SR Introduction to Hydrogen & Opportunities for Renewables CPD Seminar

Sponsored by

Welcome & Chair

Jenny Hogan
Scottish Renewables

What Can Hydrogen do for our Energy System?

Lorna Archer

Bright Green Hydrogen

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Hydrogen: The Basics & Case Study

Scottish Renewables Seminar, Thursday 28th September, 2017

Lorna Archer, Renewables Education Officer,
Bright Green Hydrogen

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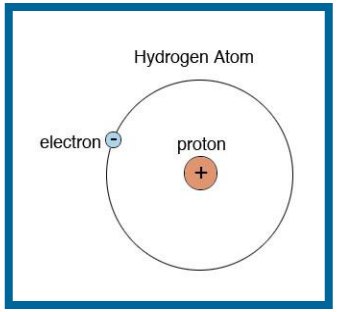
What is Hydrogen?

- Chemical element H_2, lightest gas in the periodic table
- Colourless, odourless, tasteless, non-toxic, non-metallic
- Flammable in air at 4% - 74% concentration – sensors for detection
- Stable molecular form – NOT to be confused with rare ^2H Deuterium/Heavy Hydrogen



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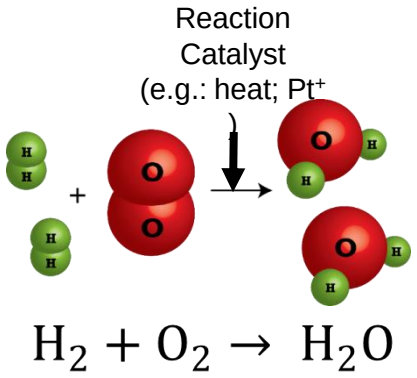
Why Hydrogen

- Zero carbon energy cycle when produced with renewables
- Can be used to in energy storage to overcome intermittency of renewables
- Can help decarbonise our energy demands: power, heat and transport



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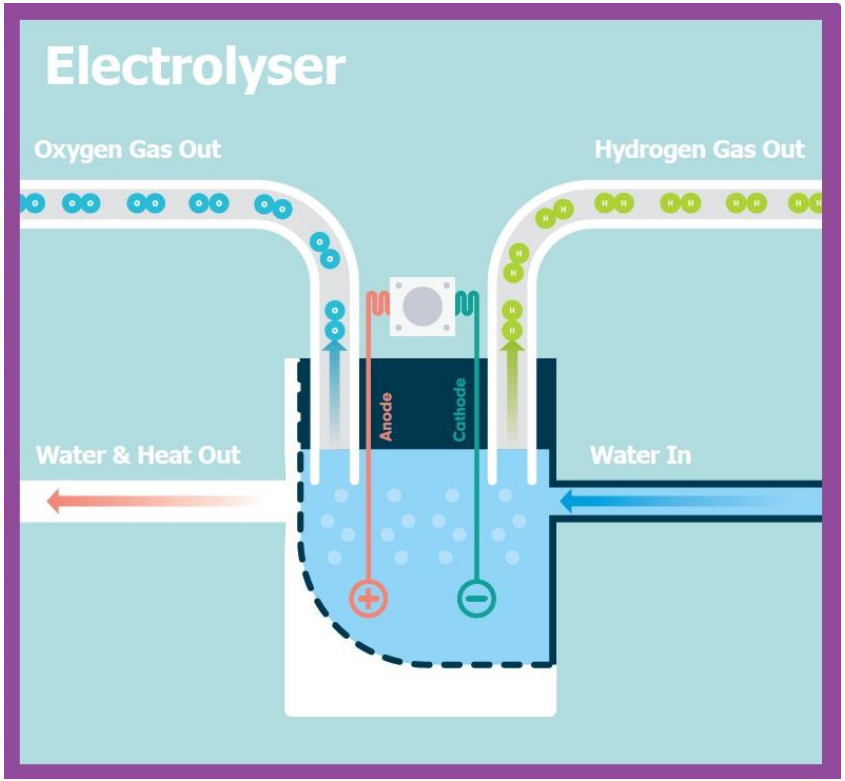

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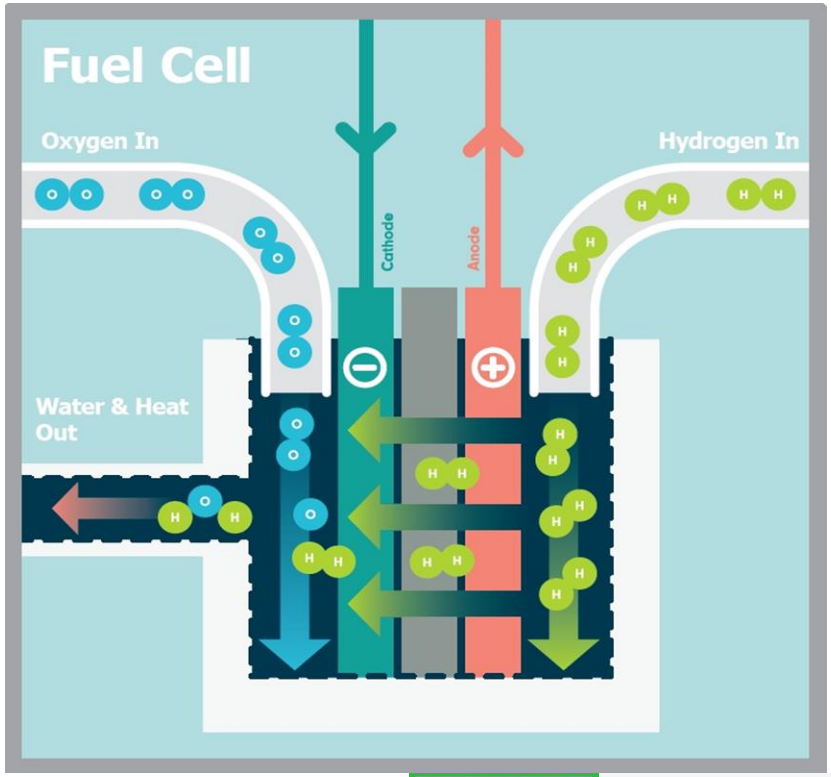

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A Case Study:
The Levenmouth Community Energy Project

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Map from Google Maps

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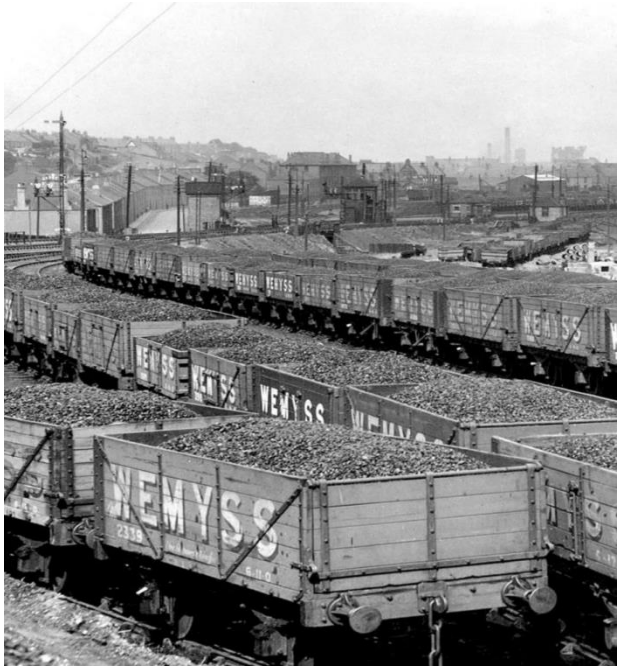

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LES Challenge Fund 2015

- Seeking a major expansion of its activities, BGH set up a consortium of organisations in 2014, involving principally Fife Council and Toshiba
- The group successfully passed both stages of the LES Challenge Fund during 2014 and 2015, resulting in a grant of £4.4m to the project
- Much-expanded, new and innovative facilities have been installed

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Levenmouth Community Energy Project

- Builds on The Hydrogen Office Project
- Showcases Energy Storage of renewable energy in the form of hydrogen
- Facilitating Sustainable Transport in Levenmouth and Fife

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Levenmouth Community Energy Project

- 910kW renewable generation
- 8 building parallel microgrid
- Toshiba H2EMS Smart Grid control
- 250kW electrolyser/100kW fuel cell ESS
- 2 hydrogen refuellers
- 17 vehicle fleet

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Our Wind Turbine

- 750kW rated power
- Provides electricity for our innovative micro-grid
- Excess wind energy sent to the hydrogen storage system

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Our Solar PV

- Solar PV designed by Forster Energy
- 160kW rated power
- Provides top-up electricity on days when there is little or no wind

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Our Micro-Grid

- 8 building micro-grid
- Powered by renewables, backed up by energy storage
- Toshiba designed hydrogen Energy Management System
- Active management of when buildings can switch to micro-grid

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Hydrogen Equipment – Electrolyser

- 250 kW PEM electrolyser
- Produces circa 100kg of hydrogen per day at full power
- Supplies hydrogen storage needs

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Hydrogen Equipment - Storage

- One tank stores 25kg of hydrogen at 30 bar
- A second tank stores 20kg of hydrogen also at 30 bar

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Hydrogen Equipment – Fuel Cell

- A 100kW PEM fuel cell
- Recombining hydrogen from storage, and oxygen from the air
- Can be used to supply the whole business park if there is no wind or solar

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Hydrogen Refuellers

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Hydrogen Refuellers

- Each refueller has their own electrolyser (60 kW)
- Each produces circa 24kg of hydrogen per day at full power
- Hydrogen is stored at 450 bar on refueller roof
- Produces hydrogen for vehicles

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Management of Refuelling Hydrogen

- Vehicle refueling with green hydrogen will take place at the Methil site
- Refueling will also take place at the Council vehicle depot at Bankhead in Glenrothes, but without hydrogen production;
- The contract for the refueling station there has recently been awarded to BOC

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Our Vehicles

- 10 Renault Kangoo converted by Symbio FC (leased by BGH)
- 5 Ford Transit converted by ULEMCo (operated by Fife Council)
- 2 Refuse Collection Vehicles converted by ULEMCo (operated by Fife Council)

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- EV conversion
- 1.7 kg hydrogen tank
- 5kW range extender fuel cell
- Range doubled to 200 miles
- Hydrogen refuelling takes ~5 minutes
- Local leasing

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- Diesel transit conversion
- 2 x 3.6 kg hydrogen tanks
- Internal combustion engine
- Reduces emissions
- Integrated into Fife Council's fleet

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- Diesel RCV conversion
- 5 kg hydrogen tank
- Internal combustion engine
- Reduces emissions
- A world first

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Our Benefits

- Zero carbon energy cycle
- Makes use of more renewable energy locally
- Electricity supplied for times there is no wind or solar
- Energy devolution from renewable electricity to renewable transport

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Conclusions

- Hydrogen is a technologically viable way to decarbonise the energy system
- Further cost reductions and technology improvements are still required
- The Levenmouth project has several world leading hydrogen applications
- Hydrogen vehicles role in Scottish Government 2032 phase out target

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SHFCA 9th Annual Conference

Low Carbon Energy Systems

with Hydrogen & Fuel Cells

Technology Innovation Centre

Glasgow, 11-12 October 2017

https://www.shfca.org.uk/2017-annual-conference

Headline conference speakers for 2017 include:

- Paul Wheelhouse MSP, Minister for Business, Innovation and Energy
- Andrew Jamieson, CEO, ORE Catapult
- John Alexander, Chair, Scottish Cities Alliance
- Jon Saltmarsh, Low Carbon Heat Innovation, BEIS
- Graham Cooley, CEO, ITM Power

Hear expert speakers on international trade and partnerships, and how hydrogen and fuel cells can be the smarter choice in Heat, Power, and Transport for low carbon deployments.

Find out more about smart integrated energy systems using hydrogen as the flexible and clean zero carbon energy vector.

- Lorna Archer, *Education Officer*
  lorna.archer@thehydrogenoffice.com
- David Hogg, *Technical Manager*
  david.hogg@thehydrogenoffice.com

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Stuart McKay
Scottish Government

Scottish Energy Strategy

The energy system and hydrogen

Stuart Greig

SCOTTISH ENERGY STRATEGY

"A modern, integrated, clean energy system, delivering reliable energy supplies at an affordable price in a market that treats all consumers fairly."

A WHOLE-SYSTEM VIEW

A STABLE, MANAGED ENERGY TRANSITION

A SMARTER MODEL OF LOCAL ENERGY PROVISION

The draft Strategy recognises the potential contribution of hydrogen to decarbonising the energy system

WHY ARE WE INTERESTED IN HYDROGEN?

New build

Existing buildings off the gas grid

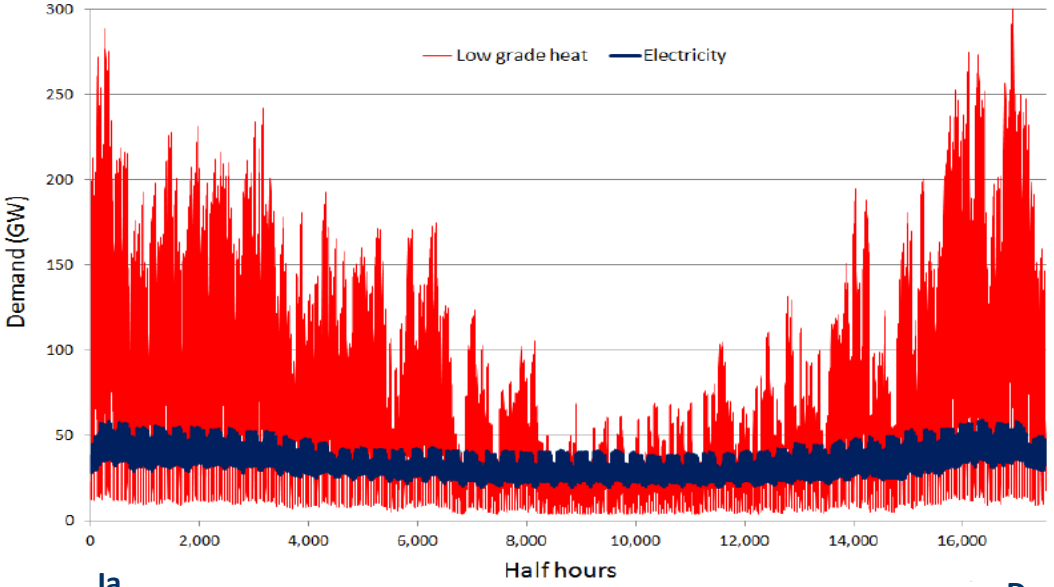
Existing buildings on the gas grid

New-build energy efficiency and low-carbon heat

Heat pumps in off-gas properties, with a supplementary role for biomass boilers

Efficiency improvemen in existing buildings

Source: Commi



WHY ARE WE INTERESTED IN HYDROGEN?

Zero carbon and zero pollution at point of use

Zero carbon and zero pollution at production (electrolysis)

Requires minimal processing for use as a fuel when produced from electrolysis

Low carbon when derived from fossil fuels with CCS

Can be transported over large distances efficiently

Efficient and potentially large scale energy storage medium

WHY ARE WE INTERESTED IN HYDROGEN?

Could help **decarbonising** heat/the **gas grid**.

Electrolysis can improve grid efficiency by **converting electricity to hydrogen during times of oversupply** for use or in other sectors, including transport.

Serve as long-term, carbon-free **seasonal storage medium** that can provide clean back-up power and buffering capacity, which is currently provided by fossil fuels.

Can act as a, long distance **renewable energy vector** to support international efforts to decarbonise the energy system (e.g. export green hydrogen)

Decarbonising transport and heat through the utilisation of fuels cells (alternative low carbon power and heat technology).

Supporting **local/distributed energy** systems;

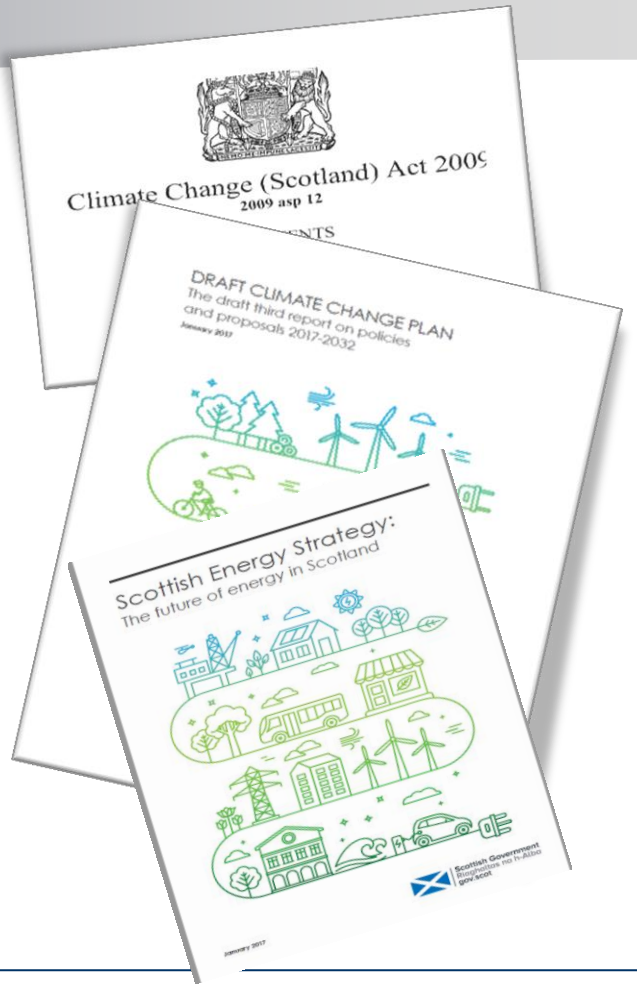
HYDROGEN AND THE SCOTTISH ECONOMY

SCOTTISH COMPETITIVE ADVANTAGES

- Active hydrogen research community
- Strong industrial-base
- Extensive renewable capacity (stranded electricity)
- Geological hydrogen storage potential?
- Modern and extensive gas grid

POLICY DRIVERS

- World leading climate (emission reduction) targets
- Systems-based Energy Strategy
- PfG- world leading targets for transitioning to ultra low emission vehicles



PROJECTS: SCOTTISH

- **Scottish gas networks –** feasibility study into 100% hydrogen gas grid.
- **National grid hydeploy project-** demonstrate natural gas containing levels of 10-20% of hydrogen can be distributed and utilised safely.
- **Orkney- valorising constrained renewable electricity** - electrolysers deployed across two remote islands, demonstrating production, transport, storage and hydrogen use.
- **Levenmouth** –provides hydrogen via electrolysis to power a fleet of small fuel cell and hybrid commercial vans and heavy vehicles.
- **Aberdeen hydrogen buses, cars and re- fuelling infrastructure**

- **UKG Renewable Fuel Transport Obligations**, proposal for the inclusion of non-biological fuels like hydrogen.
- **Hydrogen Council:** new global business initiative, £10B investment over 5 years. Scotland in contact to explore emerging opportunities.

