Future Challenges for the ICE

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EPSRC
Engineering and Physical Sciences Research Council

ADVANCED PROPULSION CENTRE UK
UNIVERSITY OF BRIGHTON
ICE Thermal Efficiency Spoke

University of Brighton
Advanced Engineering Centre

Contents

- 1989-1994 Imperial College
- 1994-2005 Ricardo – Senior Manager,

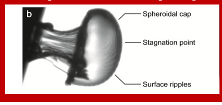
  Technology Product Group
- 2005-2008 Ceres Power – Head of Engineering
- 2008-2013 Highview Power Storage – Chief Technical Officer
- 2013- University of Brighton – Reader

  Deputy Head of the Advanced Engineering Centre

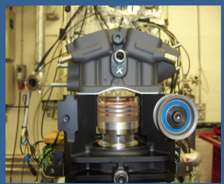
  Director of the APC ICE Thermal Efficiency Spoke

Advanced Engineering Centre

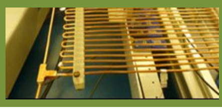
Droplets and sprays



Combustion



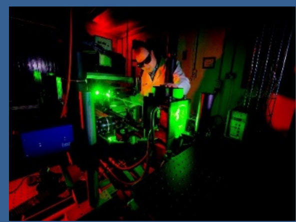
Heat and mass transfer



ADVANCED PROPULSION CENTRE UK
The Propulsion Nation

ICE Thermal Efficiency
University Of Brighton

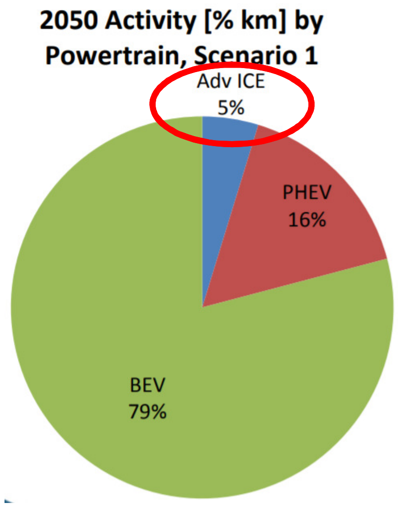
World leading facilities

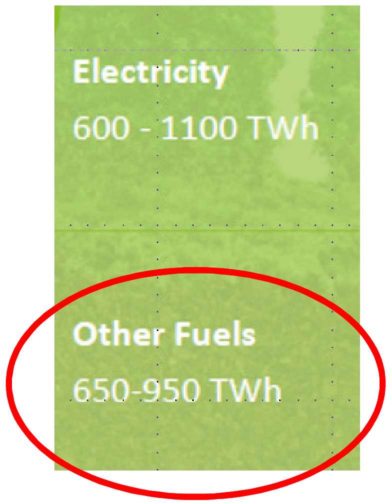


Recent industrial collaborators

RICARDO, TATA, BorgWarner, PETRONAS, HIFLUX, MMI engineers · scientists · innovators, Shell, JAGUAR, LAND ROVER, LIBERTINE, Dearman, bp, DELPHI

Why do we need an efficient engine in an electric world?

