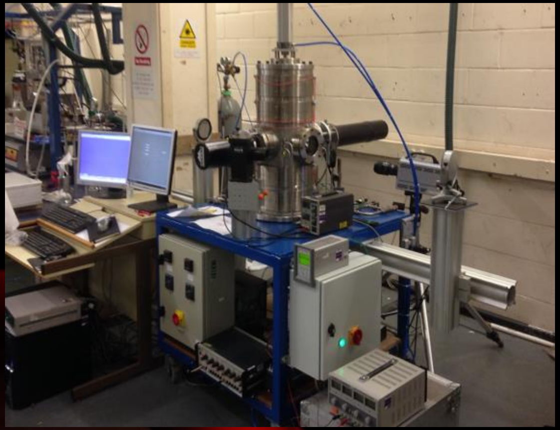
Ammonia-Hydrogen Power for Combustion Engines



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FLEXIS

SMART ENERGY FOR OUR FUTURE

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GTRC

GAS TURBINE RESEARCH CENTRE

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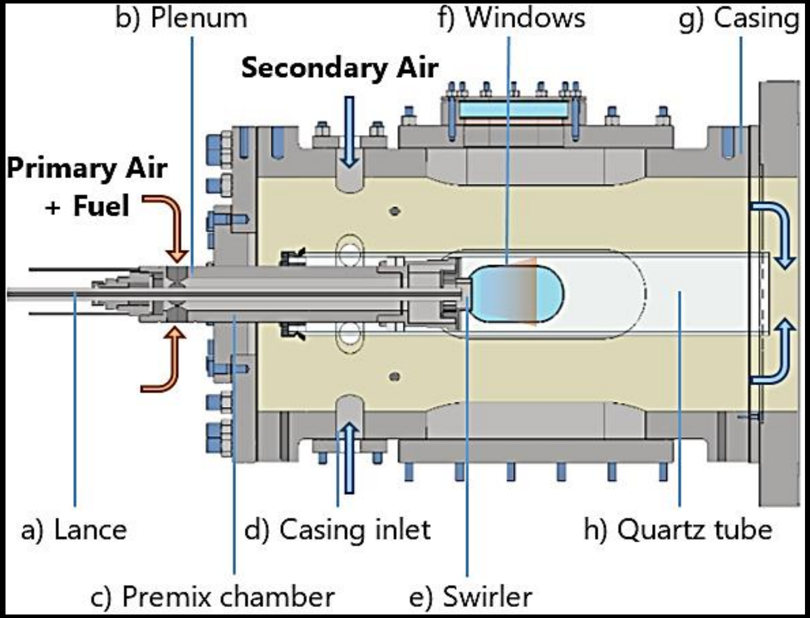
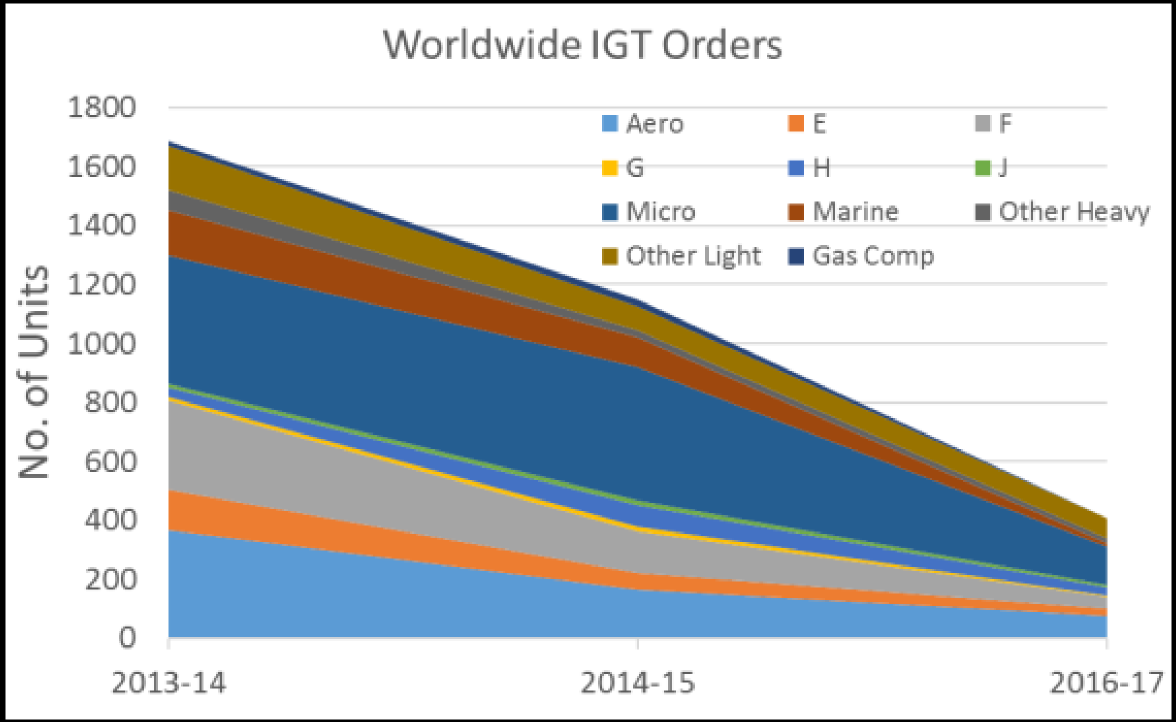