International markets, examples

- In Europe the number of hydrogen refuelling stations is expected to double biannually, with up to 400 stations in Germany alone by 2023
- South Korea plans to replace 27,000 buses with FCEVs by 2030
- Japan is exploring opportunities to import hydrogen, from places such as Norway and Australia. Both have potentially extensive renewable energy resources.

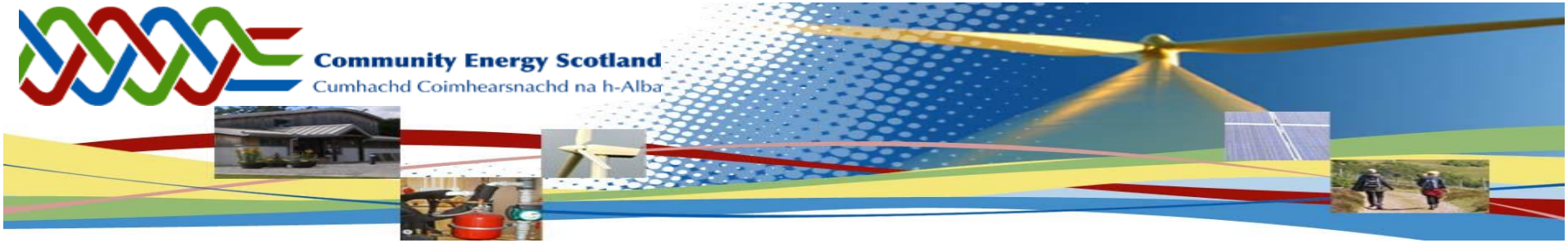
NEXT STEPS

- Publish Energy strategy by end of 2017
- Continue our engagement across the relevant sectors
- Support the development of hydrogen projects, e.g. LCITP

Thank you

Nicholas Gubbins

Community Energy Scotland



Community and Renewable Hydrogen Development - Orkney

Nicholas Gubbins, Community Energy Scotland

EMEC ORKNEY
THE EUROPEAN MARINE ENERGY CENTRE LTD

Greener Scotland
Scottish Government

ITM POWER
Energy Storage | Clean Fuel

EDAY RENEWABLE ENERGY

LOCAL ENERGY SCOTLAND

European Commission

THE CHALLENGE FUND

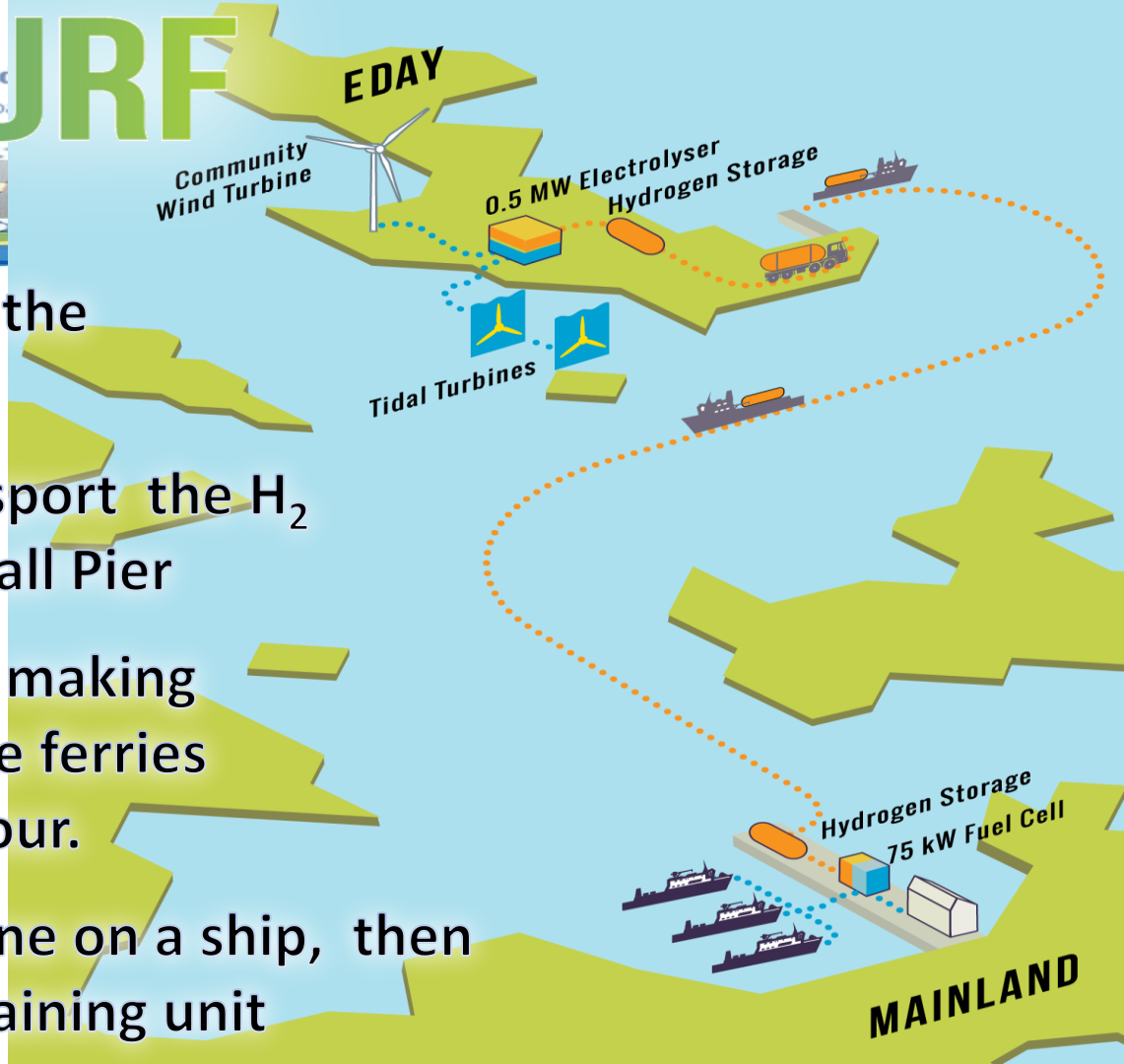
SCOTTISH Hydrogen & Fuel Cell ASSOCIATION

ORKNEY ISLANDS COUNCIL

SURF ‘N’ TURF

What we propose to do?

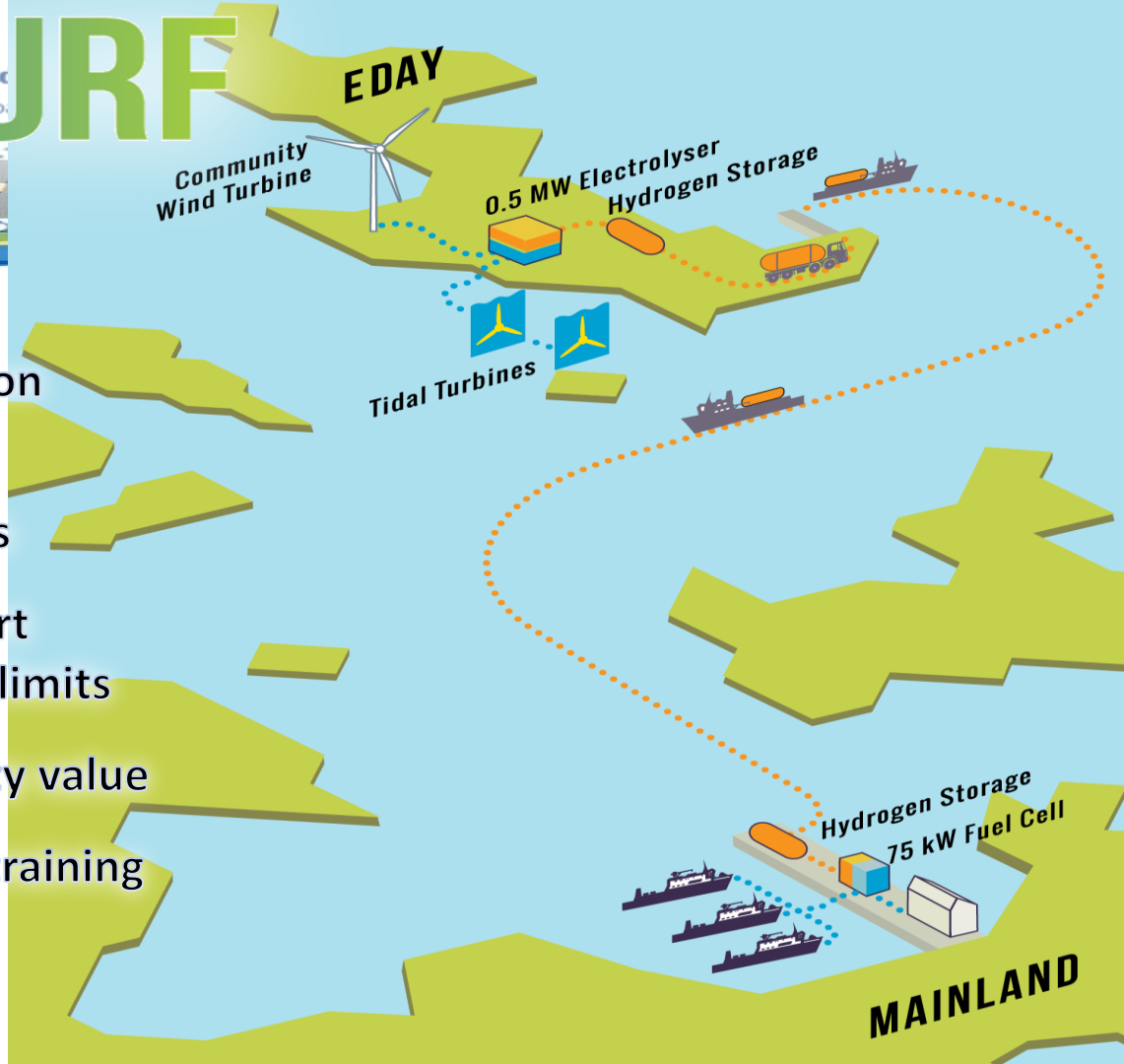
- Integrate the ERE wind to the EMEC electrolyser system
- Use mobile stores to transport the H_2 between EMEC and Kirkwall Pier
- Run a fuel cell on the Pier making electricity to cold iron the ferries and supply the local harbour.
- Adapt the FC so it is like one on a ship, then equip and run it as a H_2 training unit



SURF ‘N’ TURF

What will it achieve?

- Research integrating tidal & wind generation for H_2 production
- Optimise electricity inputs to match both curtailment patterns
- Develop production and transport to fit Pier use and infrastructure limits
- Optimise FC to increase electricity value
- UK certification/approval for H_2 training



What will be its legacy?

- Put in place a self sustaining credible local H_2 supply chain/use
- A world first, integrating curtailed wind & tide for H_2 production
- Real relief from curtailment and extra funds for the community
- Strengthen EMEC’s lead role in Eday, Scotland and worldwide
- Reduce local authority CO_2 emissions immediately
- Create a platform for increased local H_2 use and OIC investment
- A unique MCA backed UK facility for maritime H_2 training.

The BIG HIT Plan

Building Innovative Green Hydrogen Systems in an Isolated Territory

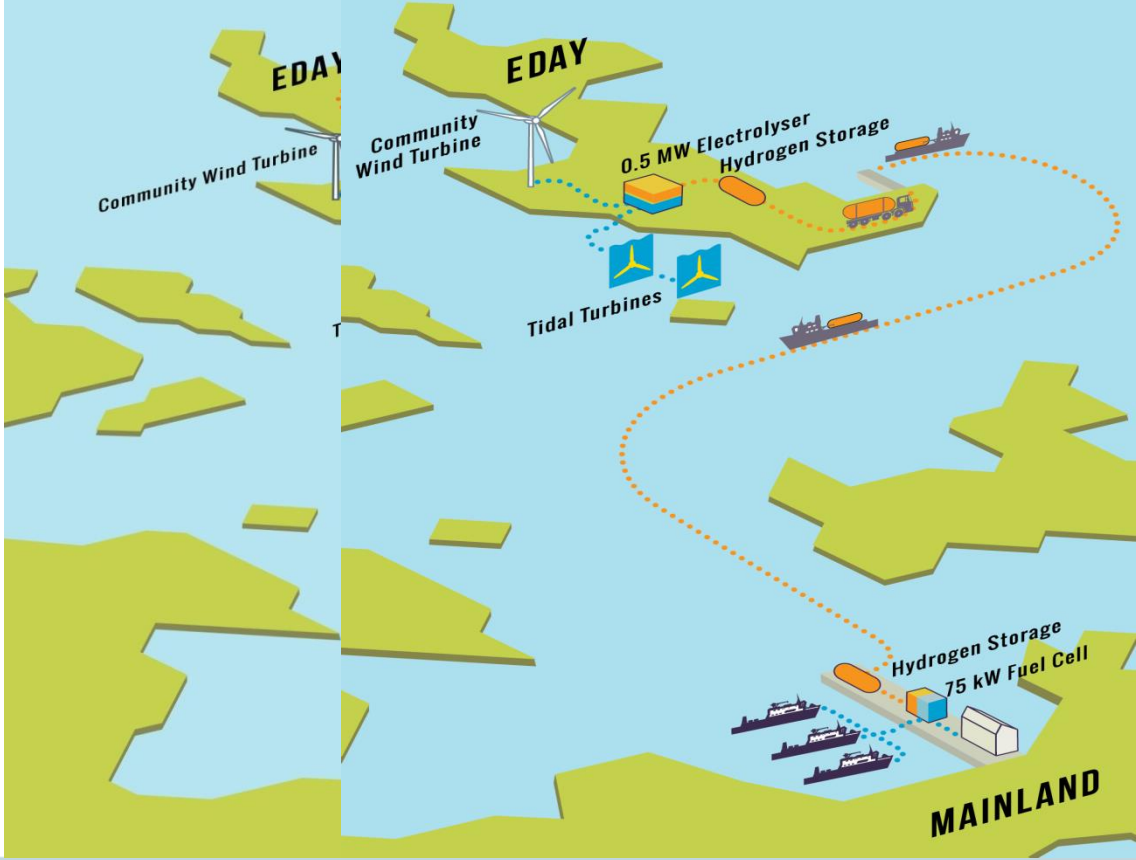
To include and expand upon existing H_2 infrastructure in Orkney

EMEC 0.5MW electrolyser,
CES's 3x tube trailers & 75kW fuel cell powering Kirkwall harbour

To add:

1MW electrolyser on Shapinsay
H_2 heating for council buildings
2x tube trailers
H_2 refuelling station &
10 fuel cell vehicles in Kirkwall

EC-funded & operational for 4 years
(post-demo commercial operation via OHT)



ITM POWER
Energy Storage | Clean Fuel

Community Energy Scotland
Cumhachd Coimhearsnachd na h-Alba

ERE turbine
and switchgear

©Colin Keldie, courtesy EMEC

Community Energy Scotland
Cumhachd Coimhearsnachd na h-Alba

EMEC Electrolyser

©Colin Keldie, courtesy EMEC

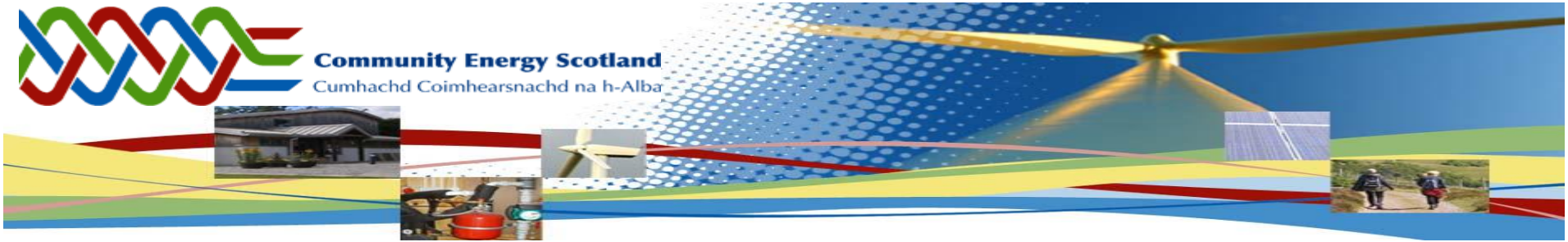
Community Energy Scotland
Cumhachd Coimhearsnachd na h-Alba

