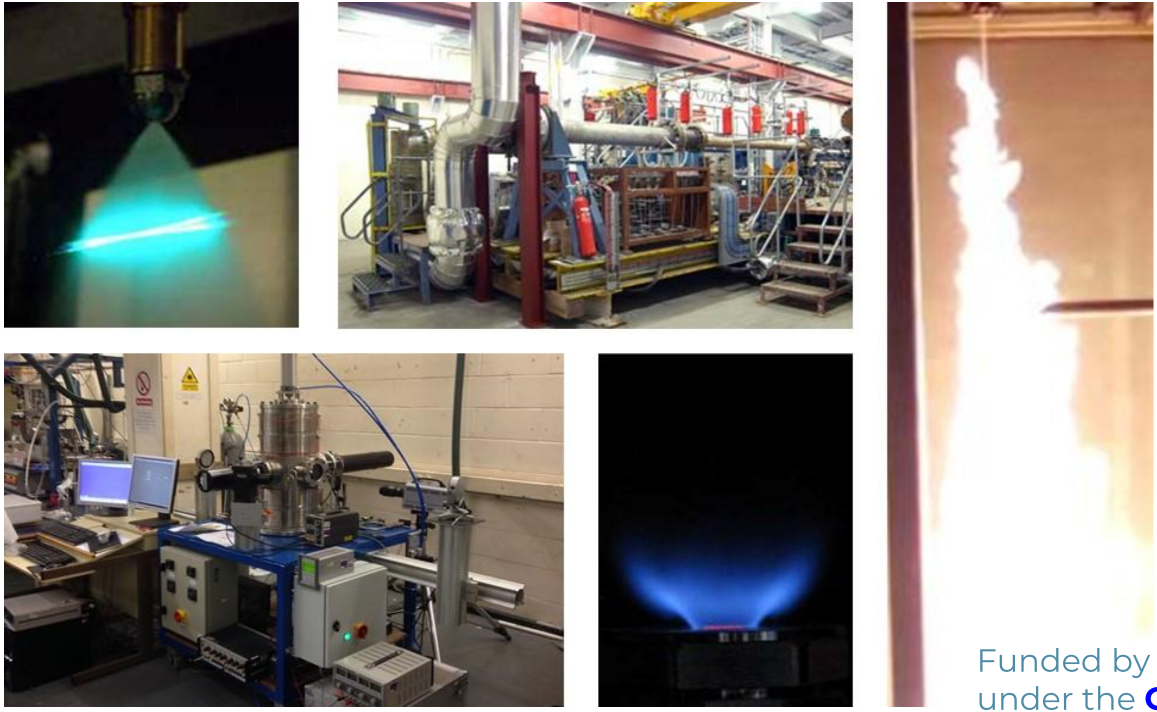
Centre of Excellence
on Ammonia Technologies

Advancements on Enhanced Plasmas Combustion for Liquid Ammonia towards NZ Propulsion Technologies

Prof. Agustin Valera-Medina



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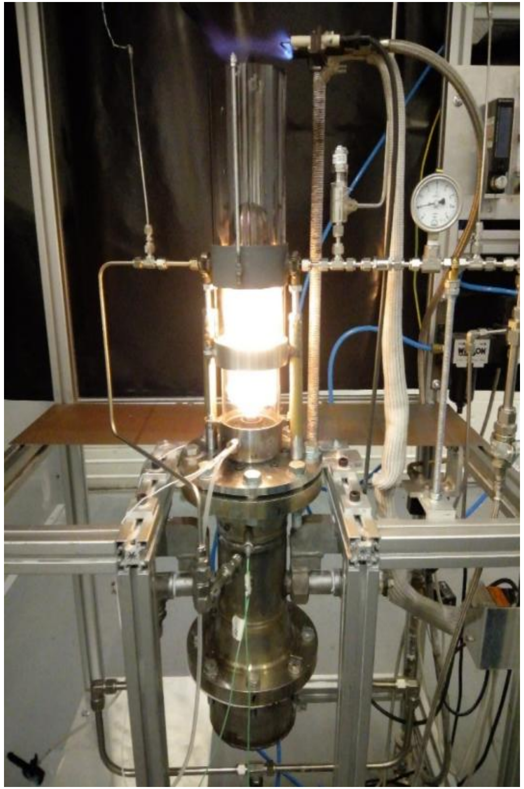
Introduction

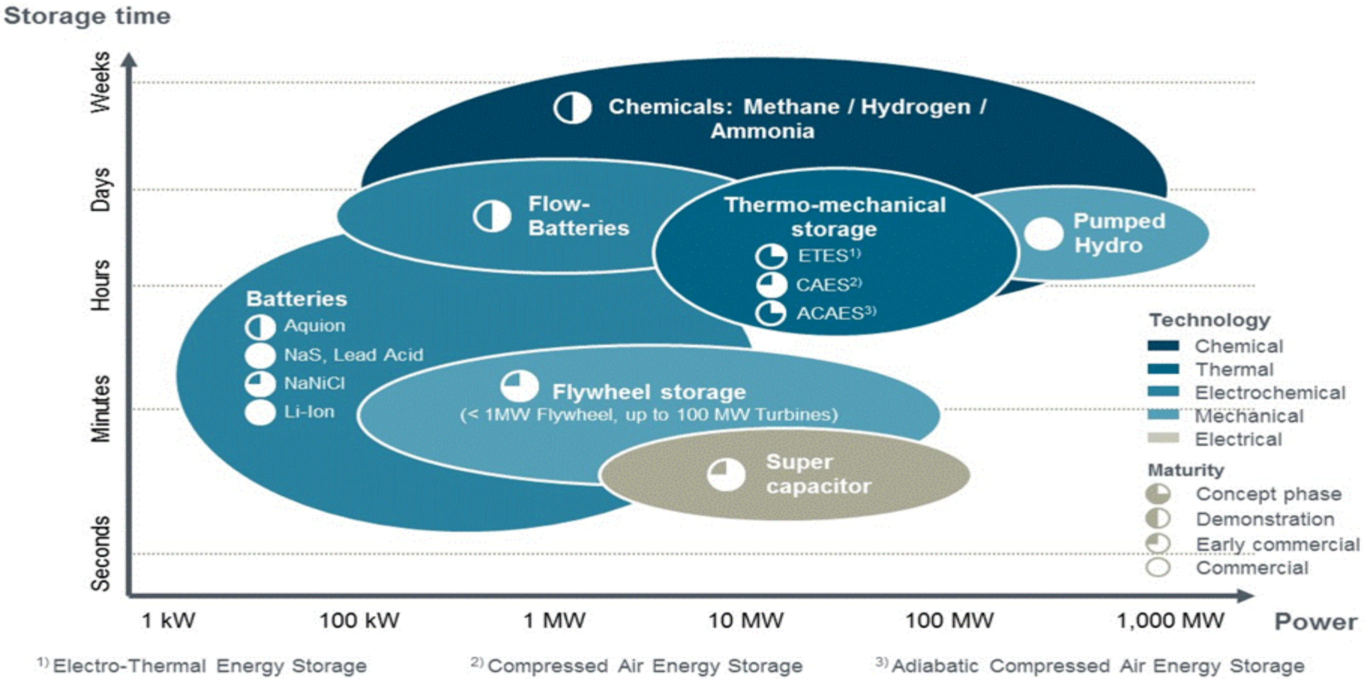
Professor at Cardiff School of Engineering. He has participated as PI/Co-I on 40 industrial projects with multi-nationals including PEMEX, Rolls-Royce, Siemens, Ricardo, Airbus and FloGas (>£38M). He has published +270 papers (h-index 51), most concerning ammonia power. Prof. Valera-Medina led Cardiff's contribution to the Innovate-UK 'Decoupled Green Energy' Project (2015-2018) led by Siemens and in partnership with STFC and the University of Oxford, which aims to demonstrate the use of green ammonia produced from wind energy. He is currently PI of various projects (incl. SAFE-AGT, FLEXnCONFU, OceanREFuel, CAIPIRINH3A, etc.) to demonstrate ammonia power in turbine engines, Internal Combustion Engines, boilers and furnaces. He has been part of various scientific boards, chairing sessions in international conferences and moderating large industrial panels on the topic of "Ammonia for Direct Use". He has supported two Royal Society Policy Briefings related to the use of ammonia as energy vector, and he is principal authors of two books concerning ammonia combustion. He chairs the topic of "Ammonia Firing" for the British Standards Institute, and he is Co-Director of the Institute of Net Zero Innovation, Director of the Centre of Excellence on Ammonia Technologies (CEAT), Cardiff University. He is a Fellow of the Learned Society of Wales and the Mexican Academy of Engineering.



