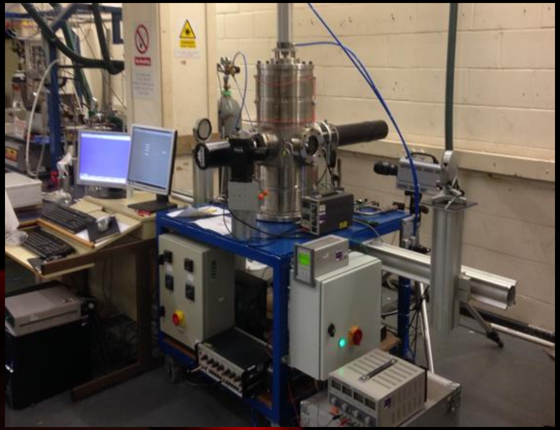
AMMONIA GAS TURBINES (AGT): REVIEW

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FLEXIS
SMART ENERGY FOR OUR FUTURE
YNNI CALL AR GYFER EI'N DYFODOL

GTRC
GAS TURBINE RESEARCH CENTRE

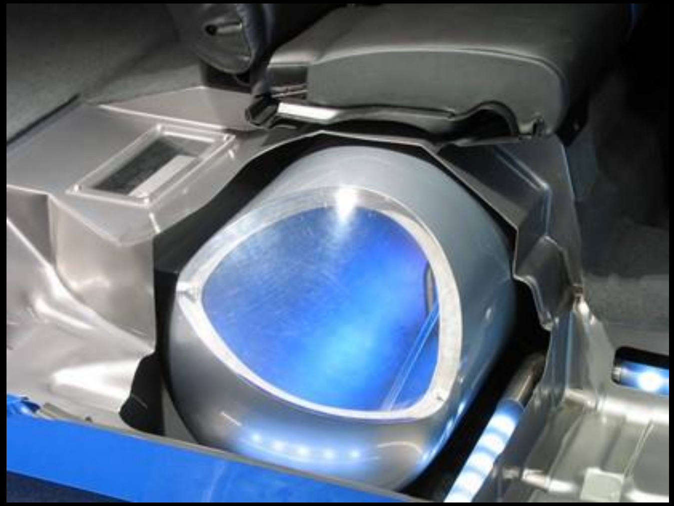
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

CONTENT

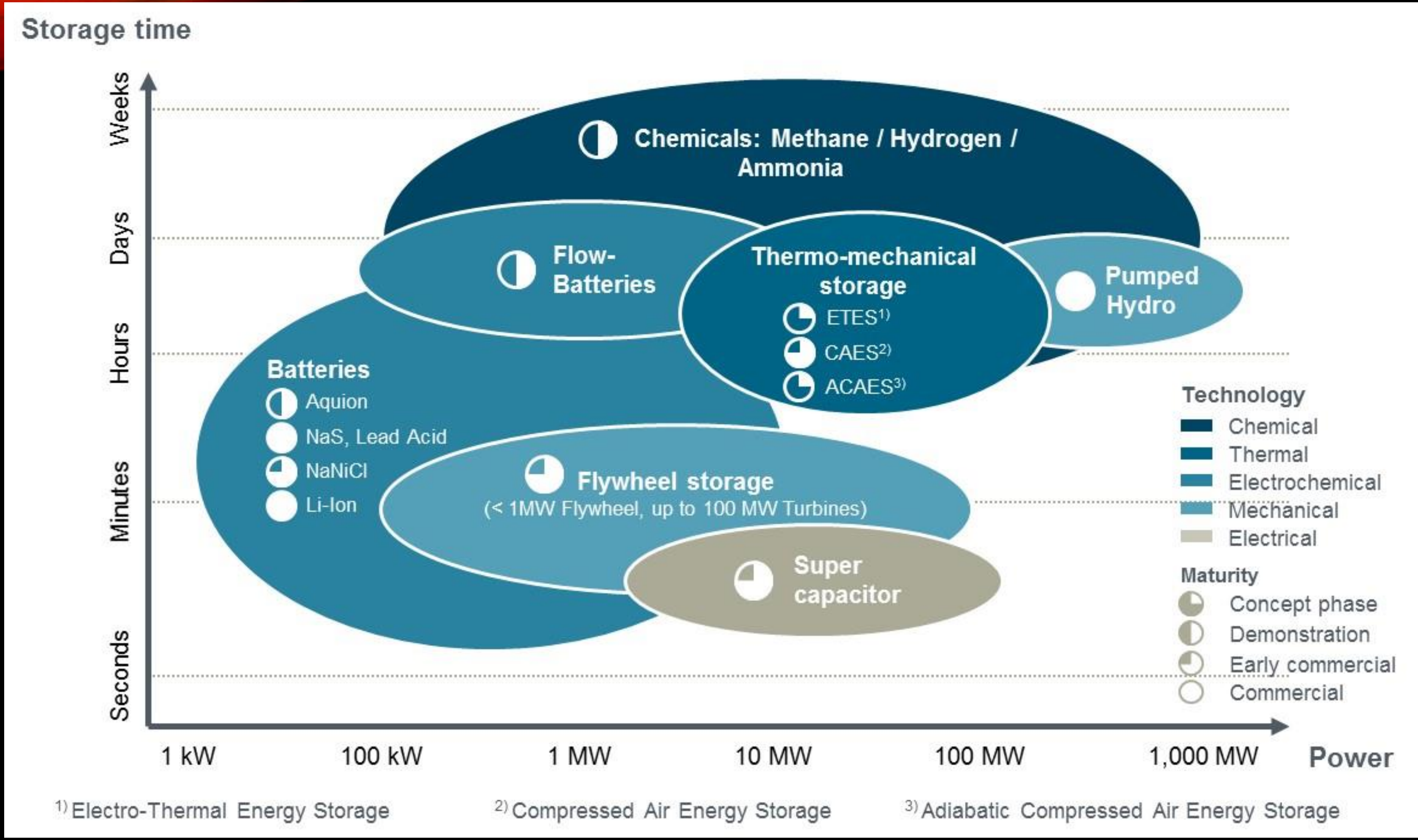
- INTRODUCTION
- CHALLENGES
- PAST WORK
- CURRENT DEVELOPMENTS
- INDUSTRIAL INTEREST
- FUTURE DEVELOPMENTS
- COLLABORATION
- AREAS OF INTEREST
- CONCLUSIONS

INTRODUCTION

- Intermittency can be solved with energy storage.
- One chemical that can potentially solve the problem of storage is hydrogen.
- However, hydrogen transportation and storage is a challenge.
- Moreover, hydrogen explosive nature combined with fast reactivity have always been a challenge for gas turbine developers to obtain large energy quantities.
- Therefore, another chemical with high hydrogen content can be used.



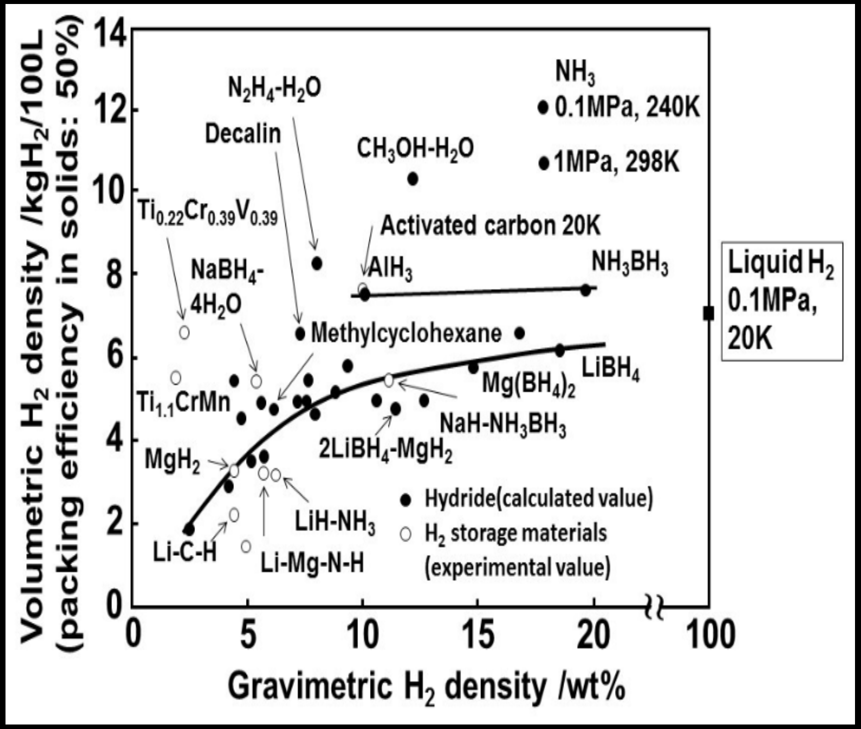
INTRODUCTION



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

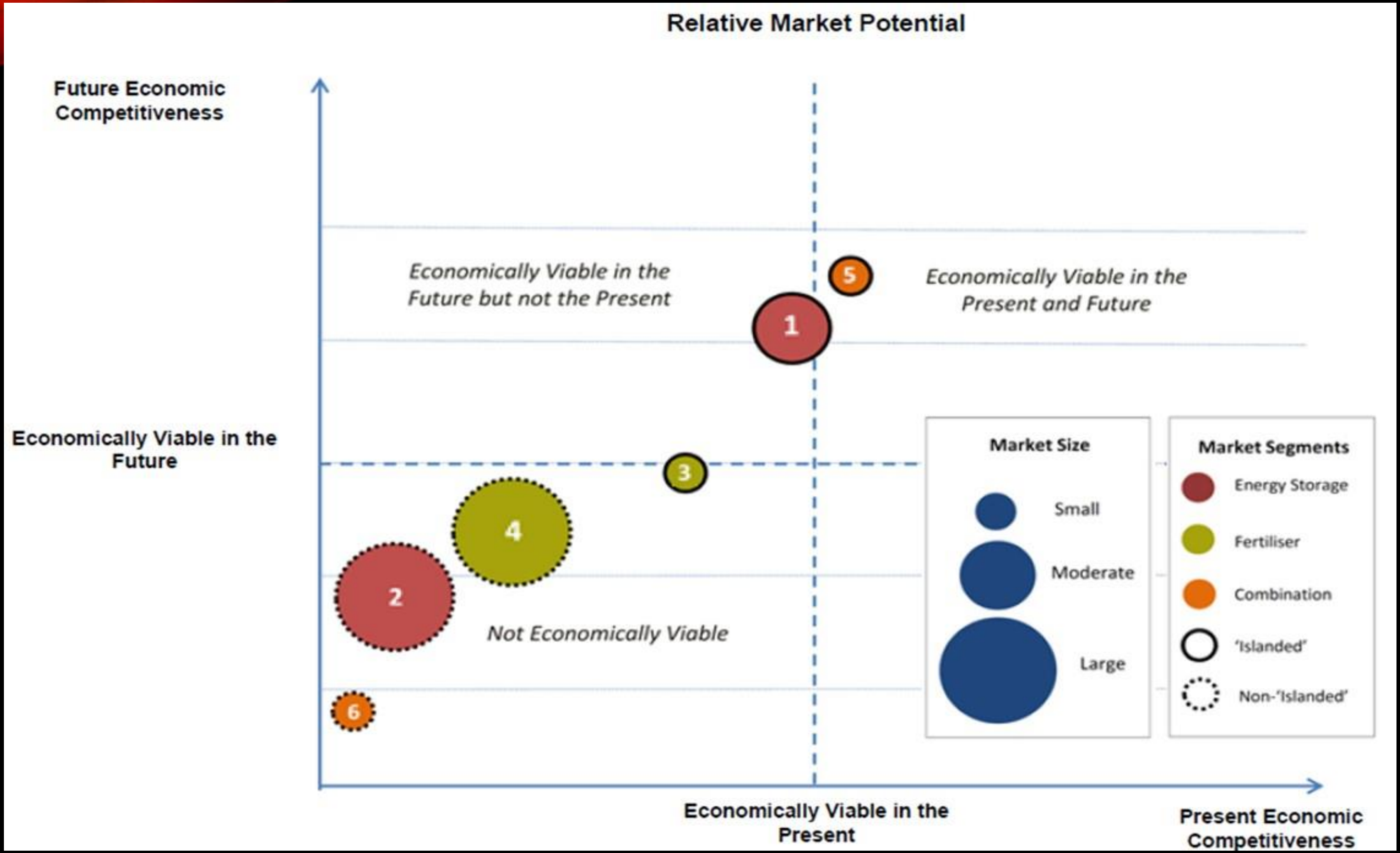
INTRODUCTION

- 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.

INTRODUCTION



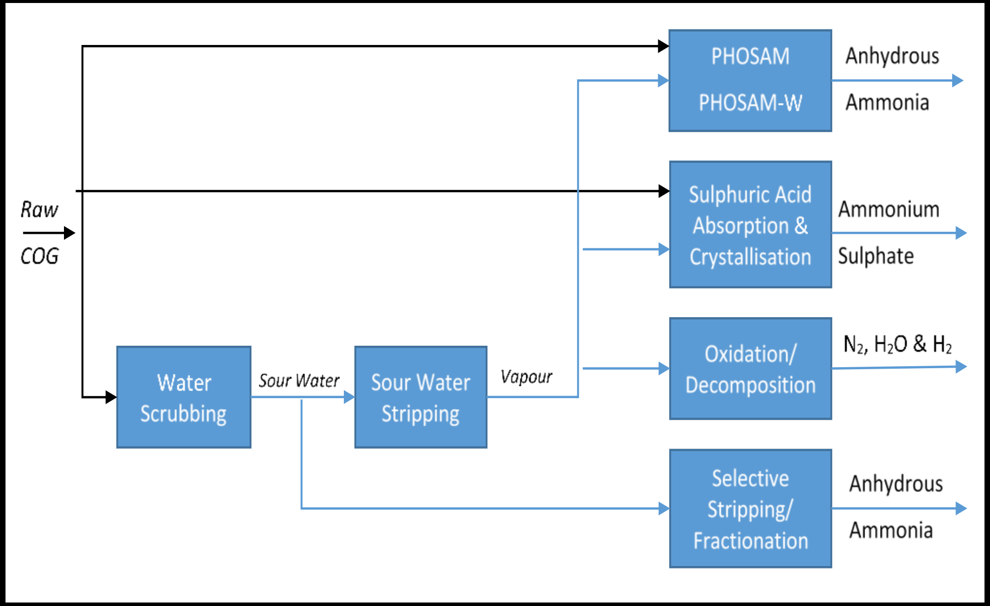
Ammonia Economy – Feasibility Study using novel techniques. [Banares R et al, 2015]

INTRODUCTION

- BF-BOF process represents 80% of UK (75% global) steel production (20% electric arc furnace)
- Around 400-500 kg coke/tonne steel
- Around 3 kg by-product ammonia/tonne coke - recovered during the cleaning of coke oven gas (COG)
- Up to 1,500 tonnes NH_3 per million tonnes of steel
- For a 4 million tonnes p.a. steel plant

