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Thermodynamic potential of Rankine and flash cycles for waste heat recovery in a heavy duty Diesel engine

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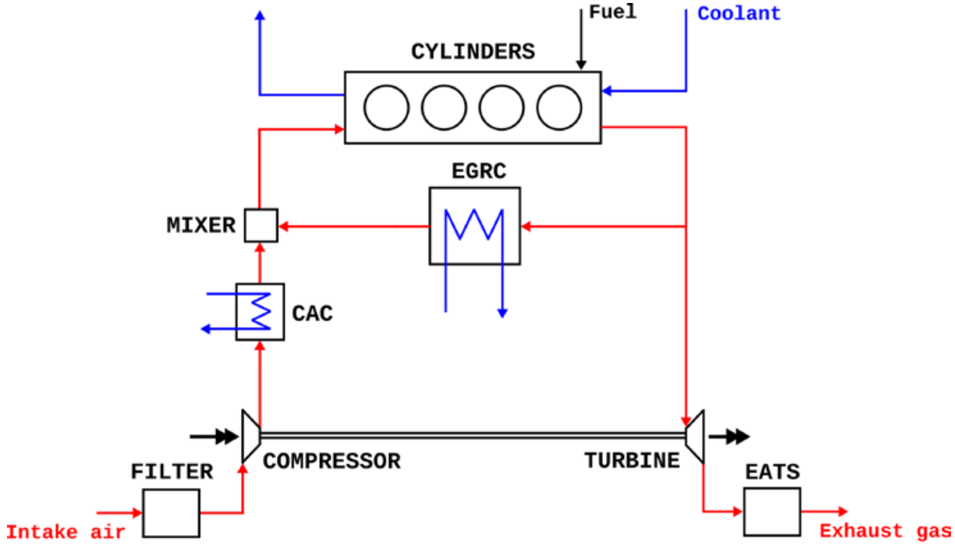
Purpose of this study

- Thermodynamic potential of WHR for low- and high-temperature heat sources in a heavy duty Diesel engine
- Identify heat sources inside the engine
- Simulations to evaluate the performance of various thermodynamic cycles using different working fluids

Heat sources



Volvo D13 EGR engine

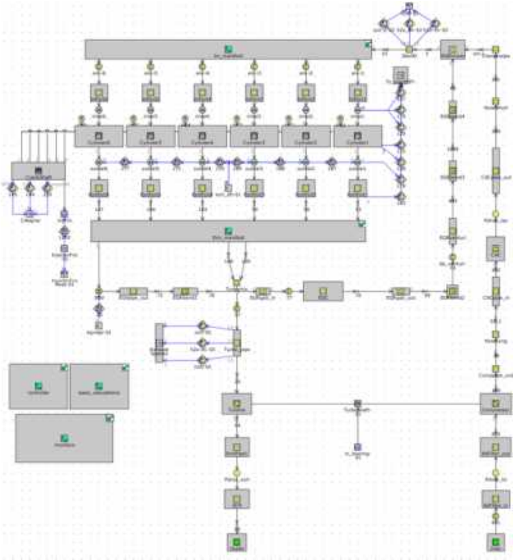
Four available heat sources:

- Charge air cooler (CAC)
- Coolant
- Exhaust gas recirculation cooler (EGRC)
- Exhaust gas out

Energy and exergy analysis

Heat sources – Methods

- GT-Power model
- Validated with experiments in previous project
- Twelve operating points of European Stationary Cycle (ESC)



