A QUANTUM LEAP FOR HEAVY-DUTY TRUCK ENGINE EFFICIENCY – HYBRID POWER SYSTEM OF DIESEL AND WHR-ORC ENGINES

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MOTIVATION

- Continuous increase in oil price
- Continuous decrease in energy reserves

OBJECTIVE

- Improvement in overall efficiency of HD diesel truck engines by recovering high-energy-level waste heat

CONTENT

- Energy levels of various sources of waste heat from a typical HD diesel truck engine
- Hybrid power system of diesel-cycle and WHR organic-fluid Rankine cycle
- Potential improvement for overall engine efficiency for HD diesel truck engines with WHR-ORC
- Summary

AN OUTLOOK OF WORLD FOSSIL FUEL RESERVES

- **Proved reserves of fossil fuels:**

  oil : ~ 161.9×10^9 tons

  NG: ~ 179.5×10^{12} m^3

  coal: ~ 909.1×10^9 tons

- **Reserves (R) to production (P) ratios:**

  (R/P)_oil : ~ 41 yrs (world average basis)

  (R/P)_NG: ~ 67 yrs (world average basis)

  (R/P)_coal: ~ 164 yrs (world average basis)

Source: BP Statistical Review of World Energy, June 2005

- Options for transportation sector to deal with coming energy shortage problem are:
  - Introduce alternative fuels, ideally, from relatively rich and long-lasting resources
  - Improve efficiency of energy utilization
    - HEV for passenger cars
    - WHR for heavy-duty trucks (Class 7-8)