  ≈ 13 to 16.5 tonnes ammonia/day

THUS – AMMONIA PRESENTS AN OPPORTUNITY AS A FUEL…



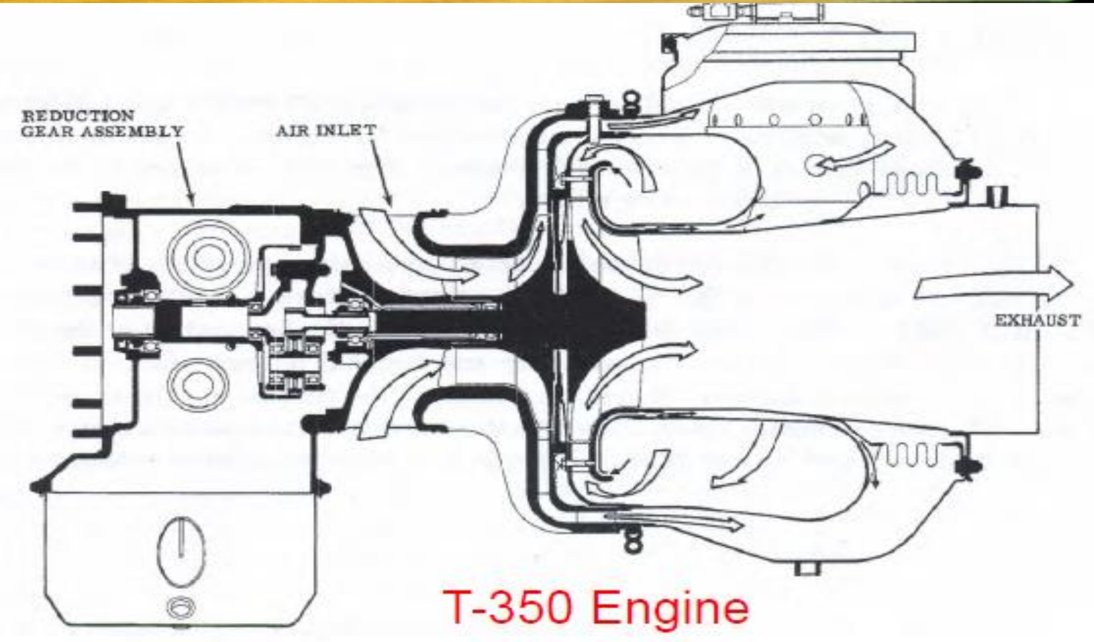
COG cleaning [Hewlett, ECCRIA, 2018]

CHALLENGES

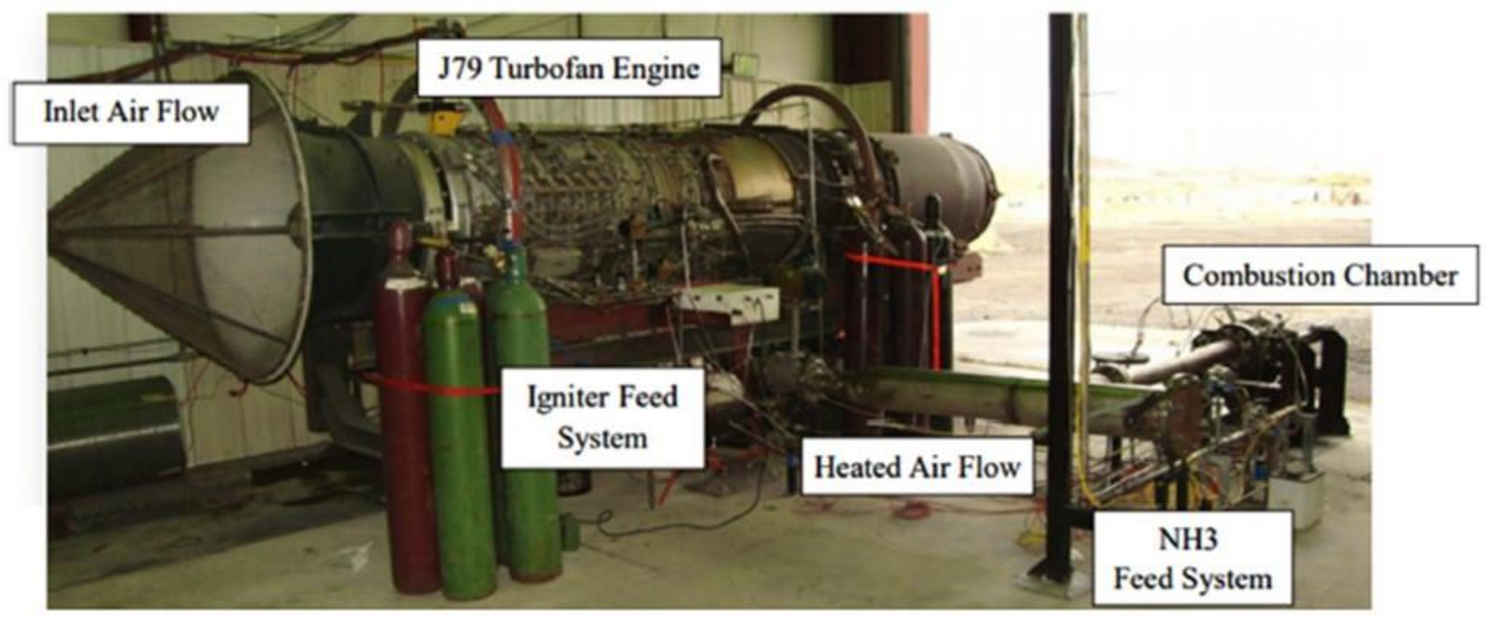
The technology faces the following obstacles,

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)

PAST WORK



T-350 Engine, Solar [Karabeyoglu et al, 2012]



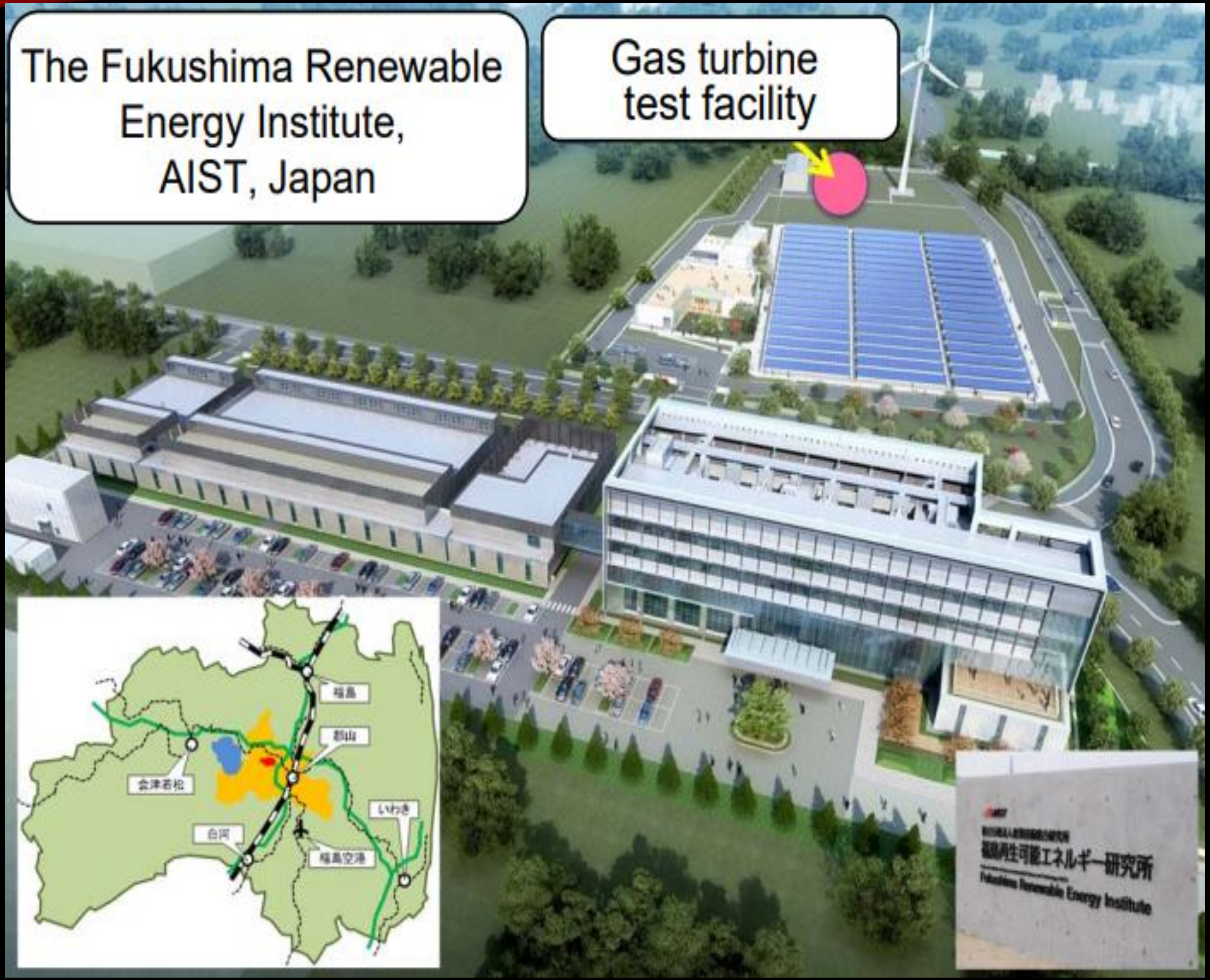
Test rig, SPG Advanced Propulsion and Energy [Karabeyoglu et al, 2012]

Oil Heating Furnace [Meyer et al, 2011]

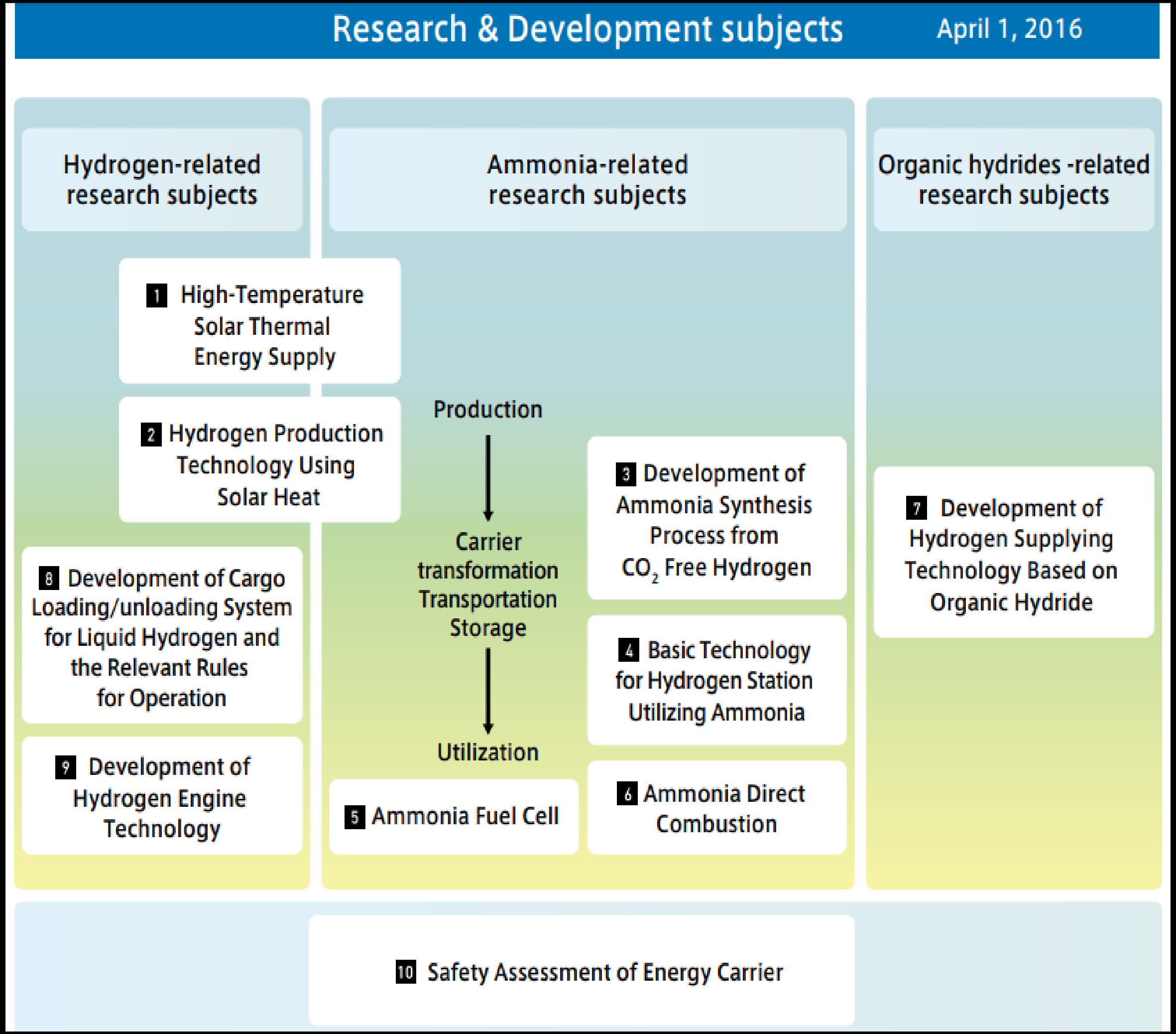
CURRENT DEVELOPMENTS – AMMONIA GAS TURBINE (AGT)

- However, due to its chemical properties, it shows,
  - Slow chemical kinetics
  - Unstable regimes when burned
  - High NOx emissions
  - High toxicity for humans and living organisms
- Therefore, programs of research 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 - JAPAN

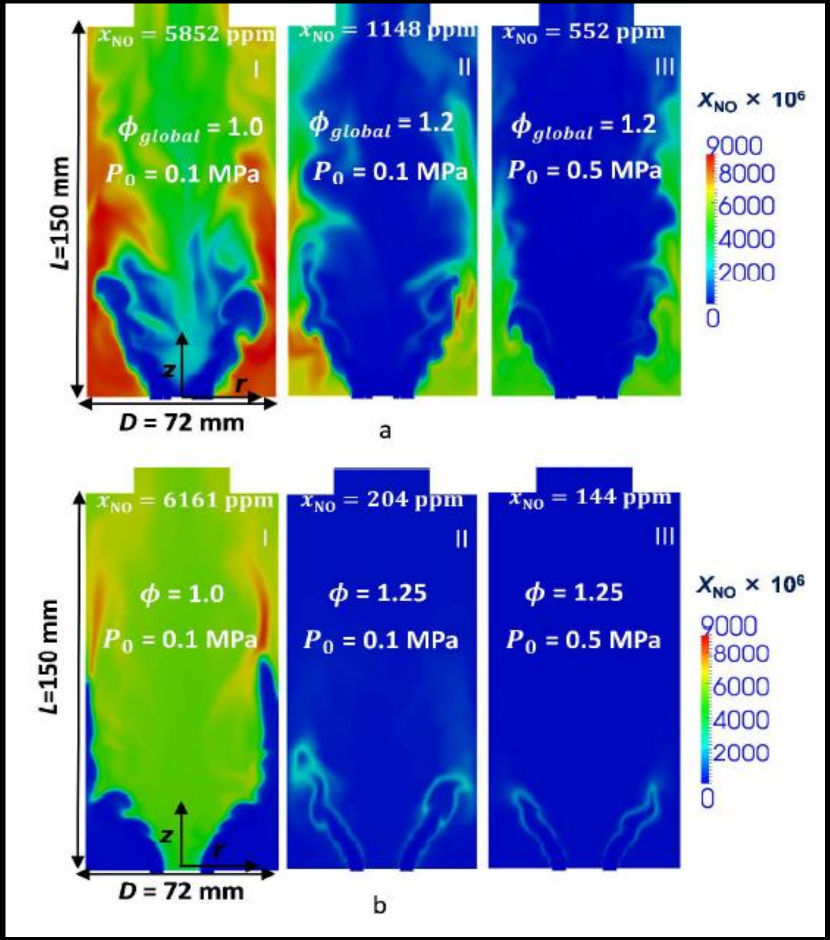


AIST Ammonia Gas Turbine facility [NH3 EU Conf, 2018]

