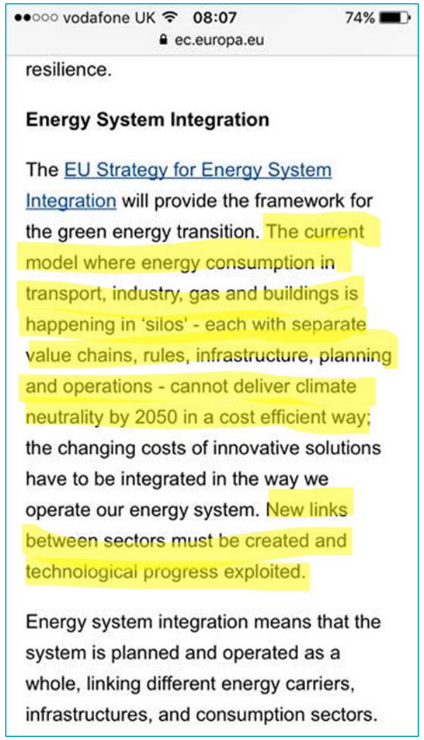
Context and rationale



The UK H2 value chain – National Advantages and Gaps overlaid on Hydrogen visual by Arup



Committee on Climate Change: Reducing UK emissions - 2020 Progress Report to Parliament



resilience.

Energy System Integration

The EU Strategy for Energy System Integration will provide the framework for the green energy transition. The current model where energy consumption in transport, industry, gas and buildings is happening in 'silos' - each with separate value chains, rules, infrastructure, planning and operations - cannot deliver climate neutrality by 2050 in a cost efficient way; the changing costs of innovative solutions have to be integrated in the way we operate our energy system. New links between sectors must be created and technological progress exploited.

Energy system integration means that the system is planned and operated as a whole, linking different energy carriers, infrastructures, and consumption sectors.

The Opportunity and The Challenge

Hydrogen is widely recognised as a critical low carbon fuel to meet global net zero ambitions. The UK has key natural advantages that must be leveraged in order to develop a thriving and world leading Hydrogen Economy: abundant access to wind energy, geological storage locations for CO2, world leading centres of excellence for R&D working in partnership with Industry and Academia, like the OGTC, APC, ATI, TWI, NPL and the Catapult Network.

However challenges exist within the future Hydrogen Value Chain that require co-ordinated intervention against both technical and non-technical issues. This cannot be addressed efficiently in sector driven silo's if we are to position the UK at the forefront of the global race to a low carbon Hydrogen economy.

The **E2E Hydro-GEN** consortium is proposed to forge the strategic linkages across the value chain and create a connected innovation backbone to deliver the following:

1. **Drive** a thriving Hydrogen Economy – driving the UK to Net Zero
2. **Secure** the UK as a Hydrogen 'Super Supplier' for domestic and export markets
3. **Accelerate** key technology innovations to secure UK as global leader in hydrogen technology
4. **Develop** UK value and sovereign UK capabilities as we create new Hydrogen Supply Chains

