MariNH3

Clean, green ammonia
engines for maritime

Hydrogen in the heavy-duty transport sector

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Outlines

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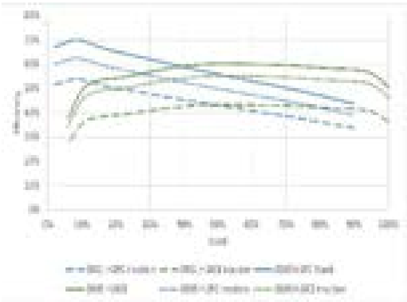
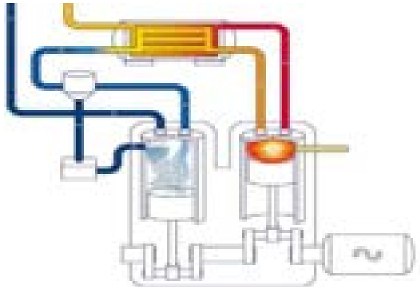
- Introduction

- H2 potential for heavy duty engine



- H2 combustion and emissions analysis



- Split-cycle engine (SCE)

- Conclusion

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Research group at University of Brighton

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Dr Penny Atkins

Prof Cyril Crua

Prof Robert Morgan

Dr Guillame de Sercey
(Teaching and research Fellow

Dr Vikas Sharma
(Research Fellow)

Many heavy-duty vehicles have high power and energy which make electrification challenging

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Urban applications

Volvo FL electric, GVW 16T
Modular battery, 200 – 300 kWh
Up to 300 km range
Estimated battery cost £18k - £27k
(pack cost $125/kWh)

Long haul applications

Overhead charging 1MW/km assuming 10 trucks per km

WMG THE UNIVERSITY OF WARWICK

Rampion windfarm,116 turbines, 400MW
= 400 km road, 10 trucks/km

Sources: Electric trucks | Volvo Trucks, DECC (2016) "Provisional estimates of UK Greenhouse Gas emissions for 2015, including quarterly emissions for 4th quarter 2015", Statistical release

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Load efficiency profiles for PEM fuel cells and hydrogen ICE suggests that they might be suitable for different applications

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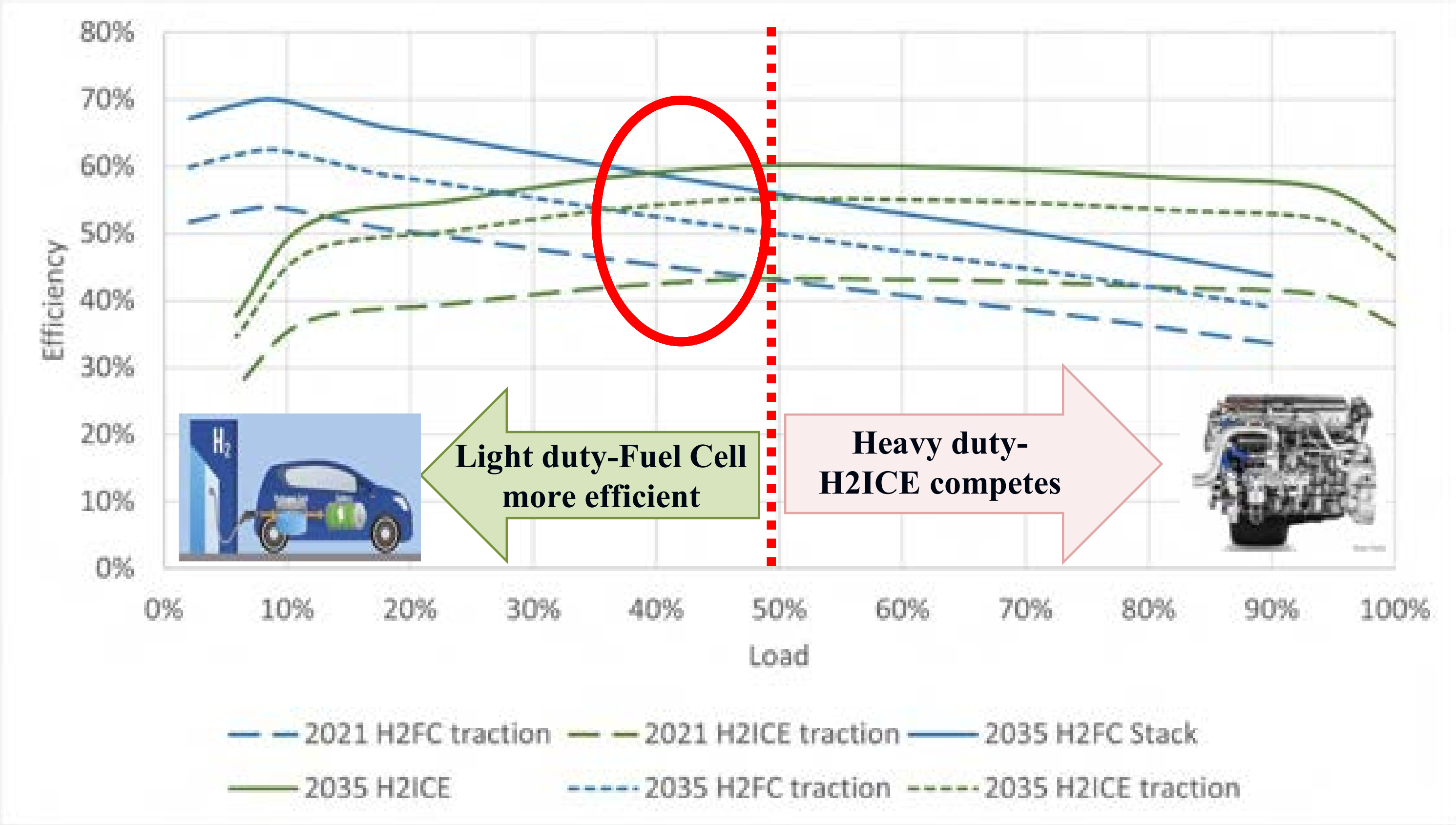

