Hydrogen –A brief history…

Mark Crowther

.

Trust
Quality
Progress

2009- Need for Low-Carbon Technologies

Climate change

Human activity is causing climate change

Greenhouse gases (CO_2, NO_X, CH_4, etc)

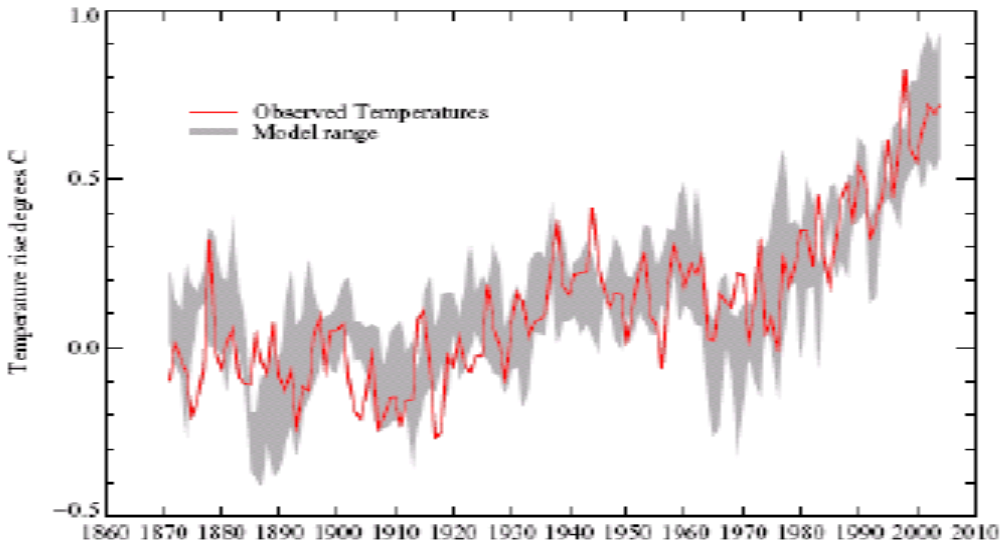
Energy security

Limited resources

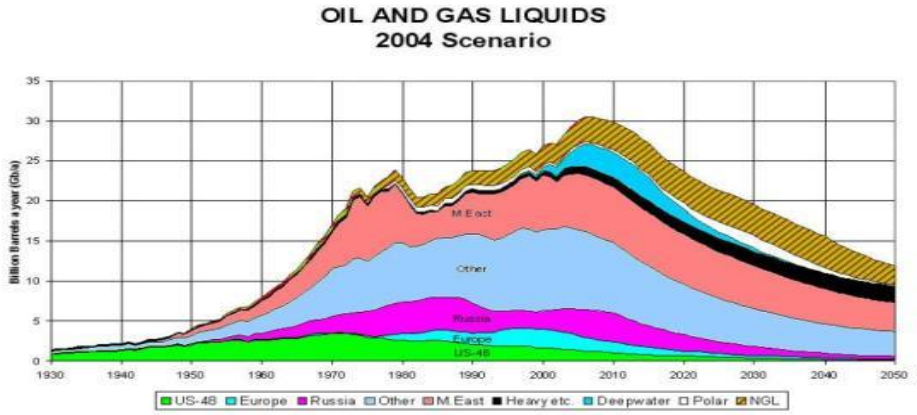
Political instability of oil-producing regions

Indigenous energy supplies (and political control)

Diversity



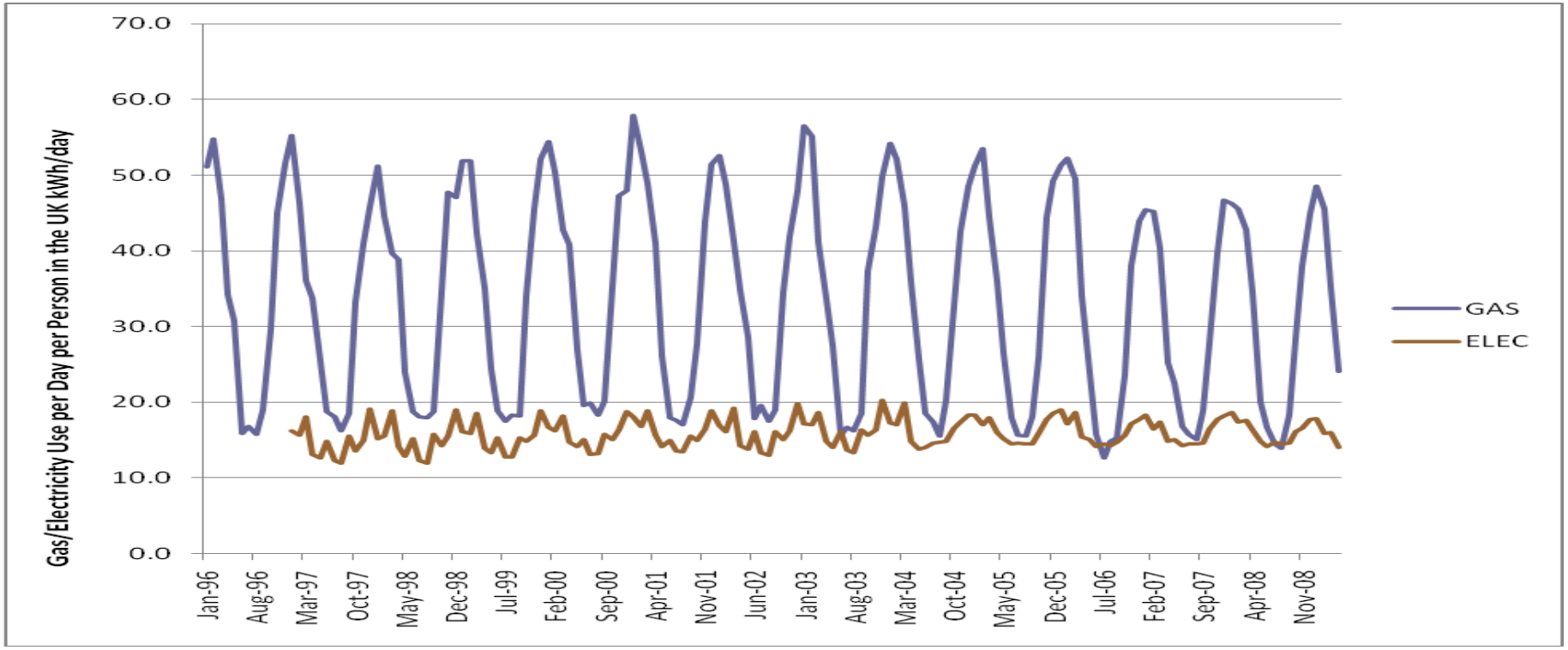
Source: Hadley Centre



2009- Challenge set by inter-seasonal demand

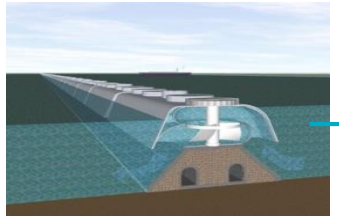
The UK gas plus electricity demand (minus gas to power stations) is strongly seasonal.

Daily gas peaks can be even twice these values.



February 2012

Kiwa Gastec (Mark Crowther) gave a presentation to UK Dept of Energy and Climate Change on bulk distributed hydrogen



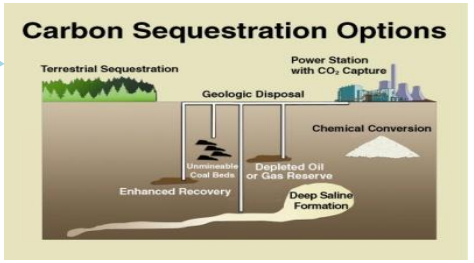
DC

Biomass gasifier

HP electrolyser

Siemens gasifier

CO_2



Underground H2 store

Existing PE network

Rutland plastics

H_2

Domestic

Commercial

Transport

Industry

2011- Sahara

Red square shows land area for UK energy supply at 300 kWh/m^2/y

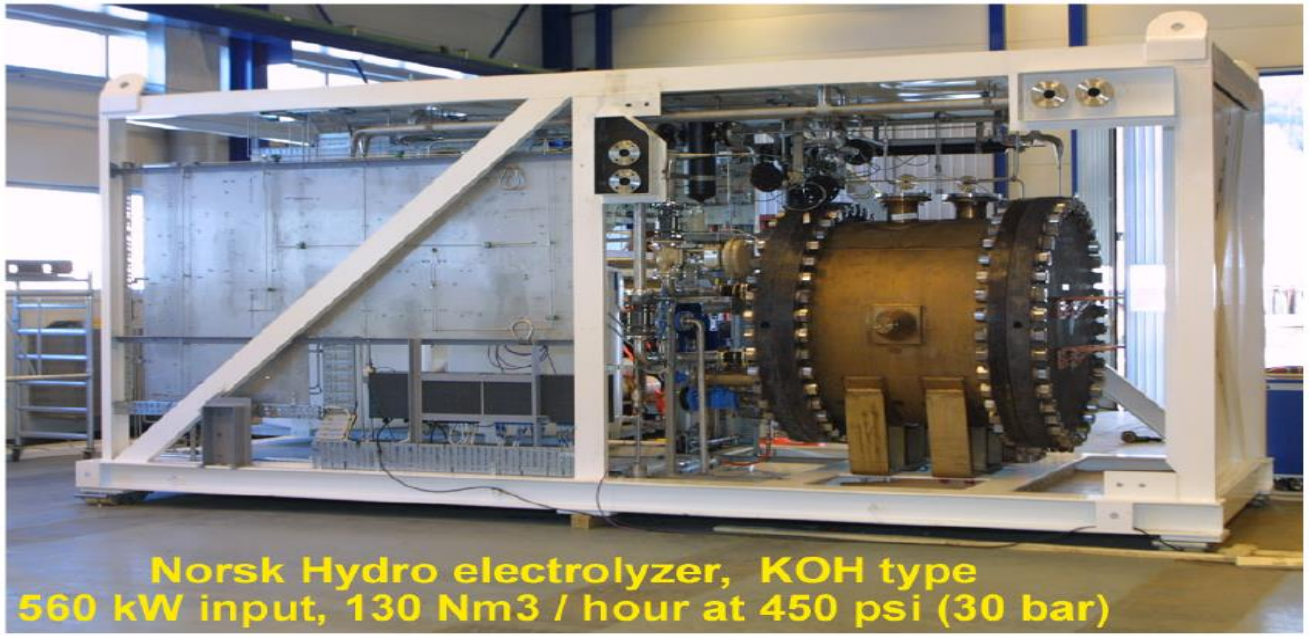
2011- Why hydrogen?