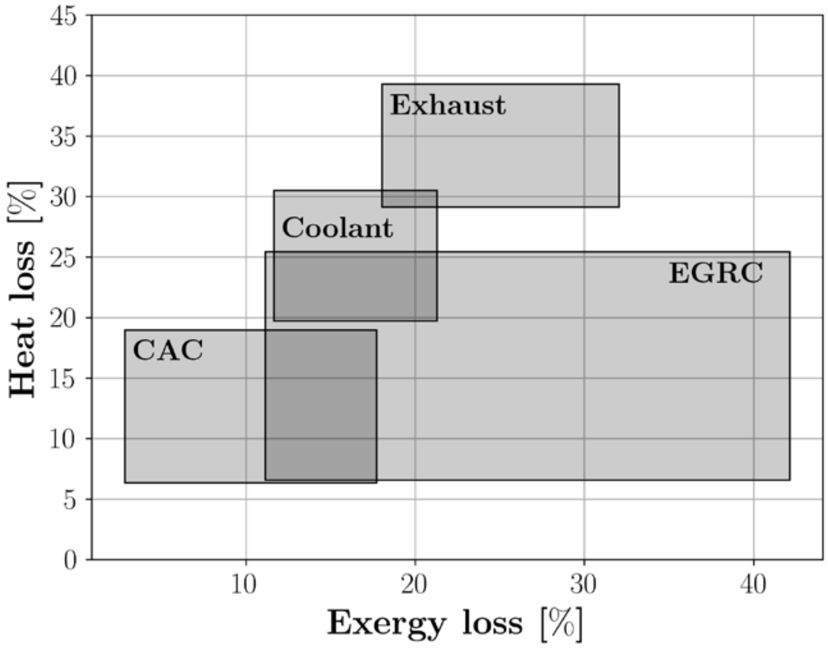
Heat sources – Results

Analysis based on heat and exergy losses for the ESC operating points

Exergy loss:

$$\dot{X}_{loss} = \dot{Q}_{loss} \frac{\bar{T} - T_0}{\bar{T}}$$

All heat sources show potential for waste heat recovery



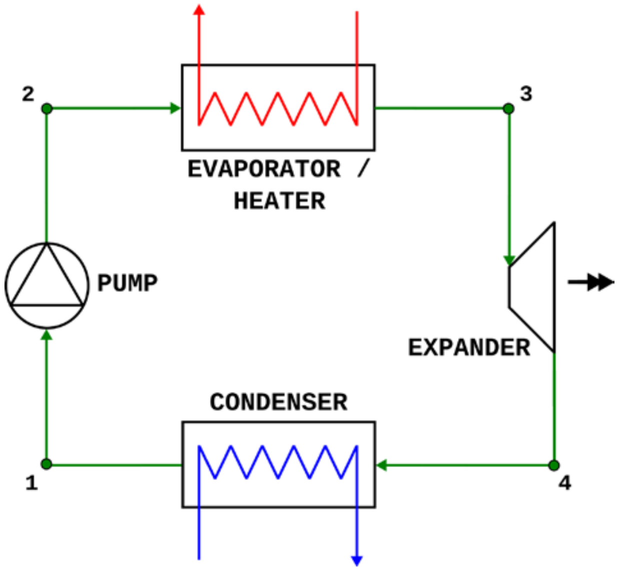
Heat sources – Results

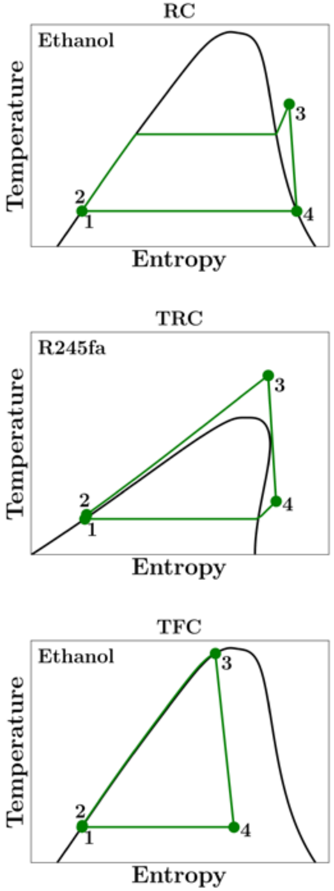
Selected operating point for cycle simulations: ESC A50

Source	Fluid	P [bar]	$\dot{m}$ [g/s]	T_{in} [°C]	T_{out} [°C]
CAC	Air	2.5	**231**	**152**	**60**
Coolant	Water	1.013	**4317**	**93**	**90**
EGRC	Exhaust gas	2.5	**73**	**472**	**95**
Exhaust	Exhaust gas	1.013	**239**	**251**	**100**