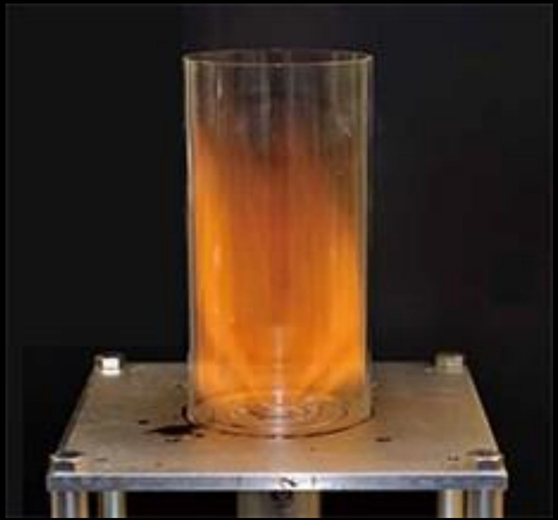


Strategic Innovation Program (SIP) – H2 vectors [JTS]

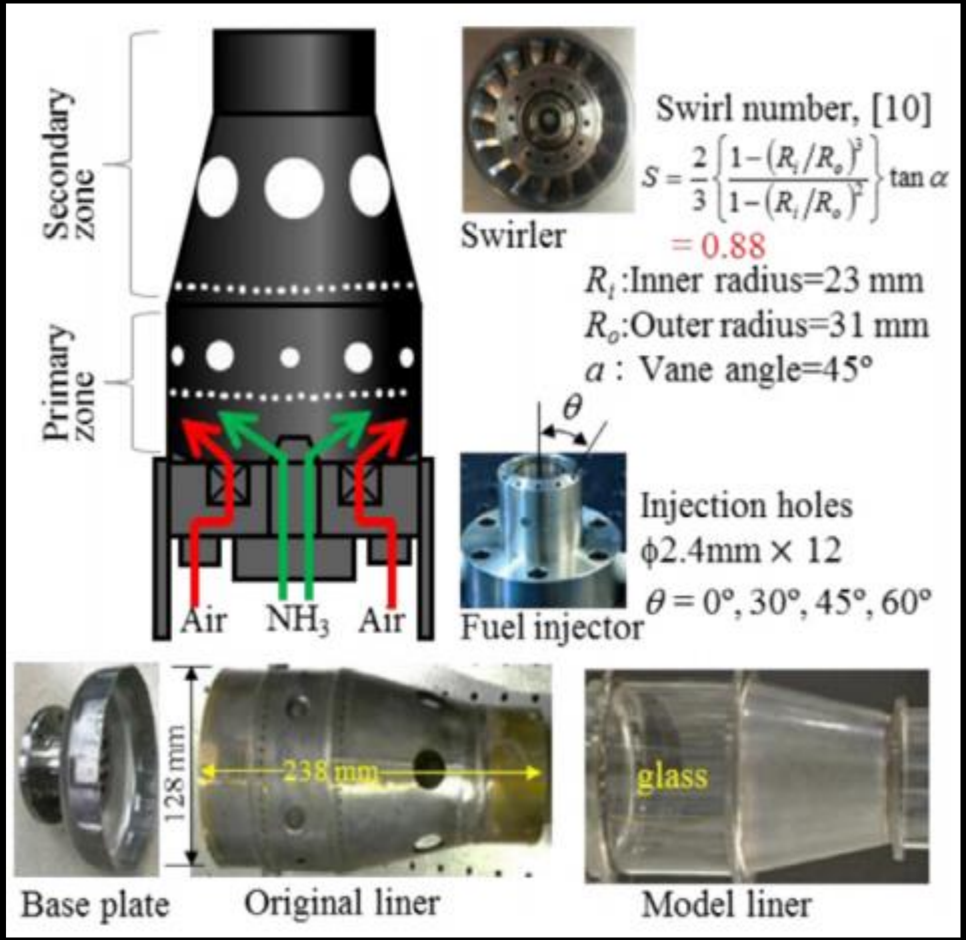
AGT DEVELOPMENTS – AMMONIA BLENDS



NO distribution in terms of global equivalence ratio and pressure. a) Non-premixed; b) Premixed
[Somarathne et al, 2017]

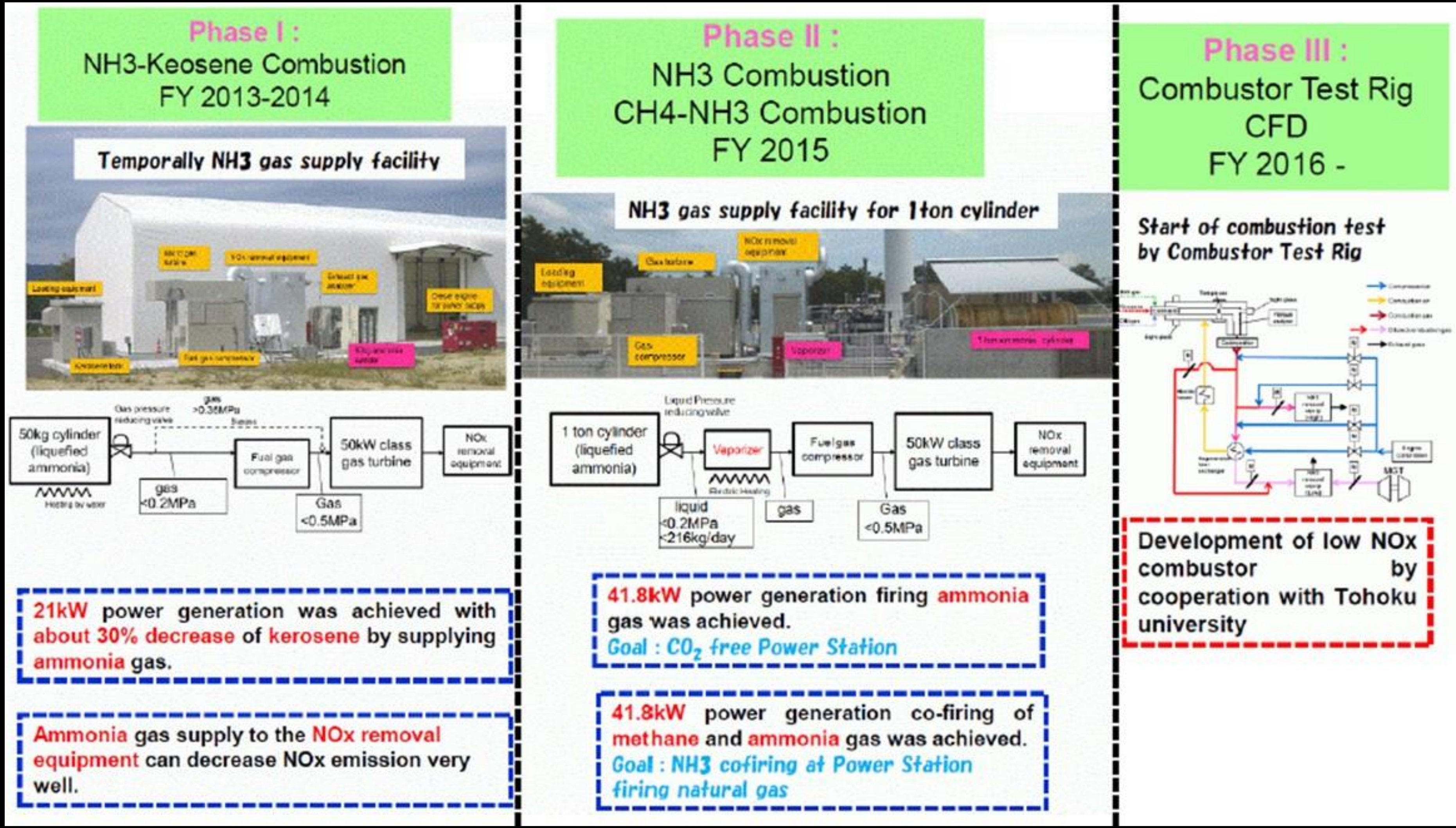


Ammonia Flame



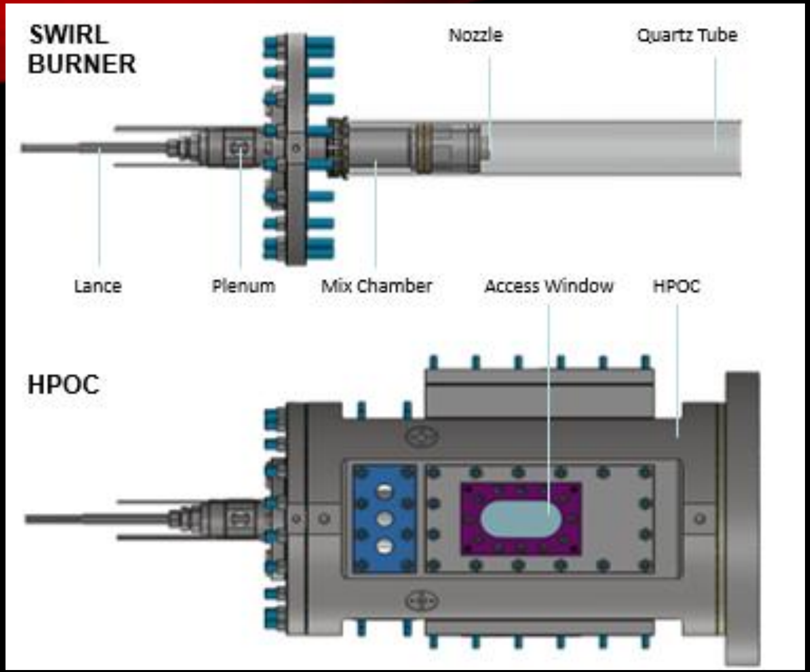
The MGT high-swirl combustor
[Okafor et al, 2018]

AGT DEVELOPMENTS – JAPAN



AIST Plan of Development [NH3 European Conf, 2018]

AGT DEVELOPMENTS – UK



Gas Turbine Research Centre

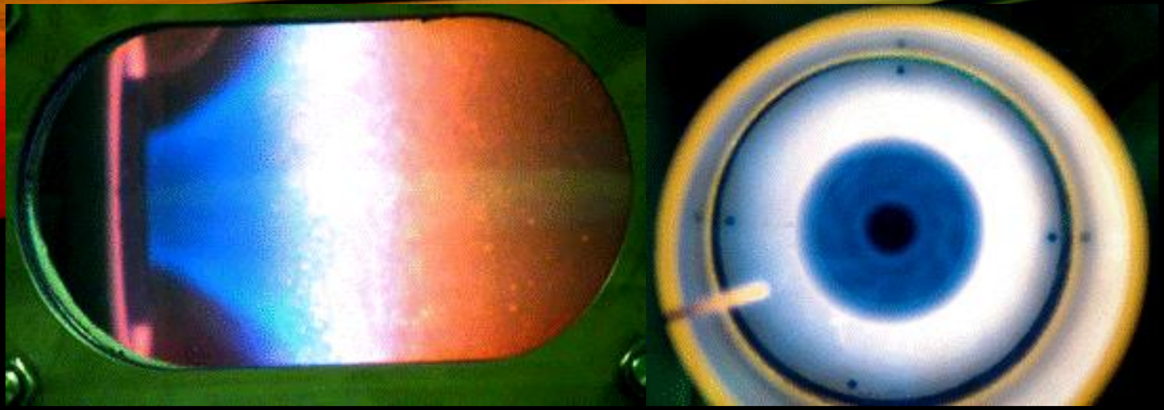
System

- High Pressure Optical Casing (HPOC) rated to 900 K, 1.6 MPa
- Axial and tangential optical access
- Liquid or gaseous fuel supply, with combustors operated in premixed or diffusion configurations
- Five lines allow for fuel/oxidant mixture blending, with precise mass flow control
- Pressurised heated steam supply to facilitate humidified combustion

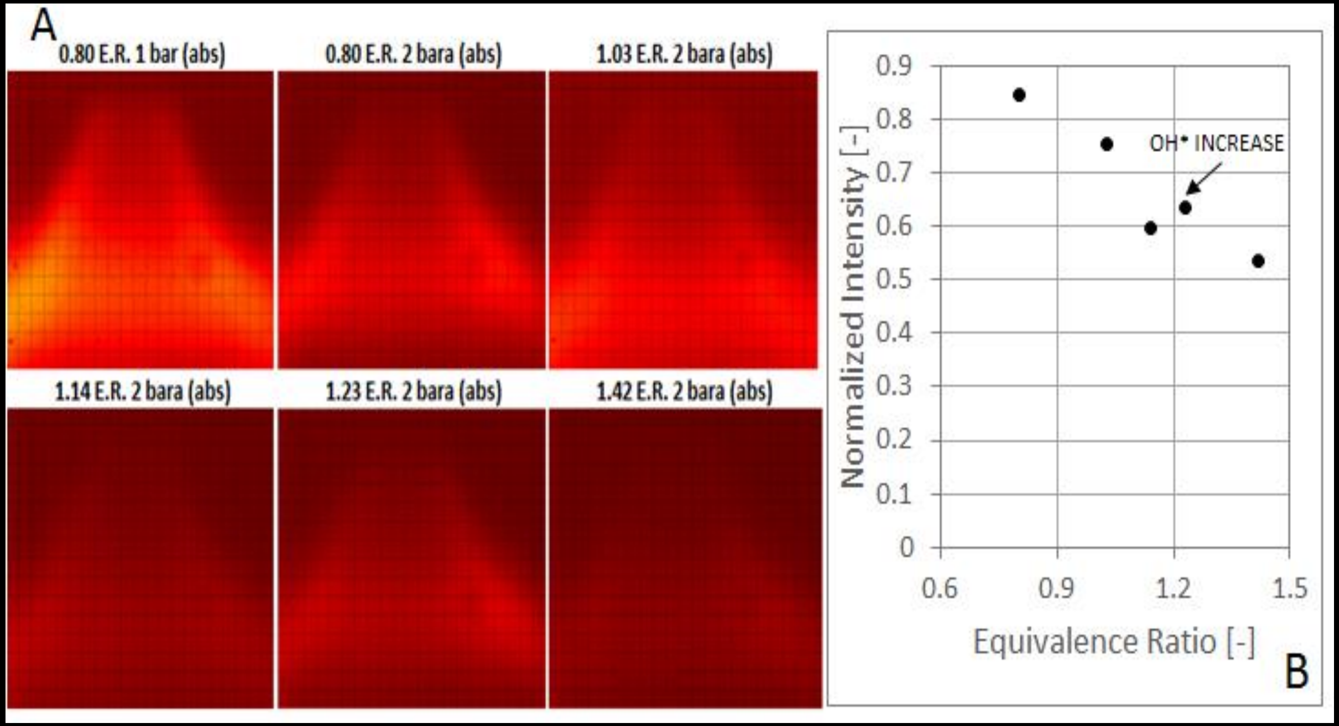
Diagnostic Tools

- Optical techniques including; high speed filming, Schlieren, Chemiluminescence, Particle Image PIV PLIF
- Dynamic pressure transducers give acoustic output of the system
- Online gas analysis for real time measurement of exhaust emissions, including; CO, CO2, NO, NO2, (Total NOx), O2, NH3 and unburned hydrocarbons