Introduction

- Renewables are one of the best technologies to provide the needed energy whilst reducing greenhouse gases.
- The problem is their intermittency (i.e. UK – 1 Million People during ~48% Wind power).

Introduction



Comparison between different storage technologies. Chemicals provide longest and largest arbitrage of storage. [Wilkinson I, 2017, 1st NH3 European Conference]

Introduction

Exhibit 11: Distribution of global hydrogen resources and demand centers

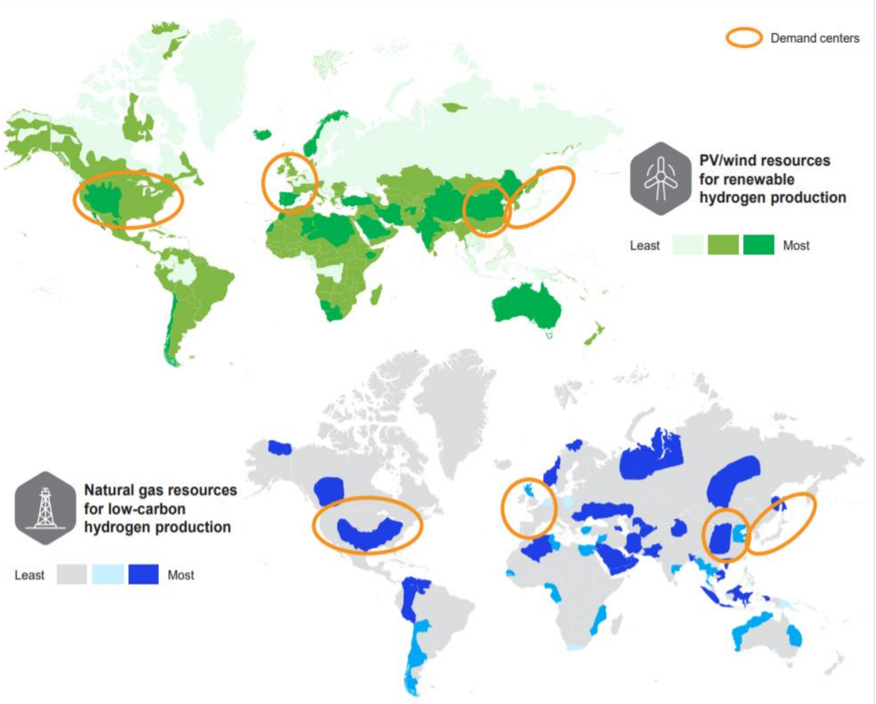
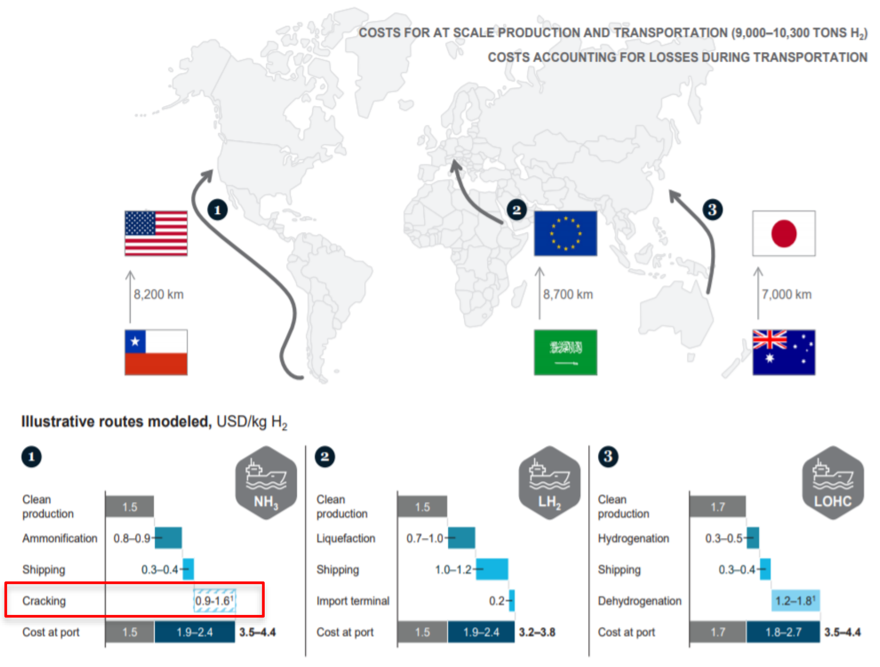


Exhibit 16: Landed costs of hydrogen at port for selected global transport routes