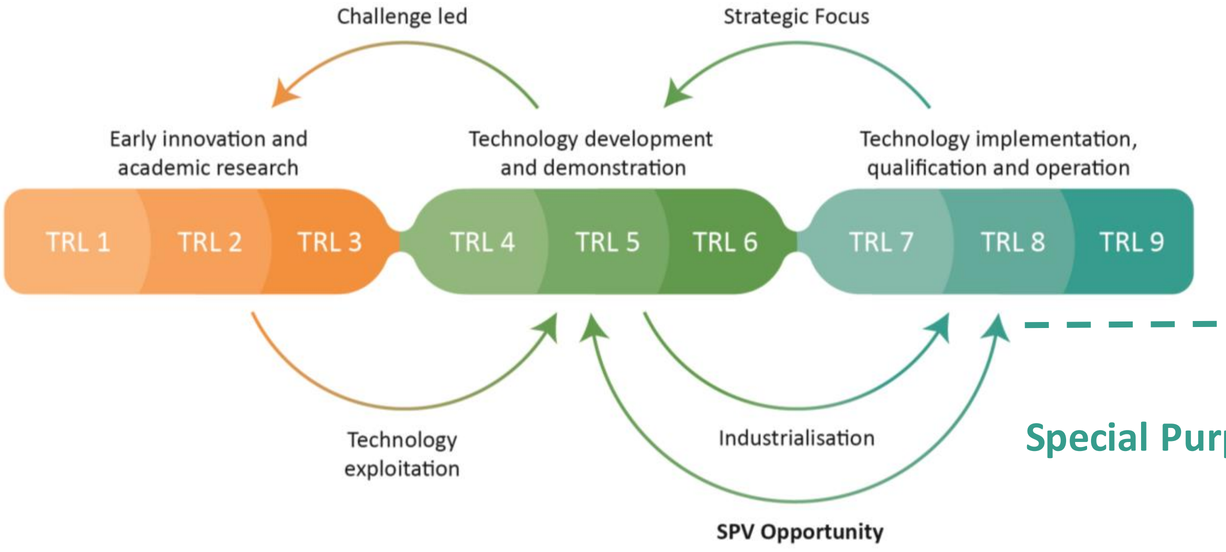
Background Gap Analysis

Generation			Distribution		Consumption		
Green Hydrogen	Blue Hydrogen ⟷	CCUS	H2 Storage	H2 Transport	H2 4 Heating	H2 4 Transport	Industrial Power
Technology Gaps							
• Lower cost Electrolysers • Low cost and durable catalyst materials • Cost effective Saltwater electrolysis • Subsea electrolysers	• High-efficient reformers / membranes / CO2 sorbents	• Capture materials • Modelling, Site selection, Injection strategy • Geological behaviour of CO2 • Site monitoring • Compact CO2 processing equipment • High efficiency CO2 conversion	• Small scale H2 Liquefaction • Minimal boil-off storage • Small scale ammonia production • Ammonia cracking • Underground storage (salt cavern vs depleted O&G fields)	• Methods for pipelines re-lining • LOHC Catalysts • Fit-for-purpose new infrastructure/pipelines • Compression for transport via road/sea • Repurposing of existing gas networks	• Appliances • Domestic and commercial supply networks / systems • Safety / Monitoring	• Fuel cell manufacturing • Fuel cell catalyst • Cryogenic storage systems / lightweight pressure vessels / fuel cells • Hybrid management systems combine EV/H2	• Combustors to retrofit turbines to H2 • Industrial decarbonisation-fuel switching compatibility • Opportunities for green foundries such as green steel
Policy & Non-Technical Gaps							
• Tech Import / Local content • Competition with power generation	• Import / not enough domestic gas	• Lack of a CO2 market framework	• HSE Regulations?	• Regulations • Network zoning • Local area energy planning • Balancing centralised vs de-centralised production	• Hydrogen Vs Gas Pricing & Taxing • Public acceptance	• Refuelling Infrastructure • Hydrogen Vs Gas Pricing & Taxing	• Hydrogen Vs Gas Pricing & Taxing

Technology Innovation Landscape

- **Electrolysers**
- **Floating Wind**
- **Methane reforming**
- **CO2 Systems**
- **Geological Storage**
- **Synthetic Fuels & H2 Carriers (ammonia)**
- **Domestic Appliances**
- **Fuel Cells**
- **H2 Turbines**
- **Pipes**
- **Pressure & Cryogenic Storage Vessels**
- **Electronic Control Systems**
- **Safety Monitoring Systems**

