Making Hydrogen Transport Work: Insights & Experience from Aberdeen

Chaired by Fergus Worthy, Cenex
with Nigel Holmes, SHFCA
Andrew Win, Aberdeen City Council
Nick McCarthy, Cenex

SCOTTISH Hydrogen & Fuel Cell ASSOCIATION

Scotland's Achievements and Ambitions for Clean Transport

Ambitious Net Zero Climate Targets

Scotland's target: Net Zero by 2045

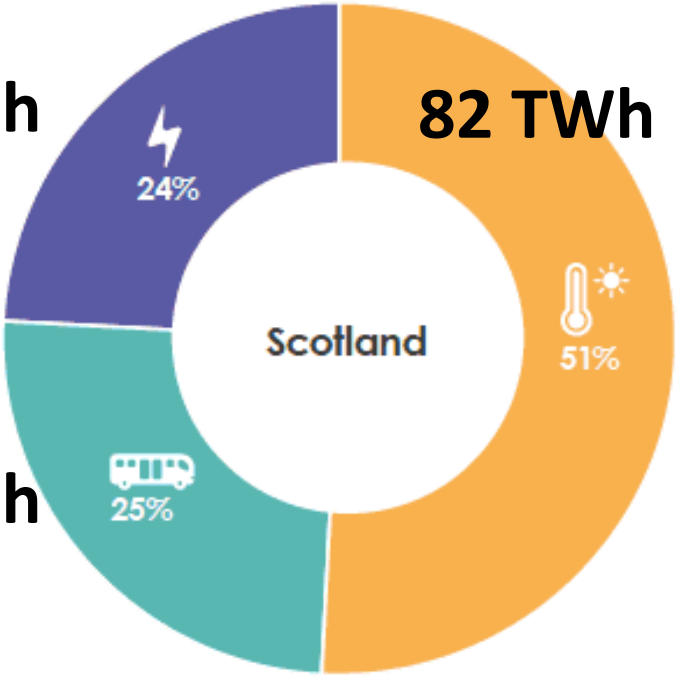
Year	Scottish CO_2 Reduction
2030	75%
2035	80%
2040	90%
2045	100%

The CCC advises combined use of renewables and CCS for rapid and effective carbon reduction

Current Scottish Final Energy Demand

38 TWh

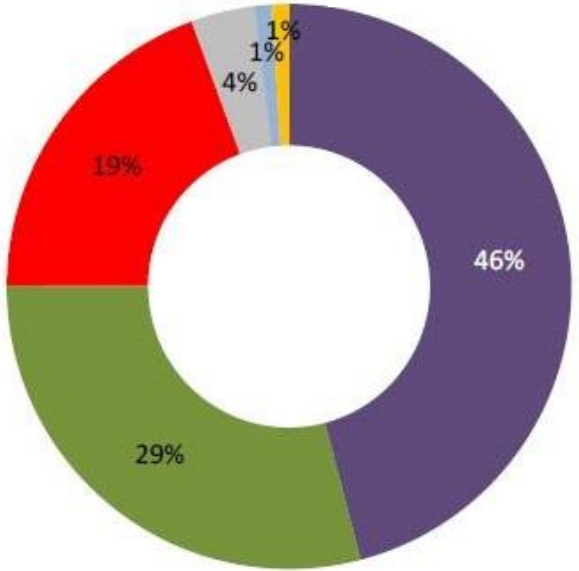
82 TWh



40 TWh

Heat
Transport
Electricity

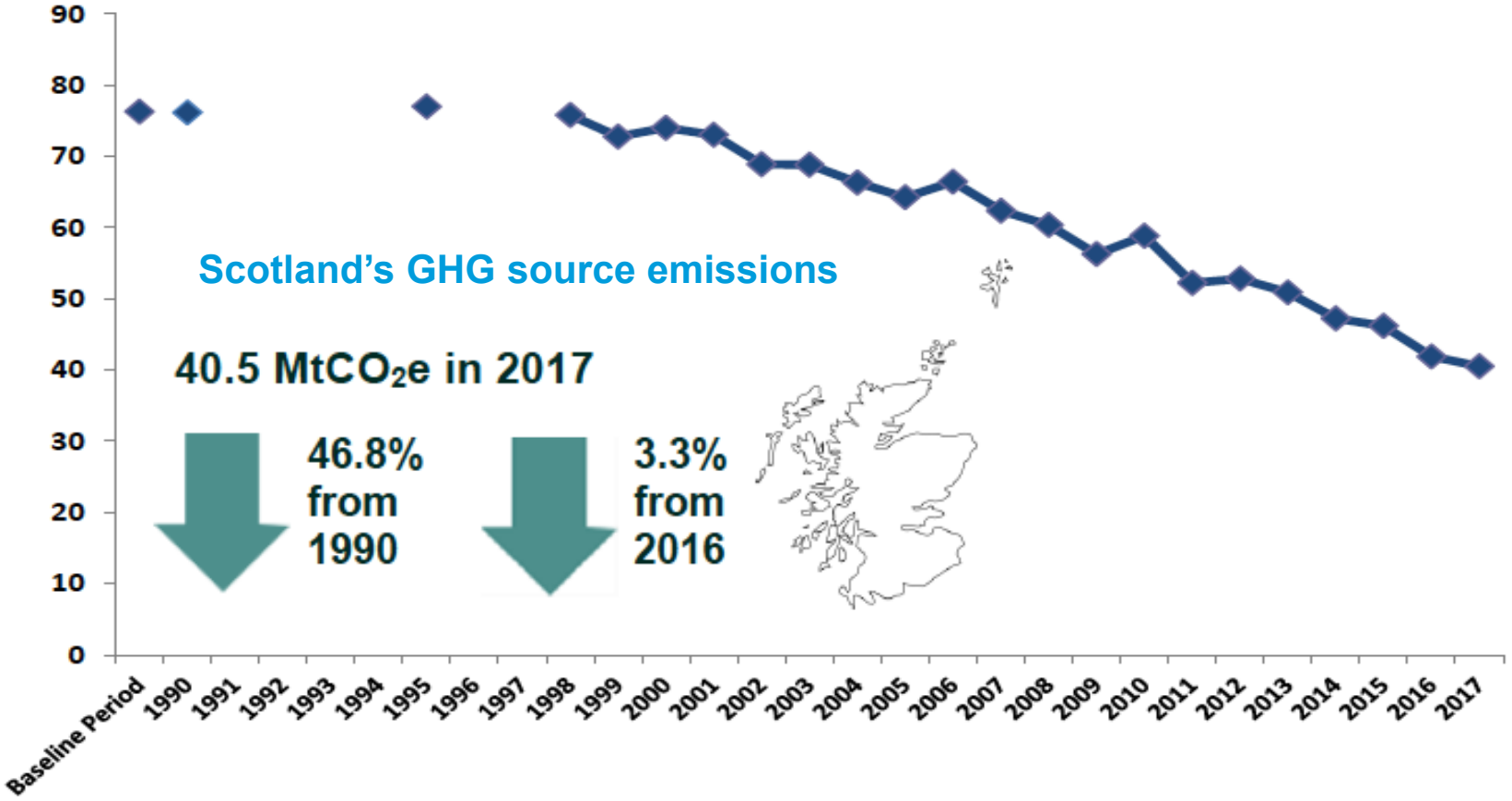
Final Consumption 160 TWh



Petroleum products
Electricity
Manufactured fuels & Other
Natural gas
Bioenergy & wastes
Coal

[Future of Energy in Scotland](): (Dec 2017)

Reducing Greenhouse Gas Emissions



The Future of Energy in Scotland – A Transition

A rapid transition from coal/oil/gas to Renewables

- From centralised to localised Energy Systems
- Whole energy system approach
- H_2 for 'hard to treat' heat, transport, and indust

A WHOLE-SYSTEM VIEW

A STABLE, MANAGED ENERGY TRANSITION

A SMARTER MODEL OF LOCAL ENERGY PROVISION

Longannet, Scotland's last coal fired power station, closed in March 2016

Scotland's Renewable Energy Growth

Diagram 4: Electricity generated (GWh) from renewable sources, Scotland, 2000-2015

68.1% of Scotland's gross electricity demand was met from renewables in 2017 (**25 TWh**)

AN INCLUSIVE ENERGY TRANSITION


BIG HIT Grant
no.: 700092
BIG HIT
Building Innovative Green Hydrogen Systems in Isolated Territories
EDAY
Community Wind Turbine
Hydrogen Storage
0.5 MW Electrolyser
Tidal Turbines
Community Wind Turbine
1 MW Electrolyser
30 kW H_2 Boiler
SHAPINSAY
Hydrogen Storage
75 kW Fuel Cell
Hatston
KIRKWALL
ORKNEY MAINLAND

