Waste heat recovery from IC engines: An ORC based approach

Guohong Tian
University of Surrey

Researcher Links UK-Russia Workshop
Scientific and technical grounds of future low-carbon propulsion
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Mechanical Engineering Sciences Dept. (MES)

- Biomedical
- **Automotive**
- Fluids
- Materials

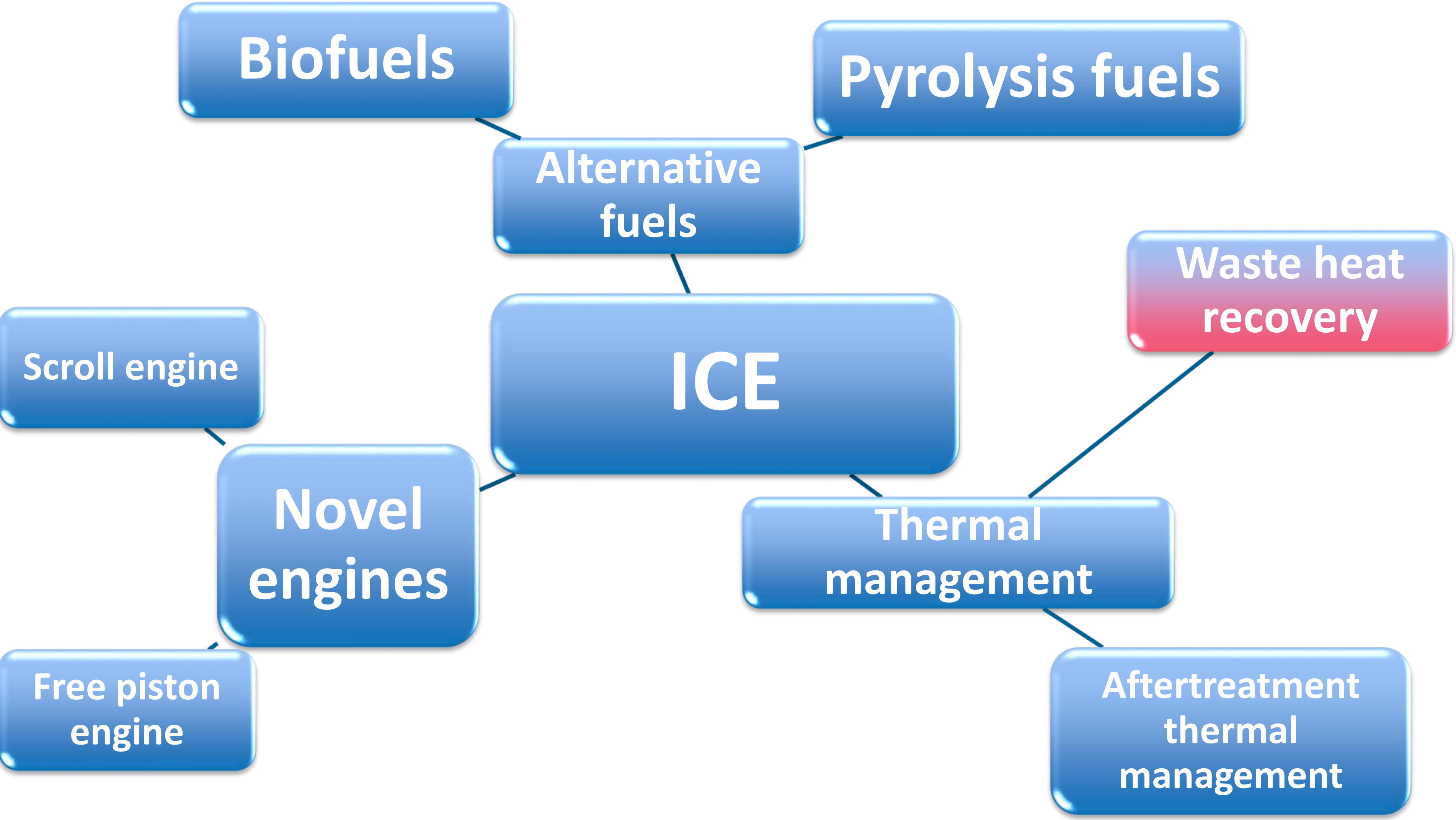
Automotive Engineering Research Centre

- Vehicle dynamics control including automated driving
- Control of transmission systems for internal-combustion-engine-driven vehicles, hybrid electric vehicles (HEVs) and battery electric vehicles (BEVs)
- **Efficiency and emissions improvement for vehicle powertrain system**
- Advanced energy management and brake regeneration strategies for HEVs and BEVs
- Hybrid energy storage systems
- Tyre modelling