Cycles

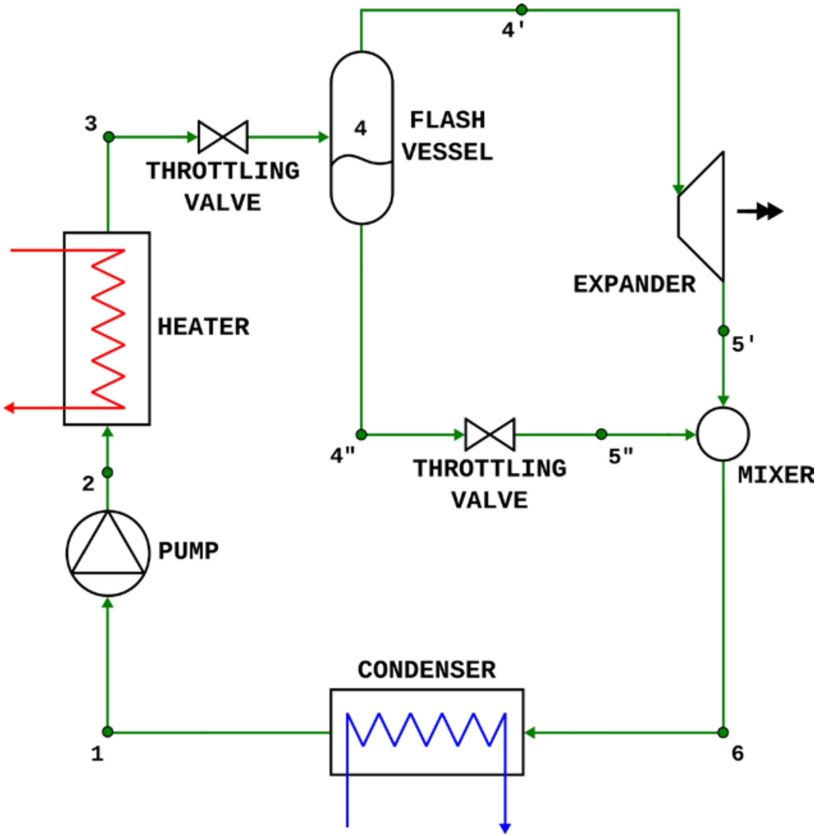
- Rankine cycle (RC)
- Transcritical Rankine cycle (TRC)
- Trilateral flash cycle (TFC)

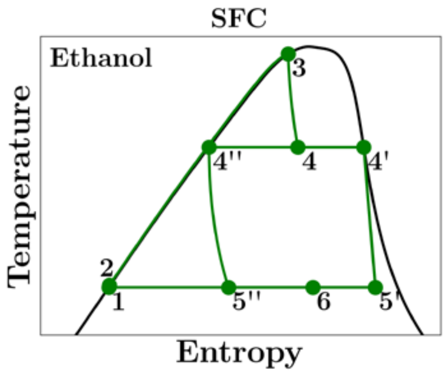




Cycles

- Single flash cycle (SFC)





Working fluids

Fluid	T_{cr} [°C]	P_{cr} [bar]	T_{1atm} [°C]	P_{40C} [bar]	Type	GWP_{100}	ODP
Cyclopentane	239	46	0.7	49	Isen.	0	0
Ethanol	240	63	0.2	78	Wet	0	0
R245fa	154	37	2.5	15	Dry	858	0
Water	374	220	0.1	100	Wet	0	0

Conditions and constraints

- Fixed heat input (constant source temperature profile)
- Potential:
  - Low condensation temperature
  - No limitation on condensation pressure
  - High efficiencies

Conditions and constraints

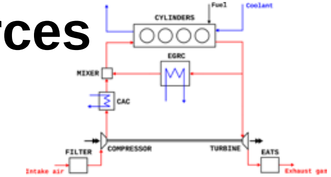
Reference and boundary conditions		
Ambient temperature	25	°C
Ambient pressure	1.013	bar
Condensation temperature	**40**	**°C**
Pump isentropic efficiency	0.80	
Expander isentropic efficiency	**0.85***	
	0.60**	
Pump vapour quality in	0	

**: RC, TRC, SFC*
***: TFC*

Constraints			
High pressure	Max.	100	bar
		$0.9P_{\mathrm{cr}}$*	
Superheating evaporation	Max.	20	K
Superheating condensation	Max.	20	K
Pinch point difference	Min.	10	K
Expander vapor quality out	Min.	0.85	