Low cost to:

- Produce
- Transport
- Store
- Distribute
- Use

By Electrolysis

By electrolysis from renewable sources - eg this electrolyser operates at an efficiency of around 80% (including ancillary power consumption)



Hydrogen transport

Low pressure H_2 - broadly similar transport properties to natural gas

At 85bar$_g$ it has a lower compressibility factor and is somewhat more difficult to compress so a new hydrogen transmission system will need slightly larger pipes and more complex compressor stations, but the cost is still very low

Natural gas can be brought from Siberia to UK for <1p/kWh

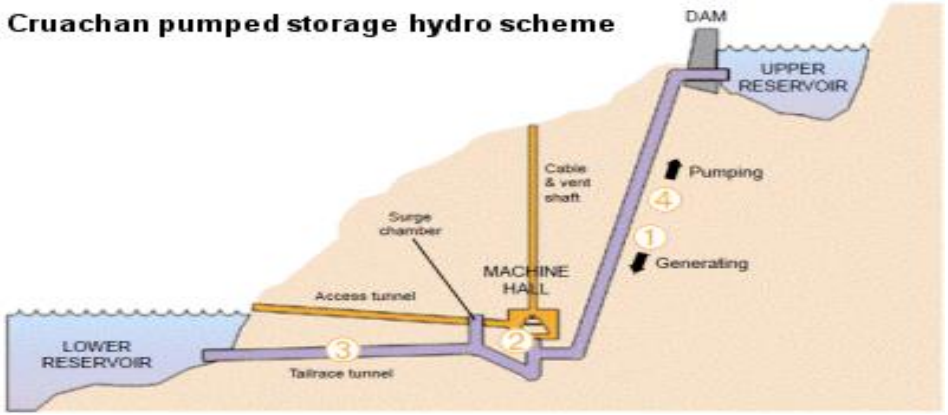
	MW	Dist km	Project Cost	£/MW.km	Ref GaC from public data
Brit Ned	1000	240	£540,000,000	£2,250	Sub-sea HVDC
Scotland wind	2700	220	£350,000,000	£589	Beauly-Denny, Scotland
S Wales NTS	24000	316	£700,000,000	£92	Milford Haven to Stroud

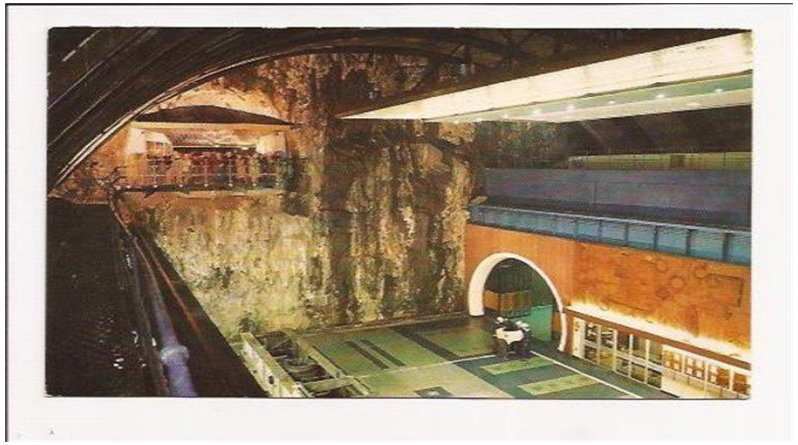
Anecdotally the transportation/delivery cost of fuel vectors was:

	Nat gas	Elecricity	District heat
Relative cost kWh/km	1	X7	X49

Hydrogen Storage

Hydrogen storage cavern for Air Liquide at the Spindletop Dome near Beaumont in southeast Texas = 50 off of these:

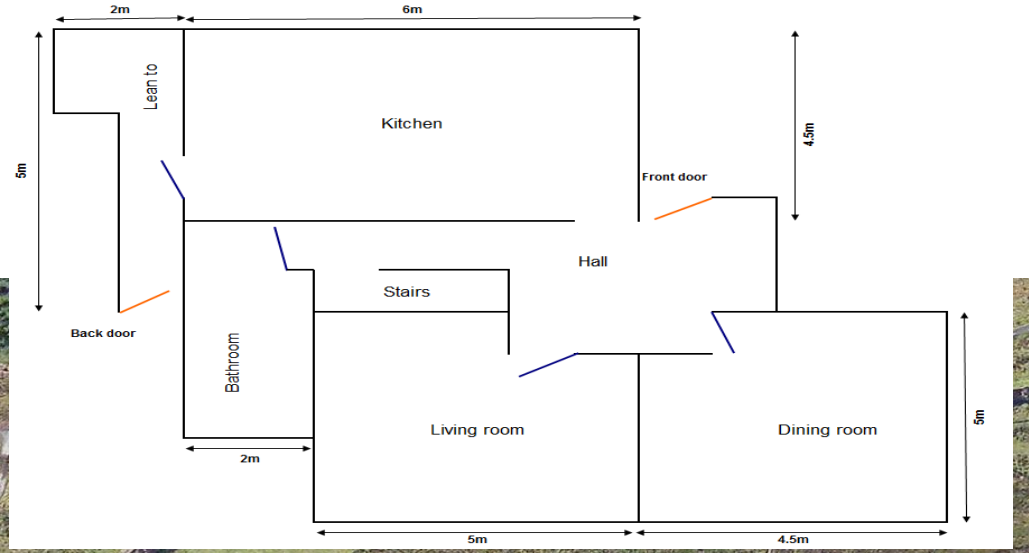




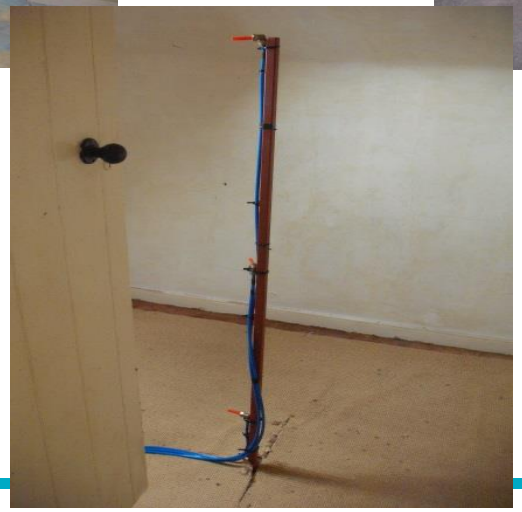
2014 Hyhouse- Kiwa Gastec first investigation of movement of hydrogen in old farmhouse

HyHouse Property Details

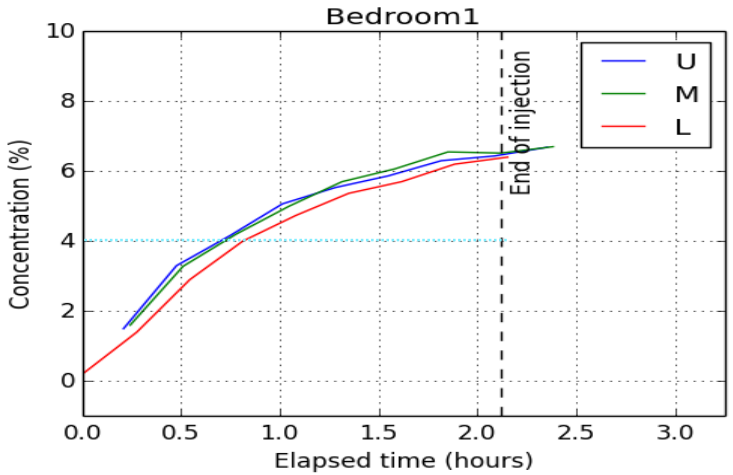
Glenglass located near Sanquhar in Scotland

