Ammonia for Boilers in Rural Locations

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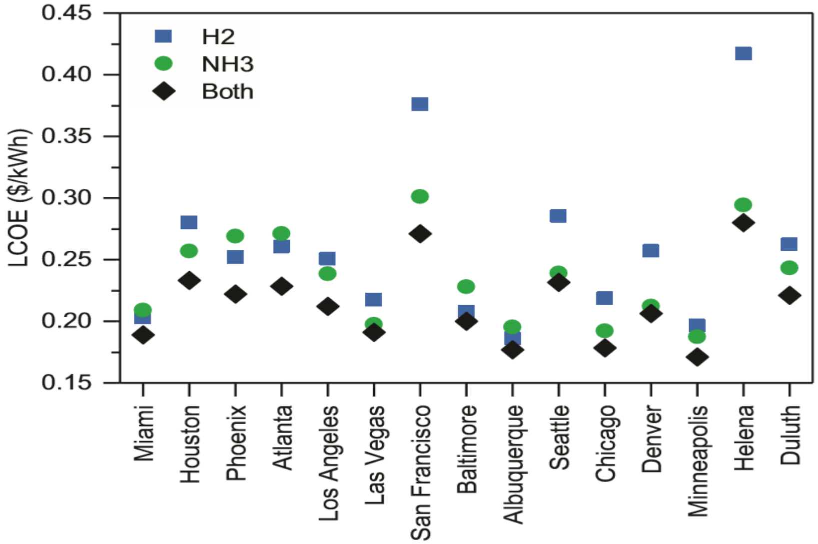
Funded by:
Department for Energy Security & Net Zero

Introduction

- Ammonia is not intended to substitute Hydrogen, but to support the use of the latter;
- Recent studies show that ammonia can be combined with the use of hydrogen to optimise energy generation systems;
- Ammonia offers the flexibility to store hydrogen over long periods at relatively much lower costs;
- Ammonia can be used to store seasonal stranded energy (ie. Summer) for its later use (ie. Winter).
- Thus ammonia **COMPLEMENTS** the hydrogen transition.



Using hydrogen and ammonia for renewable energy storage: A geographically comprehensive techno-economic study [Palys MJ et al. 2020. Computers and Chemical Engineering]

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Challenges

However, the technology faces the following obstacles,

1.Ammonia Carbon-free synthesis (cost reduction, efficiency improvement)

2.Power generation at utility-scale from ammonia production (stable, low emissions)

3.Public acceptance through safe regulations and appropriate community engagement.

4.Economics – profitable scenarios (cannot be applied everywhere)

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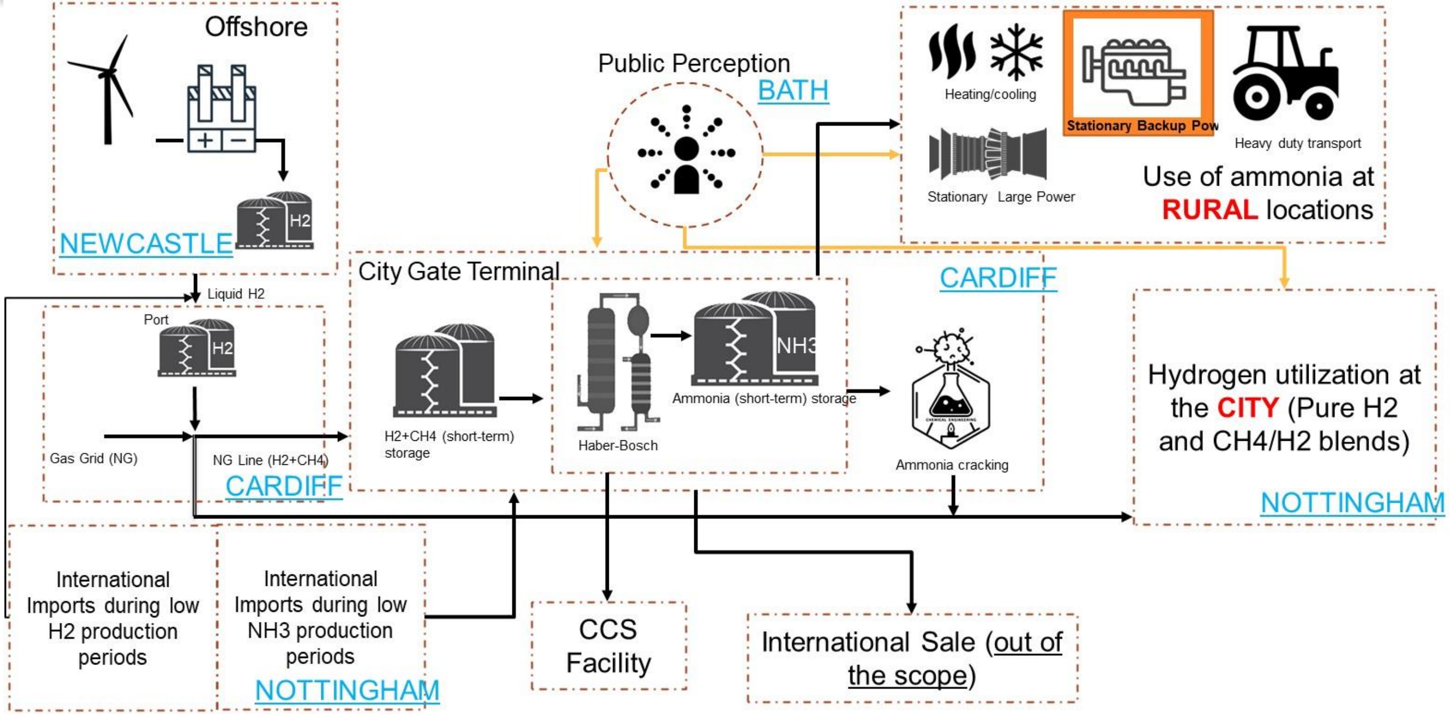
Opportunities



