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Accelerating Maritime Decarbonisation

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Introduction:

- Shipping's greenhouse gas (GHG) emissions and the associated climate impact are currently subject to intense debate within the International Maritime Organisation (IMO).
- Although global regulation on mandatory energy efficiency standards in shipping was introduced in 2013, various studies project shipping's GHG emissions to grow if additional measures are not taken.
- For example, the official IMO GHG study foresees an increase of shipping's GHG emissions of 50-250% by 2050.
- An alignment of international shipping to a 1.5°C scenario would require decarbonisation of the sector between 2035 and 2050.

Overview of measures to reduce shipping's carbon emissions:

Type of measures	Main measures
Technological	Light materials, slender design, less friction, waste heat recovery
Operational	Lower speeds, ship size, ship-port interface
Alternative fuels/energy	Sustainable biofuels, hydrogen, ammonia, electric ships, wind assistance

Overview of measures to reduce shipping's carbon emissions: main measures related to alternative fuels and energy

Measures	CO_2 emission reductions
Advanced biofuels	25-100%
LNG	0-20%
Hydrogen	0-100%
Ammonia	0-100%
Fuel cells	2-20%
Electricity	0-100%
Wind	1-32%
Solar	0-12%
Nuclear	0-100%

Southampton success on maritime decarbonisation projects:

We have worked on four winning projects from the Department for Transport's Clean Maritime Demonstrator Competition round 1.

1. Development and testing of a zero-emissions ammonia marine propulsion system: Prof. Stephen Turnock
2. Liquid hydrogen-powered un-crewed surface vessel (H-USV): Dr. Richard Wills
3. Use of innovative solid oxide fuel cell technology and batteries to replace the use of diesel generators on cruise ships: Prof. Dominic Hudson
4. Design and testing of a ammonia-hydrogen ceramic combustion engine propulsion system: Dr. Dinesh Kahanda Koralage

1. Development and testing of a zero-emissions Ammonia Marine Propulsion System: Prof. Stephen Turnock with Ocean Infinity

AMMONIA MARINE POWER SYSTEM (AMPS)

VISION

To develop and demonstrate technology that supports the transition of the OI ARMADA fleet from marine gas oil to ammonia-based power and propulsion

MISSION

To rapidly and safely demonstrate technology that enables the conversion of ammonia fuel stores to fuel-cell grade hydrogen at a marine power & propulsion scale suitable for uncrewed operation