Connected Innovation - Future Activity

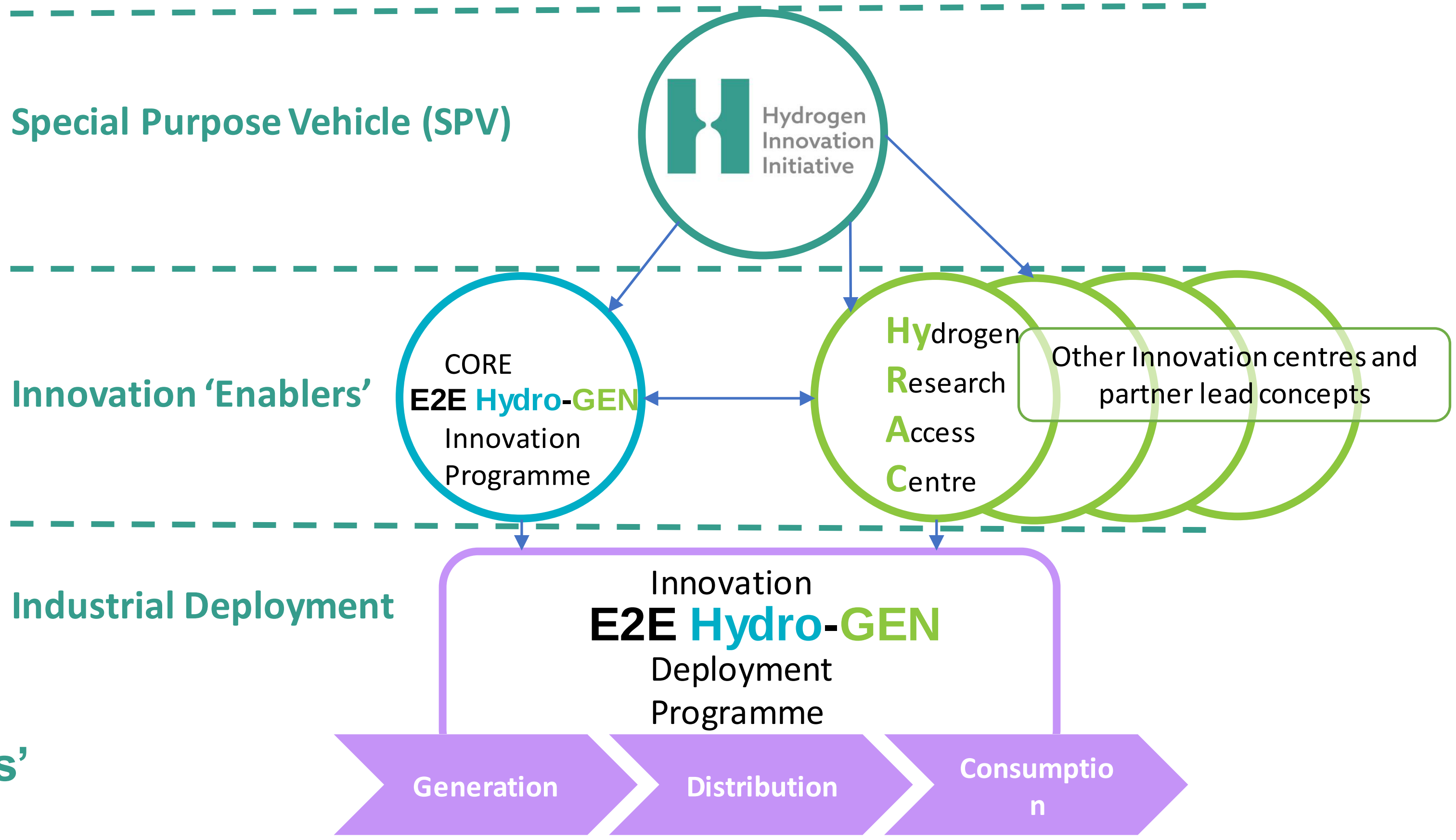


Generation

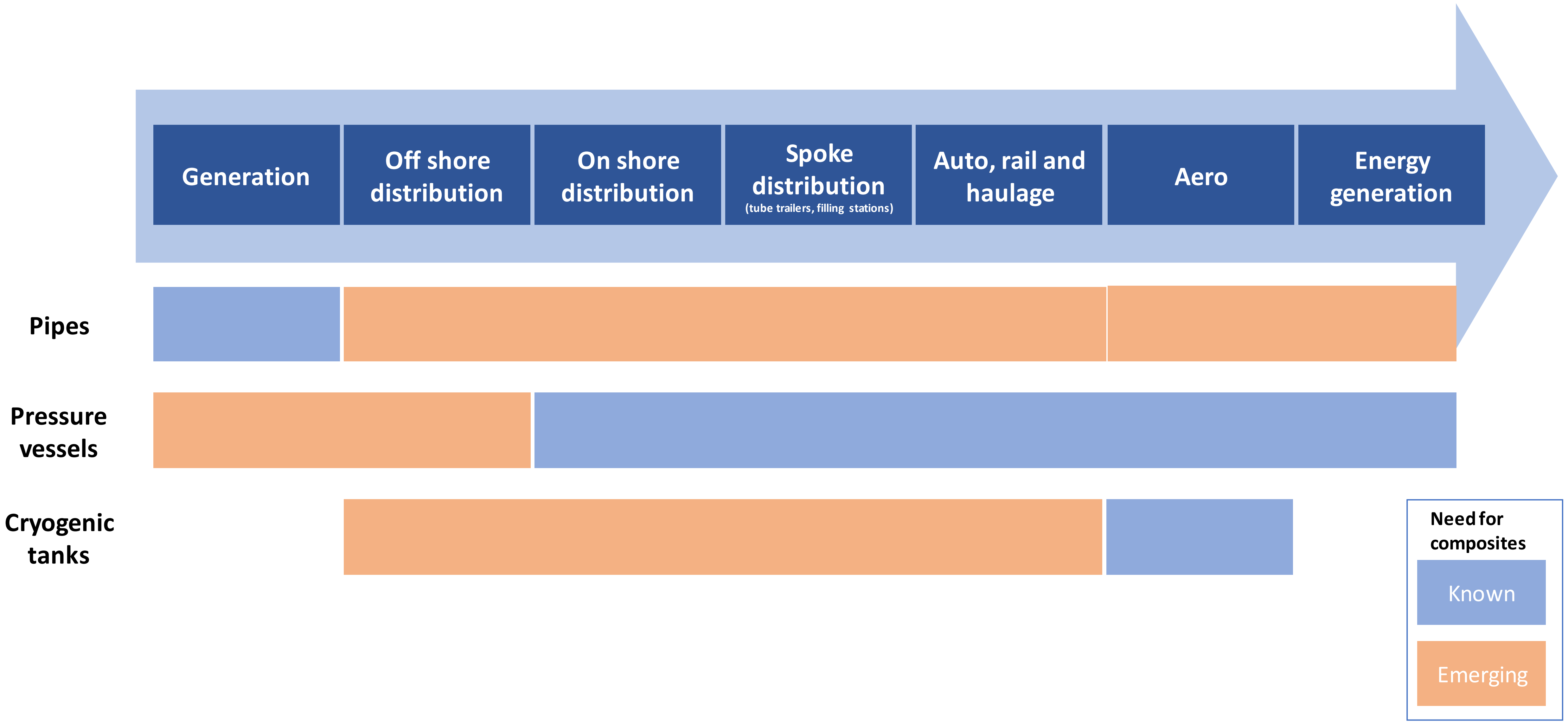
Distribution

Consumption

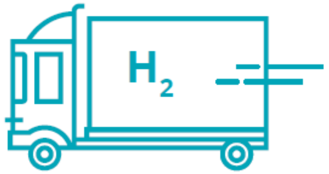
Creating the cross sectorial 'Green Threads'



Priority Applications for Composites



Hydrogen Vehicles



FCEV [176]

- Electric motor capacity: 55 kw (around 75 HP)
- fuel cell system capacity: 30kw
- Load capacity: 3.2 tons
- Driving distance: ≥305 km
- Vehicle length: 6.4m

BEV [177]

- Electric motor capacity: 120 kw (around 163 HP)
- Battery capacity: 100kwh
- Load capacity: ~3.0 tons
- Driving distance: around 200 km
- Vehicle length: 5.97m

ICEV

- ICE capacity: around 100kw [179]
- Load capacity: ~3.0 tons [178]
- Driving distance: around 400 km
- Vehicle length: 5.9m [179]