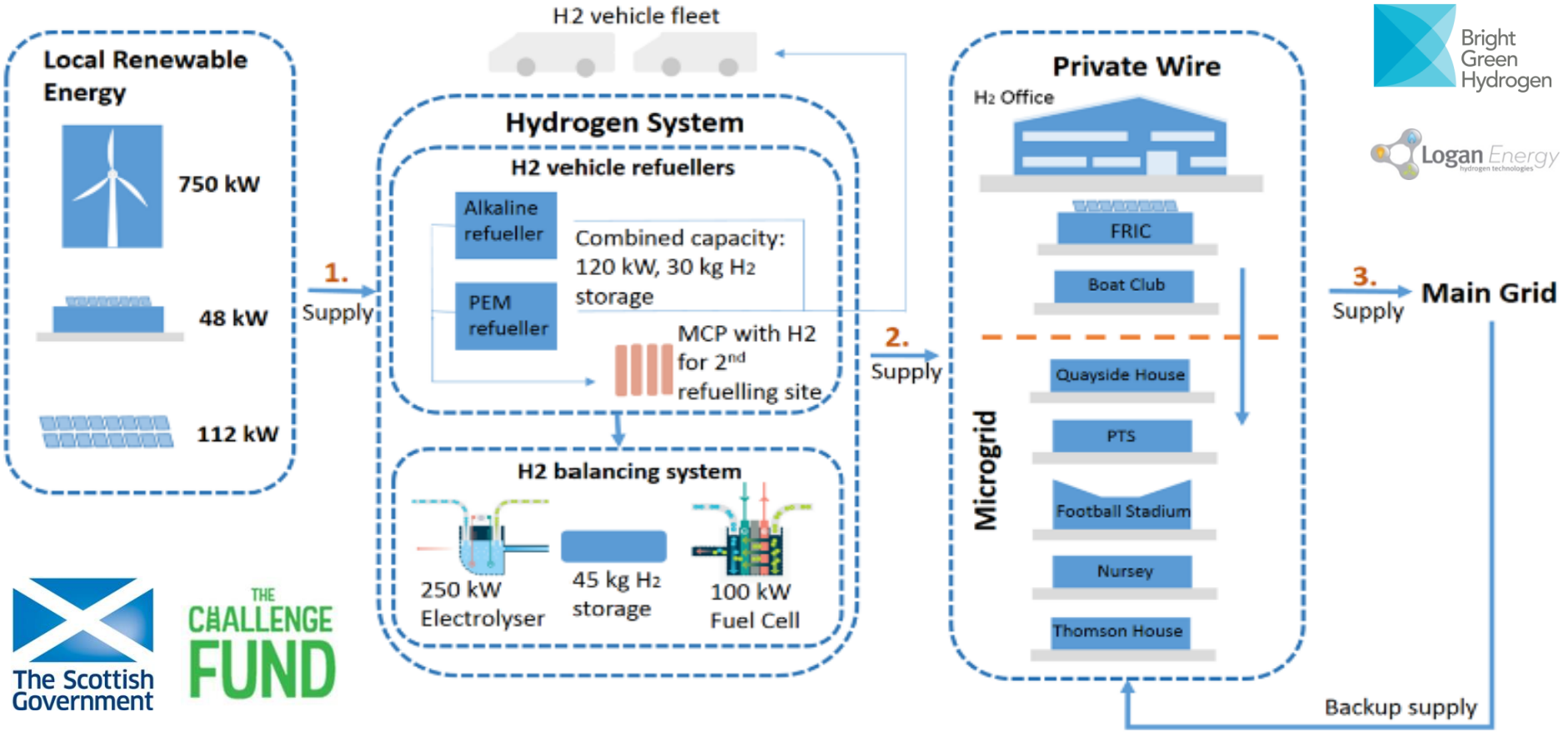

THE CHALLENGE FUND


THE CHALLENGE FUND
BIGHIT
SURF 'N' TURF

The Hydrogen Office at Methil in Fife

Levenmouth Energy System

TOSHIBA
Leading Innovation



Bright Green Hydrogen

Logan Energy
hydrogen technologies

The Scottish Government

THE CHALLENGE FUND

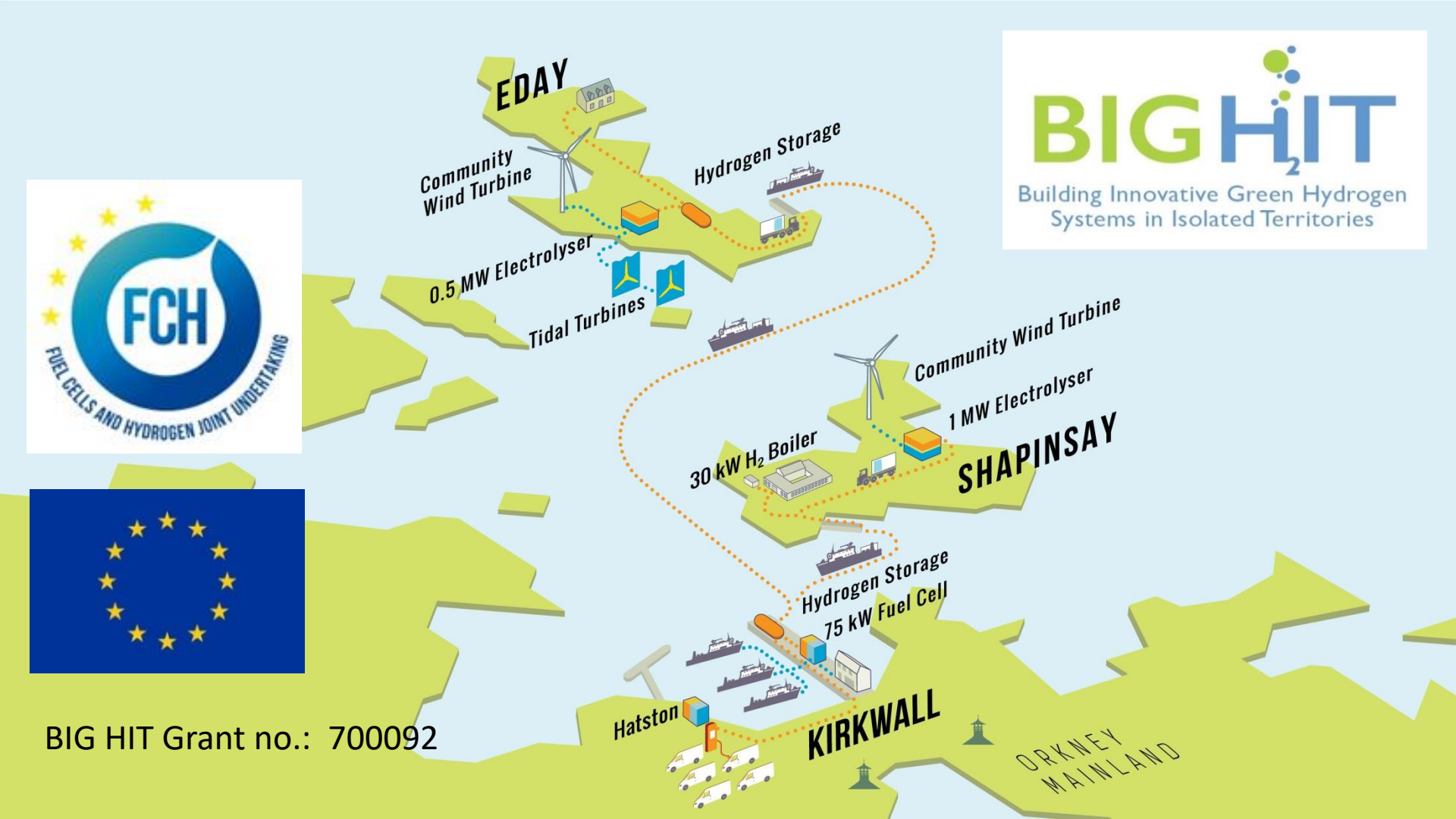
Levenmouth Fleet – with 2 RCVs

- World first H2-ICE Refuse Collection Vehicl
- Diesel-hydrogen conversion
- Carries 5kg of hydrogen at 350 bar

Orkney: 100% Green Electricity

- Renewables generate > 100% of Orkney's electricity
- Over 50MW of installed renewable capacity
- 1000 renewable installations for 10,000

By 2014 Orkney was generating 120% of its annual electrical demand from Renewables



BIG HIT
Building Innovative Green Hydrogen Systems in Isolated Territories

FCH
FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

BIG HIT Grant no.: 700092

Hydrogen into Heat, Power, Transport

Hydrogen refuelling station by ITM Power in Kirkwall, opened May 2018. Refuels the Symbio vans used by Orkney Islands Council.

Hydrogen vans from Symbio used by Orkney Islands Council together with one of the five Calvera hydrogen trailers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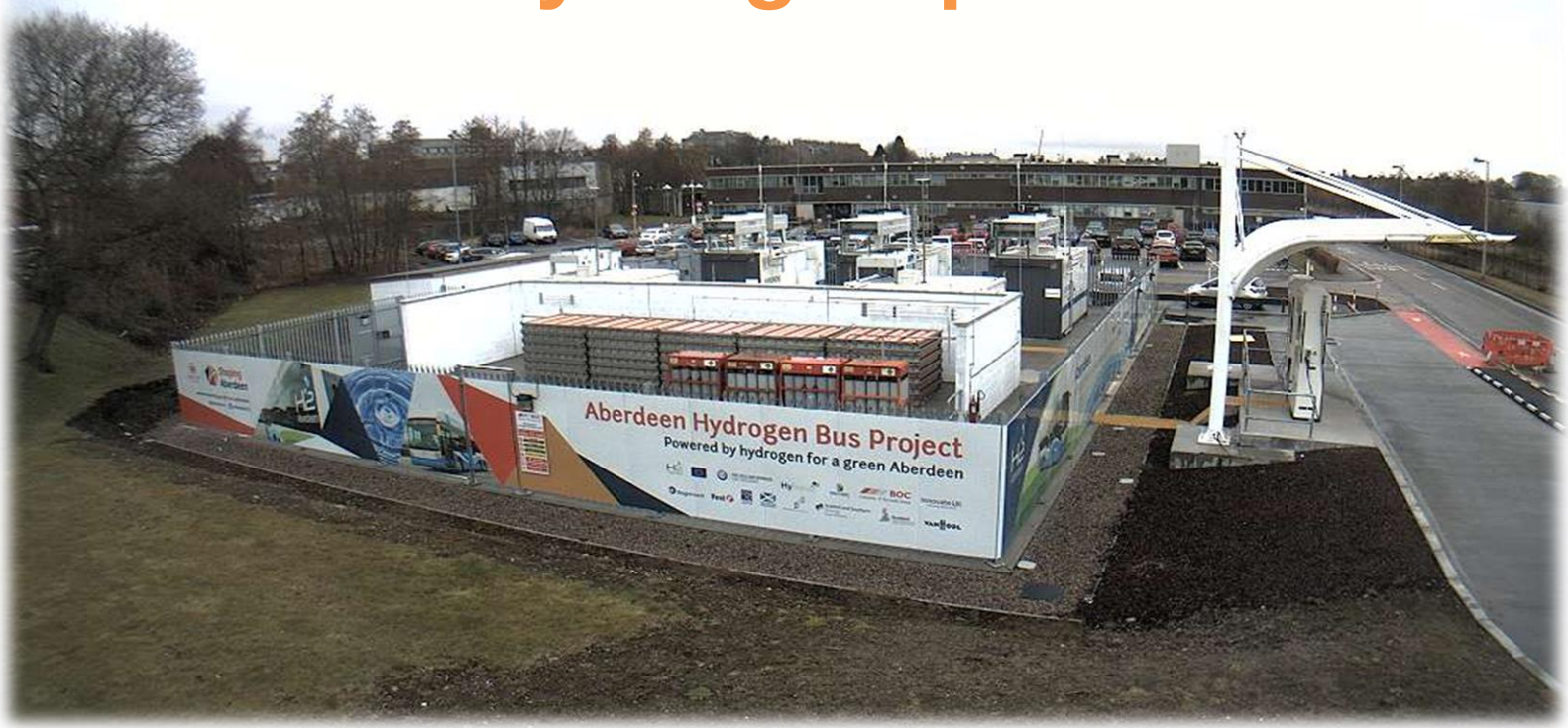
PM