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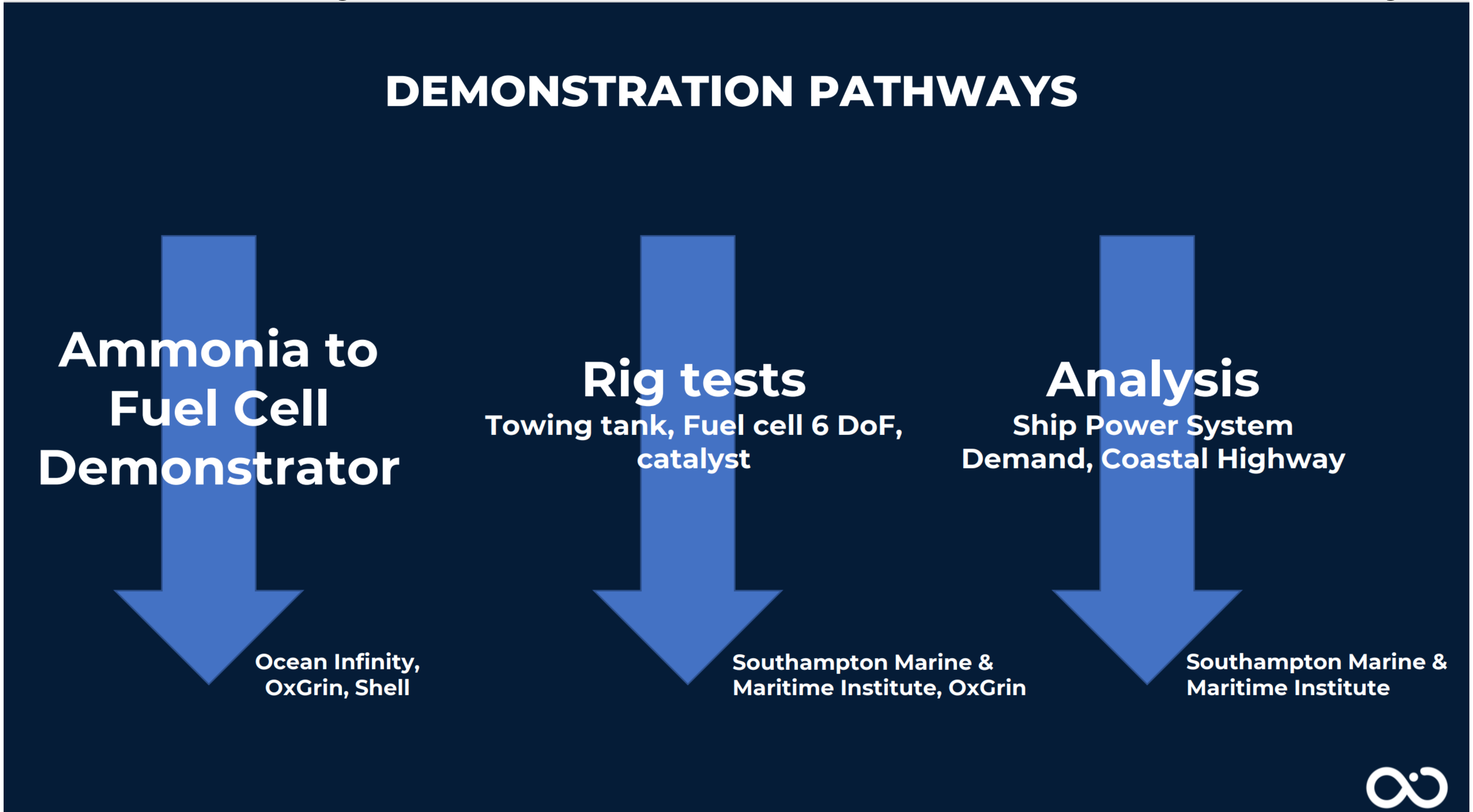
1. **Development and testing of a zero-emissions Ammonia Marine Propulsion System: Prof. Stephen Turnock with Ocean Infinity**



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1. Development and testing of a zero-emissions Ammonia Marine Propulsion System: Prof. Stephen Turnock with Ocean Infinity

VALIDATING FUEL CELL PERFORMANCE INFLUENCED BY SHIP MOTIONS

- Novel system demonstrated to assess motion from full scale, model scale, numerical or experimental and obtain time series segments suitable for use with the large ISVR 6 degree of freedom motion platform
- Methodology developed that allows generic full scale fuel cells to be tested
- Extreme motions captured from VARD tests of Armada class vessels
- Usual motions captured from KCS model test in Boldrewood tank
- Extreme motion indicates a 3-5% variation in fuel cell power
- Usual motion indicates a 1-2% variation in fuel cell power
- Study confirms that such tests would be a useful part of marinized fuel cell certification process

1. Development and testing of a zero-emissions Ammonia Marine Propulsion System: Prof. Stephen Turnock with Ocean Infinity

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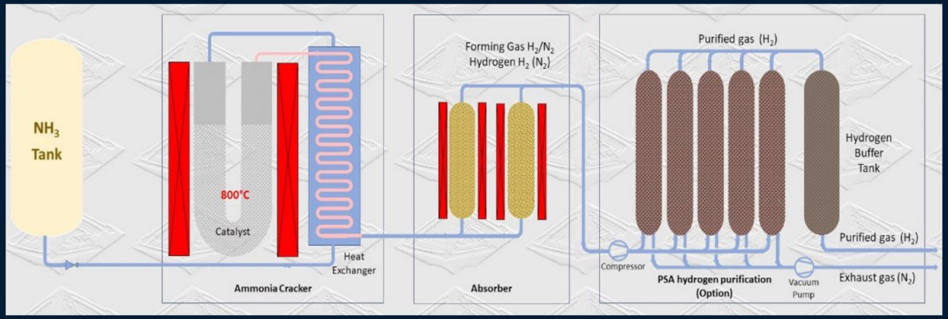
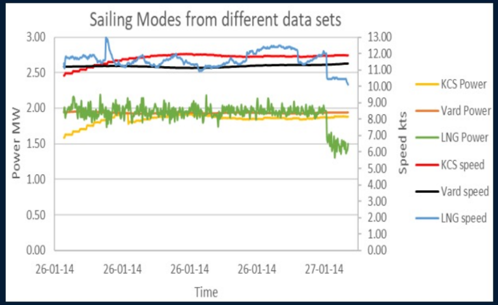
AMPS-USV POWER SYSTEM MODEL