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Hydrogen fuelled engines could provide an alternative to PEM fuel cells, accelerating the uptake of hydrogen in this sector

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- BMW offered limited volumes of 7 series powered by a hydrogen internal combustion engine in 2005-2007
- Increasing research and development on this technology in Japan, China and Europe
- Could offer faster route to market than fuel cells – industry view that H_2 ICE could be on the market by 2025
- Announcements by JCB, Cummins and Toyota

Modified piston, compression ratio, valves, valve seat, piston rings

Package injectors for PFI or DI fuelling, ignition system

Modified control system

Turbocharger and aftertreatment

H_2 safety measures – eg crank case ventilation

Powertrain system must meet market needs for power output and driveability

Must have zero impact NOx emissions

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Problem Statements

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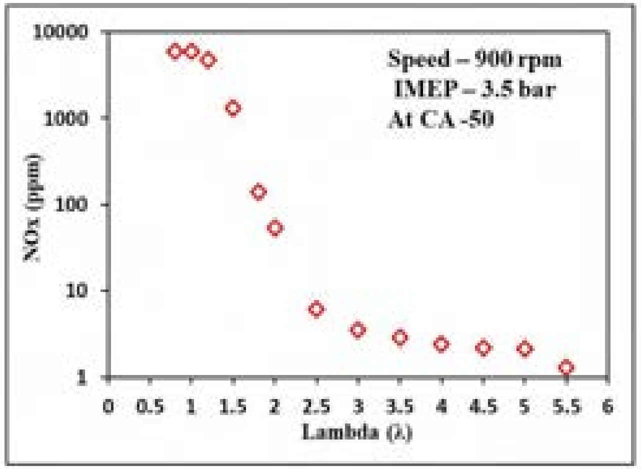
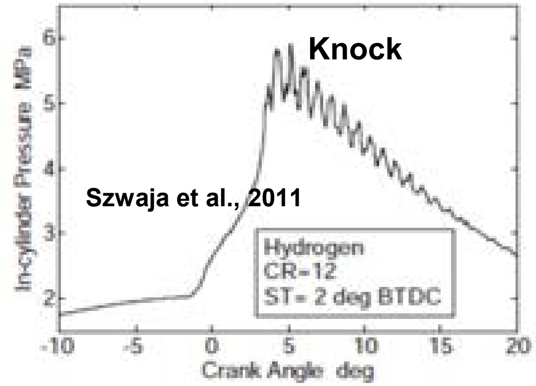
- Hydrogen is the lowest energy cost sustainable fuel, but is still expensive so efficiency is important
- Hydrogen engines produce high NOx at stochiometric AFR but very low NOx when running lean
- Hydrogen also has a low ignition energy so knock can be a problem, compromising compression ratio and therefore efficiency and power density



- Question 1 – Can stable ignition be achieved in a heavy-duty engine lean enough mixtures to produce ultra-low NOx?