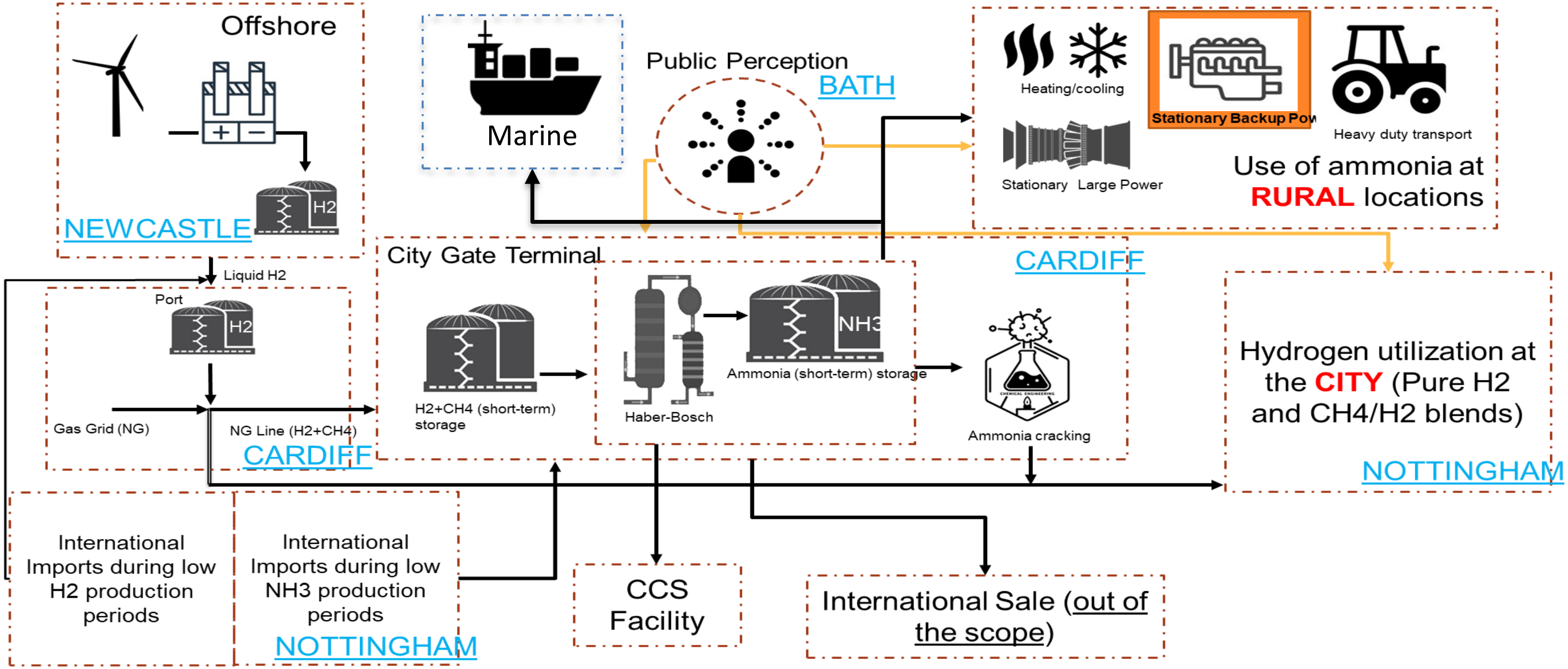


1. Dependent on whether hydrogen feedstock or heat from grid is used for dehydrogenation heating requirement

Hydrogen Distribution and comparison between vectors [Hydrogen Council 2021]

Opportunities

- Cheaper distribution, higher hydrogen content and easier operation will change the position of NH3 in the energy arena.



Offshore

NEWCASTLE

Marine

Public Perception

BATH

Heating/cooling

Stationary Backup Pow

Heavy duty transport

Stationary Large Power

Use of ammonia at **RURAL** locations

City Gate Terminal

CARDIFF

Port

Gas Grid (NG)

NG Line (H2+CH4)

CARDIFF

H2+CH4 (short-term) storage

Haber-Bosch

Ammonia (short-term) storage

Ammonia cracking

Hydrogen utilization at the **CITY** (Pure H2 and CH4/H2 blends)

NOTTINGHAM

International Imports during low H2 production periods

International Imports during low NH3 production periods

NOTTINGHAM

CCS Facility

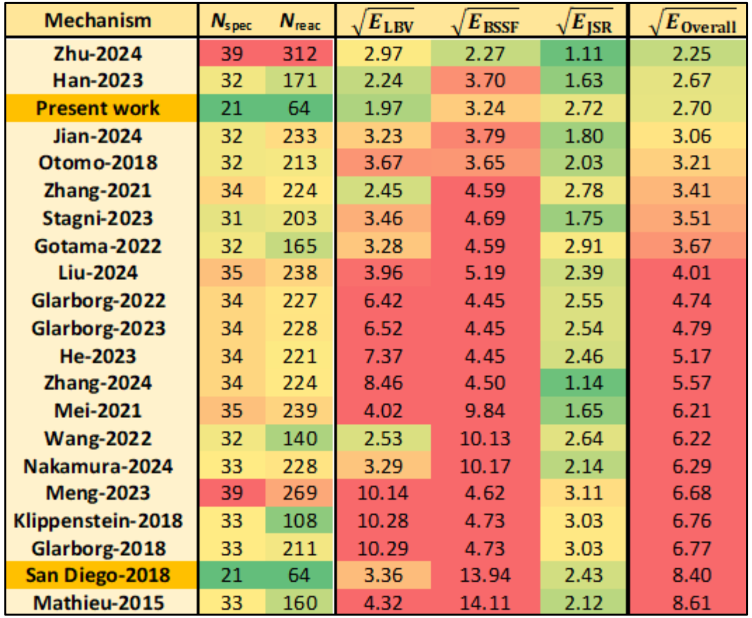
International Sale (out of the scope)

Fundamentals

	Ammonia	Hydrogen	Methane	Propane	Methanol	Ethanol	Gasoline	Diesel
Lower heating value [MJ/kg]	18.8	120.1	50	46.4	19.7	26.8	44.5	42.5
Maximum LBV [m/s]	0.07	2.91	0.37	0.43	0.50	0.47	0.47	0.52
Flammability [E.R.]	0.63–1.4	0.10-7.1	0.50-1.7	0.51-2.5	0.55-2.9	0.66-2.4	0.7-4	0.6-5.5
Auto-ignition [K]	924	844	810	723	743	638	503	498
Minimum ignition energy [mJ]	8	0.011	0.28	0.25	0.14	0.28	0.8	0.24
Density (g/L)	0.703	0.082	0.657	493	787	789	740	830

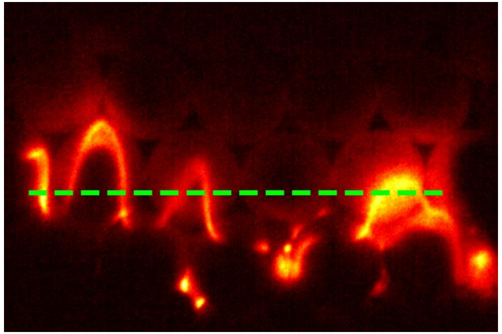
Ammonia compared to many other fuels (alternative and conventional). It is clear how ammonia’s LBV is considerably lower whilst its Ignition Energy is hundred times higher than hydrogen’s. Therefore, methods to enhance ammonia combustion have been under scope.

Fundamentals



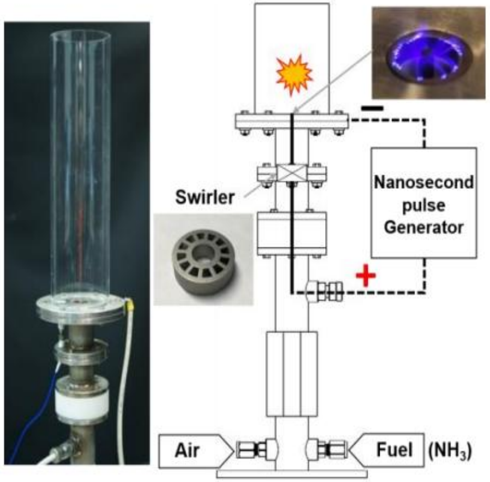
Mechanism	N_{spec}	N_{reac}	$\sqrt{E_{LBV}}$	$\sqrt{E_{BSSF}}$	$\sqrt{E_{JSR}}$	$\sqrt{E_{Overall}}$
Zhu-2024	39	312	2.97	2.27	1.11	2.25
Han-2023	32	171	2.24	3.70	1.63	2.67
Present work	21	64	1.97	3.24	2.72	2.70
Jian-2024	32	233	3.23	3.79	1.80	3.06
Otomo-2018	32	213	3.67	3.65	2.03	3.21
Zhang-2021	34	224	2.45	4.59	2.78	3.41
Stagni-2023	31	203	3.46	4.69	1.75	3.51
Gotama-2022	32	165	3.28	4.59	2.91	3.67
Liu-2024	35	238	3.96	5.19	2.39	4.01
Glarborg-2022	34	227	6.42	4.45	2.55	4.74
Glarborg-2023	34	228	6.52	4.45	2.54	4.79
He-2023	34	221	7.37	4.45	2.46	5.17
Zhang-2024	34	224	8.46	4.50	1.14	5.57
Mei-2021	35	239	4.02	9.84	1.65	6.21
Wang-2022	32	140	2.53	10.13	2.64	6.22
Nakamura-2024	33	228	3.29	10.17	2.14	6.29
Meng-2023	39	269	10.14	4.62	3.11	6.68
Klippenstein-2018	33	108	10.28	4.73	3.03	6.76
Glarborg-2018	33	211	10.29	4.73	3.03	6.77
San Diego-2018	21	64	3.36	13.94	2.43	8.40
Mathieu-2015	33	160	4.32	14.11	2.12	8.61