- A first principles model of the complete APS-USV system allows the design/sizing of the NH3 plant, cracker/purifier, intermediate H2 storage and PEM fuel cell for a given voyage energy profile
- Suitably sized hybrid fuel cell/battery system will allow enough power to cope with spikes in energy demand and in fuel cell motion induced fluctuations





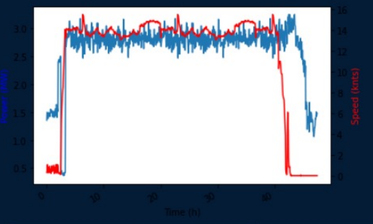


Figure 9: Power by speed plot for Southampton to Liverpool route with a target speed of 14 knots

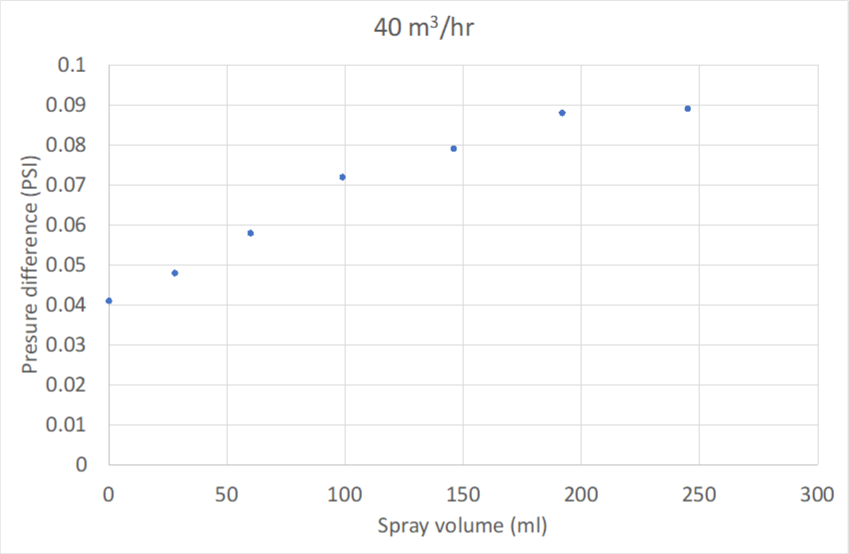
2. Liquid hydrogen-powered un-crewed surface vessel (H-USV): Dr. Richard Wills with ACUA Ocean

Concept:

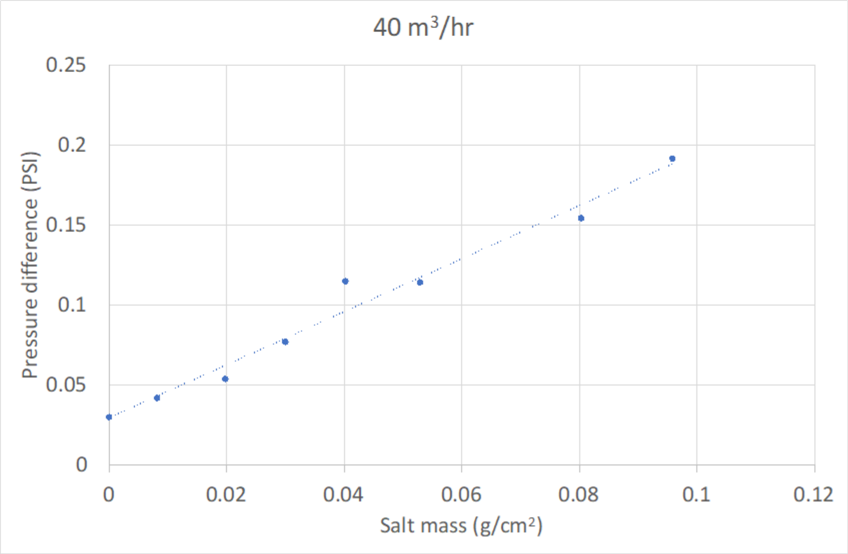
2. Liquid hydrogen-powered un-crewed surface vessel (H-USV): Dr. Richard Wills with ACUA Ocean

Fuel cell testing

- 6-degrees of freedom shaker testing
  - Simulated wave motion profile
  - Impact on physical and electrochemical performance of FC.
- Filter testing for flow rate and salt caking.