WASTE HEAT FROM HEAVY-DUTY DIESEL ENGINES

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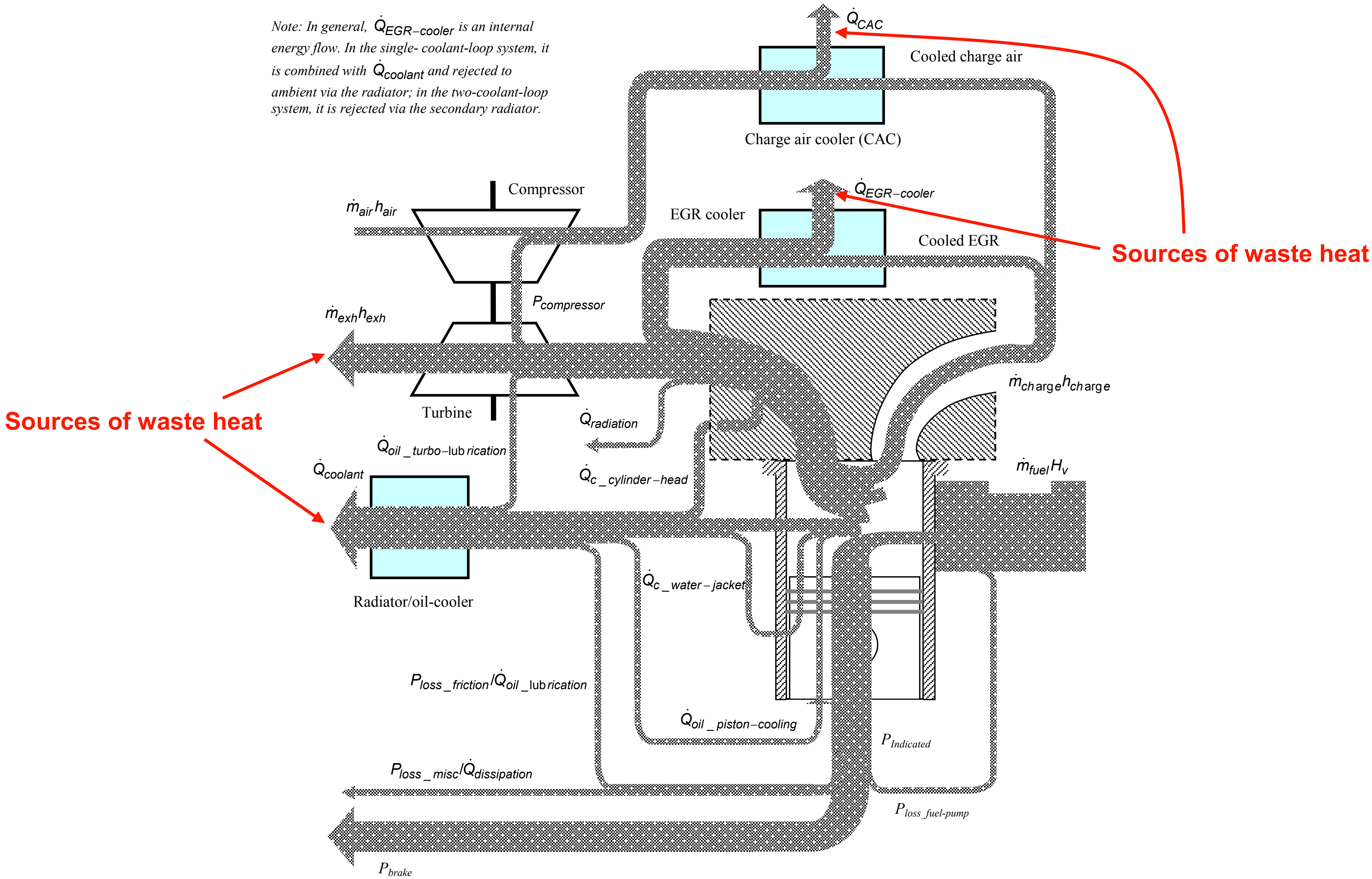
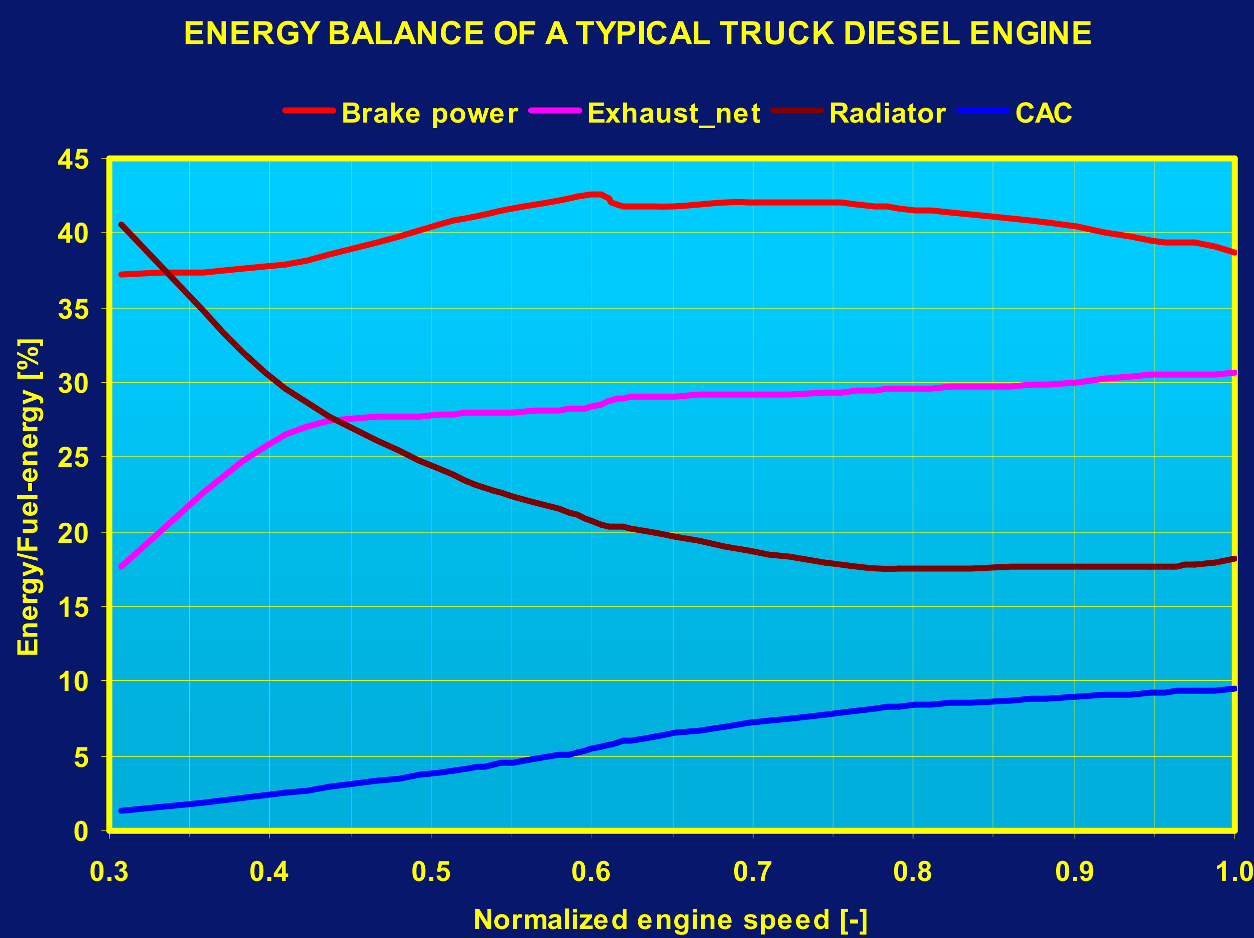


