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GAS GOES GREEN

Hydrogen Deblending

GGG Workshop

17 July 2020

Welcome

- **Thom Koller**
  Programme Lead, Gas Goes Green, ENA
- **Antony Green**
  Hydrogen Programme Director, National Grid Gas Transmission

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Agenda

Item	Speaker
Welcome	Tony Green (National Grid Gas Transmission)
Hydrogen Deblending – Work by the networks	Lloyd Mitchell (National Grid Gas Transmission)
Offshore Gas Processing	Lorman Correa (Petrofac)
Q&A	Thom Koller
Hydrogen Deblending Use Cases: - Use of Hydrgoen for **Domestic** - Use of Hydrogen for **Industry** - Use of Hydrogen for **Transport** - Use of Hydrogen for **Power**	 Keith Owen (Northern Gas Networks) Adam Baddeley (Progressive Energy) David Jones (Cadent) Phil Cahill (RWE)
Q&A	Thom Koller (ENA)
Ask the Audience	Thom Koller (ENA) & Audience
Opportunity & Next Steps - FutureGrid Programme - H21 Rig - LTS Futures	Tony Green (National Grid Gas Transmission) Tom Neal (National Grid Gas Transmission) Mark Danter (Northern Gas Networks) Nancy Thomson (SGN)

Hydrogen Deblending – Work by the Networks

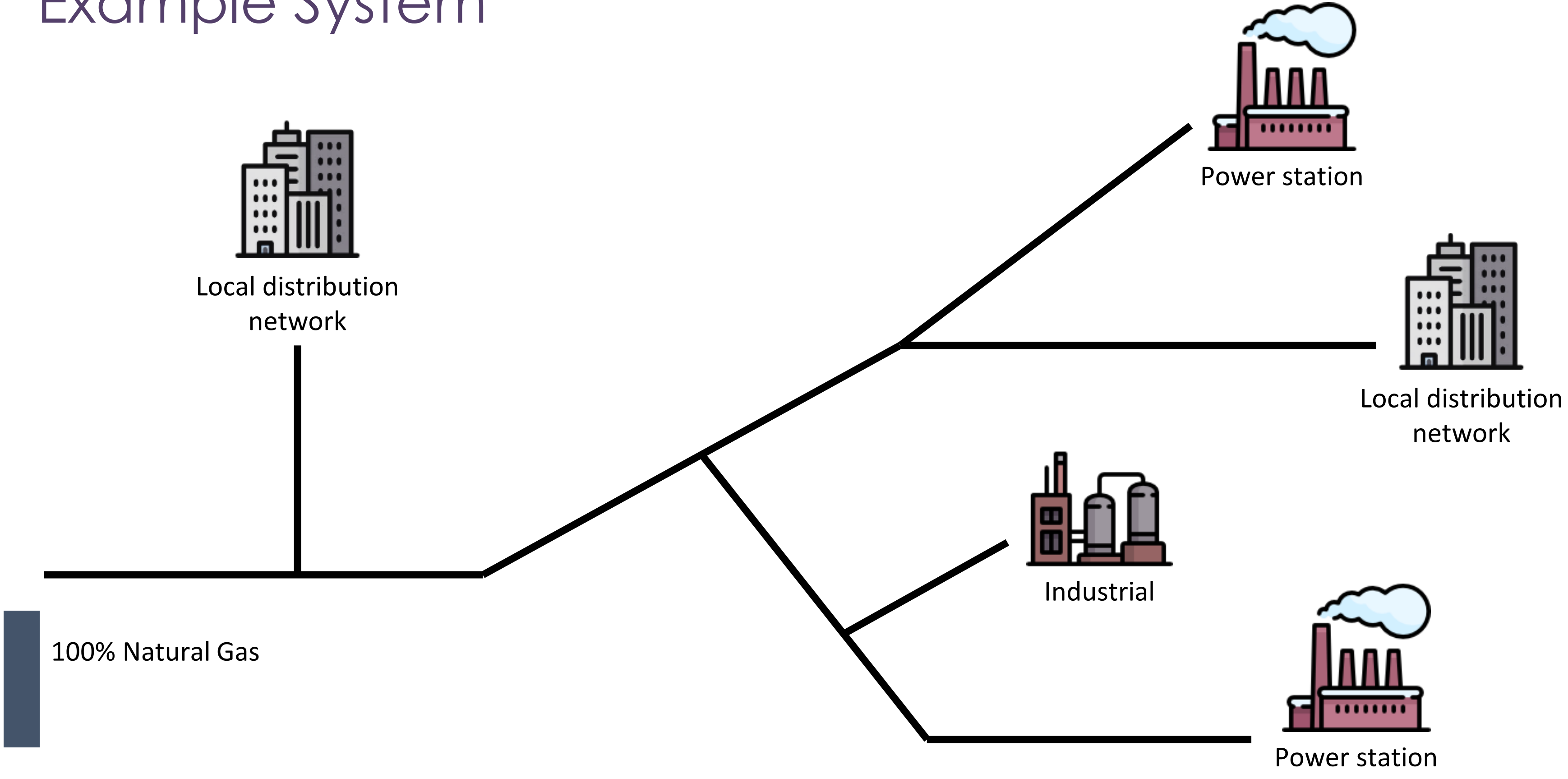
Lloyd Mitchell

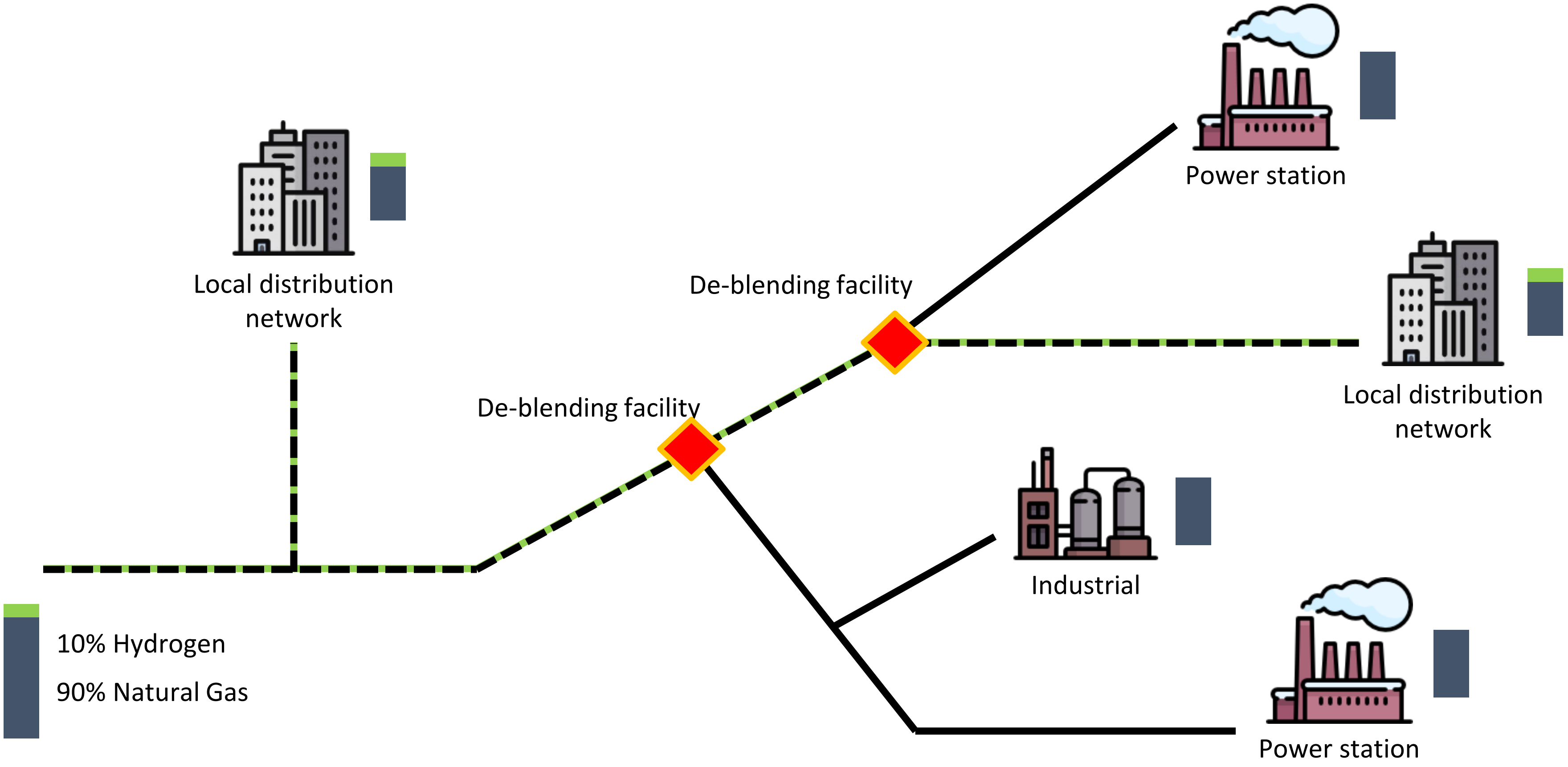
(National Grid Gas Transmission)

Why de-blending?