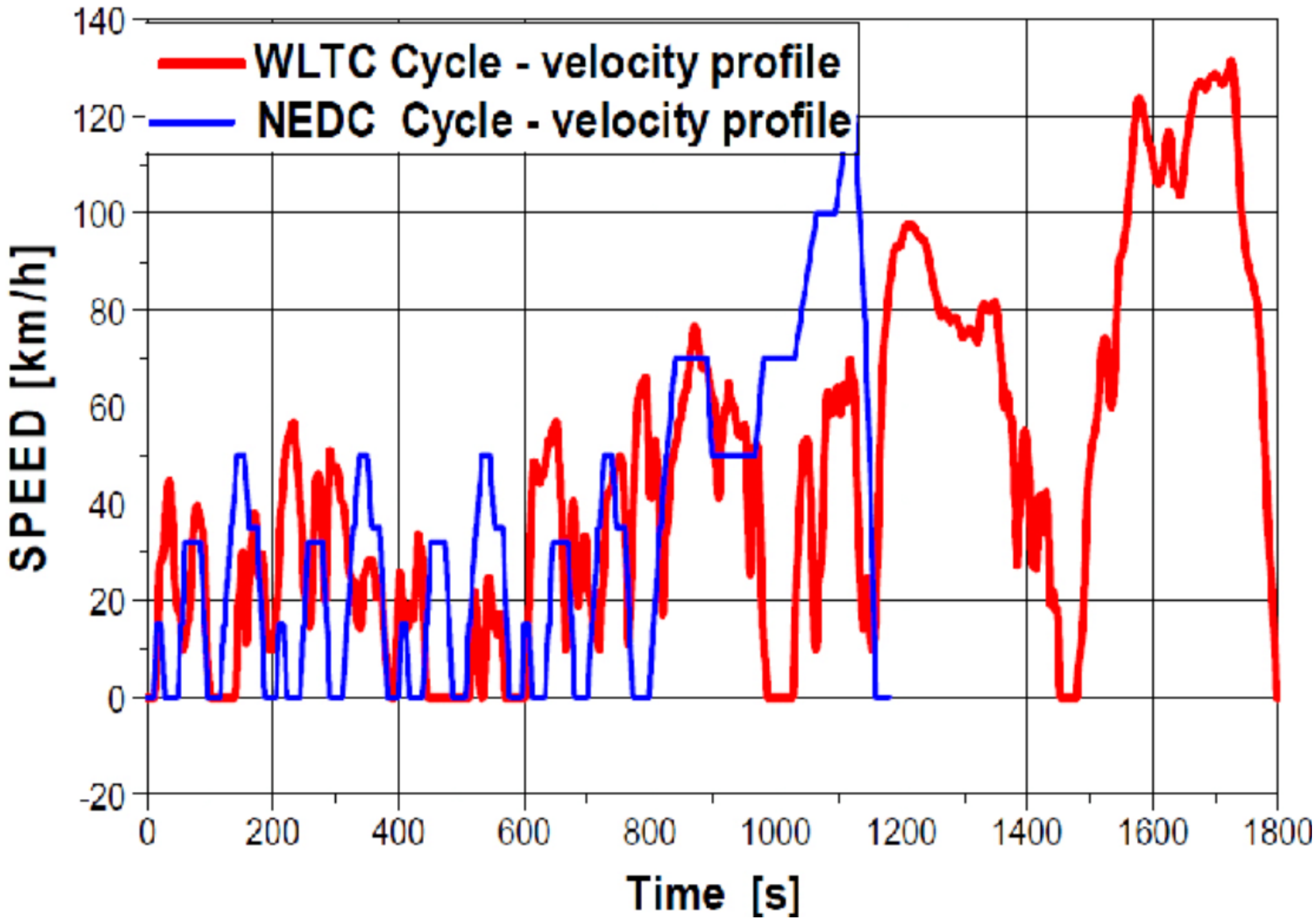




Improvements in powertrain efficiency are required to reduce the demand for sustainable fuels

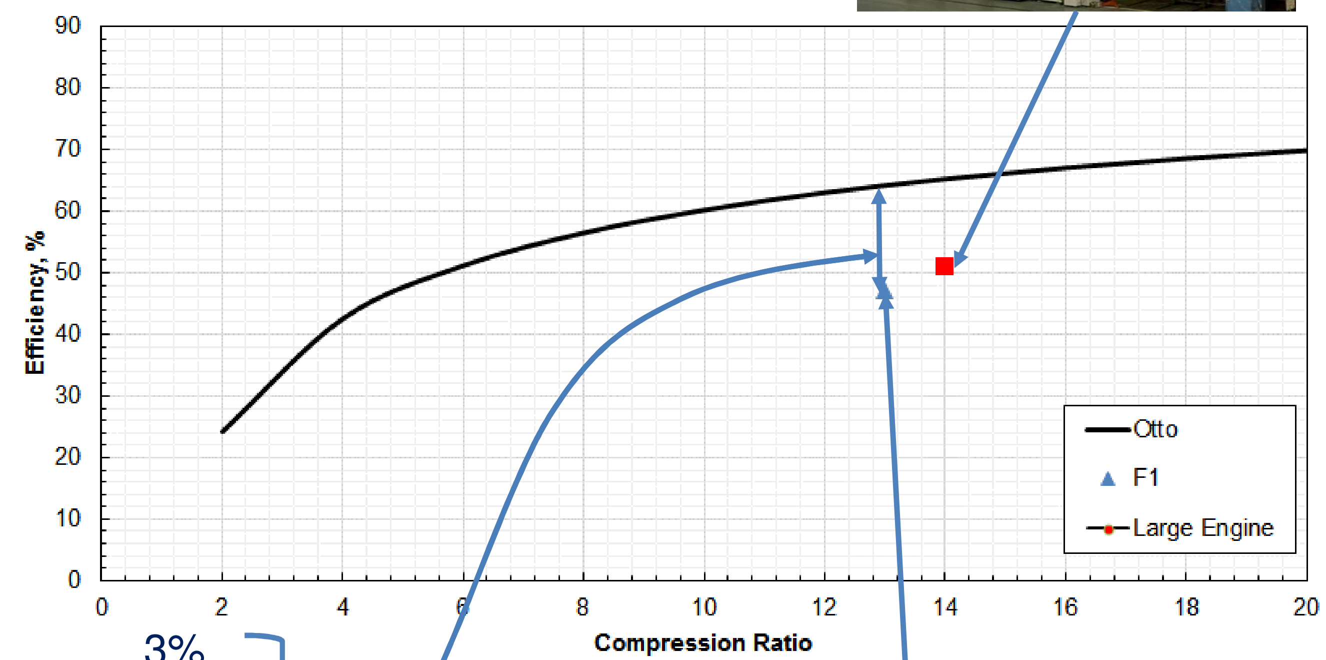
Source: Report from ERTRAC CO_2 integrated approach,
http://www.ertrac.org/uploads/images/3.%20CO2_Evaluation_Group_%20ERTRAC2017.pdf

