HEC Hydrogen Sessions

Hydrogen-to-the-Home and 100% Hydrogen Pipelines

May 21, 2021, 12:00 noon

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Agenda

- Hydrogen Energy Center
- Velerity
- Update – Hydrogen News
- Hydrogen Pipeline Industry Drivers
- Hydrogen Pipelines
- Hydrogen-to-the-Home
- Question and Answer

Hydrogen Energy Center

HEC is a professional association focused on accelerating the hydrogen as an enabling solution for renewable energy

HEC provides public forums, conducts research and implements projects focused on accelerating the clean energy future

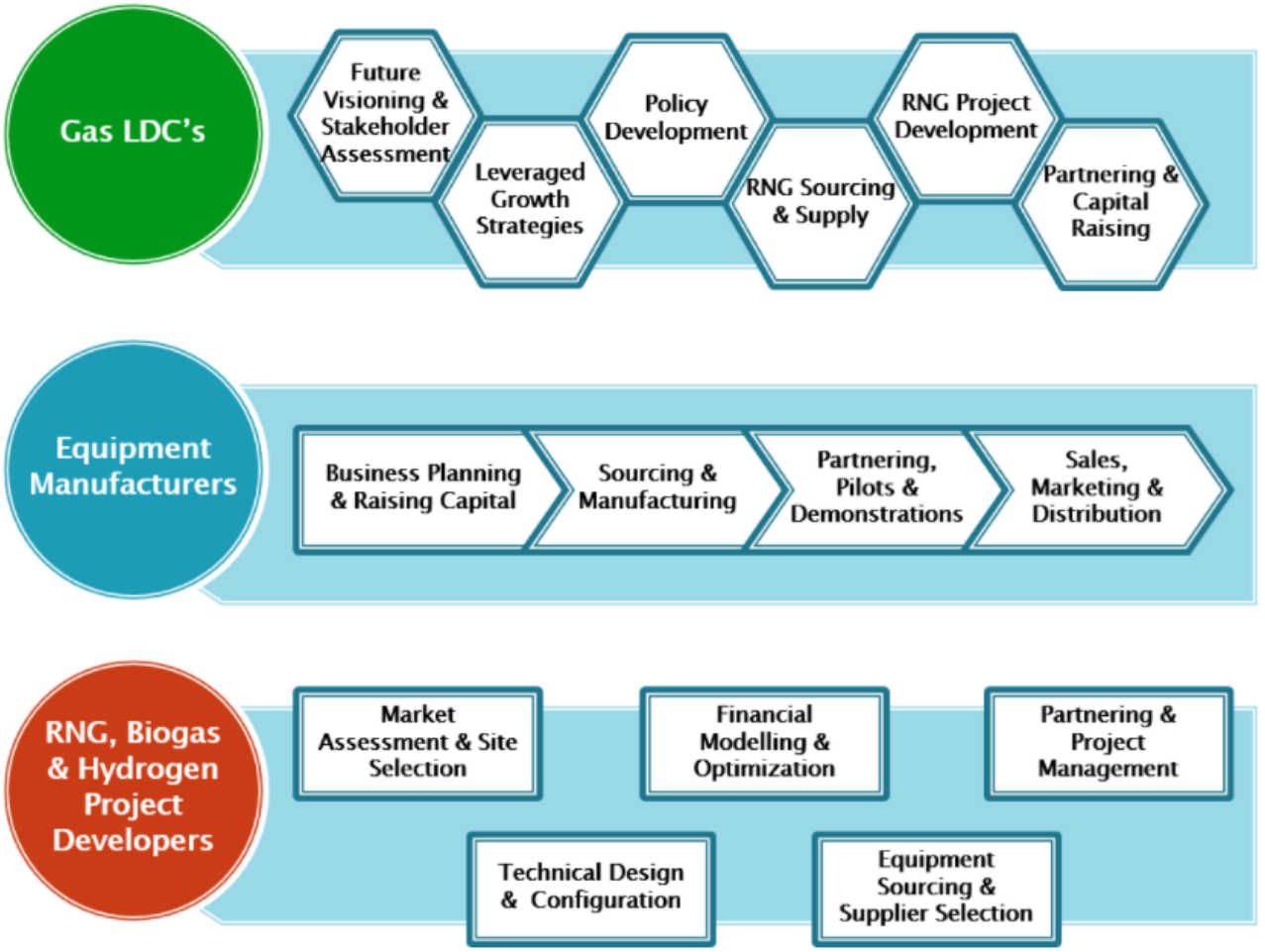
Consider supporting this important effort by becoming a member:

- Influence the course of renewable hydrogen energy technology and policy.
- Be a part of projects that really build hydrogen solutions.
- Have full access to white papers, technical reports, and meeting minutes from our projects and from other organizations.
- Immerse yourself in the hydrogen "goings-on" by connecting with developments & networking with people who are collectively driving the hydrogen "bus".