FSU, MSU and ERE Turbine

Community Energy Scotland
Cumhachd Coimhearsnachd na h-Alba

MSU en route

Kirkwall Harbour Compound: FC and MSU



http://www.surfnturf.org.uk/

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Scotland's Independent Community Energy Development Charity

http://www.communityenergyscotland.org.uk
Scottish Charity Number: SC039673

Dr Tekena Fubara
Doosan Babcock

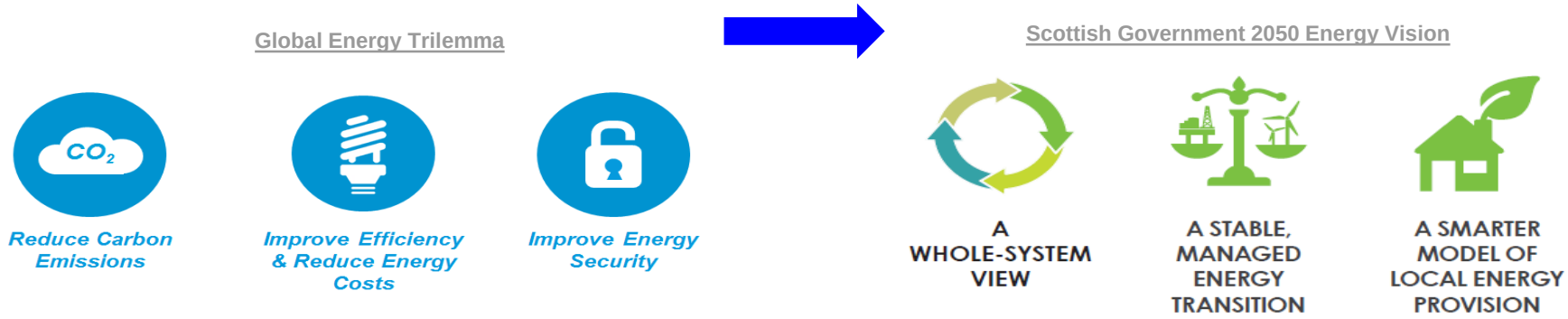
The Role of Fuel Cells in the Transition to a Hydrogen Economy

Dr. Tekena Fubara *CEng MIChemE*
Head of Applications Engineering,
Green Power Solutions, Doosan Babcock

AGENDA

- THE ENERGY TRANSITION IN SCOTLAND – NECESSITY
- TWO KEY CHALLENGES FACING THE ENERGY TRANSITION
- DE-CARBONIZING HEAT IN SCOTLAND (STEPS TAKEN)
- HOW HYDROGEN AND FUEL CELLS CAN HELP SCOTLAND
- FUEL CELL TECHNOLOGY OVERVIEW
- FUEL CELL MARKET OVERVIEW (GLOBAL, EUROPE, UK)
- FUEL CELL / HYDROGEN MARKET ENABLERS

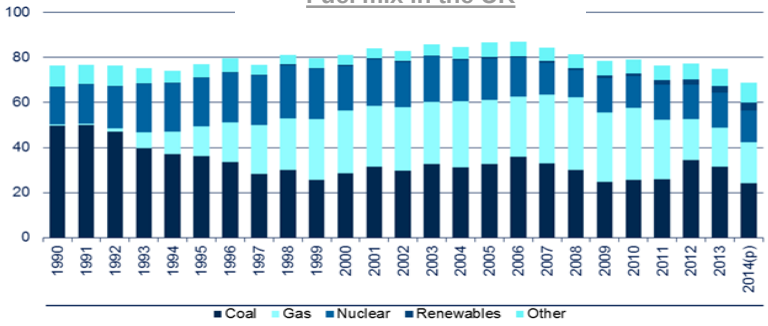
THE ENERGY TRANSITION – A NECESSITY AND A CHALLENGE



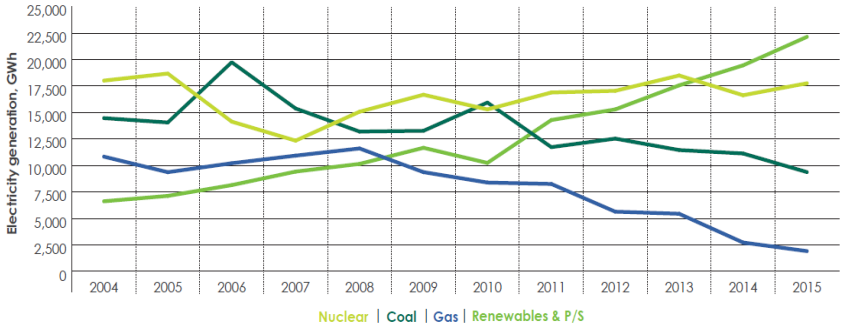
- A new Scottish Government 'all-energy' target for the equivalent of 50% of Scotland's heat, transport and electricity consumption to be supplied from renewable sources.
- Scottish Government Programme commits to a new Climate Change Bill, in response to increase in global ambition in the UN Paris Agreement. Stable and managed transition to more testing 2020 target.
- Scotland is moving away from traditional models of centralized energy provision, towards innovative local generation systems and business models.

CHALLENGE 1: CHANGING ENERGY LANDSCAPE

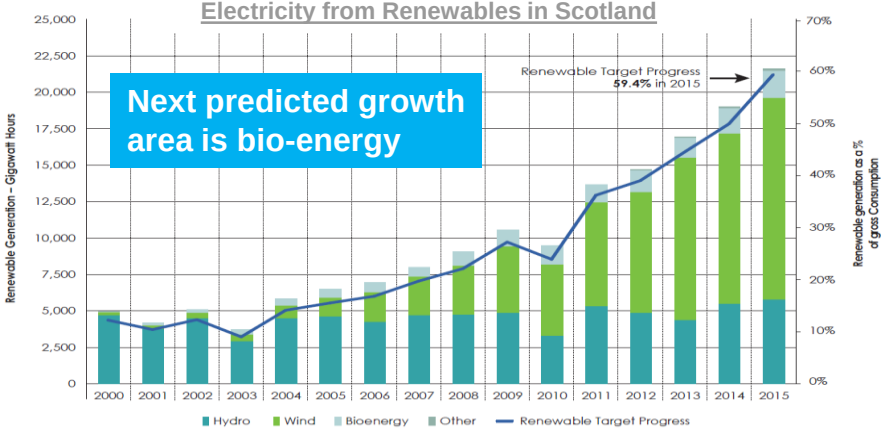
Fuel mix in the UK



Electricity mix in Scotland

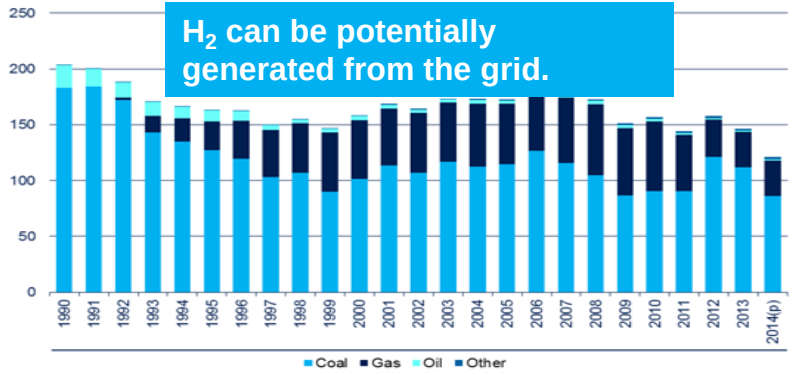


Electricity from Renewables in Scotland



Next predicted growth area is bio-energy

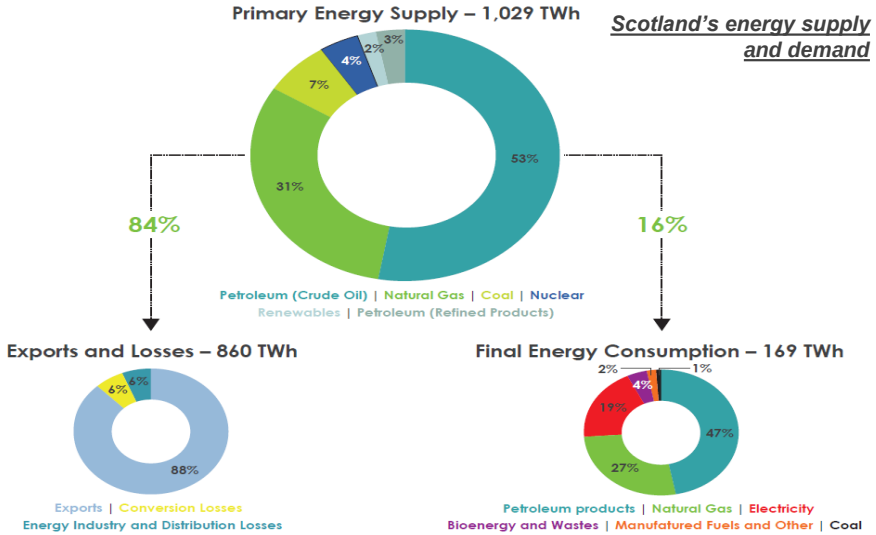
CO_2 intensity of UK Grid



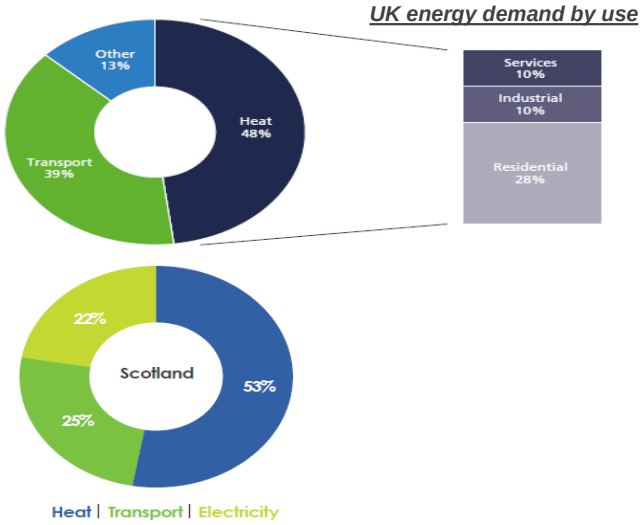
H_2 can be potentially generated from the grid.

Source: 2014 UK Greenhouse Gas emissions, Provisional Figures
Scottish Government Draft Energy Report

ENERGY SUPPLY AND DEMAND PROFILE – TODAY



Scotland's energy supply and demand



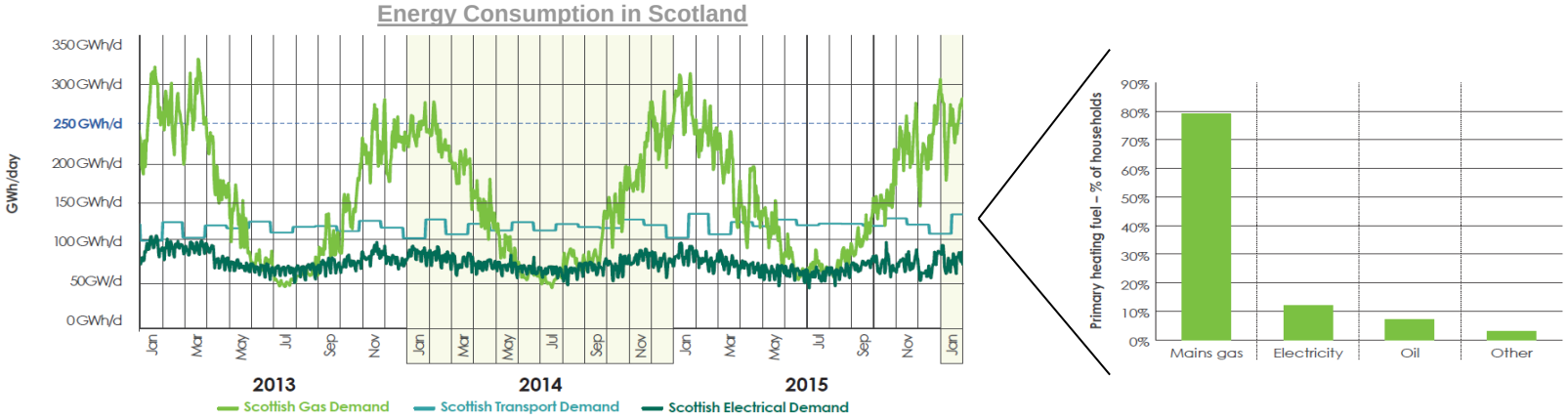
UK energy demand by use

- Fossil fuel (petroleum and natural gas) still make up a significant portion of Scotland's energy supply (84%) and demand (74%).
- 2% of Scotland's primary energy supply is from renewables, with 29% being renewable electricity.
- About half of UK / Scotland energy is used to provide heat.
- Electricity in Scotland has been significantly decarbonized with 42% - 59.4% of electricity generation being from renewables (driven by mostly offshore wind). **How do we decarbonize heat?**

UK energy supply graph sourced form Howard R and Bengherbi Z, 2016. Too Hot to Handle? How to decarbonise domestic heating. Policy Exchange.

Scotland energy supply and demand chart sourced from Scotland Draft Energy Strategy.

CHALLENGE 2: SEASONAL VARIATION IN HEAT LOAD

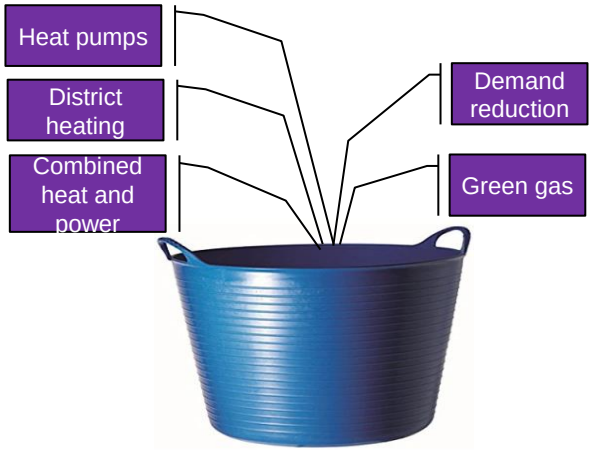


- De-carbonizing electricity looks straightforward as there is fairly stable predictable demand.
- De-carbonizing transport is similarly fairly straightforward, apart from the fact that transportation is mobile.
- De-carbonizing heat is more tricky as there are wide variations through each day, week period, season, etc.

Sources: Scotland Draft Energy Strategy.

DE-CARBONIZING HEAT IN SCOTLAND

- Electricity has been largely decarbonized in Scotland.
- The next de-carbonization focus is ‘heat’.
- Heat has acquired a “hard-to-decarbonize” reputation, compared to other sectors.

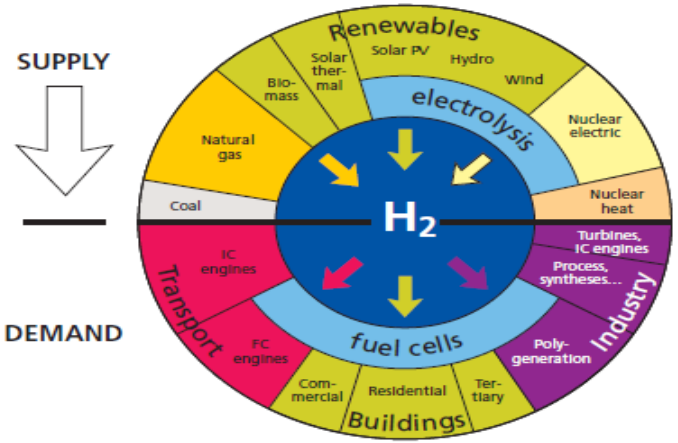


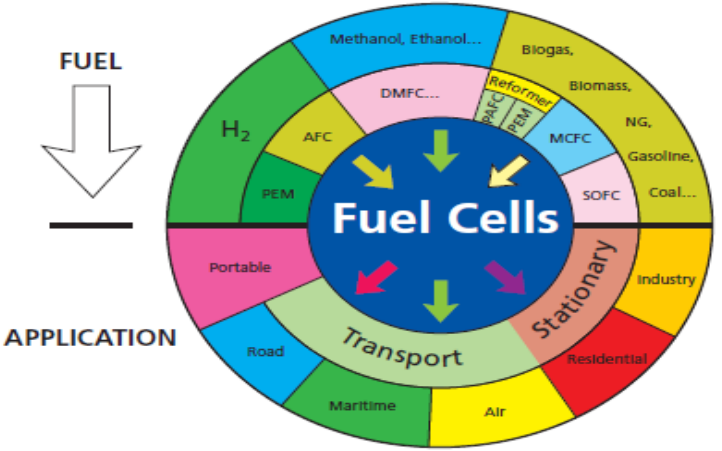
Attempt to de-carbonize Heat

KEY SOLUTIONS FOR SCOTLAND'S ENERGY FUTURE

A Unified Energy Carrier – Hydrogen is a good example.

A Unified Energy Application Technology – Fuel Cells are good examples.





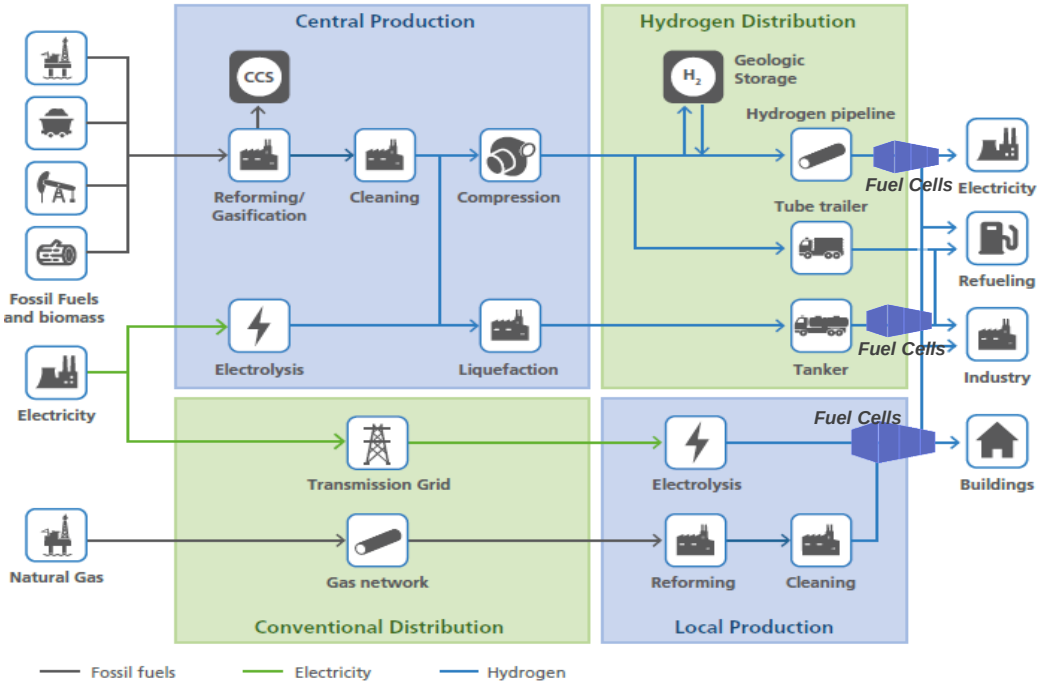
- Hydrogen has a relatively high energy weight ratio and is emission-free at the point of use.
- Hydrogen can be produced from a variety of primary energy sources and chemical substances, including water. Excess renewable energy can be used to generate hydrogen, and injected to the grid.
- Hydrogen can be applied to deliver power and heat in a variety of technologies, including fuel cells.