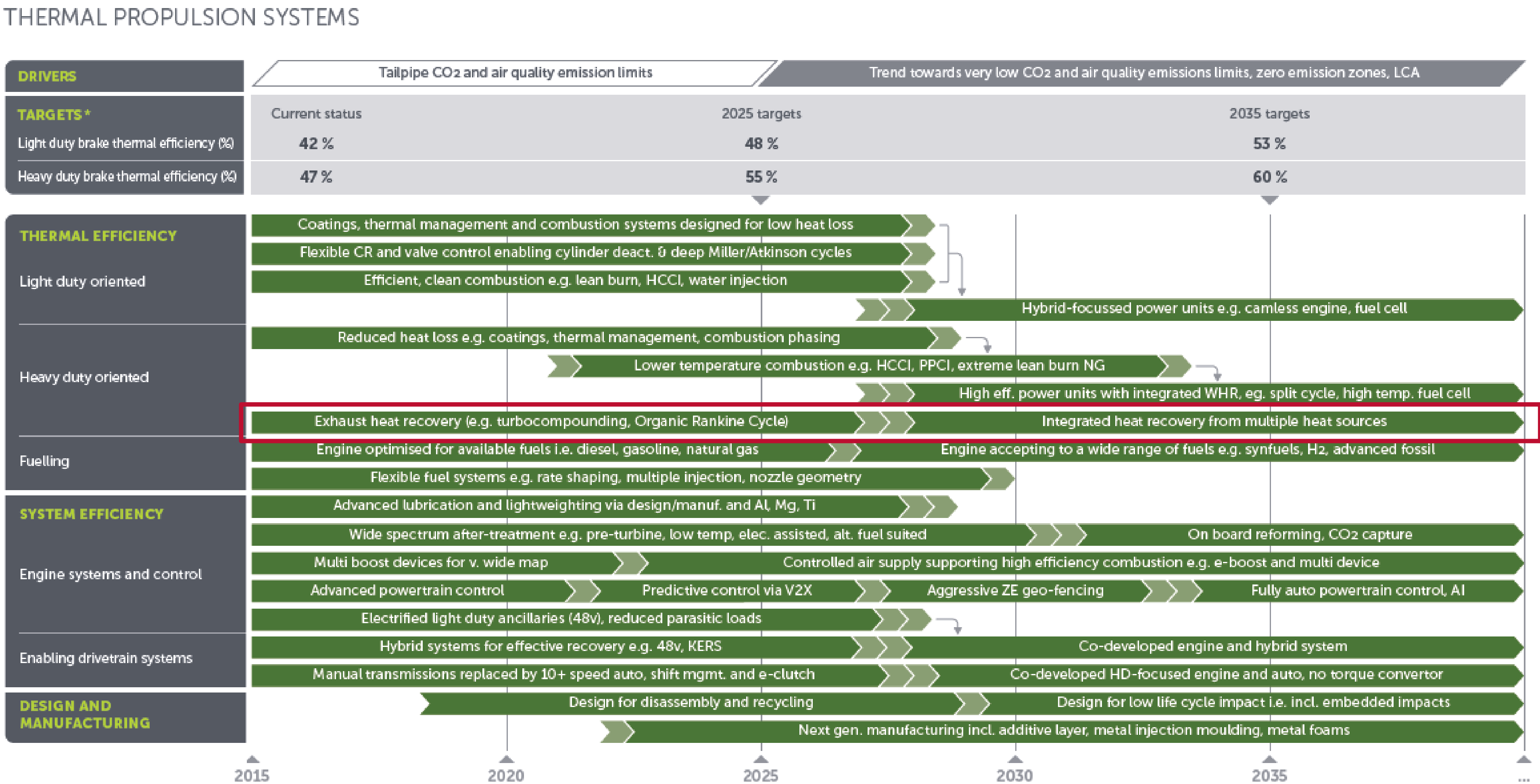
Academic team:

- Prof Aldo Sorniotti (Transmission)
- Dr Patrick Gruber (Tyre)
- **Dr Guohong Tian (Powertrain)**
- Dr Saber Fallah (Control)
- Dr Ahu Hartavi Karci (Electric machine)
- Dr Teng Zhang (Battery)
- Dr Eric Lo (Aerodynamics)
- Dr Davide Tavernini
- Dr Umberto Montanaro