Upcoming Hydrogen Sessions

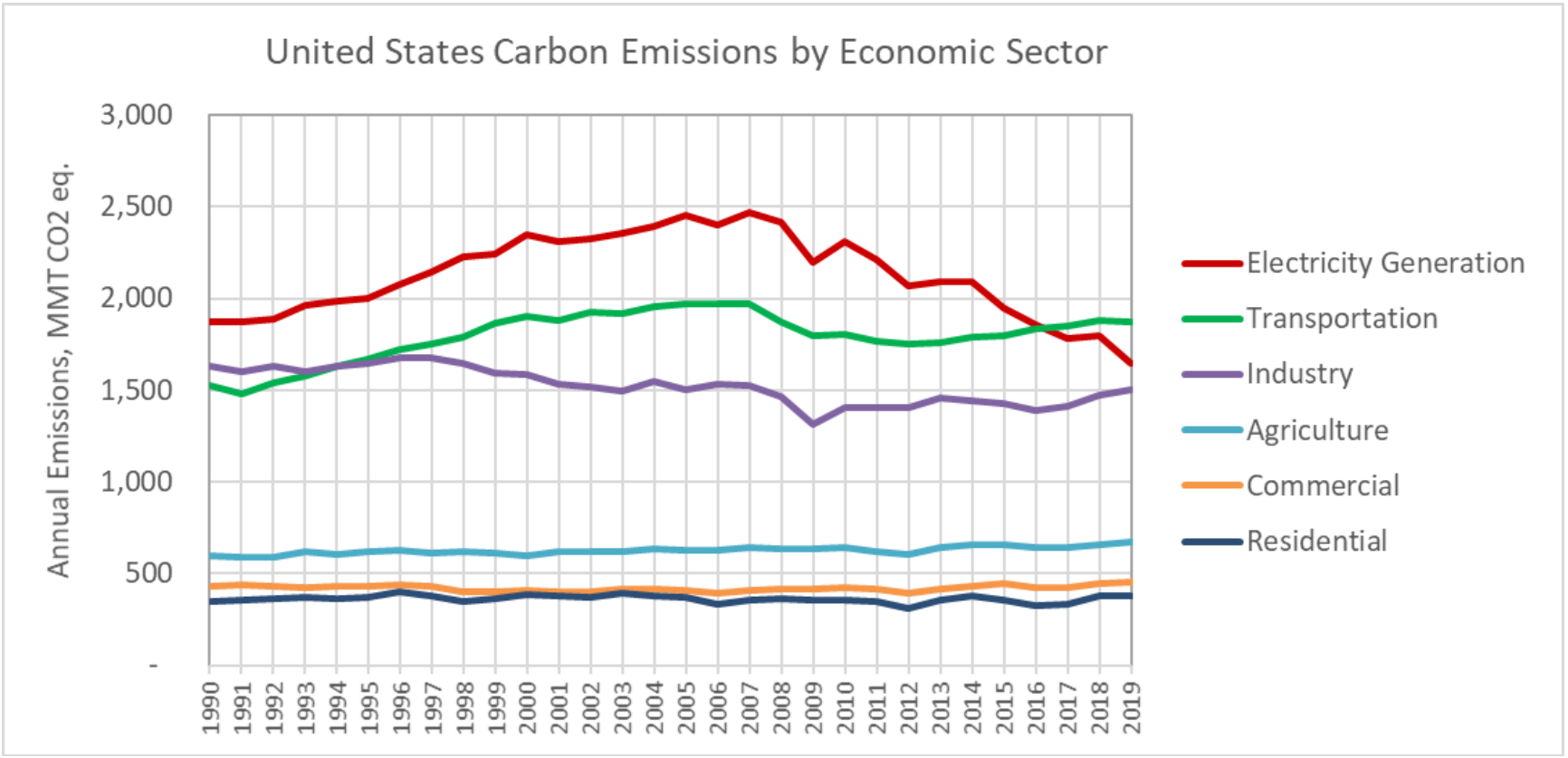
- May 28, 2021 Power Generation with Hydrogen
- June 4, 2021 Building a Global Trade in Hydrogen
- June 11, 2021 Electrolysis and Water Splitting
- June 18, 2021 Hydrogen Production with Carbon Separation
- June 25, 2021 Wind to Hydrogen

Velerity Services



Velerity – Illustrative Clients

Tightening economy wide emissions reduction targets are driving a need to identify pathways to address heat and industrial process emssions

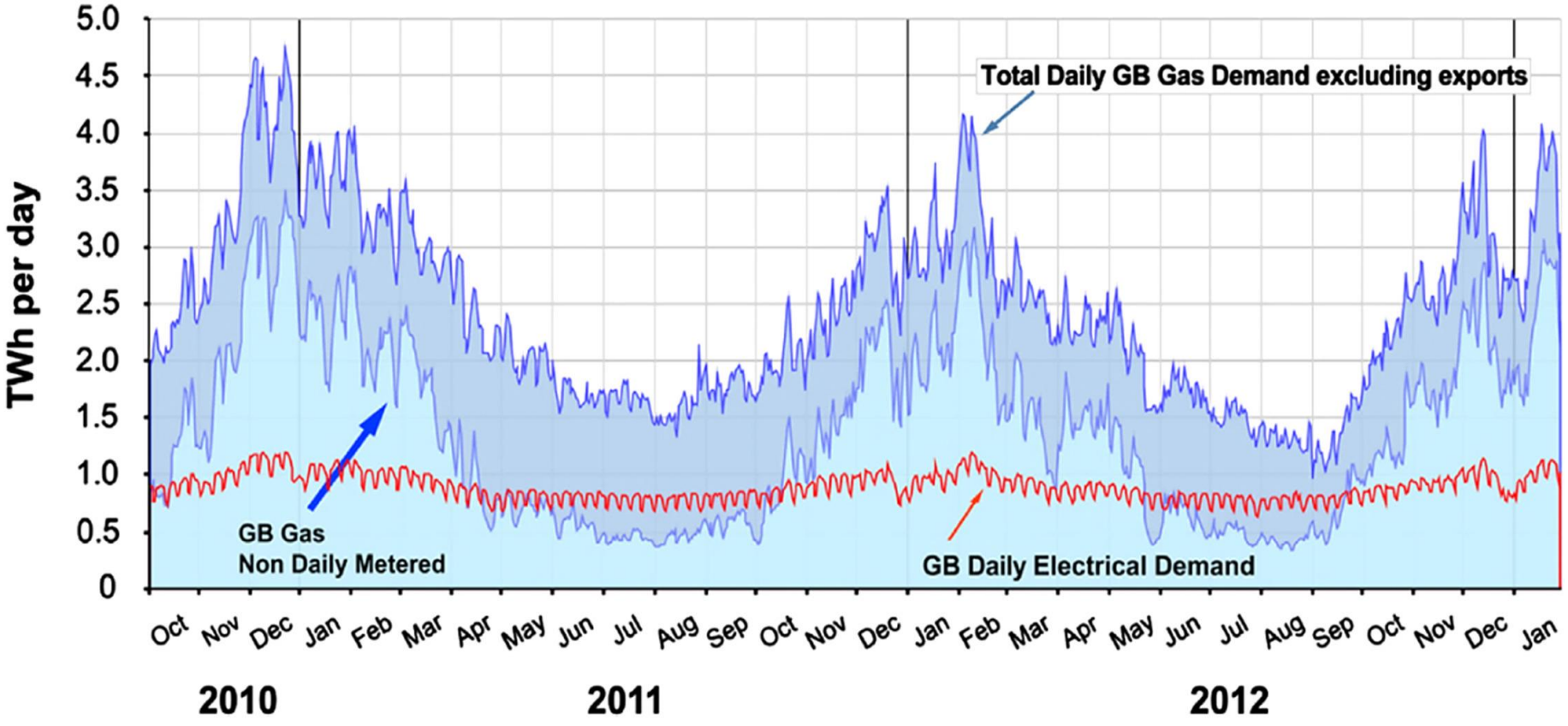


Source: Environmental Protection Agency, U.S. Greenhouse Gas Inventory Data Explorer (cfpub.epa.gov/ghgdata/inventoryexplorer/index.html)