- Question 2 – What needs to be done to predict and control knock?

- Question 3 – Can the high conversion efficiencies needed to make sustainable fuels economic be achieved?



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Engine Performance Combustion and Emission

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Our research group has investigated hydrogen DI engine technology for heavy duty truck applications with Ricardo

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RICARDO

Hydrogen heavy duty engines

- Advanced Engineering Centre is working with Ricardo to understand the potential for H2 ICE in heavy duty trucks
- Single cylinder direct injection hydrogen Proteus running in Advanced Engineering Centre test cell
- Work will investigate hydrogen combustion for an HD engine, particularly potential for very low NOx combustion

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Question 1: Very low, effectively zero NOx can be achieved by operating lean

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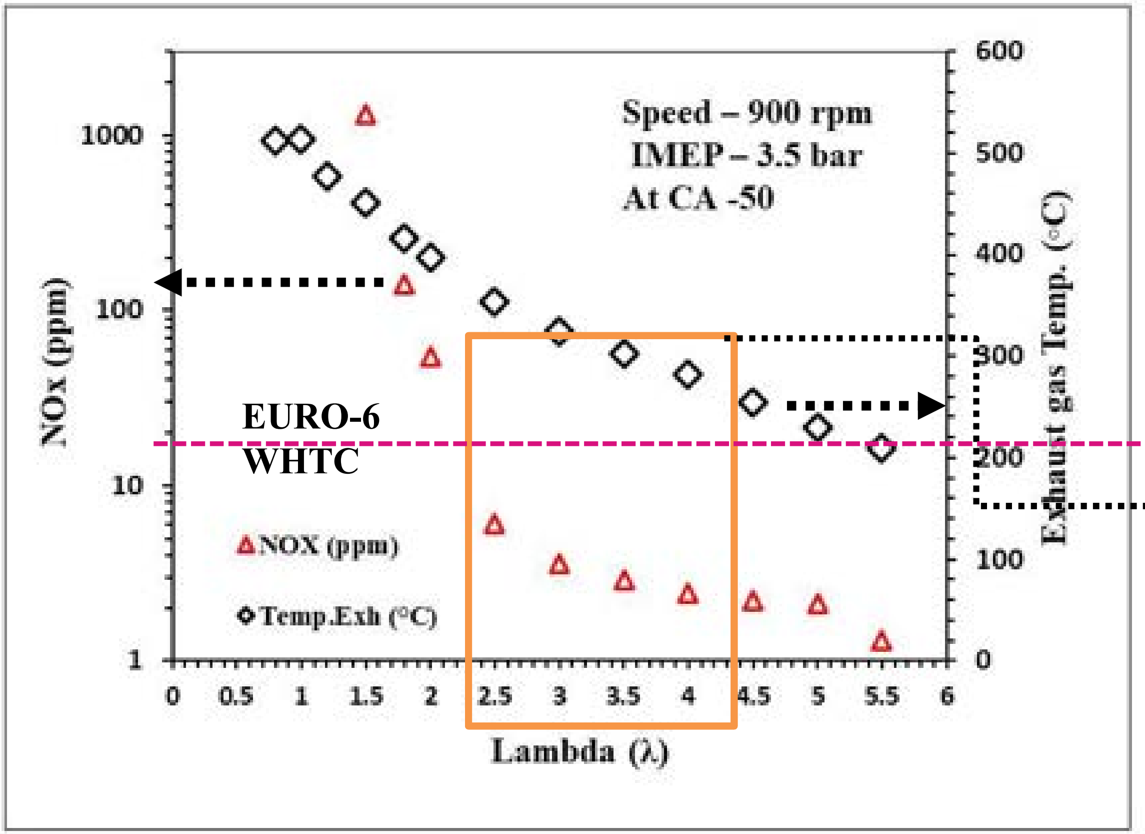

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Question 2: The fundamental reaction mechanisms need to be better understood to predict and control knock