Figure 67. Total cost of ownership of transit buses in London / USD per 100km

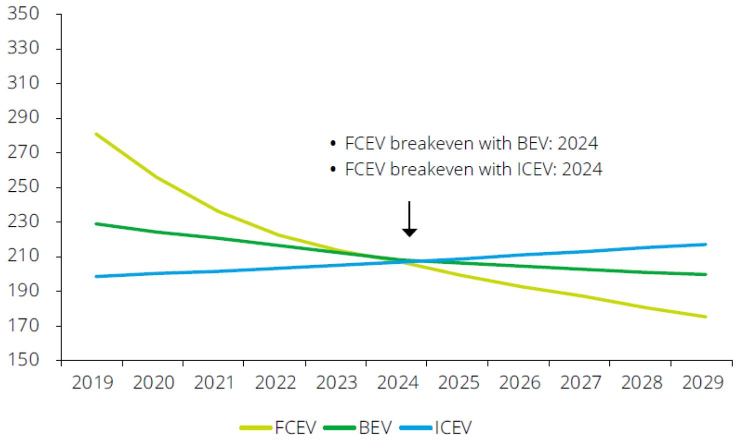
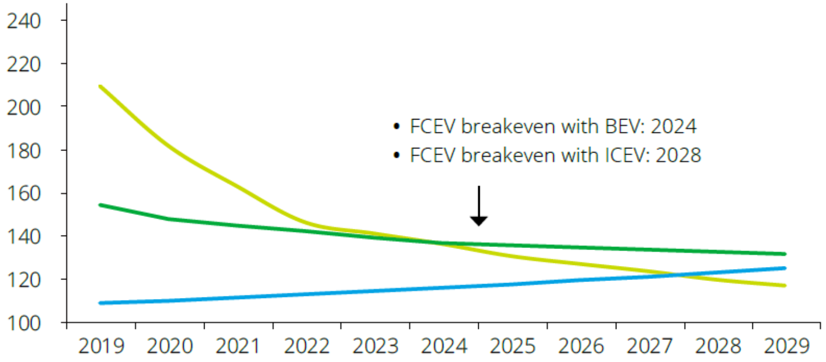