Aberdeen: Energy Transition Zone

ABERDEEN CITY COUNCIL

Scottish Enterprise

Green Hydrogen produced on Site



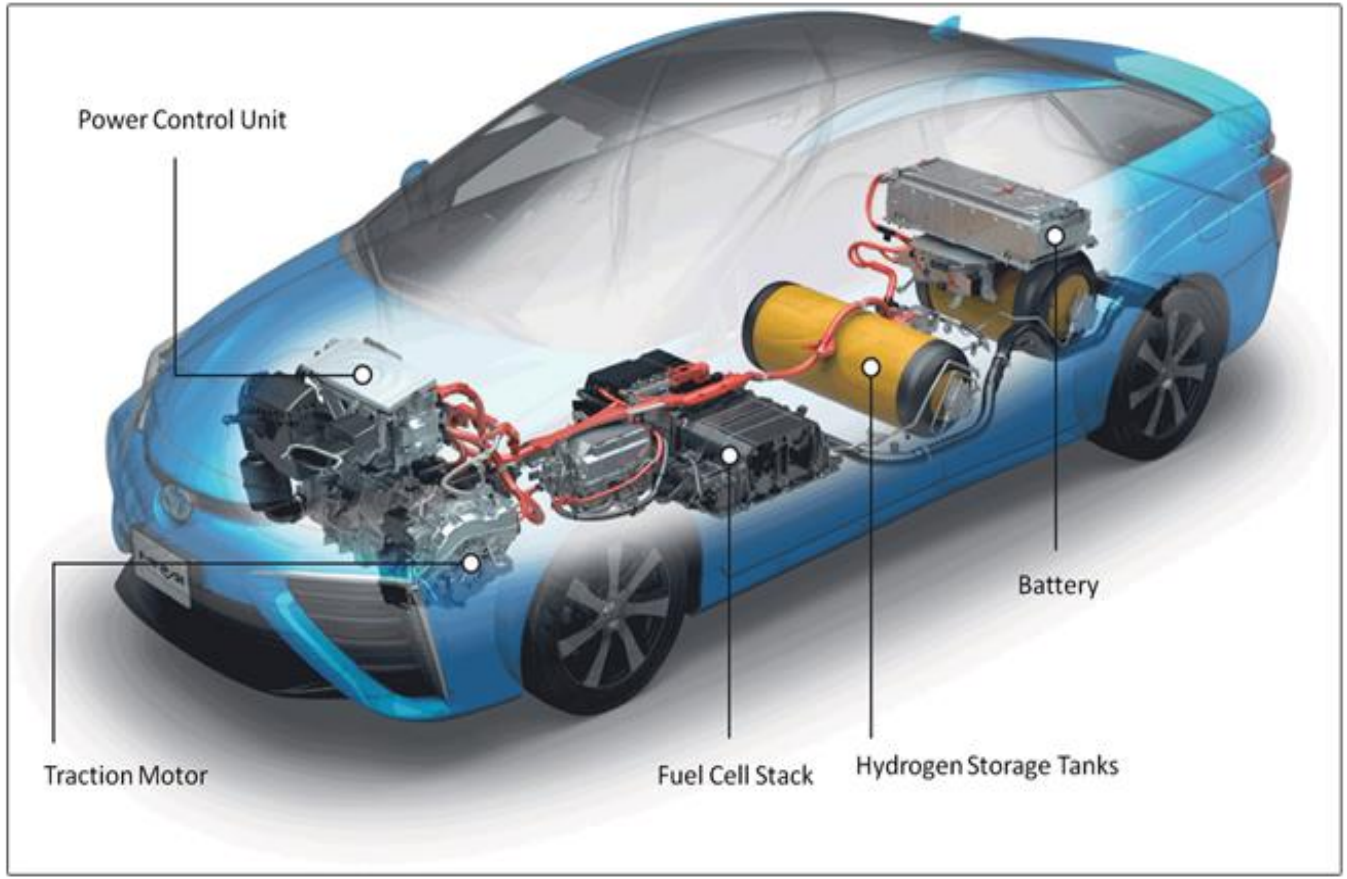
A €22m project

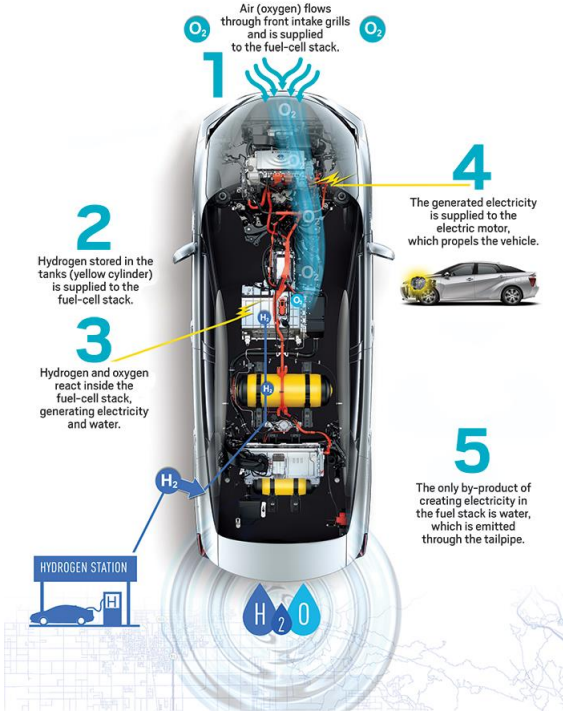
Hydrogen is produced at Kittybrewster site
Using HYDROGENICS electrolysers
Advanced Hydrogen Solutions

BOC
A Member of The Linde Group

THE LINDE GROUP
Linde

CoWheels & NHS: Toyota Mirai H_2 FCEV





[Toyota Mirai]


H2 Aberdeen
First Aberdeen
Powered by Hydrogen
FCH
FUEL CELLS AND HYDROGEN JOINT UNDERTAKING
Innovate UK

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Scotland's Clean Transport Achievements

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Real world hydrogen trials: Commercial and operational implications

Dr. Nick McCarthy

Technical Specialist nick.mccarthy@cenex.co.uk

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HyTrEc 2 Partners

ABERDEEN CITY COUNCIL

Aberdeenshire COUNCIL

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Interreg VB North Sea Region
Programme Area 2014-2020

UiT NORGES ARKTISKE UNIVERSITET

SP your Science partner

Gemeente Groningen

provincie Drenthe

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Interreg North Sea Region projects – HyTrEc 2

Project Name	Dates	No. Vehicles monitored	No. HRS monitored	Locations
HyTrEc 2 Hydrogen Transport Economy for the North Sea Region — HyTrEc	2016-2022	To date: 53 Large Van 3 Medium car 27 Midsized SUV 10 Road Sweeper 2 Small Car 2 Small Van 8 mini bus 1	To date: 3 HRS By 2020: 5 HRS*	UK, France, Germany, Denmark, Norway, Sweden

Primary focus is demonstration, skills and infrastructure creation.

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HGVs and HyTrEc2

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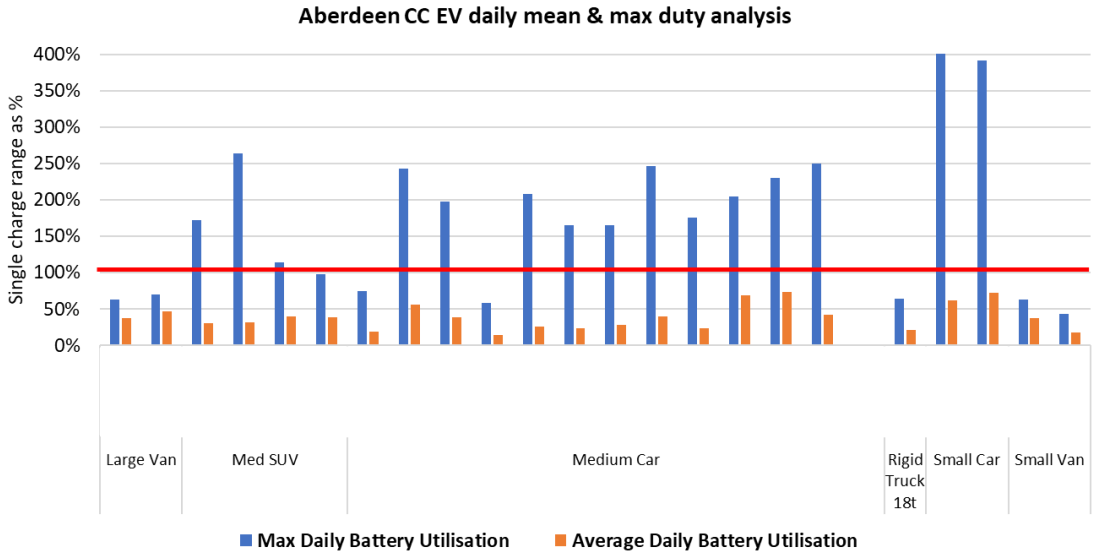
Real world utilisation and BEV compatibility



- 24 vehicles monitored
- 7 perfectly suited to BEV
- 2 multiple charges required if possible
- **15 very high utilisation**
  - **Not suited to BEV**

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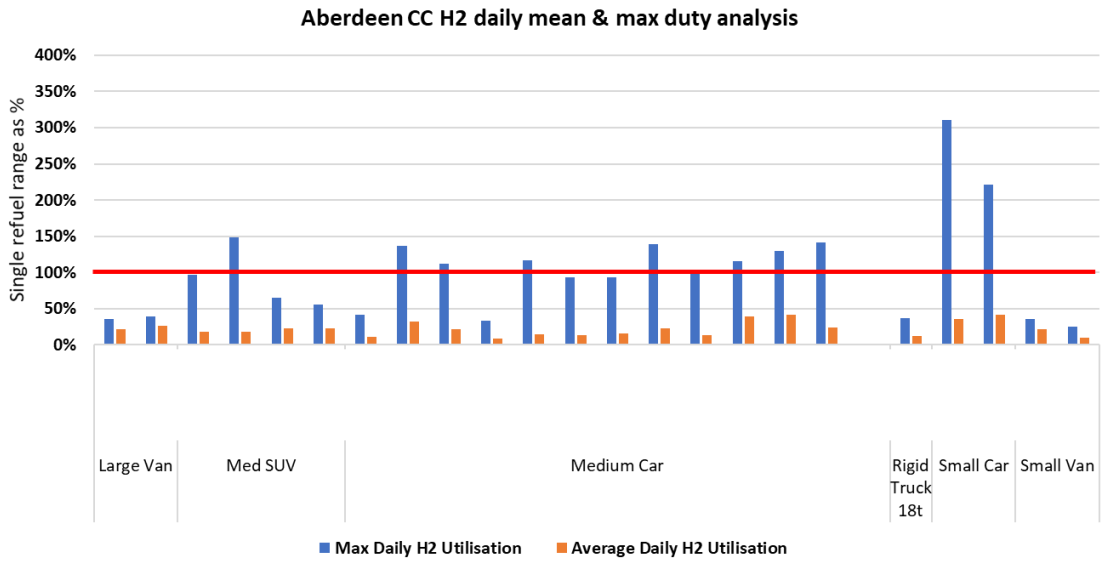
Real world utilisation and FCEV compatibility