New emission cycle, tighter limits, RDE

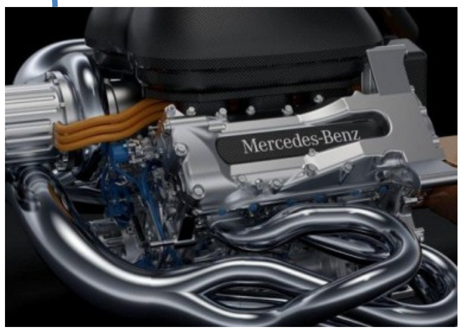


Are we at to the end of the road with conventional engine cycles?

Wartsila
RT-flex58T



Mercedes F1



Mechanical losses	3%
Finite combustion	3%
Blowby	1%
Cycle to Cycle variations	2%
Gas exchange	2%
Heat transfer	7%
TOTAL	**18%**

Stone 2012

Mass market adoption of increasingly hybridised vehicles drives challenging cost and performance targets for future thermal propulsion systems

automotive council UK

ADVANCED PROPULSION CENTRE

Drivers of change

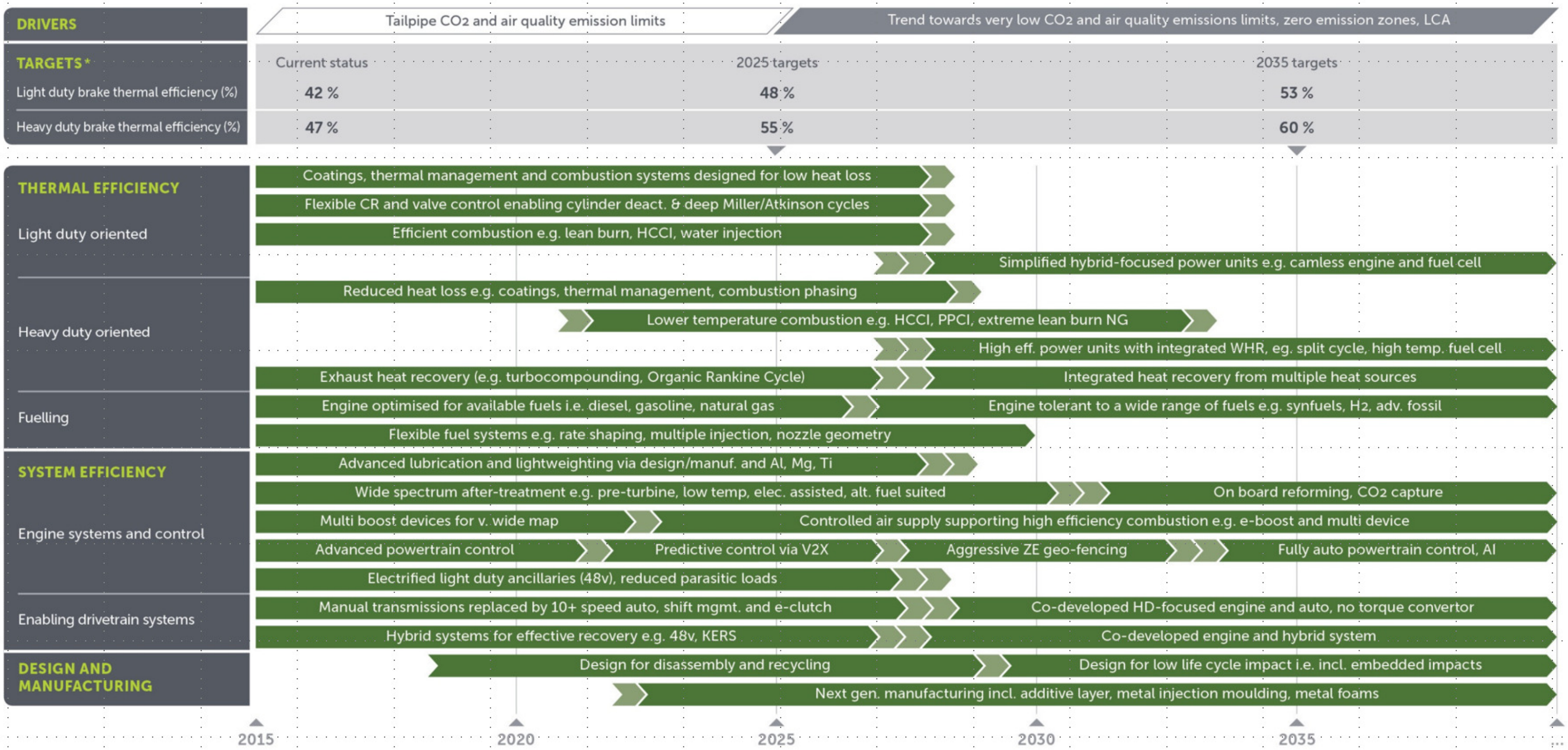
- Incremental ICE innovation has provided steady improvements over a long period, but **bigger changes are required**.
- Ambitious **targets**, that are unobtainable with existing engine technology, have been set to drive significant innovation. These targets must be achieved without compromising customer demands of exceptional cost effectiveness, range requirements, power density and recyclability.
- Reducing **air quality and CO_2** emissions challenges the current application of all ICE powertrains using conventional fuels. Future sustainable fuels and the associated engine technology are actively being developed, potentially near carbon neutral operation. Air quality and efficiency will remain key drivers.
- **Life cycle measures and materials security** will challenge all propulsion technologies, supporting the acceptability of ICEs with suitable performance against these metrics
- For **light duty** vehicles ICE will feature in all hybrid vehicles before the potential advent of fuel cell hybrids. Hybridisation implies a change in the nature of ICEs and offers higher efficiencies.
- For **heavy duty** the ICE remains core to future propulsion due to the absence of alternatives. Further improvements to efficiency and emissions are needed, including new fuel types and energy recovery.