Figure 60. Total cost of ownership/ USD per 100km



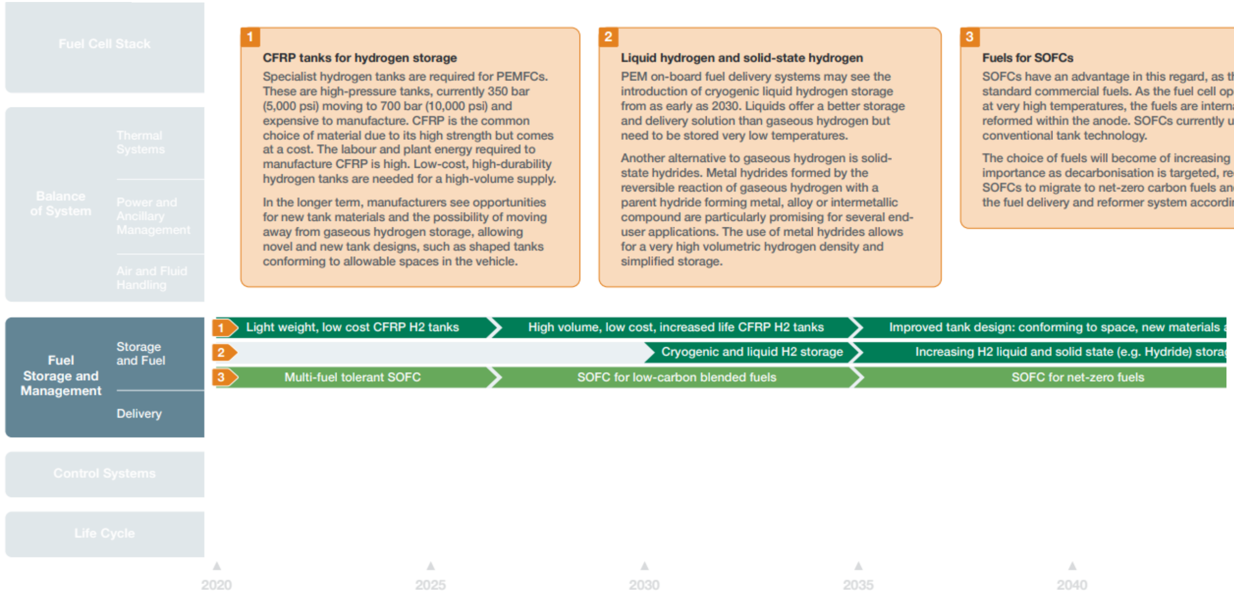
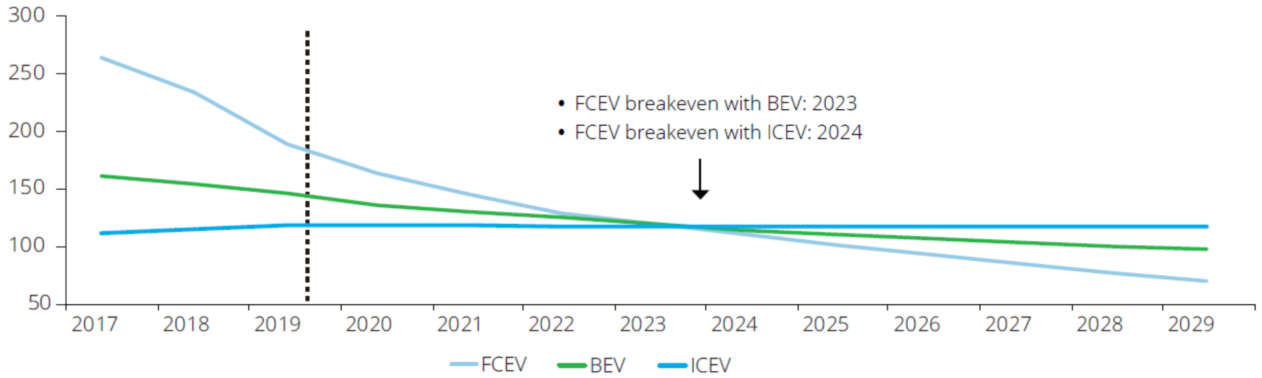
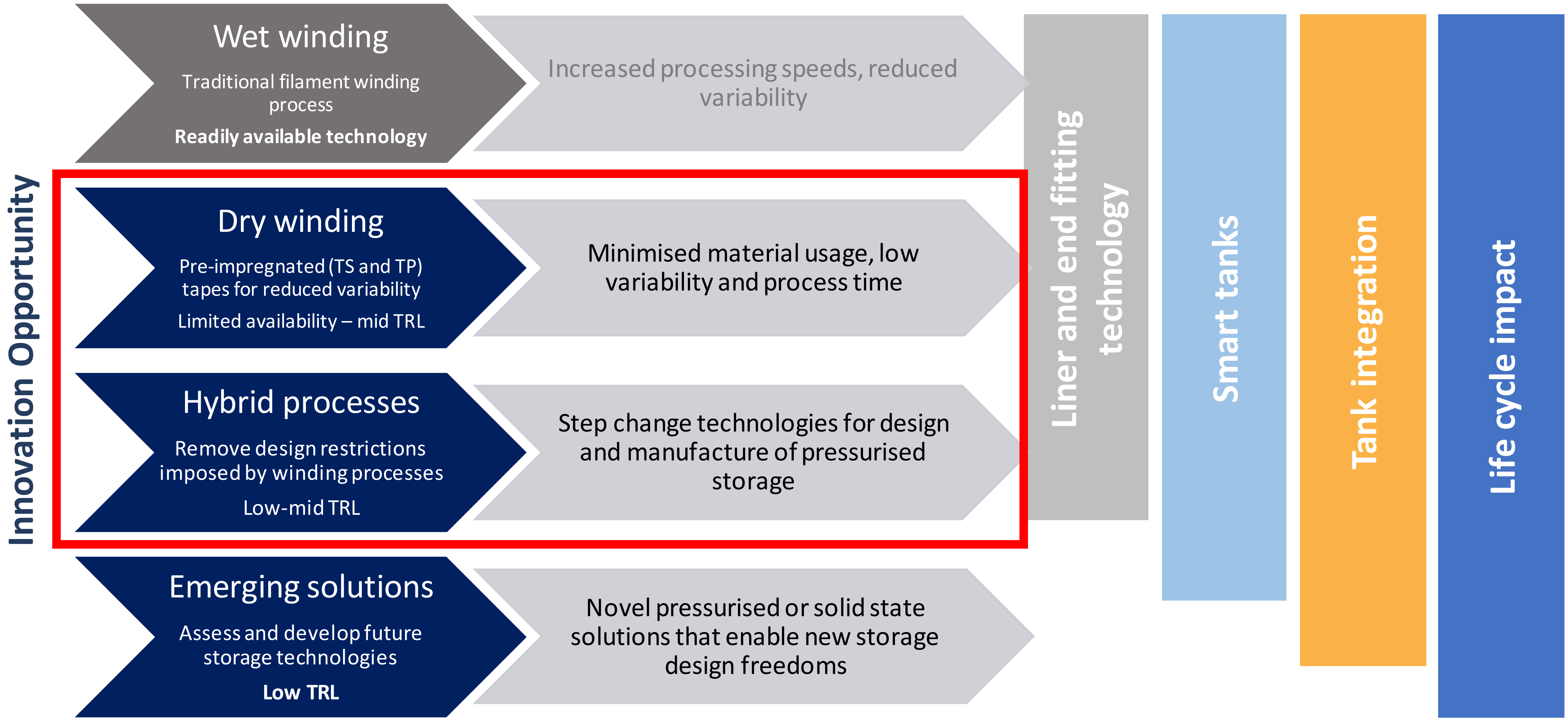