My research interests

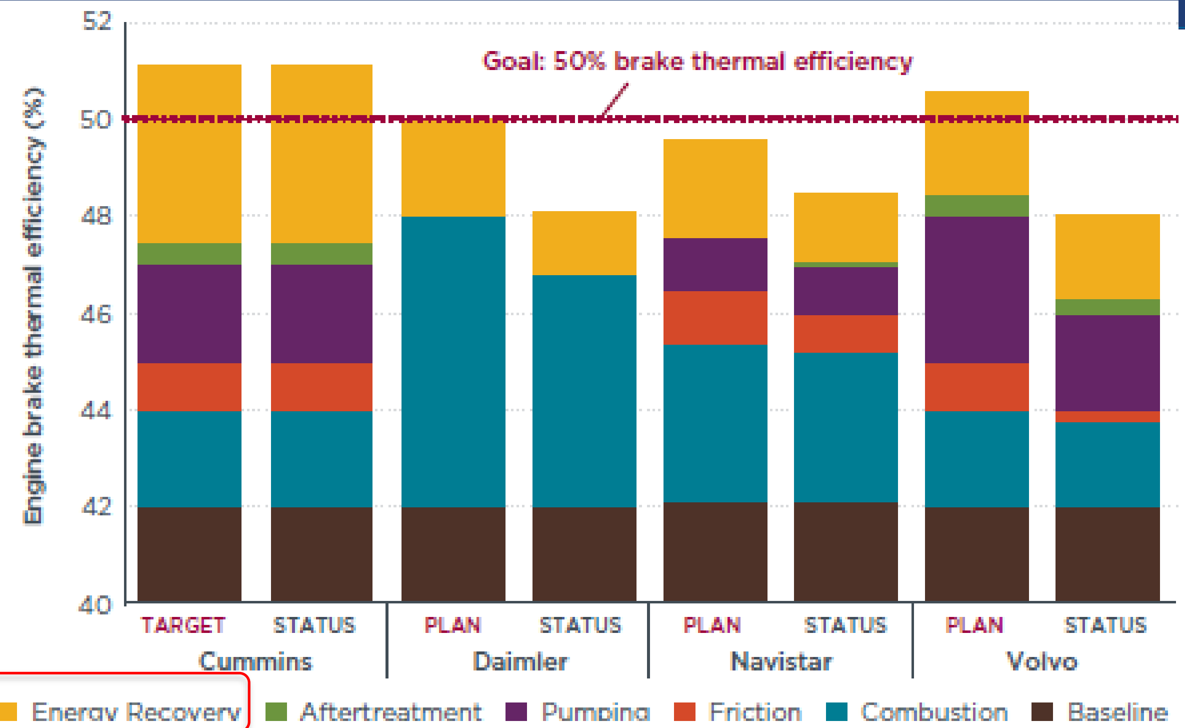


Challenges of modern internal combustion engines



THE ROADMAP REPORT, produced by APC

High-efficiency heavy duty diesel engine technical map

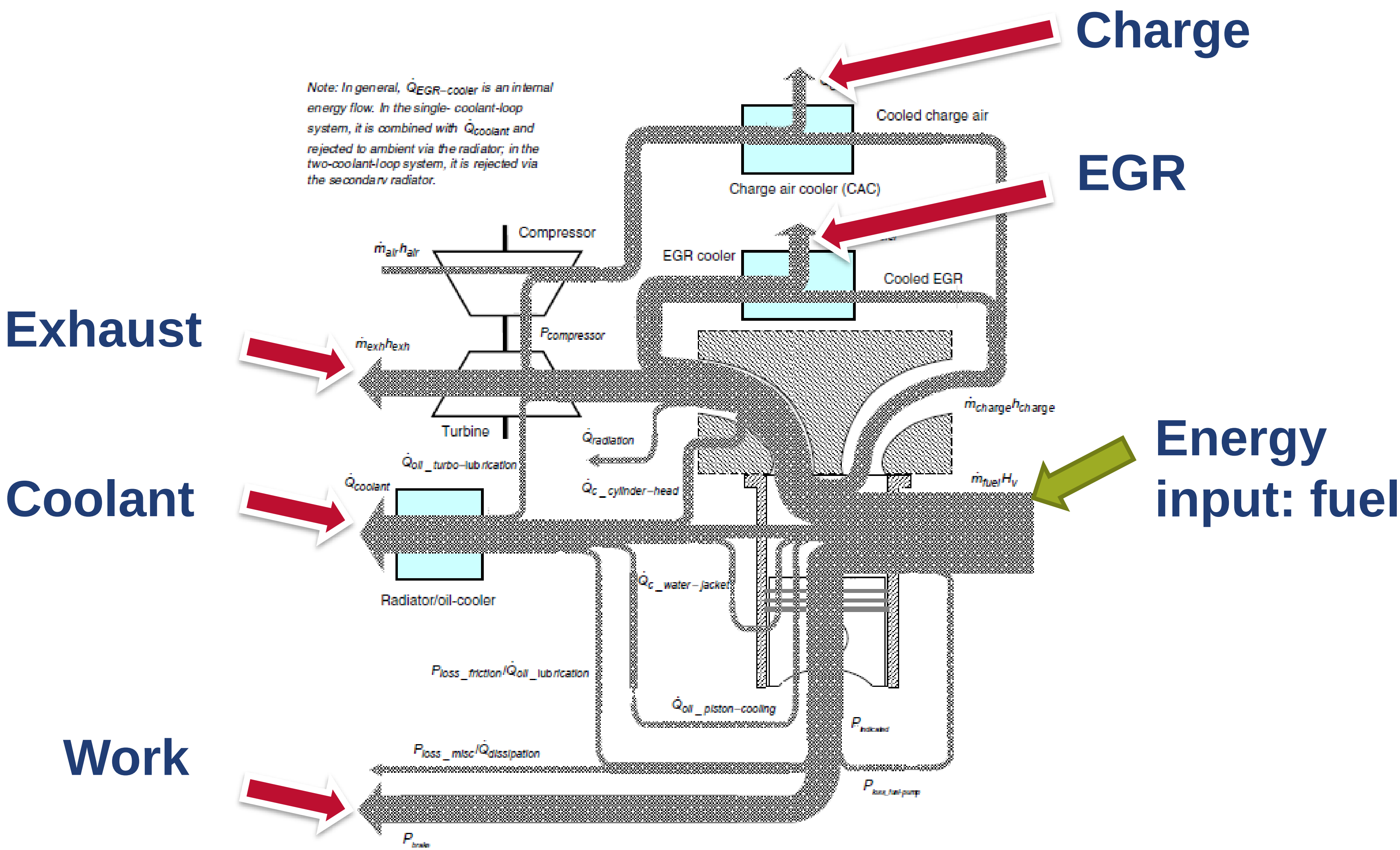


Strategy	Cummins	Daimler	Navistar	Volvo
Engine downsizing	No	Yes	No	Yes
Engine downspeeding	Yes	Yes	No	Yes
Transmission	Automated manual	Automated manual	Dual-mode hybrid	Dual-clutch automated manual
Hybridization*	No	Mild	Full (series/ parallel)	No
Organic Rankine cycle	Yes (mechanical)	Yes (electric)	No	Yes
Turbocompounding	No	No	Yes (electric)	Yes (mechanical)

* Hybridization can be described in terms of a "mild" or "full" relative power rating of the electric motor with respect to the internal combustion engine.