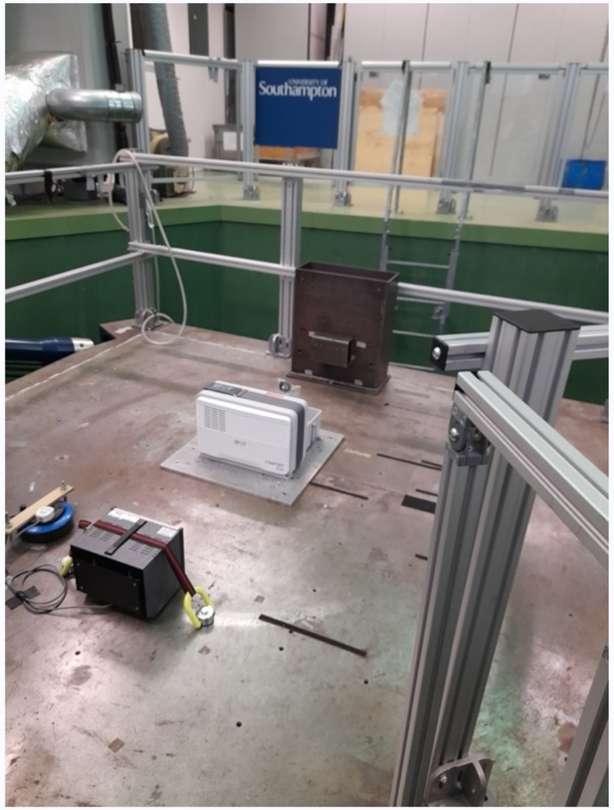
Water (pure) spray volume vs. pressure difference for air flow rates of 40 m^3/hr