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Developments – Boilers/Furnaces

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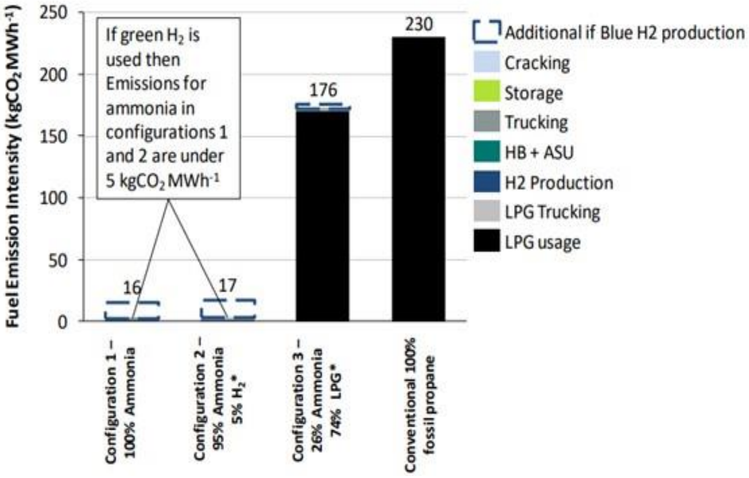
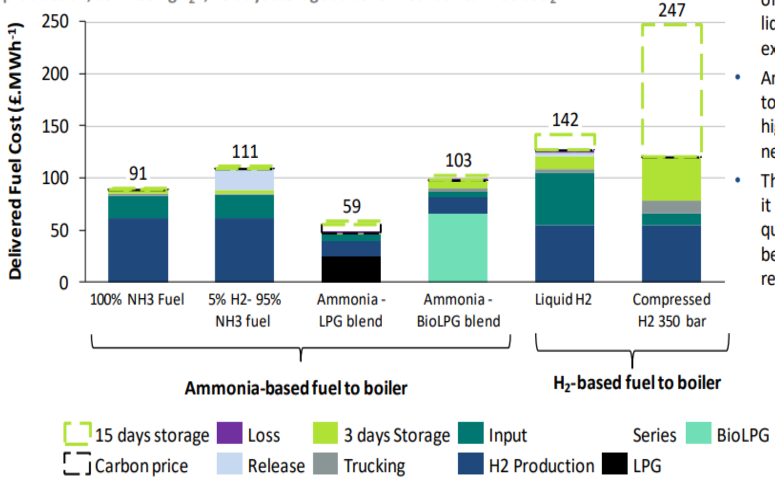


Scenario 1: Delivered cost of fuel to an industrial end users comparing low-carbon ammonia and H_2 fuels with increased end user storage at boiler site, 15 days (£.MWh^{-1}, Lower Heating Value)