INTRODUCTION

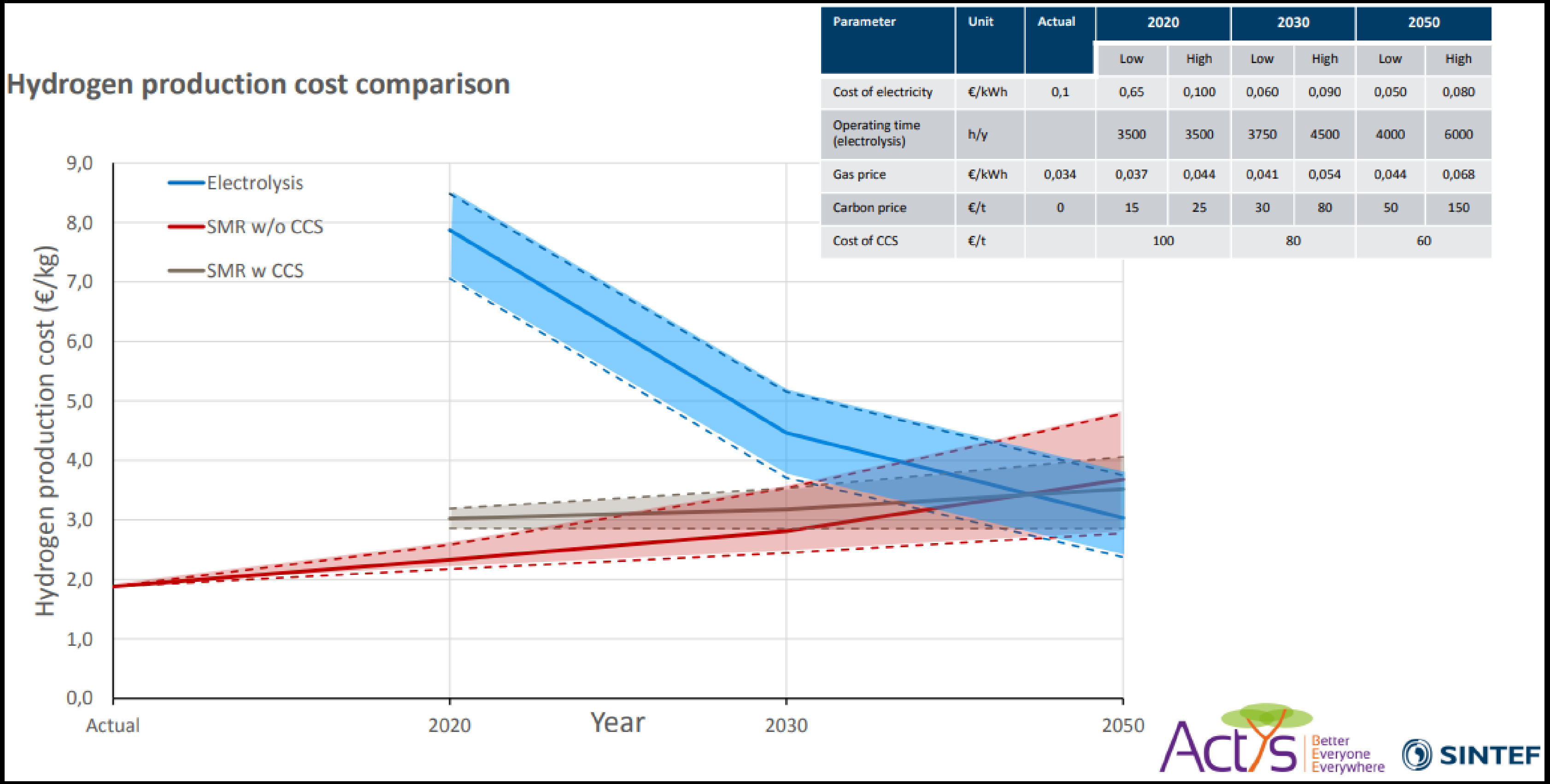
- Large power generation is generally produced via Gas Turbines (GTs).
- Unfortunately, concerns with CO2 production (climate change) and introduction of renewable energy at lower costs have decreased the commissioning of GTs worldwide.
- However, it is well-known that renewable energy presents the problem of intermittency.



The Future of Gas Turbine Technology [Rich Dennis Technology Manager NETL, 9th Int. Gas. Turbine conference, 10-11 October 2018 Brussels Belgium]

INTRODUCTION

- Thus, intermittency can be solved with energy storage.
- One chemical that can potentially solve the problem of storage is hydrogen.
- Hydrogen production is predicted to be much cheaper in a few decades.



Parameter	Unit	Actual	2020		2030		2050	
			Low	High	Low	High	Low	High
Cost of electricity	€/kWh	0,1	0,65	0,100	0,060	0,090	0,050	0,080
Operating time (electrolysis)	h/y		3500	3500	3750	4500	4000	6000
Gas price	€/kWh	0,034	0,037	0,044	0,041	0,054	0,044	0,068
Carbon price	€/t	0	15	25	30	80	50	150
Cost of CCS	€/t		100		80		60	