Corning Incorporated

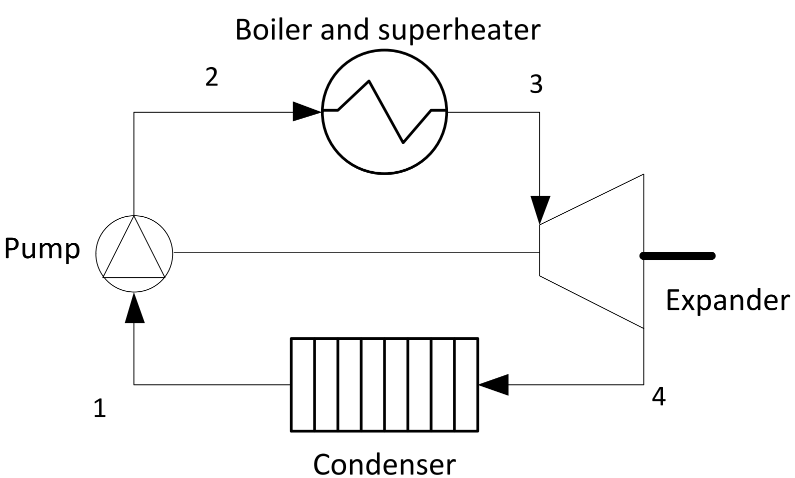
IC engine energy balance

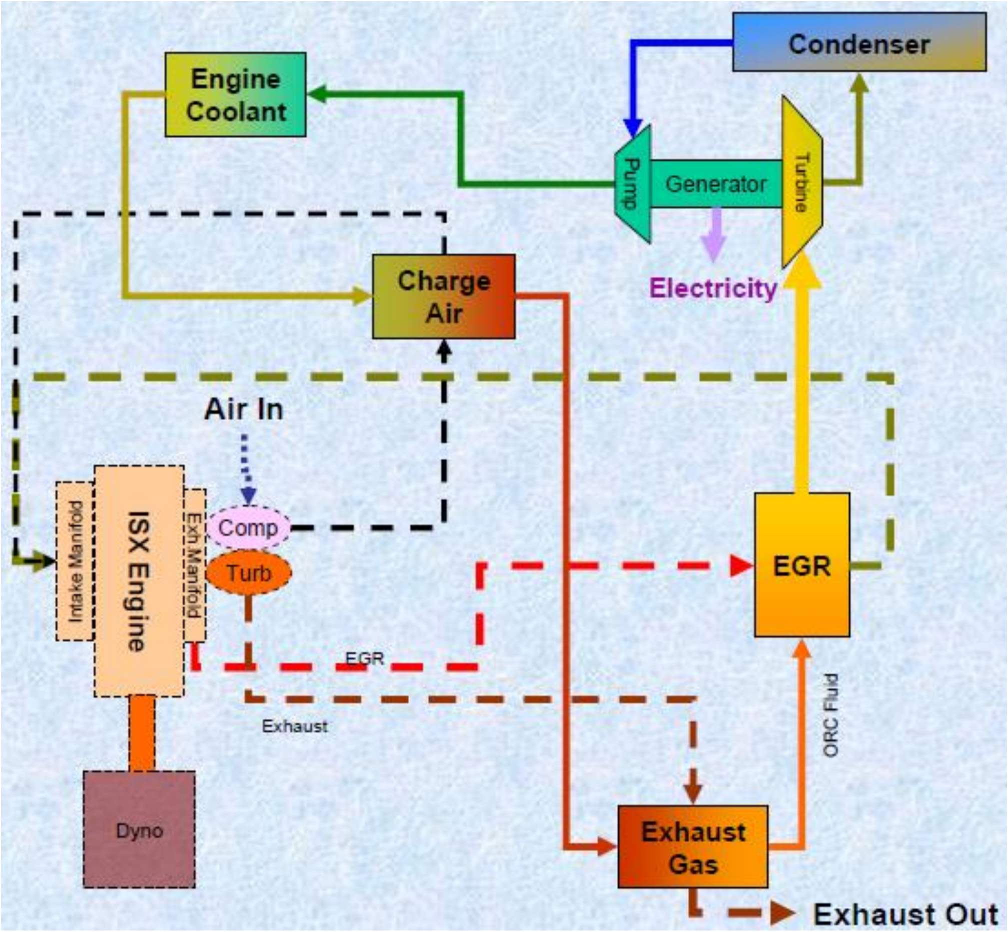


Teng et al. SAE 2006-01-3522

ORC based WHS for IC engines

- √ – Relatively mature technology
- √ – Relatively low cost
- x – Relatively complex
- x – Reverse effect on engines
- x – Relatively low efficiency （<10%）
- √ – Optimisation potential

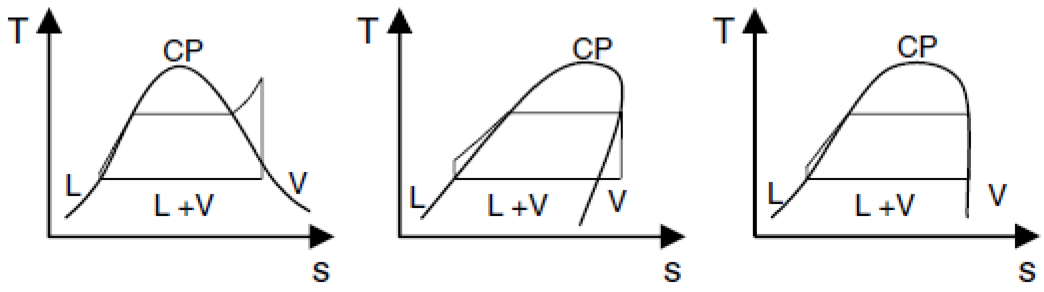


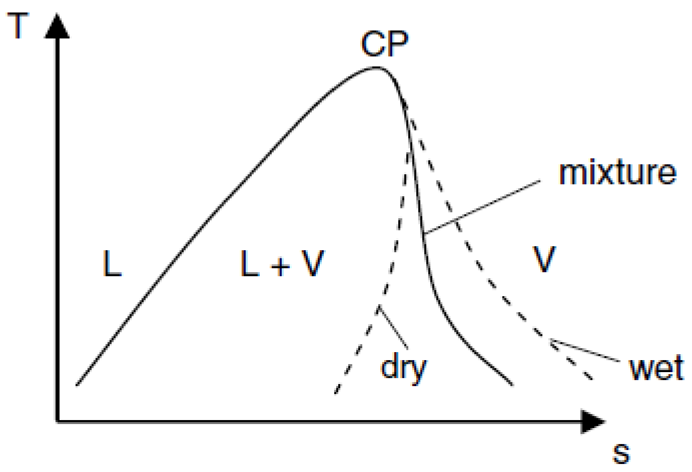


Kauranen et al. 2010

Working fluid selection

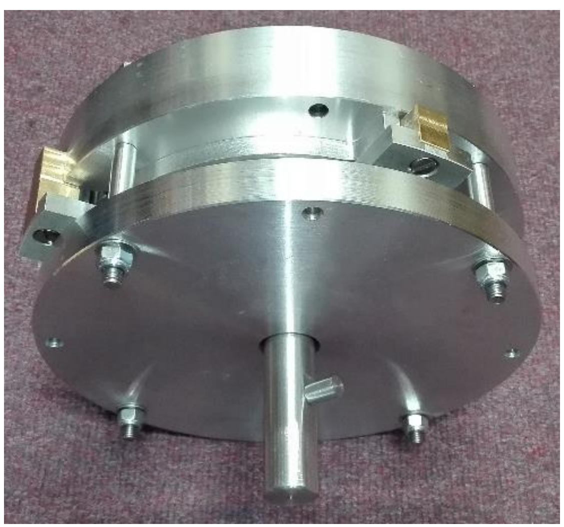
- Dry fluid vs wet fluid
  - For ORC, dry or isentropic fluid is superior over wet
- Organic fluid over water
- Other characteristics
  - Chemically stable
  - Non-toxic, non-corrosive
  - Inflammable
  - Environmental friendly
- Mixture fluids have good potentials