WASTE HEAT OF TRUCK DIESEL ENGINE AT FULL LOAD

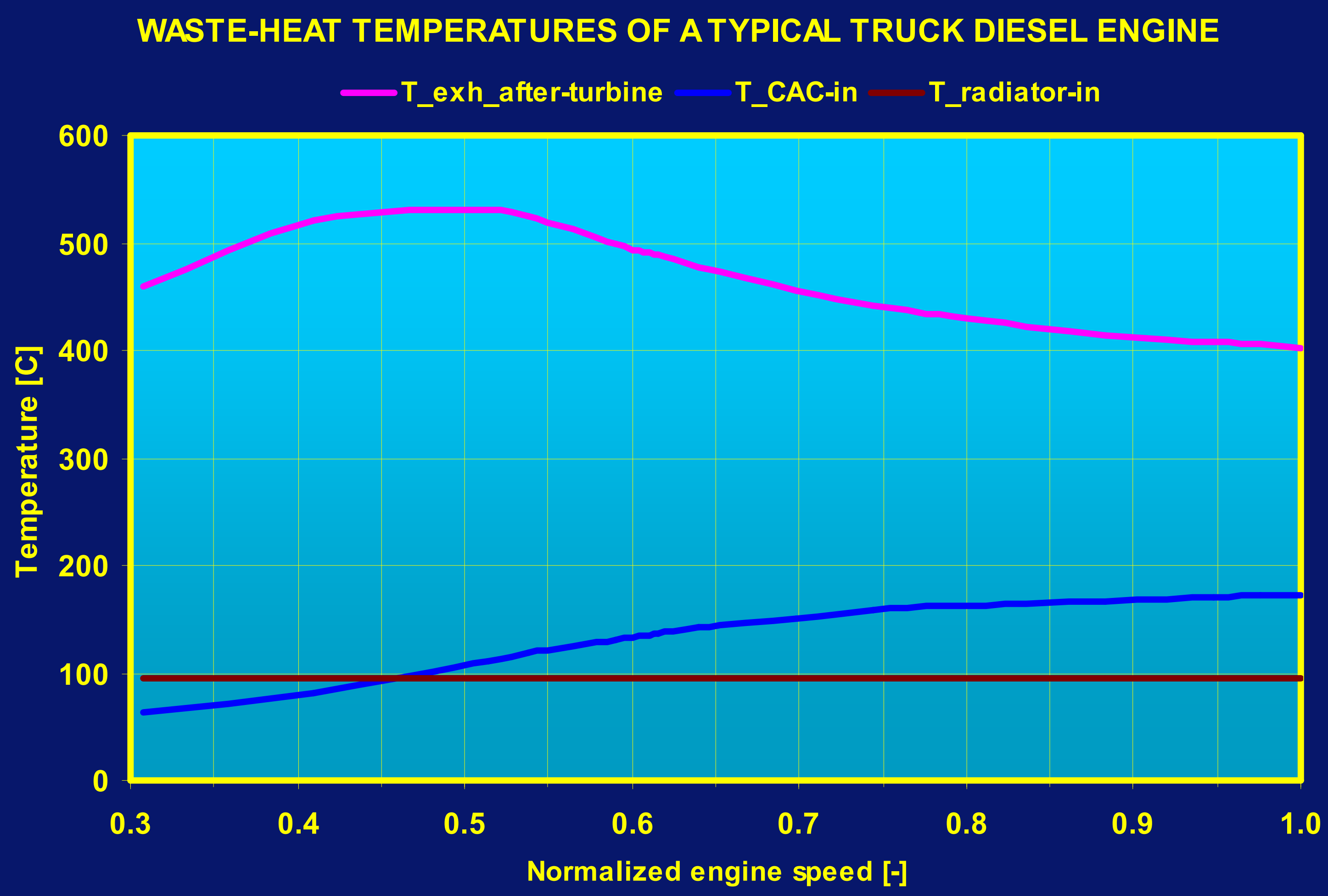


Truck diesel-engine waste heat is about 58-62% fuel energy; up to 30% of the waste heat is with high energy level.

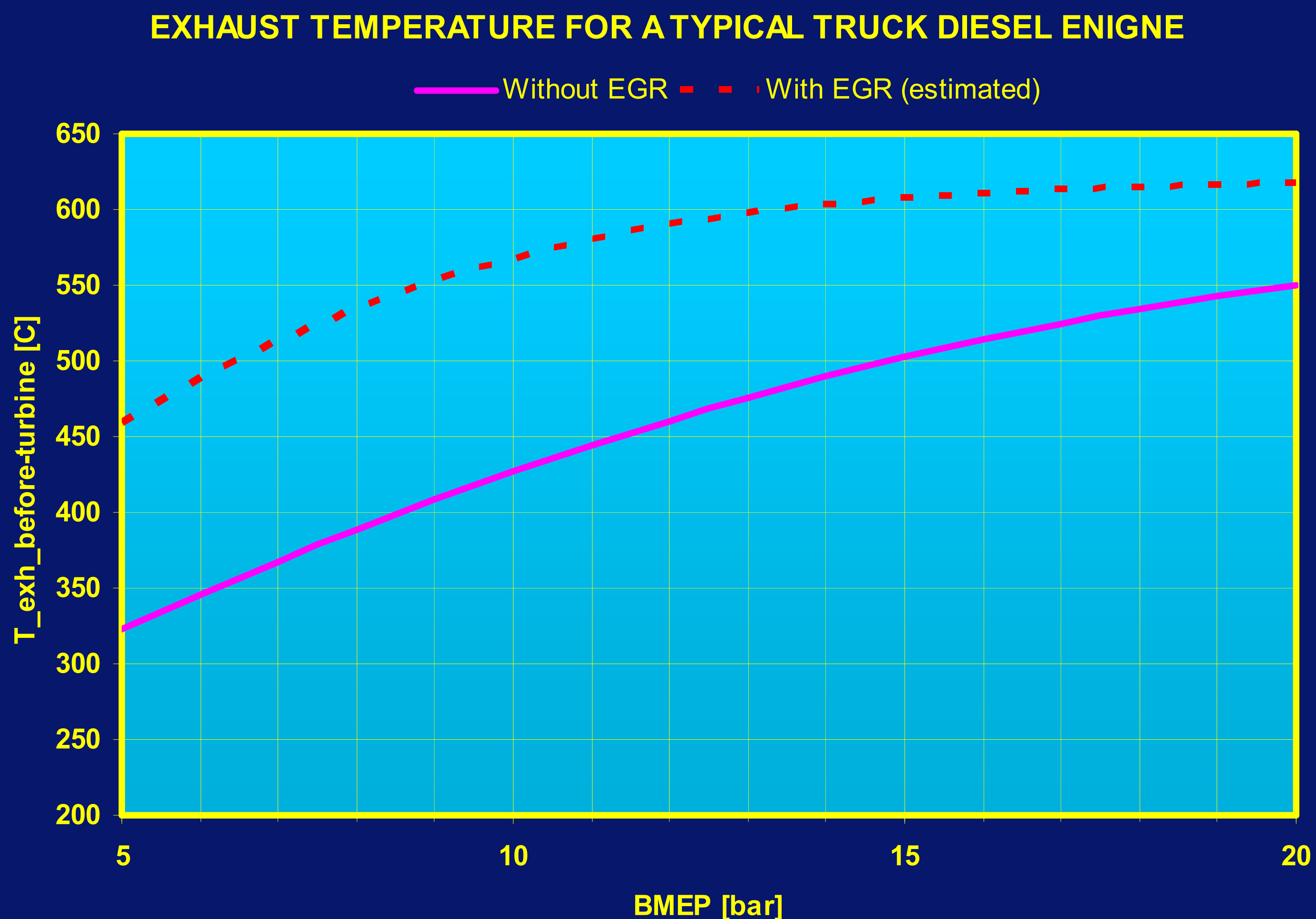
WASTE HEAT EVALUATION: ENERGY VS. EXERGY