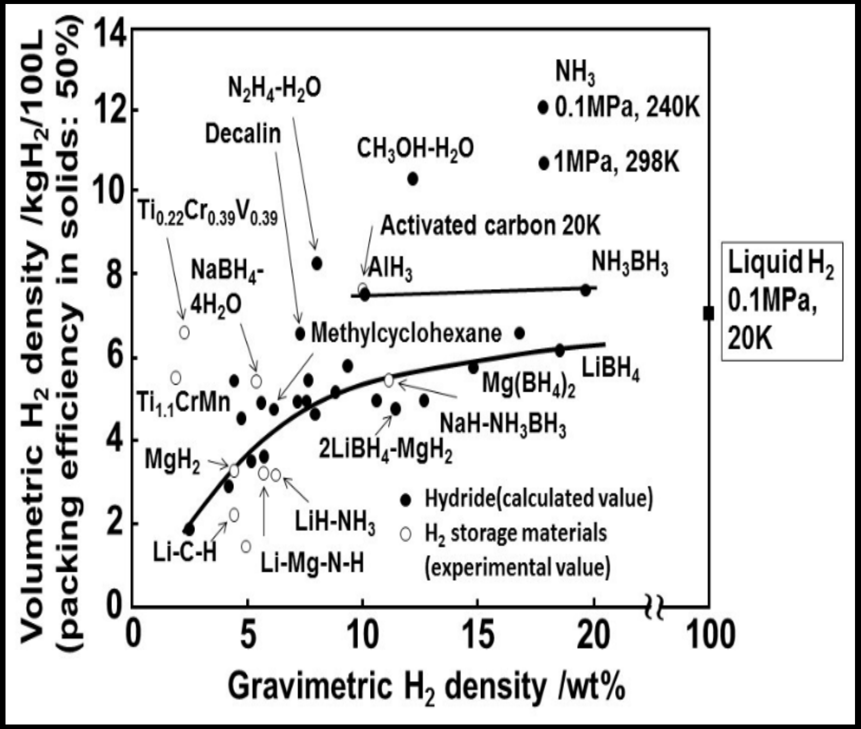
Hydrogen Cost Comparison [Dr. Nils A. Røkke, SINTEF, 9th Int. Gas. Turbine conference, 10-11 October 2018 Brussels Belgium]

INTRODUCTION

- Therefore, most gas turbine developers are back into the development of flexible hydrogen gas turbines.
- However, hydrogen transportation and storage is a challenge.
- Moreover, hydrogen explosive nature combined with fast reactivity have always been a problem for gas turbine developers to obtain large energy quantities.
- Therefore, another chemical with high hydrogen content can be used.

INTRODUCTION

- Ammonia can
  - be obtained from renewable sources,
  - allow the rescue of stranded resources,
  - enables the use of waste streams,
  - allow storage of vast amounts of energy 15 times cheaper than H2,
  - be used to produce energy in Islands or isolated regions,
  - be used as a fuel, but also as a fertilizer,
  - High hydrogen content (higher than liquid H2),
  - have a great economical potential, with a market size in Europe up to 184 Billion Euros per year.



Hydrogen densities in hydrogen carriers. Courtesy of Prof. Yoshitsugu Kojima, Hiroshima University.

CHALLENGES

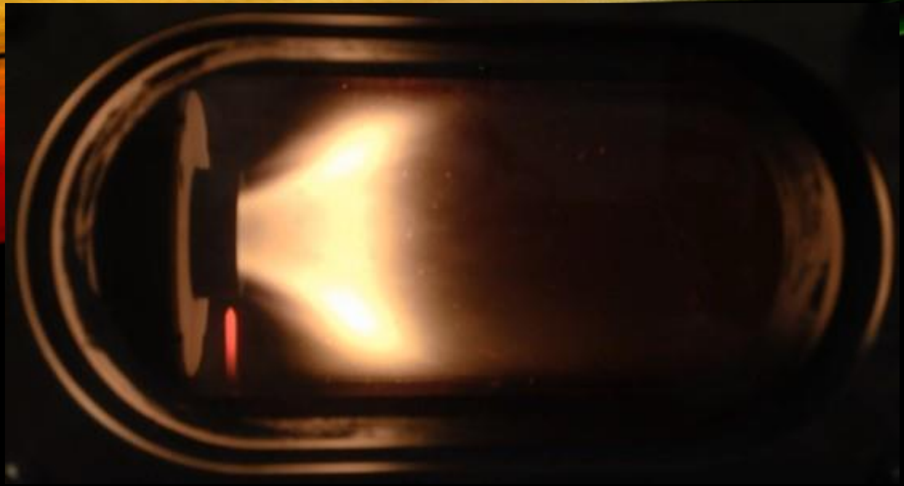
The technology faces the following obstacles,

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)

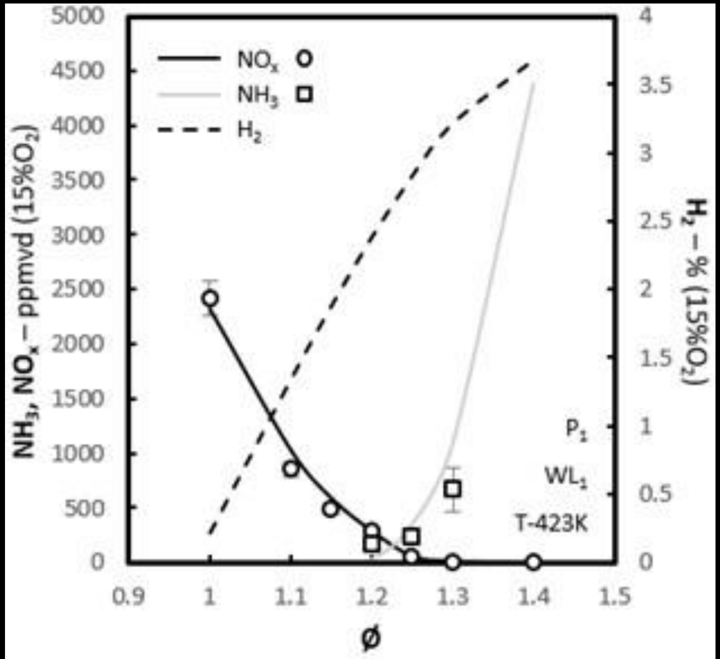
CURRENT DEVELOPMENTS – AMMONIA GAS TURBINE (AGT)

- For example, due to its chemical properties, ammonia presents,
  - Slow chemical kinetics
  - Unstable regimes when burned
  - High NOx emissions
  - High toxicity for humans and living organisms
- Therefore, new programs of research (especially in Japan and the UK) have been conducted to use ammonia as fuel for power generation in gas turbines.
- The main characteristic of using ammonia is that it can split during combustion into hydrogen and nitrogen/hydrogen radicals.