12 MW distillery, 200 km distribution distance, large scale 200MW NH_3 synthesis, Blue H_2 production, at £1.80.kgH_2^{-1}, 15 days storage at boiler – Carbon tax £50 tCO_2^{-1}



- Existing off-gas grid boiler sites have between 10 and 15 days of storage.
- If this higher storage is needed Ammonia offers a comparative cost improvement over liquid and compressed hydrogen which are expensive to store.
- Ammonia can be stored at similar conditions to LPG whilst compressed hydrogen needs high pressures (350 bar), or liquid hydrogen needs extremely low temperatures (-253ºC).
- Though this gives an advantage to ammonia, it may be that for new technologies lower quantities of storage are used due to storage being more expensive and possible regulatory/safety constraints.

Emissions and Delivery Fuel Cost of various options (report 2023, 145 pages)

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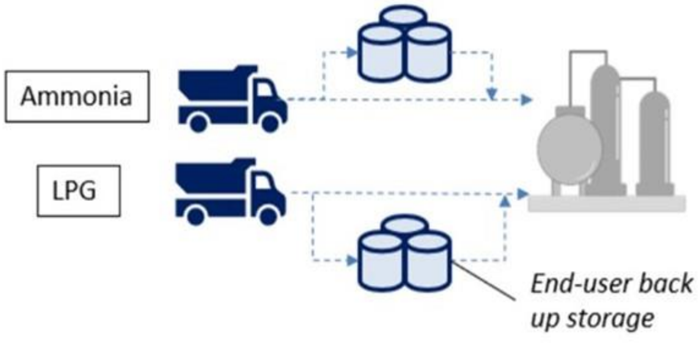
Pure and Residual ammonia can be used for extra power

- Works in collaboration with TATA steel and the South Wales Industry led to the recognition of several streams, product of waste gases, from which ammonia can be recovered for additional power generation via engines, gas turbines or furnaces.

- These work secured funding from DESZN to replace LPG by Ammonia in medium scale boilers (>1MW).



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Developments – Boilers/Furnaces

Net Zero through British Innovation

- Develop a new generation of burners and facilities capable of using NH3 with ultra-low polluting emissions;
- Novel concepts include
  - Fuel Stratification
  - Temperature Control
  - Integrated Ammonia Cracking
  - Hydrogen Sieving
  - Artificial Intelligence
  - Advanced Computational Design
  - Bespoke Storage and Delivery Systems
  - Etc.

to reach >1MW clean ammonia combustion with reduced retrofitting of existing units.

Exploitation Plan

- Developments will enable
  - Patents for
    - new burners
    - feeding systems
    - control strategies
    - cracking devices
    - etc.
  - Large academic dissemination (PhDs, conferences and industrial events)
  - Commercialization of the technology - estimated market of ~£700M in the next 15 years;
  - More than 70 direct jobs;
  - Active support in the creation of ISO Standards

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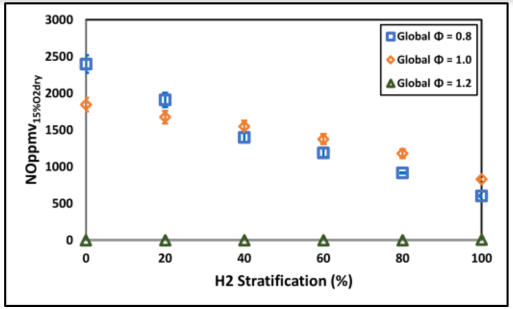
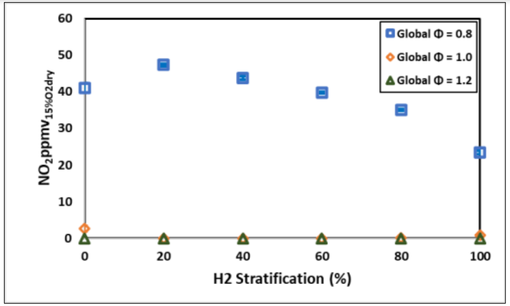
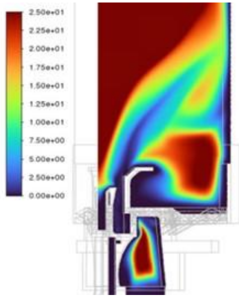
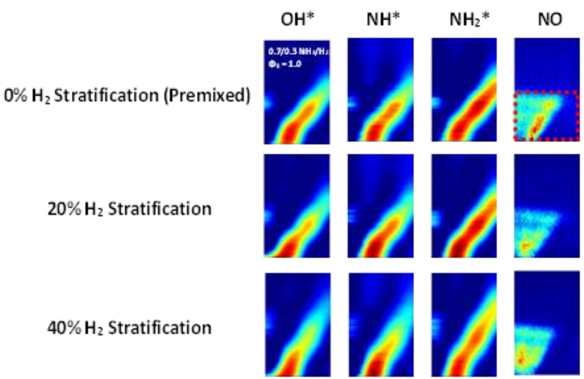
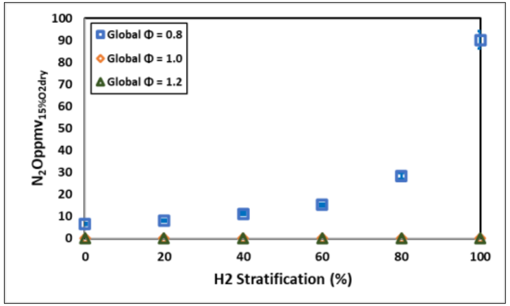