- First law of thermodynamics
  - Energy is evaluated by quantity.
- Second law of thermodynamics
  - Energy = Exergy (useful work) + Anergy (equivalent to energy in ambient).
  - Exergy is an evaluation of energy level of waste heat.
  - Exergy of waste heat increases with its temperature.

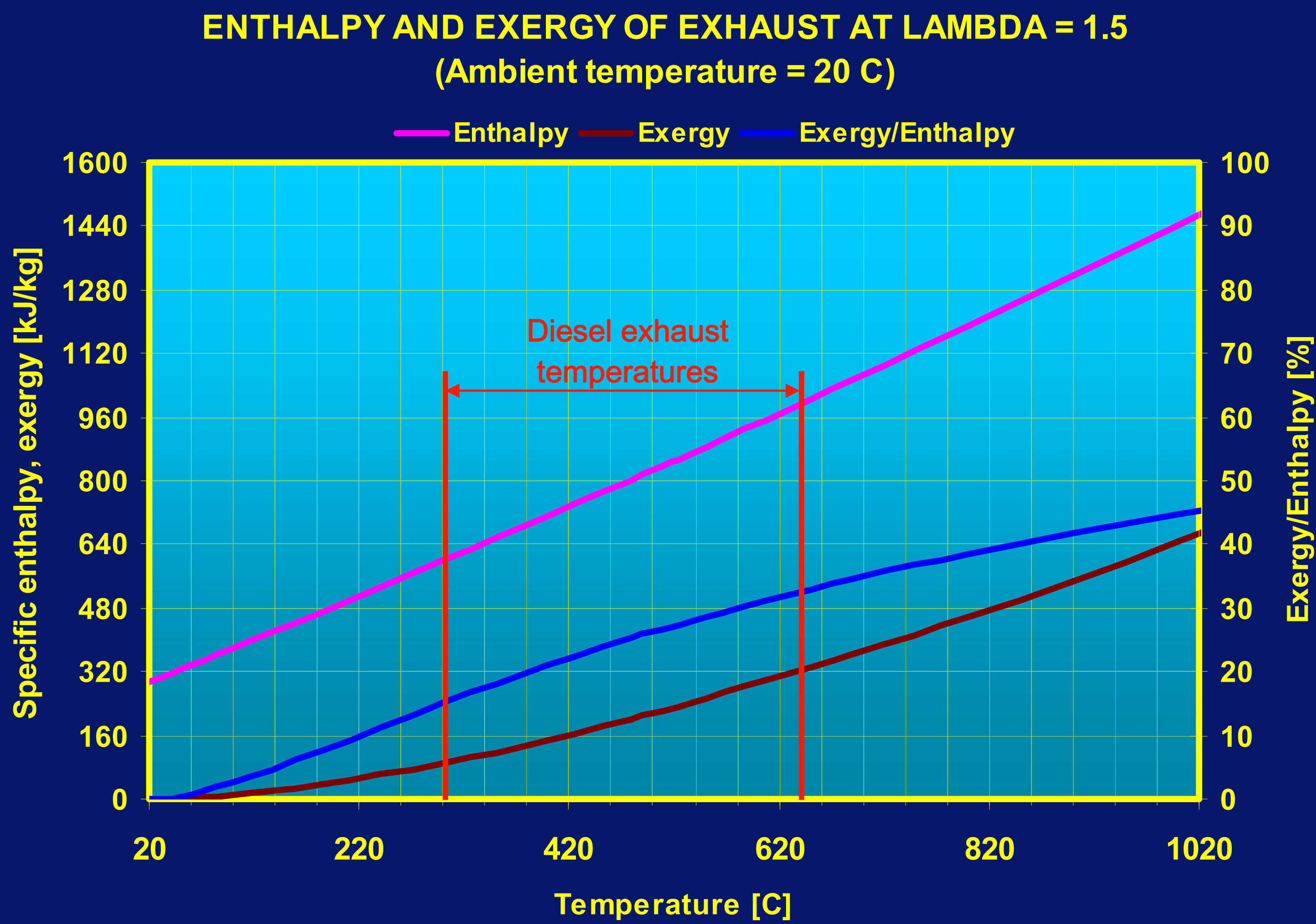
TEMPERATURE LEVELS OF TYPICAL TRUCK DIESEL ENGINE WASTE HEAT AT FULL LOAD (W/O EGR)