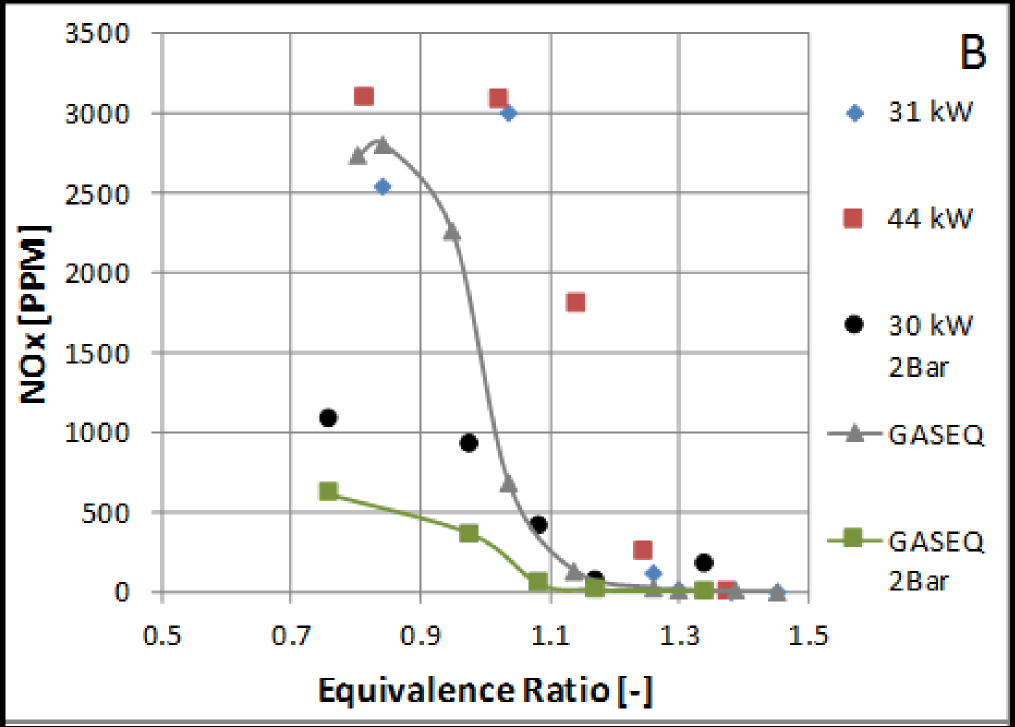
AGT DEVELOPMENTS: NH3 + CH4



66%$_{vol}$ NH3 33%$_{vol}$ CH4



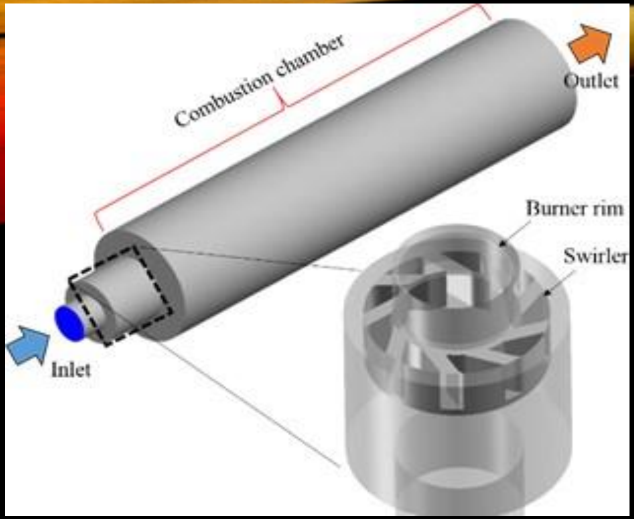
Equivalence ratio v OH Chemiluminescence



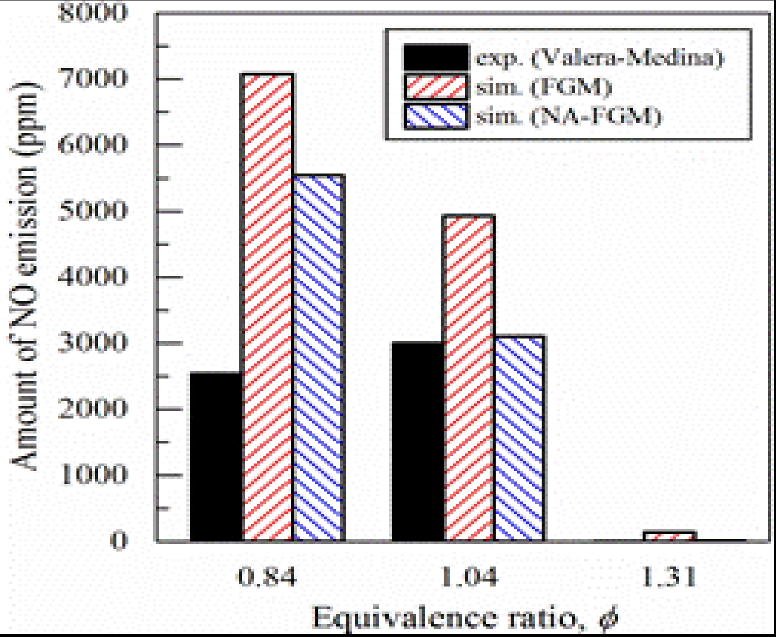
Comparison between measured and modelled NO$_x$ emissions

Measured wet on Signal 4000 VM (433K sample)

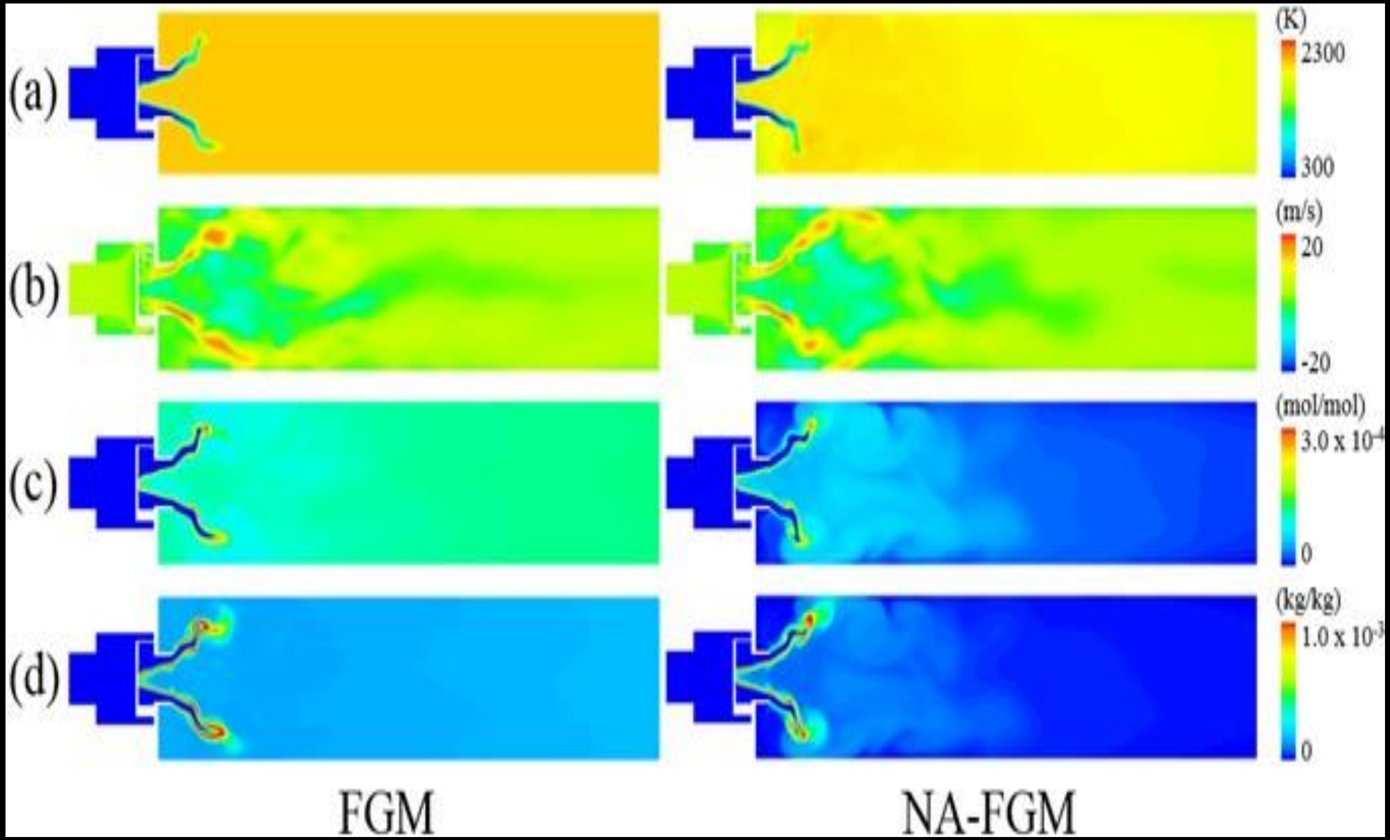
AGT DEVELOPMENTS: NH3 + CH4



CFD modelling of new swirlers

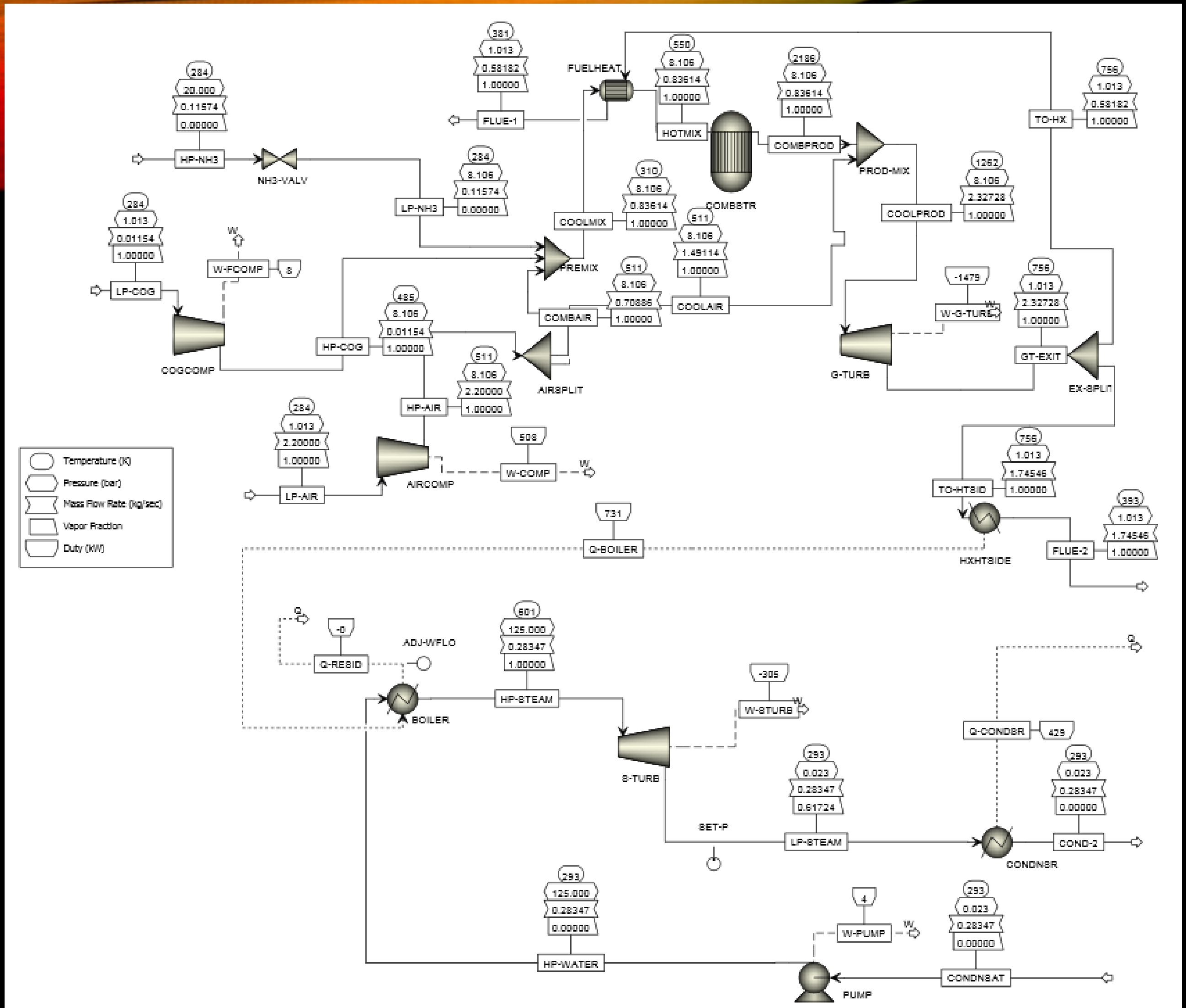


Correlation with bespoke experiments

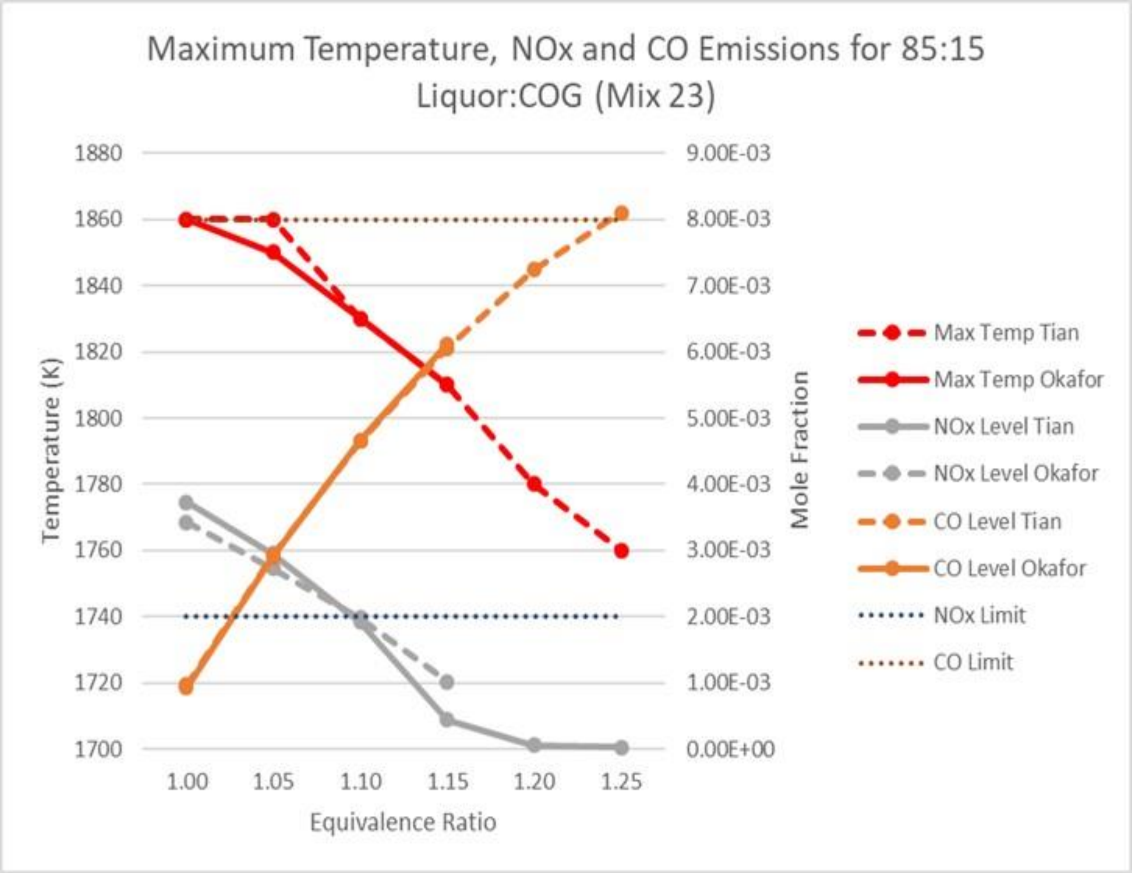


New modelling techniques show better performance – preliminary for development of new designs