Mechanism Comparison

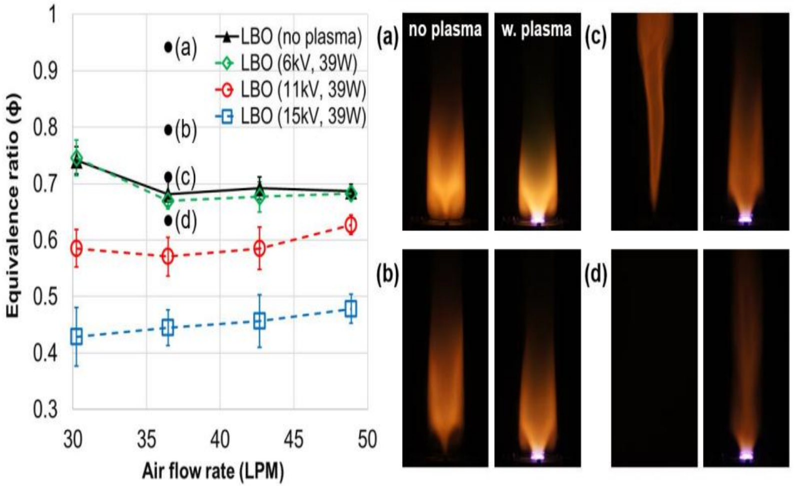


We have conducted fundamental and applied research over 13 years on the use of ammonia for combustion systems. From laminar flames, through novel combustors and reaction mechanisms, to industrial applications.

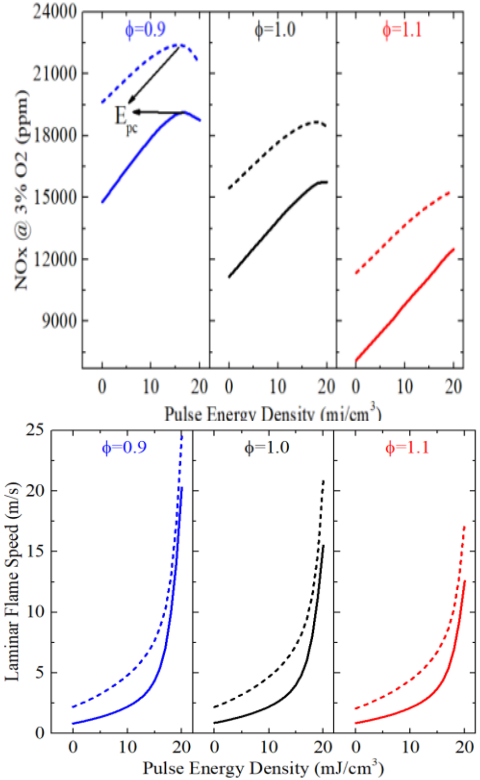
Fundamentals



Schematic of the experimental setup [Choe and Sun, AIAA, 2021]

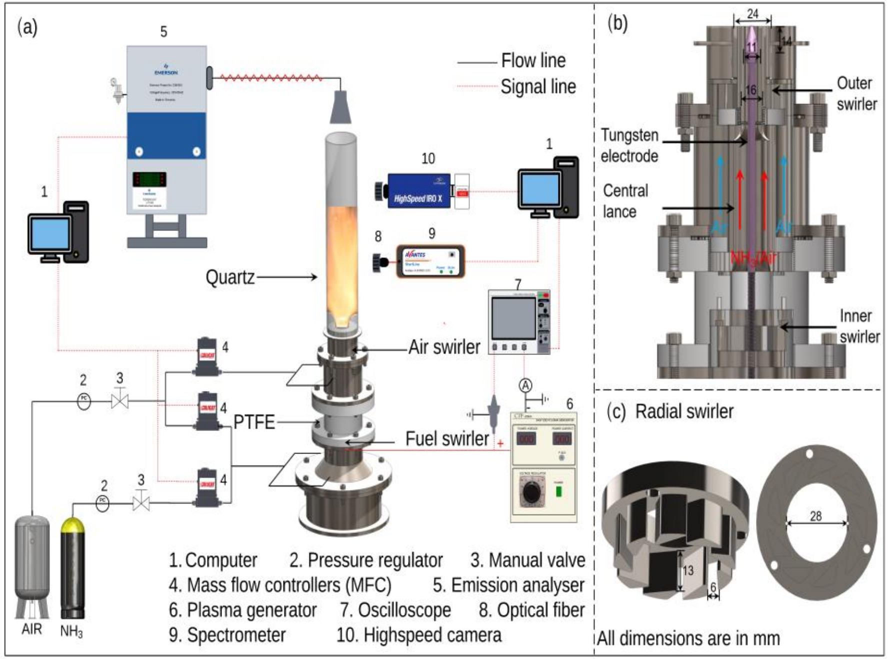


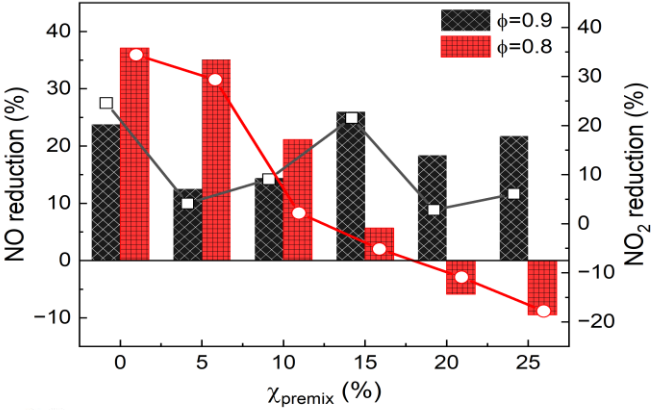
Flame stability map, and photographs of flames without and with plasma (V=11 kV, f=7 kHz, 39W)[Choe and Sun, AIAA, 2021]