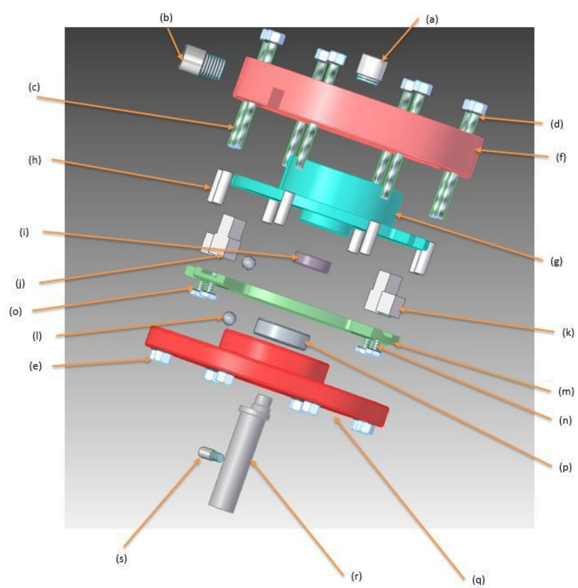


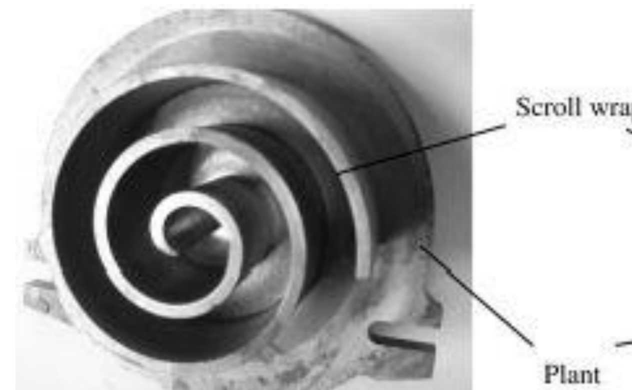


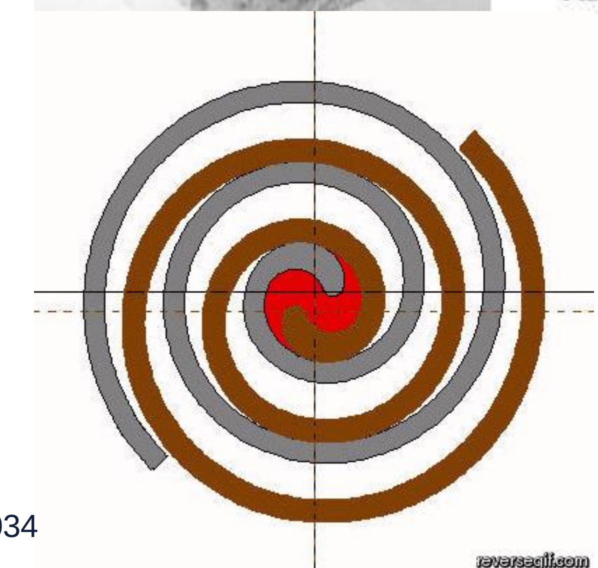
Scroll expander design and optimisation

- Key component to convert thermal energy to mechanical work
- Power range for vehicular WHR application is approximately 10 kW
- Scroll expander can achieve about 60-70% isentropic efficiency.







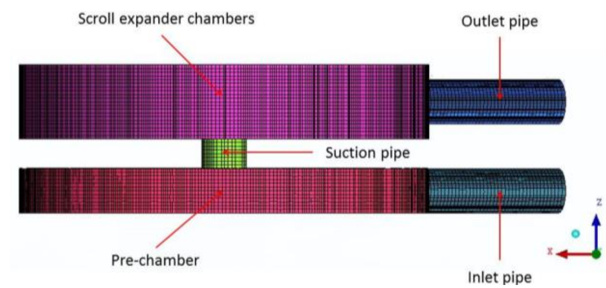


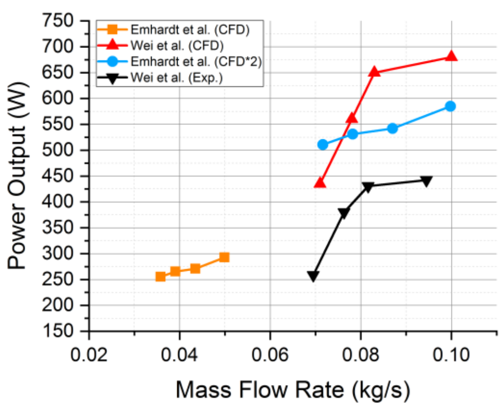
Applied Thermal Engineering, Volume 141, August 2018, Pages 1020-1034