AGT DEVELOPMENTS: NH3 + CH4

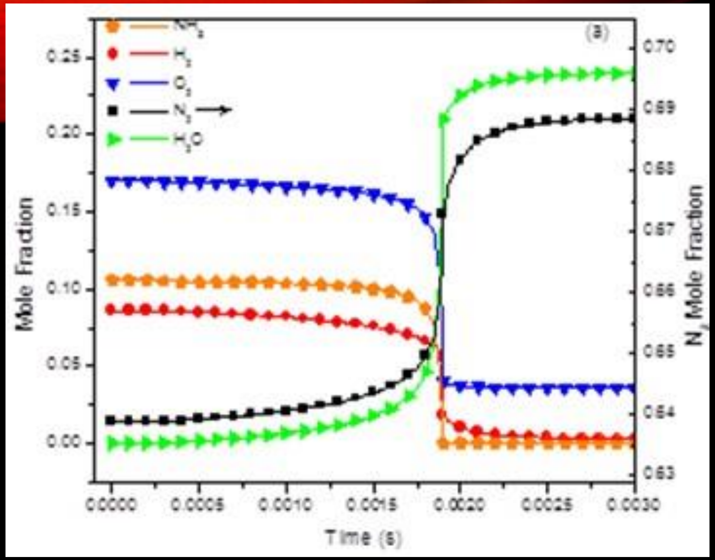


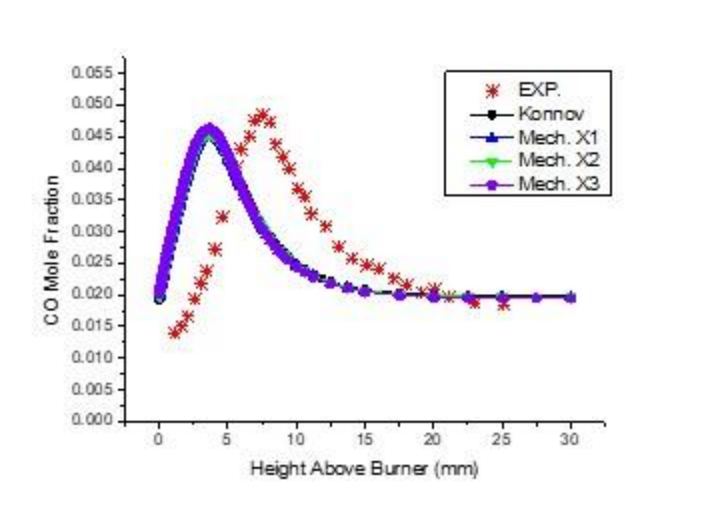
New Cycle analyses using COG/Ammonia blends

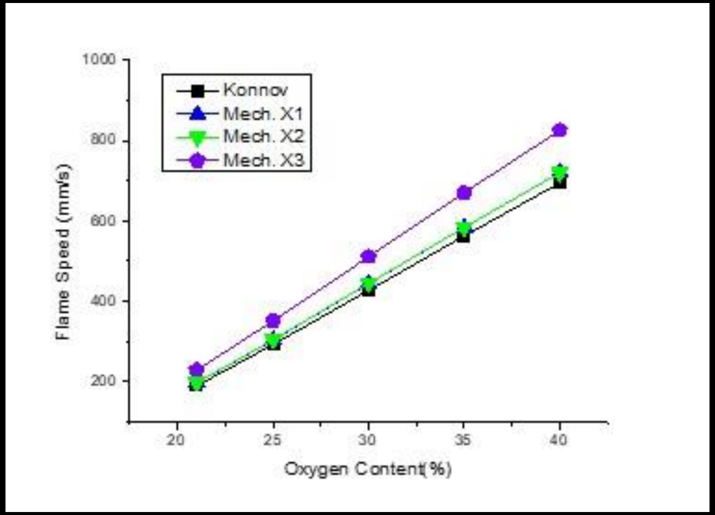


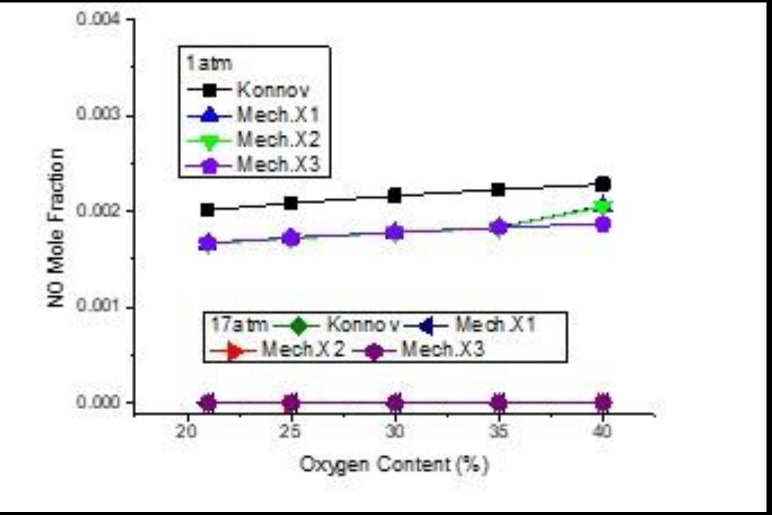
Some blends show production of pollutants lower to current legislation in the Europe

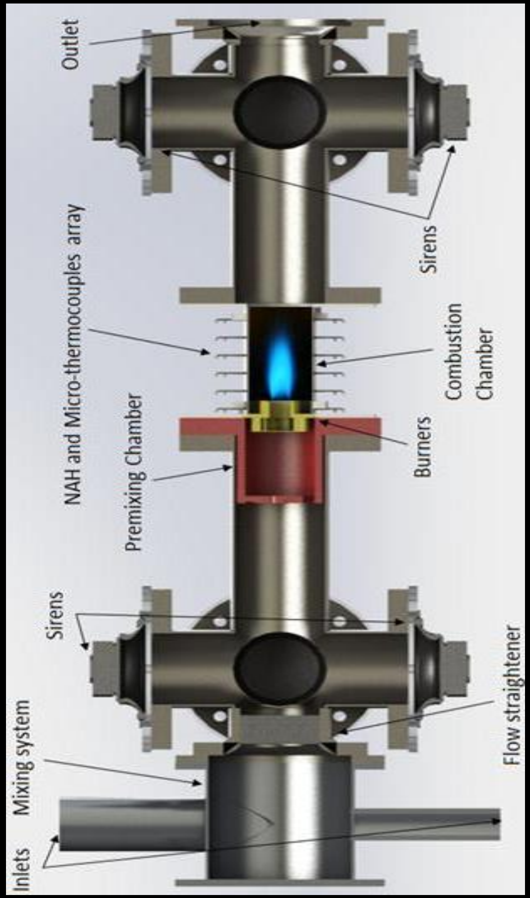
AGT DEVELOPMENTS: NH3 + CH4







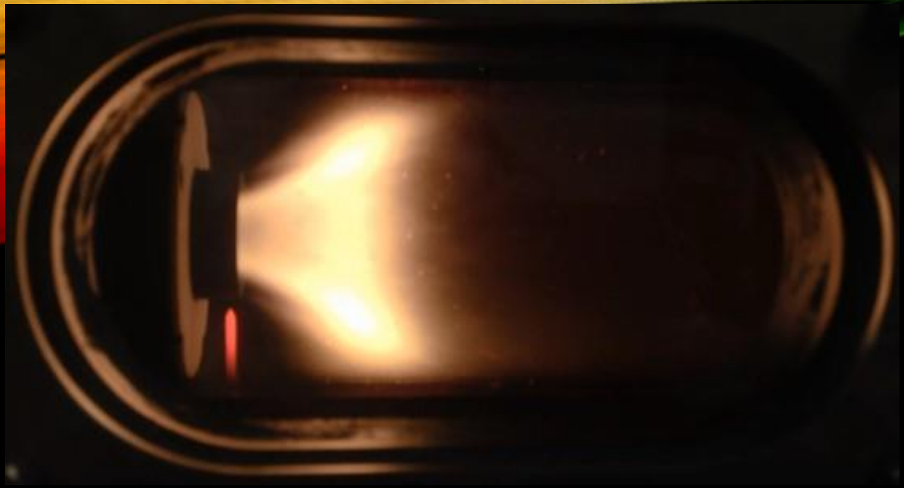




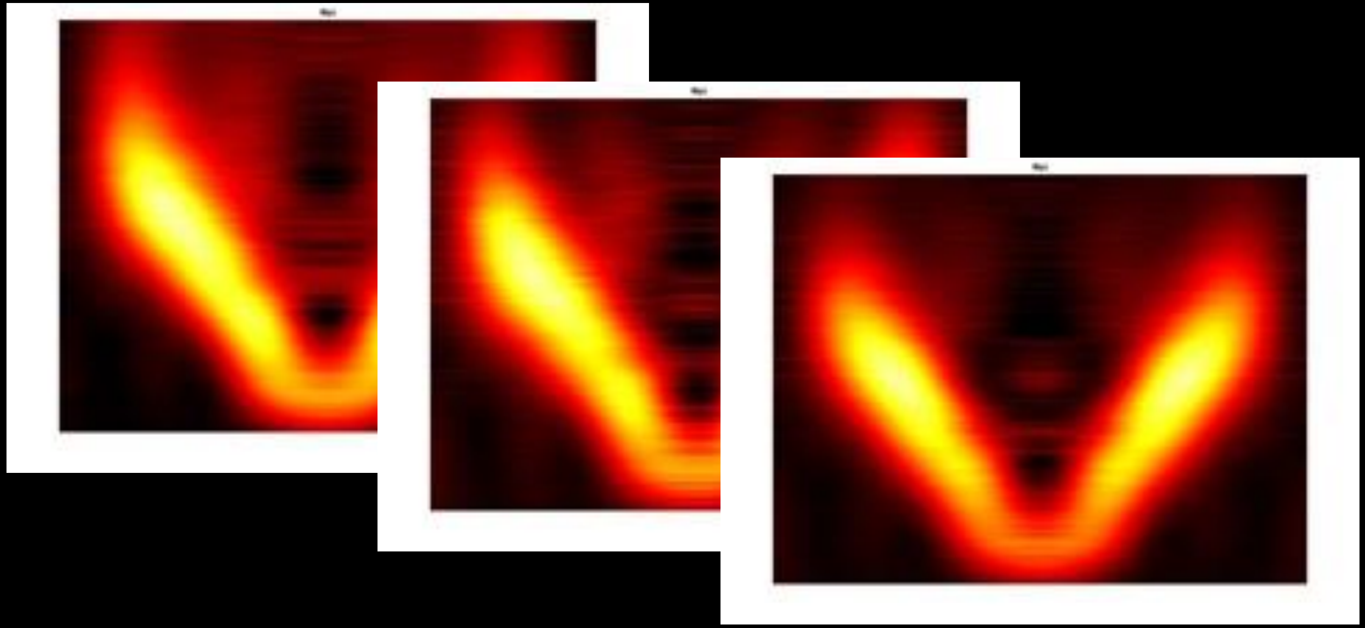
Oxyfuel combustion used to increase reactivity and produce more CO2 for capture