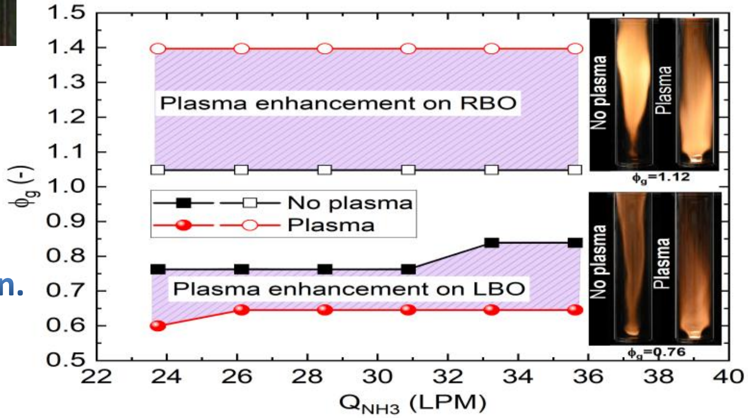


Change in NOx emissions and laminar flame speed with N2 (solid) and He (dashed) dilution

Plasmas







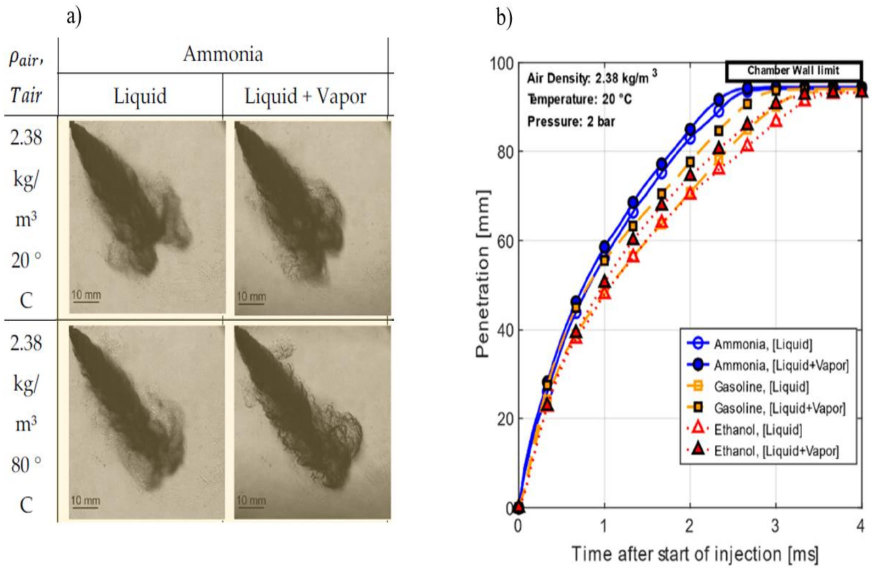
Plasma system used for ammonia/hydrogen/methane enhanced combustion.

However – for these applications, ammonia needs to be gasified.

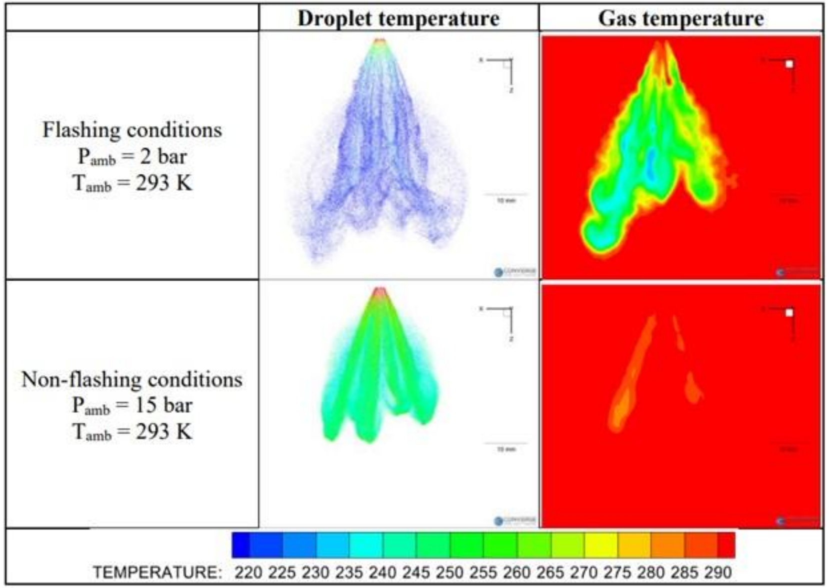
Could this be employed in smaller systems (ie. propulsion)?

Plasmas and Liquids

What about using plasmas with liquid injection?

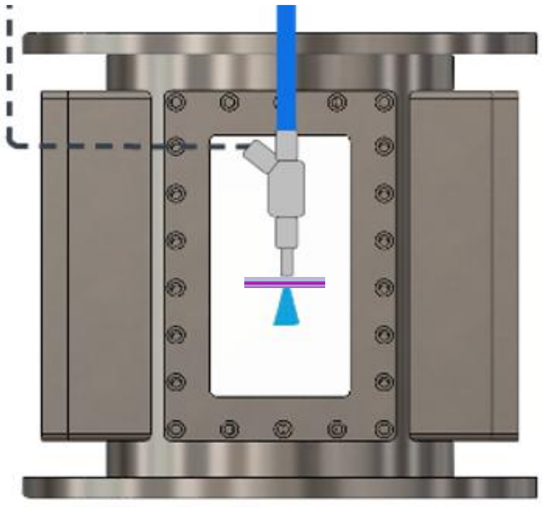


Comparison of spray shape for liquid and liquid/ vapor NH3 sprays b) Comparison of spray penetration for NH3 with more conventional fuels [Pele et al. 2021]

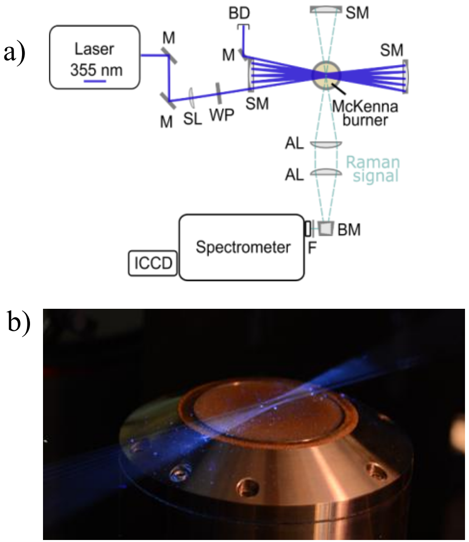


Comparison between droplet and gas temperature in flashing and non-flashing conditions. Strong impact and temperature change during vaporization [Zembi et al 2023]

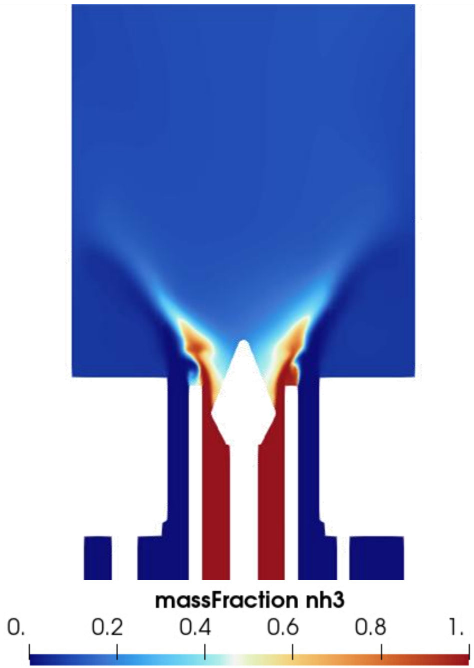
Plasmas and Liquids



Experimental confinement for analyses of injection profiles (droplet size, morphology, angle, etc.) for an industrial injector exposed to plasmas.