Light Duty	2017	2025	2035
Engine System Brake Thermal Efficiency (%)[1,2]	42	48	53
Tailpipe NOx & Particulates (Mass & Number)	In line with legislated limits	Zero in emissions controlled zones[3]	
Heavy Duty	**2017**	**2025**	**2035**
Engine System Brake Thermal Efficiency (%)[1]	47	55	60
Tailpipe NOx & Particulates (Mass & Number)	In line with legislated limits	Zero in emissions controlled zones[3]	

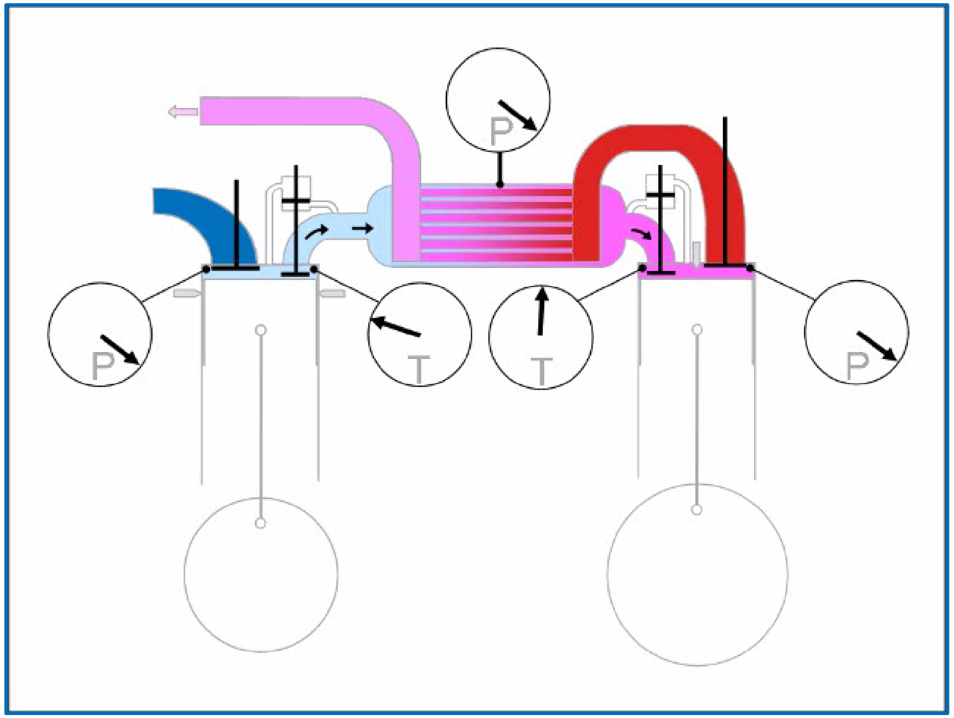
1 - Peak efficiency values shown. Increasingly important to achieve high efficiency across a wider operating range, in keeping with testing cycles based on real world performance
2 - Values reflect mid point between diesel and gasoline efficiency (current difference ~5%)
3 - Below measureable limits or below ambient (background) levels