Equivalence Ratio (Φ) = 1.0





Stratification brings down NO whilst complex CFD models validate the stable nature of the flame.

Stratification appears as a good potential for NOx mitigation whilst enabling good flame stability (Mashruk et al 2023 JAE).

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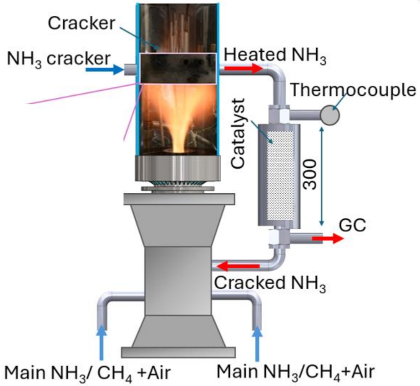

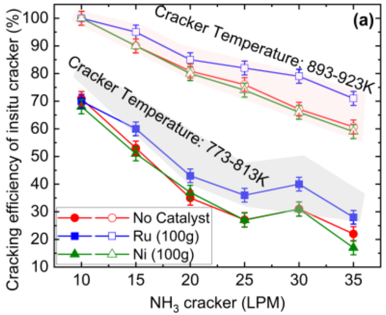

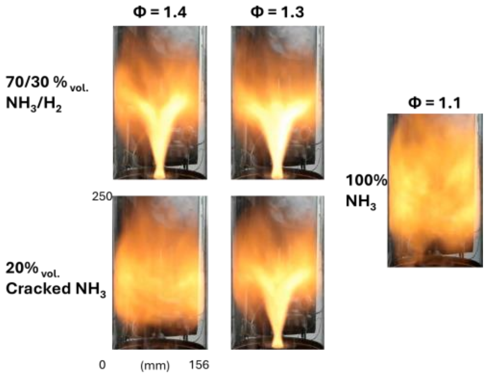

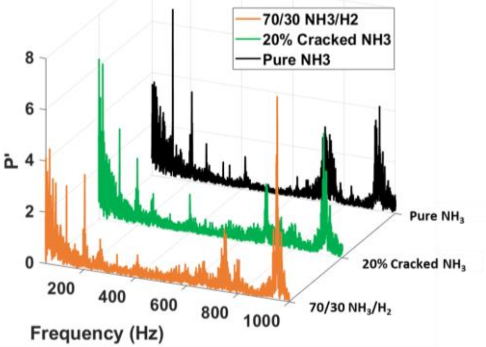

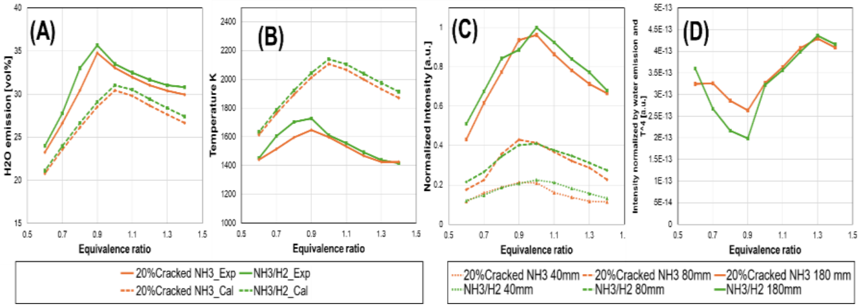