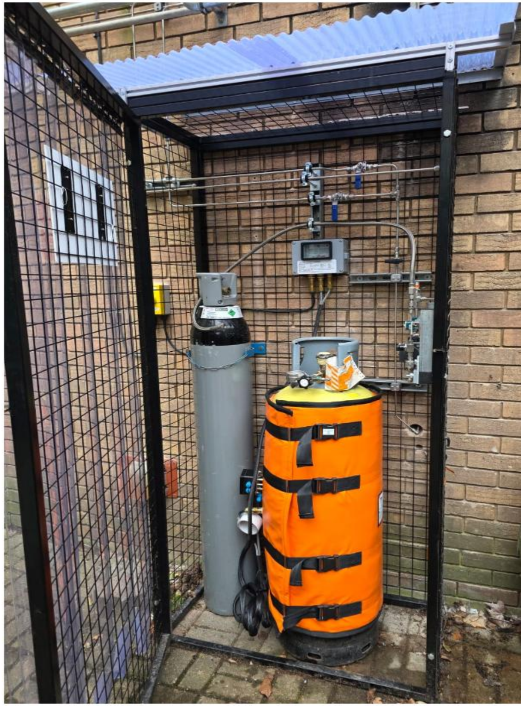


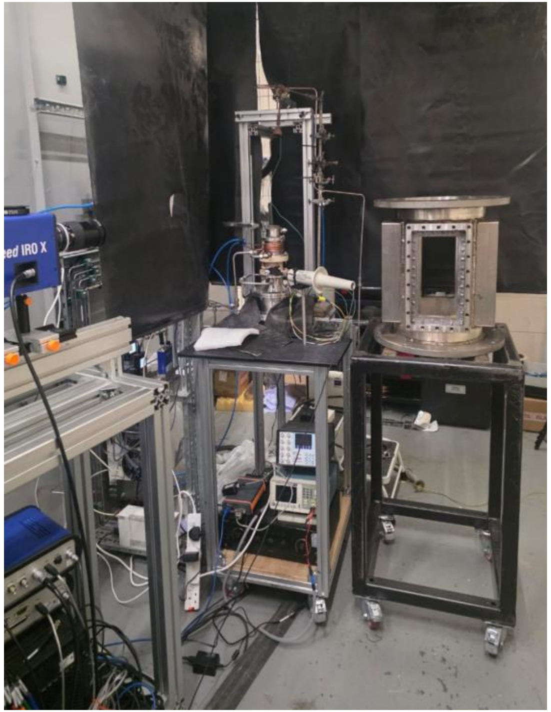
a) Schematic of the Raman spectroscopy setup for flame studies. b) A photo of the laser beam multipass arrangement.

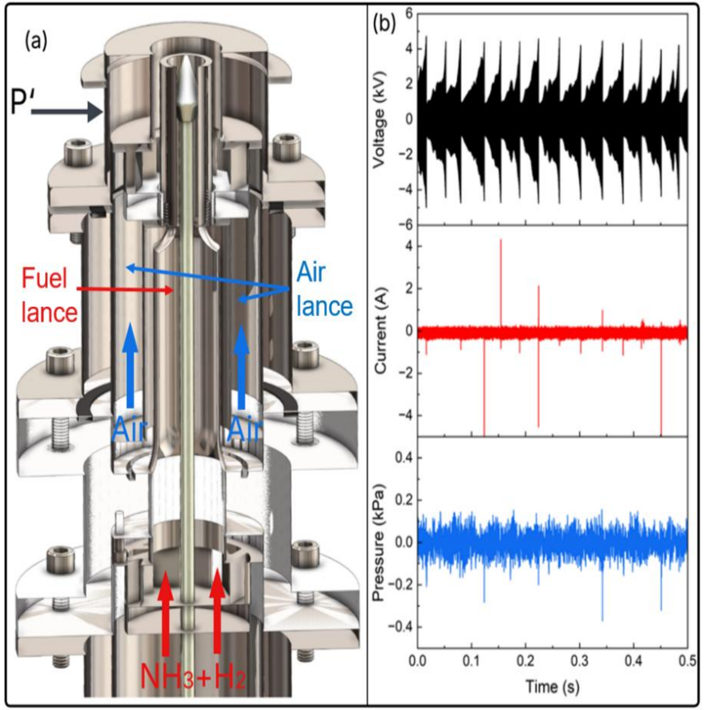


CFD modelling of Gliding arc.

Plasmas and Liquids

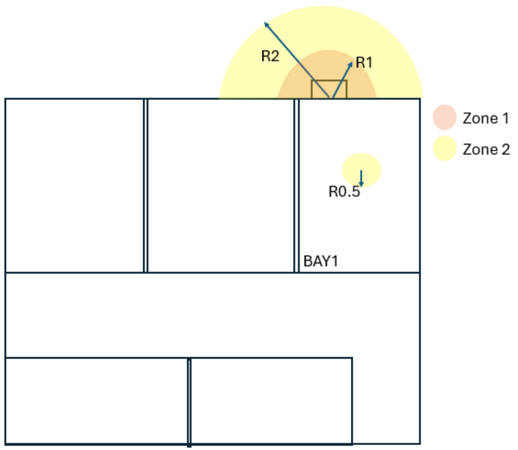




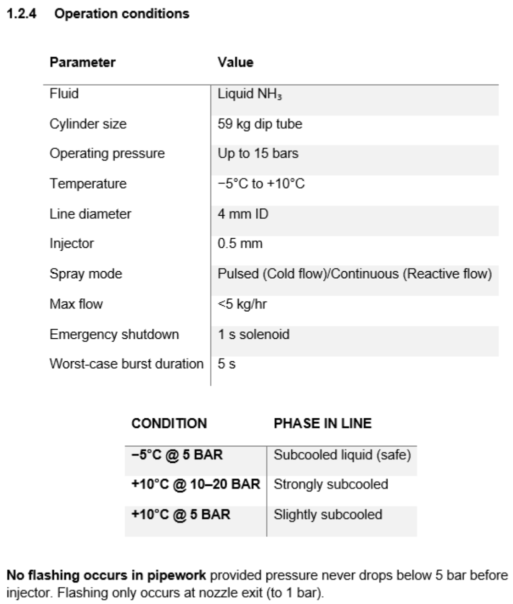


Experimental facility for the analysis and development of PLAS-Mi NH_3 injector.