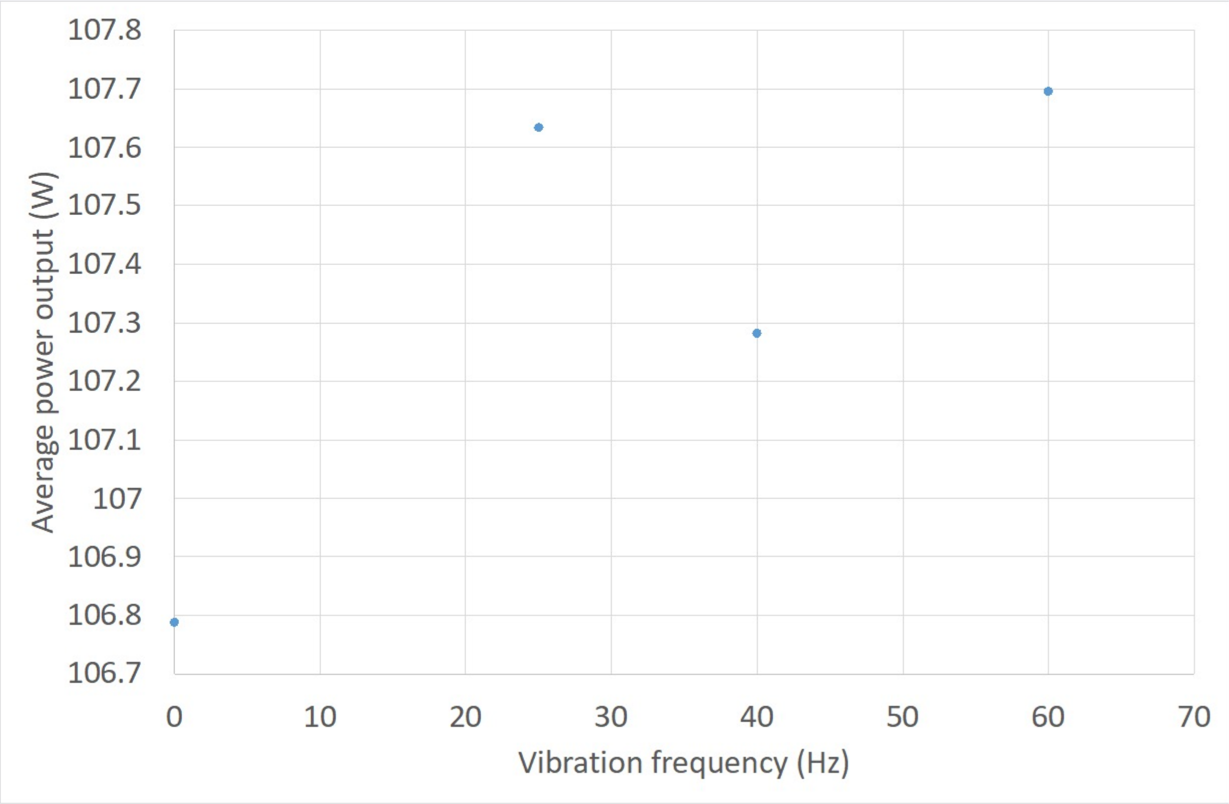


Mass of dried salts vs. pressure difference

2. Liquid hydrogen-powered un-crewed surface vessel (H-USV): Dr. Richard Wills with ACUA Ocean

- Methanol fuel cell





3. Use of innovative solid oxide fuel cell technology and batteries to replace the use of diesel generators on cruise ships: Prof. Dominic Hudson with Carnival, LR and Shell

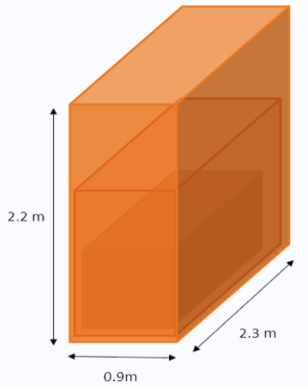
Scope of project

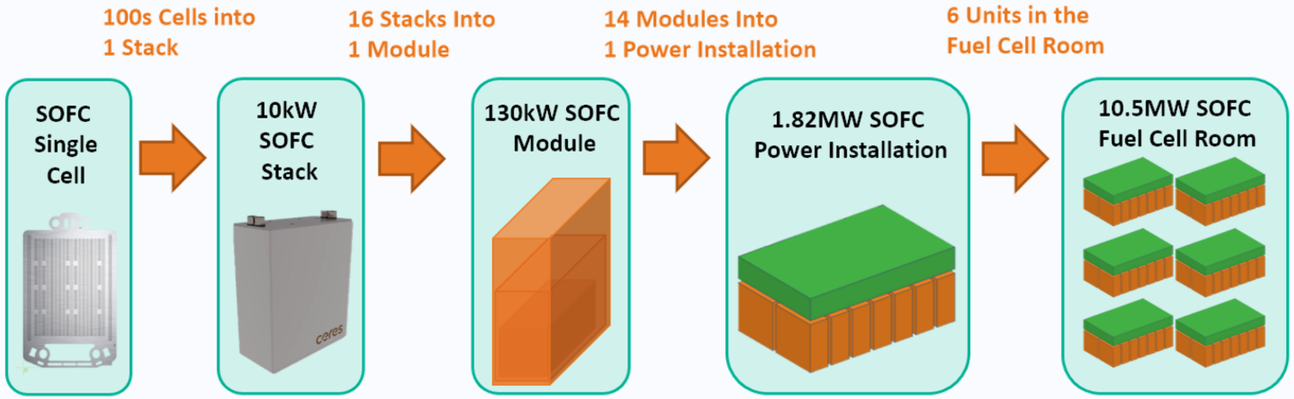
- Investigate feasibility of replacement of LNG gensets with Solid-Oxide fuel cells (SOFC) and battery storage to provide 'hotel' load
- Develop dynamic energy model, including fuel cell system, to establish fuel consumption and emissions benefits
  - Safe return to port requirements
  - Use of waste-heat recovery
- Design screening and safety assessment
- Investigate transition from LNG to Hydrogen
- Develop a roadmap for multi-MW marine SOFC systems

3. Use of innovative solid oxide fuel cell technology and batteries to replace the use of diesel generators on cruise ships: Prof. Dominic Hudson with Carnival