USING HYDROGEN TO DE-BOTTLENECK THE DE-CARBONIZATION OF HEAT

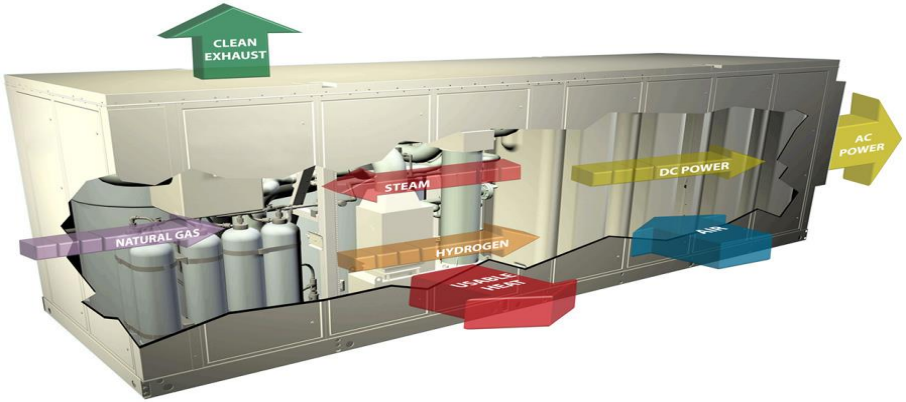
- Alternative energy sources from renewables - wind, solar, tidal, geothermal, and bio-fuels (biomass, biodiesel, bio-ethanol and biogas), have tremendous potentials, but limited mainly to electricity generation, due to location.
  - Constraints in applying to transportation and heating.

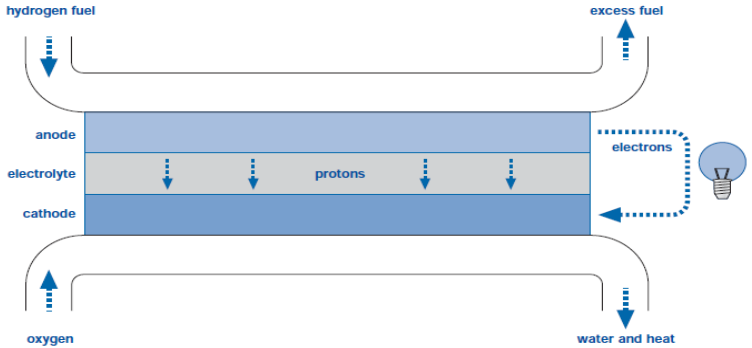
- Energy arising from wind, waves and solar sources can vary on a daily basis depending on weather conditions.

- Technology for storing electricity is well established in the form of batteries and pumped storage however coupling renewable energy sources with electricity storage requires long term storage capability (weeks or even months).



WHAT IS A FUEL CELL – AND HOW DOES IT WORK?

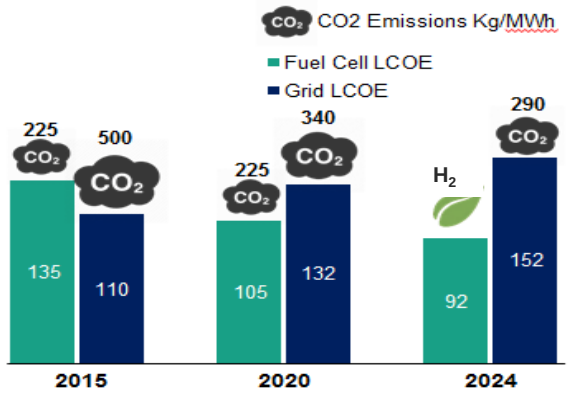




- Runs on hydrogen.
- Can be fed by natural gas, biogas, or other types of fuel.
- Electricity generation is through an electrochemical process using Hydrogen (No combustion).
- Heat is co-generated as a by-product. Total efficiency of up to 90%.
- >54% amount of CO_2 reduction due to decarbonisation of heat.
- >56% improvement in air quality (NOx, SOx and particulate matter).
- 15% to 30% energy savings for each end user.

TECHNOLOGY COMPARISON

	Wind	Solar	Conventional Engine	PureCell® System	
				Natural gas	*Hydrogen*
Overall Efficiency (LHV)	Up to 47%	~15%	Up to 88%	Up to 90%	Up to 90%
Typical Capacity (MW)	.00025 - 7	0.004	0.01 – 5	0.4	0.4
Availability	Up to 30%	Up to 20%	92-97%	98%	98%
Hours to Overhaul	n/a	n/a	25,000 – 50,000	85,000	85,000
Noise	Medium	None	High	< Low	< Low
NOx Emissions (MWh)	None	None	1.5-6.0	0.02	0
Annual Carbon Emission[1]	1226[1] tonnes	1402[1] tonnes	826 tonnes[3]	808 tonnes	0
Life	20yrs	20yrs	~15yrs	20/25yrs	20/25yrs



Benefits against other Technologies

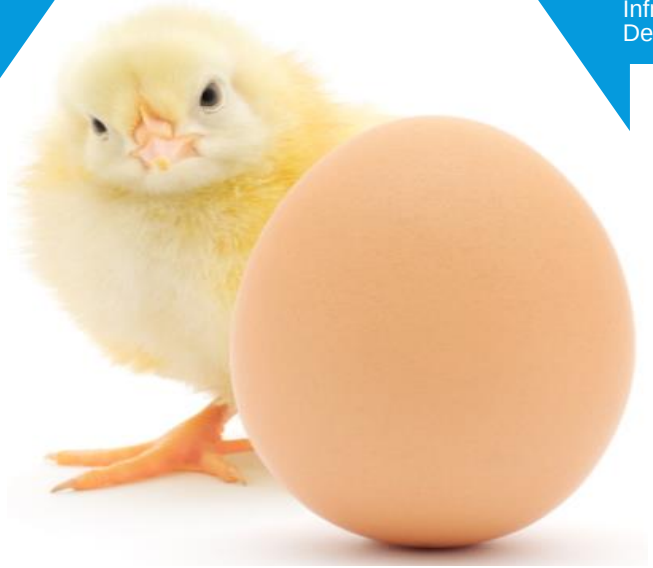
- *Up to 90% CHP efficiency*
- *Low noise & no moving parts*
- *No shutdown required for planned maintenance*
- *Ideal for space restricted, applications*
- *Exterior design adaptable to individual developments*

1.Carbon Emission based on 0.4MW electricity and taking into account capacity factor with grid back-up (UK Grid MW = 500t Carbon pa)
2.Wind & Solar inclusive of Grid
3.Based upon maximum efficiency of 88%

HYDROGEN CAPACITY DEVELOPMENT – KEY CHALLENGE

H_2 Supply Chain Infrastructure Development

Hydrogen Demand-side Infrastructure Development



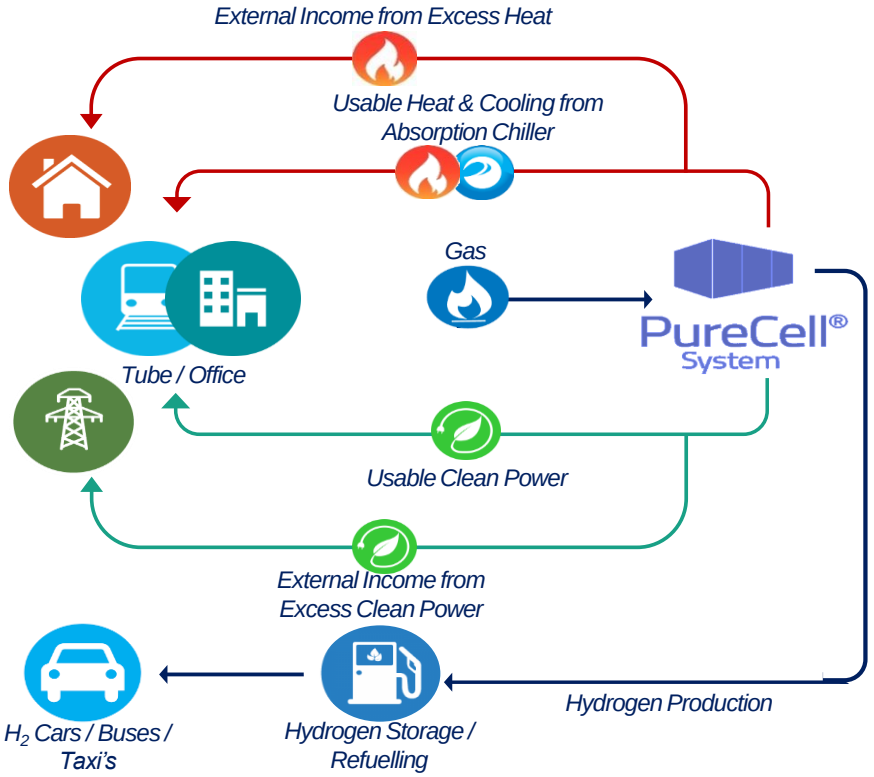
- Classic chicken-and-egg conundrum: the lack of a market in the first place deters investment, preventing the market from developing.

Image source: http://www.playbuzz.com/aurora17/the-chicken-or-the-egg

WHY FUEL CELL HOLDS THE KEY TO THE TAKE-OFF OF THE HYDROGEN ECONOMY

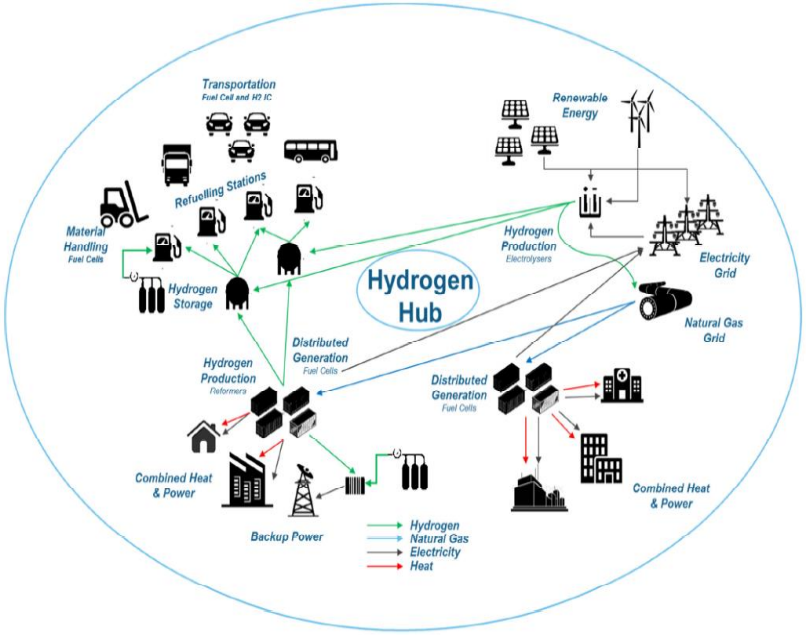
FUEL CELLS PROVIDE AN EARLY TRANSITION

- The introduction of hydrogen on a large scale could require a radical transformation of Scotland's energy-supply system.
- Consumers would also need to invest in hydrogen related equipment.
- Introducing fuel cells would ensure that hydrogen fuel would both complement existing energy systems and compete against them.
- Natural gas and coal would probably provide the main inputs to hydrogen production, while also remaining important inputs to electricity-generating plants.
- Using fuel cells will ensure that it is able to complement renewable electricity by providing a means of storing it via hydrogen, and re-use.
- Decentralized systems using combustion technologies brings air pollution closer to cities – 52,500 early deaths in UK.

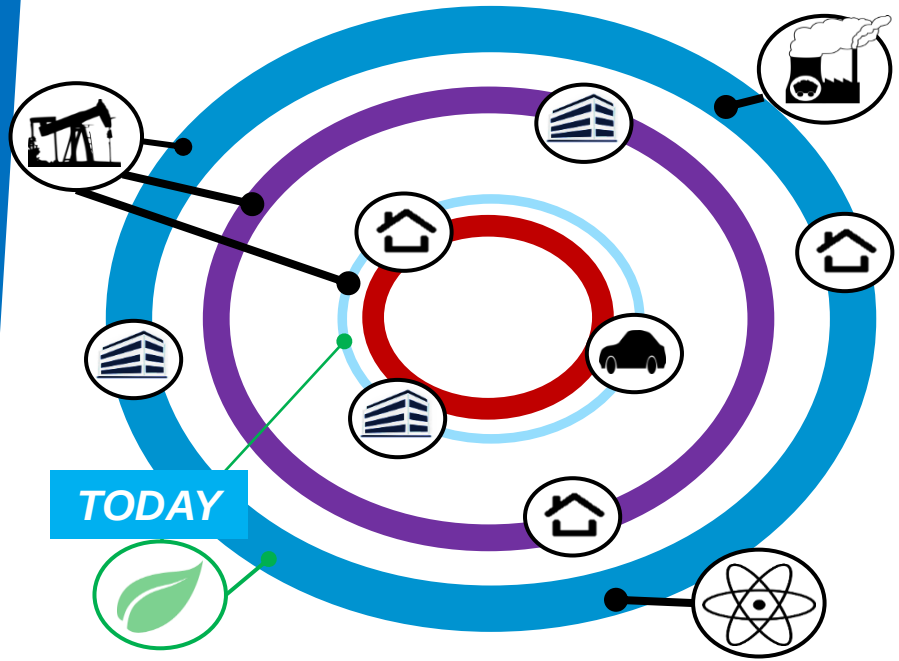


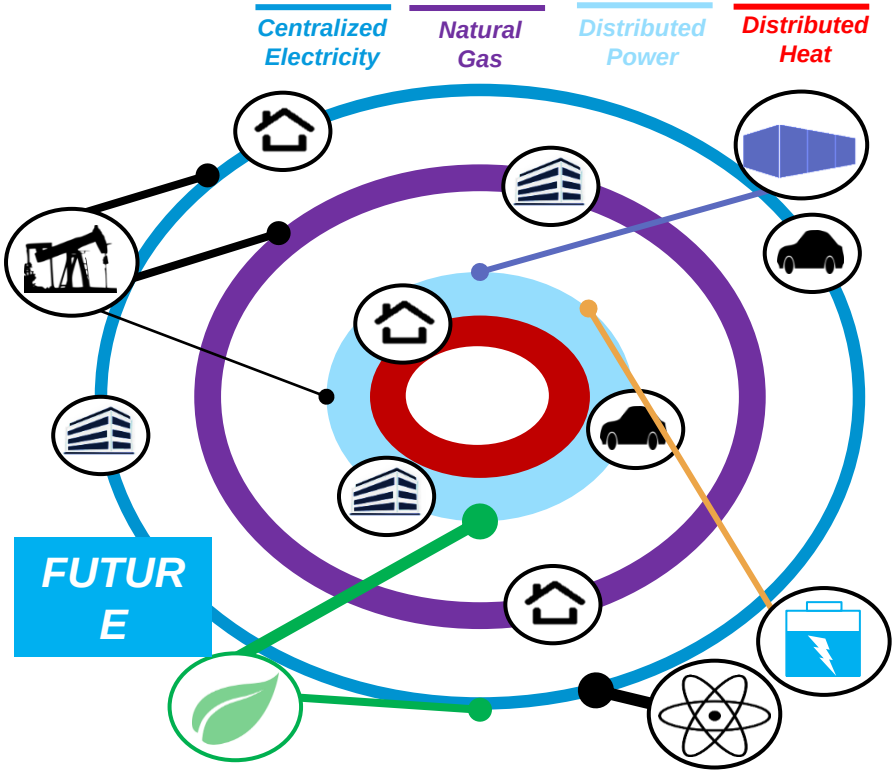
SCOTLAND AS A GLOBAL HUB FOR HYDROGEN

- LOCAL VISION: Create local hydrogen hub in Scotland.
- GLOBAL VISION: Create a local hydrogen industry in Scotland that also exports to the rest of the world.