Converting all energy related activities to the electric grid is potentially problematic, considering economic, resilience and technical perspectives

- Curtailed power could reach 25 % of all power generation
- Multi-day winter heating loads may overwhelm the electricity grid
- The cost to store long duration energy from renewable energy in lithium-ion batteries would be astronomical
- Certain industrial heat applications are not suited to electrification
- Older buildings, dense urban areas and city centers may not lend themselves to the electrification pathway
- Heavy transport vehicles, such as 18 wheeler trucks, find the heavy weight and long refueling times problematic with battery electric drivetrains

The challenge of electrifying thermal loads may create demands ahead of capacity to serve



https://www.sciencedirect.com/science/article/pii/S0301421518307249

There are a range of potential uses and applications for zero carbon hydrogen in a decarbonized society

- Long duration storage of variable renewable energy
- Decarbonizing natural gas through blending
- Converting CO2 to renewable methane
- Direct Reduction of Iron (DRI) with hydrogen for steel manufacturing
- Heavy transport including trucks, buses, trains, ships and aircraft
- Decarbonizing hydrogen for industrial feedstocks such as ammonia manufacture, methane manufacture and petroleum refining
- Providing combined heat and power in district energy systems
- Replacing natural gas in pipelines for a range of applications including providing heat to consumers and businesses

The United Kingdom has been implementing policies & initiatives to reduce carbon emissions in the residential heating sector

- United Kingdom has set aggressive carbon reduction targets
  - Net zero by 2050
  - 78% reduction by 2035
- 85% of homes in the United Kingdom heat with natural gas ~ 20 million homes
- Gas and oil furnaces will not be allowed in new homes from 2025
- Currently 1.7 million oil and gas furnaces are installed every year
- The government has an ambition to reach 600,000 heat pump installs per year
- Estimated peak domestic heat of 170 GW
- Average estimated heat load of 50 GW

Many analyses including complex energy system modelling have been undertaken in the past ten years to identify carbon reduction pathways

- **Clean Growth – Transforming Heating**
  - Heat Networks Investment Project
    - Expand Investment
    - Continued Growth
  - Renewable Heat Incentive
    - Support lower carbon heating solutions
    - Heat pumps, biomass boilers, solar water heaters, biomethane
  - Long Term Policy Framework for Heat
    - Ensure financial support for consumers
    - Enable cost effective transition across every industry and infrastructure
    - Contend with the uncertainties arising from the multi-decadal heat decarbonization timetable
      - Sources of chance: new technologies, new solutions, economy wide developments
      - Keep the process of setting priorities dynamic and flexible
    - Make sure that information is available to consumers to facilitate understanding and decision making

The studies recognize inherent uncertainties and recommend hybrid approaches and multiple pathways to manage decision risk

- **Analysis of Alternative UK Heat Decarbonization Pathways**
  - Compare the whole system costs of alternative heat decarbonization scenarios
  - Understand the implications of alternative heat decarbonization pathways on electric and gas networks
  - Analyze the impact of uncertainties in technologies and costs
- **Next Steps for UK Heat Policy**
  - Three central pathways:
    - Greening the gas supply by shifting to low carbon hydrogen
    - Electrification of heat supported by low carbon gas
    - Potential hybrid solutions with bulk of heat requirements satisfied with electric heat and supply heating peaks with green gas

Hybrid hydrogen electric solutions delivered the lowest cost on an annual cost basis