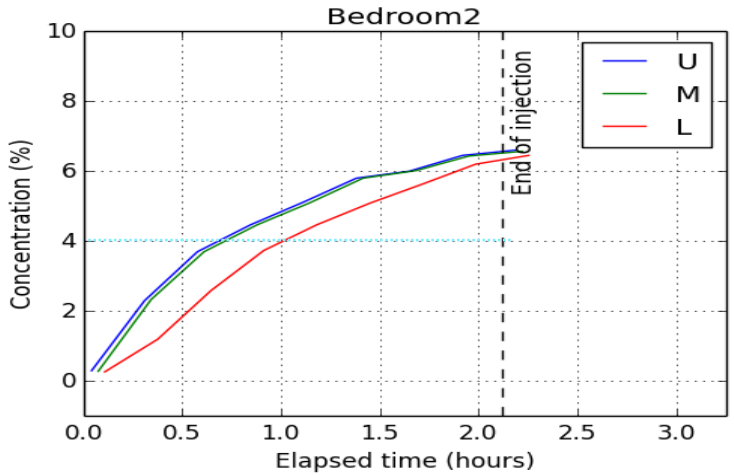


Experimental Work – Sample Points



Experimental Results (64kW) – 100% Hydrogen

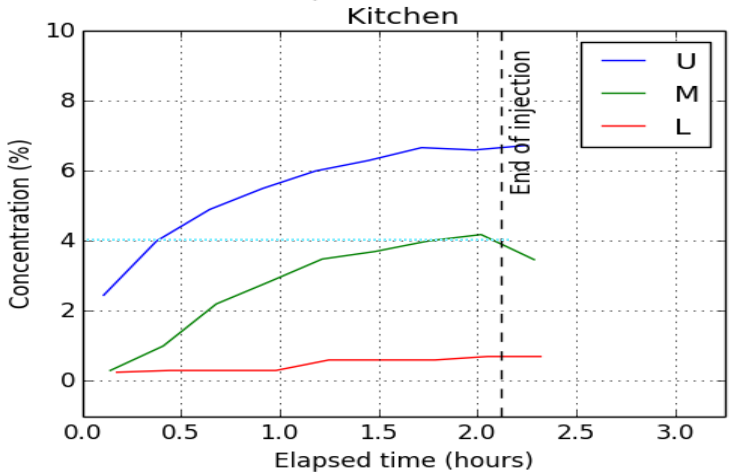


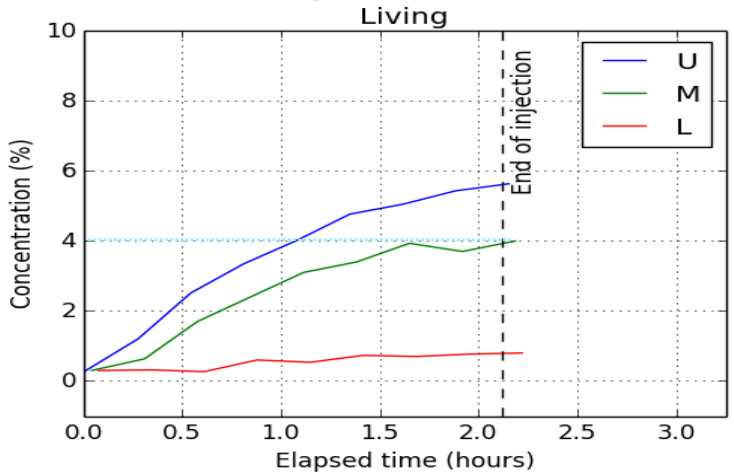


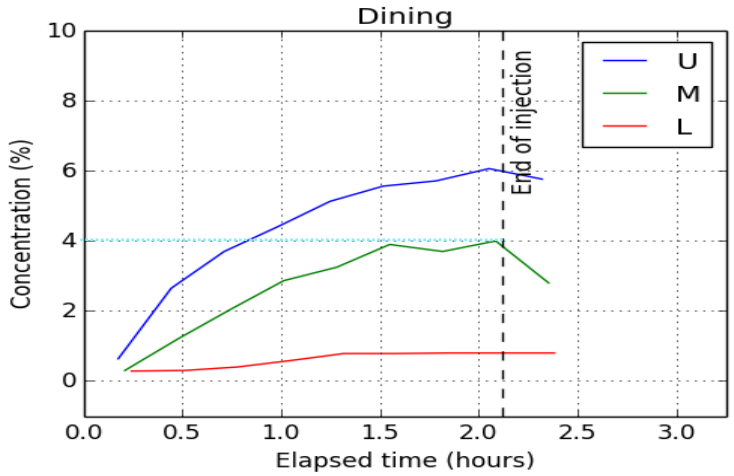
Test 030
Hydrogen

Date	14/08/2014
Start of injection	11:08:00
End of injection	13:15:00
End of test	13:31:00
H2	100%
CH4	0%
CO2	0%
Flow rate	316 l/min, 64kW
Release point	Kitchen
Wind speed	nan km/h
Zero correction	No

weather station not working. Programme froze at 13:31







2015 Kiwa Gastec main contractors for Northern Gas Networks Leeds H21 project.

The design of supply and distribution of hydrogen to a city of 260,000 properties using SMR (1024MW) at Teesside and CCS

Kiwa UK – Consultancy Projects
Leeds H21 Citygate

Provided by 4 SMRs in Teeside – Daily Storage

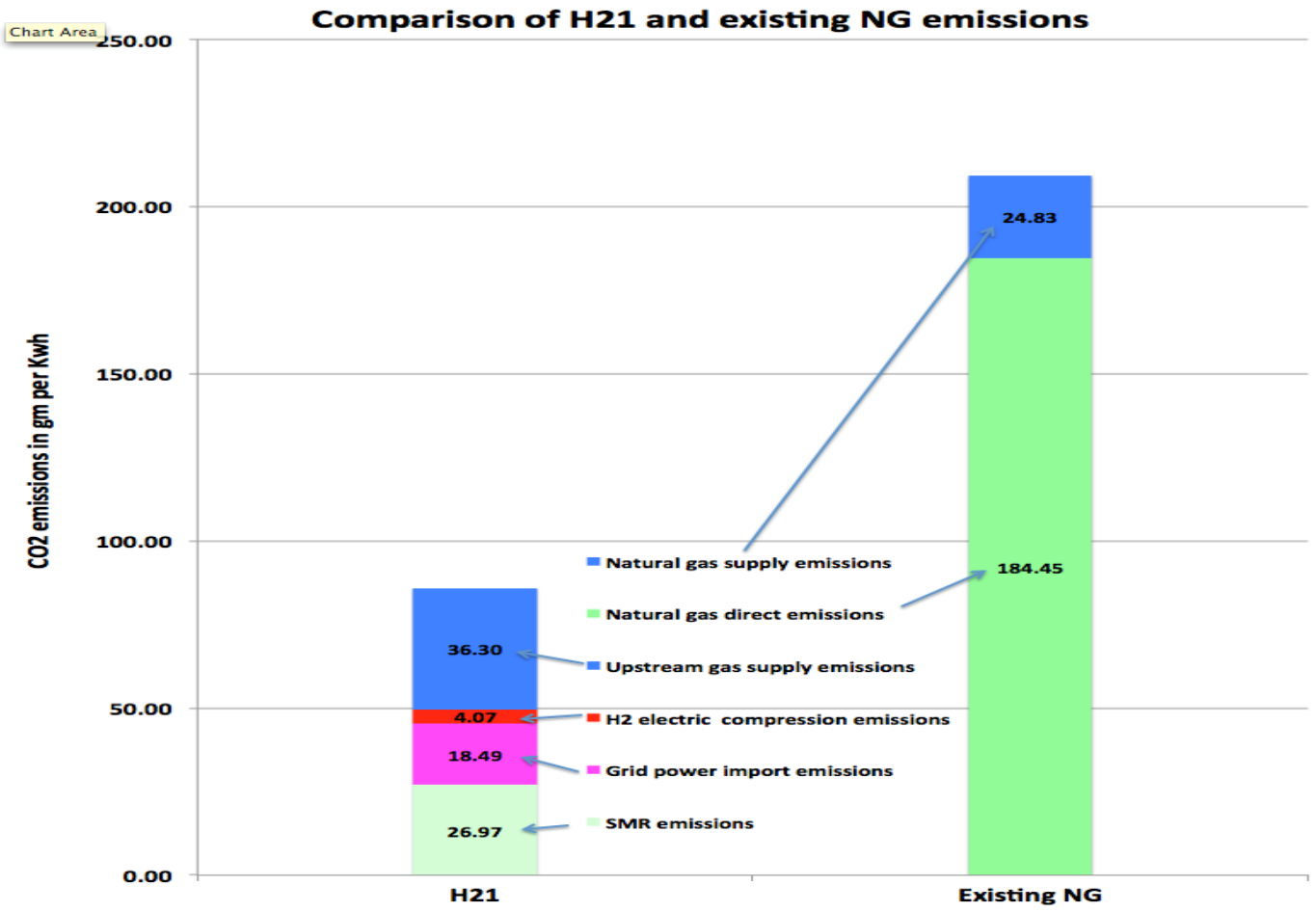
Demand Mapping - 1025 MW of pure continuous H_2 Supply is required

Overall cost £2bn 50:50 between appliance upgrades and H_2 production pipeline & storage

Initial annual costs of £140m/yr

Seasonal demand storage in Humberside salt caverns

Why SMR +CCS reduces carbon



Indicative costs of hydrogen

A few memorable numbers :
Hydrogen is more expensive than Nat Gas but much cheaper than electricity

p/kWh	H2	Nat Gas	Electricity
Retail	7.6	~4.8	15.8
Plus 1st conv:	9.3	NA	NA

•Complies with Stern valuation of global warming. 1.5% of GDP.