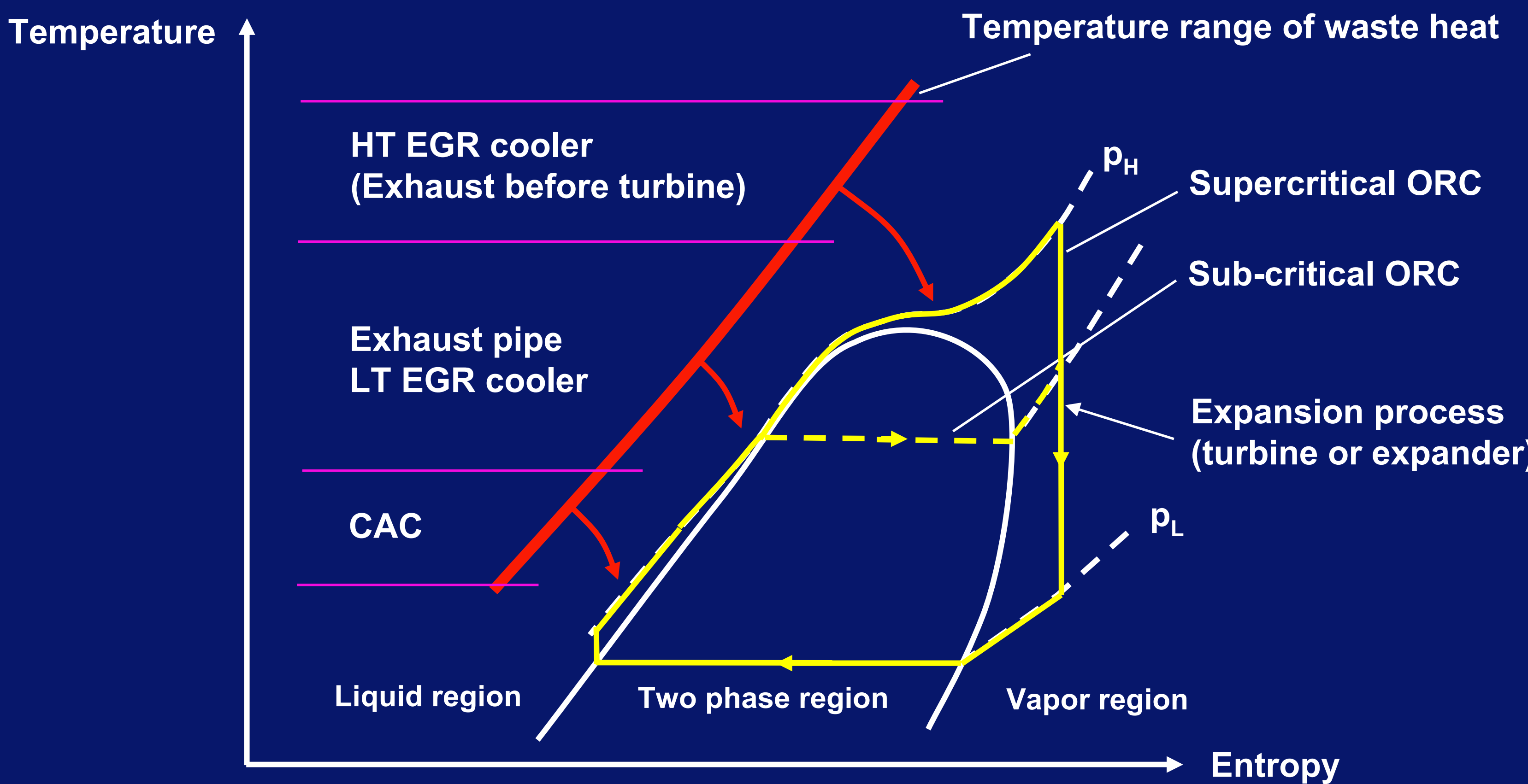
EXHAUST TEMPERATURE FOR TYPICAL TRUCK DIESEL ENGINE