TECHNOLOGY ROADMAP 2017: THERMAL PROPULSION SYSTEMS

Roadmap developed by the Automotive Council and the Advanced Propulsion Centre



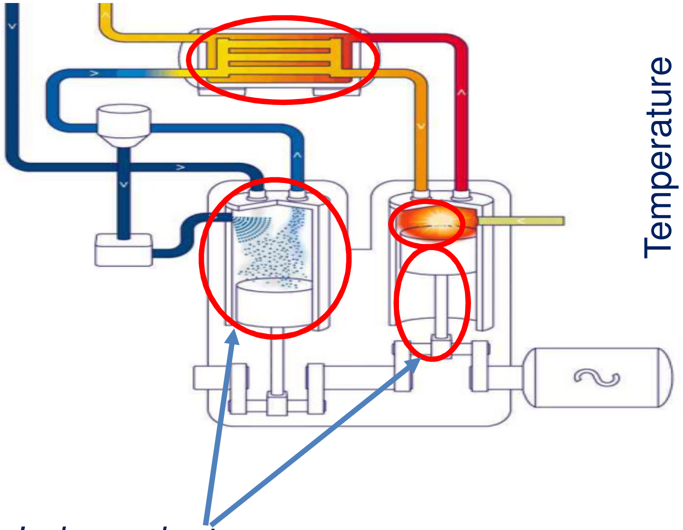
How does the recuperated split cycle engine work?

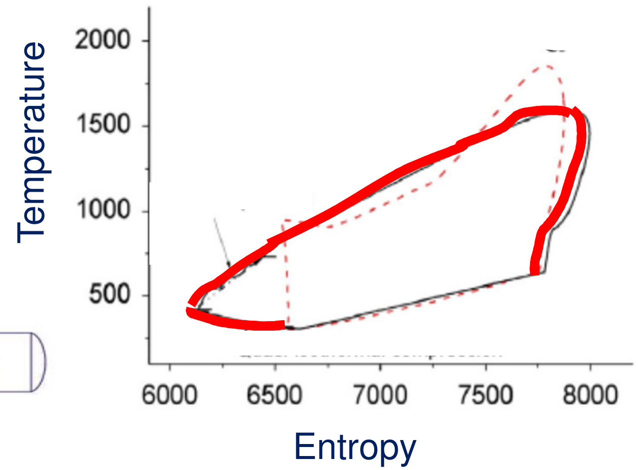


Key Facts:

- Twice as many cylinders *but* it's a two stroke cycle
- Compressor – combustor cylinders are in the ratio of 1 to 2 or 3
- Isothermal compression is critical to the cycle, and can be achieved in may ways
- Peak pressures are lower than in a conventional diesel engine
- Peak temperatures are also lower, but sustained for longer than in a comparable diesel engine

What makes the cycle efficient?





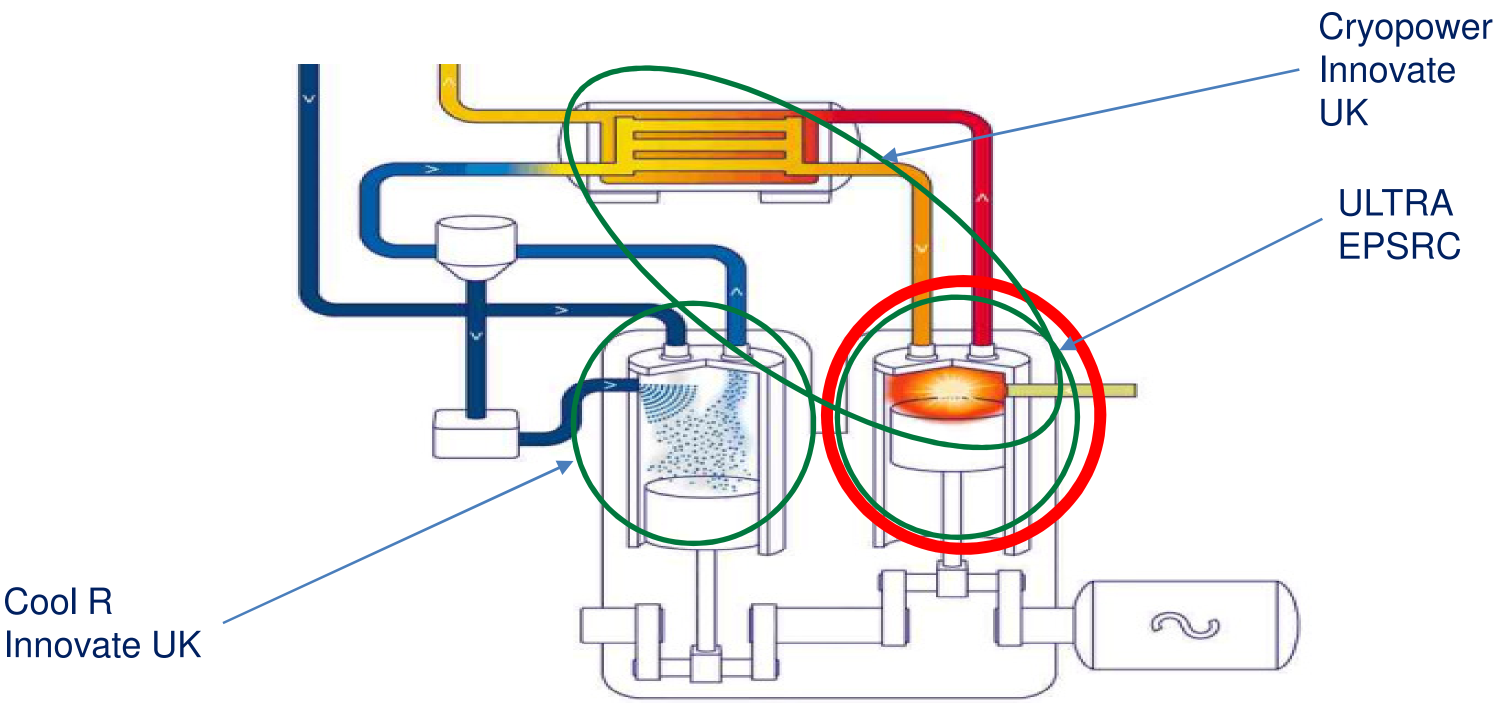
Independent optimisation of the compression & expansion cylinders