Modular fuel cell concept

- Module based system concept developed to allow straightforward vessel integration and in-life servicing
- Each 130kW LNG module includes fuel cell stacks, hot balance of plant, controls and power electronics
- The modules can be combined to build multi-MW fuel cell systems





Parameter	Value	Comment
Power Output	130 kW (EOL)	Modular design
Dimensions	2.3 x 0.9 x 2.2 m	29.6 kW/m³
Estimated mass	7000 kg	
Service life	44 kh (5 years)	End of life generally defined by acceptable net efficiency

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3. Use of innovative solid oxide fuel cell technology and batteries to replace the use of diesel generators on cruise ships: Prof. Dominic Hudson with Carnival

Predicted emissions

- CO_{2e} emissions **reductions of**
  - **35%** with LNG as fuel vs LNG internal combustion baseline
  - **62%** with H2 as fuel vs LNG internal combustion baseline
- CO_{2e} emissions **reductions of**
  - **23%** compared to using shoreside electrical power in port ("cold-ironing")
  - Saves investment in costly electrical network upgrades
  - Available for all port-calls
- Cruise industry 2020 order book: 109 cruise ships on order with an orderbook $3.68 billion, average price per ship $596 million (23 LNG ships)
- To support this orderbook, >1GW of fuel cell baseload per annum would be required

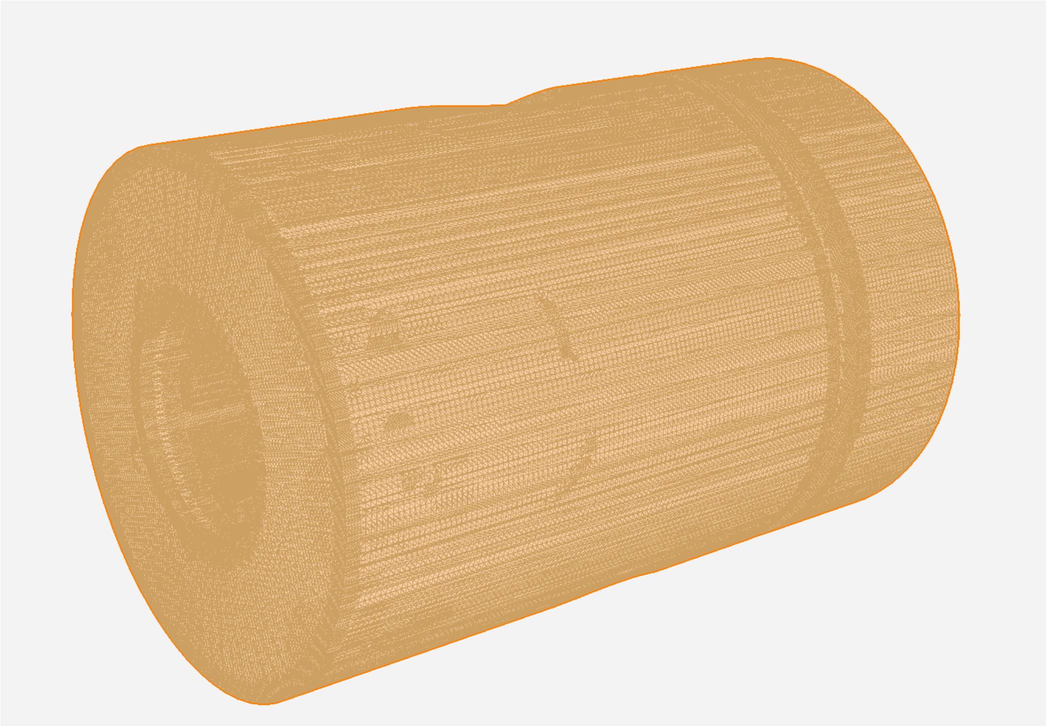
4. Design and testing of a ammonia-hydrogen ceramic combustion engine propulsion system: Dr. Dinesh Kahanda Koralage with Carnot Engines