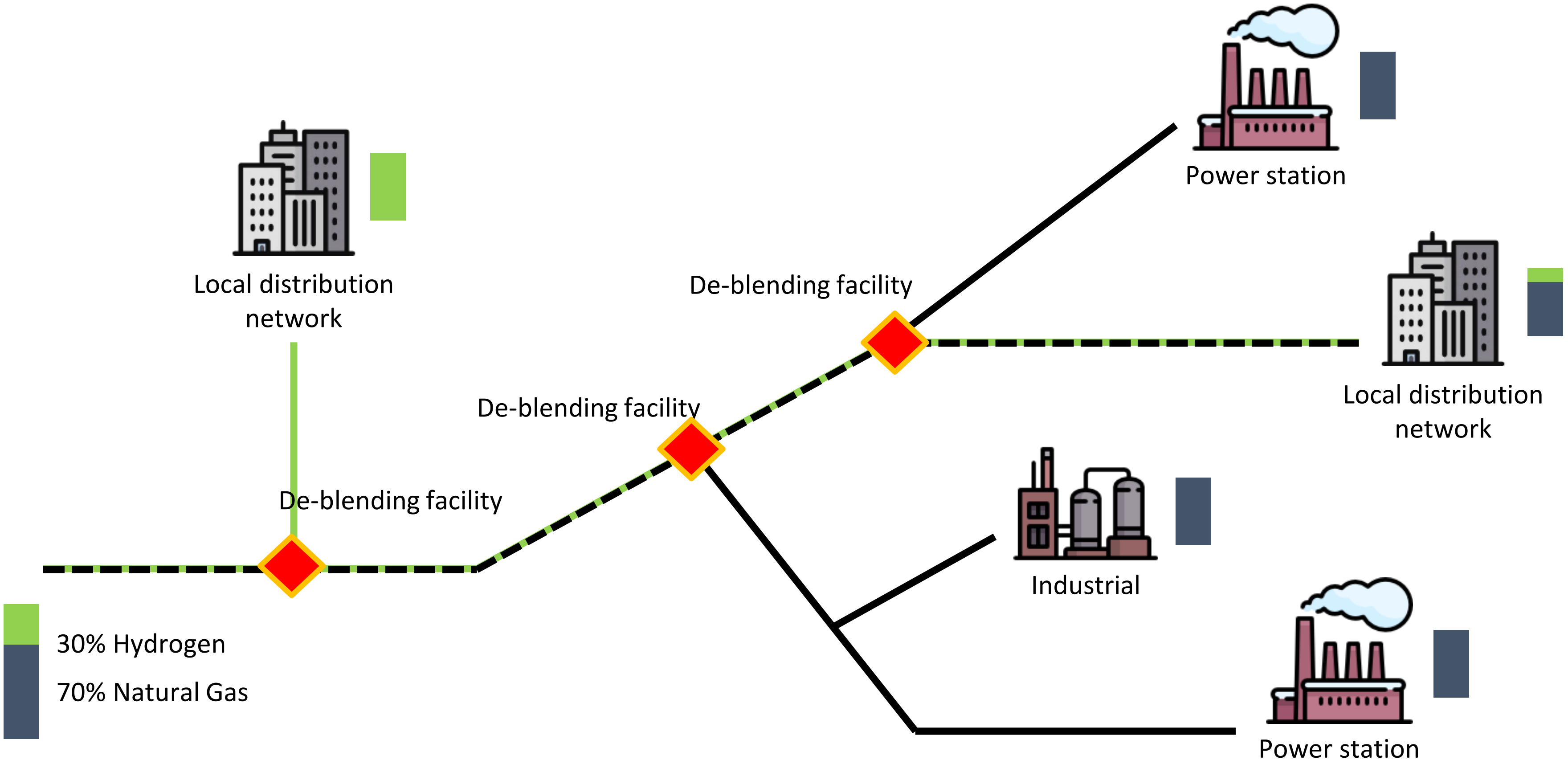
- Blending is proposed as an enabler to support a transition to a hydrogen gas system
- Certain customers will be unable to accept hydrogen blends, de-blending will allow their supply to be maintained
- Strategic de-blending will allow for an incremental increase of hydrogen concentrations
- Maintaining optionality to key consumers will prevent blockers to a potential rollout