- 24 vehicles monitored
- 10 perfectly suited to FCEV
- 12 multiple refuels required if possible
- **2 very high utilisation**
  - **Not Suited to FCEV**

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Efficiency, intensity and emissions

Understanding differing duty cycles and energy requirements

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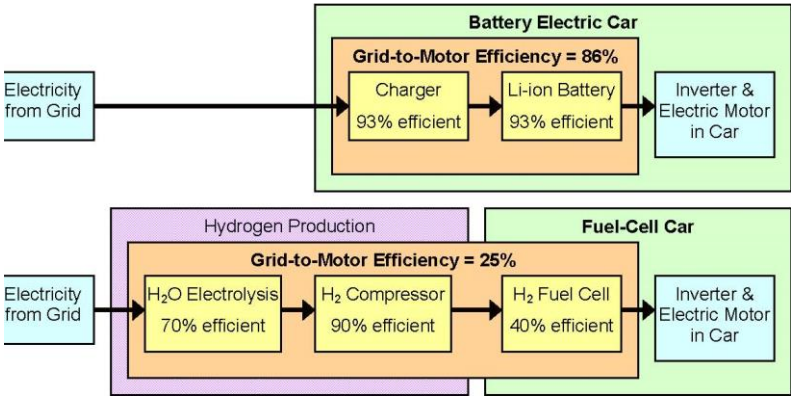
BEV ~~Vs~~ and FCEV



86%

25%

The above argument ignores three critically important issues:

- **Presents a false conflict between BEVs to FCEVs – Ignores the opportunity to displace ICE fossil fuel vehicles!**
- Duty cycles requirements and refuelling / recharging
- Self-weight of vehicles as power and range increase

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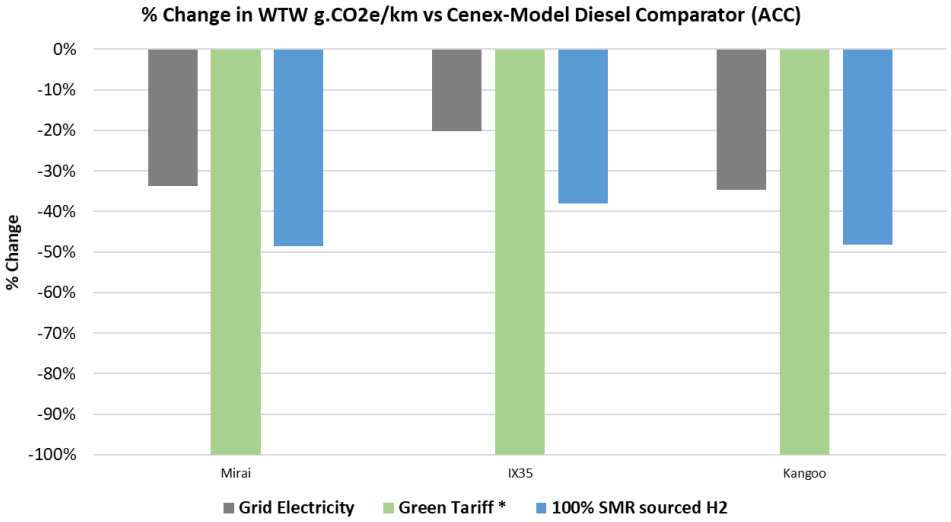
H2FCs Vs ICE



In a fuel cell system:

- SMR H2 has 38% to 46% less CO_2e emissions per km
- SMR H2 has 100% less AQ emissions at the point of use

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Bus depot commercial assessment

BEV and H2FC bus depot infrastructure comparison

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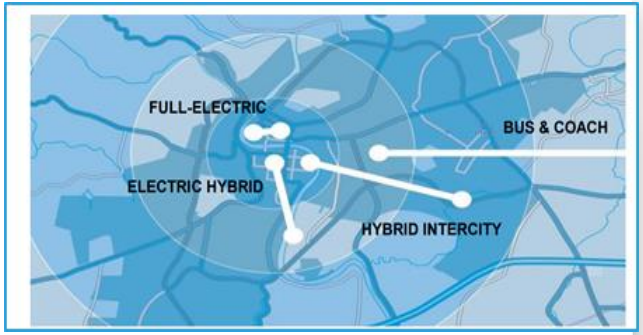
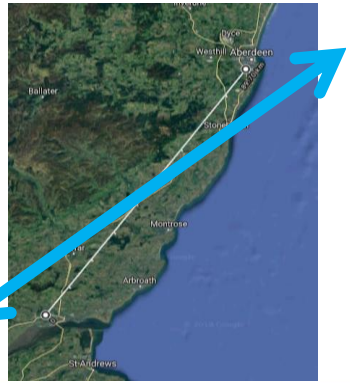
Bus duty cycle

- **BYD-Ebus (best in class 2017/18)**
  - Range =155miles, 4.5 hour* charge time
- **Average FC/hybrid bus (CHIC 2016 report)**
  - Range = 218 miles, 15 minutes refuel





Aberdeen - Dundee intercity journey (~70 miles shortest route: assume 1.5 hour journey time)

- 100% EV bus = **7 trips in 24 hours (4.5 hour break every 2 trips)**
- FC-EV hybrid = **15 trips in 24 hours (0.25 hour break every three trips)**

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Bus model back-to-base economies of scale

- BEV Bus
  - 80 to 150 kW charger
  - 1 or 2 bus?
  - 20+ chargers will require multiple million pound electrical connections
  - Extra buses for day time charging?
  - Increased depot footprint?
- FCEV Bus
  - 30 kg of hydrogen per bus
  - 4 pumps, eight nozzles
    - Through put of 8 buses in 30 minutes (or less)
  - Small scale HRS very expensive

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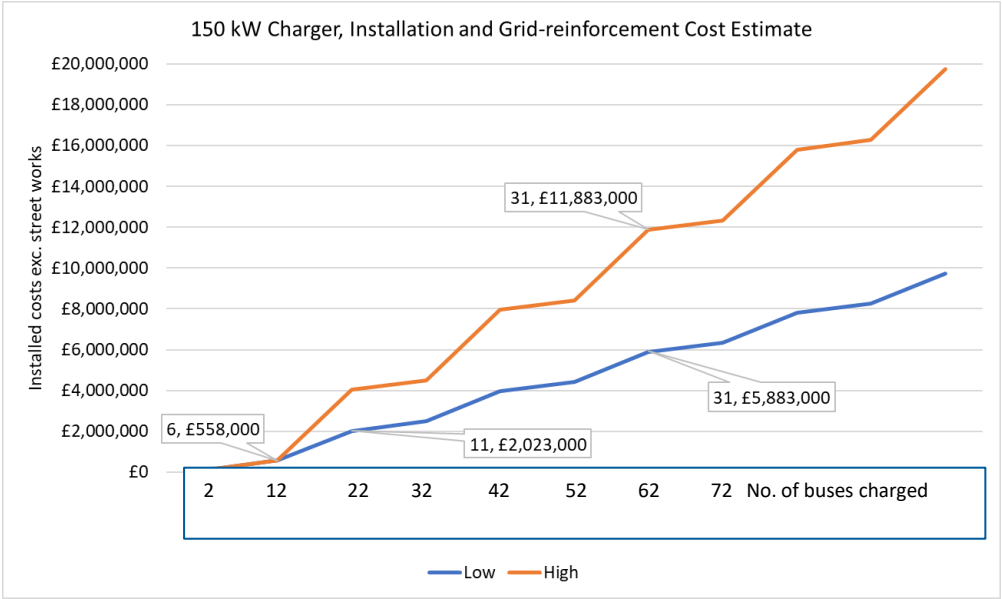
BEV and FC Bus depot example - BEV

- 150 kW Charge point = c.£93,000 installed
- Grid reinforcement per 1MVA (c.6 chargers)
  - £1,000,000
  - £3,000,000
- Assume 150 kW charger can charge two buses per night?
- Where does this graph level off?



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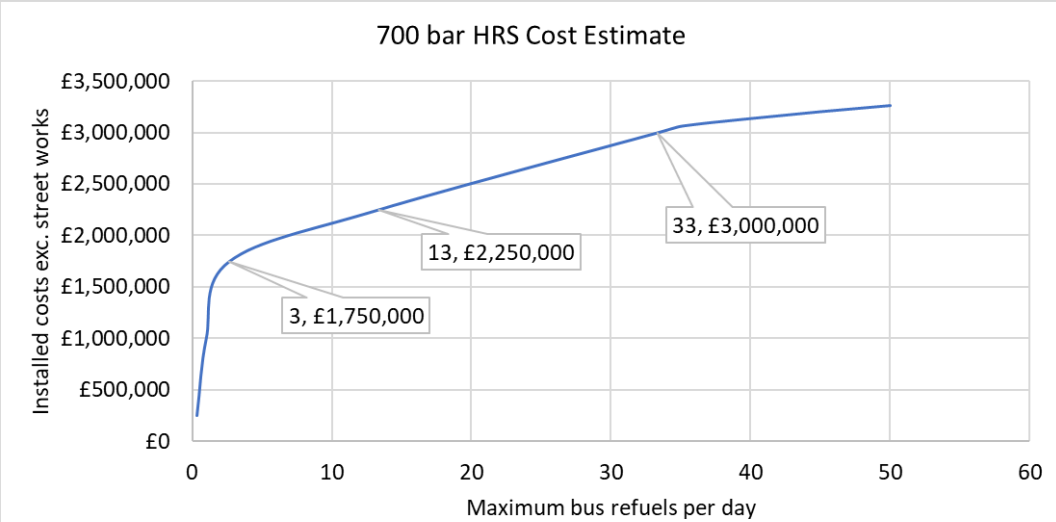
BEV and FC Bus depot example - HRS