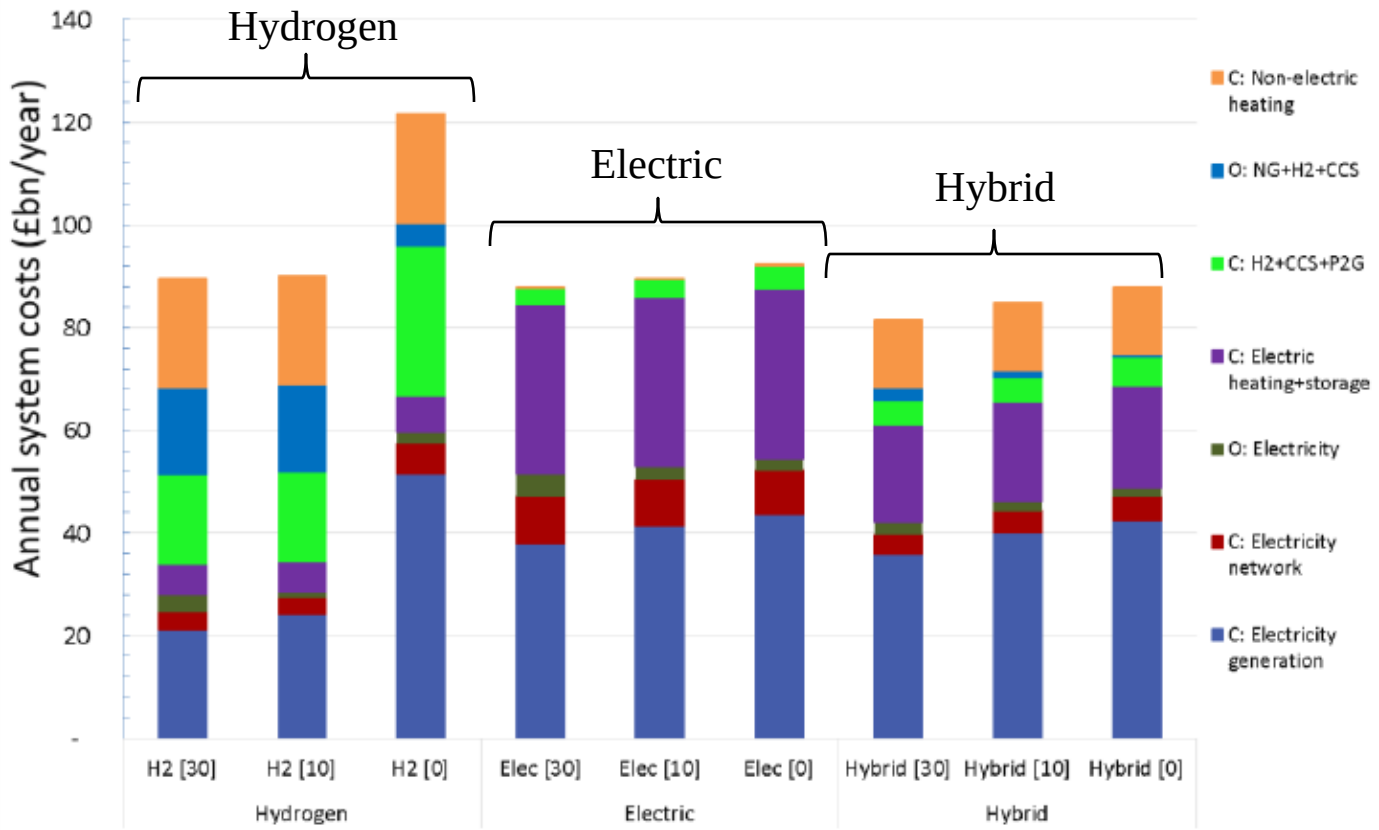


Figure E. 2 Annual system cost of core decarbonisation pathways

A National Grid heat pathways study found the hydrogen pathway delivered the lowest cost

Full system costing study [UK]: all pathways more expensive than status quo however heating cost seen to decline as % GDP regardless; lowest cost pathway uncertain as of yet

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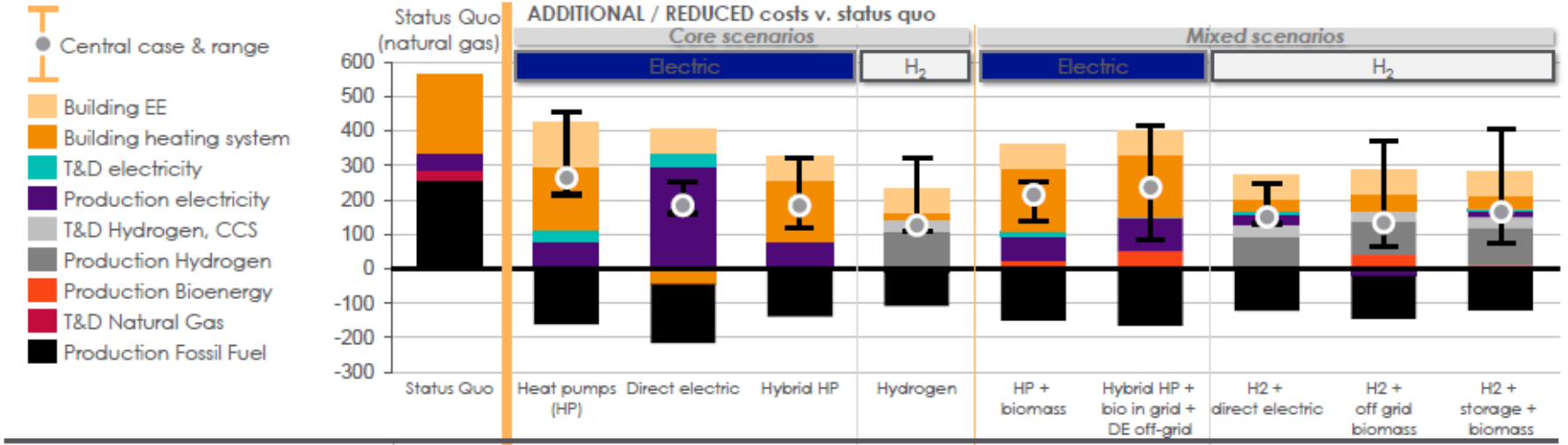
Cost comparison of different prospective UK heat solutions
£B, cumulative discounted system costs to 2050



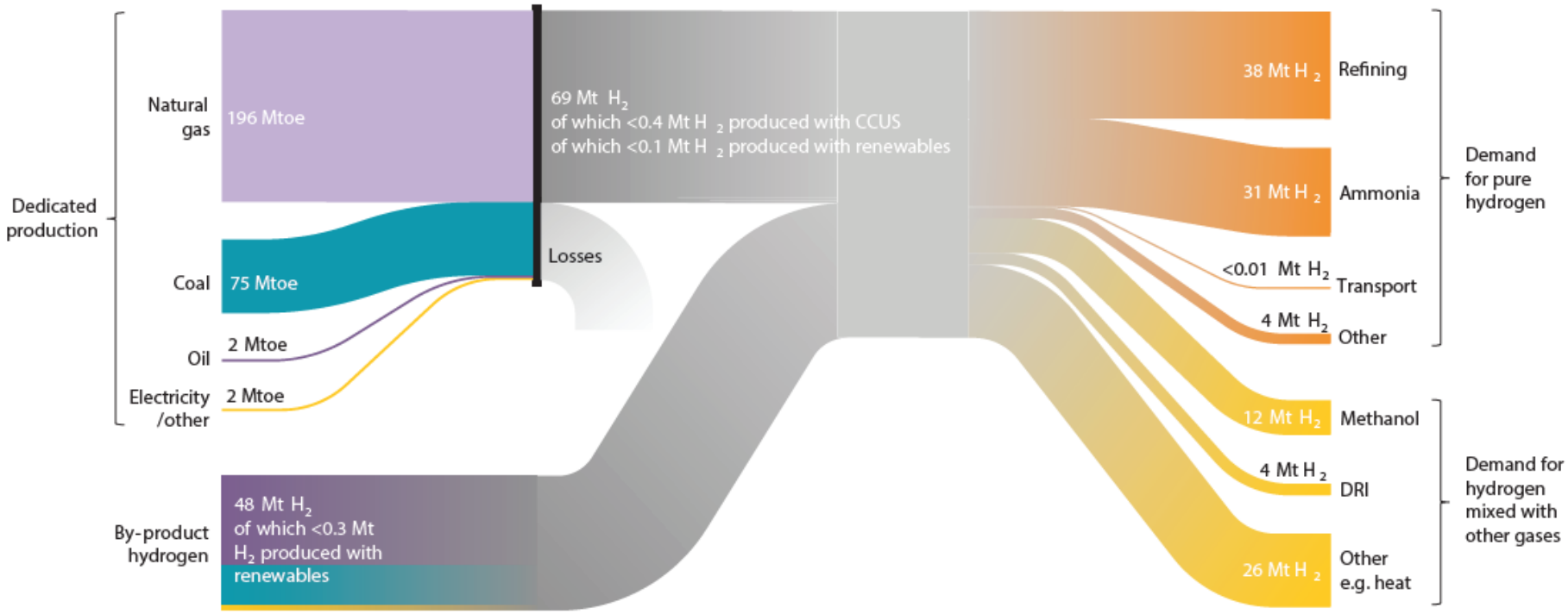
Heat as % GDP[1] (1.2% in 2015)			0.9%	0.9%	0.8%	0.9%					
Annual GHG emissions in 2050 ($MtCO_2e$)[4]		~100	5-10	10-15	20-25	20-25	5-10	10-15	10-15	10-15	0-(5)
Major uncertainty drivers	EE retrofit requirement		X				X	X			
	HP / electric heater unit cost		X	X	X		X	X			
	Grid reinforcement cost		X	X			X				
	Fuel cost: electricity			X							
	In-building retrofit cost					X			X	X	X
	Production: hydrogen					X			X	X	X
	CCS; H_2 safety & consumer[2]					X			X	X	X