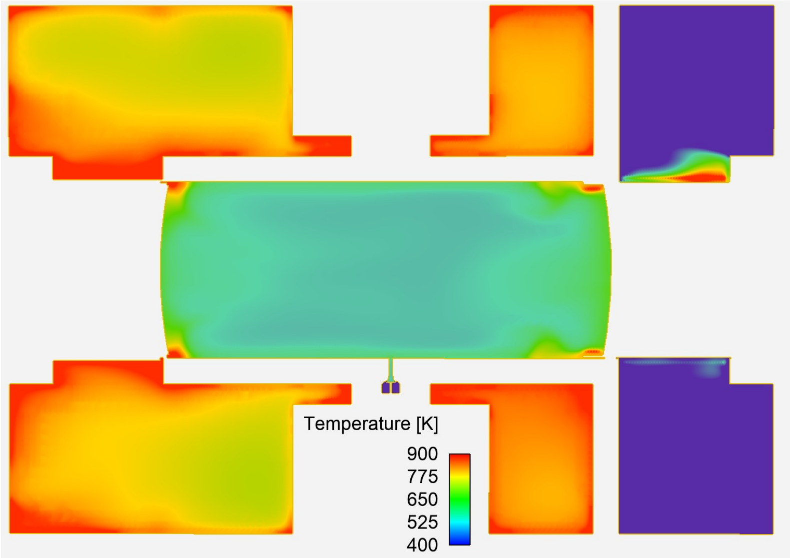
Scope of Project

Develop an ultra-efficient ceramic combustion engine for marine auxiliary power units/propulsion

Assess the technical feasibility of operating Carnot ceramic engines on a hydrogen-ammonia fuel blend

4. Design and testing of a ammonia-hydrogen ceramic combustion engine propulsion system: Dr. Dinesh Kahanda Koralage with Carnot Engines





CFD modelling of ammonia-hydrogen direct injection combustion

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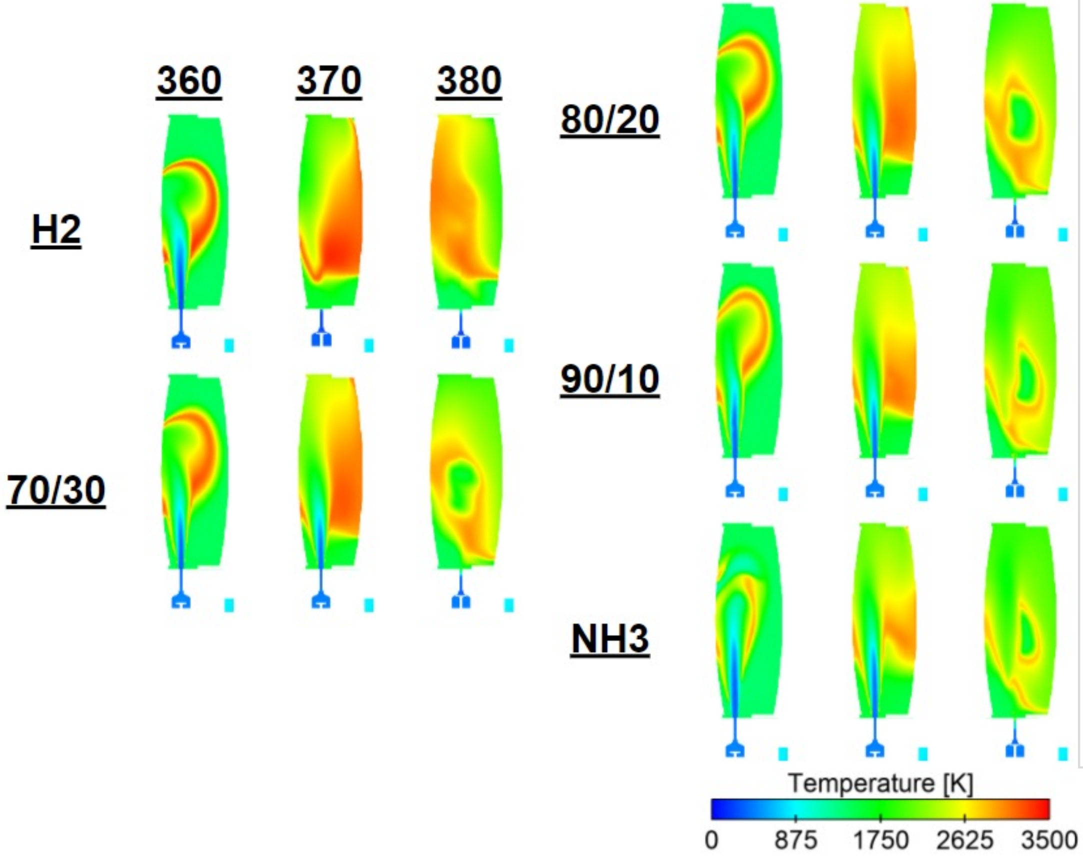