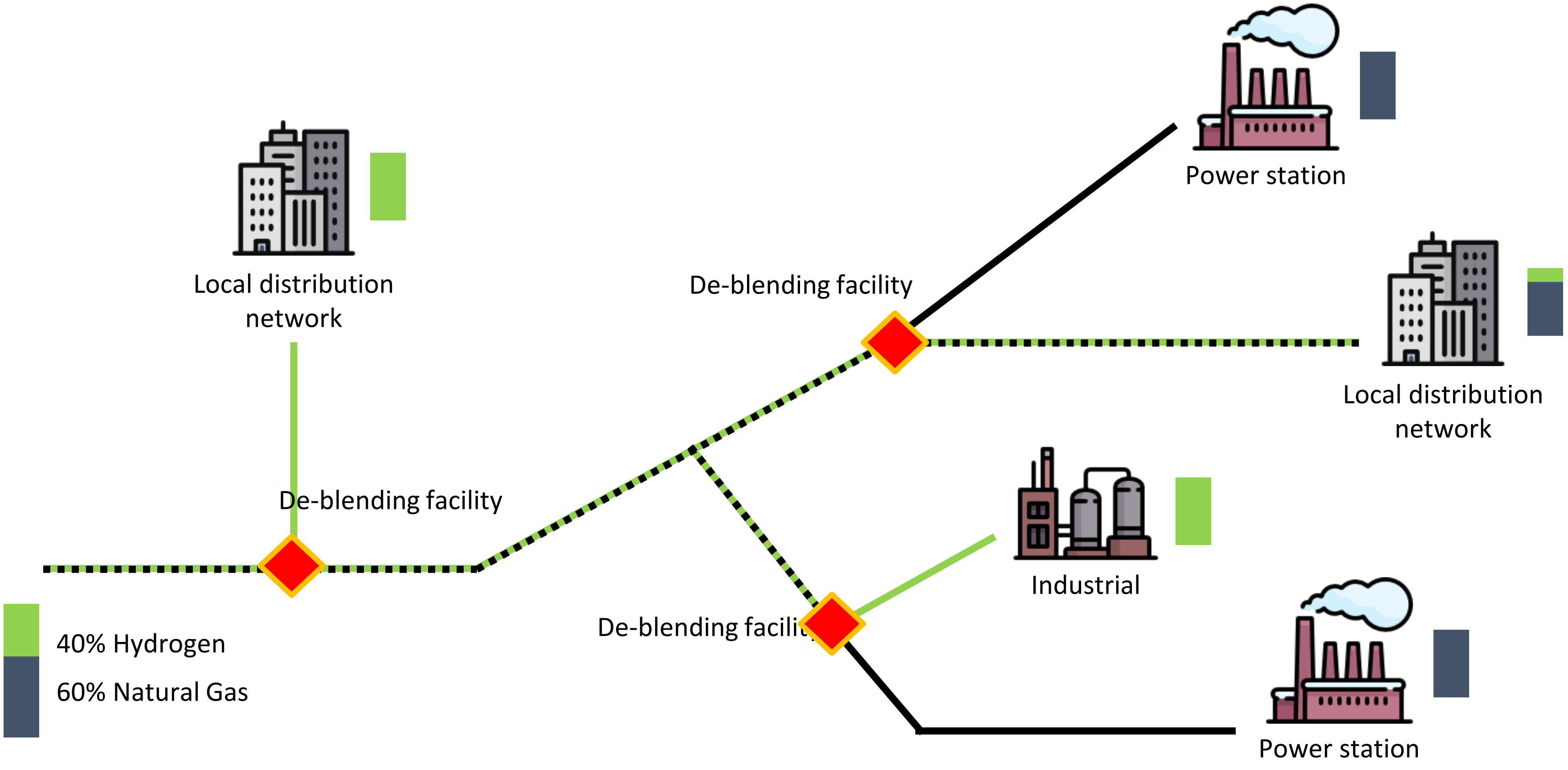
Example System

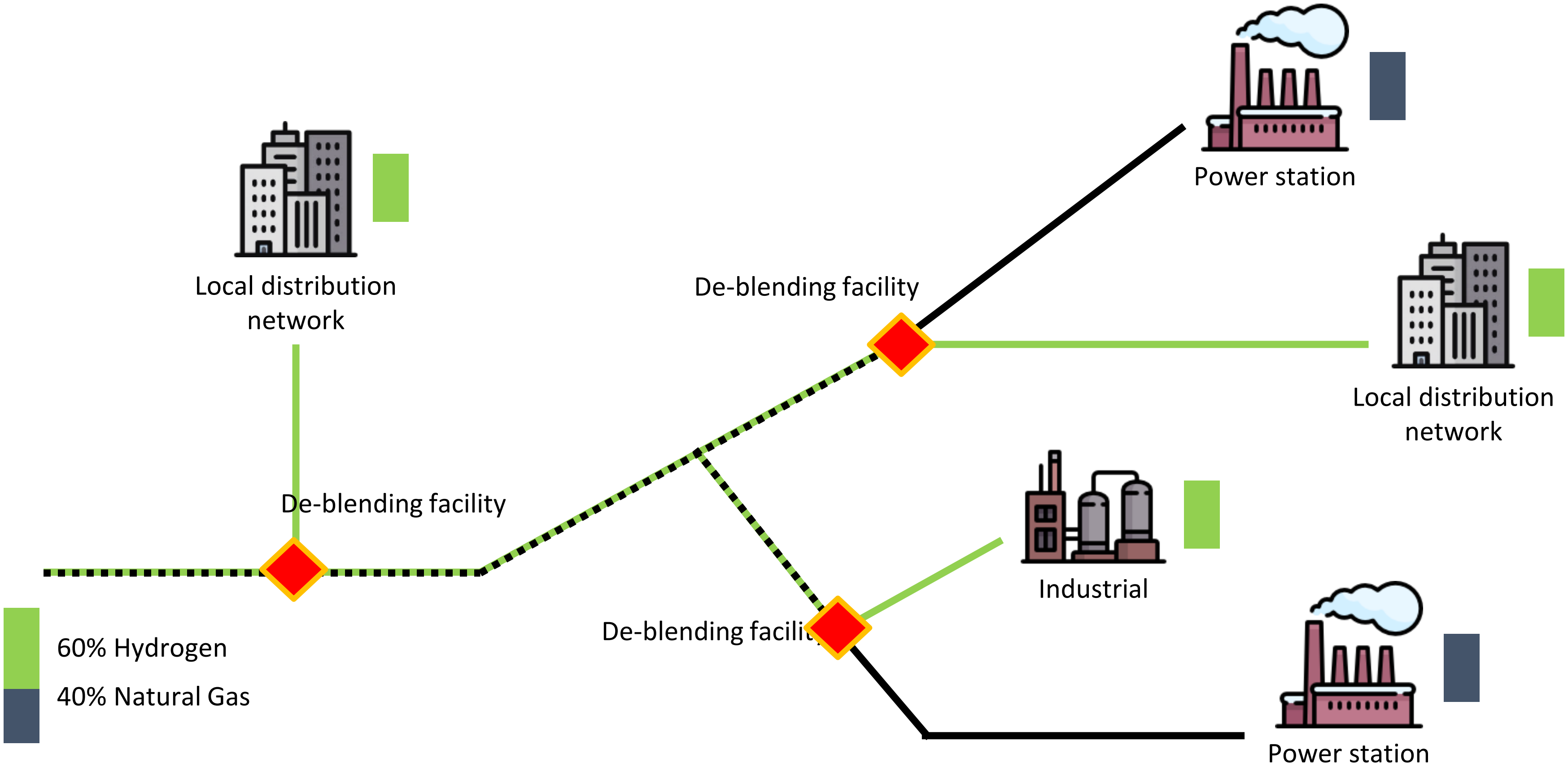




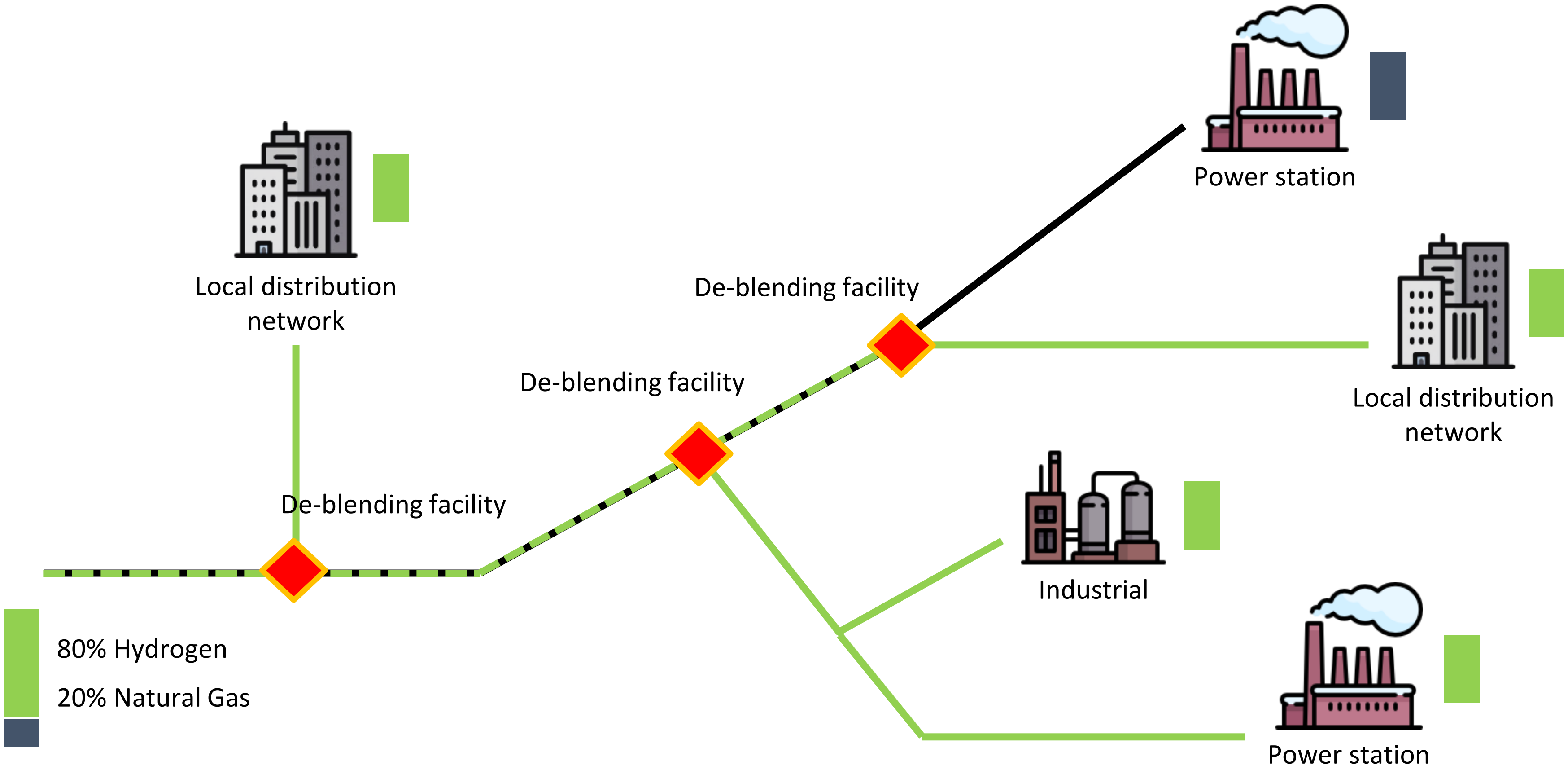
Power station
Local distribution network
De-blending facility
Local distribution network
De-blending facility
Industrial
10% Hydrogen
90% Natural Gas
Power station

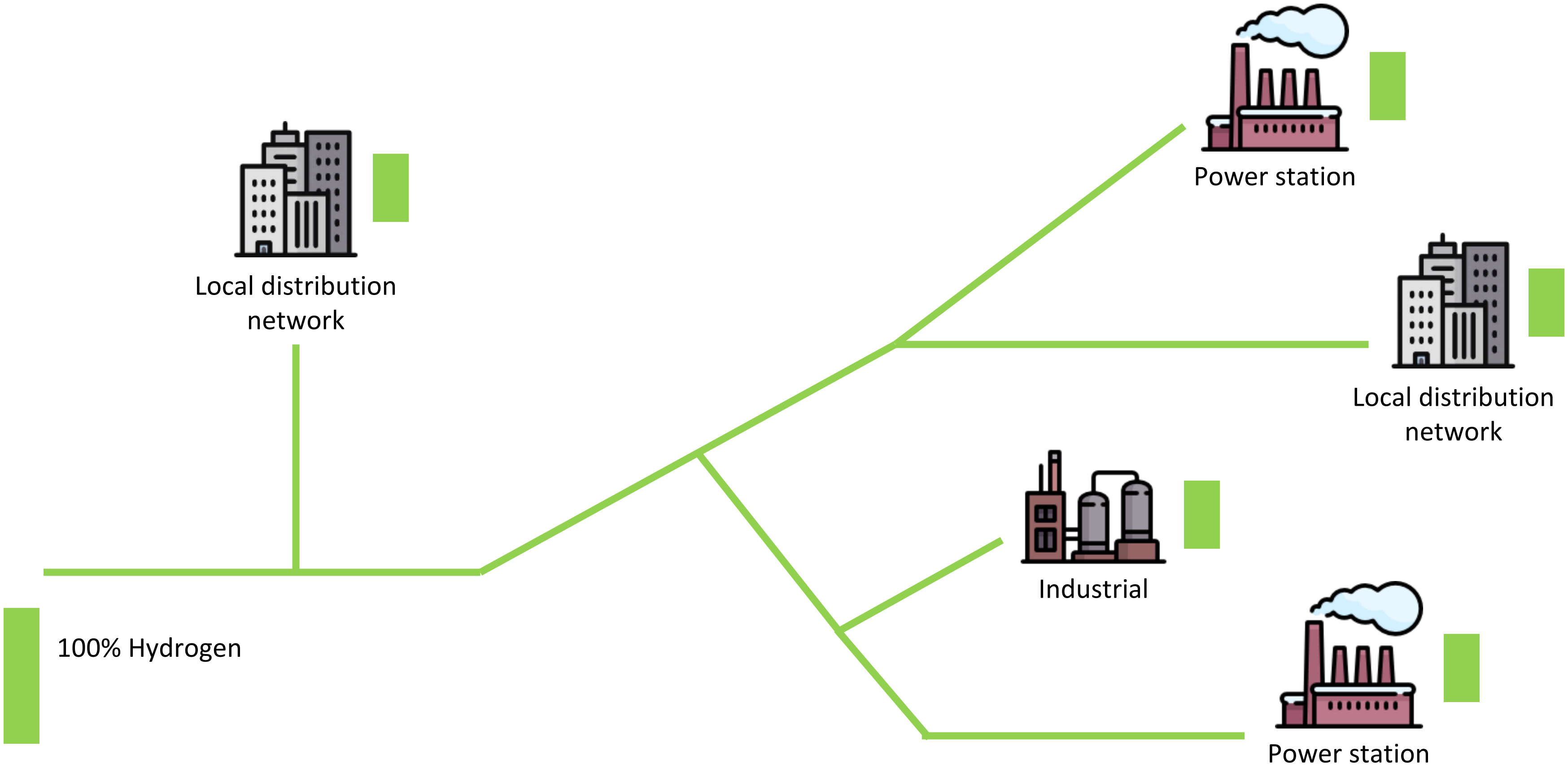

Power station
Local distribution network
De-blending facility
Local distribution network
De-blending facility
Industrial
De-blending facility
30% Hydrogen
70% Natural Gas
Power station


Power station
Local distribution network
De-blending facility
Local distribution network
De-blending facility
Industrial
De-blending facilit
40% Hydrogen
60% Natural Gas
Power station



Power station
Local distribution network
De-blending facility
Local distribution network
De-blending facility
Industrial
De-blending facility
60% Hydrogen
40% Natural Gas
Power station


Power station
Local distribution network
De-blending facility
De-blending facility
Local distribution network
Industrial
De-blending facility
80% Hydrogen
20% Natural Gas
Power station


Power station
Local distribution network
Local distribution network
Industrial
100% Hydrogen
Power station

Project Overview

- First hydrogen NIA collaborating between all networks
- Techno-economic review of deblending technologies and their application on the LTS/NTS
- Objectives:
  - Evaluate the Use cases
  - Assess the technologies
  - Technical evaluation
  - Economic evaluation
  - Demonstration project design

Networks

nationalgrid

Cadent Your Gas Network

SGN Your gas. Our network.

Northern Gas Networks

WALES&WEST UTILITIES

Partners

COSTAIN

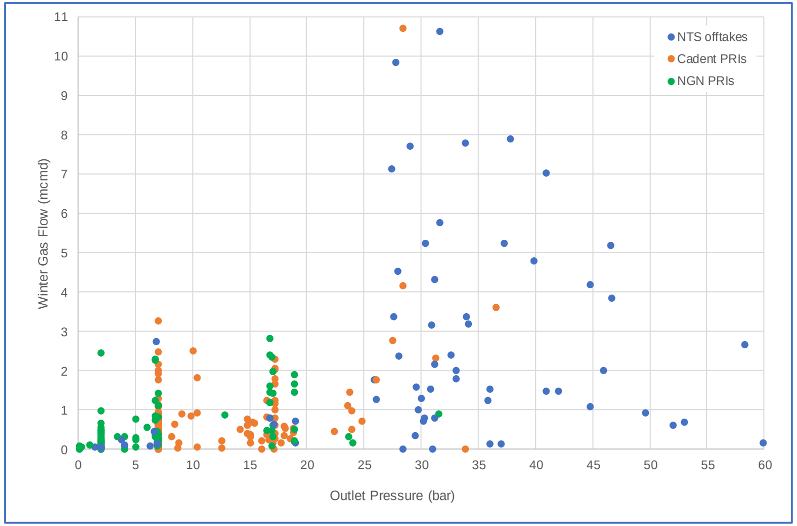
Peer Review

THE UNIVERSITY of EDINBURGH

Imperial College London

NTS/LTS Use Cases

- The study needed to understand typical offtake operating parameters in order to generate realistic use cases
- The most important factors are inlet pressure, outlet pressure and flow
  - The differential pressure can drive the separation process and reduce energy input requirements
  - Higher flows will reduce the specific cost of separation



NTS/LTS Offtakes pressure & flow data

Facility type	Feed gas flow	Inlet Pressure	Outlet Pressure	Case ID
LTS PRI	1 mcmd	30 barg	2 barg	1A
			20 barg	1B
			30 barg	1C
NTS offtake	3 mcmd	60 barg	7 barg	2A
			30 barg	2B
			60 barg	2C