National Grid

7

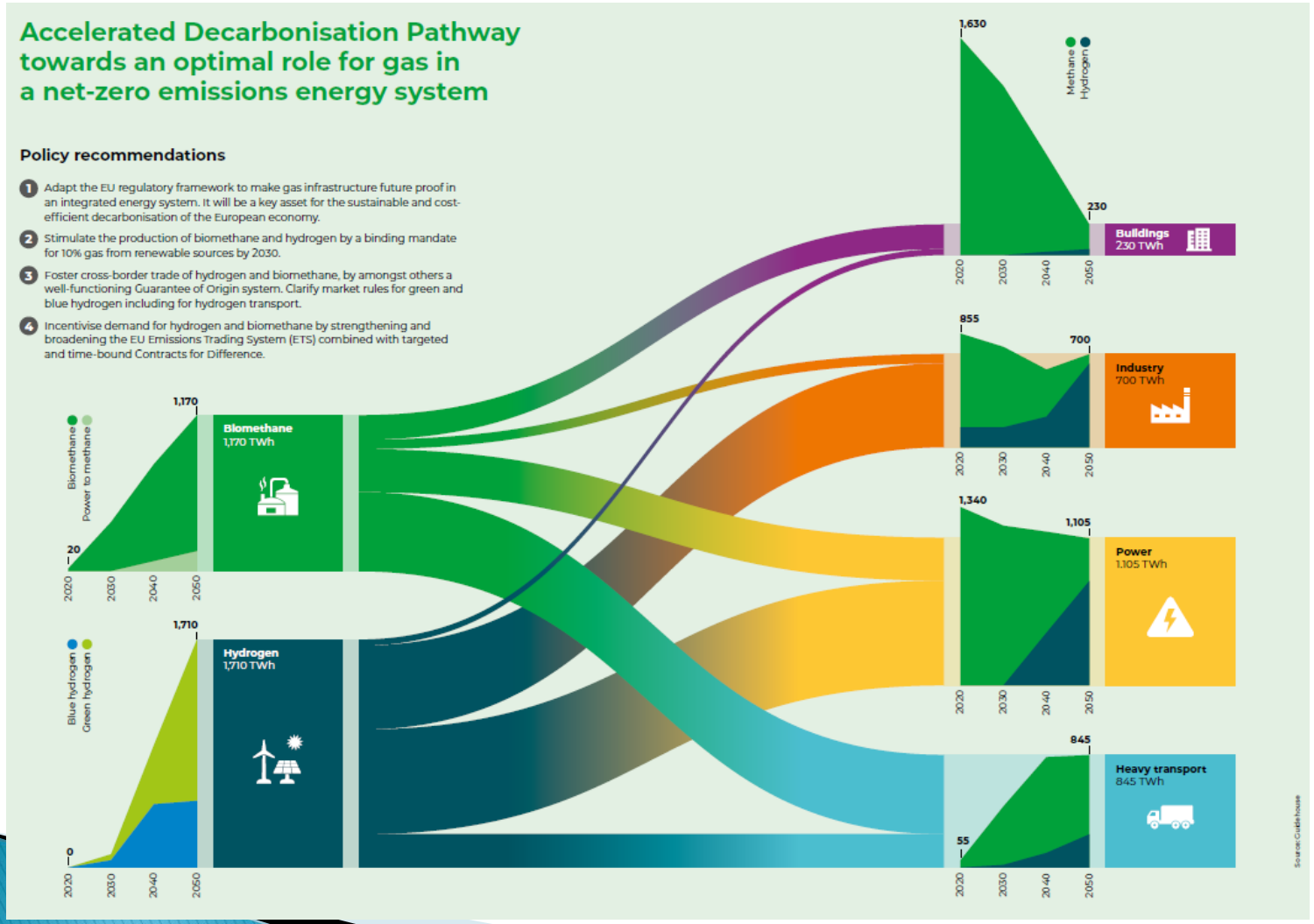
[1] cumulative cost to 2050 as % of GDP to 2050, NOT DISCOUNTED; [2] includes not just cost uncertainties but also readiness uncertainties; [3] central case assumes consumer behaviour supports a diversity factor of 2.4 v. Worst case assumes diversity factor of 1. [4] does not factor indirect GHG emissions e.g., upstream methane leaks, flaring, venting
SOURCES: Element Energy & E4tech for UK National Infrastructure Commission (2018)

The $120 billion, 115 million tonne hydrogen market is largely grey, driven by large volume petroleum refining and ammonia manufacturing