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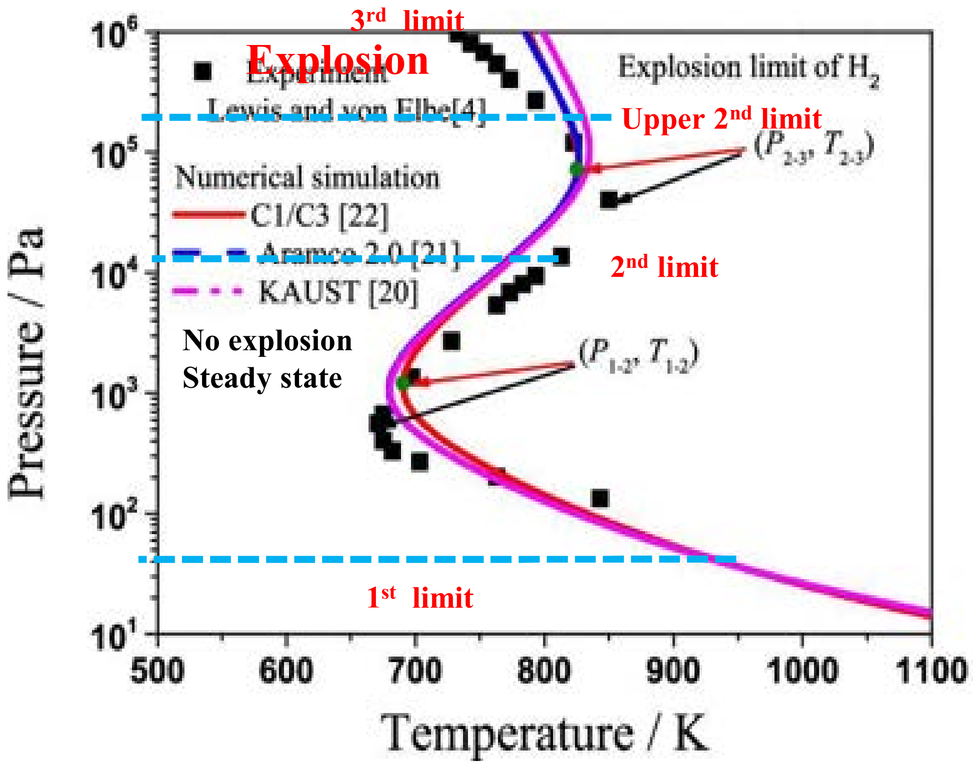
- The second explosion limit is bounded by two turning points, 2nd and upper 2nd limit.
- The turning point 2nd limit indicates the thermodynamic state that separates the first and second limits,
- and the point upper 2nd limit indicates the turning from the second limit to the third limit.
- The pressure decreases with an increase of temperature, indicating that at higher temperatures, explosion can be triggered with lower reactant concentrations.
- Experience on proteus shows you can get what you need



Jie Liu et al., ACS Omega 2020

High Efficiency Split-Cycle Engine (SCE)

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Question 3: How do you get high efficiency? Rethink the cycle!

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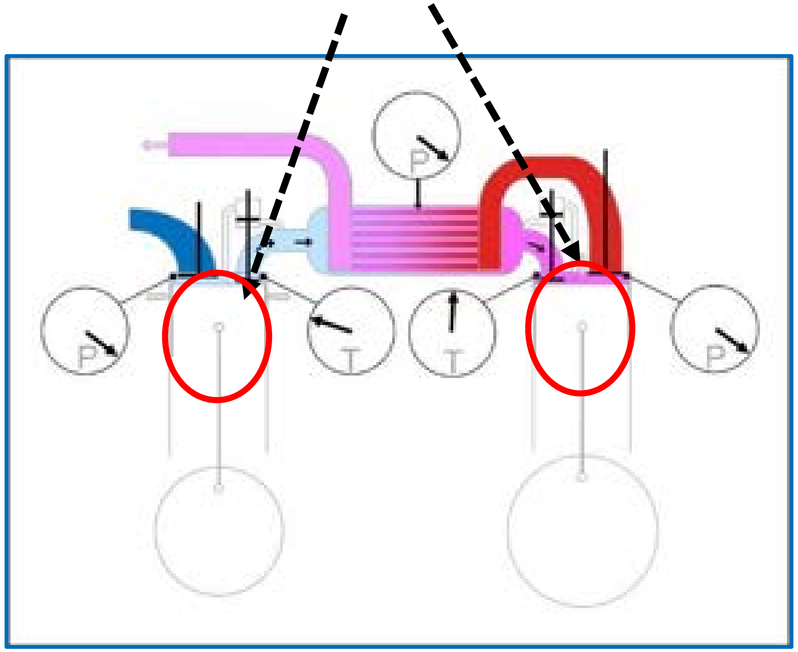
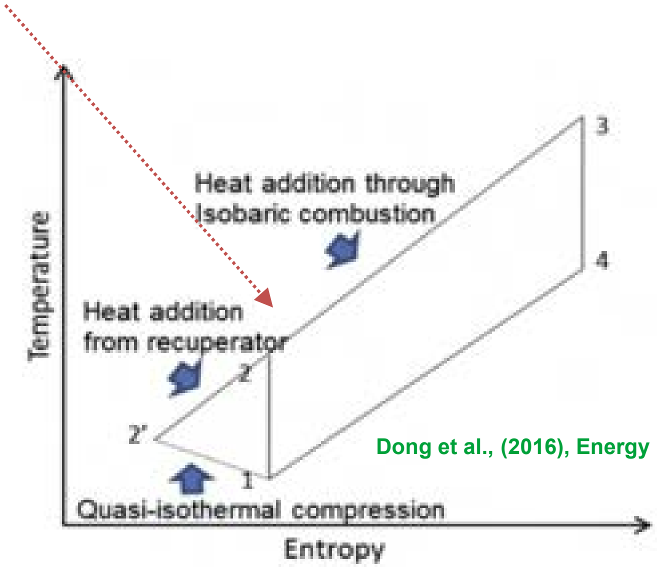
Independent optimisation of the compression & expansion cylinders