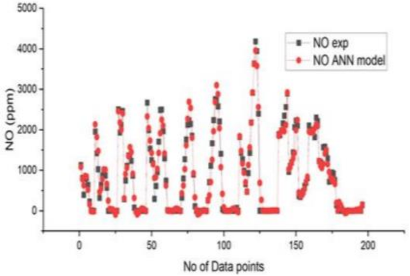

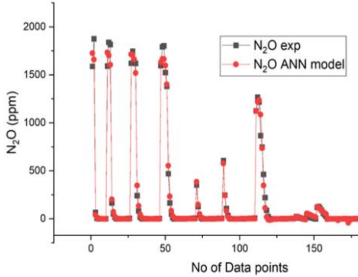

Fundamental work on cracking, thermoacoustics, radiation, neural networks and chemical kinetics (presented at the 3rd Symp Ammonia Energy)

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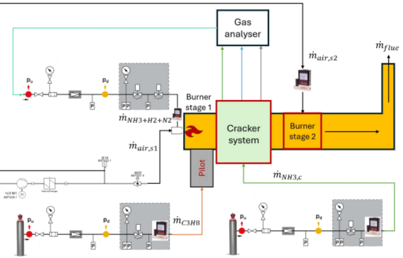
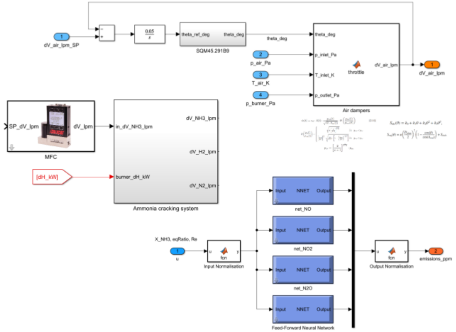
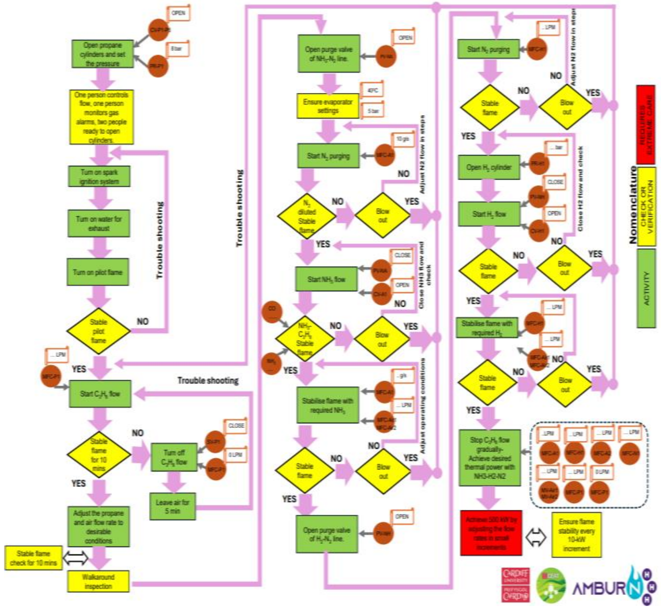
Automatic ammonia-hydrogen (NH_3/H_2) combustion system







Commissioning, Control Design using AI, Bespoke Protocols, HAZID/HAZOP, Dispersion analyses