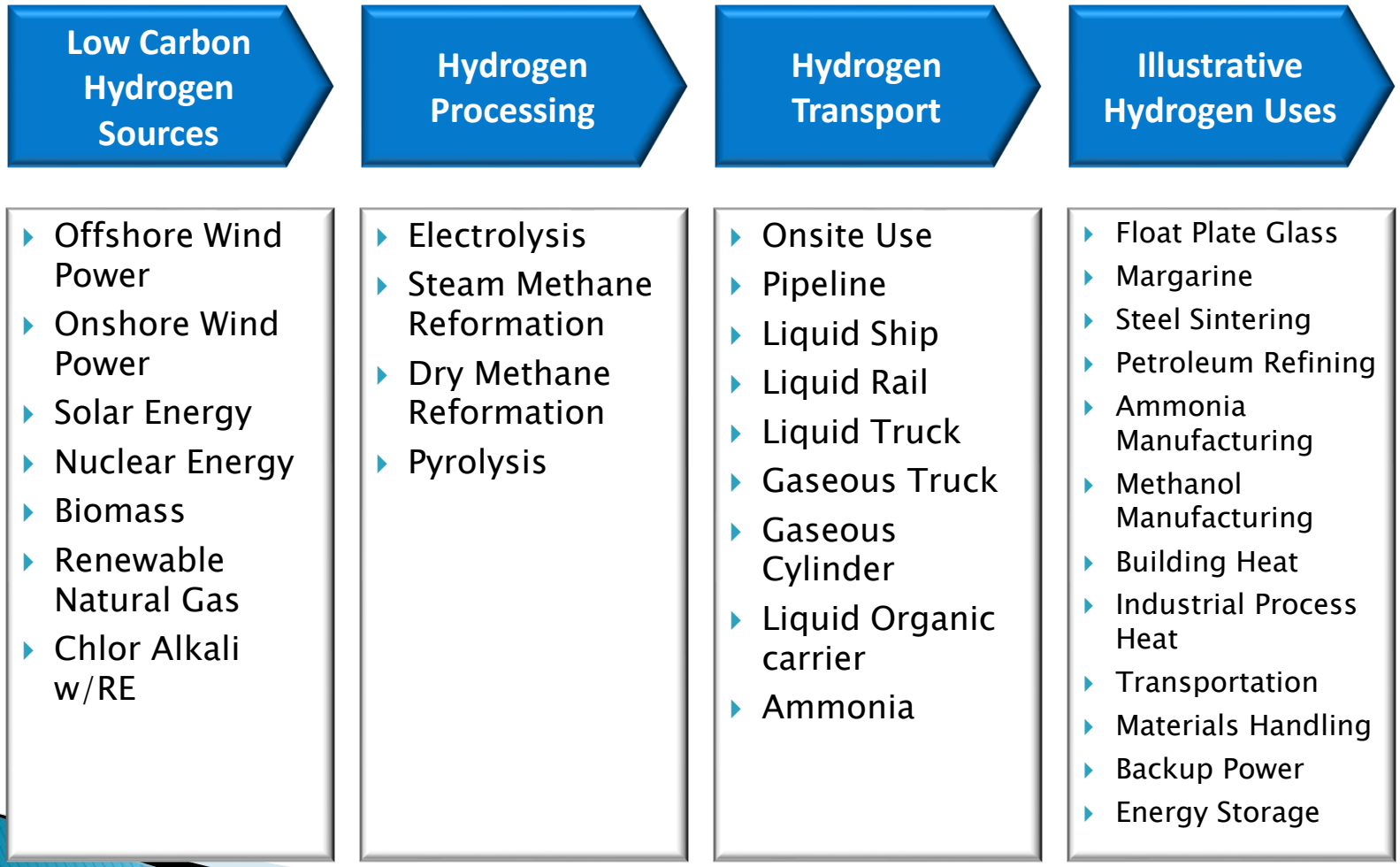


Source: IEA

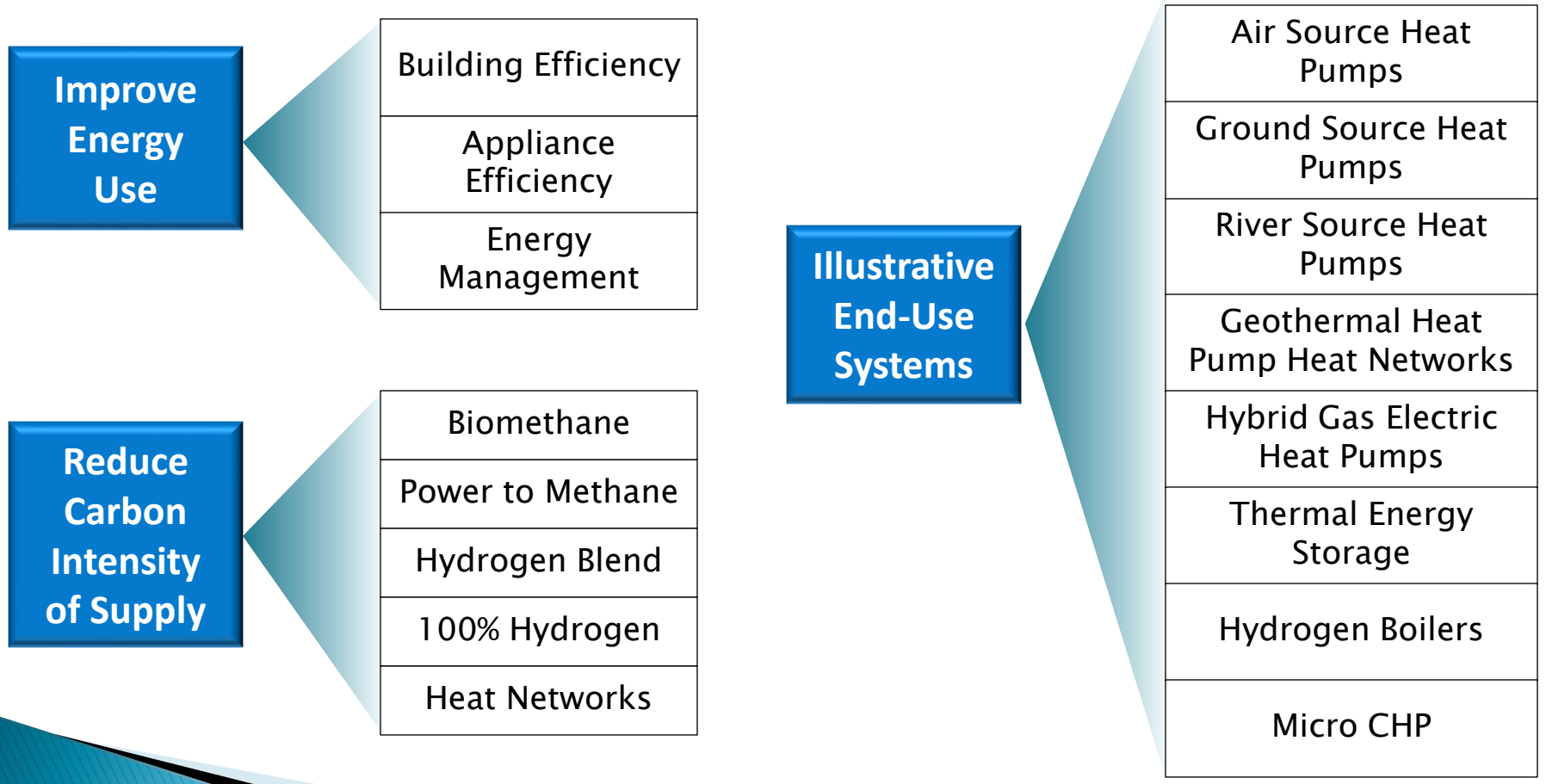
Hydrogen's future will be intertwined with expanding renewable gas, and decarbonizing transportation, building heat and industrial and petrochemical processes