Recuperated Split Cycle Engine

The temperature at the start of combustion can be precisely controlled



Dong et al., (2016), Energy 102 (2016) 576-585

1-2 Isothermal compression
2-3 Isobaric combustion
3-4 Expansion
4-1 Exhaust & heat recovery

Split Cycle Engine

Pre combustion waste heat recovery

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Macro emissions measurements suggest the fuel burns lean and well mixed

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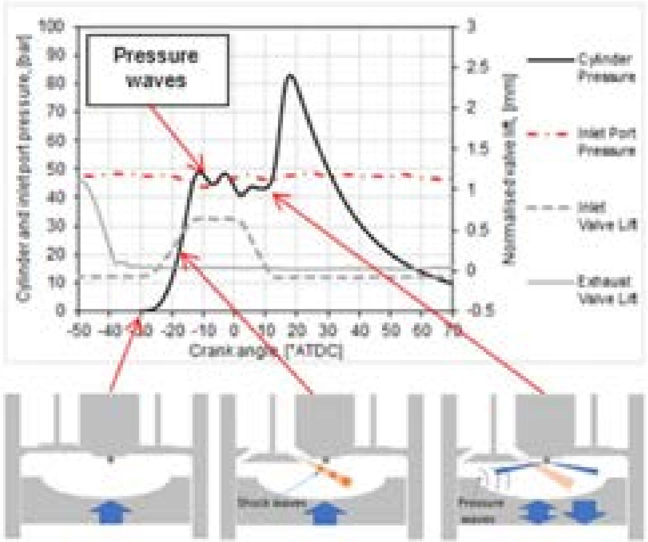

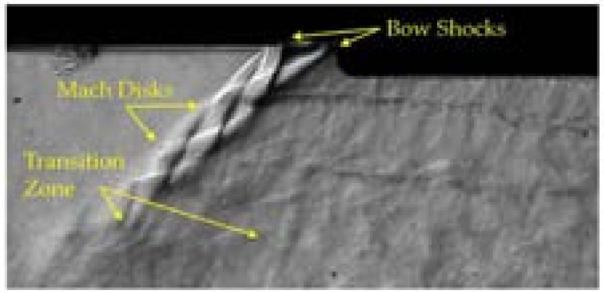

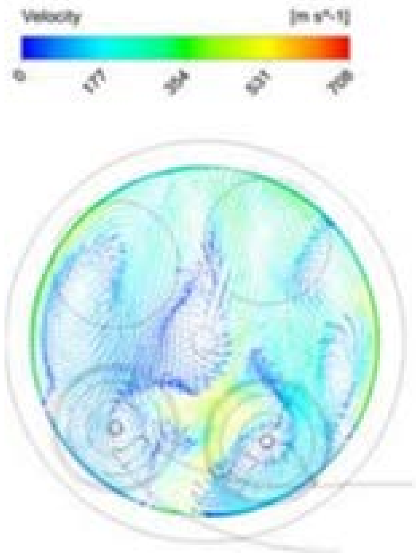


energies

Starting to Unpick the Unique Air-Fuel Mixing Dynamics in the Recuperated Split Cycle Engine

- The pressure ratio across the inlet valves during the start of induction is higher that the critical ratio for the 'nozzle'
- Cold steady state flow bench tests show evidence of shock waves in the air jet
- We think the air jet has dissipated before the start of fuel injection, but the in cylinder conditions are chaotic with very high levels of turbulence
- *Our hypothesis is the unique induction process in a split cycle engine promotes rapid mixing of the air and fuel*