Use cases for deblending study

Available technologies

- The study evaluated both established and newly developed separation technologies
- Cryogenic separation and a combination of membrane separation and Pressure Swing Adsorption were carried through for the evaluation due to their technological maturity

	Capacity (scale)	Typical feed H_2 content	Typical feed pressure (barg)	Typical feed temp (°C)	Hydrogen product pressure	Residue gas pressure	Hydrogen recovery (mol%)	Hydrogen purity (mol%)
PSA	Large	>50%	20-150	0-40 (amb)	High (feed)	Low (atm)	80-90%	99.7% (99.999% max)
Polymer membrane	Small to large	>20%	20-200	0-40 (amb)	Low (atm)	High (feed)	85-95%	95-98% (99.7% max)
Palladium membrane	Small to medium	>98%	<20	300-450	Low (atm)	High (feed)	95-99%	99.995%
Cryogenic	Large		20-50	-185	High (feed)	Low (atm)	<95%	90-98%
EHS	Small		3-15	0-40 (amb)	High (feed)	High (feed)	<95%	99.9%

Cryogenic Separation

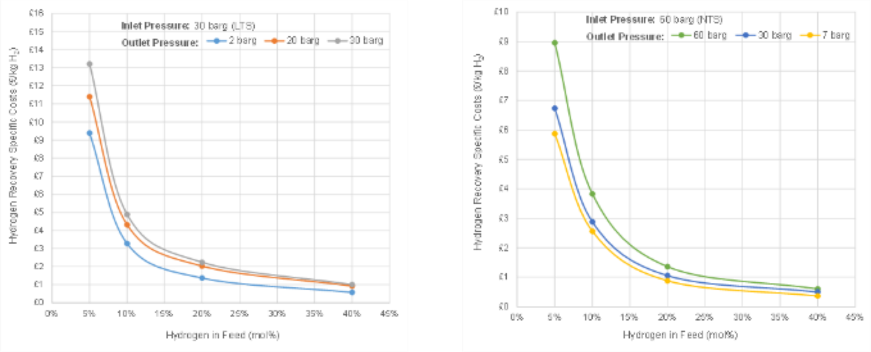
Pressure Swing Adsorption

Techno-economic evaluation: Cryogenic

- Uses gas pressure drop to drive the refrigeration process
- Hydrogen remains a vapour with most impurities dropping out as a liquid
- Produces hydrogen at high pressure
- Well suited to bulk separation
- Pre-treatment of the gas is generally required

Facility type	Feed gas flow	Inlet Pressure	Outlet Pressure	Case ID	CAPEX NPV	OPEX NPV	Specific Cost
LTS PRI	1 mcmd	30 barg	2 barg	1A	£43.5 m	£33.3 m	£1.37/kg
			20 barg	1B	£54.6 m	£57.8 m	£2.03/kg
			30 barg	1C	£56.8 m	£67.1 m	£2.24/kg
NTS offtake	3 mcmd	60 barg	7 barg	2A	£77.2 m	£70.6 m	£0.88/kg
			30 barg	2B	£88.3 m	£89.8 m	£1.05/kg
			60 barg	2C	£94.3 m	£135.1 m	£1.36/kg

Cryogenic separation – Hydrogen recovery costs



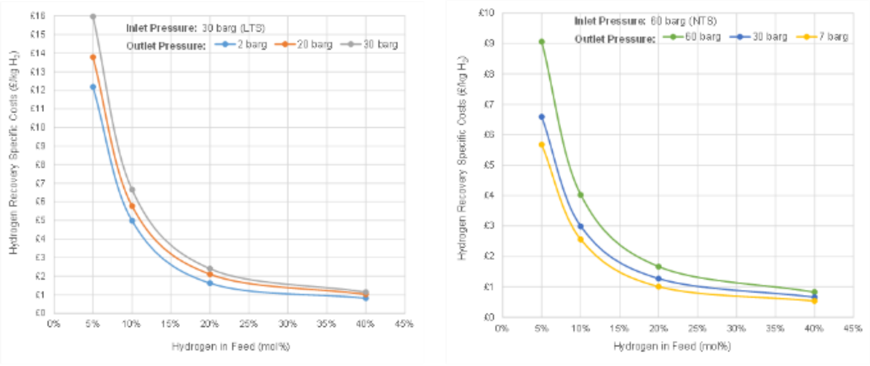
Cryogenic separation – Hydrogen specific cost comparison

Techno-economic evaluation: Membrane + PSA

- Two-stage process with a polymer membrane for bulk separation and Pressure Swing Adsorption to remove remaining impurities
- Can achieve very high levels of purity
- Highly scalable
- No heating or cooling required
- More effective at higher pressures

Facility type	Feed gas flow	Inlet Pressure	Outlet Pressure	Case ID	CAPEX NPV	OPEX NPV	Specific Cost
LTS PRI	1 mcmd	30 barg	2 barg	1A	£34.7 m	£39.4 m	£1.63/kg
			20 barg	1B	£45.9 m	£50.1 m	£2.11/kg
			30 barg	1C	£52.1 m	£83.0 m	£2.97/kg
NTS offtake	3 mcmd	60 barg	7 barg	2A	£49.2 m	£90.1 m	£1.01/kg
			30 barg	2B	£63.7 m	£112.0 m	£1.27/kg
			60 barg	2C	£72.0 m	£182.9 m	£1.84/kg

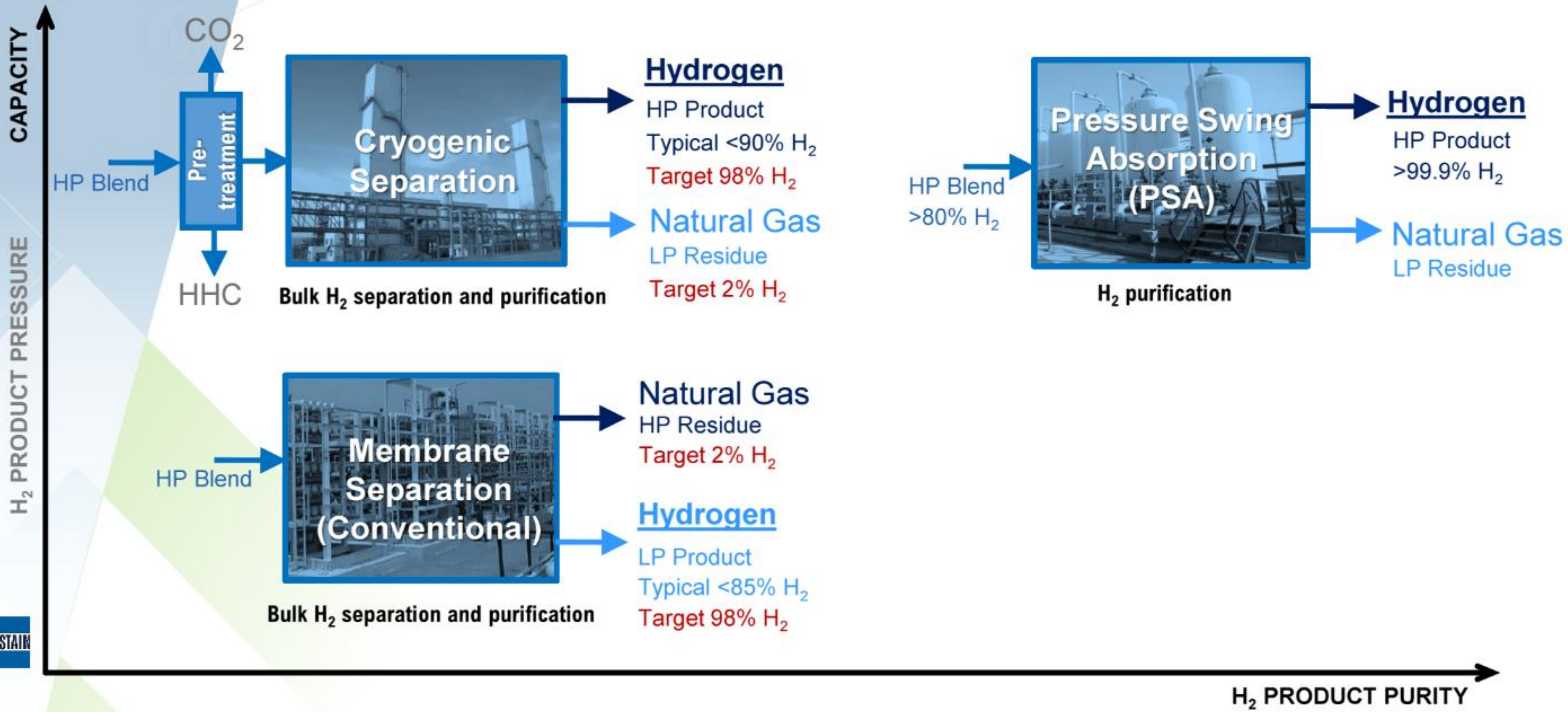
Cryogenic separation – Hydrogen recovery costs



Cryogenic separation – Hydrogen specific cost comparison

Potential Deblending Technologies

Opportunity to make use of available pressure in network to drive separation



COSTAIN

Next Steps

- Undertake a network-wide assessment of the UK's gas transmission and distribution networks to identify all locations where deblending could be deployed
- Demonstration of deblending technologies at scale

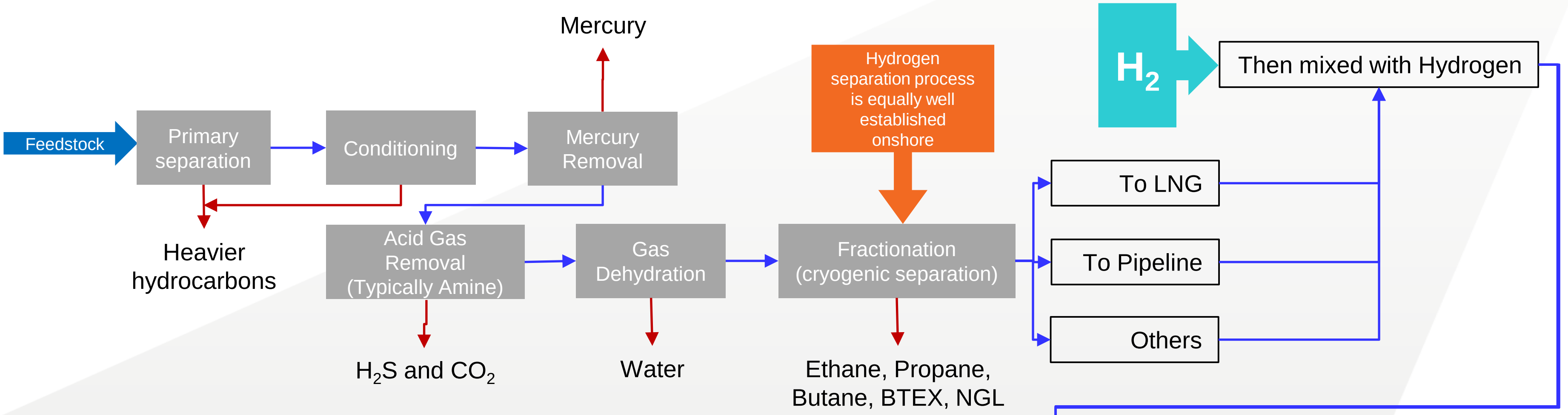
Offshore Gas Processing

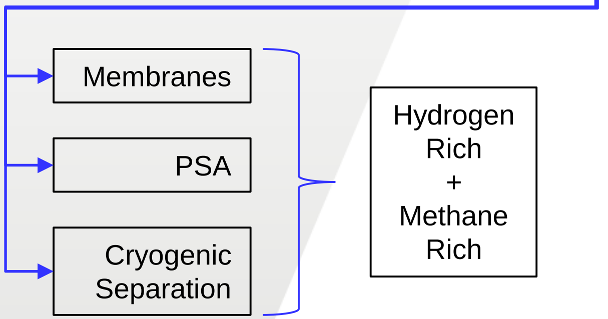
Lorman Correa
(Petrofac)

Offshore Gas Processing – The Base Process

Petrofac

Very similar to Onshore Processing but … smaller plot spaces and subject to sea motions !!!