- HRS prices widely variable
- 2017 worst case scenario presented
- Data based on multiple projects over a ten year period, extrapolated from 33 refuels onwards



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Large HGV commercial assessment commercial assessment

BEV and H2FC range and energy storage comparison for 15 t payload

15 t payload model (40 t HGV)

- **BEV semi-truck**
  - Assume 15 t payload HGV requires 550 kWh battery, and has a range of ~400 km
  - Estimated battery mass is 400 kg = 6.4 kWh/kg
  - HGV requires 1.375 kWh per km
  - mass of battery per km = (1.375/0.26) = 5.3 kg/km

- **FC semi-truck**
  - Assume 15 t payload requires 448 kg of fuel cell (228 kW peak power)
  - 5 kg of H2 requires 85 kg of tanks
  - 30 kg of H2 for ~320 km
  - mass of 224 Kw FC = 448 kg
  - mass of H2+ tank per km = 1.7 kg

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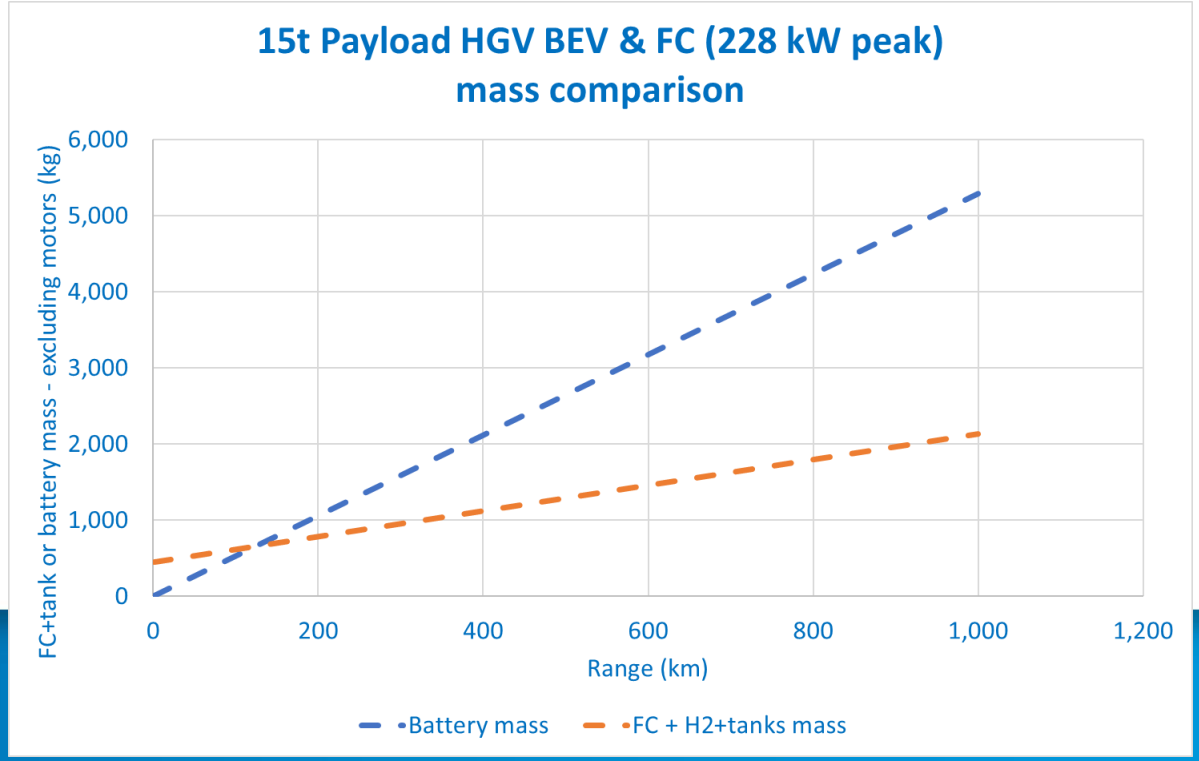
Self-weight of vehicle energy store as range increases



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TTSI/Kenworth/Toyota FCEV truck trials

2011 Vision Vehicles Class 8 FCET

Range: 150 miles

2017, Kenworth / Toyota Mk1 Class 8 FCET

Range: 200 miles

2018, Kenworth / Toyota Mk 2 Class 8 FCET,

+12 kWh battery (With sleeper cab)

Range: 300+ miles

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Other H2-HGV projects to watch

Hyzon portside H2 transports

Hyzon (Horizon)

£	??
GVW/GCW	??
Config/Cab	4x2 / Day
Range	??
H2	(3 tanks)
H2 P	??
Bat	??
FC Stack size	100 kW

- 400 trucks commissioned in 2019
- On schedule to manufacture more in 2020
  - Including downturn due to COVID19

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Hyundai Xcient

£	lease
GVW/GCW	19t / 36t
Config/Cab	4x2 / Day
Range	248 miles
H2	32 kg (7 tanks)
H2 P	350 bar
Bat	73 kWh
FC Stack size	190 kW

Switzerland (2019)

Scania

£	demo
GVW/GCW	??/ 27t
Config/Cab	4x2 / Day
Range	310 miles
H2	33 kg
H2 P	350 bar
Bat	56 kWh
FC Stack size	90 kW

Asko demonstration (2020)

Nikola Tre (CNH/IVECO)

£	Lease?
GVW/GCW	TBA
Config/Cab	6x4/ Sleeper
Range	500 miles +
H2	TBA
H2 P	TBA
Bat	TBA
FC Stack size	120 kW (TBC)

1 prototype only (2023?)

DAF (with Shell/Toyota)

£	H2SHARE
GVW/GCW	28t
Config/Cab	6x2
Range	250
H2	30 kg
H2 P	350 bar
Bat	72 kWh
FC Stack size	88 kW

1 prototype only

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ESORO

£	H2SHARE
GVW/GCW	34t
Config/Cab	6x2
Range	225 miles
H2	31 kg
H2 P	350 bar
Bat	120 kWh
FC Stack size	100 kW

1 prototype only (ended 2017?)

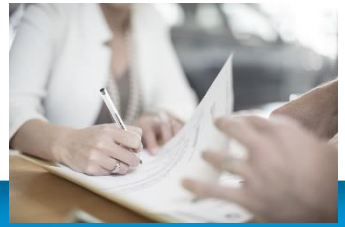
GM

Concept only

Hyundai HD6

Concept only

Freightliner (Daimler) & Mack (Volvo)



Joint venture agreement signed this year

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Not just H2FC

- All of the above companies are also involved in BEV-HGV
- Low mileage, low weight HGVs are a key market as well

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In conclusion

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- BEVs and H2FCs are **NOT** mutually exclusive – fossil fuel displacement is the goal
- BEV technology and infrastructure is improving and reducing cost every year
- H2 technology and infrastructure is improving and reducing cost every year
- Operational constraints are a dominant factor in BEV/H2FC Capex breakpoints

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Thank you for listening

Dr. Nick McCarthy

Technical Specialist nick.mccarthy@cenex.co.uk

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Andrew Win
Programmes and Projects Manager
@H2Aberdeen

ABERDEEN CITY COUNCIL

H2 Aberdeen

Aberdeen

- Aberdeen leading the global energy transition
  - Net Zero Vision with an aim to be a climate positive City
  - A Strategic Infrastructure Plan to support this vision

- Aberdeen is an established centre of excellence for hydrogen and fuel cell technologies
  - Europe's largest real-world deployment of hydrogen vehicles

- Transport is a sector enabler given that it is a higher value use compared to heat and industrial applications.
- Implemented quicker than the other sector applications, thus providing a pivotal "first mover" advantage.

Facilitate vehicle deployments by a range of stakeholders in the region

Develop hydrogen refuelling infrastructure

Aberdeen Hydrogen Bus Project

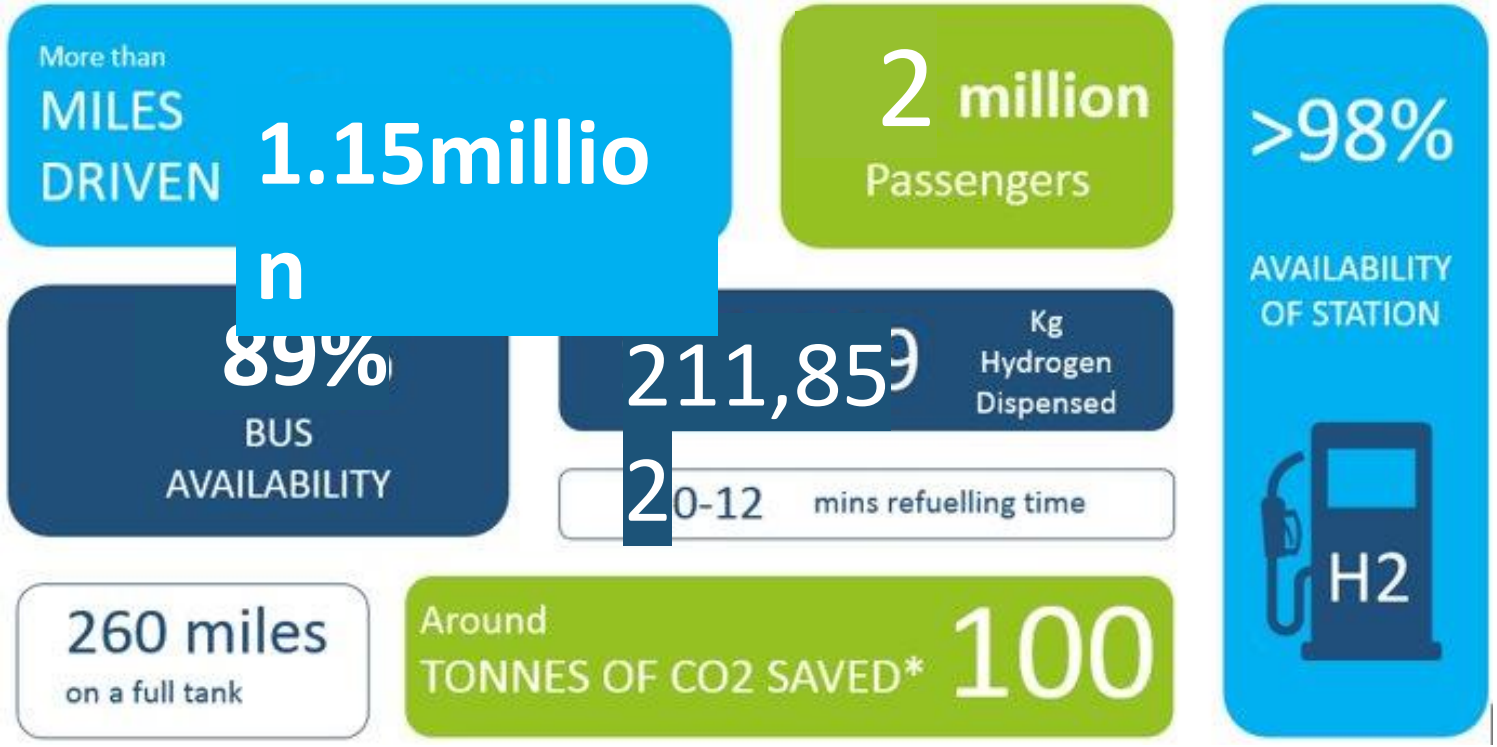
An innovative public-private partnership