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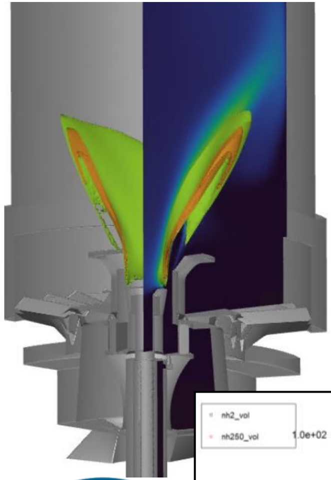
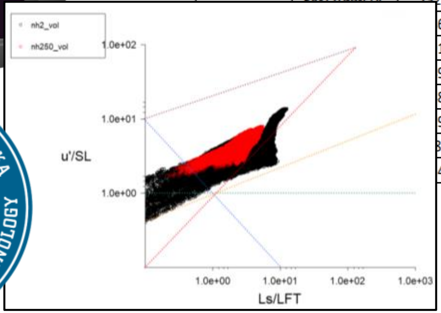
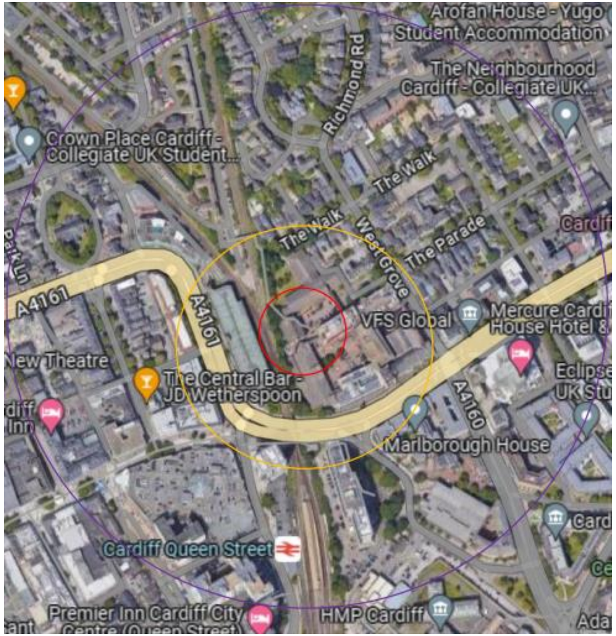


Test mode	Test point	Dry 15% O_2					Wet	MFR	Error
		NO (ppm)	NO_2 (ppm)	N_2O (ppm)	NH_3 (ppm)	O_2 (%)	H_2 (%)	(kg/s)	MFR (%)
2D* Stratification H_2 Cracked NH_3 Basic T_{in}=288K Premixed EQR	CR-090-T-B-EDC	1338.1	0.0	0.0	0.1	0.00	2.20	0.003852	6.1%
	CR-095-T-B-EDC	974.8	0.0	0.0	0.2	0.00	3.62	0.003676	1.3%
	CR-100-T-B-EDC	609.4	0.0	0.0	0.4	0.00	4.95	0.003517	-3.1%
	CR-105-T-B-EDC	286.8	0.0	0.0	3.7	0.00	6.22	0.003374	-7.0%
	CR-110-T-B-EDC	43.7	0.0	0.1	134.8	0.00	7.41	0.003243	-10.6%
	CR-115-T-B-EDC	3.7	0.0	0.0	775.6	0.00	8.41	0.003124	-13.9%
	CR-120-T-B-EDC	0.9	0.0	0.0	1782.7	0.00	9.24	0.003015	-16.9%
2D* Premixed NH_3/H_2 70/30 T_{in}=288K EDC Standard Premixed EQR	PR-060-B-EDC	2839.9	12.7	58.7	0.0	8.63	0.00	0.005433	49.7%
	PR-070-B-EDC	2947.4	7.2	0.1	0.0	6.42	0.00	0.004713	29.8%
	PR-080-B-EDC	2882.8	5.6	0.0	0.0	4.15	0.00	0.004173	15.0%
	PR-090-B-EDC	2393.1	2.9	0.0	0.0	1.92	0.00	0.003753	3.4%
	PR-100-B-EDC	1565.2	0.0	0.0	0.0	0.00	0.39	0.003417	-5.9%
	PR-110-B-EDC	758.0	0.0	0.0	0.2	0.00	3.26	0.003142	-13.4%
	PR-120-B-EDC	232.5	0.0	0.0	2.9	0.00	5.96	0.002913	-19.8%
		6.9	10.6	388.5	0.0	8.52	0.00	0.005522	52.1%
		1.8	7.8	1.8	0.0	6.31	0.00	0.004805	32.4%
		9.4	3.7	0.0	0.0	4.15	0.00	0.004267	17.5%
		8.0	2.8	0.0	0.0	1.90	0.00	0.003849	6.0%
		9.9	0.0	0.0	0.0	0.00	0.33	0.003514	-3.2%
		3.1	0.0	0.0	0.2	0.00	3.12	0.00324	-10.7%
		4	0.0	0.0	374.8	0.00	5.59	0.003012	-17.0%





Advanced CHT analyses of more than 200 cases provided details for improvement and best blend. Dispersion modelling was also used for Safety purposes.