The low carbon hydrogen value chain is extensive, considering a wide range of sources, processing approaches, distribution means and use cases

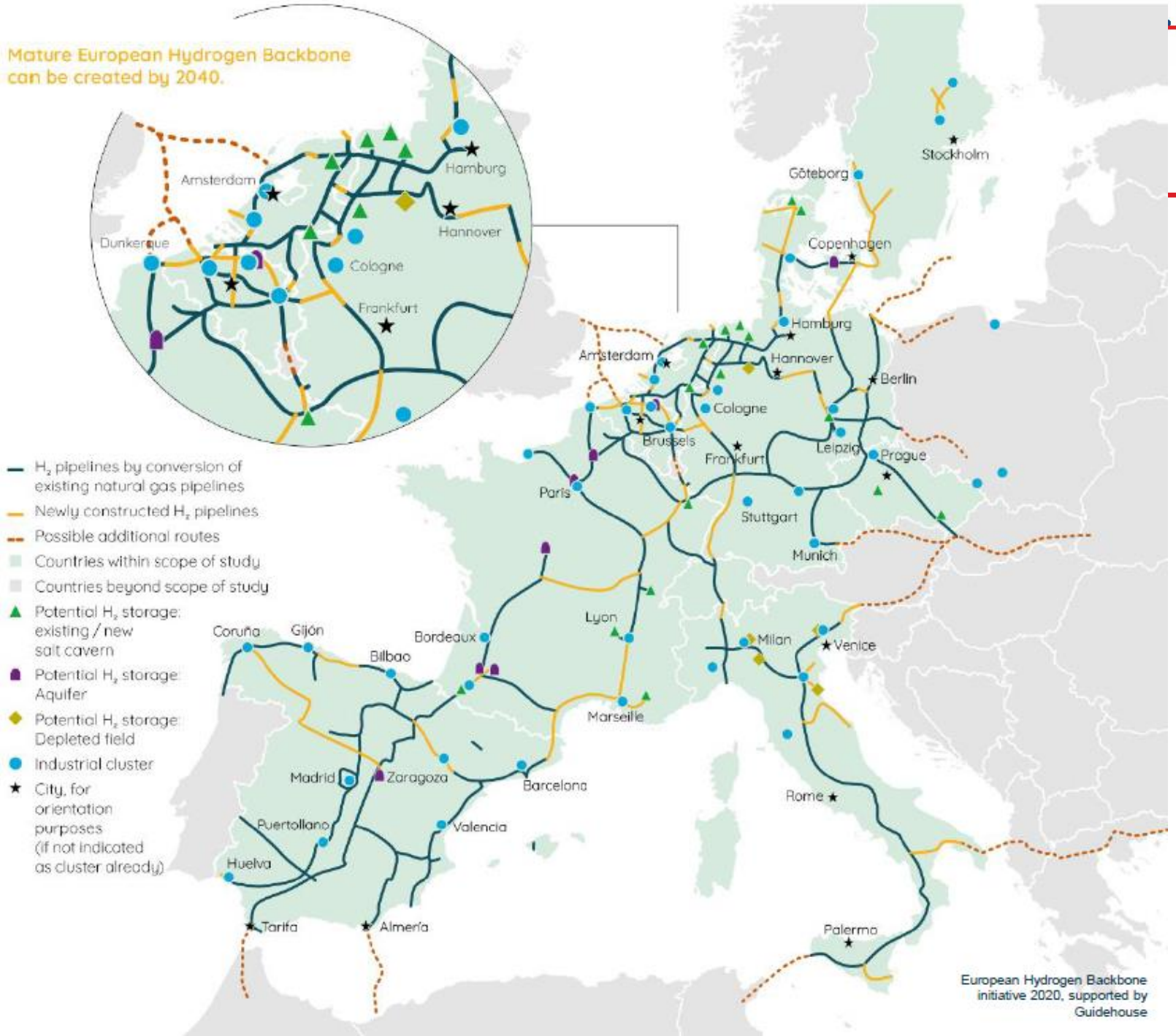


Multiple approaches are being implemented to reduce the carbon emissions associated with heating buildings



EHB – The European Hydrogen Backbone
A 24,614 mile hydrogen pipeline network in 21 European countries

- 12 gas transmission system operators (TSOs) from 11 European countries
- A vision for 24,614 mile hydrogen pipeline network in 21 countries
- Two-thirds of the network is based on repurposed natural gas pipelines


Mature European Hydrogen Backbone can be created by 2040.
Amsterdam
Hamburg
Hannover
Dunkerque
Cologne
Frankfurt
Stockholm
Göteborg
Copenhagen
Hamburg
Amsterdam
Hannover
Berlin
Cologne
Brussels
Frankfurt
Leipzig
Prague
Paris
Stuttgart
Munich
Lyon
Milan
Venice
Coruña
Gijón
Bilbao
Bordeaux
Marseille
Madrid
Zaragoza
Barcelona
Puertollano
Valencia
Huelva
Tarifa
Almería
Rome
Palermo
H_2 pipelines by conversion of existing natural gas pipelines
Newly constructed H_2 pipelines
Possible additional routes
Countries within scope of study
Countries beyond scope of study
Potential H_2 storage: existing / new salt cavern
Potential H_2 storage: Aquifer
Potential H_2 storage: Depleted field
Industrial cluster
City, for orientation purposes (if not indicated as cluster already)
European Hydrogen Backbone initiative 2020, supported by Guidehouse