1. Isothermal compression
2. Isobaric heating
3. Mixed cycle heat addition
4. Expansion

Less work of compression

Pre combustion waste heat recovery

Progress to date



Whats difficult about the implementation?

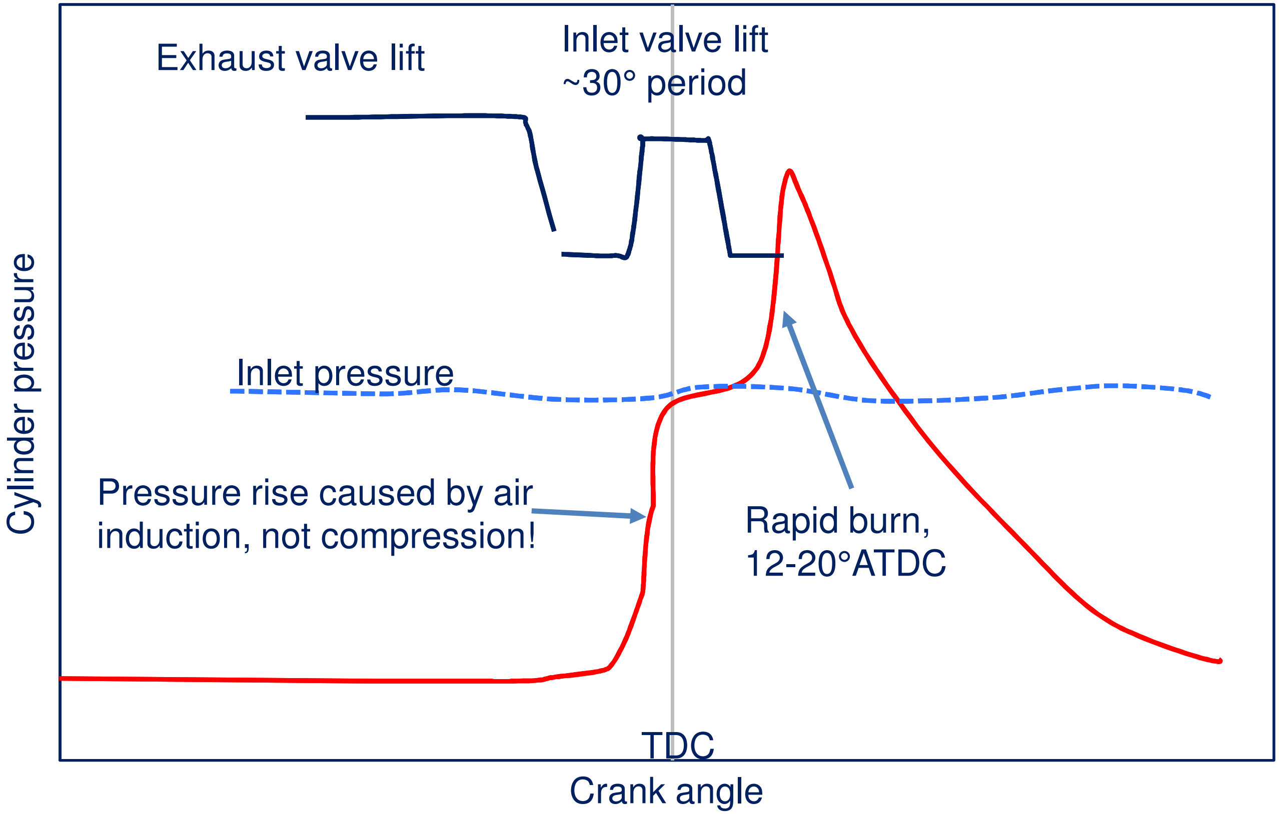
- Starting:
  - The exhaust and therefore recuperator are cold
  - The combustion chamber is also cold

- Combustion:
  - Very little time to get the air into the combustion chamber
  - Also not much time to get the air and fuel mixed
  - So very little time to get the fuel burnt!