SEC Performance

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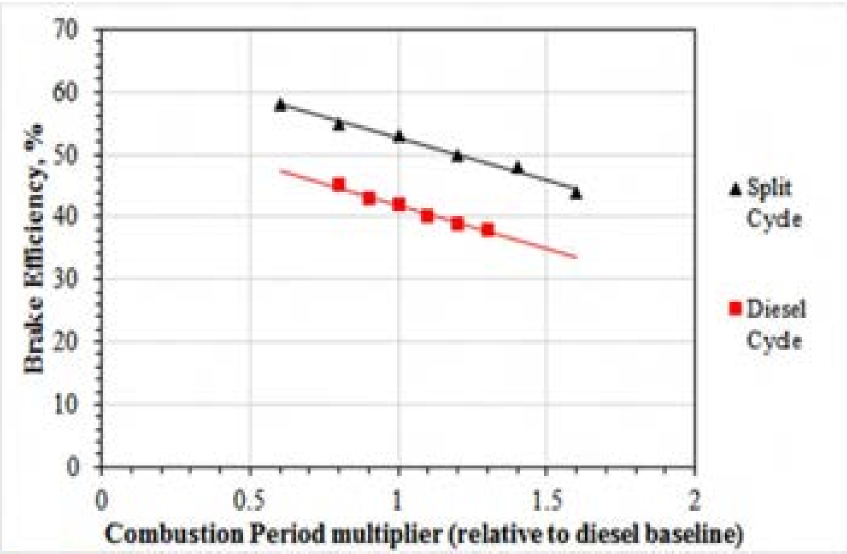
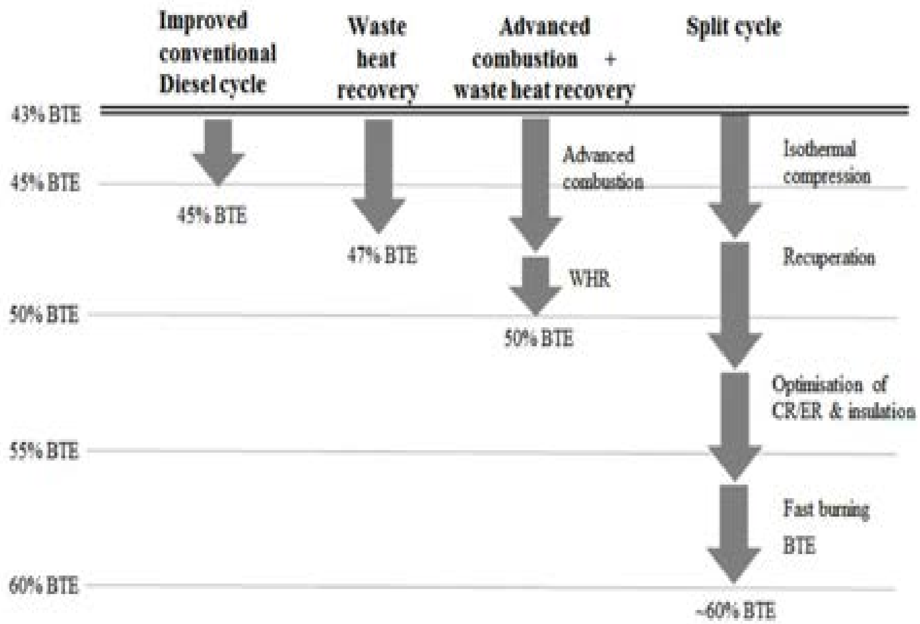
Brake efficiency





Conclusion

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Conclusions

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- Long-range heavy-duty vehicles are challenging to electromobility
- PEM fuel cells are entering the marketplace, but industry consensus suggests maturity will be slow in heavy duty applications
- Hydrogen IC engines offer a more mature propulsion solution in the short term, accelerating demand for green hydrogen
- Experimental results shows that H2 IC engine able to operate at lean-mixture to achieve ultra-Nox emissions without compromised thermal efficiency.
- Knock-Intensity could be controlled while running on lean-mixture
- Split-Cycle Engine could be a promising technology in future for H2 and NH3 combustion to achieve lower emissions and higher thermal efficiency.

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Thank you for listening

Thank you to the Research team for producing valuable results

Please contact me at v.sharma2@brighton.ac.uk

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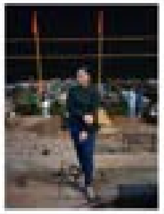

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