Ann Gas	kWh/y	£	6,000,000,000
H2 Leeds H21	£/kWh	£	0.093
Current cost NG	£/kWh	£	0.047
Marginal cost	£/kWh	£	0.046
Total marginal	£/yr	£	276,000,000
GVA Leeds	£/yr	£	18,800,000,000
Leeds H21 as % GVA			1.47%

Costs from H21 Leeds

Cost of Leeds H21	
£	£ 2,054,000,000
Houses	266,000
Cost/house (Well to SOFA)	£ 7,721.80
Roughly	
Appliance change over	£1bn
Hydrogen supply	£1bn
Compared to	
Hinckley C	£18-24bn
Sellafield wires ONLY	£2.8bn

2017 Kiwa Gastec technical consultants H100

SGN ‘s project to provide a new purpose built network to provide hydrogen to 300-500 houses somewhere in Scotland.

2017 – Kiwa Gastec Technical Lead on £25m BEIS Hy4Heat

Hydrogen:

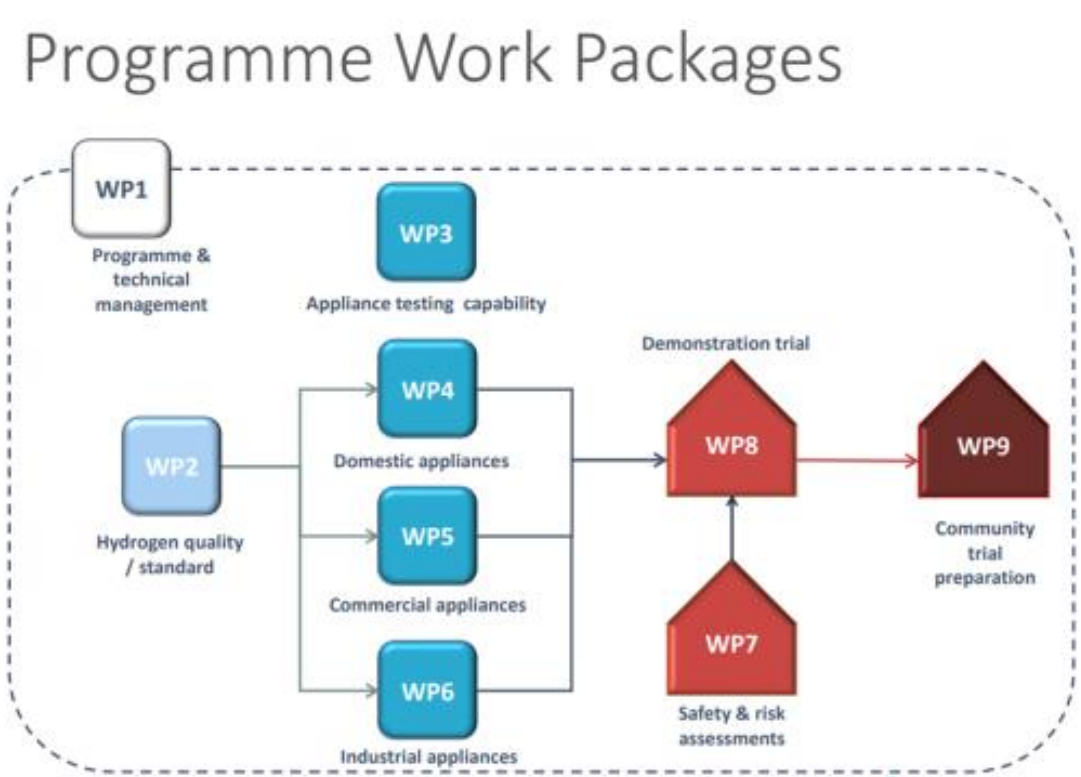
Boilers

Cookers

Fires

Evidence:

Occupied Trial



Department for Business, Energy & Industrial Strategy

kiwa

ARUP

Hy4Heat

kiwa

H100 Examples of Kiwa Gastec projects

Kiwa Gastec have been retained by the SGN H100 project

to ignite mocked-up kitchens subsequent to

a number of simulated natural gas and hydrogen leaks.

The gas release is predominantly within a sink cabinet fitted with

stainless single drainer and plates and pans.

Two fire dummies siting a table with books, newspapers etc.

(The work has been carried out in a Fire Investigation Box at the National Fire College Morton in Marsh)

Fire Service College FIB fired with 10% Hydrogen

Some final thoughts.

Life has risk.

Global warming is increasingly seen to offer tangible risk.

All energy vectors have risk, although some more than others.

Can lessons from one sector be transferred to another?

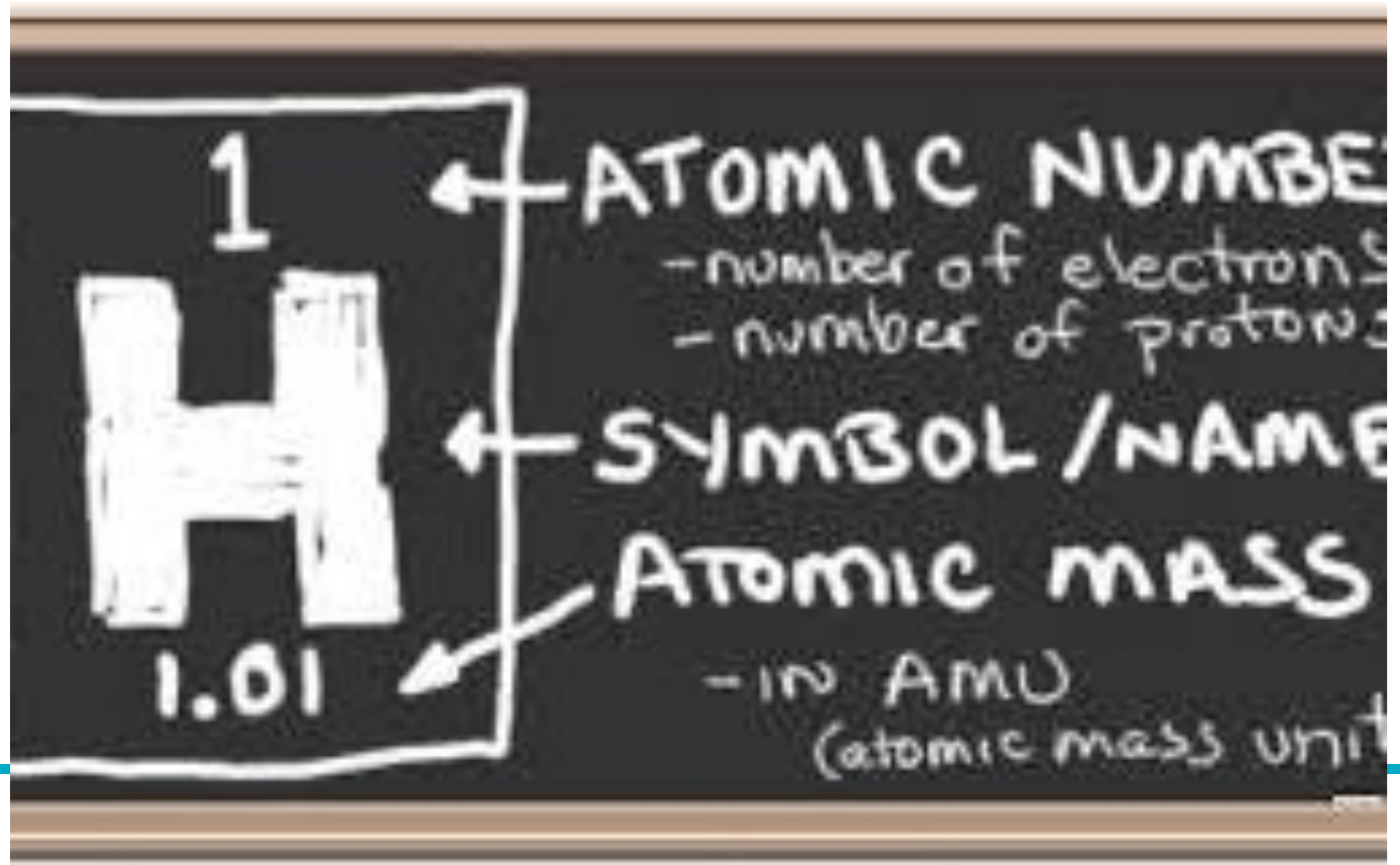
Using BOTH

- Historical and
- Experimental data

can we optimise designs to provide outcomes acceptable to all?