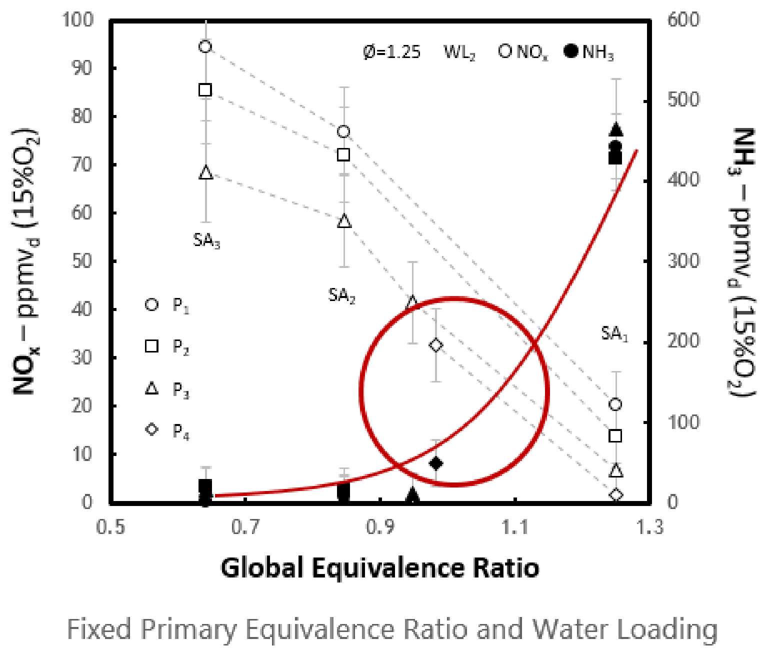
AGT DEVELOPMENTS



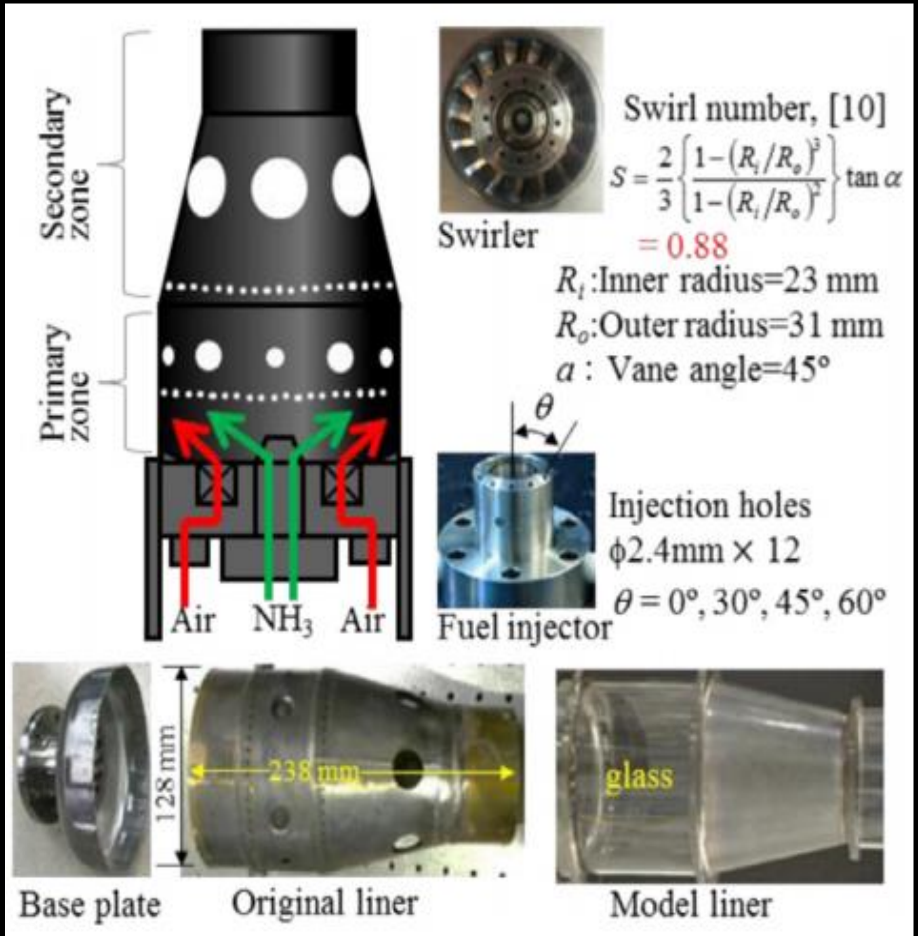
70%$_{vol}$ NH3 30%$_{vol}$ H2. Cardiff University.