Element Eins
100 MW Power-to-Gas Partnership

- **Partners** – Gasunie Deutschland, TenneT and Thyssengas
- **Size** – 100 MW power-to-gas facility in Lower-Saxony
- **Strategic Location** – Located to take advantage of landing zones for wind power facilities in the North Sea and access to gas infrastructure
- **Wind Power Growth** – By 2035 an additional 23 GW of wind power will be commissioned
- **Renewable Gas Production** – Phased Includes hydrogen blending and synthetic methane production through methanation of biogenic sources of carbon dioxide

Element Eins
Phased approach to transition to a zero-carbon gas system

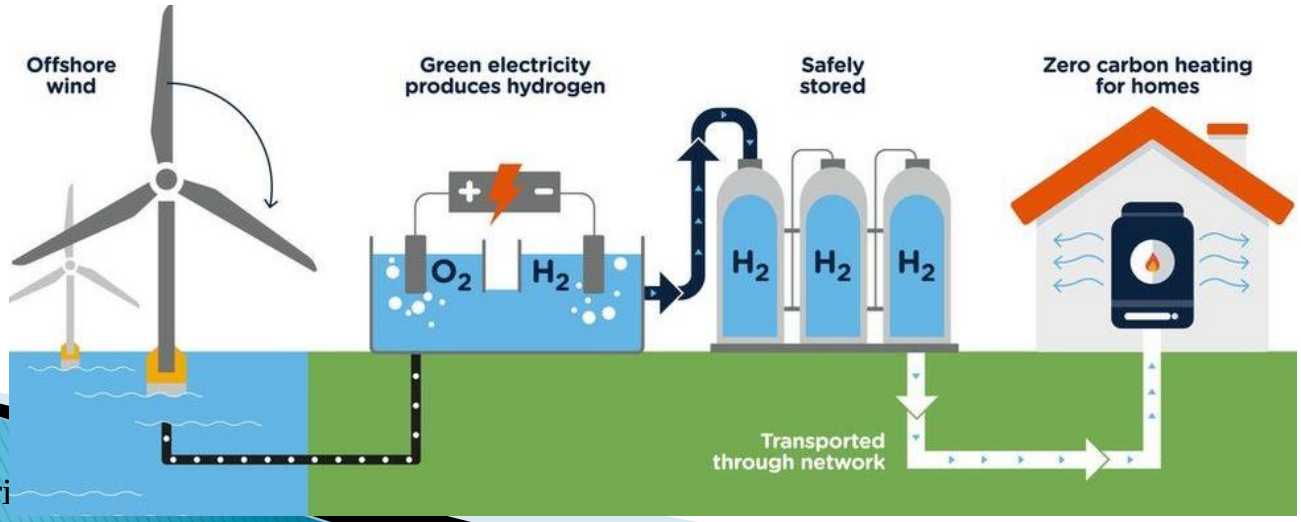
Phase 1 &2	Phase 3	Phase 4	Phase 5
• Build 100 MW wind powered electrolyzer plant • Hydrogen blending in natural gas pipelines • Direct truck transport for hydrogen fueling	• Produce renewable methane from biogas derived CO2 and Green Hydrogen through Methanation • Inject the renewable methane into existing natural gas pipelines	• Integrate the nearby cavern storage facilities into the system	• Convert natural gas pipelines to transport 100% hydrogen • Transport hydrogen directly to industrial customers in North Rhine-Westphalia, one of the most industrialized areas in Europe

White Dragon
A phased program to decarbonize the Macedonian region of Greece

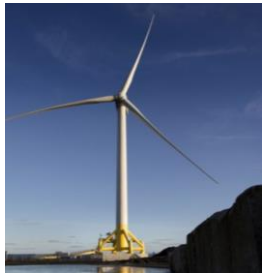
- The project is intended for district heating, hydrogen export via the Trans Adriatic Pipeline (TAP) and for fueling buses and trucks.
- Once fully developed, it will produce 16,000 tons of green hydrogen per year
- The output will be compressed and stored in tanks, and some excess quantities will be transmitted via Albania to Italy through the Transadriatic Pipeline (TAP).
- Other quantities of hydrogen will be transmitted through another hydrogen pipeline to three Greek refineries (in Corinth, Aspropyrgos and Thessaloniki), to Hellenic Fertilizers and Chemicals (ELFE) and to the Attica and Thessaloniki bus fuel depots.
- Other elements of this phased project:
  - Solar PV - Implement 1.7 GW of solar PV
  - Electrolyzer – 670 MW Solid Oxide Electrolyzer
  - Fuel Cell CHP – 167 MW fuel cell
  - Storage – 40 GWh LOHC hydrogen storage
  - District Heat - Supply heat to 120,000 residents

H100 Fife Project – Levenmouth, Scotland
300 Homes to be heated with green hydrogen

- 300 homes in Levenmouth on the east coast of Scotland to be fitted with free boilers, heaters and cooking appliances
- Pay the same rate as for natural gas and receive free maintenance
- New pipes will be laid alongside 1,000 properties
- Customers will get the choice of staying with natural gas or switching to green hydrogen
- Funding includes $25.6 million from Ofgem, $9.8 million from the Scottish Government, and additional funding from SGN shareholders and Britain's three other gas distribution networks



The wind turbine will produce 4X as much energy as required for the 300 homes, while reducing carbon emissions by nearly 1 million tons per year



7 MW Off-shore Wind Turbine

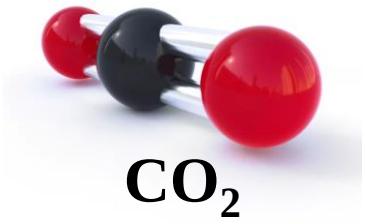
Electricity Production 21,462 MWh/yr

7 MW Electrolyzer

Hydrogen Production 429,240 kg/yr

300 Homes 360 kg/yr/House

Hydrogen Requirement 108,011 kg/yr



300 Homes 5,914 lbs/yr/HH

Carbon Reduction 1,774,240 lbs/yr

Hydrogen boilers and fuel cells CHP appliances

Giacomini
H_2ydroGEM
5.36 kW gas condensate flameless catalytic hydrogen boiler with no NOx

Worcester-Bosch
Hydrogen Boiler

Baxi
Hydrogen Boiler

Viessmann
Vitovalor Fuel Cell CHP

BDR Thermea Group Hydrogen Boiler

Question and Answer