New reaction mechanisms to evaluate new technologies

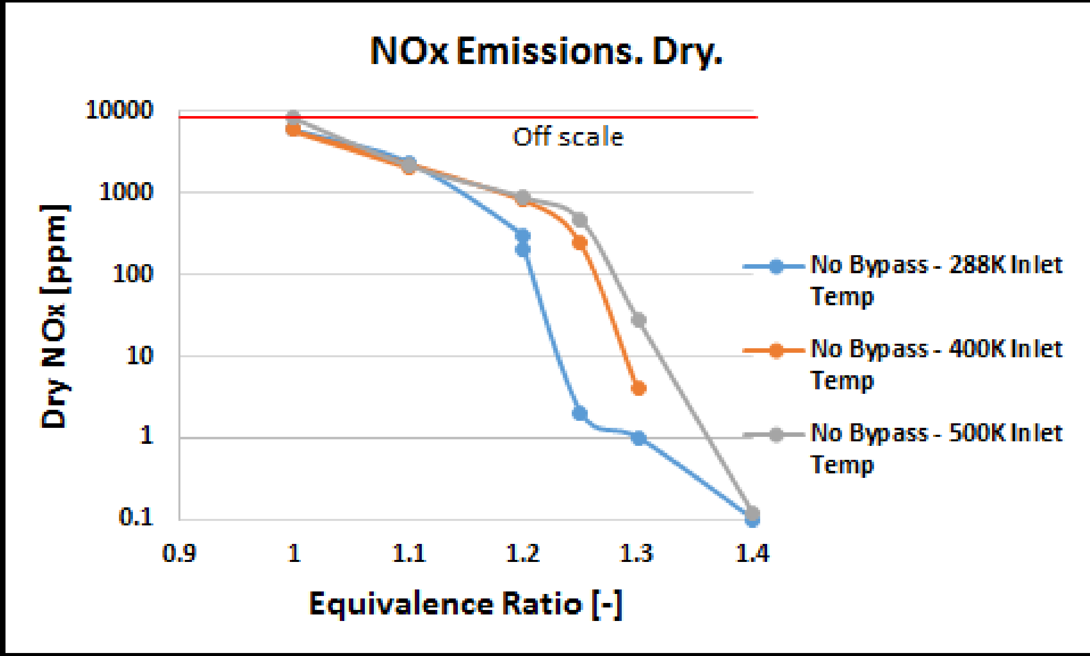
AGT DEVELOPMENTS: NH3 + H2



70%$_{vol}$ NH3 30%$_{vol}$ H2

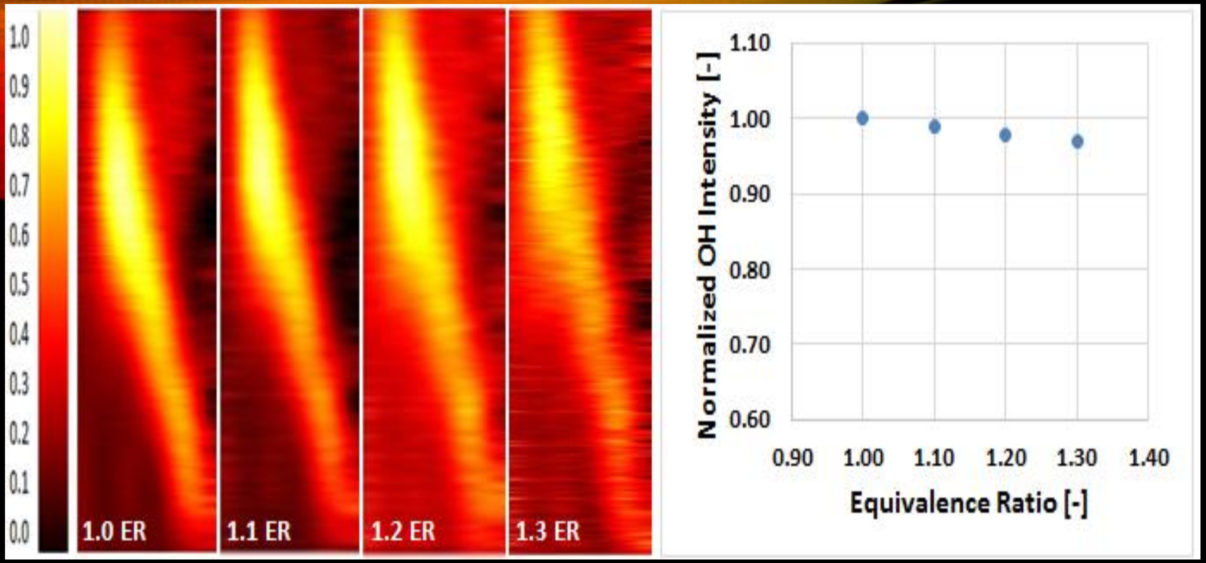


OH Chemiluminescence, Abel Deconvolution

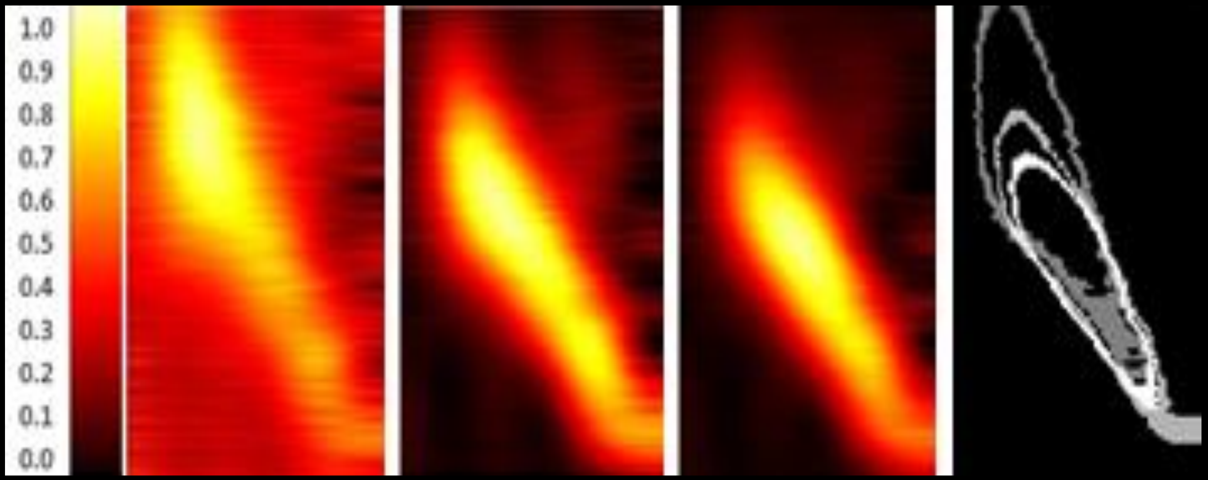


NOx comparison between cases at different inlet temperature.

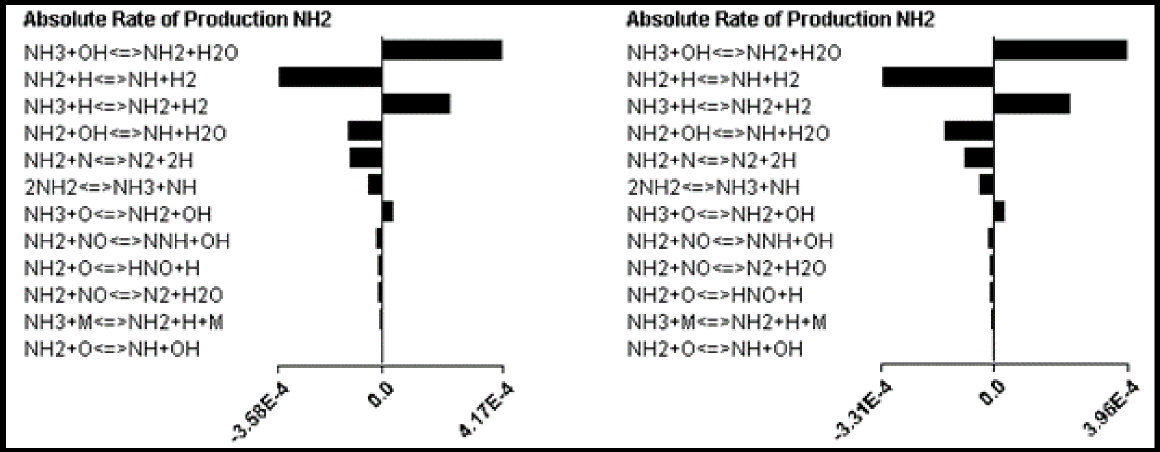
AGT DEVELOPMENTS: NH3 + H2

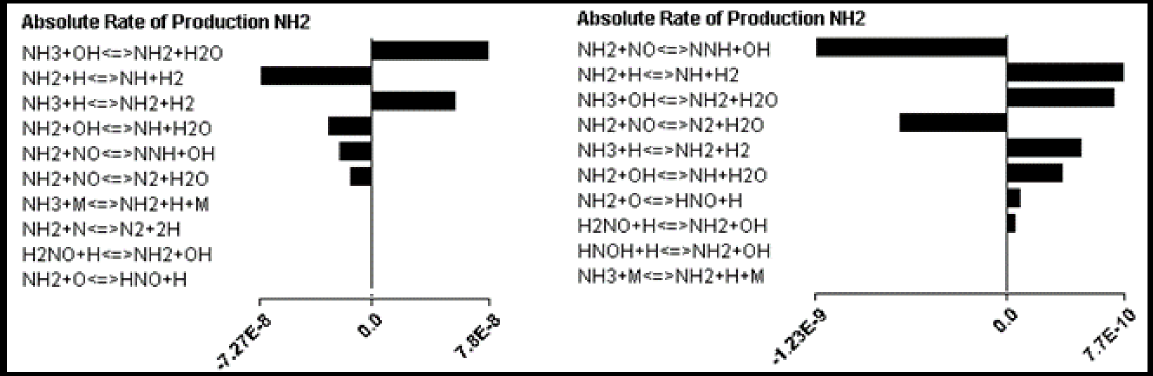


OH profiles and Normalized values, room temperature



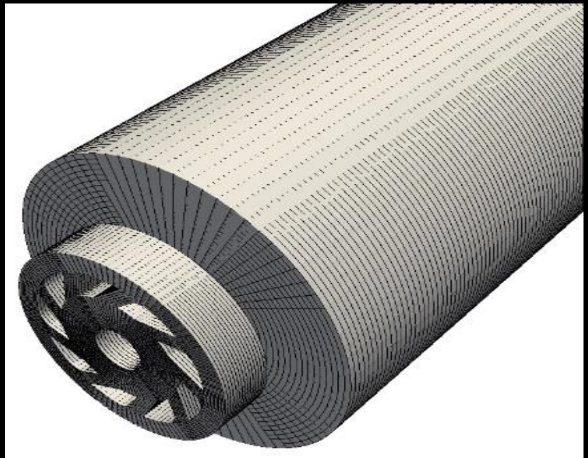
OH profiles and Normalized values. A) 288K; B) 400K; C) 487K; D) Comparison

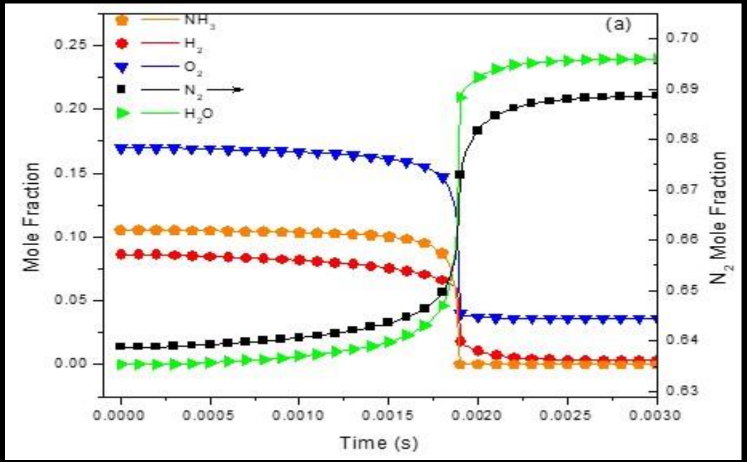




NH2 rate of production at 1) the flame zone and 2) post-combustion zone; left) 288K, right) 288K.

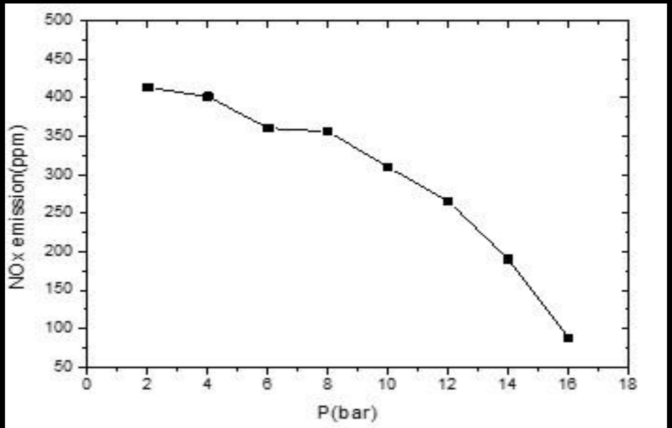
AGT DEVELOPMENTS: NH3 + H2

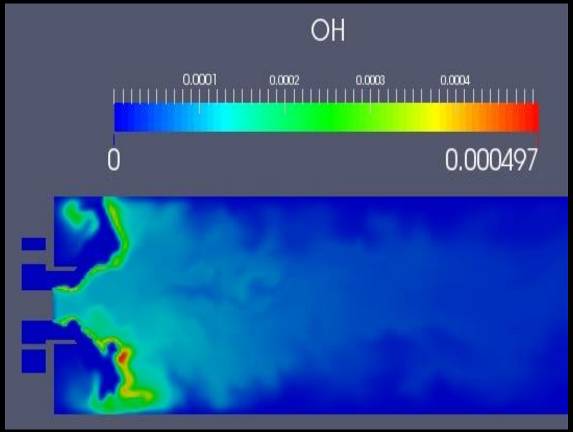


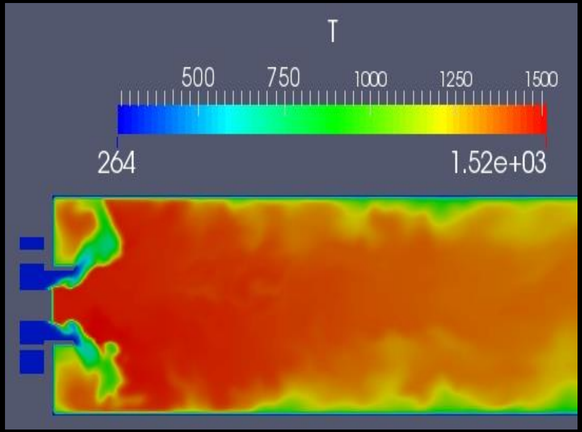


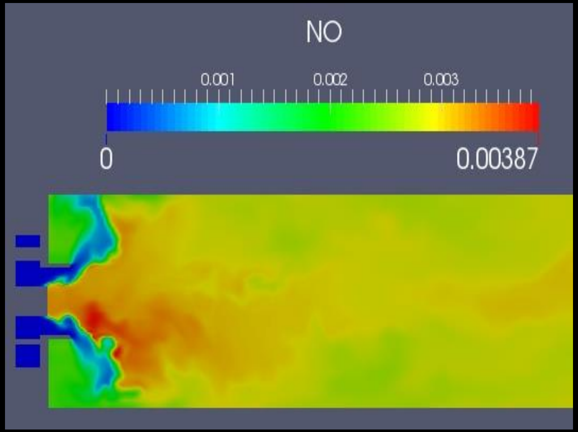
LES combined with full chemistry resolution (using reduced mechanisms).

Models have demonstrated that more accuracy is needed for new scenarios (i.e. ammonia/hydrogen with other species not investigated yet).