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Developments – Boilers/Furnaces

Concluded

- HAZOP and Dispersion Analyses
- 300-500 kW facility at Cardiff University
- Ultra-low emissions at 25 kW
- High quality validation of CFD modelling
- Acquisition of advanced measuring systems

Ongoing

- Testing 300-500 kW burner
- Develop bespoke ammonia delivery unit
- Design of novel fuelling control
- Discussions for a new Technical Specification
- Evaluation of novel methods for emissions control

Next Steps

- Commissioning offsite 1MW facility
- Technical Specification
- Demonstration 4 weeks continuous running 1MW
- Leaning out components manufacturing for cost reduction

Final Outcomes

- Design of a burner/cracker concept for medium heating scale heating applications
- Techno-economic analysis for national/international implementation

Acknowledgements

- Staff/PDRAs/Technicians – High level of skills.
- Industrial steering – fast TRL progression
- DESNZ support has enabled the transition of lab to demonstration scale in months rather than years (total funding £3.45M)

Public Perception and Safety

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100% Ammonia Configuration

Hazard Guideword	Potential Hazard	Failure Mode/ Cause	Direct / Indirect Consequences	Safeguards / Safety Systems	Action Required
	Impact on land.				
	Impact on biodiversity.				
	Emergency/upset discharges.				
	Waste disposal.				
Security	Terrorism	Unauthorised release of ammonia.	See toxicity and flammability scenarios.	Accessibility is no different to that of propane either on the road or at the site.	**26.** Due to additional toxicity of ammonia, seek advice whether additional security measures are needed on sites to prevent malicious damage leading to a release.
	Facility access				
Transportation	Incidents involving railroad/railcar				
	Vehicle traffic incidents	Impact of vehicles with ammonia system.	See toxicity and flammability scenarios.	Tanks and pipeworks are protected from vehicle collision.	
				Supply pipeline under public road has 800mm surface cover.	
		Road accidents involving ammonia tanker.			**27.**Review current emergency procedures for road tanker accidents and modify to take account of ammonia hazards.
	Aircraft				
Operational	Simultaneous operations.				
	Crew change.				
	Start-up/shutdown.	Increased ammonia into	Contributes to air pollution including		

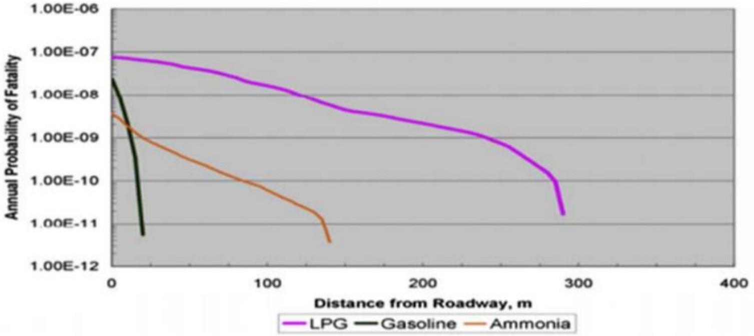
HAZID and HAZOP analyses for the system at Cardiff, Spadeadam and final user site

TABLE 10.6

Reported Accidents With Transporting Anhydrous Ammonia and Ammonia Solutions, United States, 1971–2019 (Reports Only for Anhydrous Ammonia).

	Total reported	Total fatalities	Total hospitalized injuries	Total nonhospitalized injuries
Highways	3209 (797)	25 (23)	36 (29)	744 (602)
Rail	2460 (2301)	11 (11)	23 (21)	321 (290)
Water	21 (14)	0 (0)	0 (0)	4 (4)

Appl Energy 2017. https://doi.org/10.1016/j.apenergy.2016.10.088.



Quest Consultants Inc. Comparative Quantitative Risk Analysis of Motor Gasoline, LPG and Anhydrous Ammonia as an Automotive Fuel. Iowa, USA: 2009. Courtesy of Quest.)

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Conclusions

- Ammonia can be used for power purposes via combustion;
- Green ammonia produced from renewables is capable of storing and delivering stranded energy;
- Rural locations are a preferred option for the chemical for direct fuelling applications;
- Fundamental analyses show stable regimes, whilst the potential of in-situ cracking improves combustion features;
- Robust developing, complex integration and advanced modelling have served to establish a unique facility for large scale demonstration.

Thanks

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