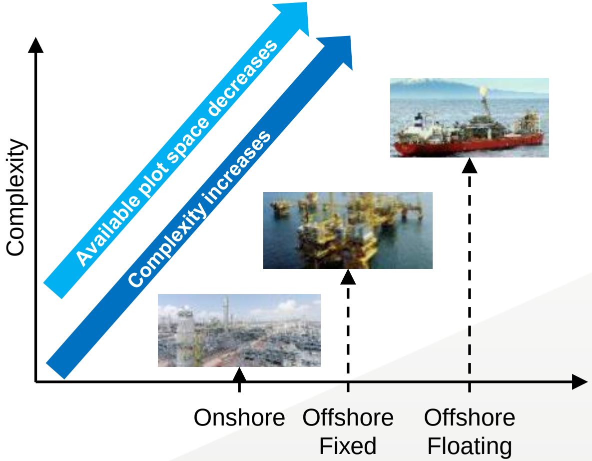


All well known and solid industry processes which have been around for decades !!!

So why is gas processing required?

- Remove feedstock contaminants: H_2S, CO_2, Water (moisture), Mercury, Heavier Hydrocarbons (typically Pentane and heavier with special requirement for BTEX)
- Conditioning to meet specifications for further downstream processing or direct export to end users: LNG, pipeline gas, others
- Depending on the quality of the feedstock some of the processing may not be required prior to hydrogen deblending

Offshore Gas Processing – Modularisation



Key message:

1. If it can be designed and built for Offshore Floating it can be designed and built relatively easier for Onshore
2. As plot space reduces there is increasing value in modularisation to make developments more compact and relatively easier to install

With land and labour costs at a premium in the UK it is worth looking into developments which are more compact and are quicker and cheaper to install by implementing modularisation based solutions …

<u>offshore approach to the onshore world !!!</u>

The largest offshore gas processing capacity I've seen is 1,000 MMSCFD or approx. 30 MMCMD which is also very large for onshore

These vessel are very large (400+ metres long), still space is at a premium and multilevel structures and modular construction are essential

A modular design that can be replicated in different locations will help save time and design costs … even fabrication costs if the volumes are there

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Q&A

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Hydrogen Deblending Use Cases: Domestic

Keith Owen
(Northern Gas Networks)

H21 NIC: Phase 1

*Seeks to demonstrate the suitability of the **existing** natural gas infrastructure to convey 100% hydrogen.*

Phase 1a HSE Derbyshire

Leakage Testing

- Comparing leakage rates between natural gas and hydrogen.
- Testing on existing 0-7bar network assets.

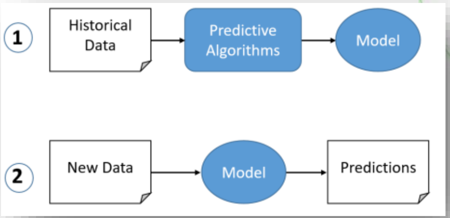
Phase 1b DNV GL Cumbria

Consequence Testing

- to establish the consequences of a hydrogen leak.
- Observation of tracking, dispersion, ignition potential and explosive limits.

H21 NIC: Quantitative Risk Assessment

- The QRA measures the probability of leaks, failures and subsequent ignition events for natural gas.
- Results from H21 Phase 1a and 1b are being analysed and input into the updated QRA for 100% hydrogen.
- Allows comparisons between the overall safety of a 100% hydrogen and natural gas network.



energynetworks association

Project Funded under OFGEM's Network Innovation Programme

RIIO NIC Northern Gas Networks Cadent SGN WALES&WEST UTILITIES

Findings to be published Sept. 2020

H21 NIC: Social Sciences

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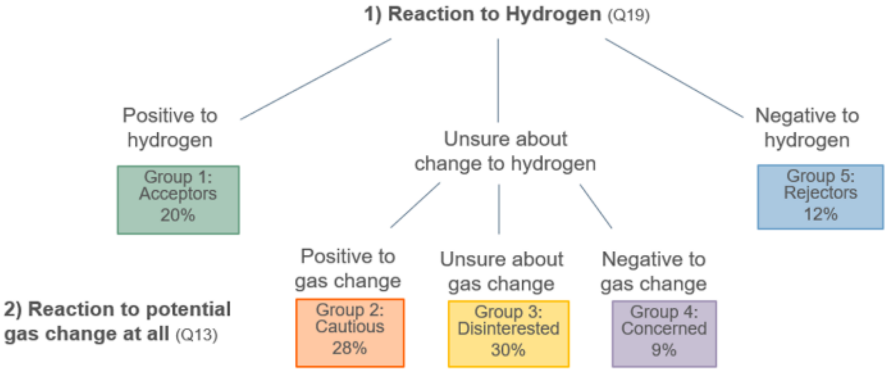
High Level Results:

- Safety not a major concern for the public.
- Cost (general and of appliances) and disruption / impact are barriers to change.
- Able to digest quite technical information, retain and explain it.
- Difficulty with some of the terms we use e.g. Decarbonisation, CCS, SMR, ATR etc.
- Want to be brought along the hydrogen journey.
- Want to be told the facts.



H21

ena energynetworks association

Project Funded under OFGEM's Network Innovation Programme

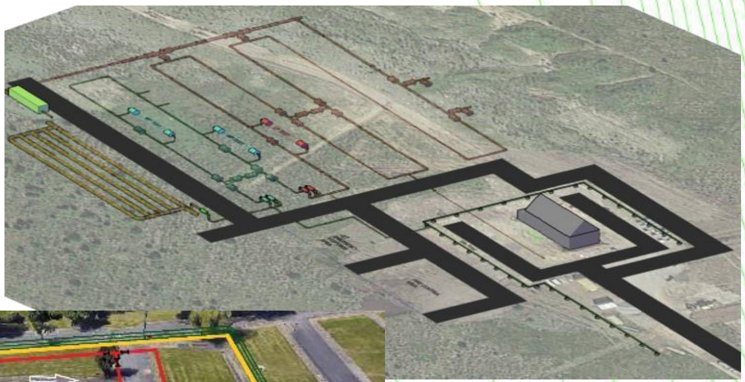
RIIO NIC Northern Gas Networks Cadent Your Gas Network SGN WALES&WEST UTILITIES

H21 NIC: Phase 2

- The project will provide the next stage of quantified safety-based evidence to confirm the gas distribution networks of GB are suitable to convey 100% hydrogen.

- The H21 Phase 2 NIC consists:
  - 2a – Appraisal of Network Operations [via micro gas grid]
  - 2b – Unoccupied Network Trials
  - 2c – Combined QRA
  - 2d – Social Sciences

- Next Steps: H21 Phase 3 – Occupied Trials

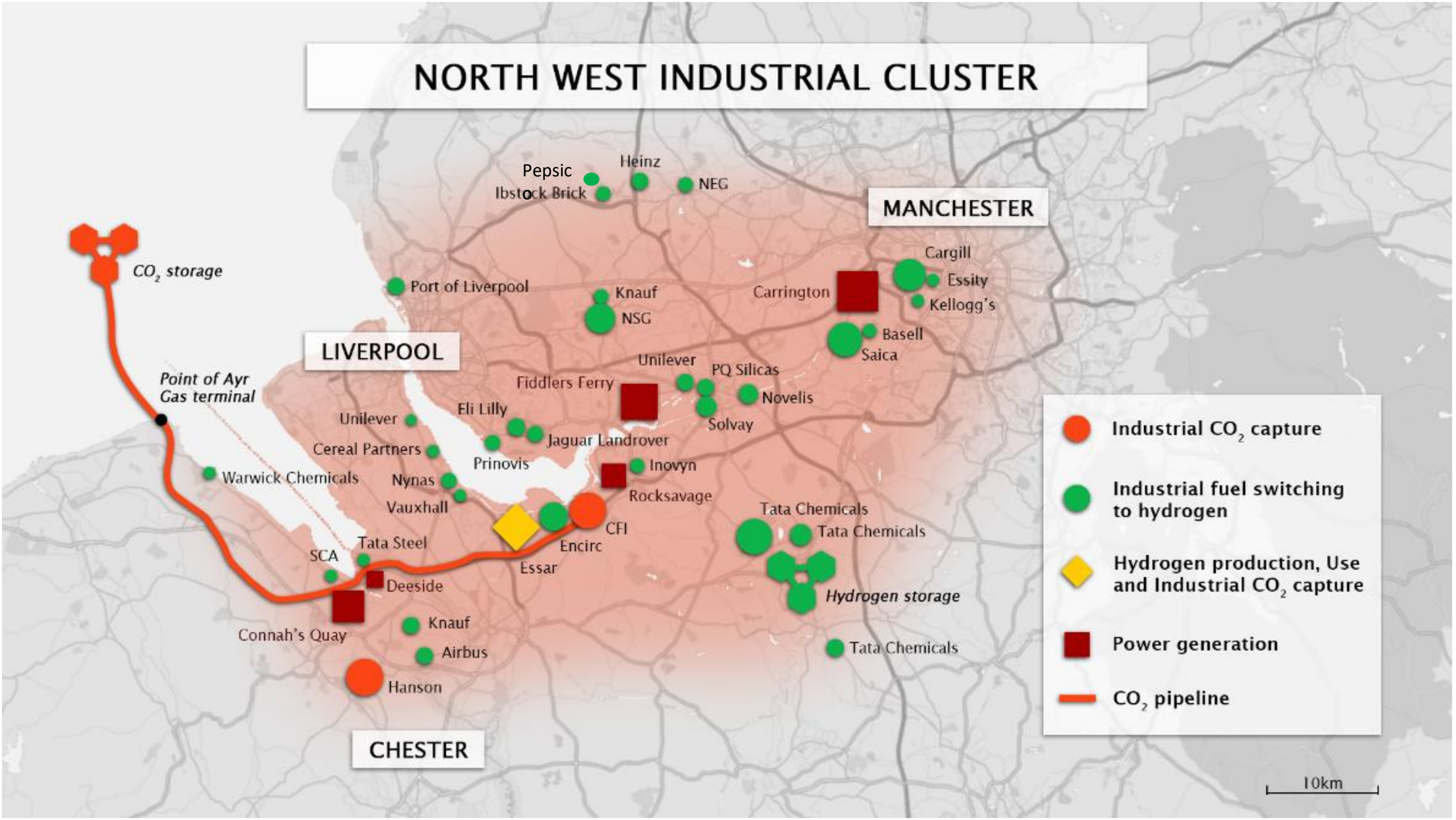


Project Funded under OFGEM's Network Innovation Programme

Hydrogen Deblending Use Cases: Industry

Adam Baddeley
(Progressive Energy)

NW Industrial Cluster



Could deblending be useful for industry?