Clear reduction of NOx at high E.R. and high concentration of hydrogen



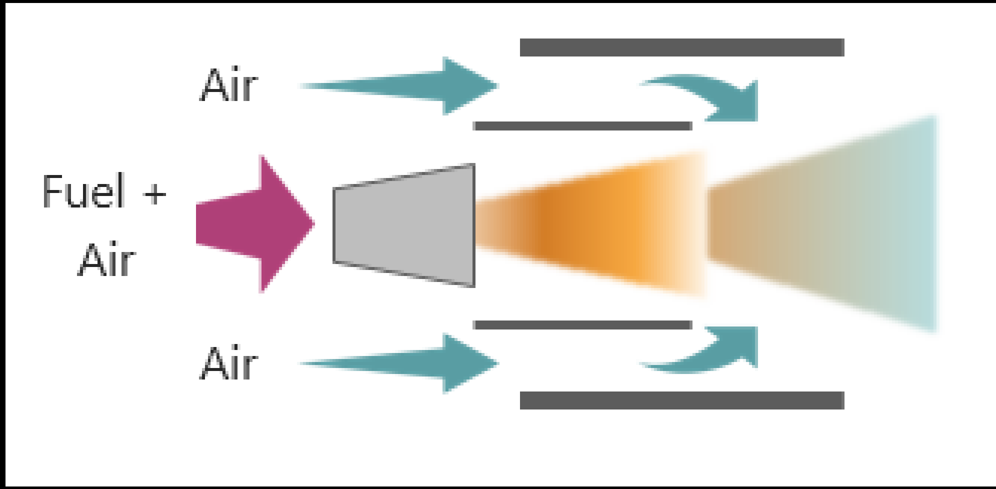
Secondary Air (SA) addition with steam injection. Cardiff University [Pugh et al, 2018]



The MGT high-swirl combustor
[Okafor et al, 2018]

AGT DEVELOPMENTS

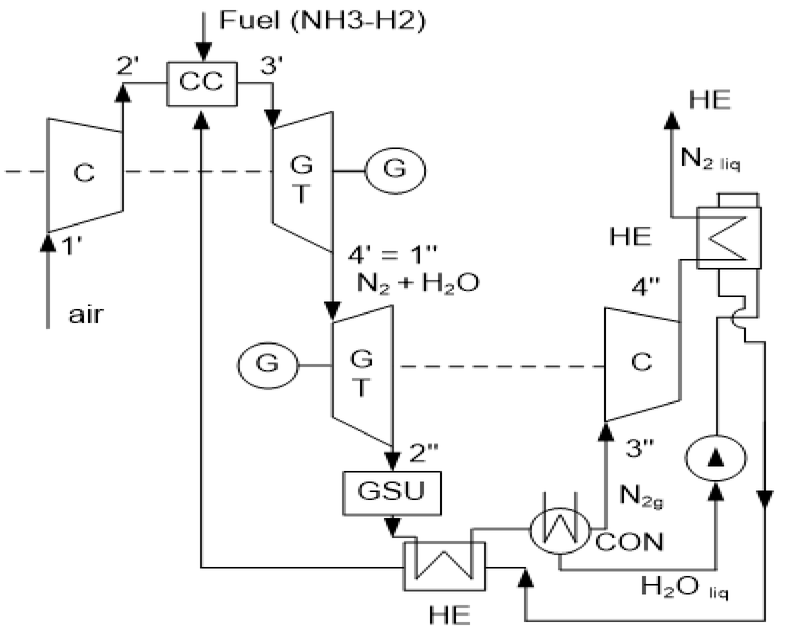
- Therefore, ammonia based flames not only provide the required heat and power, but also dissociate NH3 into large quantities of hydrogen and small traces of unburned ammonia that can be consumed post-flame.
- Therefore, most works on the field are now focusing on staged combustion, running rich at the flame front, leaner at the back of the burner,



Cardiff proposal for a RQL burner fuelled with ammonia/hydrogen/steam[Pugh et al, 2018]

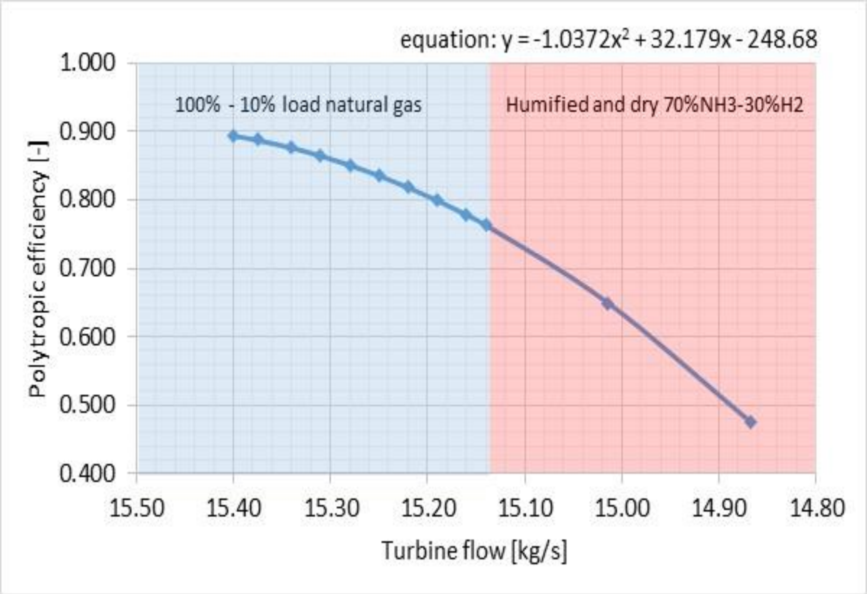
AGT DEVELOPMENTS

- Now, research is focused on ultra-low NOx combined with high efficiencies and power outputs.