ENERGY INFRASTRUCTURE PREDICTIONS

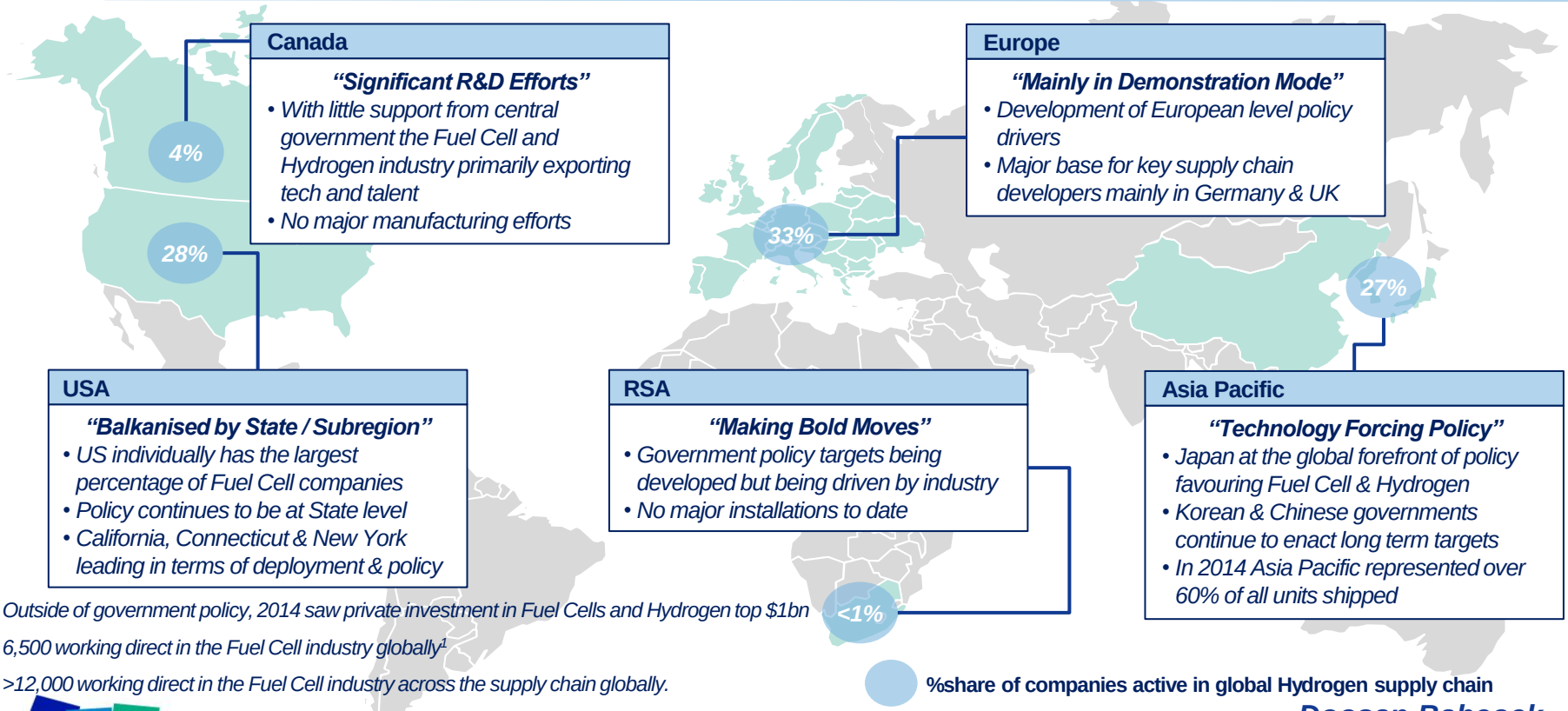




- Global energy systems are undergoing significant changes as a result of increasing environmental concerns.
- Reductions in emissions, better energy security and increased efficiency are key drivers in energy and transport landscapes.
- Hydrogen has come into the spotlight as a key enabler in developing these low carbon energy systems and supporting economic growth

OVERVIEW OF KEY DEVELOPER AND ADOPTER NATIONS

The Global Fuel Cell market is estimated to be worth ~$26bn by 2020 and ~$180bn by 2050



Canada

"Significant R&D Efforts"

- *With little support from central government the Fuel Cell and Hydrogen industry primarily exporting tech and talent*
- *No major manufacturing efforts*

Europe

"Mainly in Demonstration Mode"

- *Development of European level policy drivers*
- *Major base for key supply chain developers mainly in Germany & UK*

USA

"Balkanised by State / Subregion"

- *US individually has the largest percentage of Fuel Cell companies*
- *Policy continues to be at State level*
- *California, Connecticut & New York leading in terms of deployment & policy*

RSA

"Making Bold Moves"

- *Government policy targets being developed but being driven by industry*
- *No major installations to date*

Asia Pacific

"Technology Forcing Policy"

- *Japan at the global forefront of policy favouring Fuel Cell & Hydrogen*
- *Korean & Chinese governments continue to enact long term targets*
- *In 2014 Asia Pacific represented over 60% of all units shipped*

- *Outside of government policy, 2014 saw private investment in Fuel Cells and Hydrogen top $1bn*
- *6,500 working direct in the Fuel Cell industry globally[1]*
- *>12,000 working direct in the Fuel Cell industry across the supply chain globally.*

%share of companies active in global Hydrogen supply chain

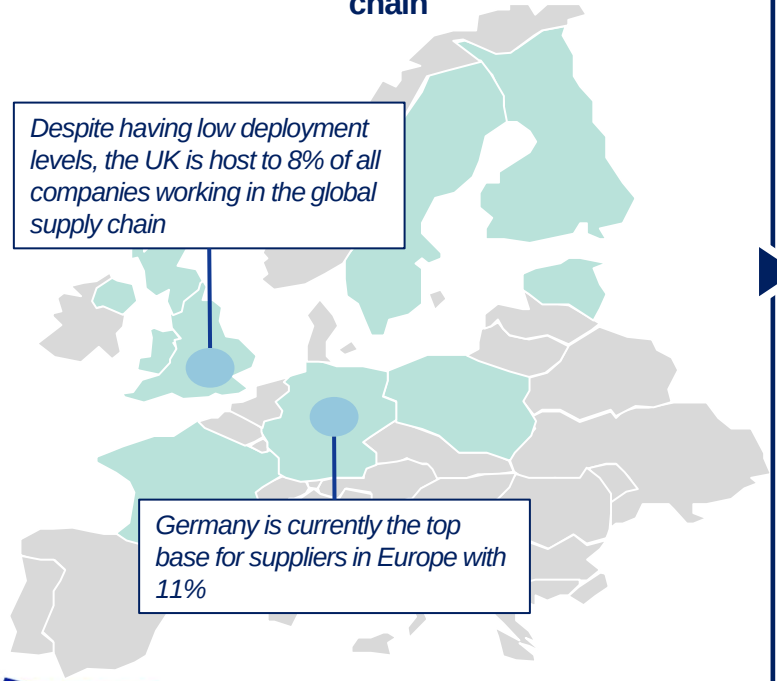
DOOSAN

Source: The Fuel Cell and Hydrogen Annual Review 2015; 4th Wave Energy

EUROPEAN DEVELOPMENT OPPORTUNITY

Europe has a strong foundations in Hydrogen & Fuel Cell but lacks the driving force to lead development

Europe is currently the location for 33% of companies working in the global Fuel Cell supply chain



Source: The Fuel Cell and Hydrogen Annual Review 2015; 4th Wave Energy

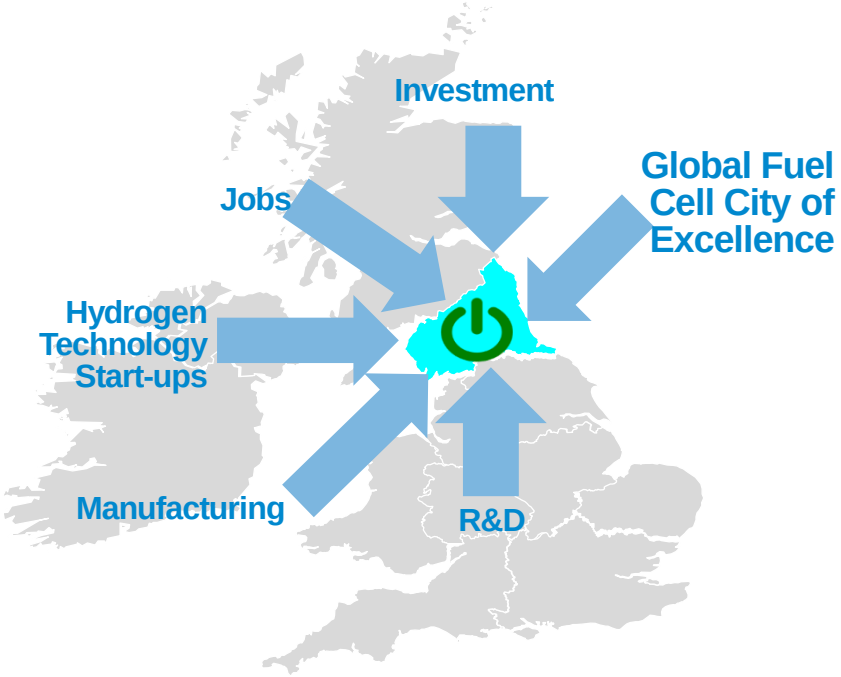
Europe's energy landscape is facing major challenges as it evolves against the back drop of an ambitious climate agenda

Enabling Hydrogen & Fuel Cell Technologies

- *Germany & the UK have established themselves as the powerhouses of European Hydrogen Technology with major supply chain players and increasing government awareness*

- *With 3 installations, London has the main concentration of large stationary Fuel Cells in Europe however, the city's precarious lead is under threat.*
  - *Aberdeen launched a 2020 Strategy Framework outlining a vision for the City to become a hydrogen economy including the installation of 3x400kW Fuel Cells.*
  - *In Germany, E.ON have partnered with FCE to launch 1.4MW DFC plant in Mannheim on the back of strong govt support.*

FUEL CELL OPPORTUNITY FOR SCOTLAND

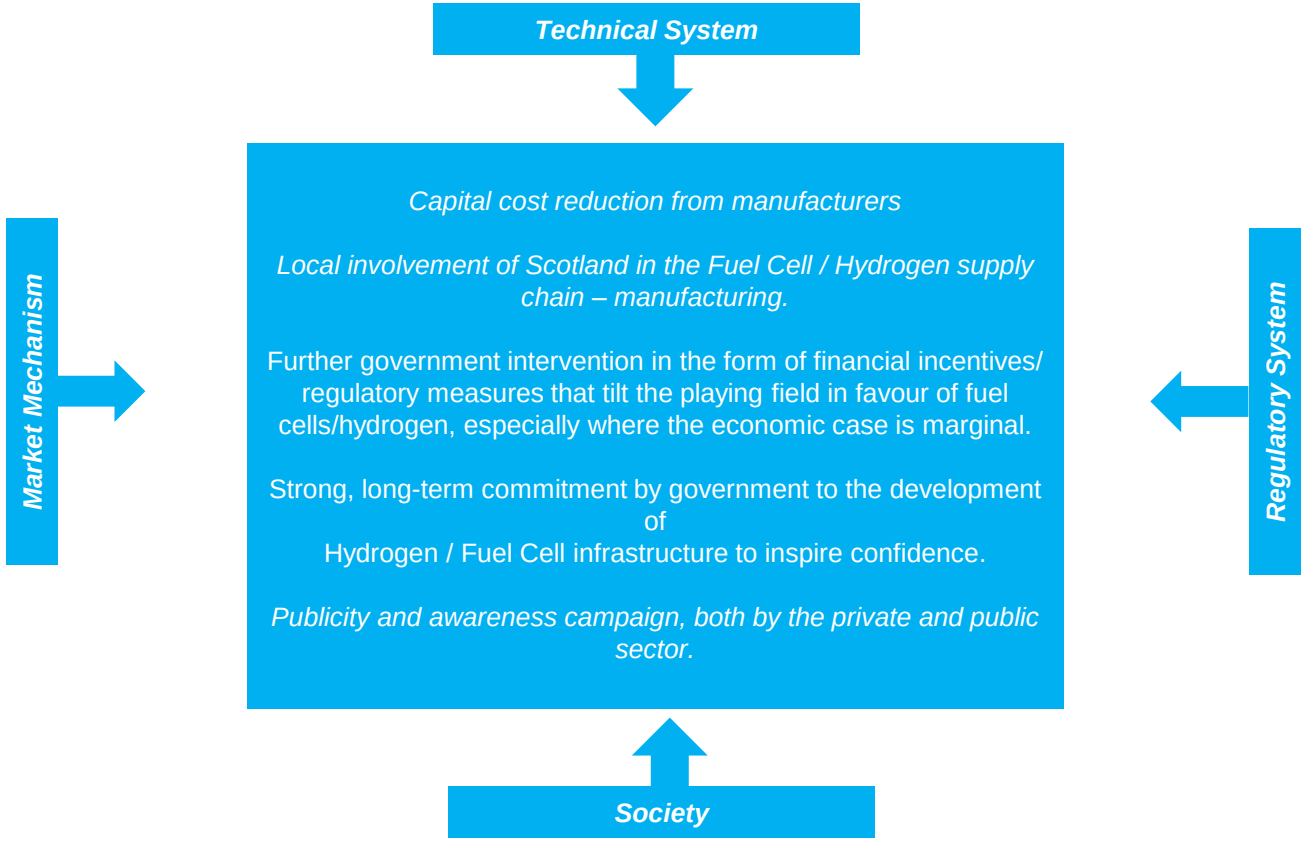


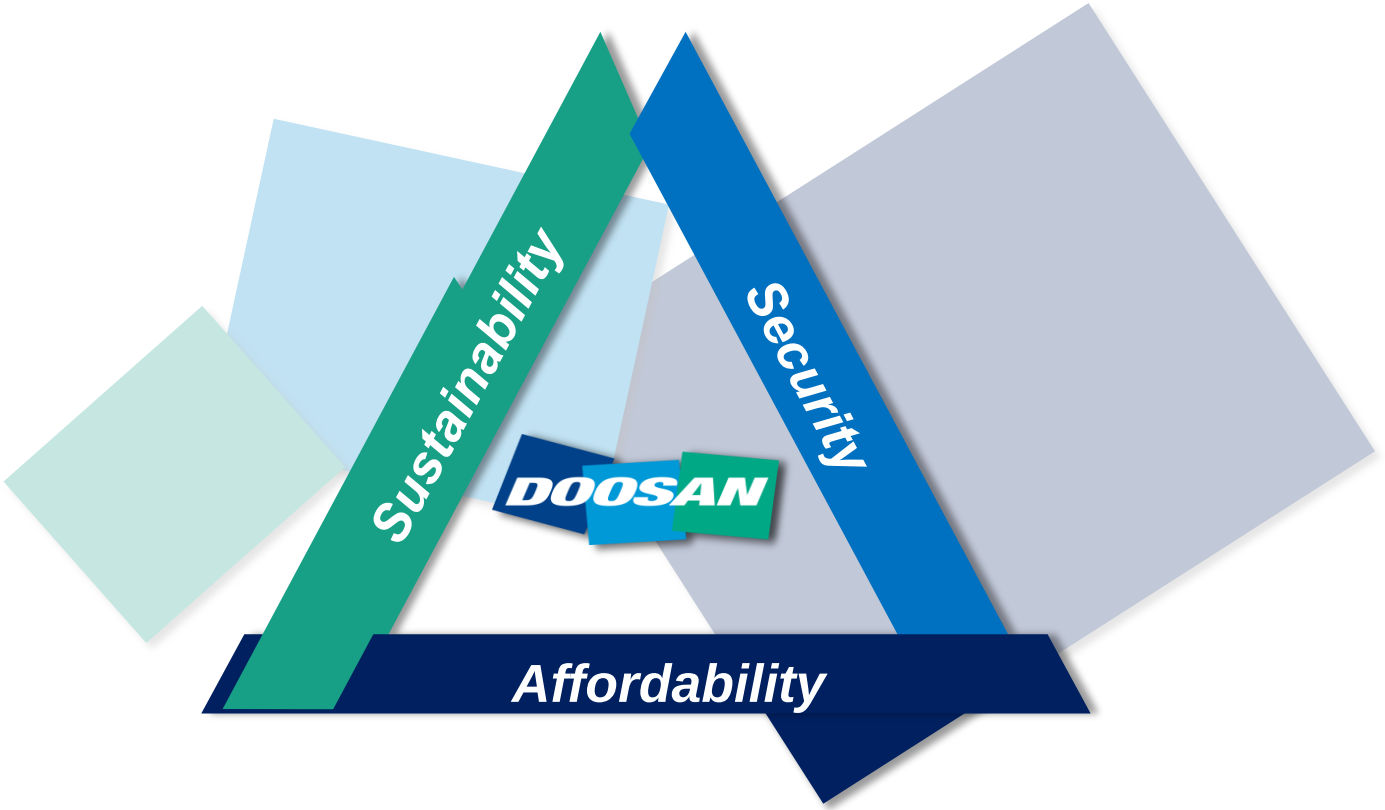
Global Fuel Cell Market is forecast to grow from ~$5bn to ~$26bn by 2020

Scotland can take leading role to attract rapidly emerging "high-tech" industry to the UK

- *Creating a centre for Fuel Cell and energy related technology development and innovation.*
- *Stimulating jobs in Research and Development as well as installation and maintenance.*
- *Tackling climate change through significant carbon reduction.*
- *Providing heat & power at the lowest possible operational costs.*

FUEL CELL: ENABLERS




Sustainability
Security
DOOSAN
Affordability

Thank You For Listening,

Any Questions?