Was Europe's largest fuel cell electric bus fleet: 10 buses in total

- 4 buses
- 6 buses
- 1 production & refuelling station
- Dedicated bus maintenance facility

PROJECT DEVELOPMENT	NEGOTIATION	PREPARATION	LAUNCH	OPERATION	AND BEYOND?
2010-2011	2011	2012-2013	June 2014	March 2015-March 2019	

Aberdeen Hydrogen Bus Project

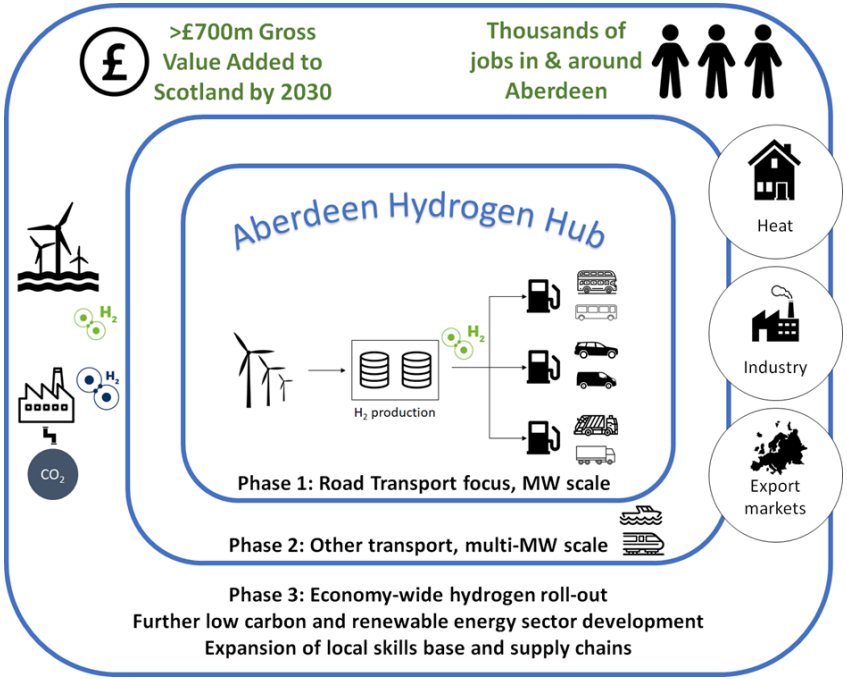


Market Constraints

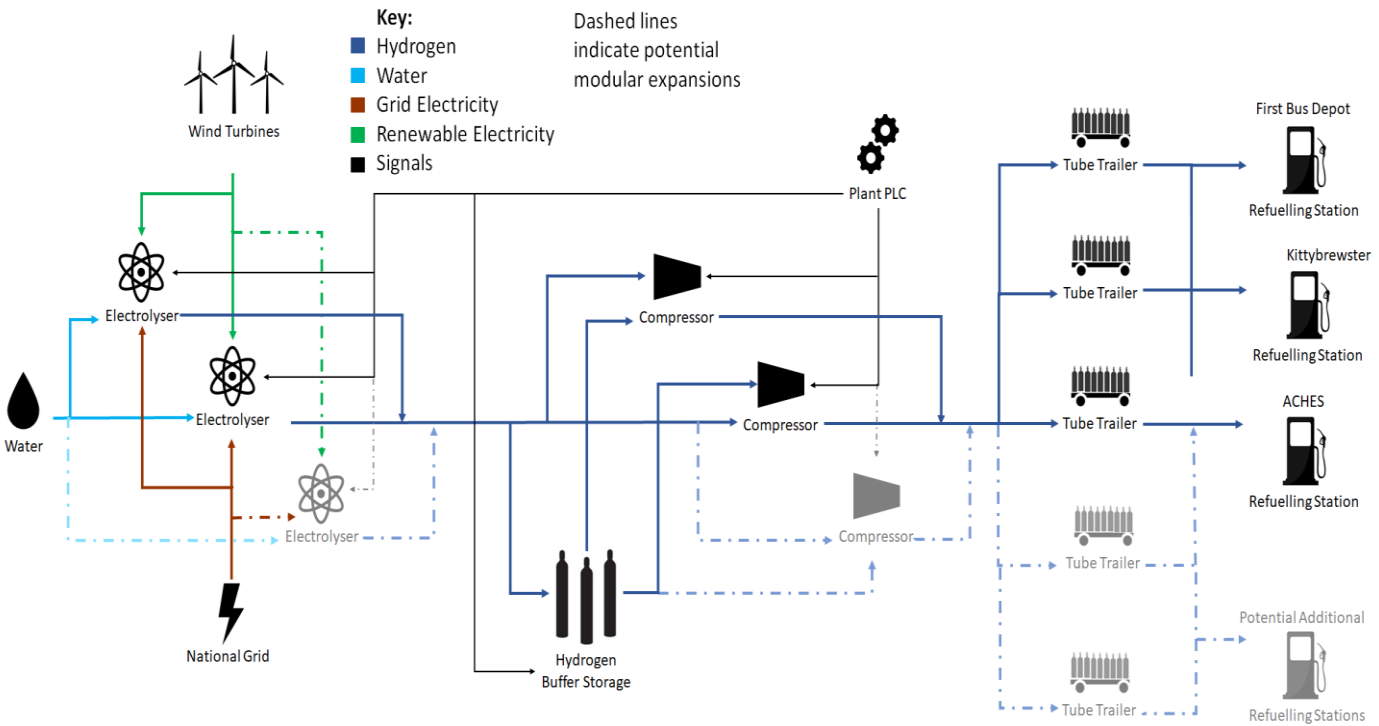
- Vehicle Price
- Component and Servicing Costs
- Servicing Supply Chain
- Maintenance & Technicians
- Hydrogen production & infrastructure costs

Aberdeen Hydrogen Hub

- **Phase 1** – provision of a resilient, cost effective supply of green hydrogen on a commercial basis to the market to support the existing and proposed transport projects.
- **Phase 2** – Expansion in the short to medium term to connect to larger volume utilisation of hydrogen – trains, trucks and marine.
- **Phase 3** – Whole system approach to supply and demand. Innovation, skills and transition hub to support expansion of the local supply chain. Pursue the ambition for Aberdeen to be the centre of a brand new Energy production business, exporting H2 to the world.



Aberdeen Hydrogen Hub Schematic



Aberdeen Hydrogen Hub Opportunity

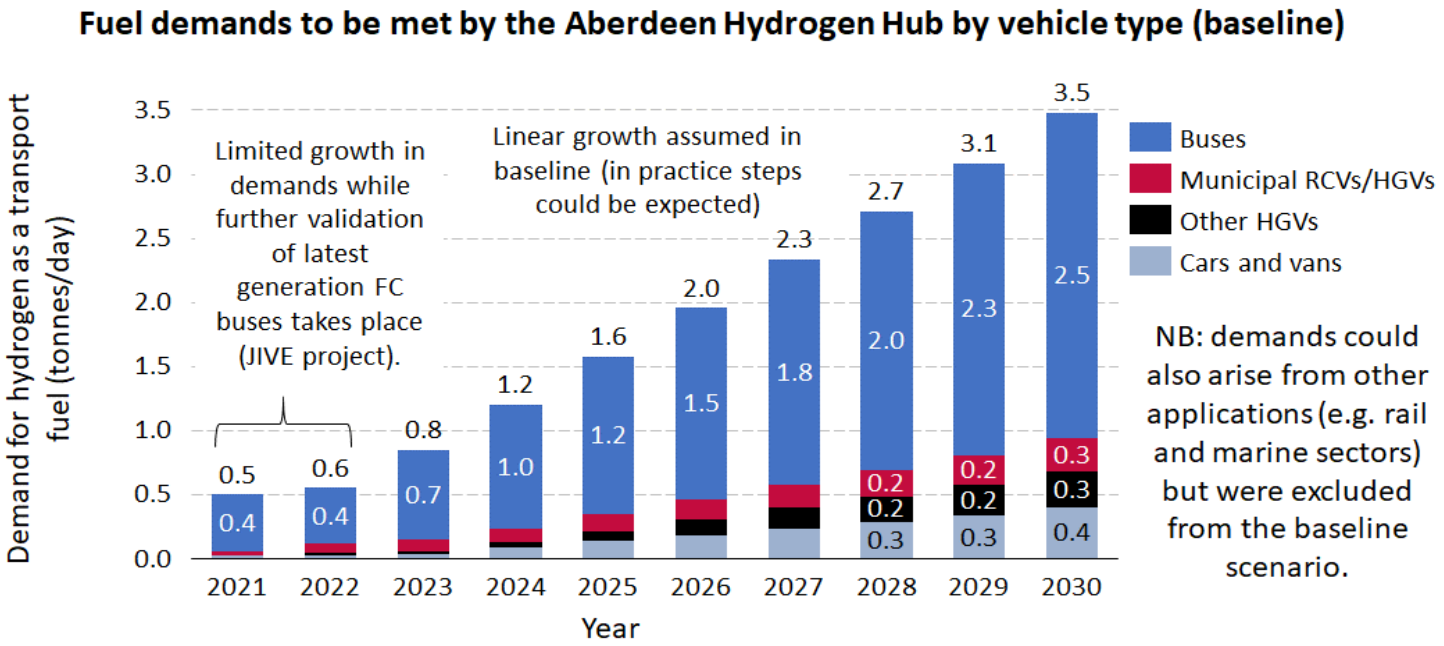
- Opportunity is to deliver a commercially robust hydrogen supply project in Aberdeen

- **Key issues** :

  - **Identify a firm, long term demand picture:**
    - building off existing Public Sector commitments:
    - a firm contribution from the Private Sector would support this.
    - acting on an emerging opportunity from the rail sector could provide required scale

  - **Address additional supply challenges:**
    - better understanding eligibility to claim RTFC's in the long term impacts likely H2 fuel price.