- **Access to hydrogen for use as a fuel for industry**
  - Could facilitate earlier conversion of some plant located *outside* industry clusters
  - But, deblending of large volumes likely to impact upon % blend supplied to others
    - Could technical use (burner) and metering challenges be managed sufficiently?

- **Removal of hydrogen to enable ongoing use of *natural gas* by industry**
  - Could facilitate widespread blending without need to 'prove' hydrogen use for all types of industrial heat (and power) generation
  - Relevant for specialist forms of 'direct firing' along with CHP (turbines and engines)
    - But possibly simpler to develop the evidence base to enable all sites to operate on hydrogen?

Structure of HyNet IFS Programme

PROGRESSIVE ENERGY

WP1: Project Management

- **WP2: H_2 Supply**
  - Lead / Partner: PROGRESSIVE ENERGY
  - Contractors: BOC — A Member of The Linde Group
- **WP3: Direct Firing**
  - Lead / Partner: PILKINGTON
  - Contractors: OTTO SIMON
- **WP4/5: Boilers**
  - Lead / Partner: Unilever
  - Contractors: GHD; DUNPHY
- **WP6: Refinery**
  - Lead / Partner: ESSAR
  - Contractors: COSTAIN

Objectives of HyNet IFS Programme

- **To provide evidence to enable…**
  - Participating sites to convert to hydrogen as soon as it is available from HyNet
  - Wider sites in the North West (and beyond) to convert to hydrogen as soon as it is available
- **To determine the costs of converting to hydrogen**
  - In most industries, it will be *conversion* rather than the need to buy new plant and equipment
- **To prove that there is no detrimental impact upon existing plant and equipment**
  - Different 'properties' of hydrogen, e.g. greater flame speed and moisture content must be managed
- **To demonstrate that hydrogen can be used…**
  - Safely as a fuel for industry and in conformance with all related safety regulations
  - Without any greater environmental impact than natural gas and without need for significant permit variations

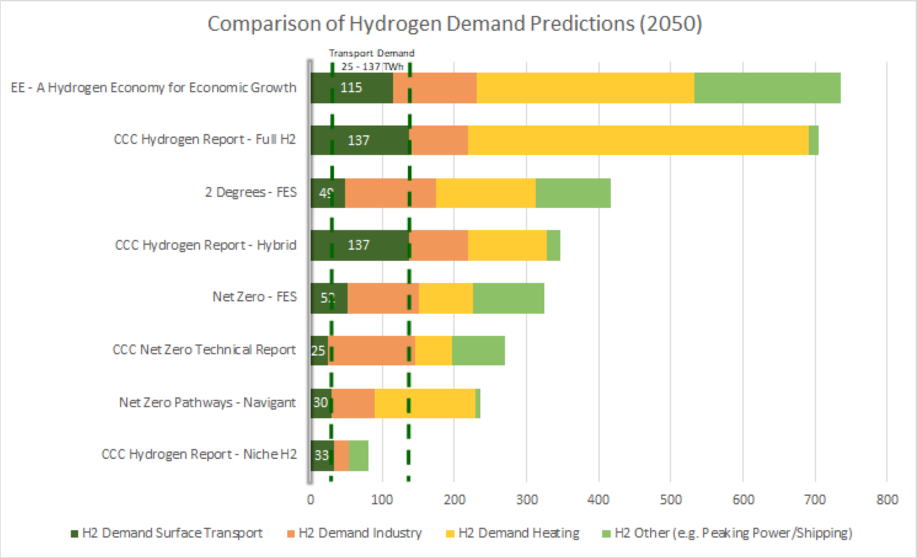
Hydrogen Deblending Use Cases: Transport

David Jones
(Cadent)

With Net Zero, the transport landscape has changed with greater roles for biomethane and hydrogen

- Hydrogen has the potential to meet a significant proportion of mobility demand by 2050
- Scenarios range from 25TWh to a more optimistic 140TWh
- A central estimate of 80TWh seems reasonable
- Plans to scale hydrogen face significant challenges, but the majority can be overcome

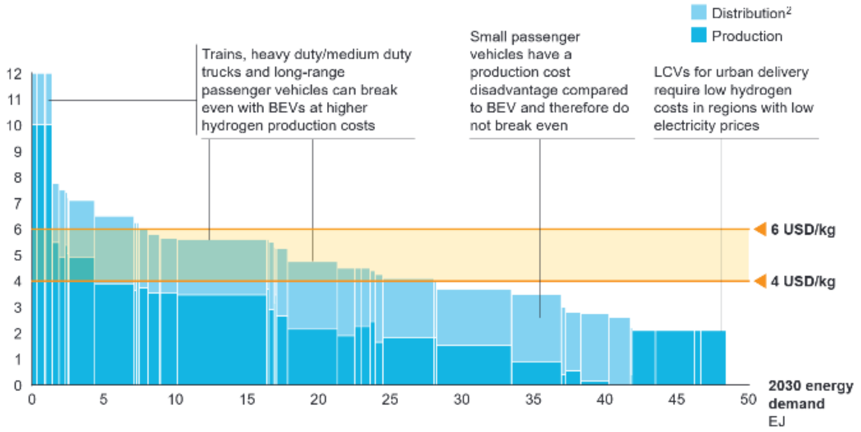
There is a range of hydrogen demand predictions between 25 and 137 TWh by 2050, average of 80TWh.



Decarbonisation is necessary - Hydrogen can meet a large share of mobility energy demand by 2030

- Hydrogen has a key role to play in "hard to decarbonise" sectors
- At $6/kg (price at pump, including production, distribution and retail), hydrogen can meet circa 15% of transport energy demand
- Cost profile to become viable in most regions and use cases by 2030
- If cost of alternative >$4/kg, hydrogen could meet >50% of mobility sectors energy demand
- Trucks, long distance buses, and large passenger cars are particularly competitive (due to high cost of battery alternatives)

Breakeven hydrogen costs at which hydrogen mobility applications becomes competitive against low-carbon alternative in a given segment in focus regions[1]
USD/kg at nozzle

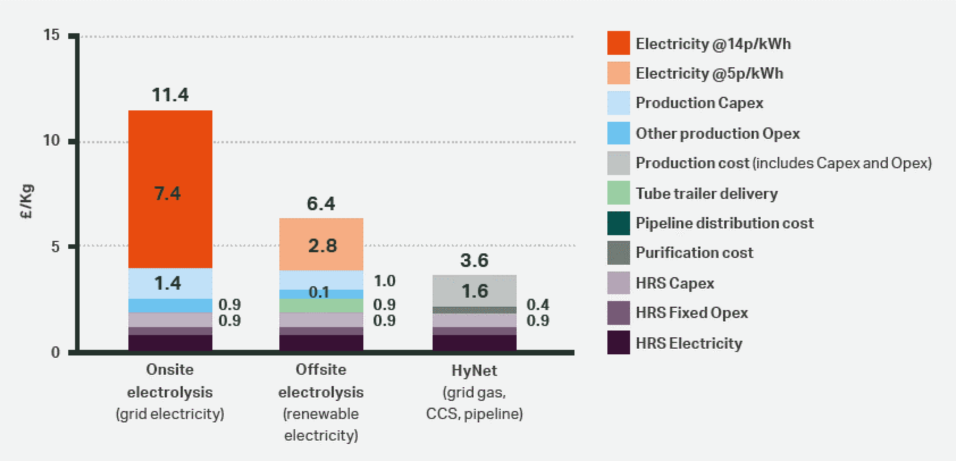


1. Regions assessed are the US, China, Japan/Korea, and Europe
2. No distribution costs for aviation as it can be distributed as liquid fuel

Source; Hydrogen Council; Path to Hydrogen Competitiveness; A Cost Perspective (Jan, 2020)

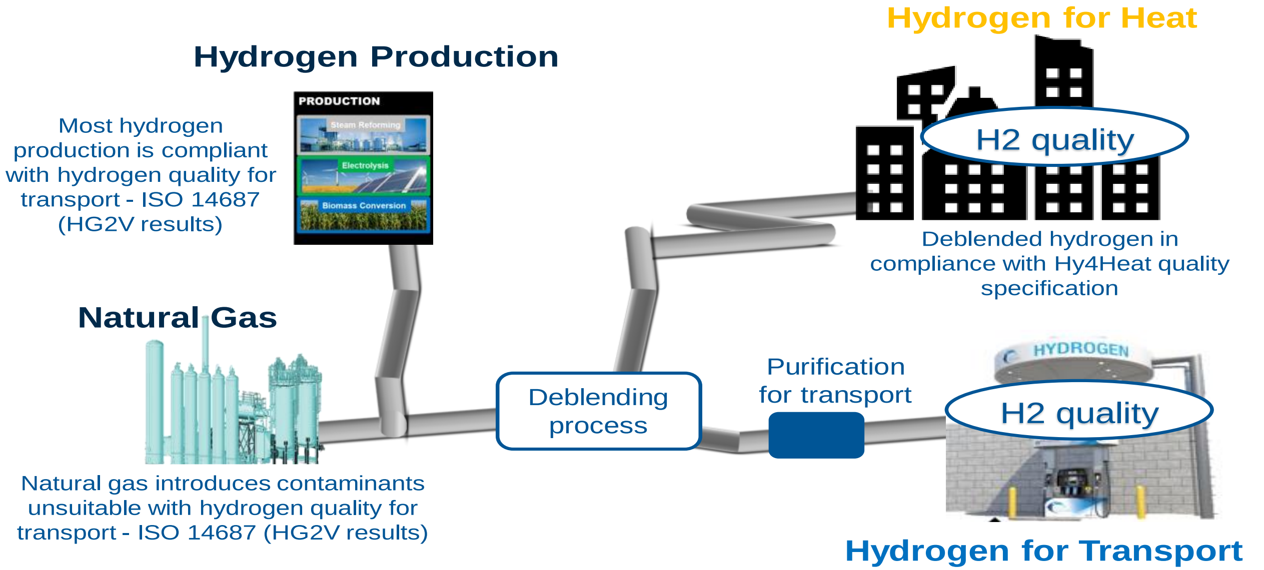
Network supplied hydrogen unlocks low carbon transport opportunities