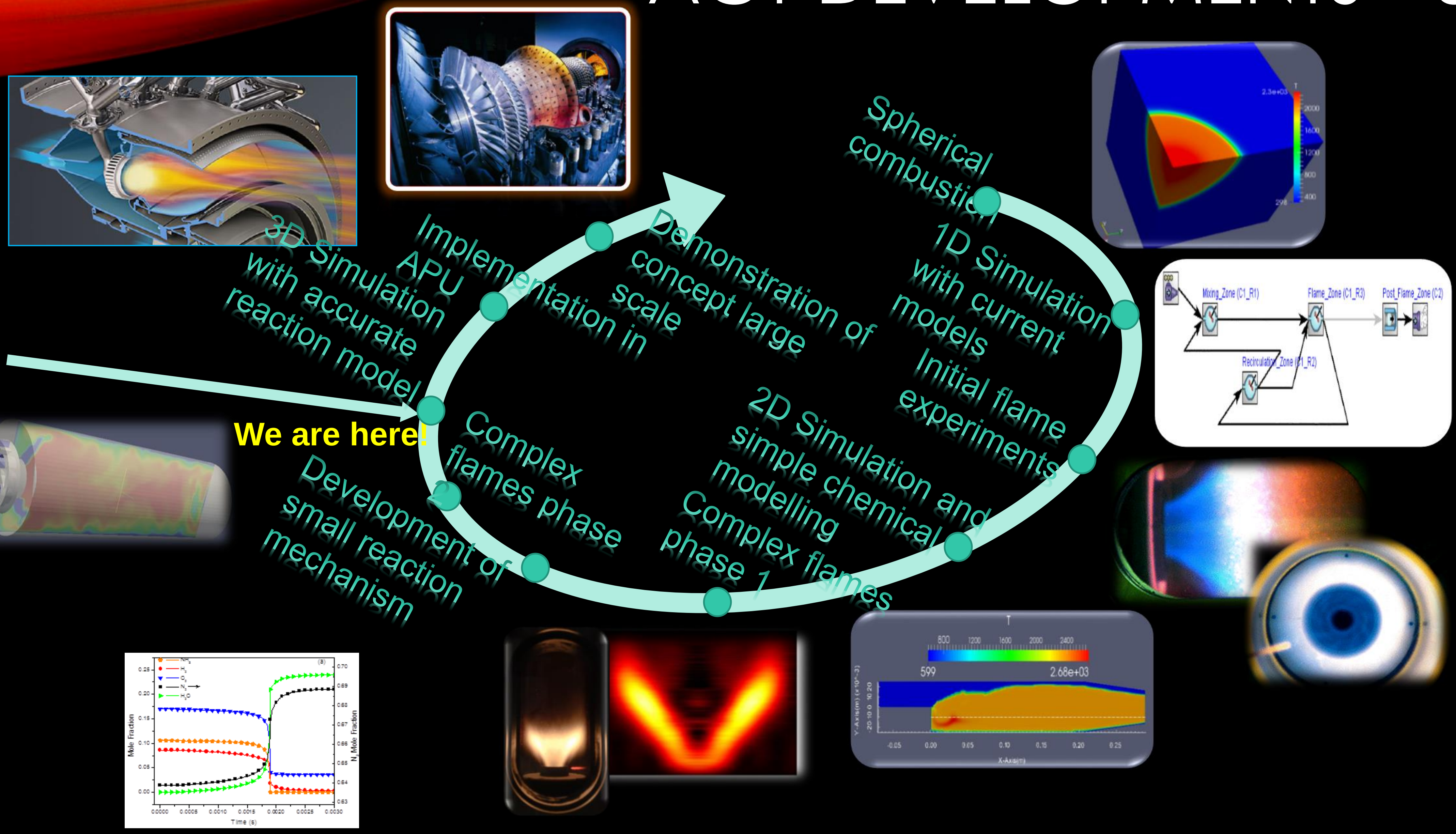
Modified Brayton Cycle
Inlet temperature 1260K
Outlet temperature 827K
Supplied heat 10.45MWth
Power 3.56MWe
Plant efficiency 34%

Trigeneration Cycle
Cooling+Power+Heating
Initial calculations: 72%
(compared to 80%)



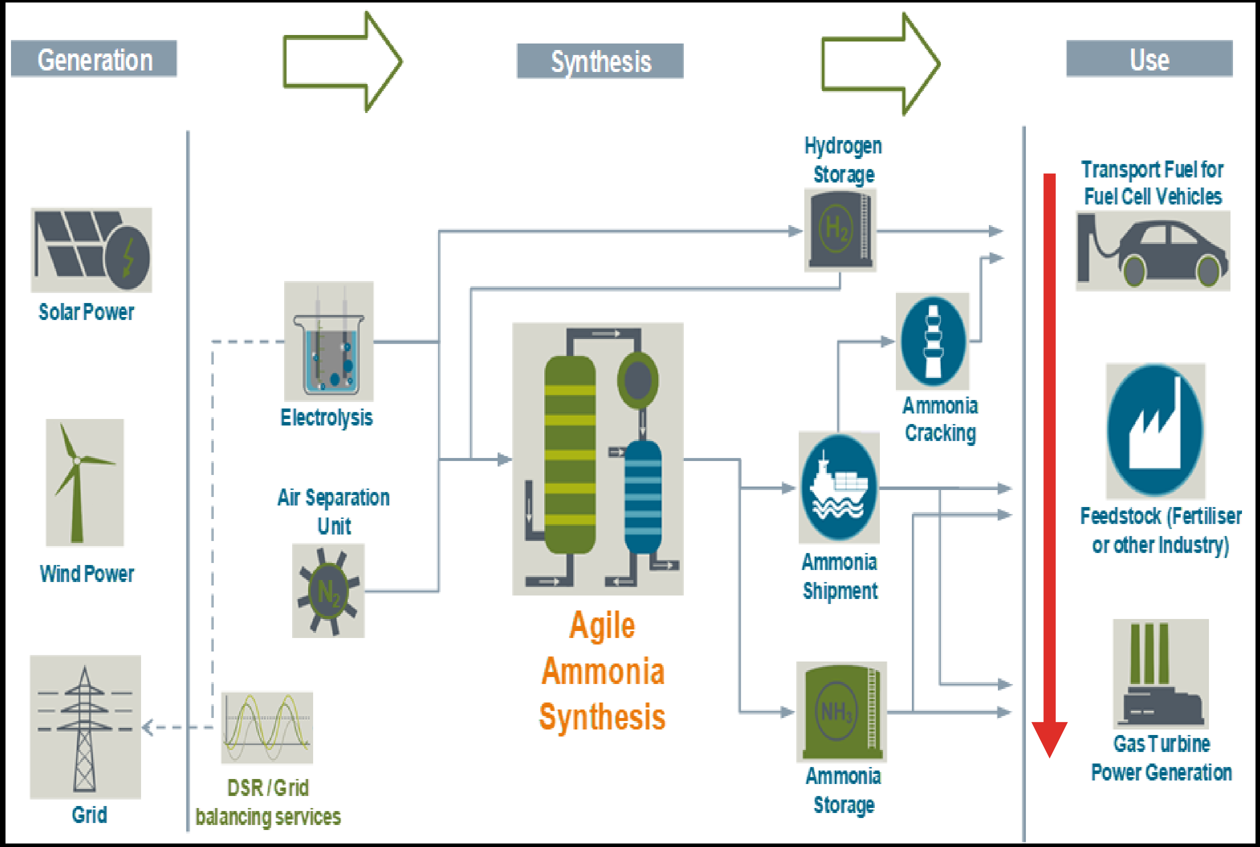
Different cycle strategies are under research to determine a conditions for high efficiencies a whole ammonia/hydrogen/steam cycle comparable to DLN technologies.