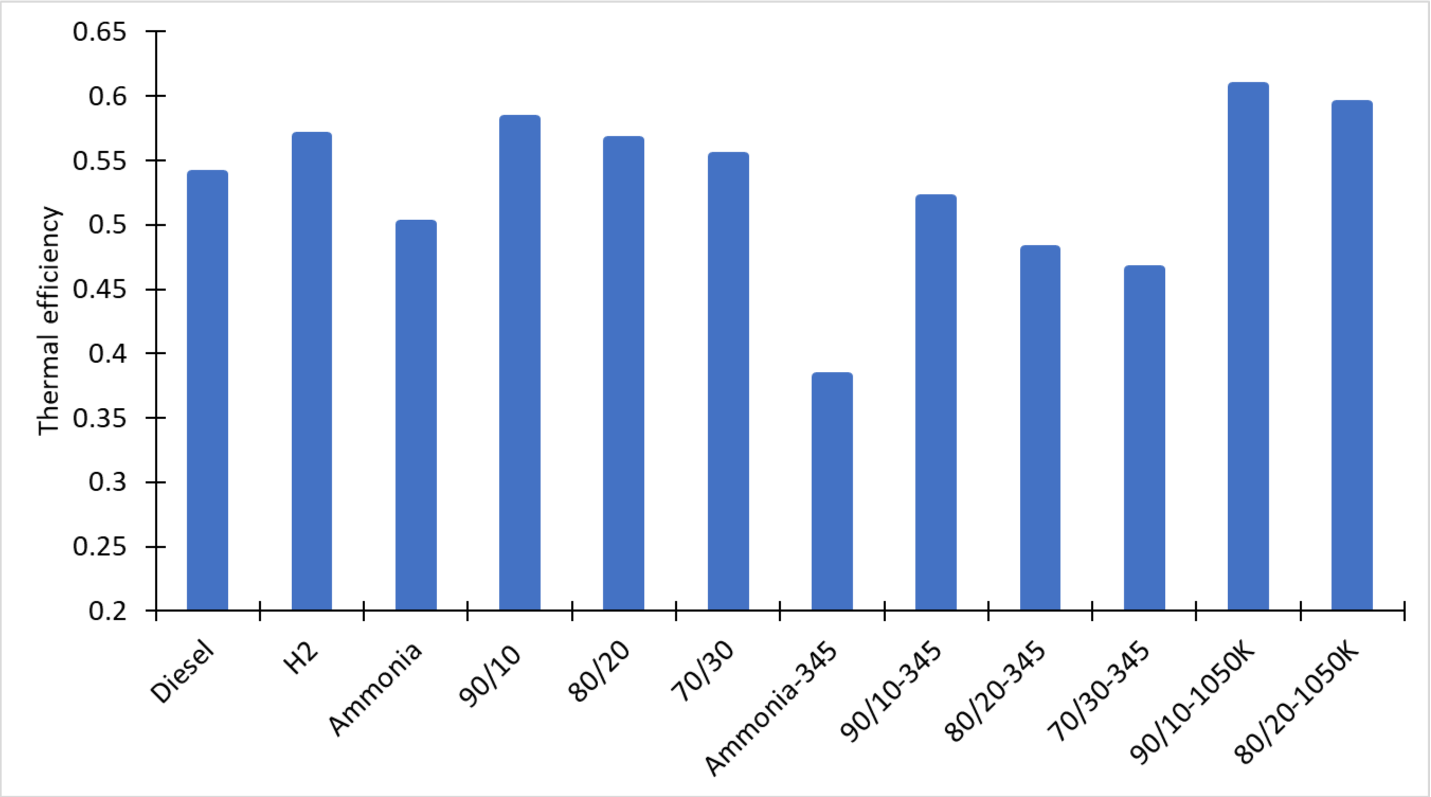

CFD modelling of ammonia-hydrogen direct injection combustion