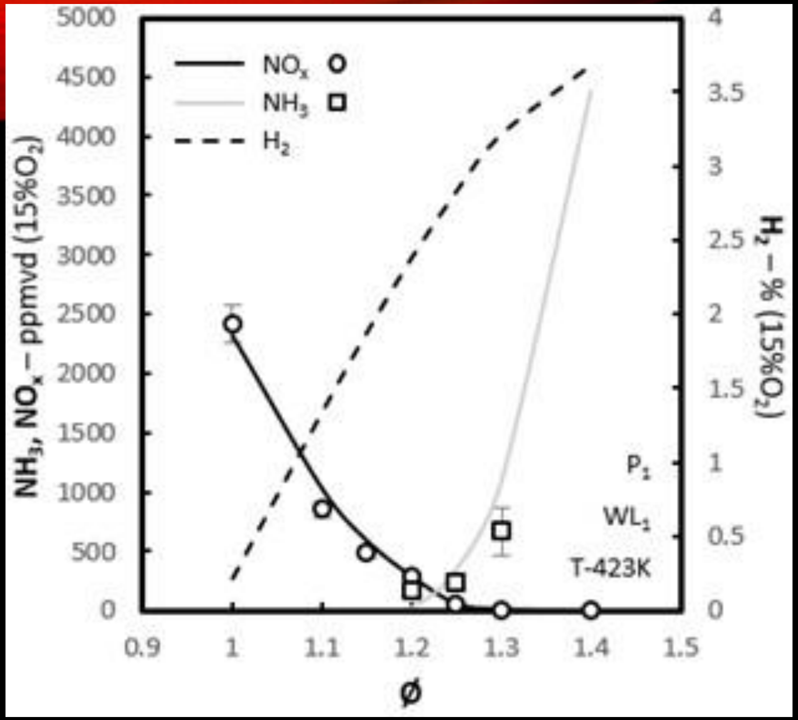




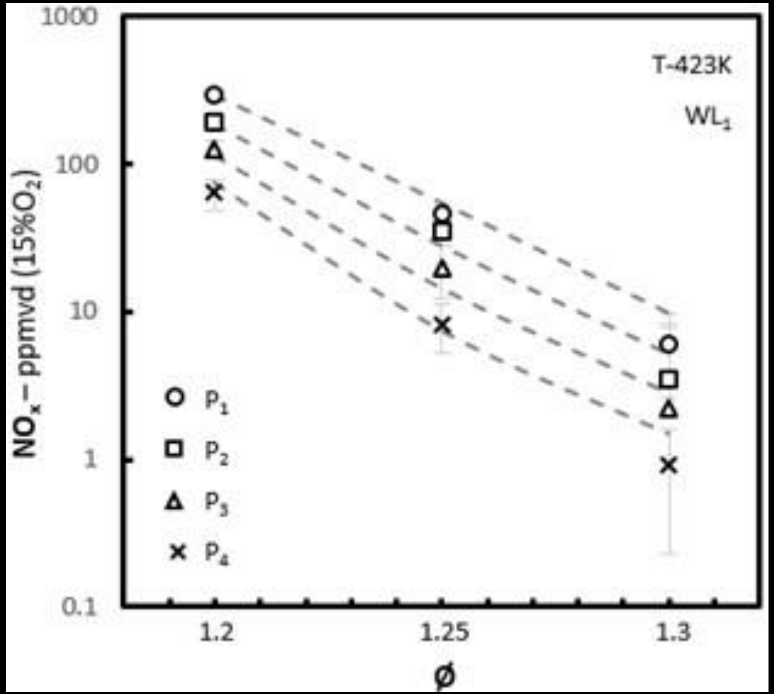


CFD analyses for initial NH3/H2 tests (Lean conditions). Results reflect OH generation and NO close to Experimental results.

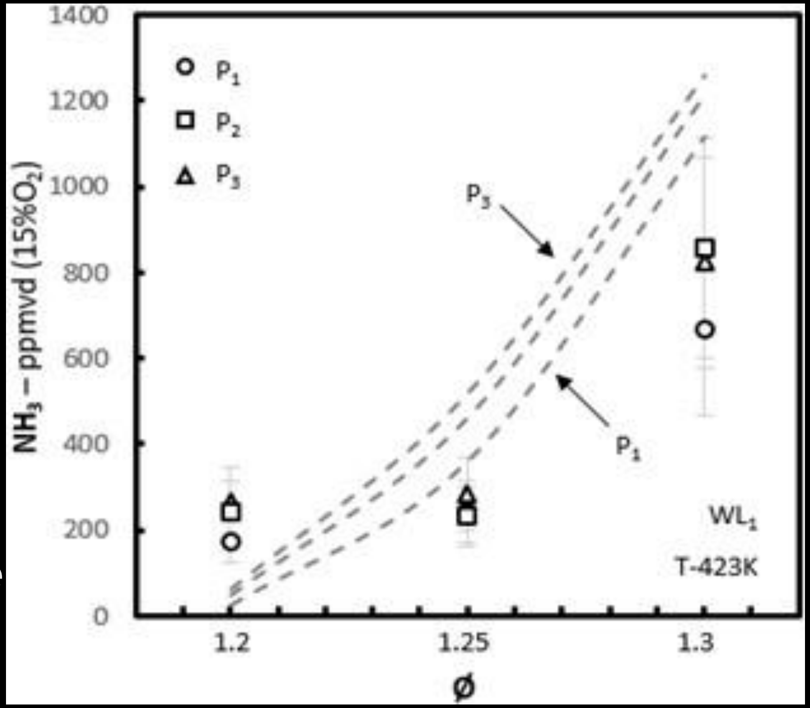
AGT DEVELOPMENTS: NH3 + H2 + H2O



Clear reduction of Nox at high E.R.

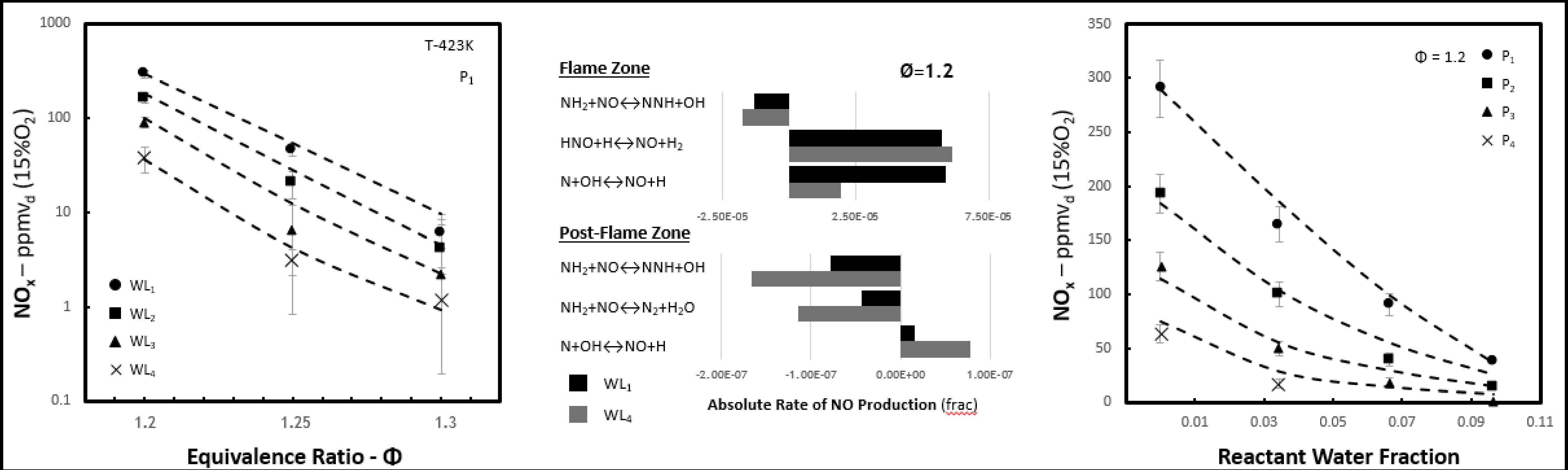


Clear reduction of NOx at high pressure (up to 0.184 Mpa)



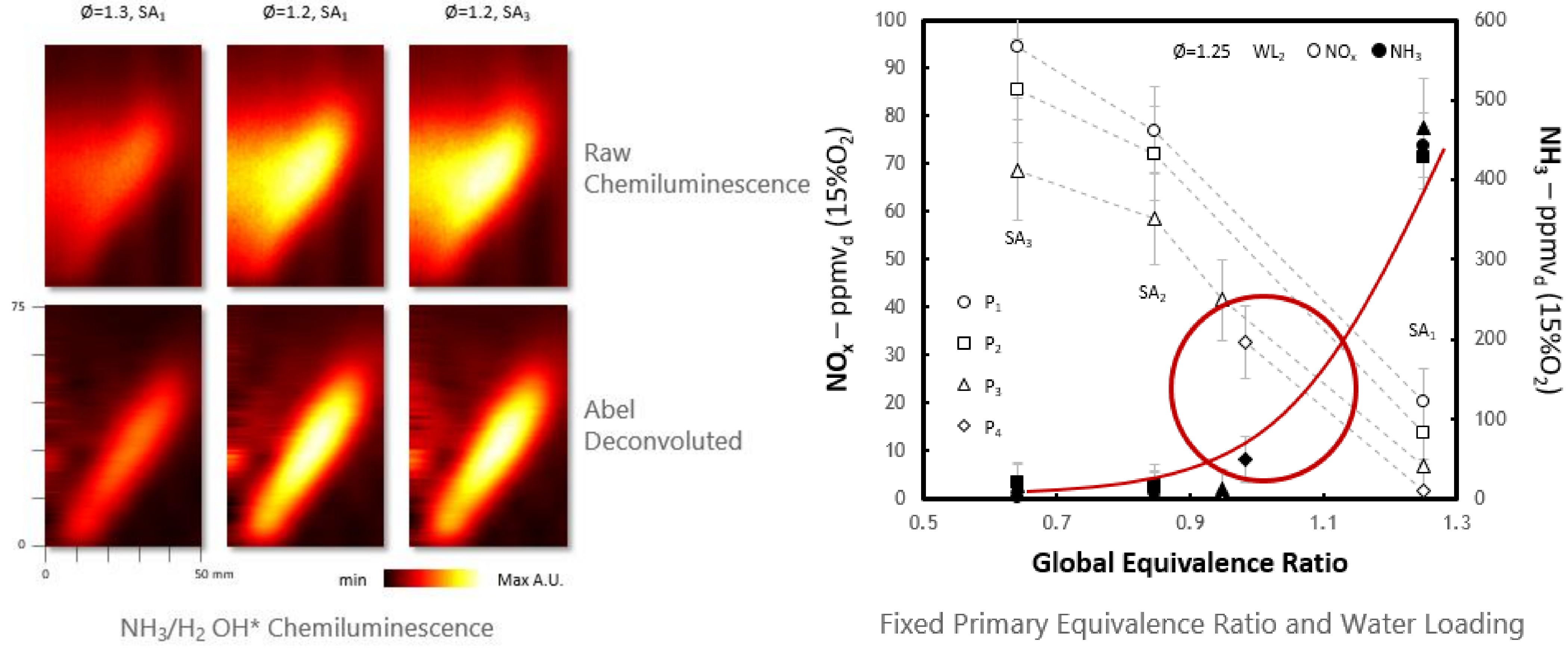
Current technology shows increase of NH3 at high pressure

AGT DEVELOPMENTS: NH3 + H2 + H2O



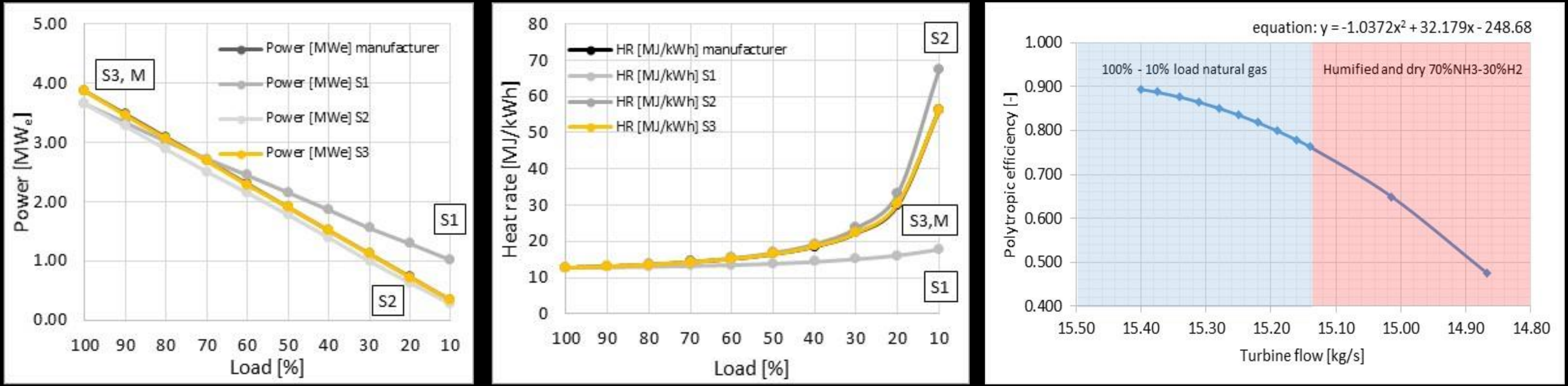
NOx reduction with water loading and pressure. Different reaction parameters with steam addition.

AGT DEVELOPMENTS: NH3 + H2 + H2O



Secondary Air (SA). OH Chemiluminescence at the flame front barely changes. NOx increase with SA, but a point of balance has been found for the current combustor.