Demand Growth Scenario



Public Sector Fleet

Ultra-low emission public sector fleet and buy-in by private sector partners by 2025

- Engaged vehicle manufacturers to map out real world, commercially available solutions
- Undertake fleet renewal programmes and establish H2 demand for various vehicle categories
- Develop a Joint Procurement Framework with interested public sector partners.
- Profile of additional demand that regional private sector partners could achieve, with support of ONE and Scottish Enterprise

Public Sector Fleet

Ultra-low emission public sector fleet and buy-in by private sector partners by 2025

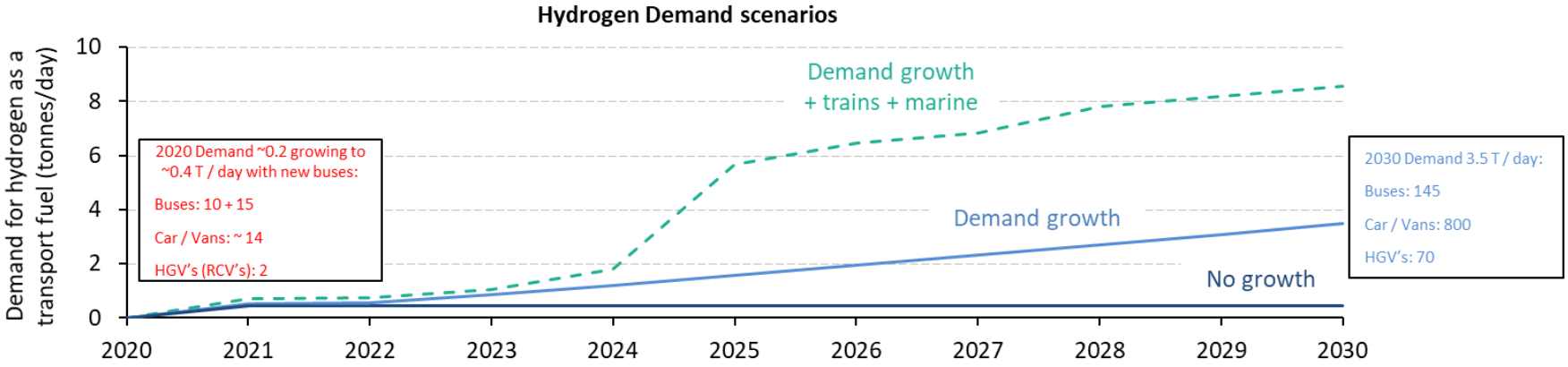
- Aberdeen City Council, with its public sector partners and Universities have committed to a fleet replacement programme to deliver 2025 public sector targets
- Now includes SEPA, Scottish Water and SNH and other North East Scotland Local Authorities
- Commissioned a fleet review to identify appropriate vehicle type and operational requirements for the adoption of ULEV (BEV and Hydrogen FCEV)
- Inform a joint procurement of fleet vehicles across the organisations by spring 2021

Public Transport: Buses

100% hydrogen-fuelled bus fleet by 2030

- Deployment of JIVE-funded bus project (15 vehicles) by 2020.
- Expand the existing hydrogen bus fleet to 25 buses by 2021 to support Low Emission Zone policy and hydrogen hub commercial model.
- Private sector investment in hydrogen fuel cell buses by 2022
- 100% hydrogen-fuelled bus fleet by 2030 through a partnership between vehicle OEMs, operators, Government and stakeholders.

Securing Demand is Essential to Deploying Hydrogen Production at Scale



Scenario	Summary	Key transport segments	Level of demand in 2030
No growth	25 buses only; no new demand	Buses	0.4 tonnes hydrogen/day
Demand growth	**Gradual transition of public sector fleets & local freight to hydrogen**	**Buses, cars (e.g. taxis), council RCVs, HGVs**	**3.5 tonnes hydrogen/day**
Demand growth + trains and marine	As above + 10 trains in 2025 + 8 boats by 2028	Buses, cars, council RCVs, HGVs, trains, boats	8.5 tonnes hydrogen/day

Note: the potential for Aberdeen to be involved in Hydrogen train trials, starting +/- 2025 has increased recently, which would double the Demand growth case.

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Programmes and Projects Manager
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30 kW H_2 Boiler
SHAPINSAY
Hydrogen Storage
75 kW Fuel Cell
Hatston
KIRKWALL
ORKNEY MAINLAND

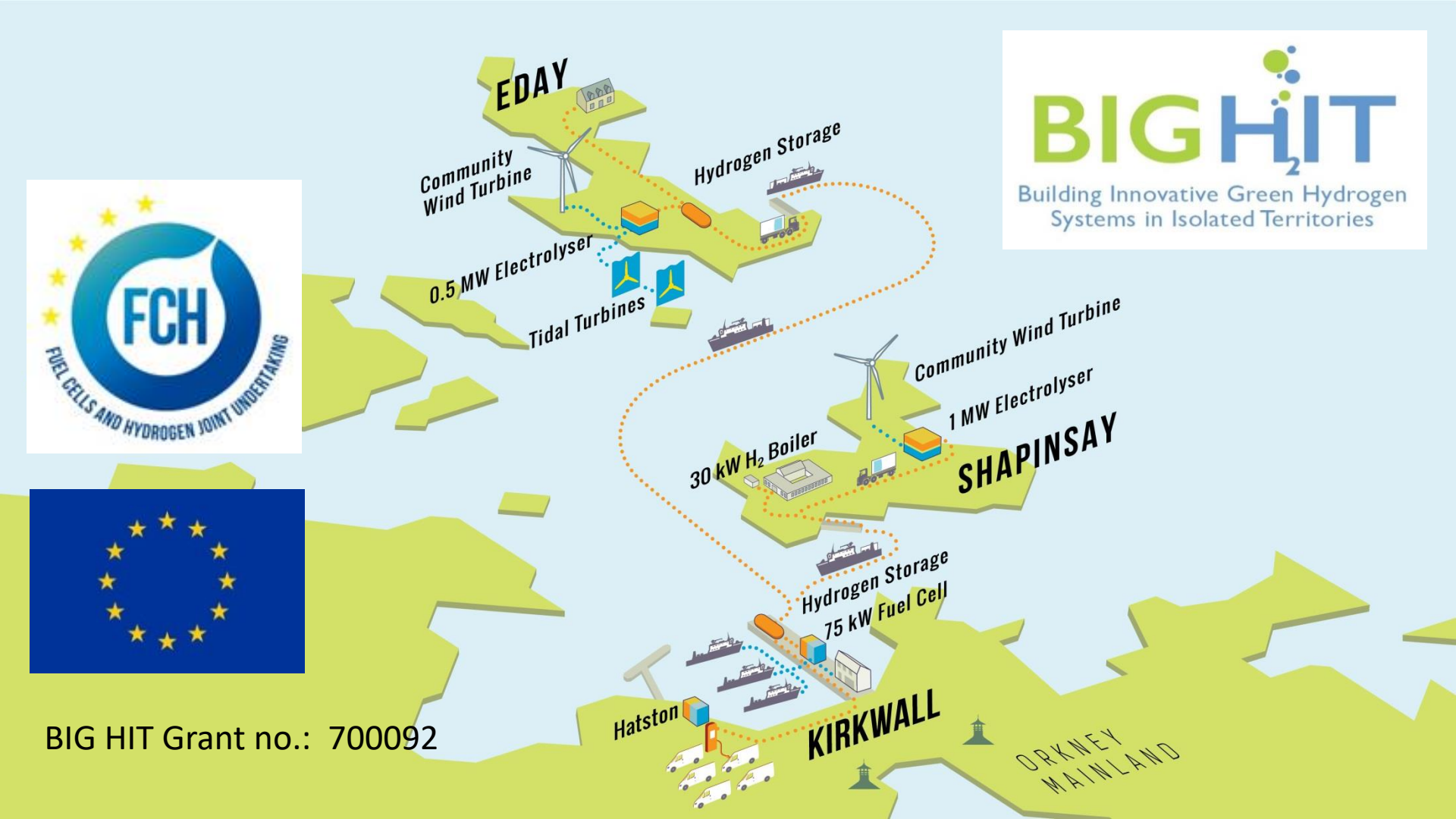

THE CHALLENGE FUND


THE CHALLENGE FUND
BIGHIT
SURF 'N' TURF

Orkney: >>100% Green Energy

- Offshore renewables - massive potential
- 765GW of viable Scottish offshore wind
- Connected with hydrogen pipelines

Orkney can be a future hub for TWh supply of green hydrogen from offshore renewables



BIG HIT
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BIG HIT Grant no.: 700092

Growing the Orkney H_2 project portfolio

HySeas III – H2020 €21m EU funded project World first fuel cell ferry now scheduled for construction and destined for operation in Orkney

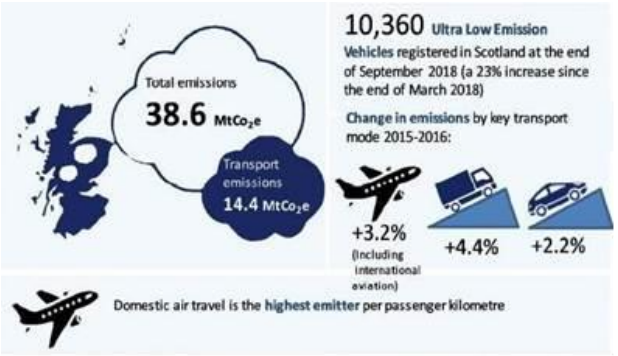
HyDime – Innovate UK project UK's first H_2 injection system for hydrogen/diesel APU for Shapinsay ferry. Led by Ferguson Marine with Orkney Islands Council & EMEC as partners.

€11m EU INTERREG (ITEG) £28.5m BEIS ReFLEX project for Orkney Virtual Energy System

Orkney projects with Hydrogen now approximately £65M in total.