Plasmas and Liquids: H&S



Example calculations for Health and Safety analyses to bring Liquid Ammonia into the laboratory

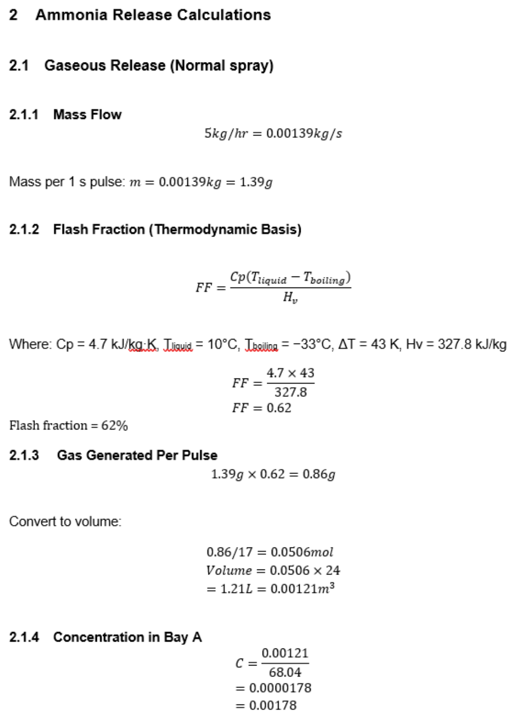


1.2.4 Operation conditions

Parameter	Value
Fluid	Liquid NH_3
Cylinder size	59 kg dip tube
Operating pressure	Up to 15 bars
Temperature	−5°C to +10°C
Line diameter	4 mm ID
Injector	0.5 mm
Spray mode	Pulsed (Cold flow)/Continuous (Reactive flow)
Max flow	<5 kg/hr
Emergency shutdown	1 s solenoid
Worst-case burst duration	5 s

CONDITION	PHASE IN LINE
−5°C @ 5 BAR	Subcooled liquid (safe)
+10°C @ 10–20 BAR	Strongly subcooled
+10°C @ 5 BAR	Slightly subcooled

No flashing occurs in pipework provided pressure never drops below 5 bar before injector. Flashing only occurs at nozzle exit (to 1 bar).



2 Ammonia Release Calculations

2.1 Gaseous Release (Normal spray)

2.1.1 Mass Flow

$$5kg/hr = 0.00139kg/s$$

Mass per 1 s pulse: $m = 0.00139kg = 1.39g$

2.1.2 Flash Fraction (Thermodynamic Basis)

$$FF = \frac{Cp(T_{liquid} - T_{boiling})}{H_v}$$

Where: Cp = 4.7 kJ/kg·K, T_{liquid} = 10°C, $T_{boiling}$ = −33°C, ΔT = 43 K, Hv = 327.8 kJ/kg

$$FF = \frac{4.7 \times 43}{327.8}$$
$$FF = 0.62$$

Flash fraction = 62%

2.1.3 Gas Generated Per Pulse

$$1.39g \times 0.62 = 0.86g$$

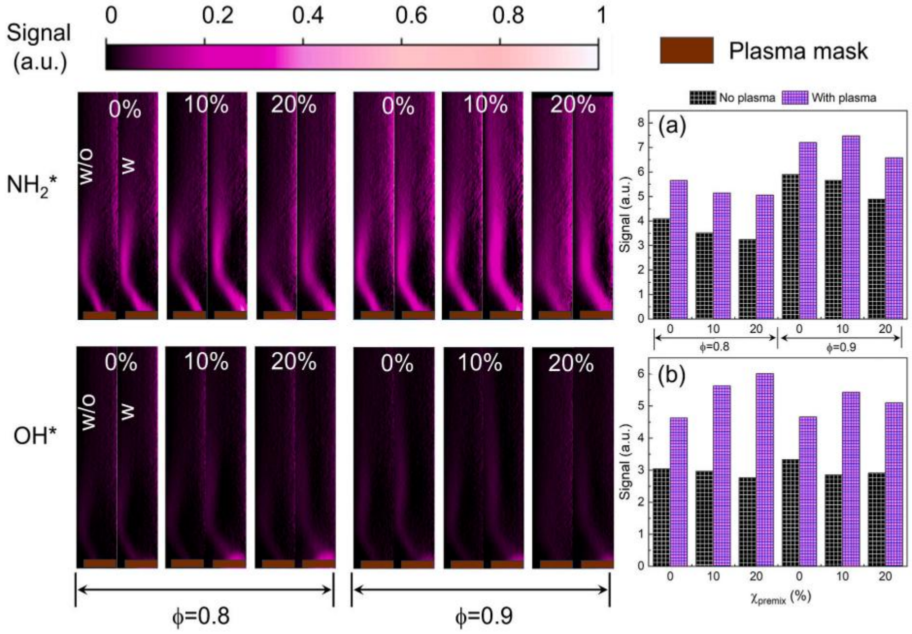
Convert to volume:

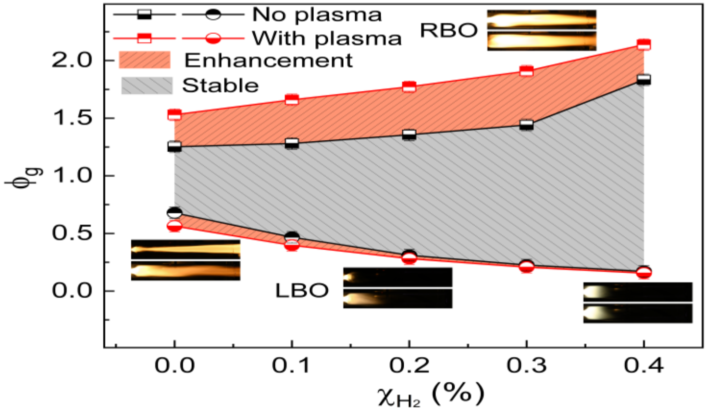
$$0.86/17 = 0.0506mol$$
$$Volume = 0.0506 \times 24$$
$$= 1.21L = 0.00121m^3$$

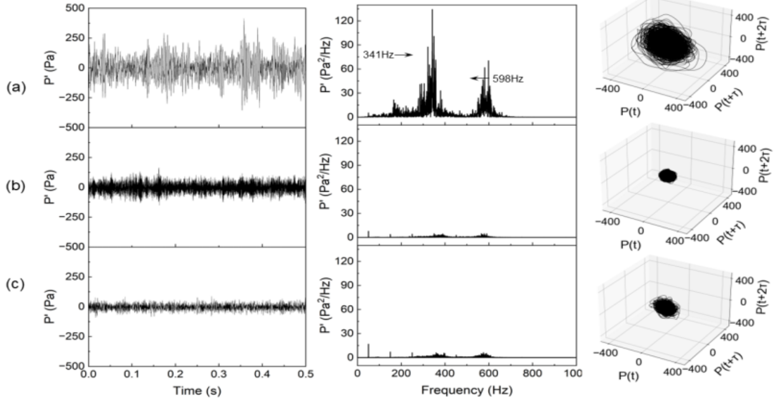
2.1.4 Concentration in Bay A

$$C = \frac{0.00121}{68.04}$$
$$= 0.0000178$$
$$= 0.00178$$

Plasmas and Liquids





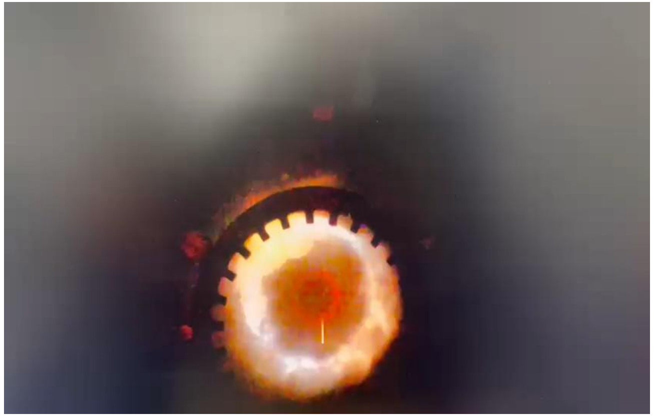
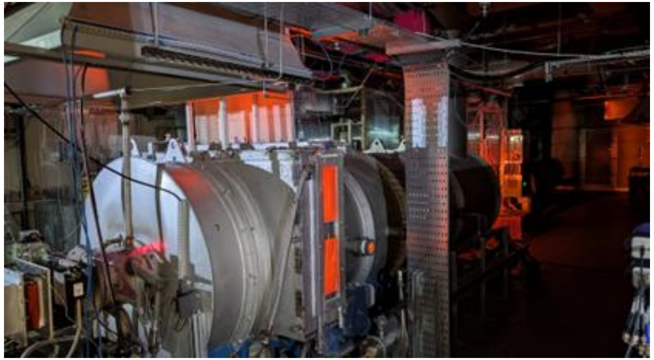


Radical variation has been observed with plasmas. Similarly, enhanced stability and greater operability ranges. Estimated power requirements <3% of flame power outputs!!!!