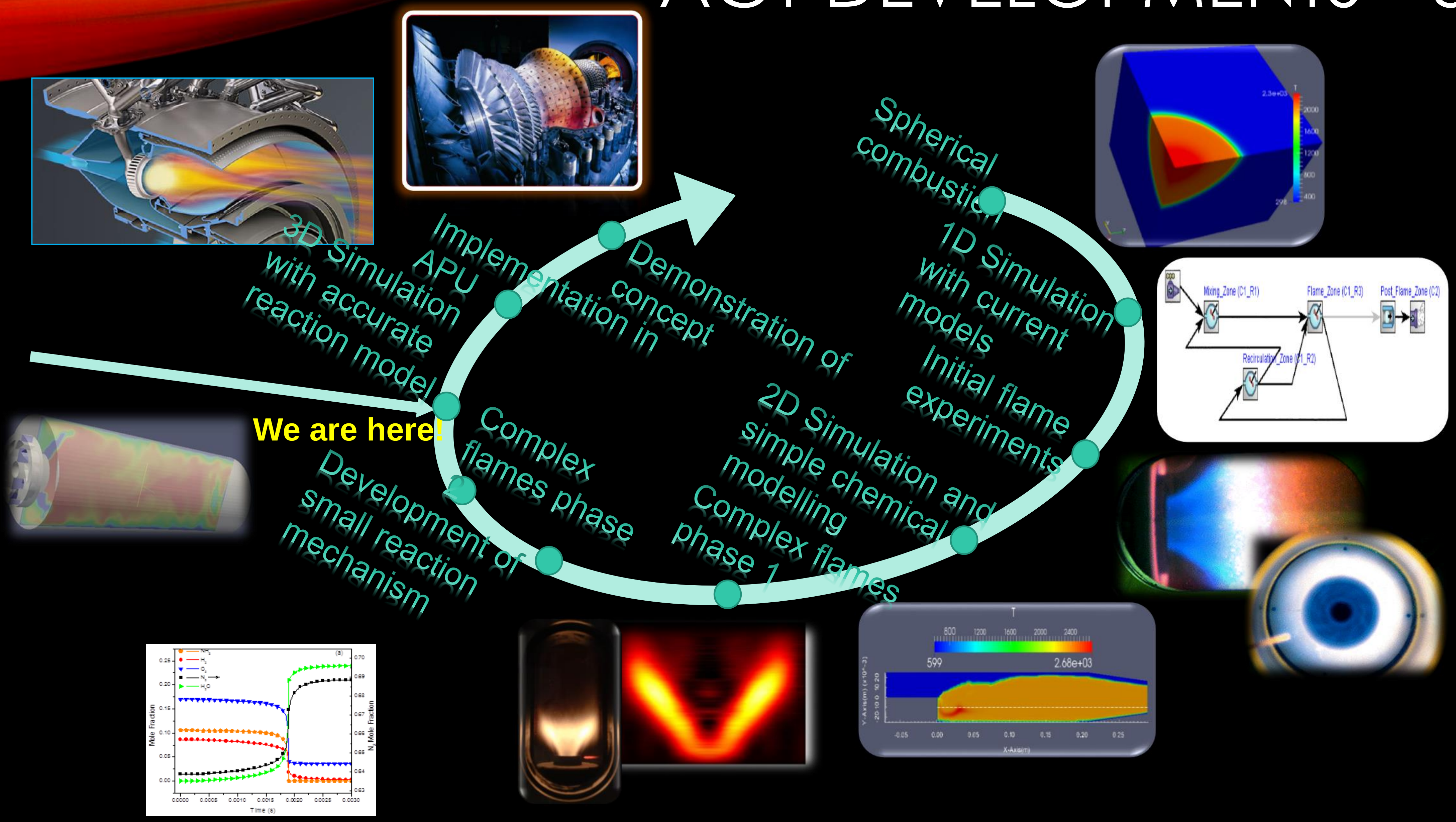
AGT DEVELOPMENTS: NH3 + H2 + H2O



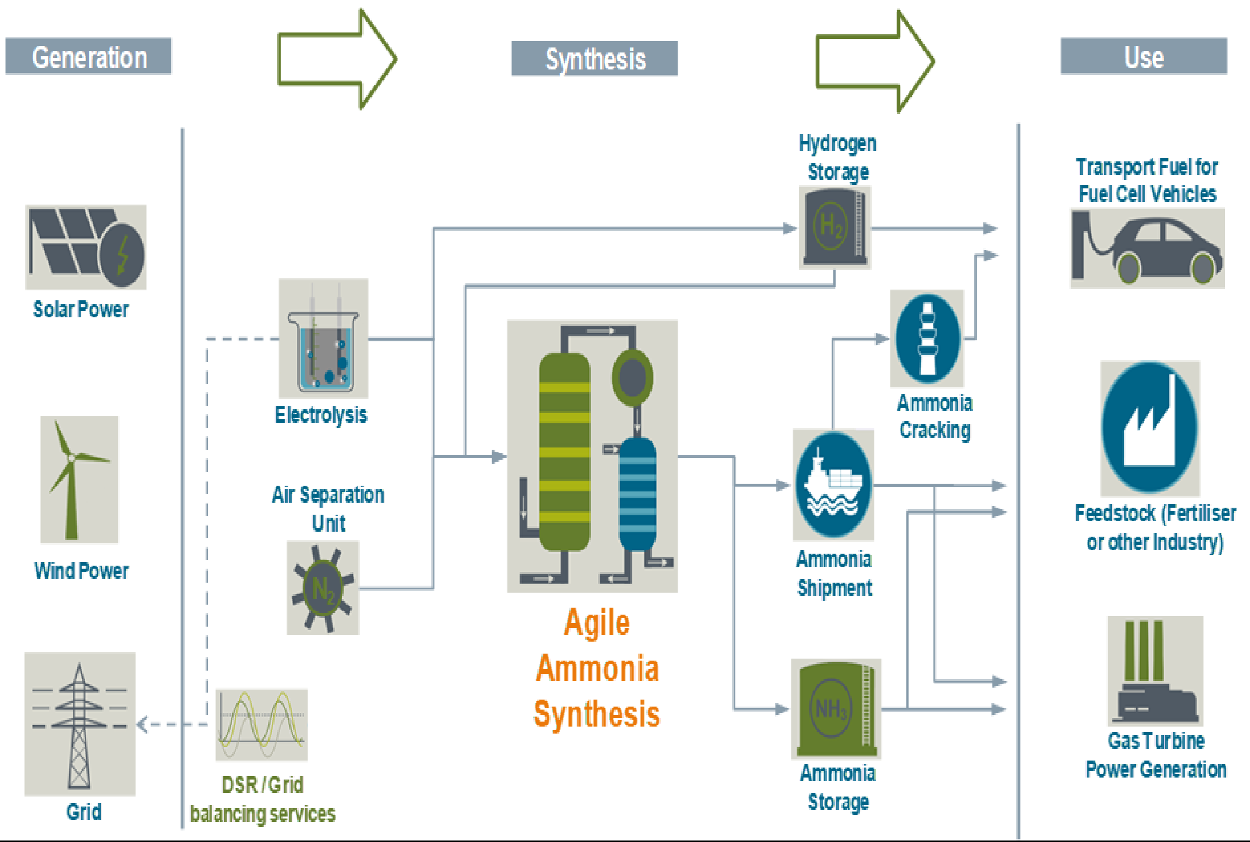
Fitting performance between numerical and industrial values using bespoke codes. Different injection strategies were presented and extrapolating polytropic efficiencies proved to be the initial step to determine efficiencies of a whole ammonia/hydrogen/steam cycle.

Best Case: Efficiencies of 9.77% (v19.36%) dry.
Humidified: 29.8% (Similar to current NG efficiency)

AGT DEVELOPMENTS - UK



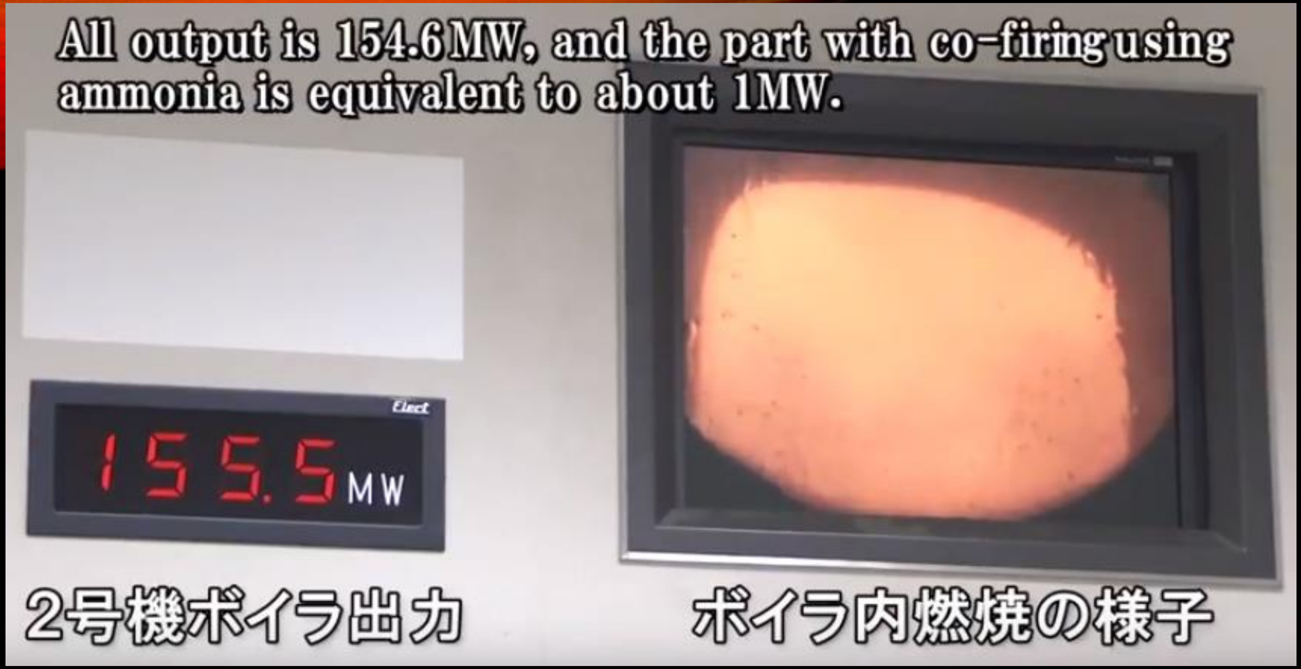
INDUSTRIAL INTEREST



Green Ammonia/Hydrogen Economy
[Wilkinson I, Rotterdam, 2018]

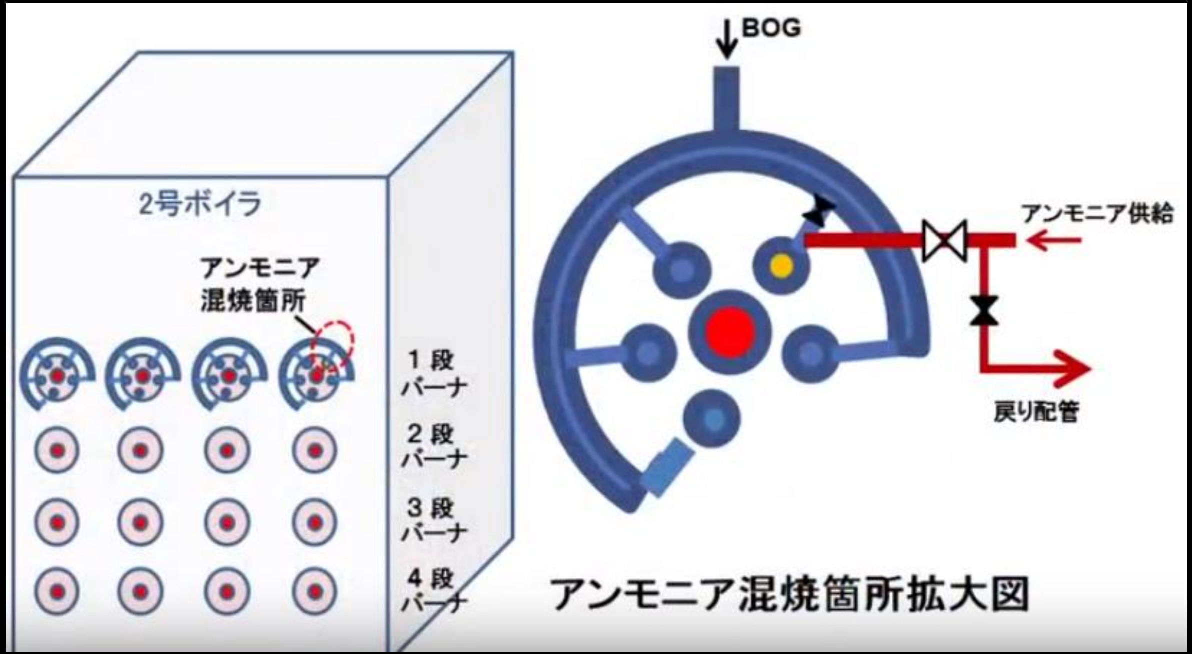
Ammonia Plant – [NUON, 2016]

INDUSTRIAL INTEREST



Ammonia/Pulverised coal flame
[link below]

Chogoku Electric Power announced in 2017 successful trials burning 450 kg/hr of ammonia in a Coal based burner. Substitution of NH3 brought down CO2 while maintaining the same NOx levels of the system.

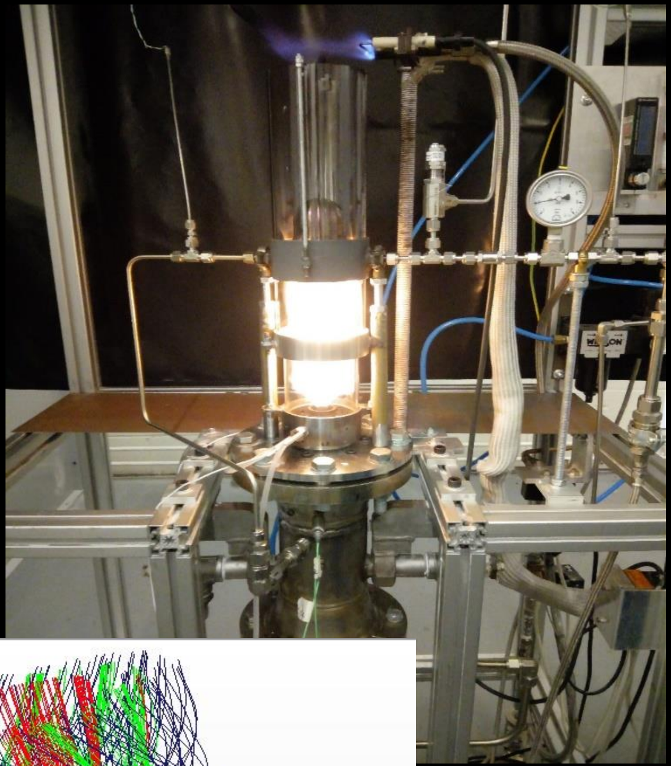


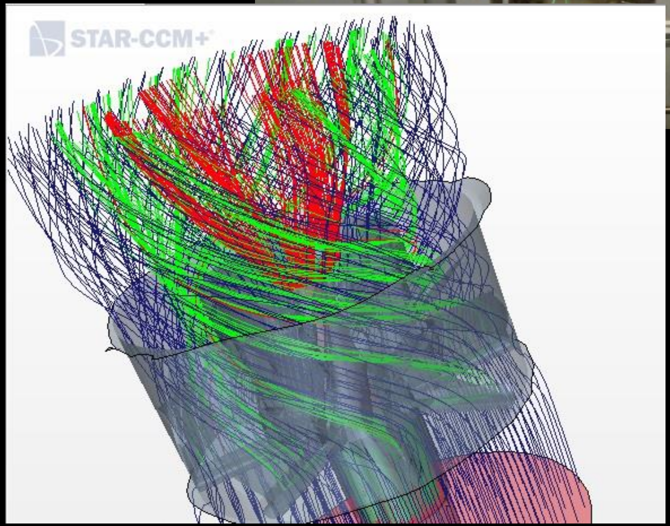
Change of LNG line to ammonia, Chogoku Plant
[link]

Although this is not directly linked to Gas Turbines, Japan is heavily pursuing a Hydrogen economy in which ammonia will play an important part through development of new GTs using the chemical
[link:
https://www.youtube.com/watch?v=ldU-qMvWFDk]

FUTURE DEVELOPMENTS AGT

- Future developments include,
  - NO and OH PLIF/high P analyses in RQL burner
  - NO, OH, NH2 PLIF analyses in Rich-Flameless burner
  - NH3 liquid spray work at significantly high pressures
  - Development of NH3 pre-cracking systems
  - Plasma cracking and radical formation
  - Thermoacoustic analyses using different NH3 blends
  - New reduction mechanisms for CFD analyses
  - Development of new 3D Printed injectors
  - New LES modelling for NH3/H2/Steam
  - CFD modelling for MicroGT annular combustor
  - Demonstration unit using 200HP APU
  - New CCHP cycles using humidified ammonia (Estimated AGT efficiencies of ~35%).





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

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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.

CURRENT LIST OF JOURNAL PUBLICATIONS

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3. Xiao H, Howard MS, Valera-Medina A, Dooley S, Bowen P, 2016. "A Study on Reduced Chemical Mechanisms of Ammonia/methane Combustion under Gas Turbine Conditions", Energy and Fuels, DOI: 10.1021/acs.energyfuels.6b01556.
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THANKS FOR YOUR ATTENTION

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