DOOSAN BABCOCK

Employees
~6,000

Revenues
~$900m USD

Headquartered
Gatwick, UK

Major Locations
Glasgow, UK
Krakow, Poland
Berlin, Germany
Atlanta, USA
Hong Kong, China
Dubai, UAE

Proud Heritage

- **1891** — *Babcock & Wilcox established*
- **1956** — *Steam System for World's first commercial Nuclear power station*
- **1960** — *World First Steam System for Gas Turbine Power Plant*
- **2002** — *Babcock acquires Rolls Royce Nuclear Engineering*
- **2006** — *Acquired by Doosan*
- **2009** — *Worlds Largest Carbon Capture Test Facility Opened*
- **2014** — *Doosan Acquires Fuel Cell Technology*

Doosan Babcock
Building a Low Carbon Future

Doosan Babcock
Building a Low Carbon Future

FUEL CELL ADOPTERS IN THE UK – PALESTRA BUILDING (TFL)

FUEL CELL ADOPTERS IN THE UK: QUADRENT 3 (REGENT STREET, LONDON)

MULTI-MW FUEL CELL INSTALLATION (KOREA)

Client:
KOSEP

No. of Units:
70 x PureCell® Model 400

Total MW:
30.8MW

Award date:
October 2015

Detail:
Design, manufacture & installation of multi MW Fuel Cell structure

Purpose:
Provide clean power and heat to a new residential development in Busan

Key Stats

Largest PAFC[2] generation project in the world

Largest urban fuel cell site in Korea

Power 71,500 Korean homes

Multi-story structure will occupy less than 1 acre[3]

Fully scalable to meet future energy needs

[1]KHNP=Korea Hydro and Nuclear Power, Busan – second largest city in Korea
[2]PAFC=Phosphoric acid fuel cell
[3]231 acres of solar panels will be required to generate same amount of power

PURECELL® MODEL 400 - KEY FEATURES

Cleanest source of continuous on site energy generation

Output and Efficiency

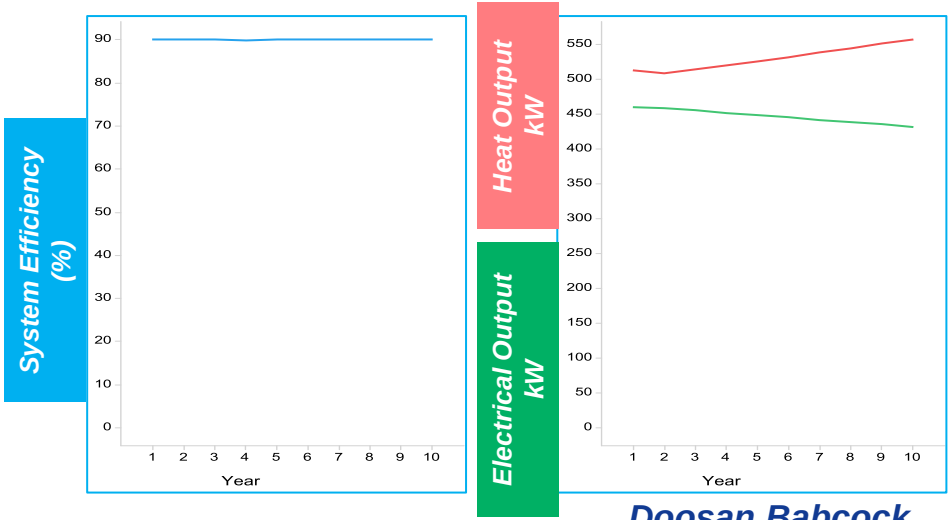
- 460kW electric output
- 513kW heat output
- 42% electrical efficiency
- 90% system efficiency

Design Features

- Grid-independent operation
- Electric load following
- Low pressure natural gas fuel & H_2 ready
- Low noise and vibration
- Low emissions

Performance

- High fleet availability 98% -12 month rolling average



FUEL CELL APPLICATION & CLIENT LIST

More and more commercial and government-run buildings are becoming less dependent on their local energy grids and fuel cells are playing a major role in facilitating this independence

DATA CENTERS/ TELCOM

UNIVERSITIES

HOSPITALS

INDUSTRIAL

UTILITIES

RETAIL

COMMERCIAL

GOVERNMENT

DOOSAN

Key Client Examples

Coca-Cola

verizon

Adventist Health

First National Bank
One with You.®

WORLD TRADE CENTER

PRATT & WHITNEY
DEPENDABLE ENGINES

CT TRANSIT

WHOLE FOODS MARKET

CBS

KOSEP

Doosan Babcock

DOOSAN BABCOCK

GREEN POWER SOLUTIONS

Flexible Sales Packages

Operation & Maintenance

Feasibility & Design

Installation, Integration & Commissioning

Q & A

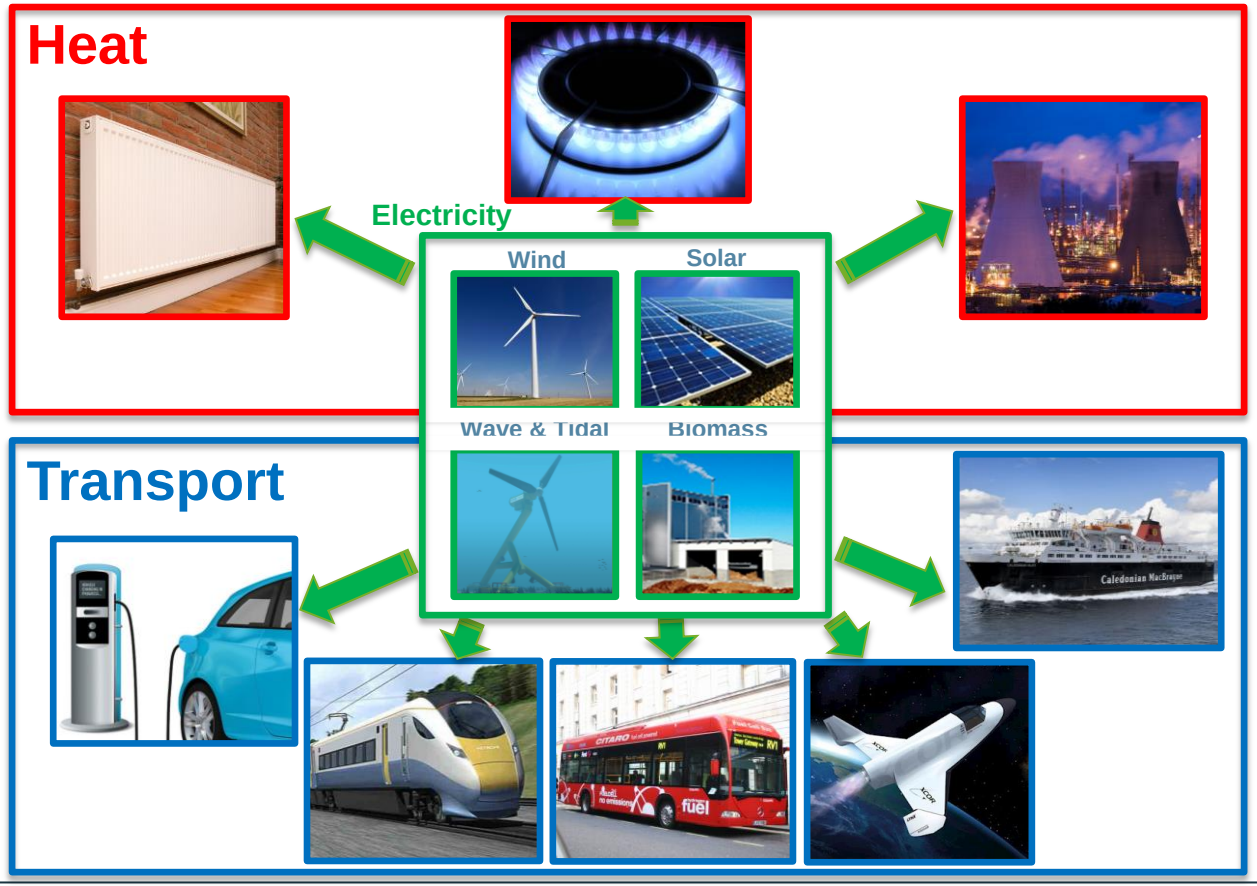
Networking Break

Hydrogen and Renewables

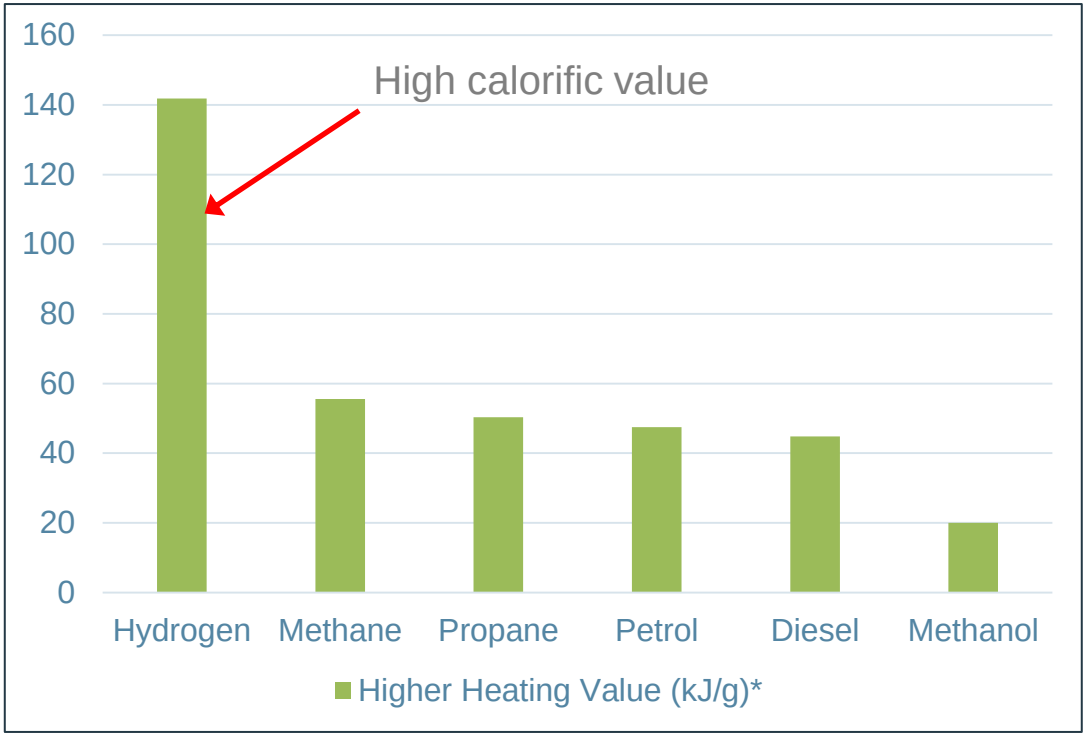
Alan Mortimer
Wood Group

Hydrogen & Decarbonisation

Renewables can decarbonise all energy…



Main Benefits of Hydrogen

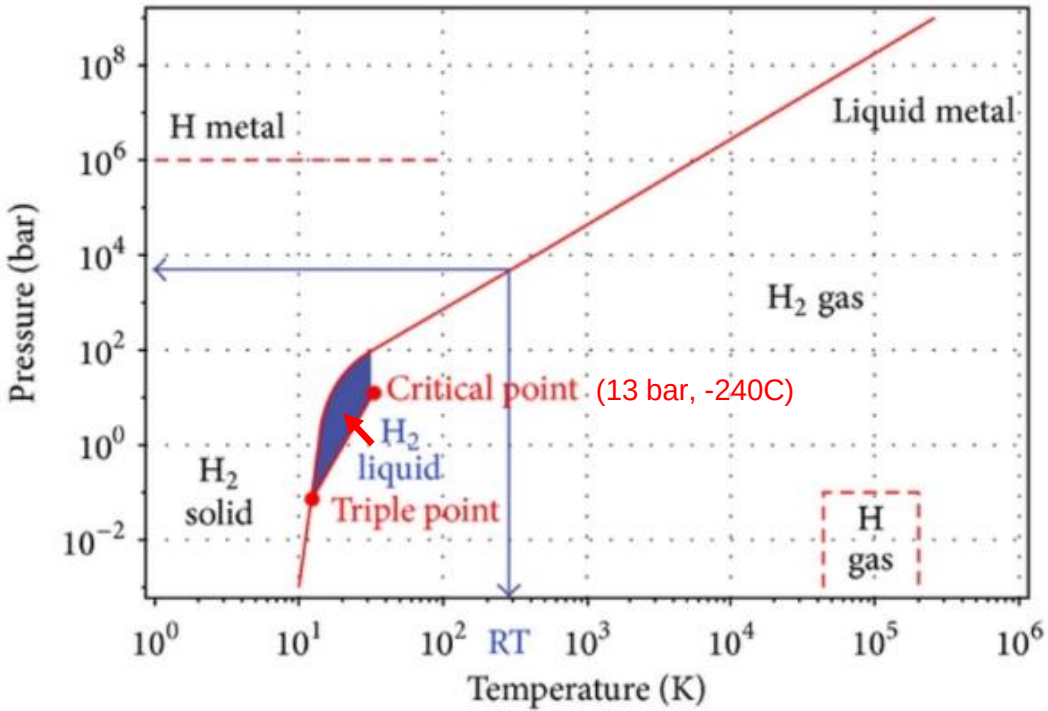


Plus:

Super abundance

Clean combustion

The Storage Challenge….

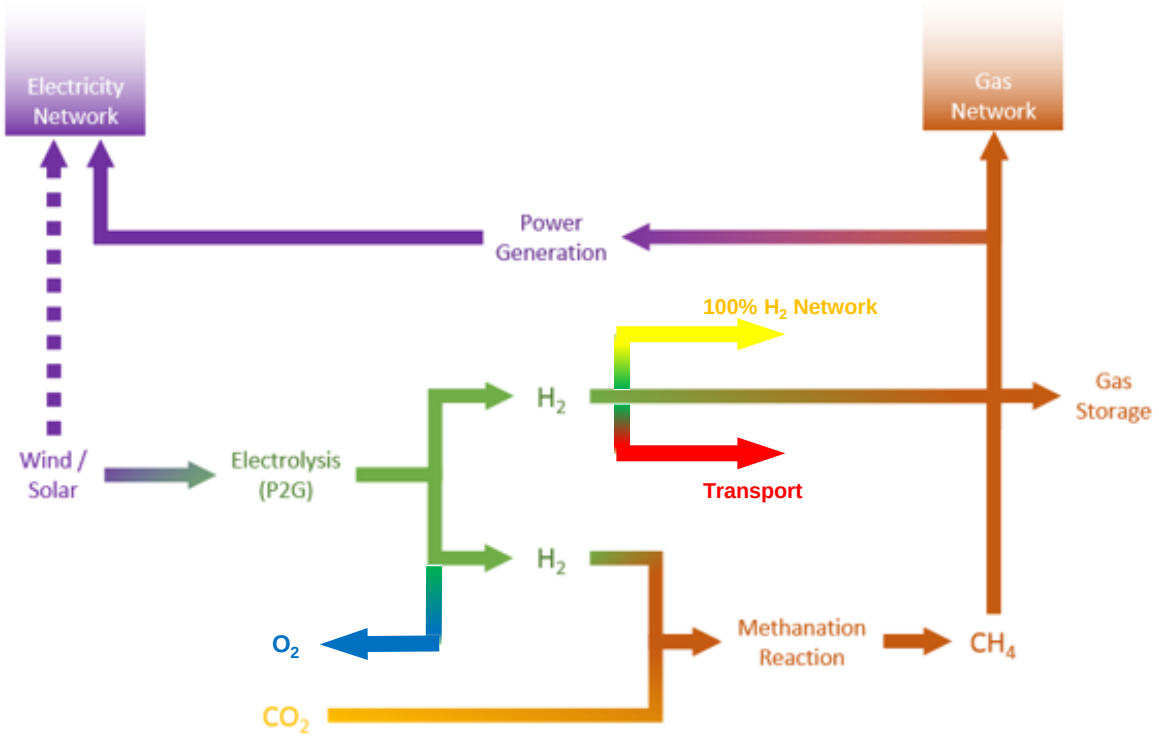


Renewable Hydrogen – Wood Group Perspective

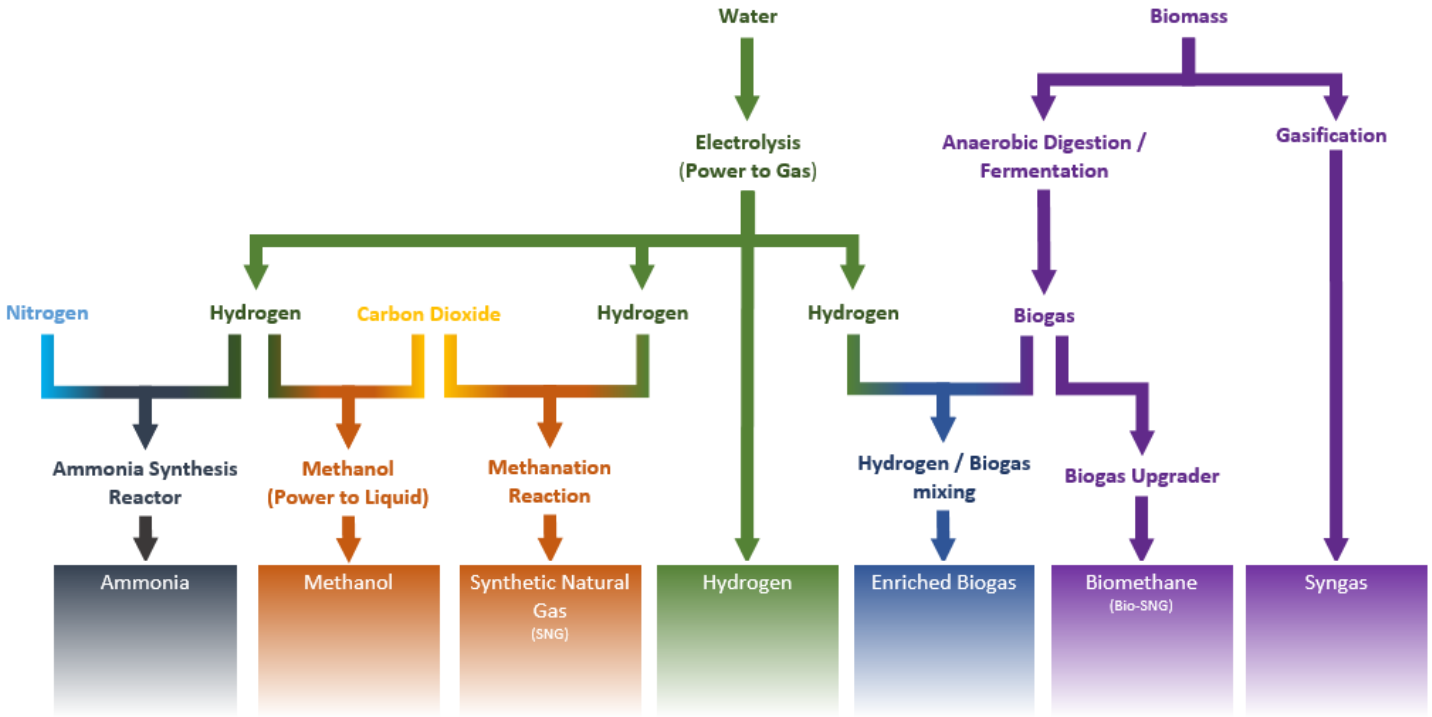
Internal review completed:

- Renewably generated gas costs are falling
- Natural gas and “brown” hydrogen costs rising
- We need to get ready for the cross-over
- We should support moves to use hydrogen for energy decarbonisation
- Wood Group is uniquely placed:
  - Oil & Gas plus Renewables expertise
- Planned participation in Transport & Gas Networks projects

Energy System Integration



Wider Hydrogen Applications



Safety & Technical Considerations

- The dangers of hydrogen need to be respected:
  - Risk of leakage
  - Risk of explosion
  - Risk of poisoning (esp. as H_2S)
- Rigorous safety case required
- Technical challenges due to hydrogen properties:
  - Small molecules: leakage
  - Low density: storage challenge (high pressure / low temperature)
  - Difficult to transport
  - Embrittlement of metals (impact on fatigue & crack properties)
  - Flame properties (different from natural gas)
- Technical standards need to be adapted
- These issues can be addressed with appropriate expertise

Hydrogen & Gas Networks

- Heat makes up over 50% of our carbon emissions
- Decarbonisation of Gas is now a Government objective
- Electricity is already being increasingly decarbonised
- “Power to Gas” therefore has a key role to play
- UK gas operators incentivised to find solutions
- Options include:
  - Hydrogen injection in existing networks (<10%)
  - New 100% hydrogen networks
- Progression from brown to green hydrogen over time
- Hydrogen Demo Projects are essential
- Wood Group looking to advise and support this work

Hydrogen Fuelled Transport

- High energy density: suits energy intensive applications:
  - Ships, trains, trucks, buses, aircraft
- Offers another deployment route for renewable energy
  - e.g. remote areas with limited grid
- Significant additional benefits:
  - No local pollution
  - Much quieter
- Demand pattern is relatively constant
- Benefits from fuel cell technology development

Hydrogen Ferries Example Application

- Hydrogen can fuel key transport service for remote areas
- Fuel from local, community-owned renewable projects
- Demand and production patterns need to be modelled
- Gas transport and shore side storage issues need to be addressed
- Integration with heat and power needs to be considered
- The global market for (green) hydrogen needs to be reviewed
- Potential to support economic growth in areas with limited opportunities
- Serving as a test bed for larger scale deployments in future

NCOC Kashagan EPC Contract, Atyrau, Kazakhstan

Customer:

NCOC

Location:

Atyrau, Kazakhstan

Services

- Engineering
- Construction
- Commissioning
- Project management
- Support services

Kashagan Challenges

Technical Challenges

- High H_2S content
- High Pressure
- Extreme temperature variations of -40°C to + 40°C
- Ice conditions 5 months of the year
- Shallow sea level and fluctuations in sea levels
- Remoteness and landlocked sea area
- Environmentally sensitive area

Project Challenges

- Availability of local resources
  (Kazakh, Russian, UK, Indian, Trinidadian, Filipino, Australian, Pakistani, Sri Lankan)
- Three month accelerated production start-up schedule
- Procurement and material lead times
- Execution of construction and commissioning works

Summary & Conclusions

- Hydrogen has key role to decarbonise all energy
- Whilst maximising use of Scottish renewable resources
- Technical & Safety challenges are surmountable
- Oil & gas sector has relevant expertise:
  - Hydrogen handling & storage
  - Safety case delivery
  - Safety management
  - Infrastructure design
  - Integrity management
  - Pipeline operational management
- Initial applications may use brown hydrogen
- Migration to green hydrogen as economics improve
- Economic benefits extend from national down to community level

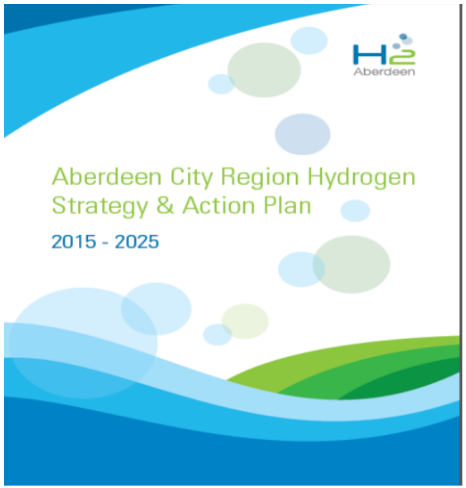
Cameron Baillie
Aberdeen City Council

H2 Aberdeen
Aberdeen Hydrogen Economy

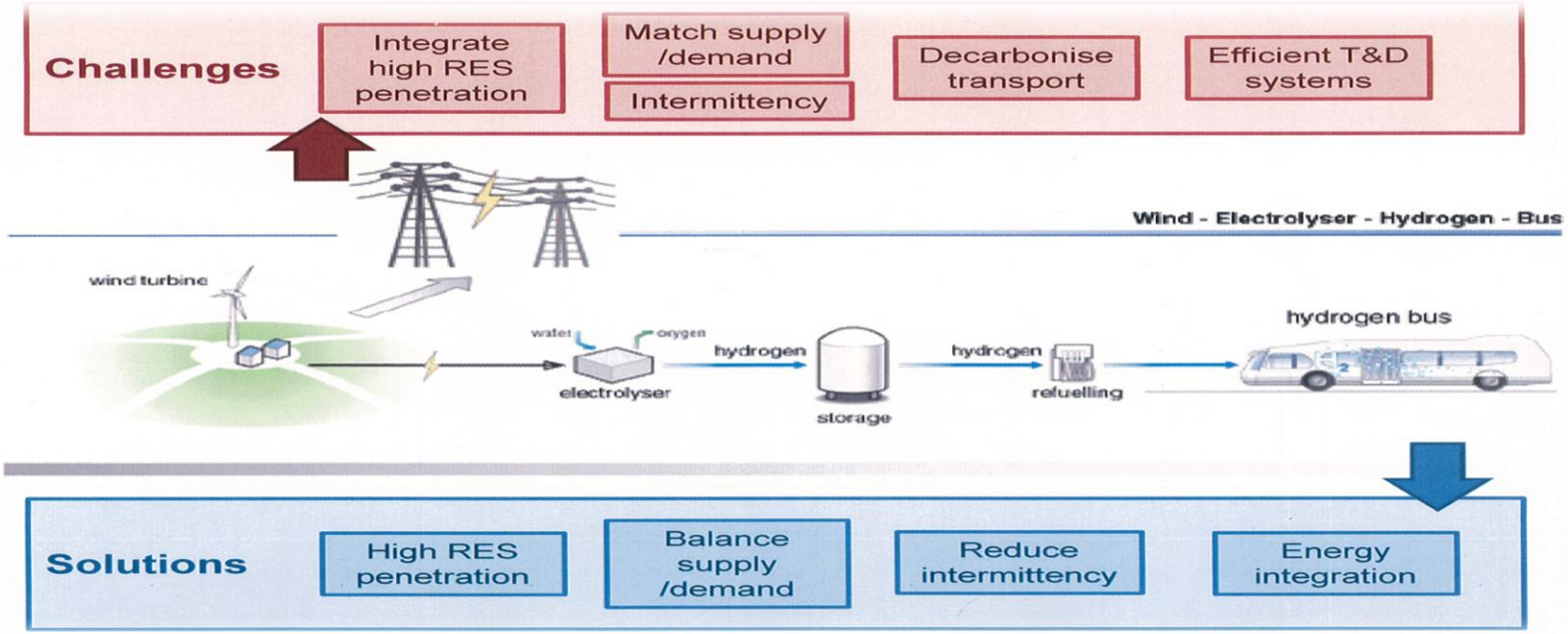
Cameron Baillie
Senior Project Officer
Aberdeen City Council

H2 Aberdeen

- **Cement the city as a leader in the emerging hydrogen and fuel cells sector**
- **Outlines actions required over the next 10 years**
  a. Opportunities to diversify activities
  b. Develop the supply chain
  c. Develop supporting infrastructure
  d. Deploy first generation vehicles
  e. Support Aberdeen City as early adopter after London



Our Energy/Transport Challenge



Credit Norman Adams, Aberdeen City Council

Aberdeen Hydrogen Bus Project

- £21 million demonstration project
- Ten hydrogen fuel cell buses – largest fleet in Europe
- Hydrogen production & re-fuelling station
- Dedicated bus maintenance facility
- Use hydrogen storage as a means of managing electrical grid constraints
- Operation of buses in a commercial environment

Project Partners & Funders

H2 Aberdeen

FCH
FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

HIGHVLOCITY

HyTransit

ABERDEEN
CITY COUNCIL

Stagecoach

Innovate UK
Technology Strategy Board

First

BOC
A Member of The Linde Group

Scottish and Southern Energy
Power Distribution

VANHOOL

The Scottish Government

TRANSPORT SCOTLAND
The Scottish Government

Scottish Enterprise

Scotland Gas Networks
A Scotia Gas Networks Company

Facts & Figures

- **Hydrogen Buses**
  - 50kg of hydrogen
  - 260 miles
- **Refuelling Station**
  - 360kg of hydrogen per day
  - 420kgs of storage
  - Refuel a bus in less than 10minutes

ABERDEEN INVESTLIVEVISIT

H2 Aberdeen


Stagecoach
Union Square X17
SY64 BPZ


BOC
Powered by
Stagecoach
SY64 DMU
GB


Powered by Hydrogen
H2
Aberdeen

Refuelling Station

H2 Aberdeen

Maintenance Facility

Operation

Buses

- 2 years of operation
- >75 % availability
- 6 days per week
- > 1.8 million KM
- > 1.5 million passengers

Refuelling Station

- > 150,000 kg dispensed
- 3.7 Million KWH used to generate hydrogen
- 99.99% station availability
- 5-7 min per filling

Lessons Learned

- Vehicles need to align with infrastructure construction
- Roles and responsibilities need to be clearly assigned in contracts
- Manage expectations for new technology, especially in a commercial environment
- Clear and regular communication with regulatory bodies, stakeholders, end users

Longer Term Actions

Further Vehicle Deployments

- Bus fleet expansion/continue existing bus operations beyond 2018
- Car Club/ Fleet Expansion

Expand Refuelling - Infrastructure/Expansion

- 2nd refuelling station – ACHES – Cove – now operational
- Kittybrewster Expansion - Duel pressure (350 & 700 bar) dispensing - 2017

Aberdeen City Hydrogen Energy Storage (ACHES)

Aberdeen City Hydrogen Energy Storage (ACHES)

- **Launched February 2017**
- **Aberdeen's 2nd Hydrogen Refuelling Station**
    a. 130kg of hydrogen per day
    b. 50kgs of storage
    c. Cooling to enable fast fuelling of cars and vans

Aberdeen City Hydrogen Energy Storage (ACHES)

- **Operational model**
- **Health & safety**
- **Learning facility**
- **Engagement:**
  a. Local community
  b. Emergency Services

H2 Aberdeen

27th February 2017

Toyota Mirai and Aberdeen City Hydrogen Energy Storage (ACHES) Launch Event

TOYOTA

ABERDEEN CITY COUNCIL

HYDROGENICS
SHIFT POWER | ENERGIZE YOUR WORLD

TRANSPORT SCOTLAND

Go Ultra Low

EUROPE & SCOTLAND
European Regional Development Fund
Investing in your Future

nestrans

Hydrogen Toyota Mirai

10 Toyota Mirais in Aberdeen from Feb 17

a. 5 used by NHS

b. 3 used by Co-Wheels Car Club

c. 1 used by Scottish Environmental Protection Agency (SEPA)

d. 1 used by Aberdeen City Council

Hydrogen Toyota Mirai

- Range - > 300 miles (500km)
- Combined fuel economy – 66mpg
- Most fuel efficient hydrogen vehicle
- Largest range in market

H2 Aberdeen - What Next:

FC Train Project

To produce an accredited college training course for fuel cell technicians.

Hytrec 2 Project

Supply chain, hydrogen standards and vehicle demonstrations & renewable energy production

HyTime

Demonstration of 3 hydrogen waste/refuse vehicles

JIVE

10 more hydrogen buses!

H2 Aberdeen

ABERDEEN CITY COUNCIL

H2Aberdeen@aberdeencity.gov.uk

ABERDEEN INVESTLIVEVISIT

Dr Romain Viguier
SCCS

Enabling Net-Zero CO_2 Emissions

Dr Romain Viguier

Research & Business Development Executive

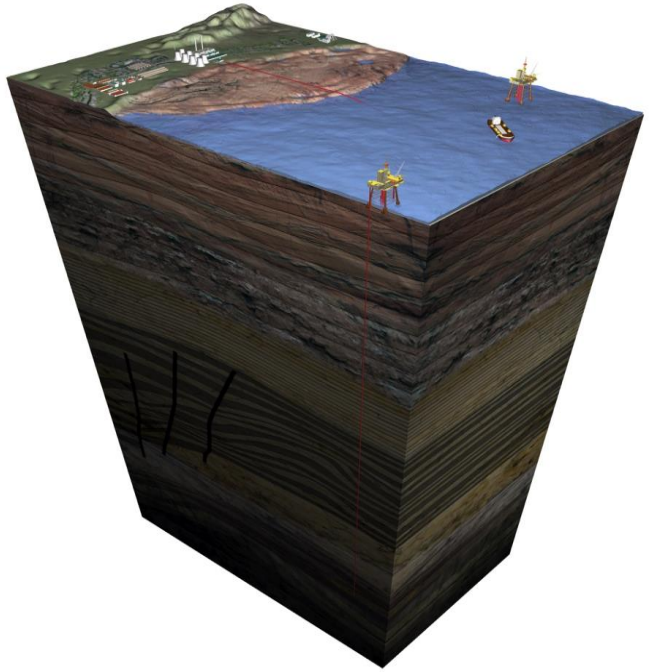
The SCCS partnership

- The UK's largest group of researchers working across full CCS chain
- Joint industry projects and EU/global collaborations
- Policy input at Scotland, UK and EU level
- Knowledge exchange and public engagement
- Education and training

SCCS

What is CCS?

- CAPTURE of carbon dioxide from point sources, compression.
- TRANSPORT
- Geological STORAGE



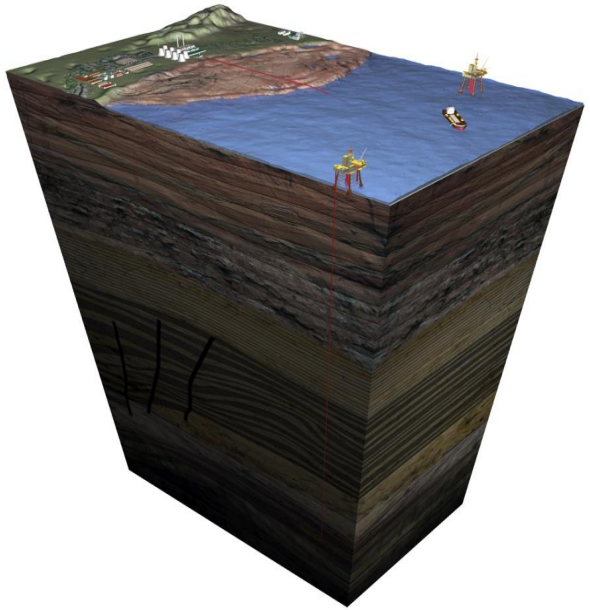
SCCS

CCS research for RES?