HyFlyer – H2 Fuel Cell Plane

- 6 seater plane
- 300 mile range
- Trials in 2020



HyFlyer ZeroAvia 6-seater zero-emissions aircraft

Aberdeen: Energy Transition Zone

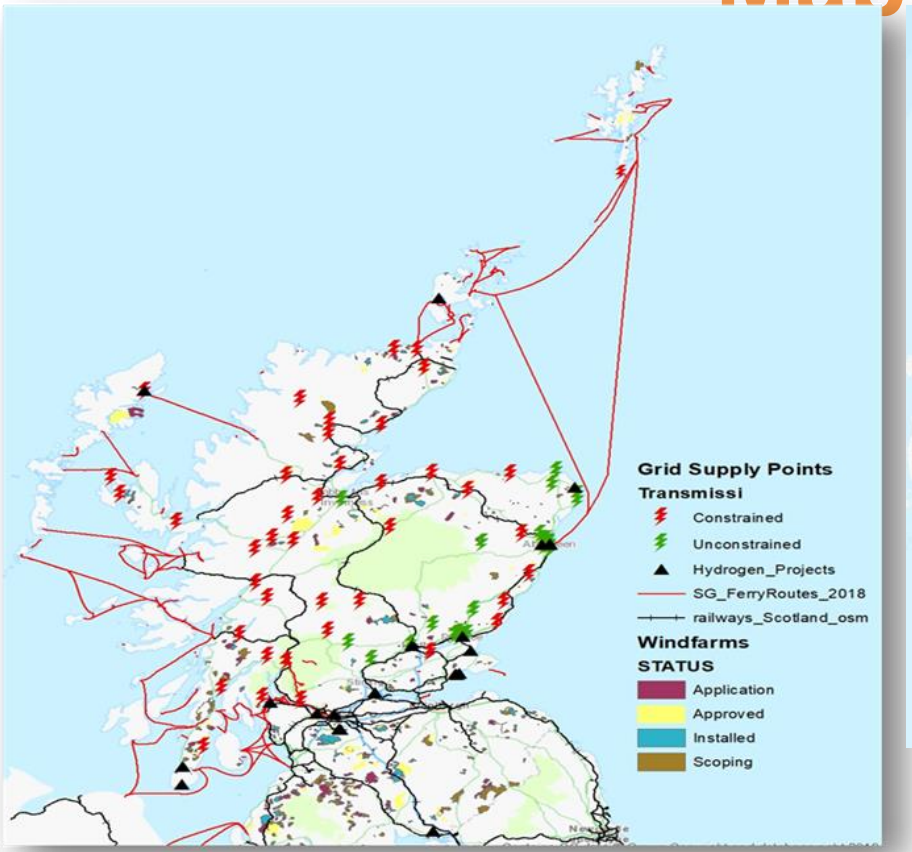

DD71
ISOLATOR SWITCH IN CAB
SCREENWASH

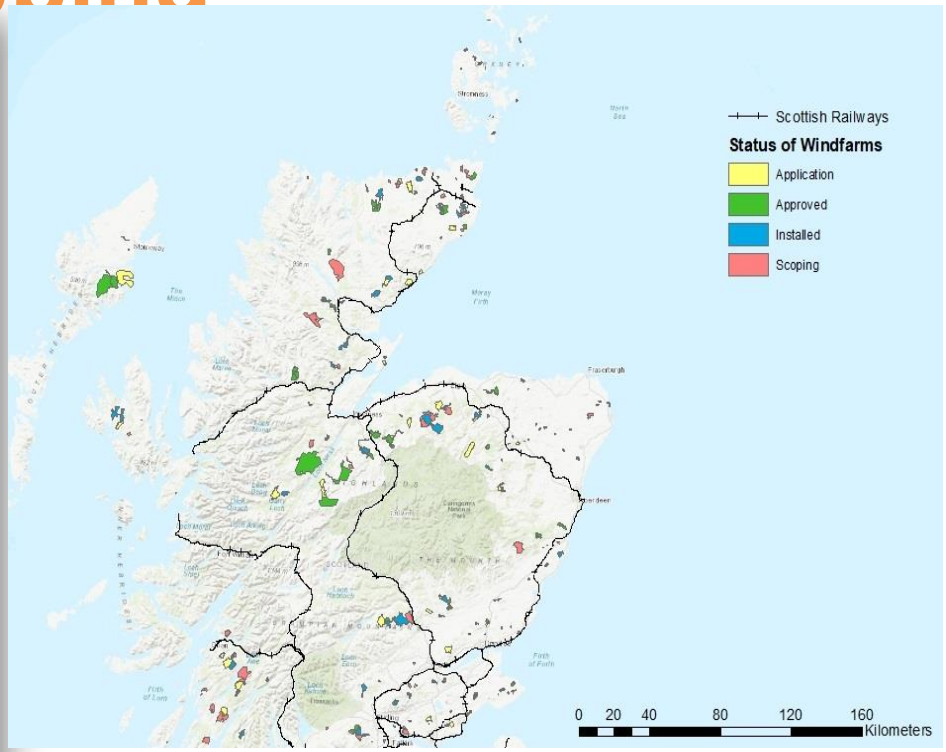
Aberdeen's Ambition: Energy Capital of Europe


Aberdeen’s South Harbour
£350M infrastructure investment
Logistics for offshore renewables
Hub site for green hydrogen

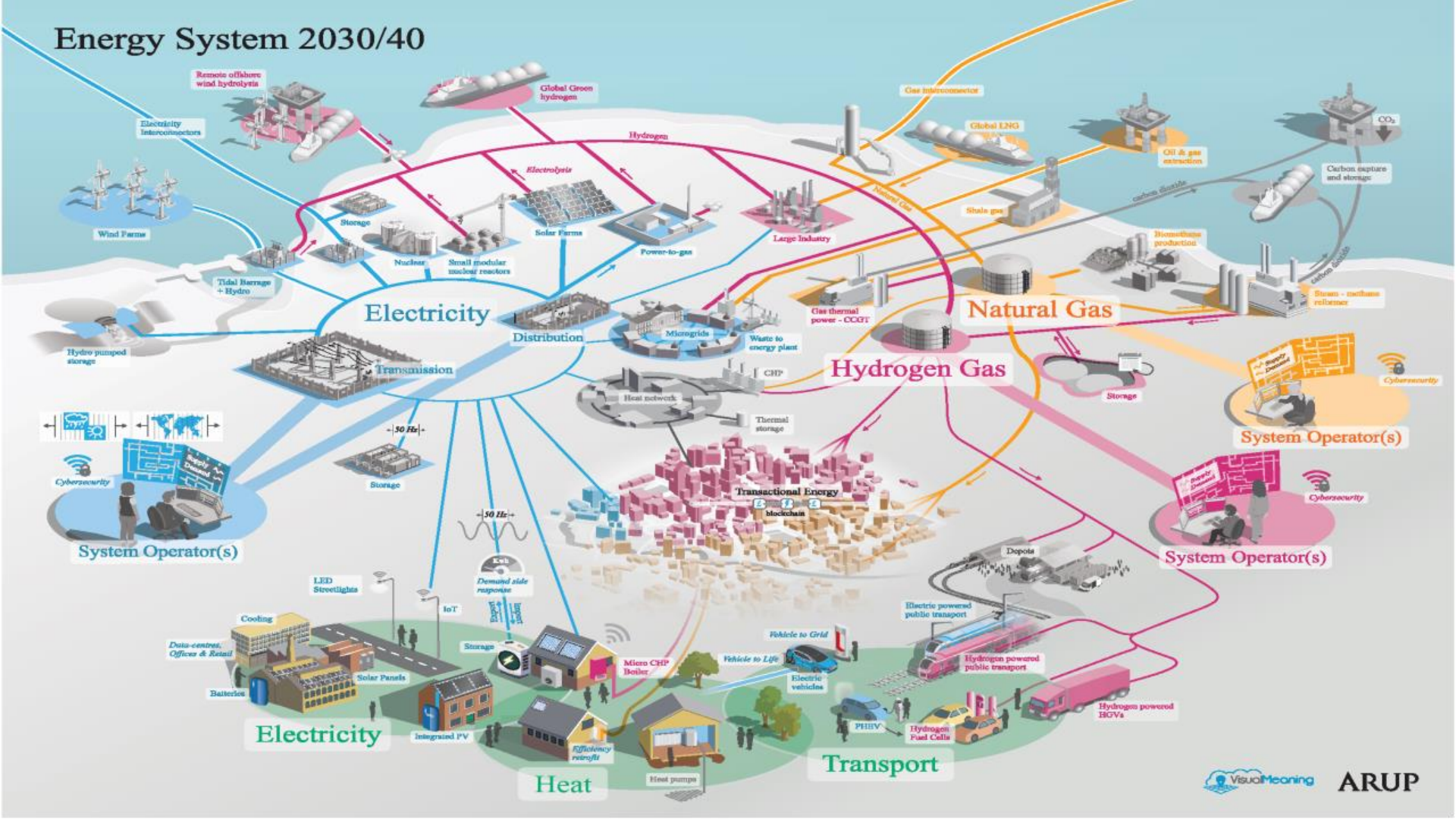

CREATING A ZERO-EMISSIONS WORLD
POWERED BY TOYOTA HYDROGEN FUEL CELL TECHNOLOGY

Hydrogen Transport – Opportunity Mapping





Grid, Windfarms, Ferries & Rail Integration


Energy System 2030/40
Remote offshore wind hydrolysis
Global Green hydrogen
Electricity interconnectors
Hydrogen
Electrolysis
Gas interconnector
Global LNG
Oil & gas extraction
Natural Gas
Shale gas
Carbon capture and storage
Wind Farms
Storage
Nuclear
Small modular nuclear reactors
Solar Farms
Power-to-gas
Large Industry
Tidal Barrage + Hydro
Hydro pumped storage
Electricity
Distribution
Transmission
Microgrids
Waste to energy plant
CHP
Heat network
Thermal storage
Gas thermal power - CCGT
Natural Gas
Biomethane production
Steam - methane reformer
Hydrogen Gas
Storage
System Operator(s)
Cybersecurity
50 Hz
Transactional Energy
blockchain
Demand side response
LED Streetlights
IoT
Cooling
Data-centres, Offices & Retail
Solar Panels
Batteries
Storage
Micro CHP Boiler
Integrated PV
Efficiency retrofit
Heat pumps
Heat
Vehicle to Grid
Vehicle to Life
Electric vehicles
Depots
Electric powered public transport
Hydrogen powered public transport
Hydrogen powered HGVs
PHHV
Hydrogen Fuel Cells
Transport
VisualMeaning
ARUP

SCOTTISH Hydrogen & Fuel Cell ASSOCIATION

Scotland's Achievements and Ambitions for Clean Transport

Interreg North Sea Region HyTrEc2 European Regional Development Fund

SCOTTISH Hydrogen & Fuel Cell ASSOCIATION

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Recording available on request
Slides available at www.Cenex.co.uk/Resources