Boilers/Furnaces

The unit will be used for demonstration in a Poultry farm. The system currently has been operated using 93% ammonia and 7% LPG, reducing ~80% CO2 at 900kW.

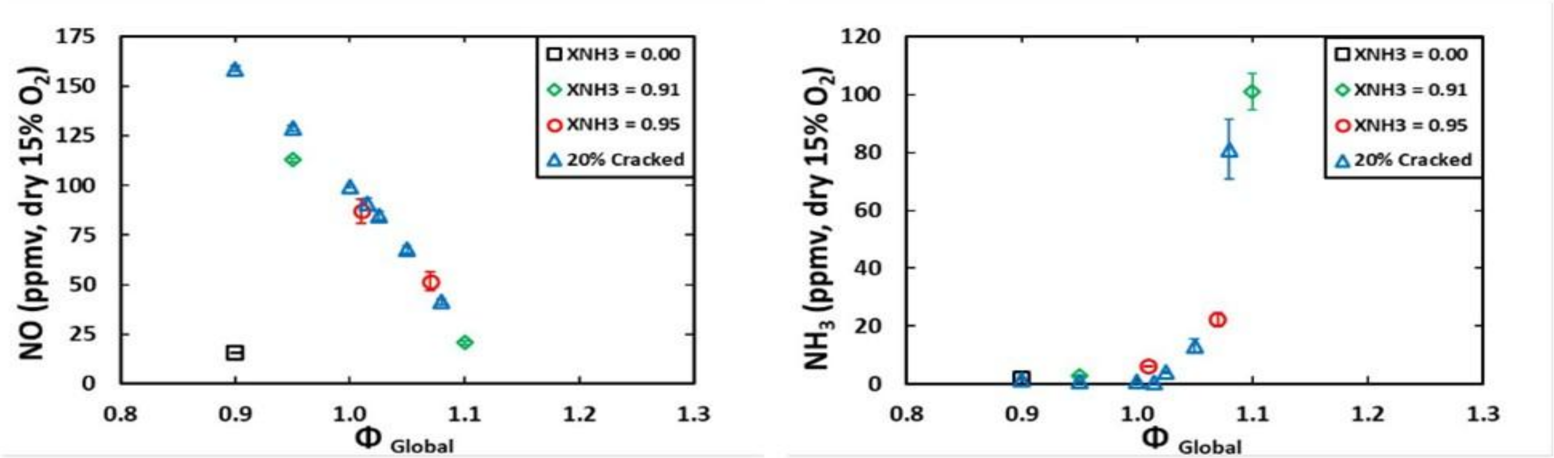


Boilers/Furnaces

Emissions: NH_3/C_3H_8 and Cracked NH_3 – Air Staging

500 kW, Φ_P = 1.2



* Negligible N_2O, NO_2 and H_2 measured


737
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Collaborations

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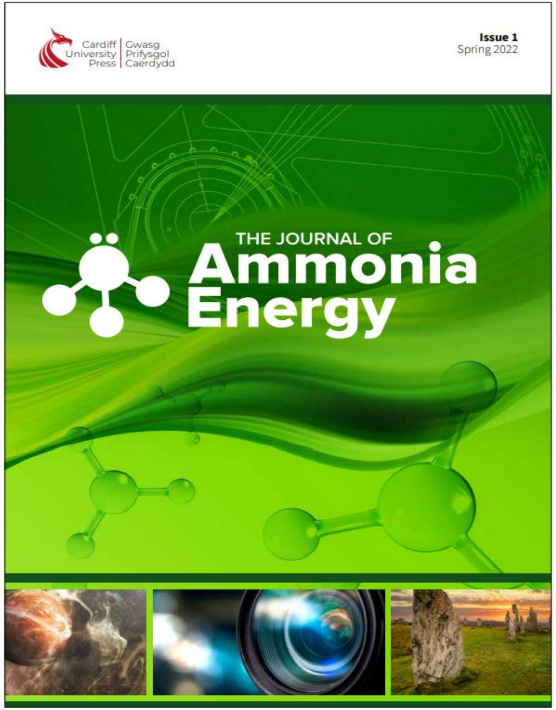

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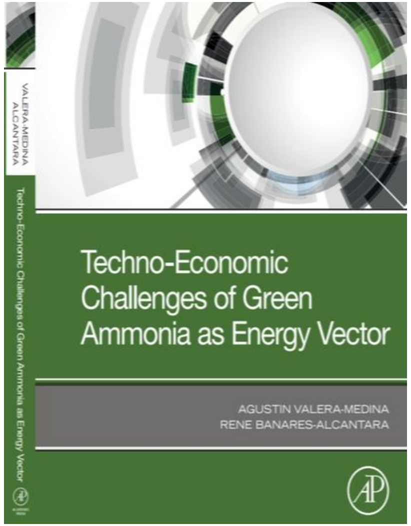
5th SYMPOSIUM on
AMMONIA ENERGY

3rd LATAM MEETING ON GREEN AMMONIA AND POWER-to-X

September 28th - 30th, 2026 | Santiago, Chile



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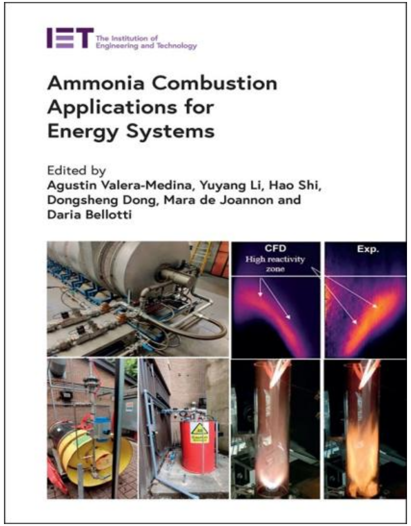
Techno-Economic Challenges of Green Ammonia as Energy Vector

Techno-Economic Challenges of Green Ammonia as Energy Vector

AGUSTIN VALERA-MEDINA
RENE BANARES-ALCANTARA



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Ammonia Combustion Applications for Energy Systems

Edited by
Agustin Valera-Medina, Yuyang Li, Hao Shi, Dongsheng Dong, Mara de Joannon and Daria Bellotti

CONCLUSIONS

- Ammonia can be used to store energy for long distances and long periods of time.
- Ammonia’s low reactivity require additional methods for combustion improvement.
- Plasmas enhanced combustion is a solution.
- Practical mobile applications can benefit from the use of liquid ammonia injection, making PLAS-Mi NH3 a real solution.
- Ammonia in rural locations can also benefit from PLAS-Mi NH3, with demos at ~1MW showing the potential of the chemical.

THANKS FOR YOUR ATTENTION

FURTHER INFORMATION:
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