UK linked deaths/year	
% of world carbon emissions	1.10%
Excess deaths from climate change/year	250,000
UK climate change linked deaths/year	2,750
Electrocutions/year	About 20
Gas deaths from fire & explosion/year	1 to 2

UK Hydrogen Projects



Trust
Quality
Progress

UK Hydrogen journey

- UK committed early to carbon reduction
  - Quick wins achieved – power generation, EE
  - Heat and transport a challenge
  - Low carbon electrification – grid reinforcement ££££
- The “hydrogen economy” is not a new concept
  - JS Haldane 1923, Cambridge University
  - John Bockris 1970, GM Technical Centre
- Kiwa Gastec ***championed*** hydrogen as an energy vector with UK Govt.
  - Technology agnostic – H2 enables/drives an integrated energy system
- UK Govt. Clean Growth Strategy – 2030 and 2050 targets in mind
  - Hydrogen pathway described
  - “Lay the groundwork” now
  - Decisions in first half of next decade

Clean Growth Strategy

Evidence now, decision early 20s

The Future of Heat Decarbonisation

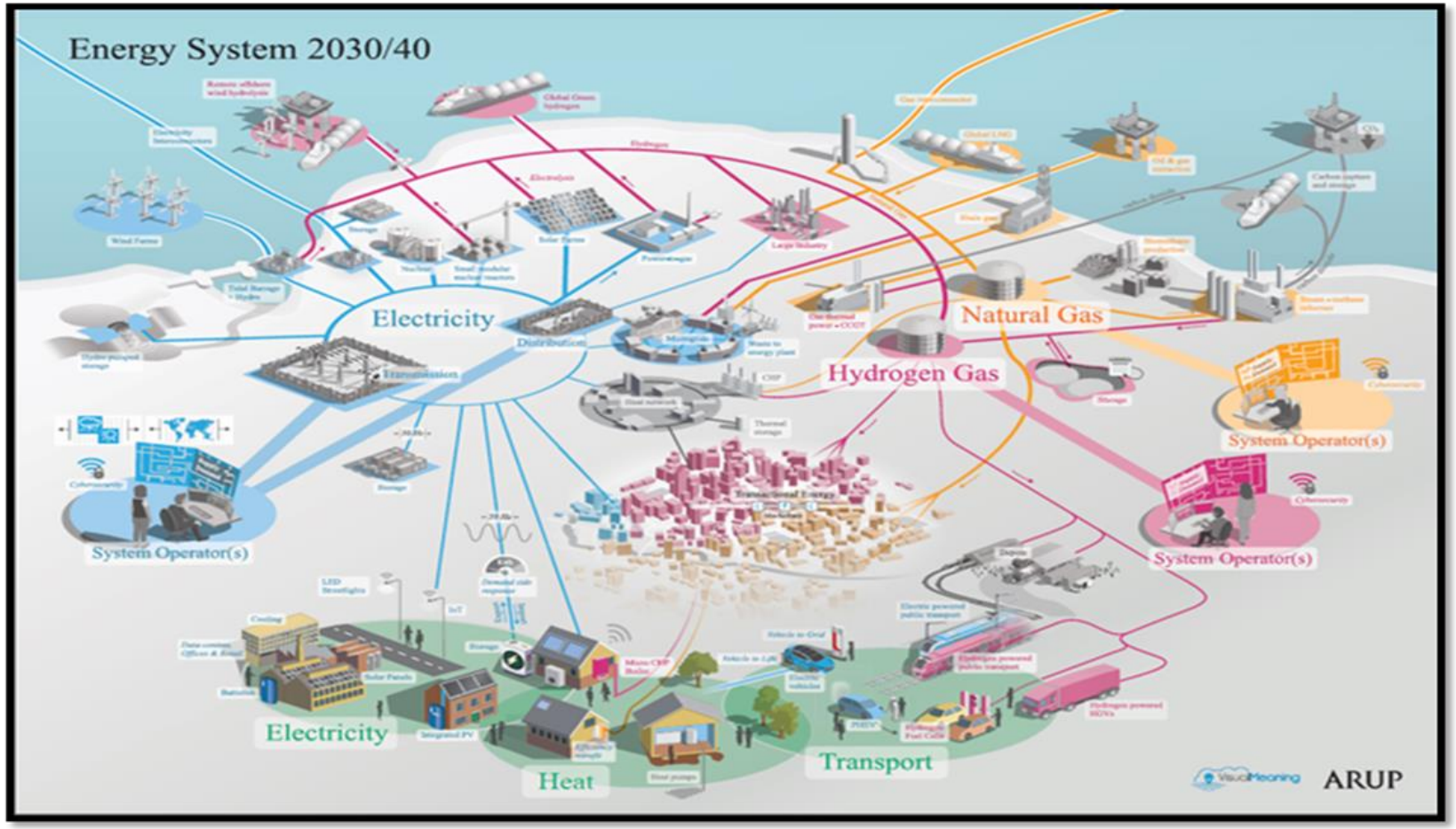
Heating our homes, businesses and industry accounts for nearly half of all energy use in the UK and a third of our carbon emissions. Nearly 70 per cent of our heat is produced from natural gas. Meeting our target of reducing emissions by at least 80 per cent by 2050 implies decarbonising nearly all heat in buildings and most industrial processes. Reducing the demand for heat through improved energy efficiency will have an important role to play but will not by itself suffice to meet our 2050 target.

We need to lay the groundwork in this Parliament to set up decisions in the first half of the next decade about the long term future of heat. The demands on our energy infrastructure will change as low carbon heating technologies take over from fossil fuels, with a greater dependence on electricity and potentially new infrastructure needed for system balancing and the generation of low carbon gases. Supply chains will need time to grow to provide products and services consumers across the country will need.

There is a range of low carbon heating technologies with the potential to support the scale of change needed. These include the electrification of heating with households moving away from gas or oil boilers, to electric heat pumps; decarbonising the gas grid by substituting natural gas with low carbon gases like biogas and hydrogen; and heat networks (which are likely to be particularly effective in dense urban areas). At present, it is not clear which approach will work best at scale and offer the most cost-effective, long term answer. We will work with industry, network operators, manufacturers, and consumers to achieve a clear and shared understanding of the potential as well as the costs and benefits and implications of different pathways for the long term decarbonisation of heat. This includes modelling the costs and benefits of different approaches, establishing the likely level of change for households and demands on the electricity grid building on the work of others in this field.

Government has commissioned research into different heat demand scenarios, the use of hydrogen, what changes might be needed to the electricity grid in response to large scale uptake of heat pumps, the role that bioenergy might play in decarbonising heat and international activity. We plan to publish initial findings from a number of studies later this year, and a full report on our review of the evidence by summer 2018.

What might the future look like?



Hydrogen is increasingly in the news

MET POLICE GOES ZERO-EMISSION WITH FLEET OF TOYOTA MIRAI HYDROGEN CARS

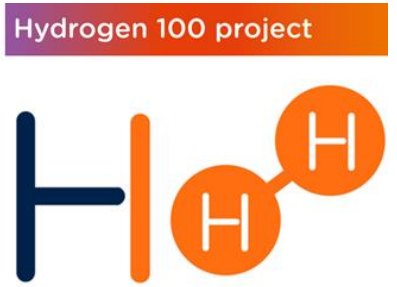
Hydro, hydro, hydro: what's all this, then?

Green Tomato Cars were founded by 2 ex-legal eagles in 2006. Their belief was that a car service can combine high standards and an environmentally focused approach. Eleven years later and that ethos has proven correct. Whilst other car companies play catch up with technology and environmental laws, we create and embrace change.

From being the first car service in London to operate the Toyota Prius as their flagship vehicle we are now the first to use the Hydrogen Fuel Cell Toyota Mirai.

Our quirky Green Tomato logo dotted all over our vehicles originally caught London's eye. As we have matured as a business, so has our logo. The locator imagery reflects how seriously we take duty of care, highly visible on our vehicle's roofs and driver's name boards.

We deal with people, not numbers. We have always resisted the 'call sign' approach when addressing our drivers. We are more "Good morning Jonny"; than "Come in B214". Beyond this we ensure all drivers meet the staff in our head office when they start and attend monthly questions days and bi-annual director briefings.



Our Hydrogen 100 project has been designed to demonstrate the safe, secure and reliable distribution of hydrogen.

Transport a slow start but growing – but OLEV not driving H2

Hydrogen 700 bar Refuelling Hubs

10 open now:

- **5** London S.E.
- **2** Swindon
- **1** Sheffield
- **1** Aberdeen
- **1** Beaconsfield

6 opening 2018 -2019

- +1 Aberdeen – Nov 27
- Gatwick - Dec
- Derby
- Birmingham
- +2 London

AIR PRODUCTS

BOC
A Member of The Linde Group

ITM POWER
Energy Storage | Clean Fuel

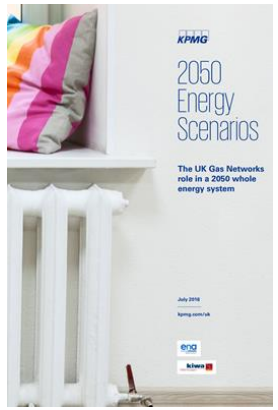
HYDROGENICS

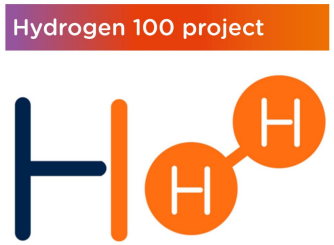
TOYOTA

Hydrogen and Fuel Cell Sho[illegible]

Projects – a selection – laying the groundwork

- HyHouse
- Island Hydrogen - EcoIsland – Isle of Wight
- Strategy
  - ENA Future Energy Scenarios
  - Policy Exchange “Fuelling the future”
  - IRENA – H2 from Renewable Power……technology Transition
- Transport – HyTransit, HyTEC, HYFIVE, JIVE, HyDIME
- BEIS H2 Appliances – Kiwa, Fraser Nash
  - Hydrogen Appliances £25M
  - Hydrogen supply £20M
- HyDeploy
- HyNet
- H21 Citygate –led to BEIS engagement, H21 North of England
- Hy4Heat – driving standards, safety case and supporting appliance development
- H100
- HG2V – Network purity
- Technology research – Neptune, Heatstack, AutoRe
- OEMs testing heating and mCHP systems, components





HyHouse

Kiwa and SSE project

- Aim - to investigate the behaviour of leaks in a domestic property
- Method –
  - Remote farmhouse – sealed and unsealed
  - Fed with 100% Natural gas, 3 mixes of NG/H2, 100% hydrogen
  - Various leaks simulated and gas concentrations evaluated within property

- Outcomes – demonstrated to the gas industry that hydrogen does not inherently offer risks over and above other flammable gases, for example Natural Gas, with appropriate engineering