- Hydrogen supplied by HyNet delivers mobility-grade hydrogen at 40 – 70% lower cost than electrolysis (at 2019 prices)
- Hydrogen cars, buses, trains and ships are ready for deployment – policy and infrastructure are what's needed
- Still a challenge to bring hydrogen HGVs to the UK (but one of the most important sectors!)
- Cost of managing impurities/contamination associated with new hydrogen networks appears reasonable (HyNet example)



Source; HyMotion Report (NIA); Network-supplied hydrogen unlocks carbon transport opportunities (June, 2019)

Hydrogen Grid to Vehicle (HG2V) … key challenges for deblending from a transport perspective



- Sulphur based odorant is unsuitable for transport applications
- What hydrogen quality will be obtained after deblending?
- After deblending, what purification steps are required due to contamination of hydrogen by natural gas
- Purification for transport: feasible, technology available (if contaminant and concentration known)
- New PE network less contaminated than repurposed network (HG2V results)

Key Questions:

- No strategic plan for UK scale-up of hydrogen in transport
- Hydrogen delivery by gas network will need clean-up due to the nature of contaminants and their impact on Fuel Cell Electric Vehicles
- Gas quality standards reflect use of hydrogen in heating … need to consider use of hydrogen in transport
- Cost at pump needs to be competitive with zero-emission alternatives circa £3 - £5/kg
- Need investible transition pathway between biomethane and hydrogen to support transport
- Need early demonstrations to address challenges, develop experience and provide confidence

Hydrogen Deblending Use Cases: Power

Phil Cahill
(RWE)

Context for Deblending Discussion

Existing CCGTs can be part of creating the initial demand for hydrogen

RWE Carbon Neutral

- RWE is committed to be carbon neutral by 2040
- 1st July 2020 – Renewables are now fully incorporated into RWE

RWE Generation UK - major Natural Gas Consumer

- 6 major CCGTs total of c. 7 GW
- range of OEMs, portfolio includes some of UK’s newest and most efficient plant
- largest natural gas customer on the NTS

RWE Renewables - Green Hydrogen Potential, noting we are ‘colour blind on hydrogen’

RWE Generation UK
Deblending Thoughts

Existing CCGTs are the largest single point consumption locations for Natural Gas

- a 2.2 GW CCGT consumes 50t/h/unit of natural gas ~ >250t/h
- 20% hydrogen by volume would require about 1.5t/h/unit of H2
- The key issue therefore is will power stations be sensitive users of NG/H2?
- If sensitive users (require deblending) this could be a major obstacles to hydrogen into NTS

Challenges:

- Commercial implications – business models must work
- Technical issues - Gas quality (Wobbe Index and flame speed) – risk of derate and emissions
- Variability and rate of change
- Operations and Maintenance implications

How do we establish the limits?

- RWE Activities as part of SWIC

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Q&A

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Ask the Audience

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Opportunities & Next Steps: FutureGrid

Tom Neal
(National Grid Gas Transmission)

HyNTS FutureGrid
Roadmap to Hydrogen

This ambitious programme seeks to build a hydrogen test facility from decommissioned assets at DNV GL Spadeadam, building on the existing H21 facilities. This will allow for comprehensive testing to demonstrate the ability to transport hydrogen within the National Transmission System (NTS) and accelerate the energy system transition to Net Zero by 2050.

Planning Phase
Pathway to FutureGrid

Defining the principles, specification and pipeline configuration of the test facility through an NIA project, to allow for timely building and testing.

Duration
May 2020 – Mar 2021

Funding
NIA Funding

Phase 1
NTS Hydrogen Test Facility

Build an offline hydrogen test facility using decommissioned assets to assess the impact that blends of hydrogen up to 100% will have, to facilitate the gas network transition to hydrogen.

Duration
Apr 2021 – Apr 2023

Funding
NIC 2020 Bid

Phase 2
Deblending & Compression

Validate deblending technologies to separate hydrogen from natural gas and demonstrate its impact on operating compressors, to enable a flexible system transition to hydrogen.

Duration
2022 – 2024

Funding
SIF or BEIS

Phase 3
Third Party Testing & Collaboration

Open the facility for third party testing, to allow for new technology trials and manufacturer led impact assessments, to accelerate the supply chain transition to hydrogen.

Duration
2023 Onwards

Funding
Various Innovation Funds

Opportunities & Next Steps: H21 Distribution Facility

Mark Danter
(Northern Gas Networks)

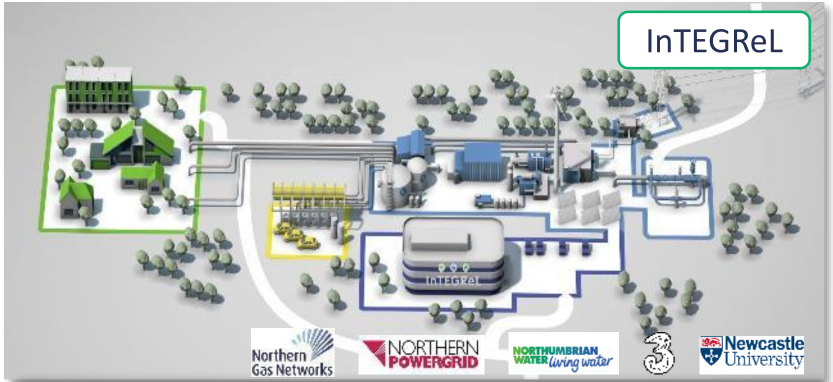
Real world demonstrator

HYDROGEN

Cookers Fires Boilers Metering

Industry Collaboration: Develop a typical family home at the InTEGReL site in Gateshead, fitted with 100% hydrogen appliances.

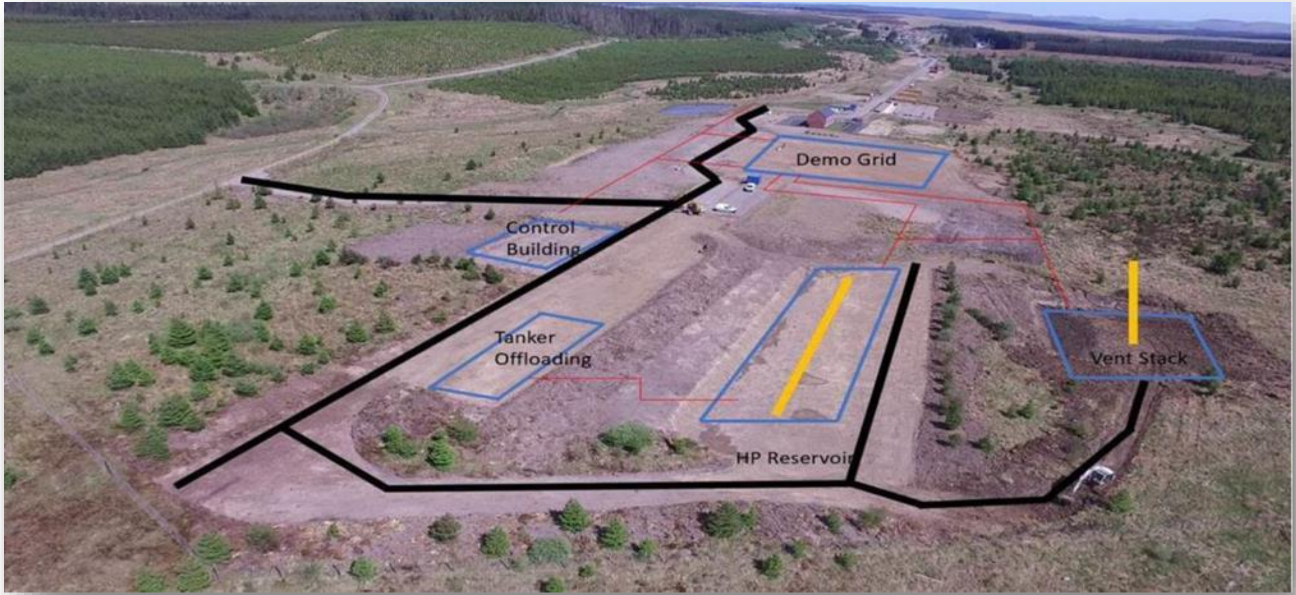
- Customer gain insight into supply chain capability
- Breaks down barriers for hydrogen heat solutions
- Celebrates UK capability and innovation
- Points towards a Net Zero future for the GB gas industry
- Simple and accessible illustration of a possible Net Zero future