Figure 38: Bus TCO outlook in Europe (unit: USD/per 100 km)



Deloitte - Fuelling the future of mobility, APC Fuel Cell Roadmap 2020

Pressure Vessels: Enabling H2 Propulsion



Pressure Vessels: Enabling H2 Propulsion

Design

Materials

Manufacture

V&V, Certification

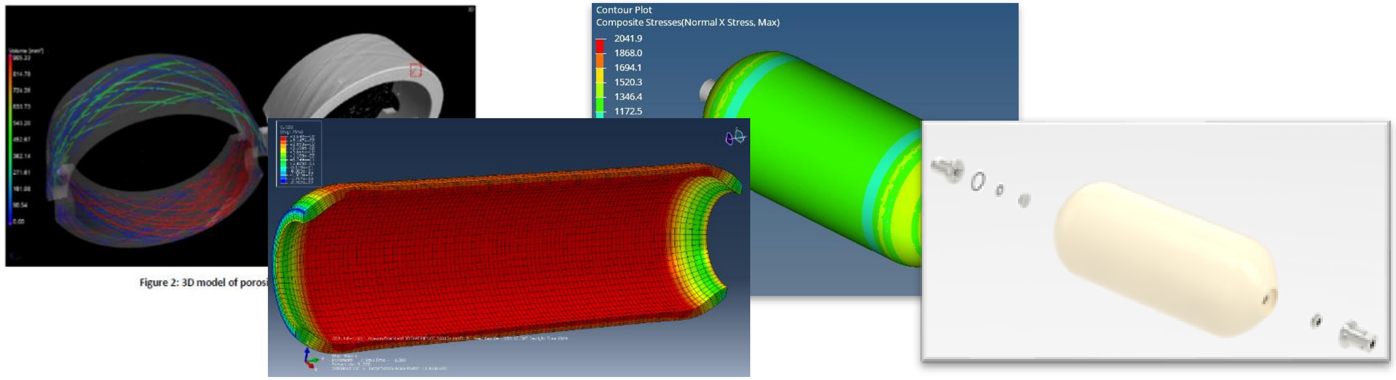


Figure 2: 3D model of porosi

AFP (gantry-type)	AFP & FW (robotic-type)	AFP & ATL (robotic-type)	Wide tape placement Wide fabric placement (gantry-type)

Small Scale

Large Scale