HyDeploy

- Funded by OFGEM NIA, Cadent, NGN hosted at Keele University

- Aim is to establish the potential for injecting up to 20% Hydrogen in the natural gas grid:
  - Phase 1 safety
    - testing of appliances in situ using bottle wagons of limit gases
    - Development of quantitative Risk Assessment – evidence for HSE
  - Phase 2 Build and commission
  - Phase 3 –production of H2 from 0.5MW ITM Power electrolyser and 12 month trial of injected hydrogen

- The goal of HyDeploy is to demonstrate that a blend of hydrogen and natural gas can be used by customers without any changes to their behaviour or existing gas appliances.
  - Grid injection an important step in growing competency and resource - Hubs

- Status – safety case successfully reviewed

Hy4Heat

Department for Business, Energy & Industrial Strategy

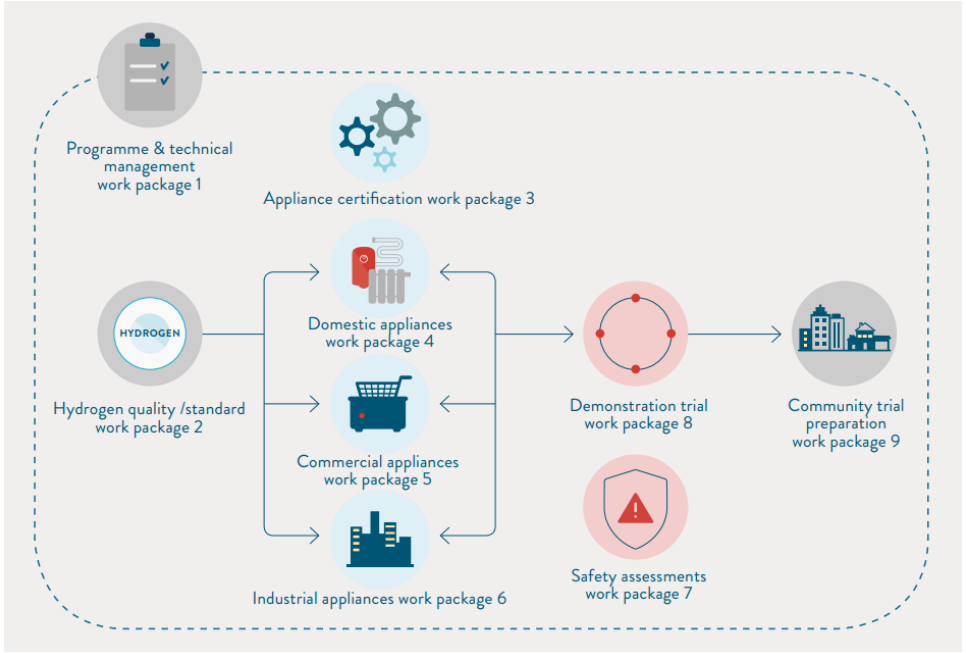
- Arup+ Team – Arup, Kiwa, YOEnergy, Progressive Energy, Embers

- Project mission - To establish if it is technically possible, safe, and convenient to replace natural gas (methane) with hydrogen in residential and commercial buildings and gas appliances. This will enable the government to determine whether to proceed to a community trial

- Method
  - Interconnected work packages
  - aimed at de-risking the decision to proceed with trials

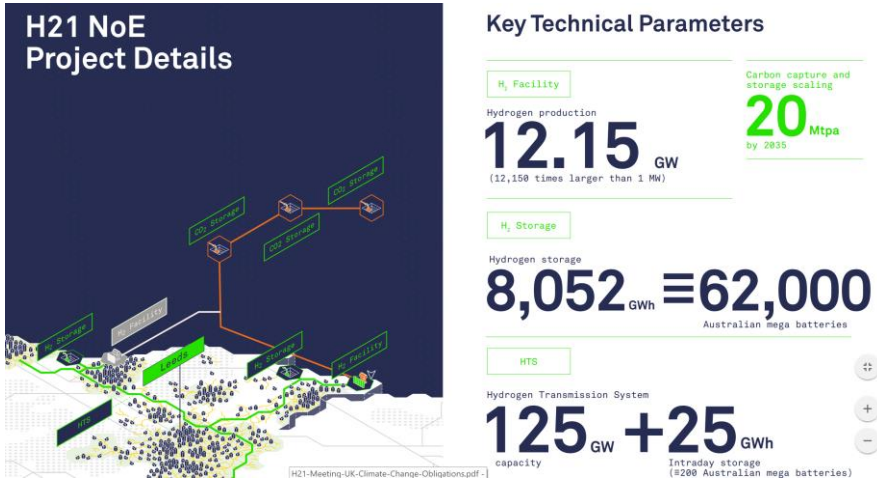
- Status
  - live and ongoing
  - Extended to metering, safety case
  - contracts let on various WPs
    - Including gas quality

Hy4Heat programme work packages



H21 North of England

- Project partners NGN Cadent Equinor
- H21 North of England is a detailed engineering solution for converting 3.7 million UK homes and businesses from natural gas to hydrogen
- Presents a bold vision of how a future deep decarbonisation of heat and transport using hydrogen could look; H21XL proposes summertime diversion of H2 to power generation
  - Posits potential 80% of remaining carbon reduction requirement could be met with roll-out
- Financial indicators:
  - £22bn CAPEX
  - £955M opex
  - Gas bills ↑ £57 – 7%
- Proposes a £250M FEED study



Hydrogen 100

SGN project designed to demonstrate the…

- Safe
- Secure
- Reliable

…distribution of Hydrogen.

A feasibility study that…

- Builds on prior work
- Develops site specific evidence
- Has a “social proof roadmap”

Hydrogen 100 project

…to support the construction of a physical 100% hydrogen demonstration.

Common themes and learnings……

……over to Mark

Kiwa Gastec – Moving towards Piped Hydrogen in the UK

Dr Mark Eldridge 10th December, Apeldoorn 2018

Kiwa Gastec

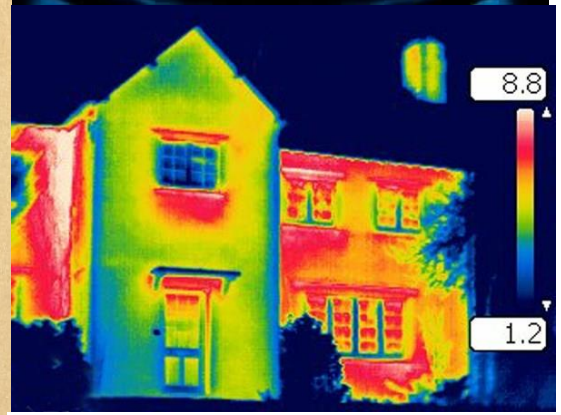
Trust
Quality
Progress

Key themes

1. The decarbonisation of Heat, Transport and Industry
2. The Whole Energy System
3. Future Networks and Markets

Scale – Cities, Counties, GDNOs, National Policy

Hydrogen Perspectives?



Hydrogen & KIWA

Experience by doing – Kiwa holds a unique position

Practical (on the ground experience)

Technical Expertise (40 years)

Thought Leadership – UK Plc

UK Notified Body, Test House and Consultancy

Project Breadth of knowledge
We are technically agnostic
The devil is in the detail of doing

Government Policy

Flexibility and skill in moving from end to end

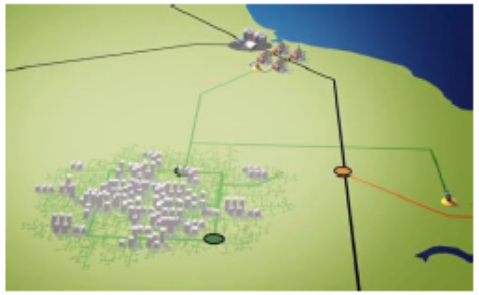
Kiwa UK – Hydrogen in the Gas Grid

Hydrogen Grid Feasibility – Progress over time

Safety?

HyHouse

Economically Feasible?



Leeds H21

Technically Feasible?