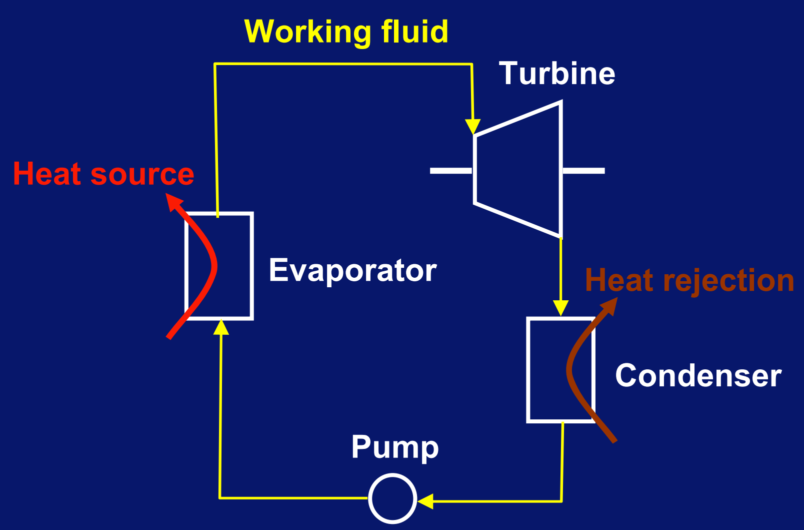
EVALUATION OF WASTE HEAT BY ITS EXERGY VALUE



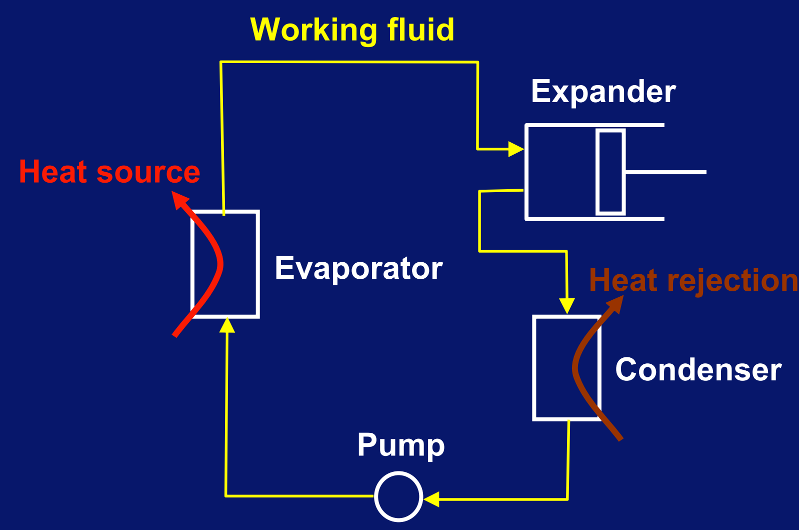
Organic fluid Rankine cycle (ORC) for waste heat recovery:



- **Turbine and reciprocating Rankine engines**



Turbine Rankine Engine

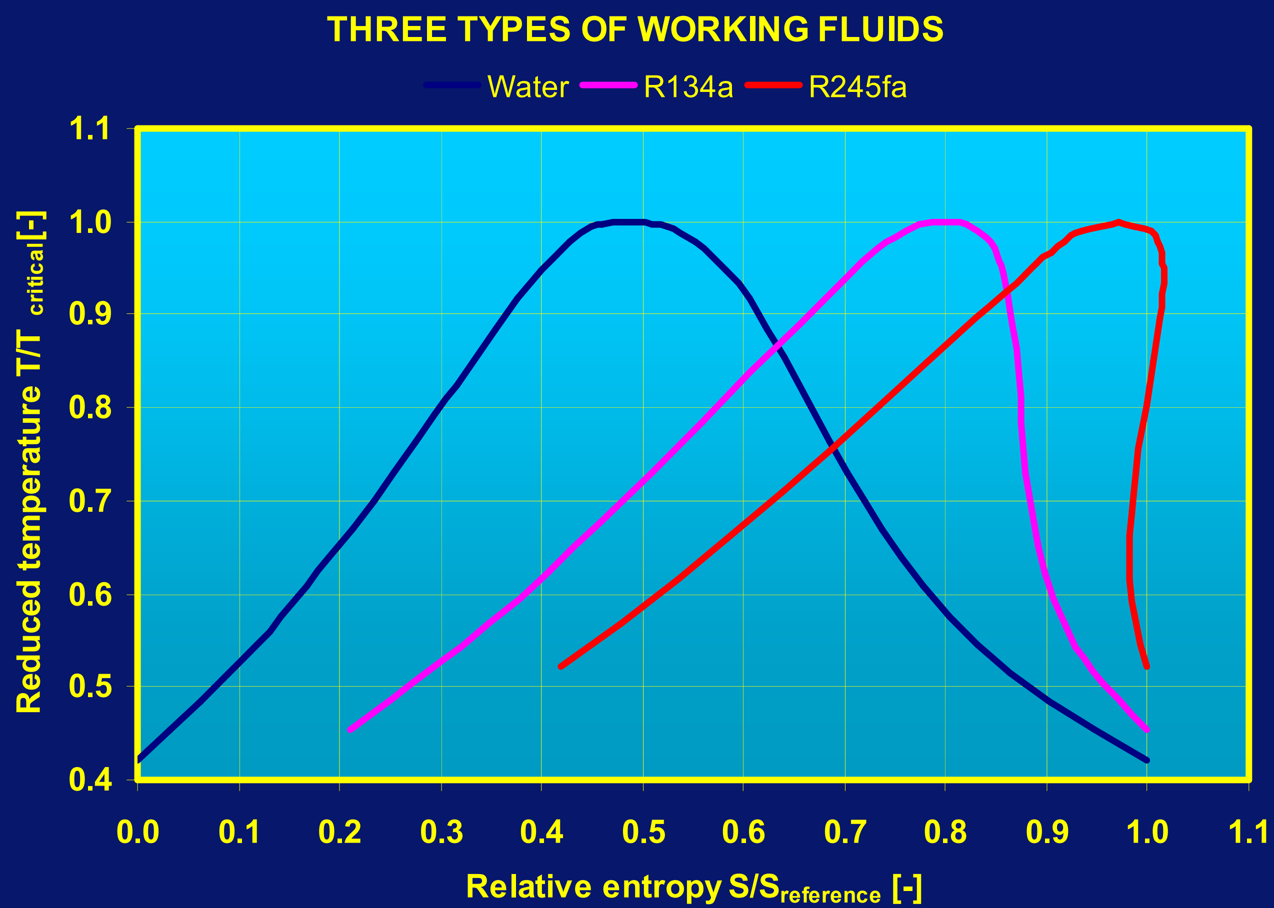


Reciprocating Rankine Engine

- Expansion in a steam/vapor turbine is limited by the condensation temperature.
- Expansion in a reciprocating engine is limited by the ambient pressure.

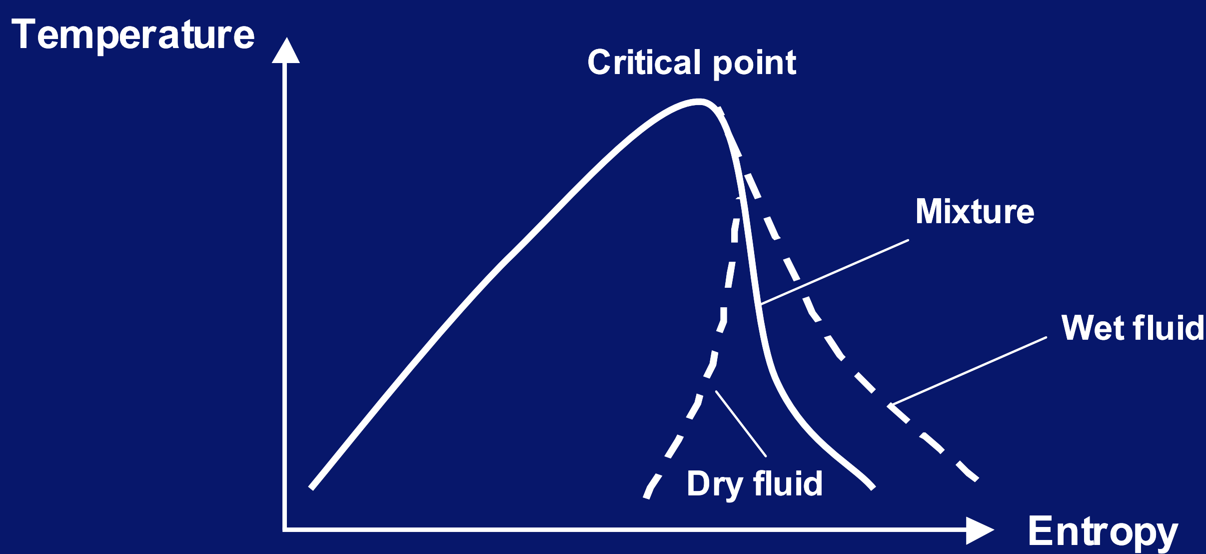
WHR SYSTEM: WORKING FLUIDS (1)

- **Three types of working fluids: wet-fluid (e.g., water), isentropic fluid (e.g., R134a), and dry-fluid (e.g., R245fa)**