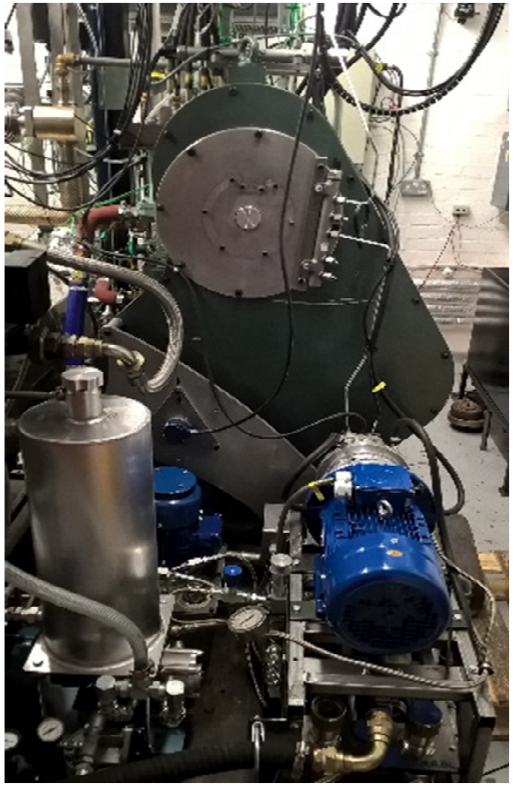
- Hot end thermal load:
  - Although peak temperatures are lower than in conventional diesel engines, the high temperatures are sustained for longer
  - There is also no charge air cooling of the cylinder during induction
  - This results in higher thermal loading than in a conventional engine

2004 “ISOENGINE”

What are we looking for?