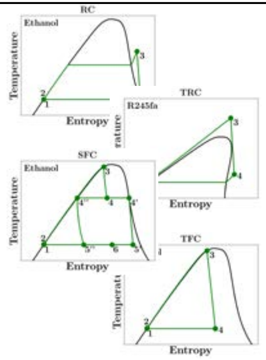
**: RC, TFC, SFC*

Four heat sources



Dymola / Modelica
CoolProp
Python

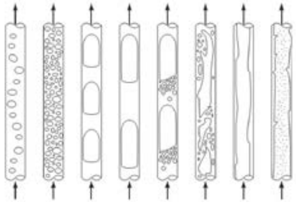
Four cycles



Simulations

Results

Four working fluids



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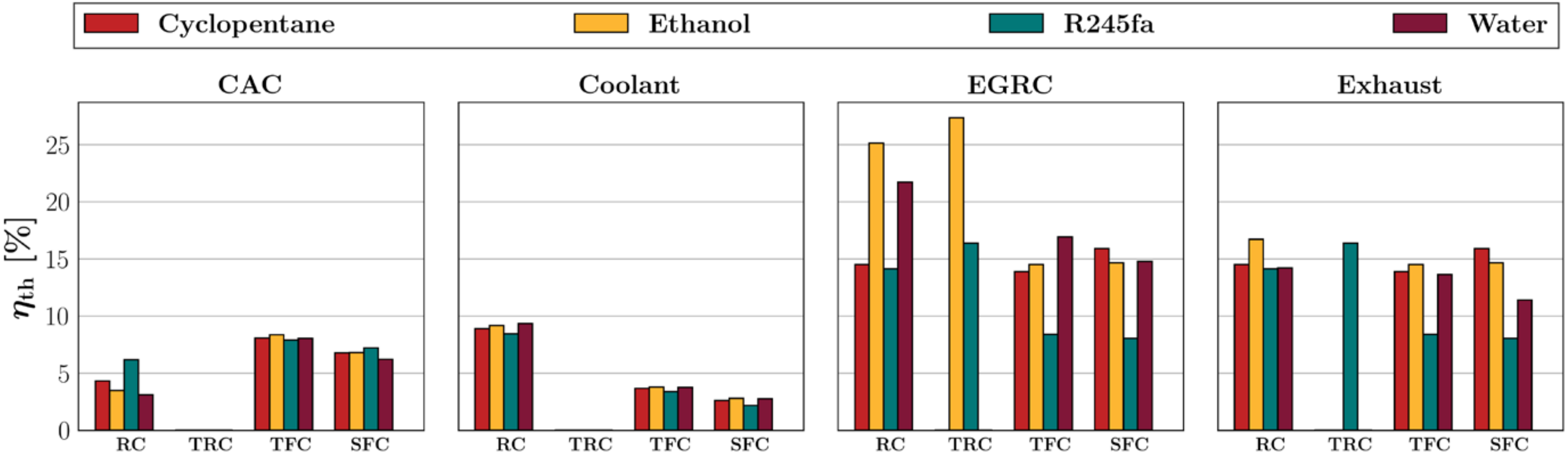
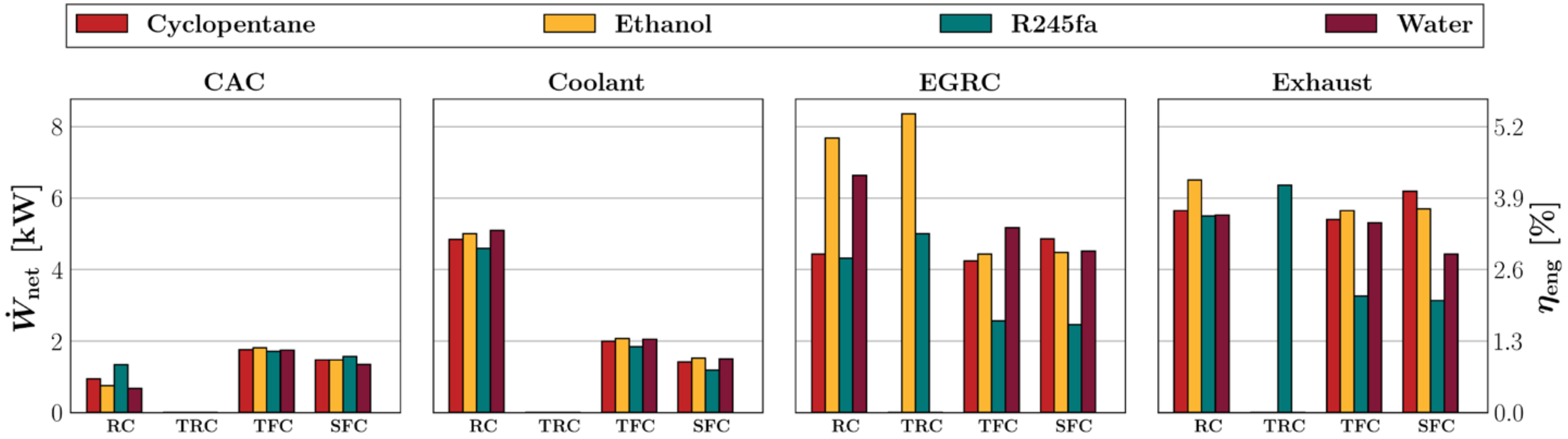
Results – Thermal efficiencies



Results – Net power



Conclusions

- All four available heat sources inside the engine show potential for waste heat recovery
- Best performing cycles and working fluids depend on heat source:
  - **CAC**: SFC, TFC - All fluids → 2 kW power
  - **Coolant**: RC - All fluids → 5 kW power
  - **EGRC**: RC, TRC - Ethanol → 8 kW power
  - **Exhaust**: All cycles - All fluids → 6 kW power
- Choice of cycle showed largest impact on performance
  - Thermal matching and cycle constraints

Acknowledgements

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KTH VETENSKAP OCH KONST

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