- STORAGE of hydrogen storage geological formation

- CONVERSION of CO_2 with H_2

- Bioenergy with CCS



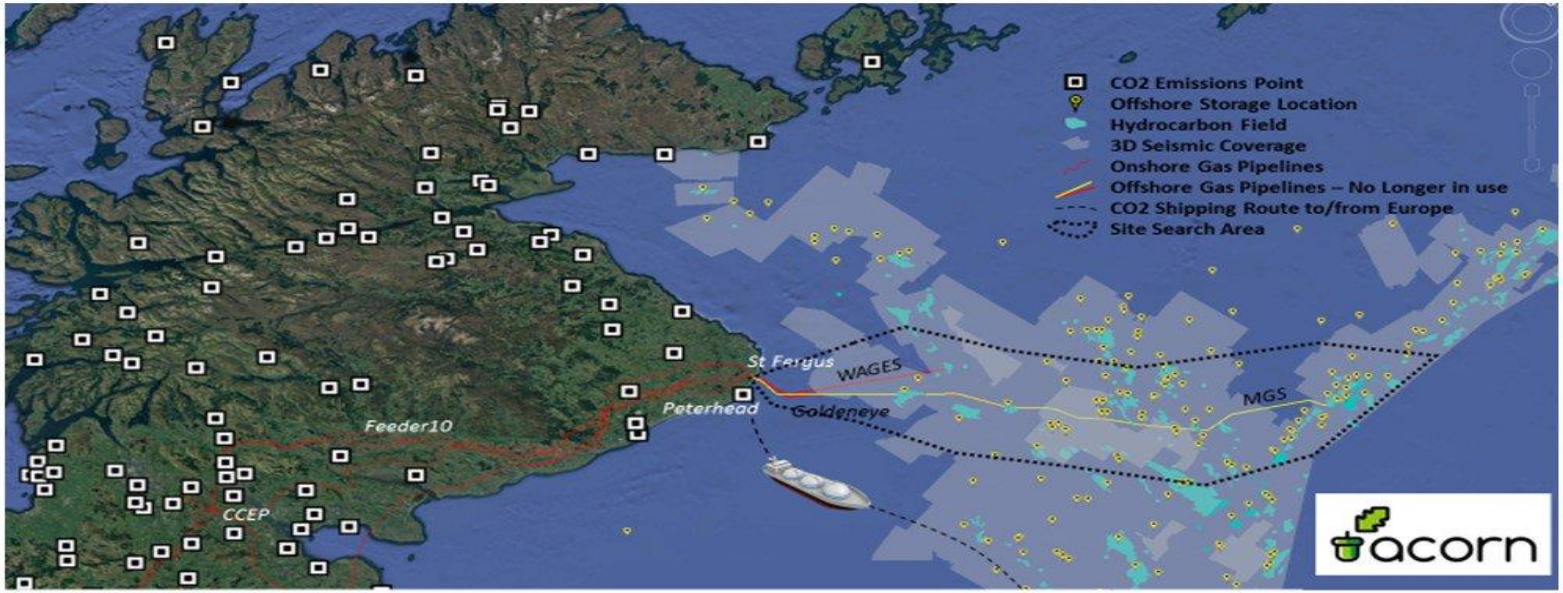
SCCS

20 years of offshore CCS operation at Sleipner, Norway

SCCS

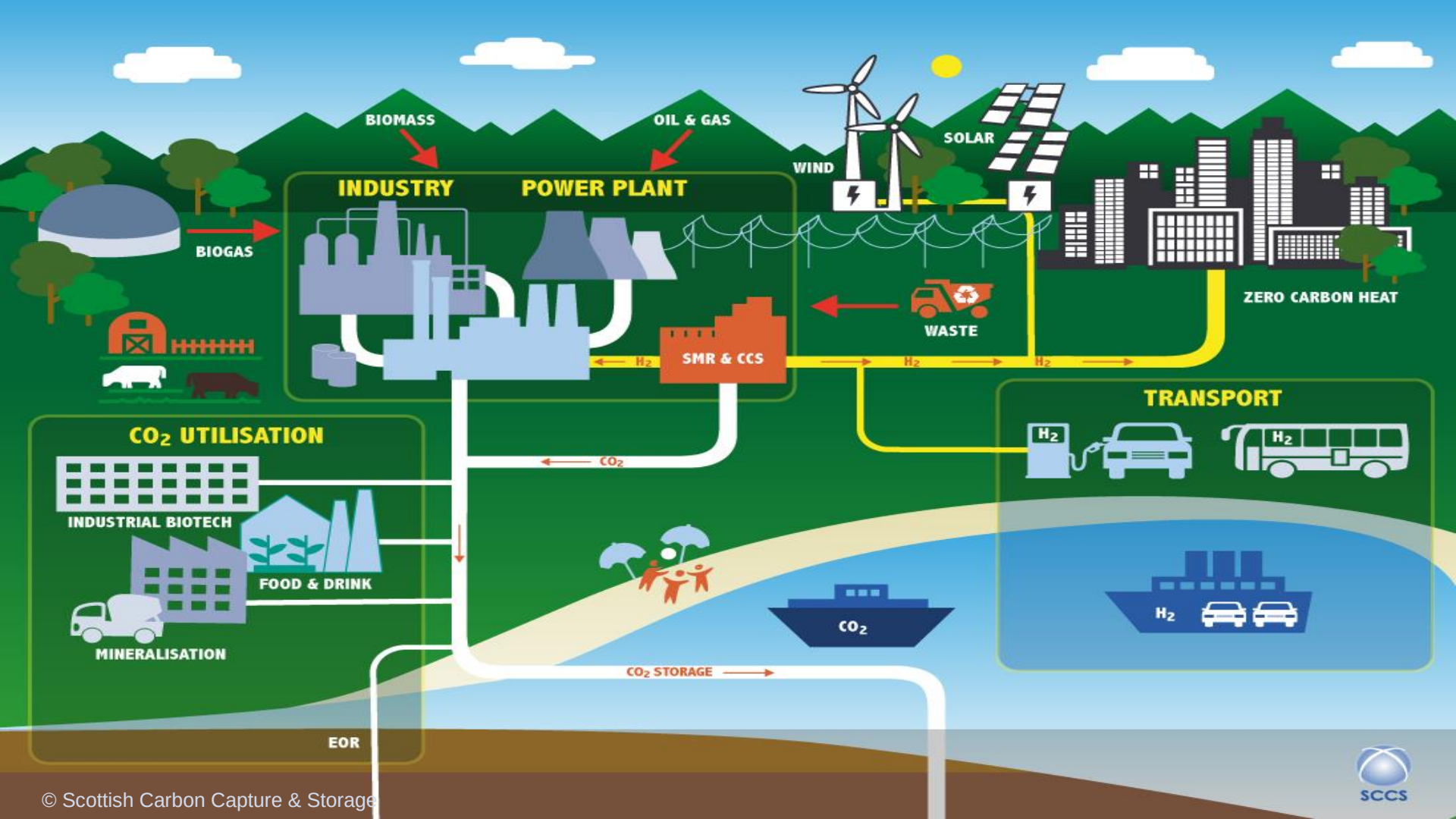
Full-chain CCS has been operating safely since the 1990s and new projects are coming on stream every year. Explore the world of CCS with our Global CCS Map: **www.sccs.org.uk/map**

Acorn CCS Project



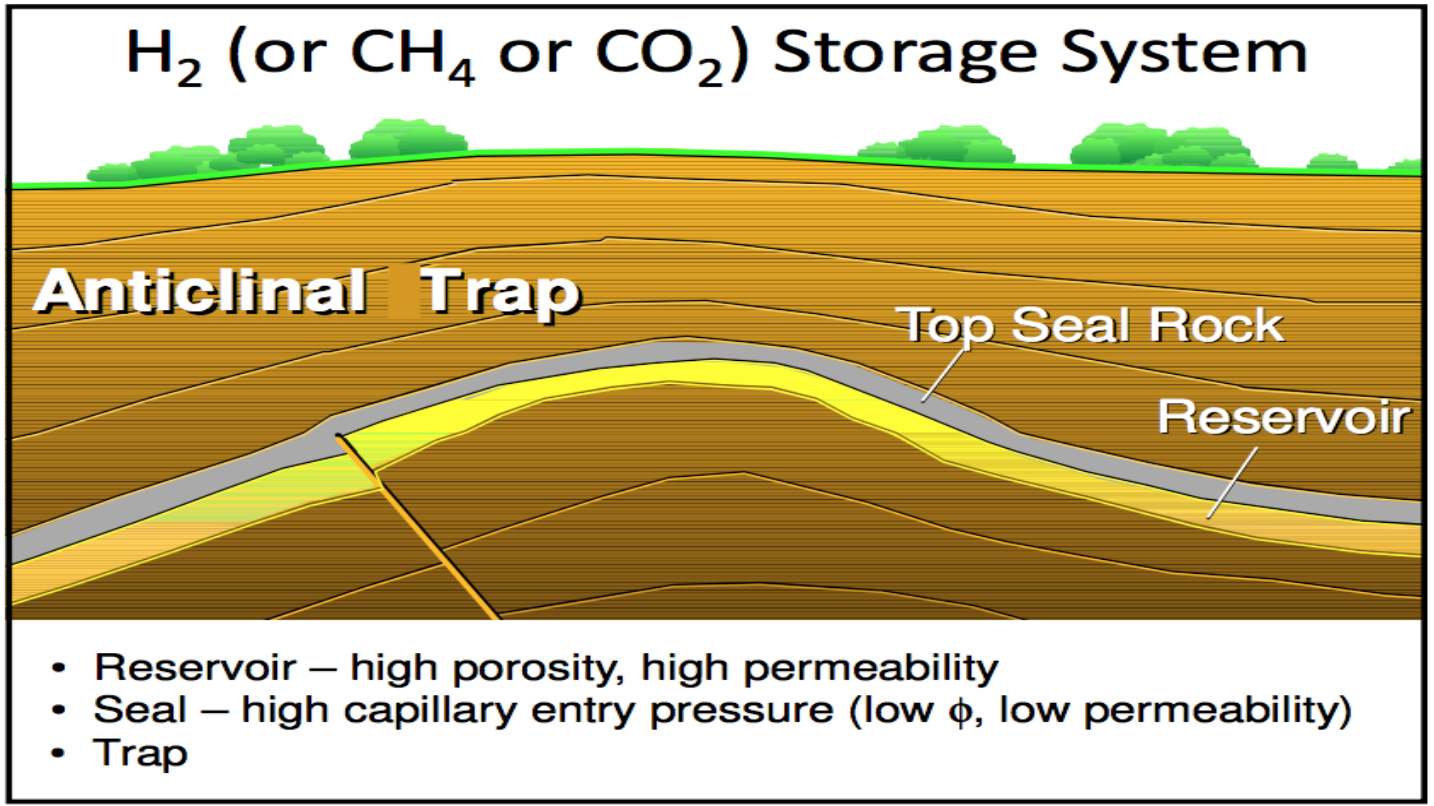
SCCS

acorn

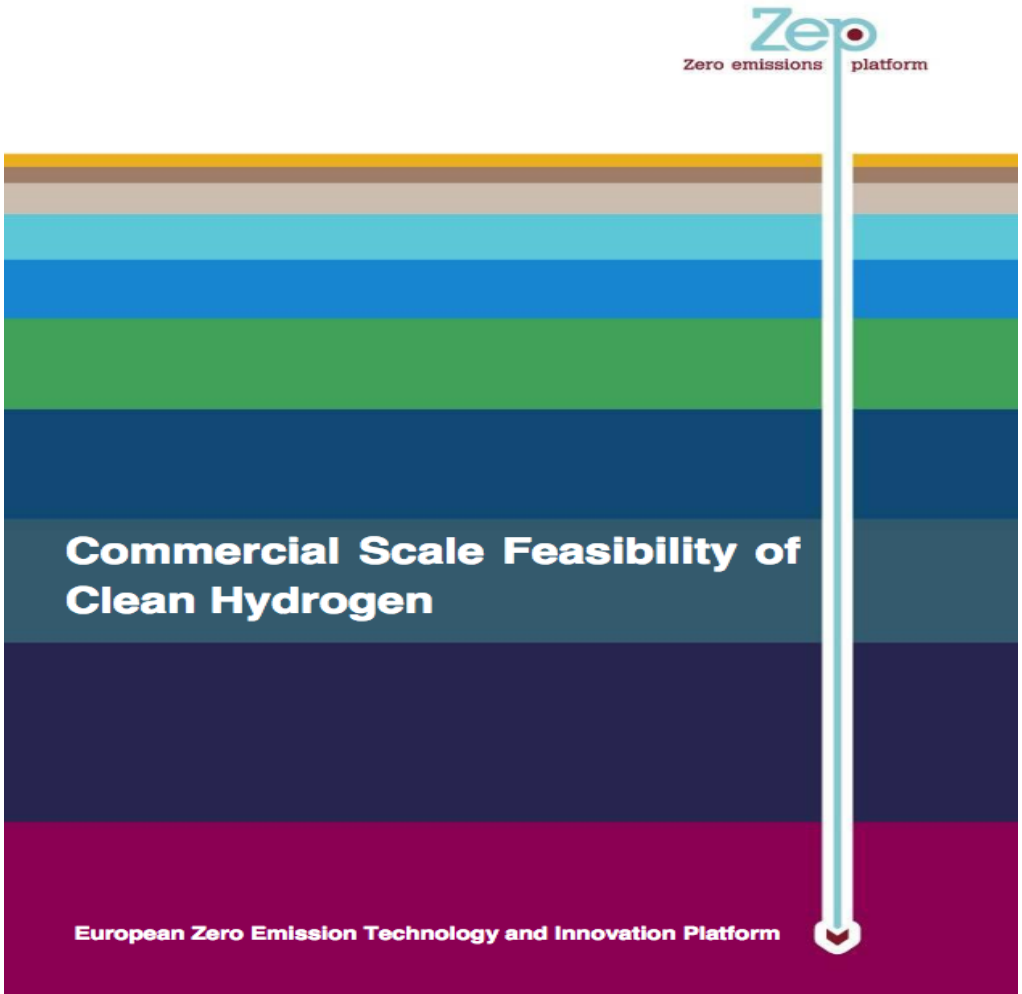


SCCS

H_2 storage in geological formations



Adrian Amid, Dimitri Mignard, Mark Wilkinson,, 2016, International journal of hydrogen energy, 41, 12, 5549-5558.



Recommendations:

- Policies and support mechanisms
- New projects
- Local clusters
- Role clean Hydrogen
- R&D
- CO2 transport and storage infrastructure

SCCS

climate change — Scotland's centre of expertise connecting climate change research and policy

http://www.climatexchange.org.uk

Hydrogen with CCS for decarbonised heat in the Scottish context

Rūta Karolytė, University of Edinburgh

August 2017

ClimateXChange commissioned this short review[1] as a summary of current knowledge about the potential for deploying hydrogen as a heat vector through repurposing of the natural gas grid. This report reviews recent literature

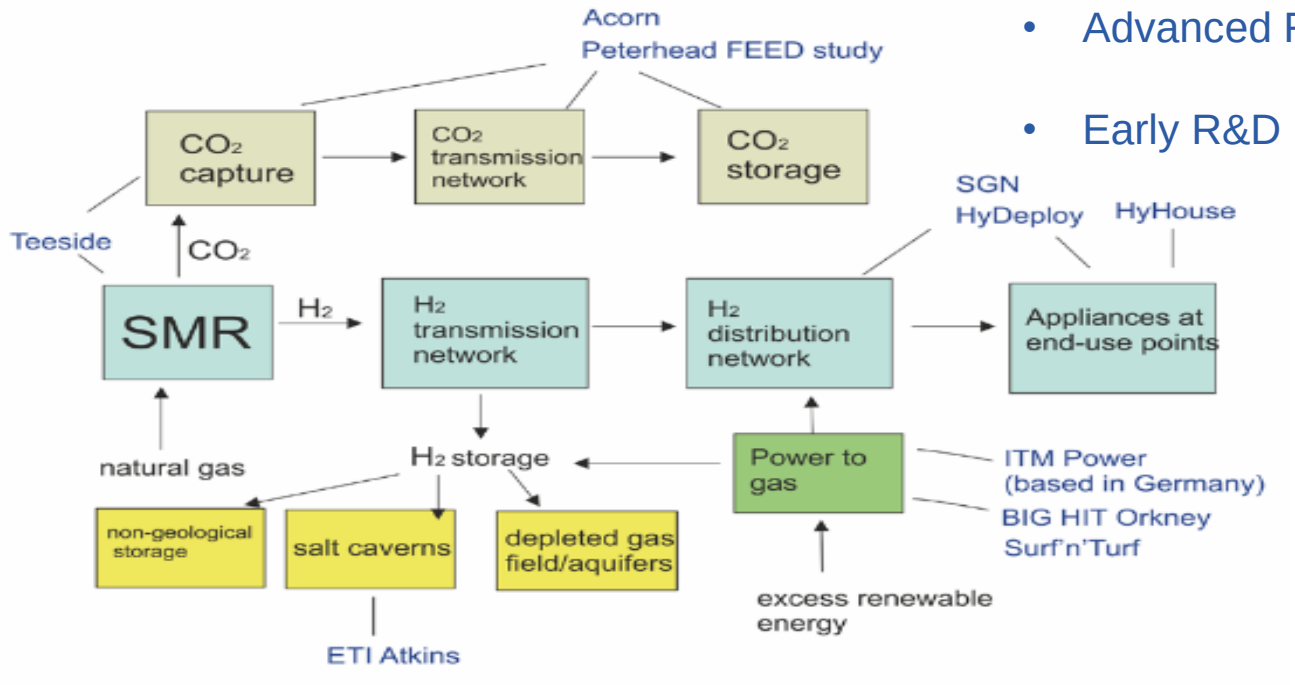


Figure 1. The Hydrogen for Heat chain. Projects currently active in the UK marked in blue, indicating their focus.

Summary of current progress:

- A Mature Technology
- Advanced R&D
- Early R&D

Projects calls - H2020 18-20

- CE-SC3-NZE-2-2018: Conversion of captured CO_2 (with renewable H_2)
- LC-SC3-NZE-3-2018: Strategic planning for CCUS development
- LC-CLA-02-2019: Negative emissions and land-use based mitigation assessment

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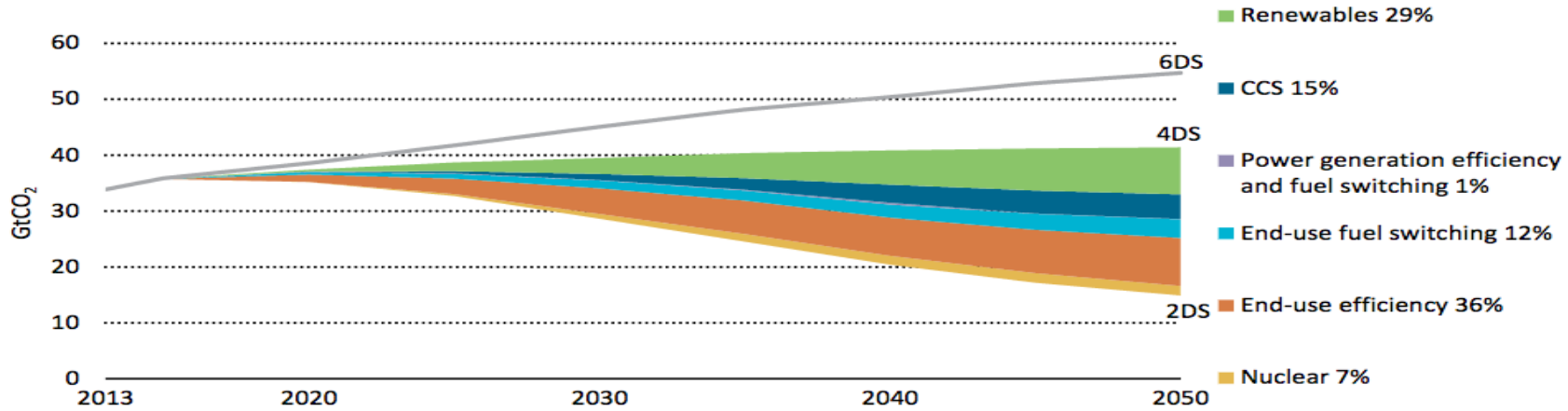
Question & Answer

Why do CCS?



Source: IEA (2016b), *Energy Technology Perspectives 2016*.

Global decarbonisation scenarios rely on negative emissions

SCCS

Carbon reduction without CCS?

- Estimated to be twice as expensive to decarbonise without CCS
- CCS is only route to decarbonising crucial heavy industries
- CCS (via hydrogen production) can also decarbonise heat at city scale and transport
- Biomass with CCS could actually create negative emissions

SCCS

Q & A

SR Introduction to Hydrogen & Opportunities for Renewables CPD Seminar

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