HyDeploy

Keele University

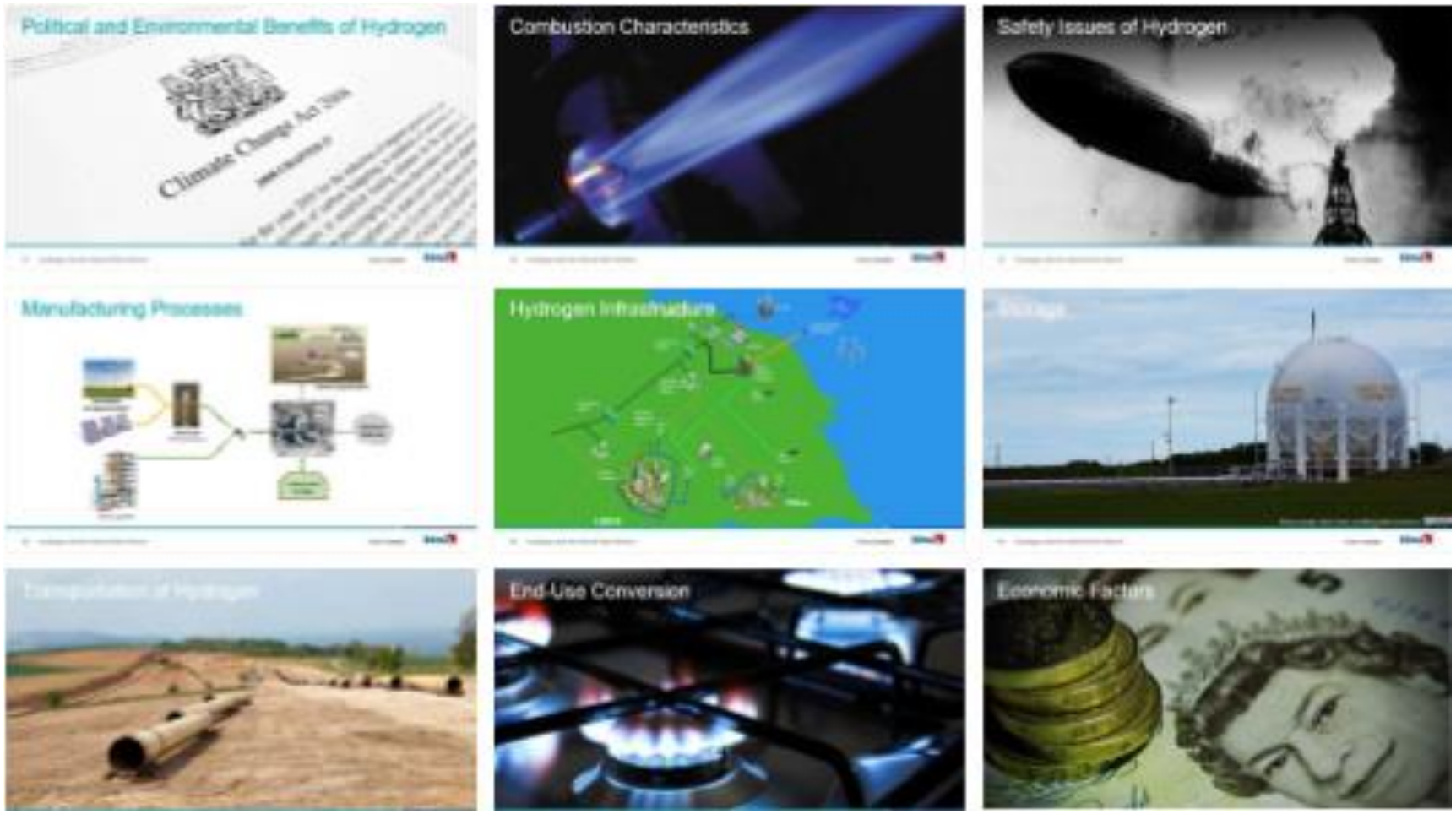
Practicality?

Hy4Heat

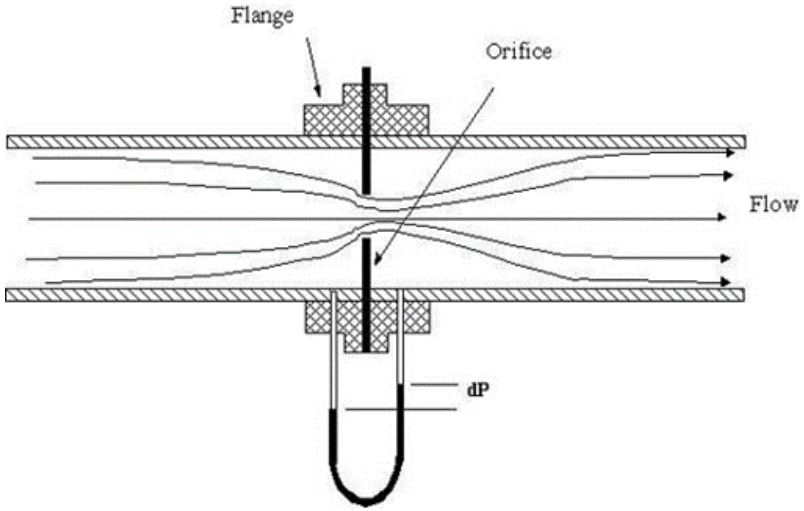
Hydrogen 100 project

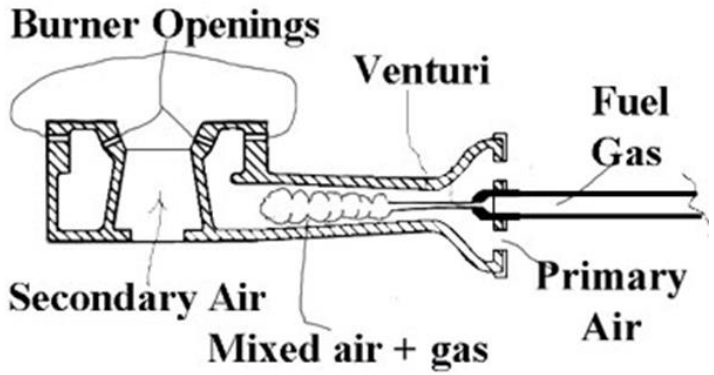
Hydrogen Technology Enabler?

Kiwa Hydrogen – Training? Where do the next generation of Engineers come from?
Hydrogen & The Natural Gas Network



Areas to consider. Imagine a pipe – Hydrogen and Methane – Gas Flow





Where Today is Kiwa UK Adding Value

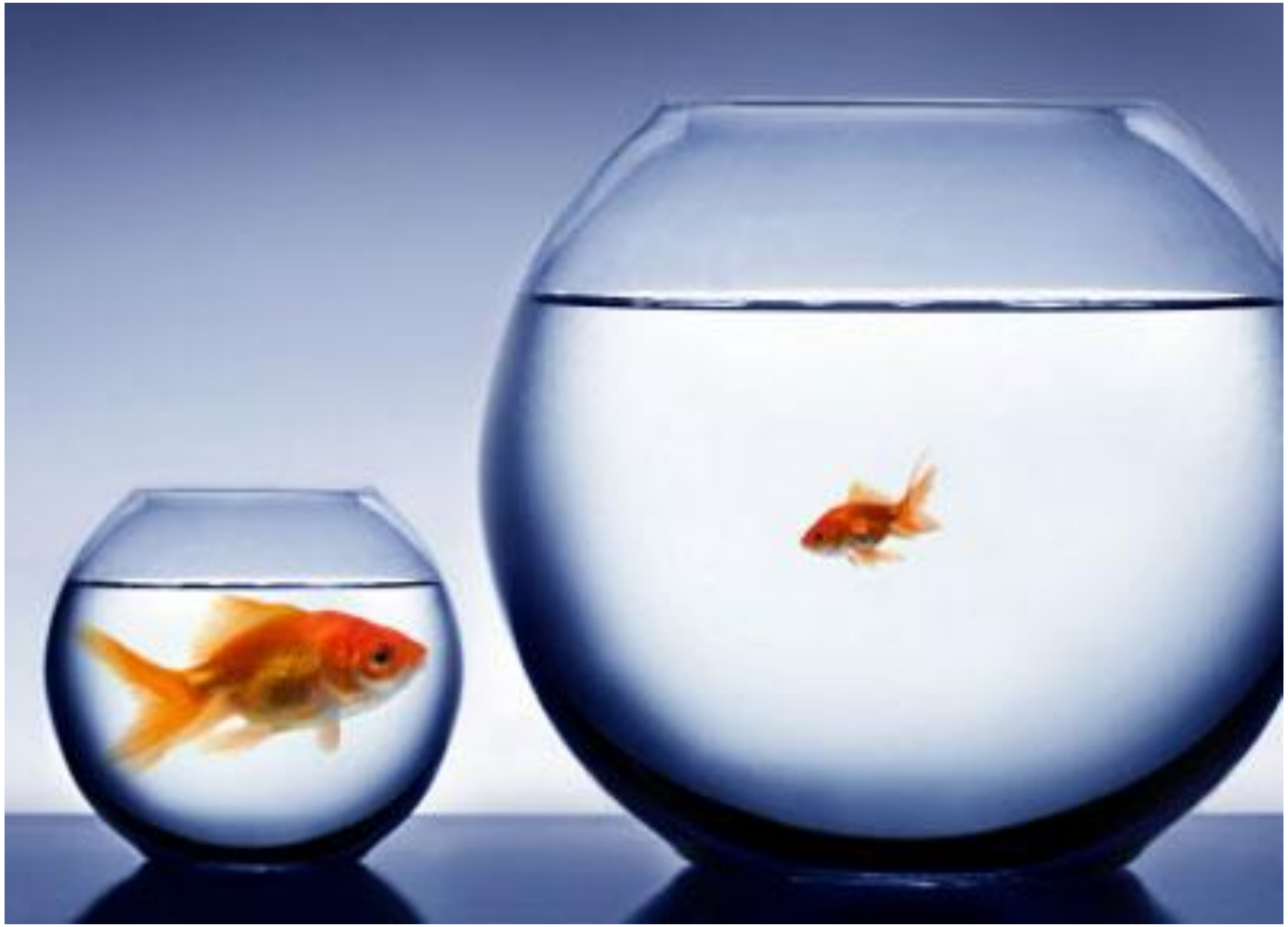
- Understanding and Awareness – training and information
- Building up the Safety Case for the Differences between Methane and Hydrogen
- Quantified Risk Assessment (QRA) between Methane and Hydrogen

- Hydrogen Standards – What are they. Working with IGEM and other UK Bodies such as BSI / HSE

- Macroeconomics - What are the Infrastructure Economics for Hydrogen Roll-Out – How are these Modelled

- What are the challenges of Hydrogen Roll-Out ???
  - At a network level
  - At a safety level – upstream and downstream of the meter
  - What is the pipework infrastructure upstream and downstream of the meter
  - What appliances exist for Boilers, Cookers and Fires
  - How do you develop these
  - How do you demonstrate these
  - What would be required to achieved an occupied trial
  - How would the consumers feel and receive such a change
  - How quickly can you do this based on the time we must achieve change.