Whole Energy Systems Research and Demonstration facility

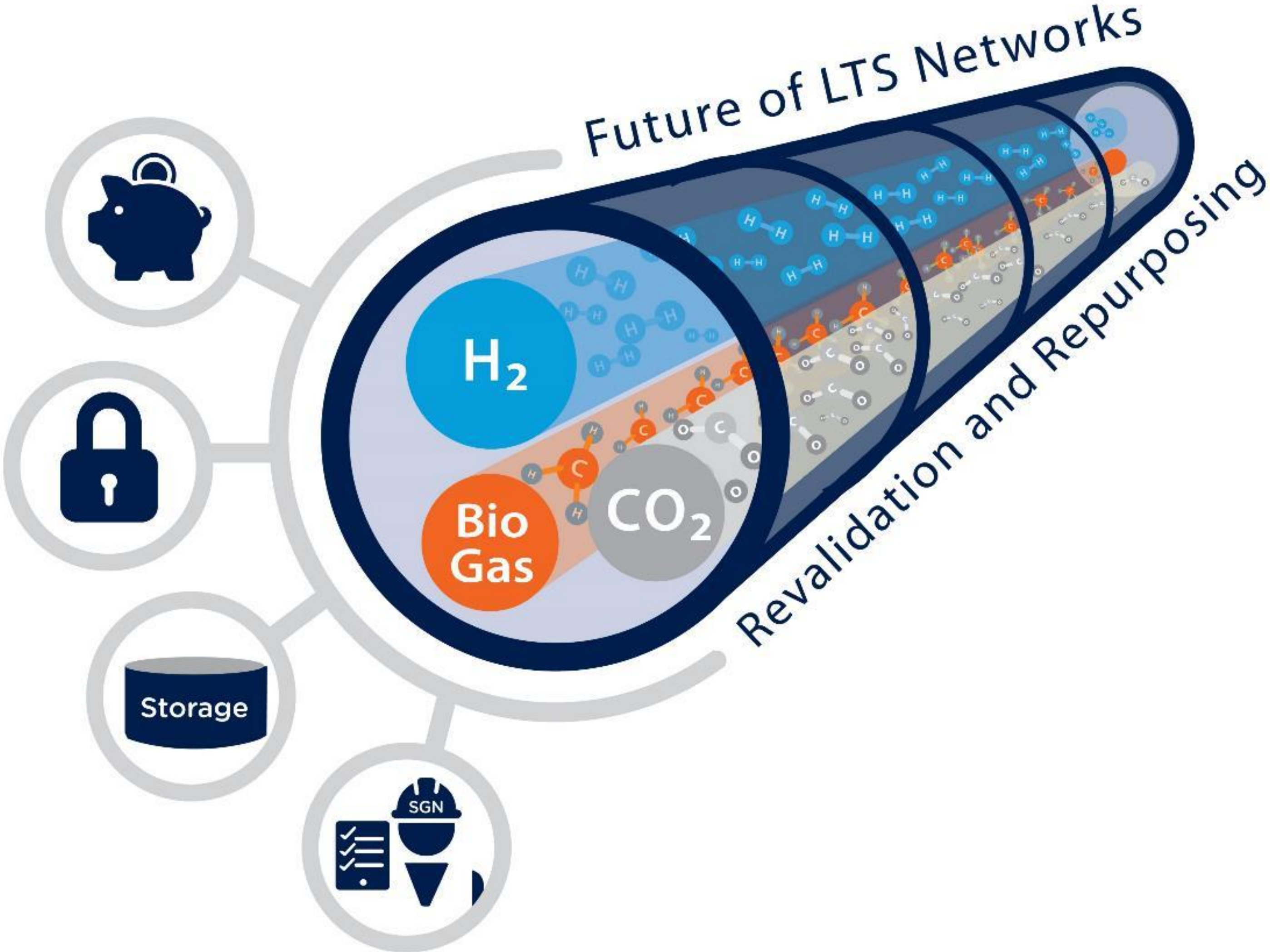
H21 Phase 2: Micro Grid Development

- H21 Micro Grid Construction 2020
  - To replicate distribution conditions and test operational practices
- NG Future Grid expansion 2021
  - to create a comprehensive Transmission and Distribution Test Environment

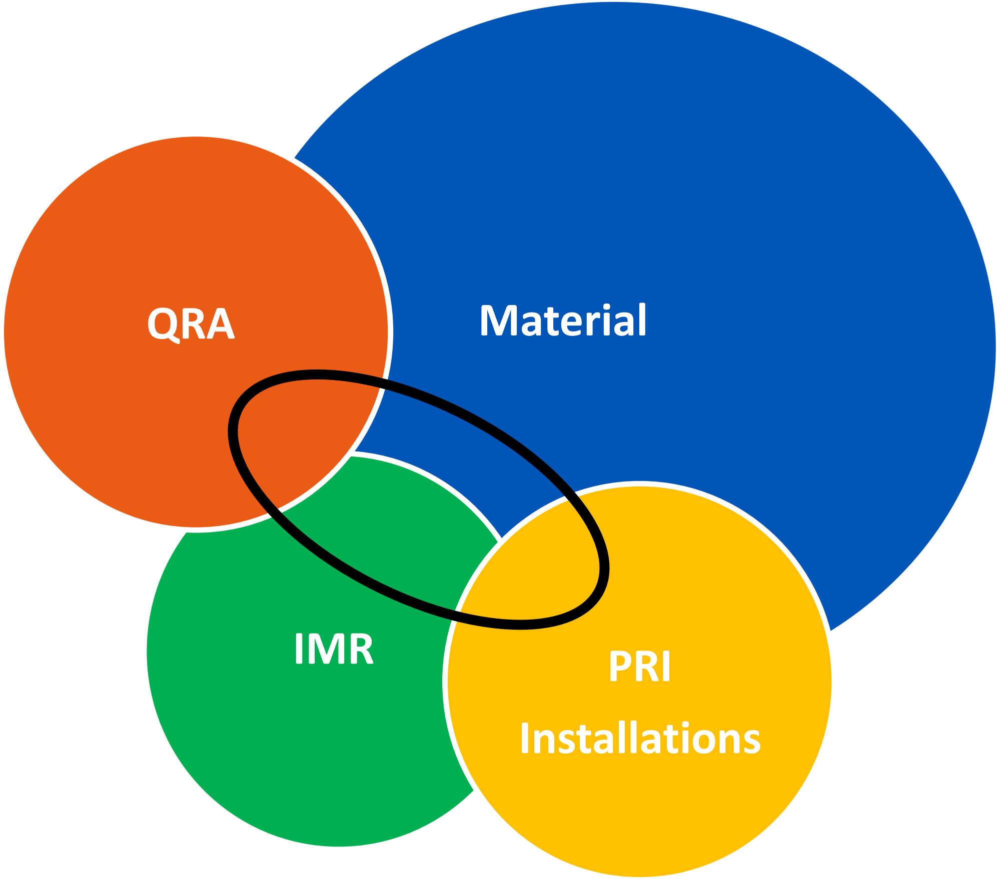


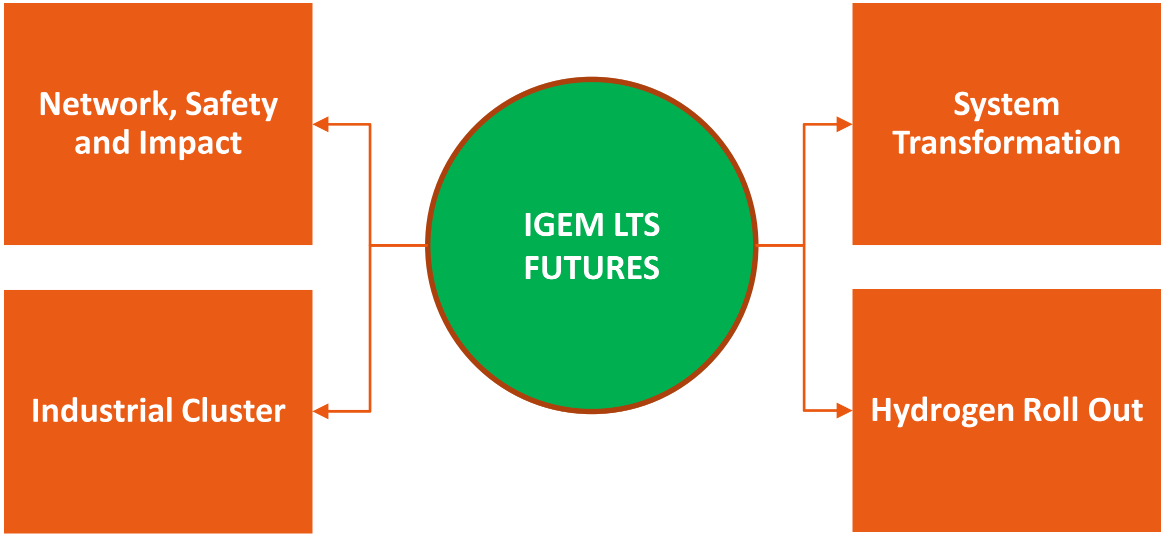
Opportunities & Next Steps: LTS Futures

Nancy Thomson
(SGN)

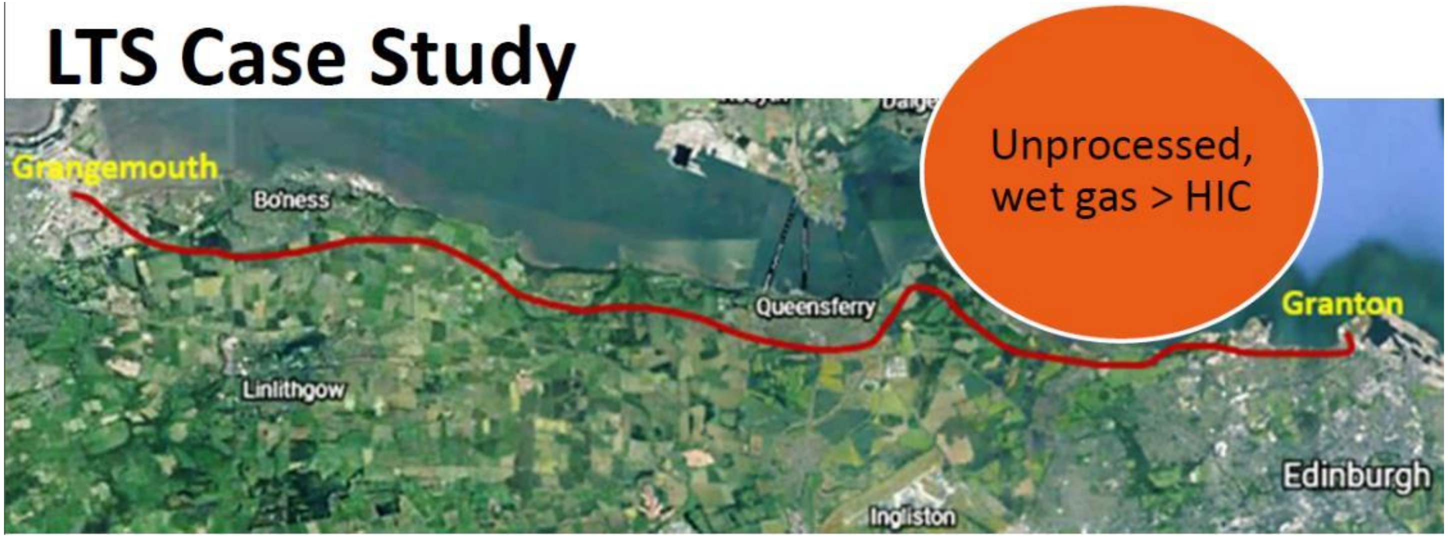

Future of LTS Networks
Revalidation and Repurposing
H_2
Bio Gas
CO_2
Storage
SGN

GAPS




Network, Safety and Impact
Industrial Cluster
IGEM LTS FUTURES
System Transformation
Hydrogen Roll Out

LTS Case Study



Wrap up & summary

Antony Green

(National Grid Gas Transmission)

THANK YOU

GAS GOES GREEN