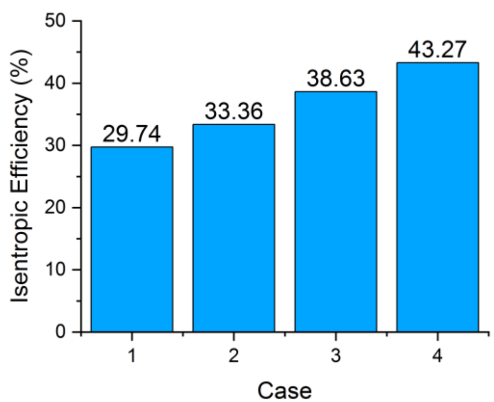
Scroll expander design and optimisation

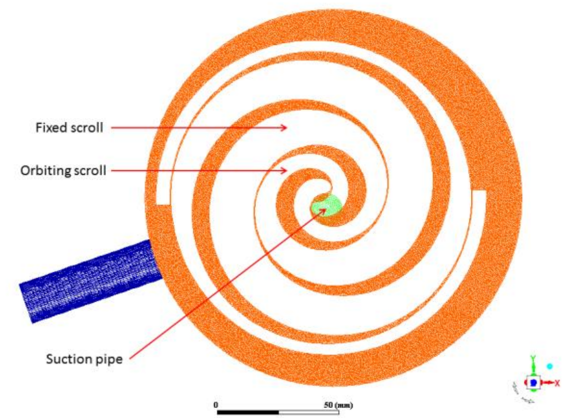
Internal flow simulation

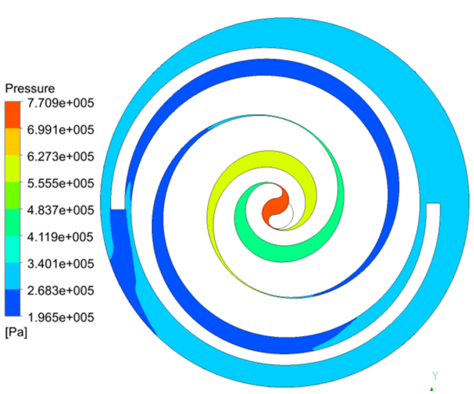
- Novel variable wall thickness design
- 3D unstructured computational grid
- Dynamic mesh technology including smoothing/ remeshing schemes and user-defined-functions (UDF)

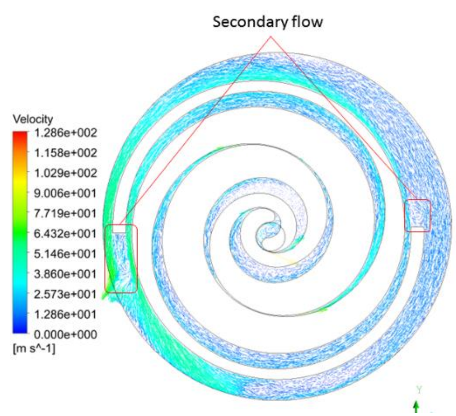


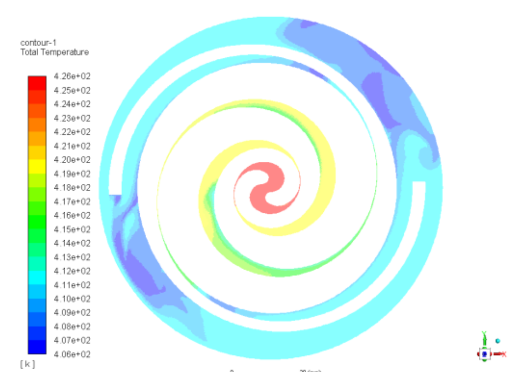








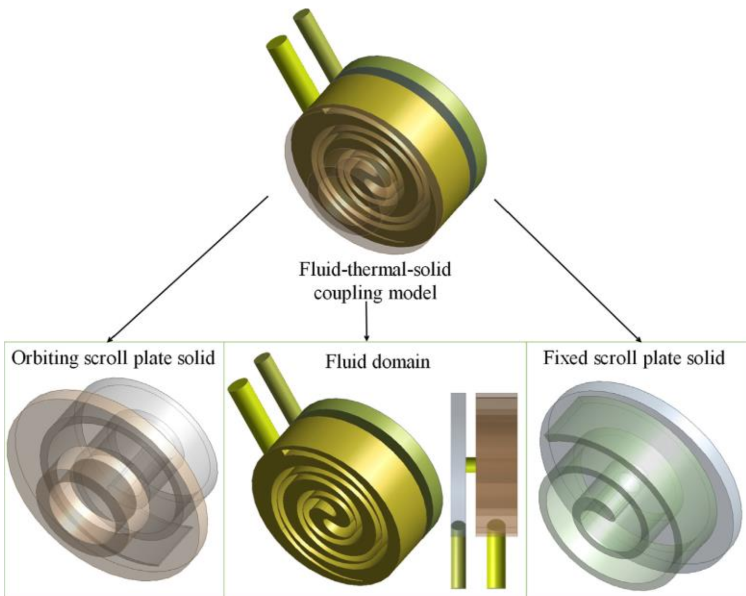




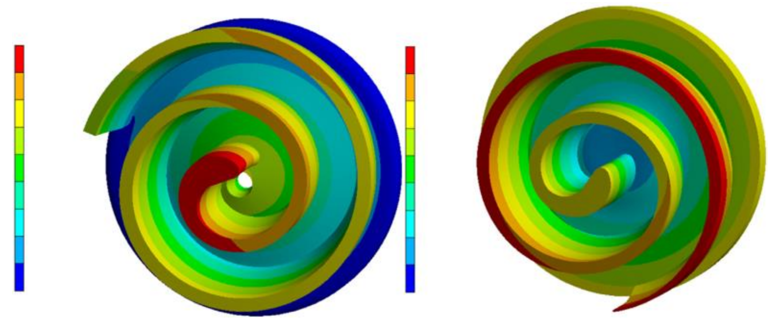
Scroll expander optimisation

Fluid-thermal-solid coupling analysis

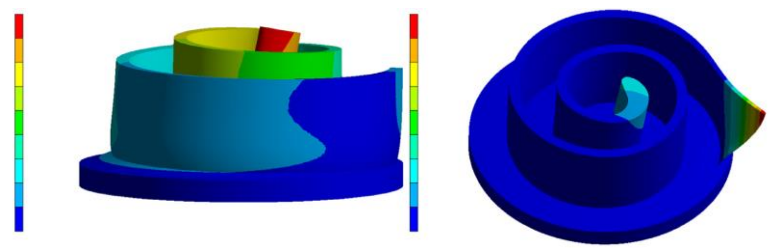
- Coupled simulation to investigate the deformation which is important for sealing and cooling design.
- Thermal deformation predominates but also need to consider pressure and inertial force deformation.