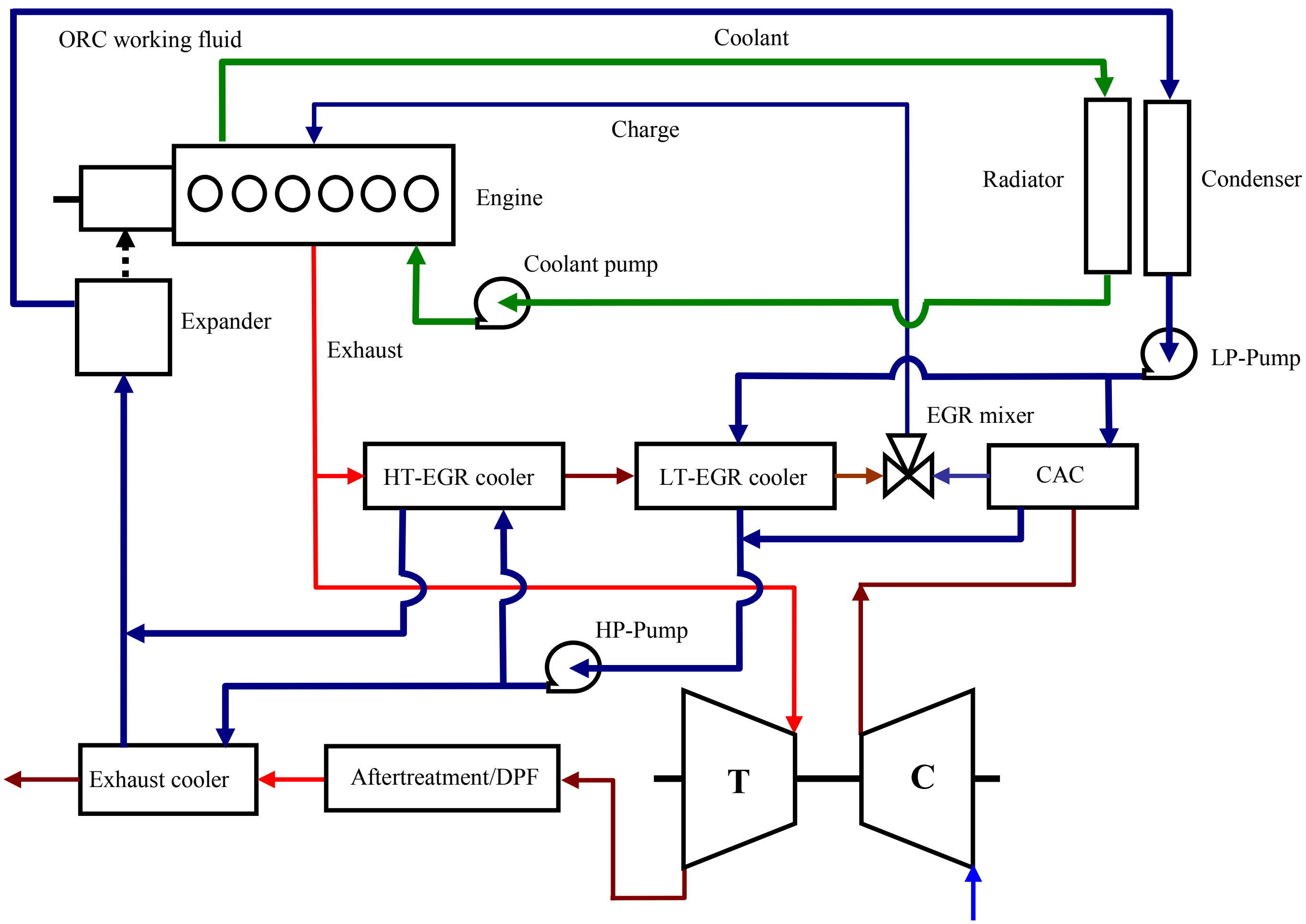


WHR SYSTEM: WORKING FLUIDS (2)

- Isentropic and dry fluids are appropriate working fluids for both turbine and reciprocating Rankine engines.
- Ideal working fluid for given waste heat condition can be developed with a mixture of dry- and wet-type fluids.



HYBRID POWER SYSTEM OF DIESEL AND RANKINE ENGINES W/ LTC LOOP INTEGRATED IN RANKINE LOOP



WASTE HEAT RECOVERY: A CASE STUDY

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Case study of a HD diesel engine at rated power, with a supercritical Rankine loop being integrated with the LTC loop:

Energy carriers	Brake power	Exhaust	Radiator	EGR	CAC
Energy [kW]	275	391	166	78	55
Energy/Input-energy [%]	27.6	39.2	16.6	7.8	5.5
Exergy [kW]	275	109*	~ 17	45*	15*
Exergy/Energy [%]	100	28	~ 10	34	8

- Evaluated by enthalpy before energy transfer process

169 kW

29.5% recovery

Simulation result:

Power of the supercritical reciprocating Rankine engine ≈ 50 kW

Power of the diesel-Rankine hybrid system = 325 kW

Improvement in overall efficiency ≈ 18%

WASTE HEAT RECOVERY: APPLICATIONS

- Most attractive on-road-vehicle applications of WHR-ORC are heavy-duty diesel trucks for long distance hauling (Class 7-8).
- Supercritical WHR-ORC system may be more practical (the high-cost evaporator can be avoided).
- The WHR-ORC system can function as a LT-coolant loop for EGR and charge air cooling.
- The expander/turbine can be bypassed when waste heat level is too low – the Rankine loop reduces to a regular LT-coolant loop.

A QUANTUM LEAP FOR HD TRUCK ENGINE EFFICIENCY?

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- If waste-heat temperatures > 400 °C, it is possible for the efficiency of the WHR Rankine engine to be 15 ~ 20%.
- Cost comparison for 18% recovery case:

  200,000 miles/yr / 6 mpg × \$3.15/gal = \$105,000/yr

  \$105,000/yr × 0.18 = \$18,900/yr

- With a diesel/Rankine hybrid power system, class 7-8 truck engines could possibly reach an overall efficiency up to

50%

↑ **Quantum Leap**

42% (current level)

THANK YOU FOR YOUR ATTENTION!