Hydrogen and Risk vs Methane - Comparison



Hydrogen Risk – What is the risk assessment for transition?

Can never eliminate risk entirely in life – but what is acceptable?

- Electricity: 1400 injuries; 8 fatalities per year

Number of fatalities from gas incidents is comparable to those from dog bites or lightning strikes

Kiwa UK have an established expertise in this area

Safety of the Gas Industry….

The GB gas industry is very safe.

About 23million connections

About 430,000 publically reportable escapes per year

Responded to:
If Controllable (ie in the house or ECV) <2 hours
Uncontrollable <1 hour

Resulting in about 300 serious incidents per year (since 2012)

20 to 40 injuries per year

0 to 4 deaths per year

Compared to about 1400 injuries/deaths per year from electricity.
Gas deaths (excluding CO) comparable with lightening strike deaths

Nature of leaks and injuries

	Av per year 2012/16
Total Significant incidents/near miss	297
Inside source	46
Outside source	251
Total injuries	21
From Internal leaks	18
From external leaks	4
Total injuries	21
Associated with gas cookers	7
Associated with mailign activity	5
Associated with gas leak from pipework or similar	6

Whilst most leaks are external , nearly all injuries (83%) arise from internal leaks

Gas cookers are currently a major cause of injury (over 30%)
Malign activity may be involved in about 25% of injuries (but many do not secure a conviction)

Comparative Risk Assessment

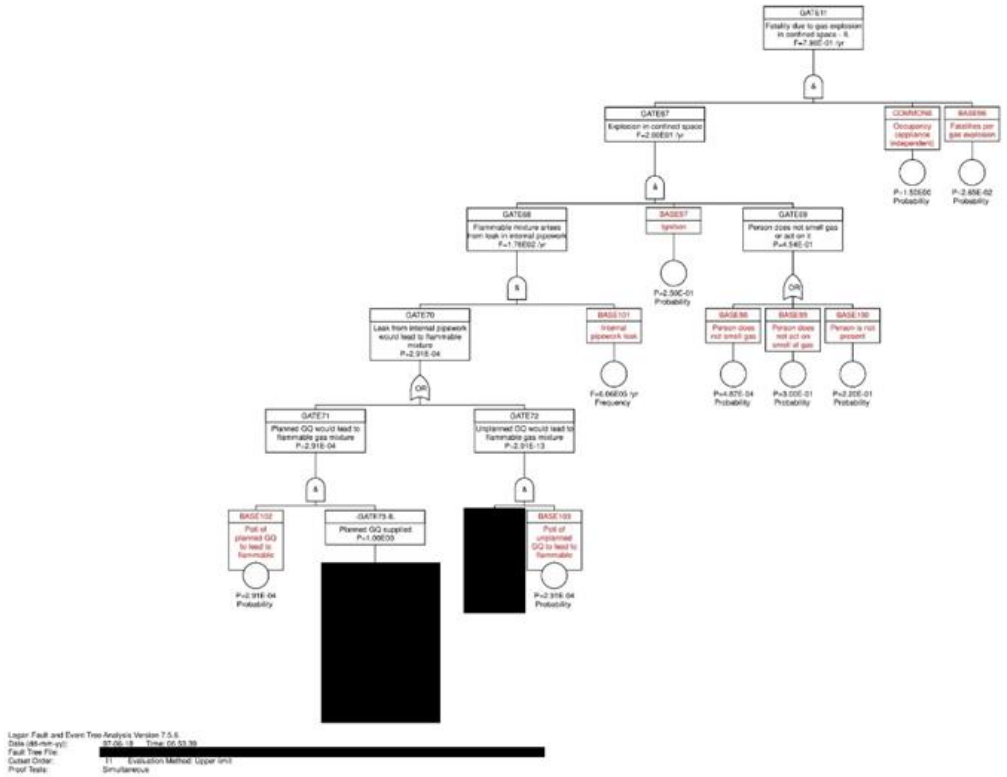


FIGURE A9. FAULT TREE FOR FATALITY DUE TO GAS EXPLOSION IN CONFINED SPACE - IL

Fault tree approach used to determine how hazardous events can occur

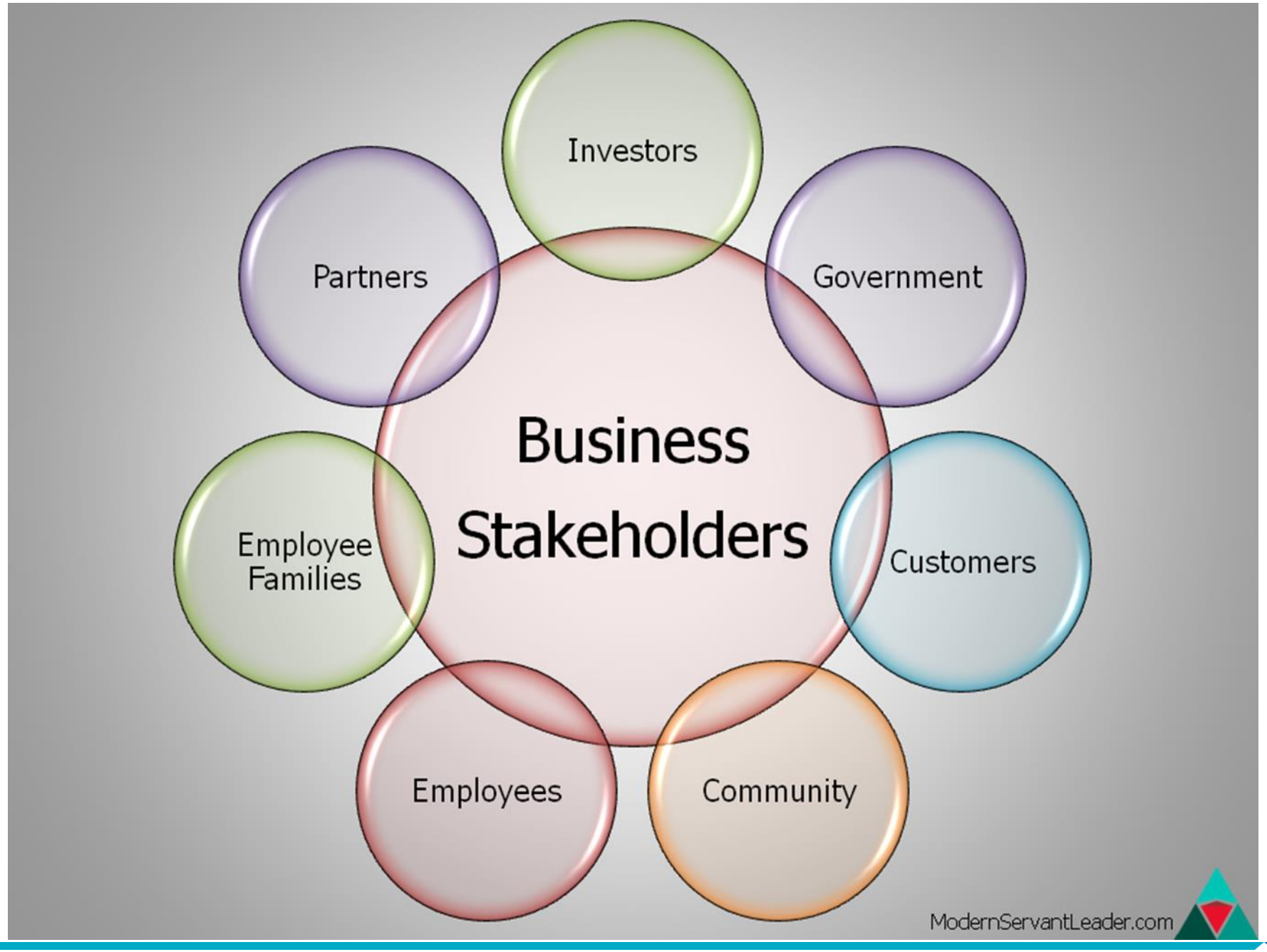
Example build-up for QRA

Simple approach

Only considering fatalities

Need data to quantify risk

Who has the loudest most Influential Voices


Investors
Partners
Government
Business
Stakeholders
Employee
Families
Customers
Employees
Community
ModernServantLeader.com

Building the Evidence Case and Who are the Voices

Who are the Stakeholders in the Transition

Government

Department for Business, Energy & Industrial Strategy

GDNOs

SGN

IGEM
Institution of Gas Engineers & Managers

HSE / Institutions / trade Bodies / Legislation

HSE Health and Safety Executive

Manufacturers

WORCESTER Bosch Group

BAXI

Technical / Engineering

kiwa

ARUP

Test Houses

kiwa

Certification

bsi.

kiwa

Sharing and Learning

This is not a UK issue… How can we learn/accelerate the Dutch Hydrogen Position

Why…

The Climate Change Act 2008 requires the UK to have reduced carbon emissions by at least 80% by 2050 from 1990 levels. This needs to be achieved while maintaining security of supply and providing energy at lowest cost to consumers. The UK can lead the world in taking climate action, with businesses and society coming together to deliver the ambitions set out in the Government's Clean Growth Strategy.

Thank you for listening we are here to support you..

Kiwa Testing

Trust
Quality
Progress