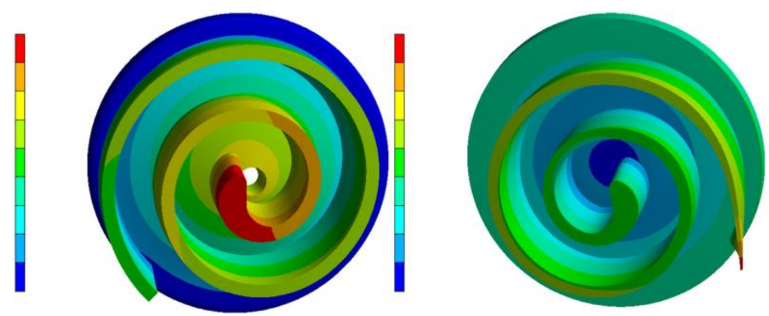
Computational domains



Thermal deformation distributions



Pressure deformation distributions



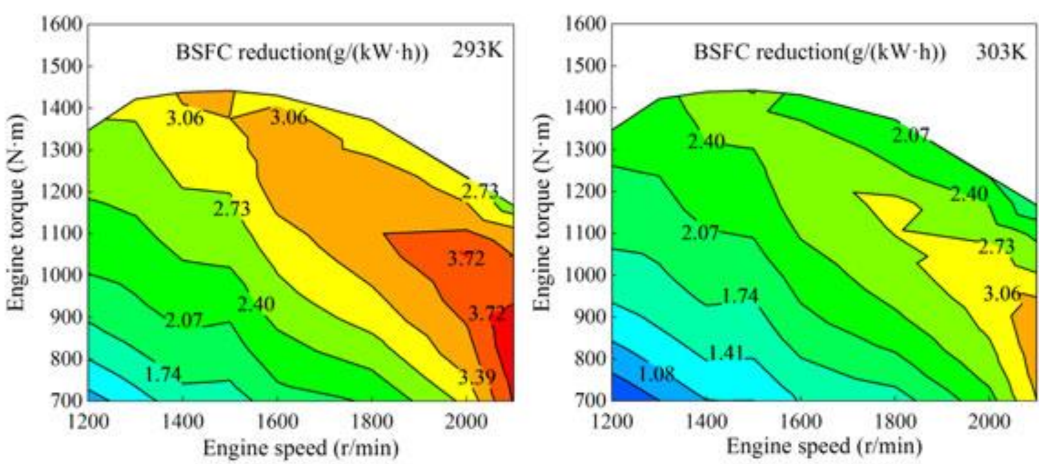
Deformation distributions under coupling action

Applied Thermal Engineering, Volume 138, 25 June 2018, Pages 72-82

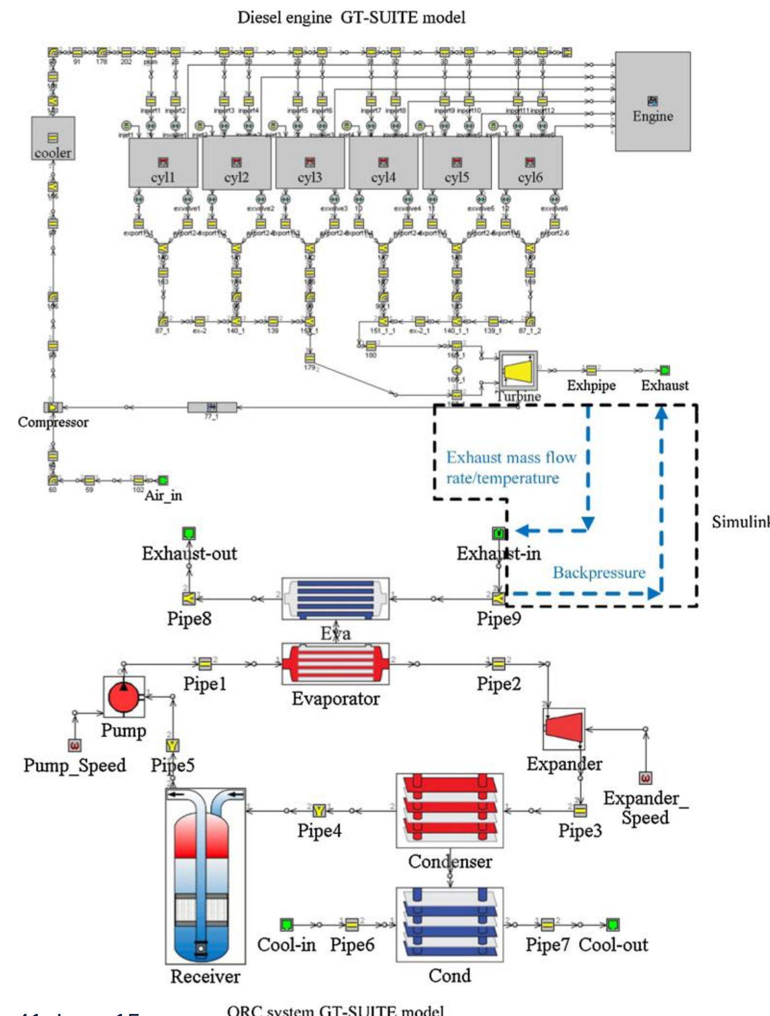
ORC system simulation

Powertrain system simulation

- Both Engine and ORC system developed in GT-suite separately
- Two models dynamically coupled
  - Forward: exhaust mass flow rate and temperature
  - Backward: back pressure
- Air cooling vs. water cooling for the ORC system condenser.



(A) (B)