AGT DEVELOPMENTS - UK



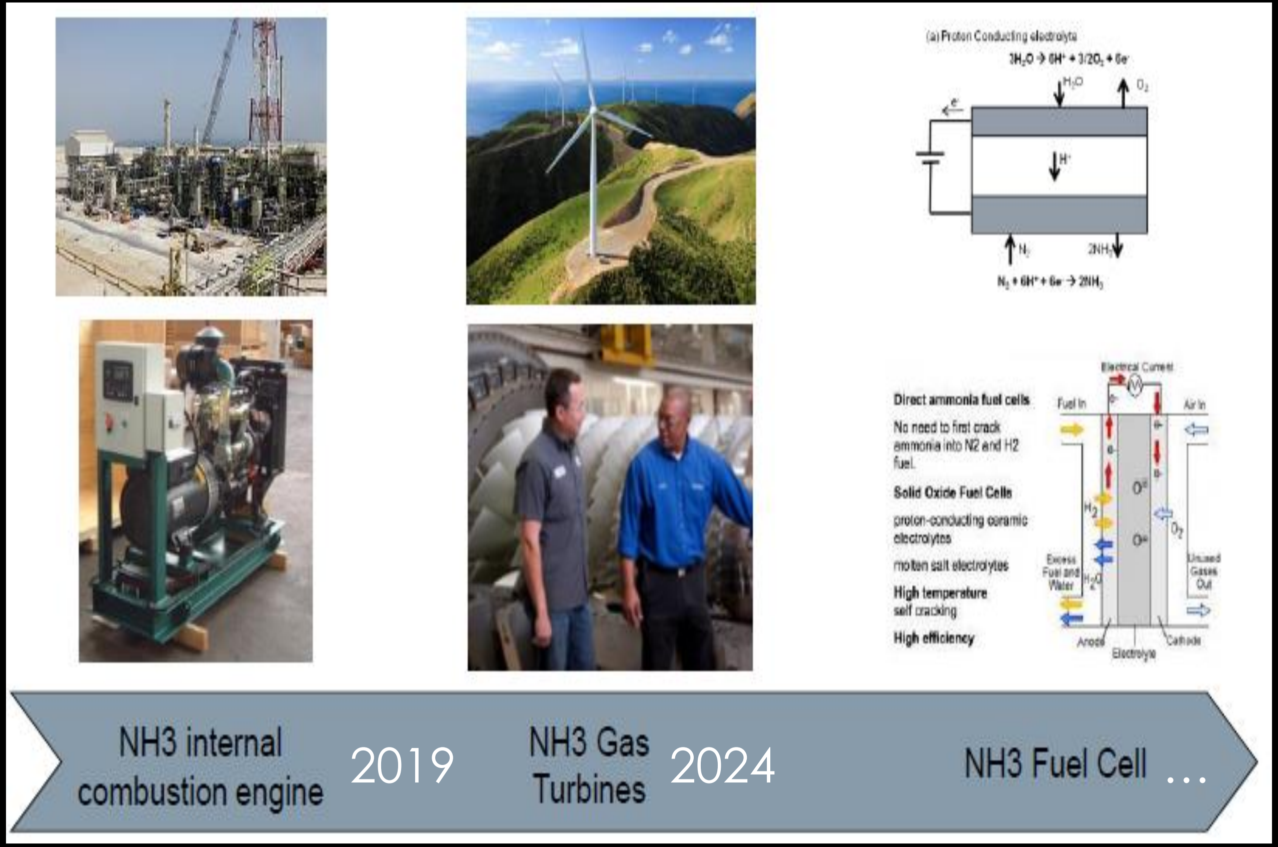
ROADMAP

- Although ammonia combustion is still seen as the lowest end of the use of ammonia for energy, cheaper distribution, higher hydrogen content and easier operation will change the position of NH3 gas turbines in the energy arena.