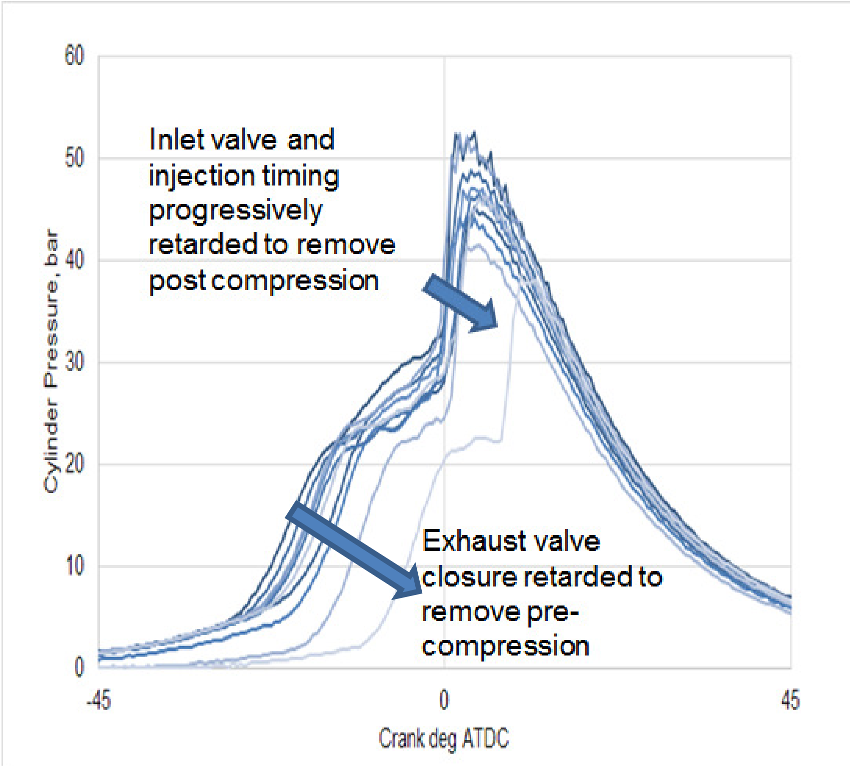
Split cycle test facility



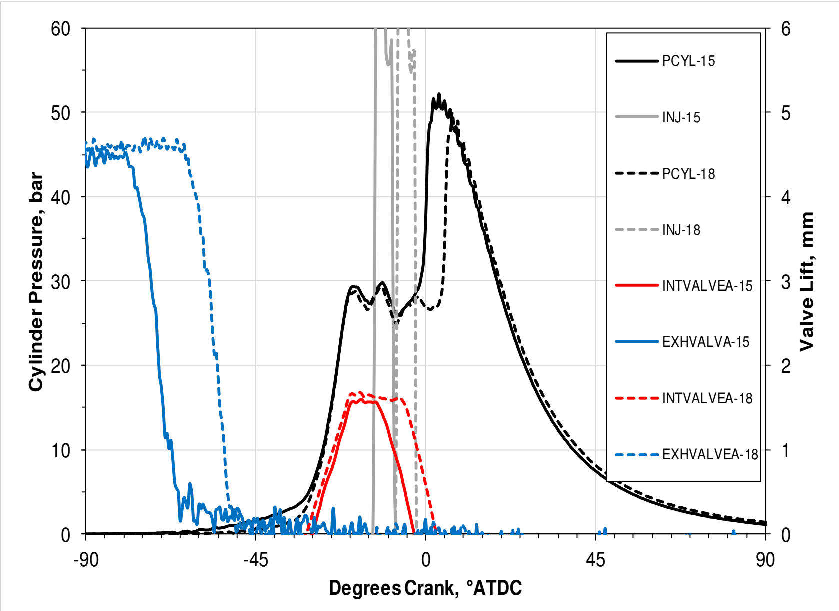
- One I/cyl. Single cylinder test rig, based on a Ricardo Titan engine
- Fully configurable hydraulic valves (research rather than production solution)
- Prototype recuperator, heated by a gas burner to replicate the exhaust
- High pressure gas supply in place of the isothermal compressor
- Two independent oil and three independent coolant circuits

Results - starting

- Starting is one of the biggest challenge in a split cycle engine
- Initial tests used high cetane fuel and compression of trapped residuals
- Advancing the inlet and exhaust valves was found to provide sufficient charge air heating to start the engine from cold
- The valves could be progressively retarded to the ideal split cycle timings

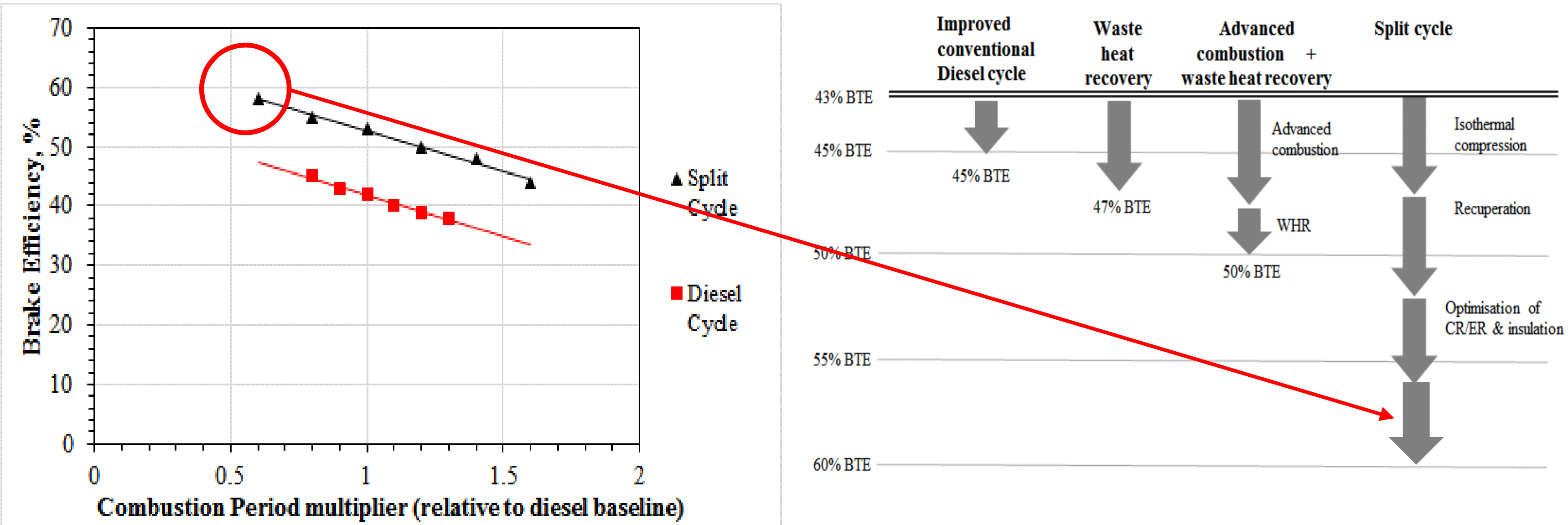


Combustion results at 1200 rpm



- Fuel is injected together with the intake air
- Classical and CFD analysis show the air flow is choked across the inlet valve
  - Very high cross chamber air motion
- The air motion provides significant mixing energy and is thought to by why the fuel burns so quickly
  - Preliminary kinetic analysis suggests the fuel is burning highly premixed

Efficiency walk



Conclusions

- There is still a role for a chemically fuelled engine in an electric world

- Massive challenge in achieving high efficiency and zero emissions from an internal combustion engine

- What do we need?
  - Practical lean compression ignition compatible with RDE
  - New approaches to achieve >break efficiency