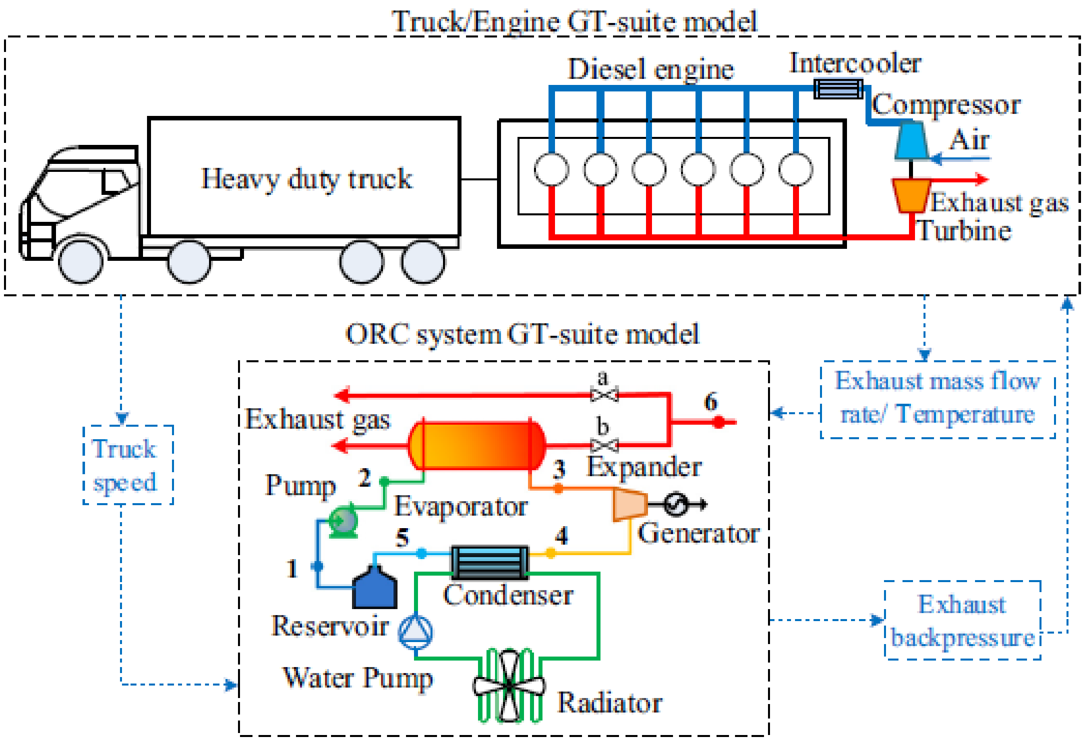


Applied Thermal Engineering 115 (2017) 221–228 Int. J. of Energy Research, 2017 Volume41, Issue15

ORC system simulation

Vehicle simulation

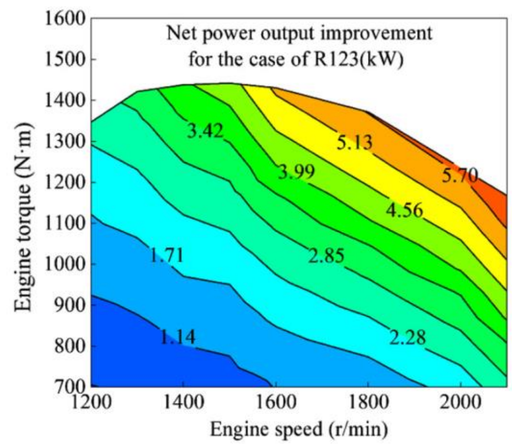
- Powertrain dynamic model was expanded to consider vehicle operation.
- Considered vehicle speed → engine operation by gear selection.
- Impact of engine speed on ORC cooling considered.

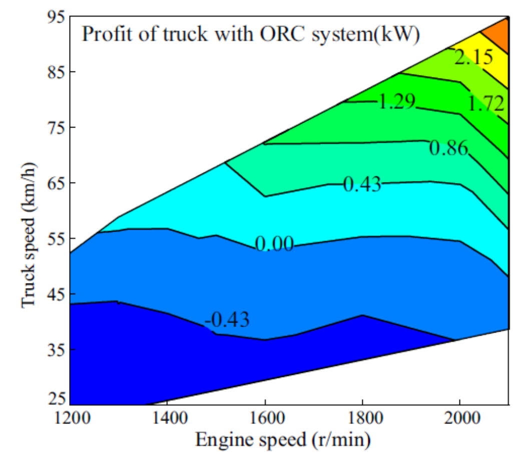


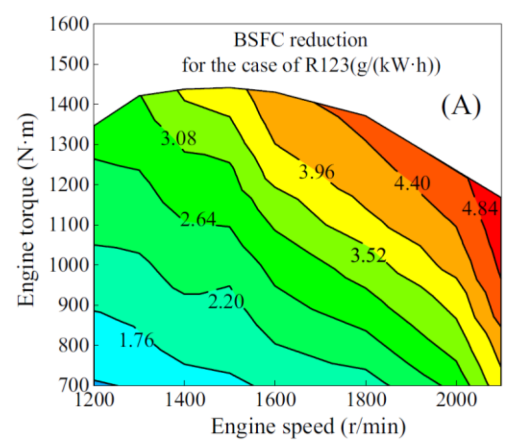
ORC system simulation

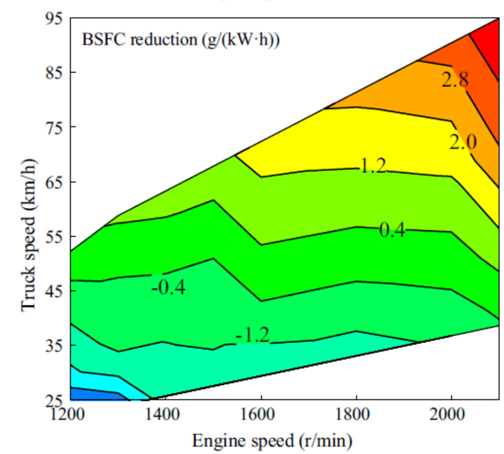
Vehicle simulation

- Powertrain dynamic model was expanded to consider vehicle operation.
- Considered vehicle speed → engine operation by gear selection.
- Impact of engine speed on ORC cooling considered.
- not always beneficial in all conditions
- Maximum extra power 5.7 kW， fuel benefit nearly 5 g/kWh
- May increase engine back-pressure, thus negative impact to engine operation
- Aftertreatment system not yet considered









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Conclusions

- ORC based waste heat recovery systems have good potential to considerably improve system efficiency
- A 5% efficiency improvement is likely achievable without an over complicated system
- Negative impact on engine operation – back pressure, aftertreatment system – must be carefully considered
- As the key energy conversion device, the expander plays a critical role – optimisation still needed

Thank you!
Q&A

Guohong tian: g.tian@surrey.ac.uk
http://www.surrey.ac.uk/mes/people/dr_guohong_tian/
https://www.researchgate.net/profile/Guohong_Tian