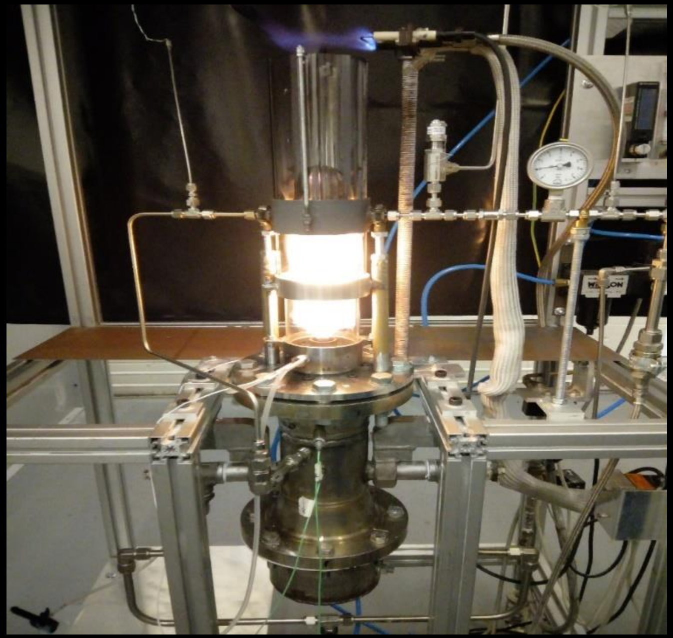
Green Ammonia/Hydrogen Economy

[Wilkinson I, Rotterdam, 2018]

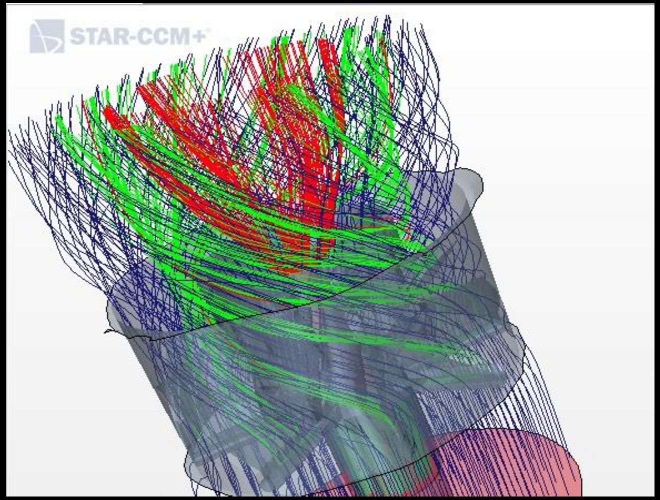


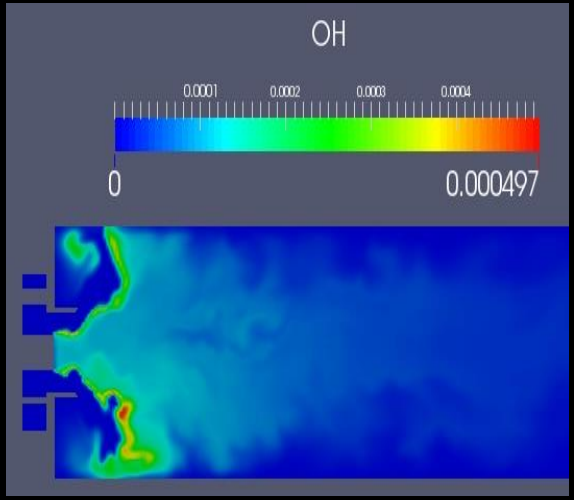
Roadmap Ammonia Power

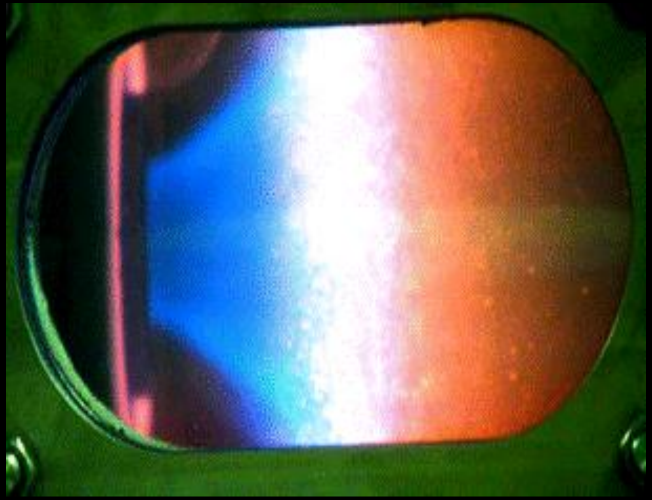
FUTURE DEVELOPMENTS AGT



- Future developments include,
  - Full characterisation of RQL systems
  - Injection of liquid sprays
  - Improvement of pre-cracking devices
  - Improved chemical mechanisms for large scale design
  - More demonstration units
  - Development of novel power cycles
  - Other areas (public perception, toxicology, etc.)







COLLABORATION

NUS National University of Singapore

University of Exeter

Universitas Amoiensis

University of Leicester

Imperial College London

Science & Technology Facilities Council

University of Oxford

Trinity College Dublin, The University of Dublin

Tokyo Gas

Tata Steel

University of Twente, The Netherlands

UCL

Kyoto University, Kyoto Japan, Founded 1897

Yara

Lunds Universitet

C-JOB Naval Architects / Engineers

European Turbine Network

Siemens

PRISME – Laboratoire Pluridisciplinaire de Recherche Ingénierie des Systèmes, Mécanique, Énergétique

TU/e Technische Universiteit Eindhoven, University of Technology

CIDESI®

University of Birmingham

CONCLUSIONS

- Ammonia can be burned efficiently with very low emissions NOx without using catalysts.
- Ammonia blends can be used efficiently, with low NOx, and production of species that can be burned post-combustion.
- Research is on its way to implement new technologies in medium size GTs that can be deployed to small, isolated locations.
- However, for the "Hydrogen through Ammonia" economy to happen, lower costs and higher efficiencies of conversion from renewables are needed.
- Support needs to be provided to all different fronts to achieve the profitable implementation of AGTs worldwide.

THANKS FOR YOUR ATTENTION

FURTHER INFORMATION: VALERAMEDINAA1@CARDIFF.AC.UK

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