

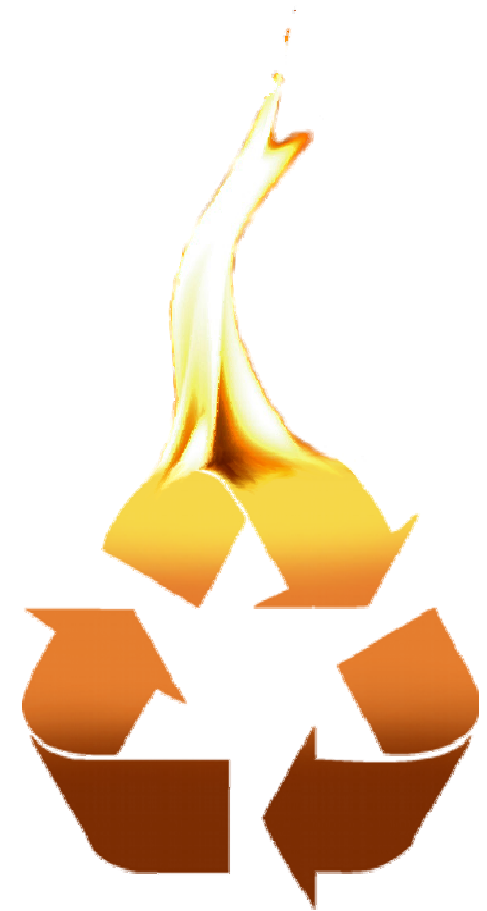
Organic Rankine Cycles for Waste Heat Recovery

NASA/C3P - 2009 INTERNATIONAL WORKSHOP
ON ENVIRONMENT AND ALTERNATIVE ENERGY

“Global Collaboration in Environmental and
Alternative Energy Strategies”

11. November 2009

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Waste Heat Recovery Overview



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What is Waste Heat Recovery (WHR)?

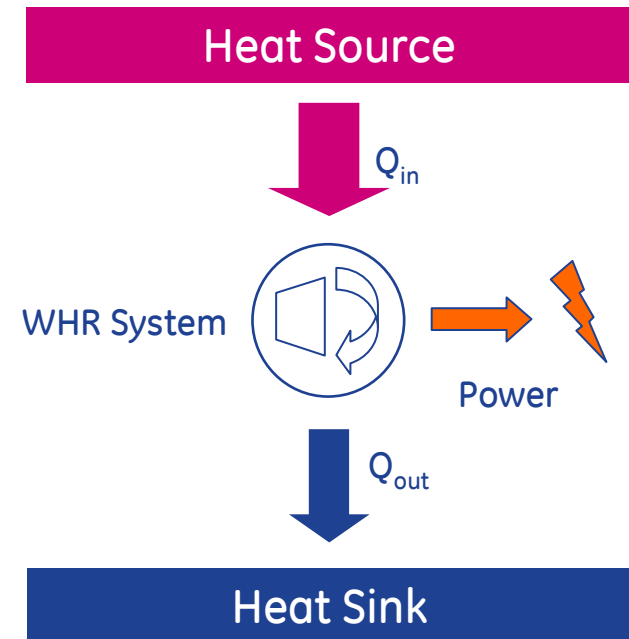
Benefits

- CO₂-free additional power
- Increased plant / process efficiency
- Fuel savings

Driving forces

- Fuel, electricity prices / incentives
- CO₂ or emissions constraints
- Grid independence

Key CTQ: CAPEX (\$/kW)



Capturing low grade heat sources for energy production



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Waste Heat Recovery Segments



Geothermal & Solar

- 100 GW geothermal potential (MIT)*
- 200 GW solar potential*

Reciprocating Engines

- Approx. 5% pts efficiency boost
- Reduced fuel consumption & emissions



Industrial Waste Heat

- Approx. 950 PJ heat losses (100-200°C)*
- \$6 B/yr energy wastes*
- Refineries, cement, pulp & paper, ...

Gas Turbines

- WHR adds up to 20% power

(* US only)

Green, CO₂ free technology

Waste Heat Recovery Organic Rankine Cycle (ORC)



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Organic Rankine Cycle

Cycle Principle

- Expansion of organic fluid

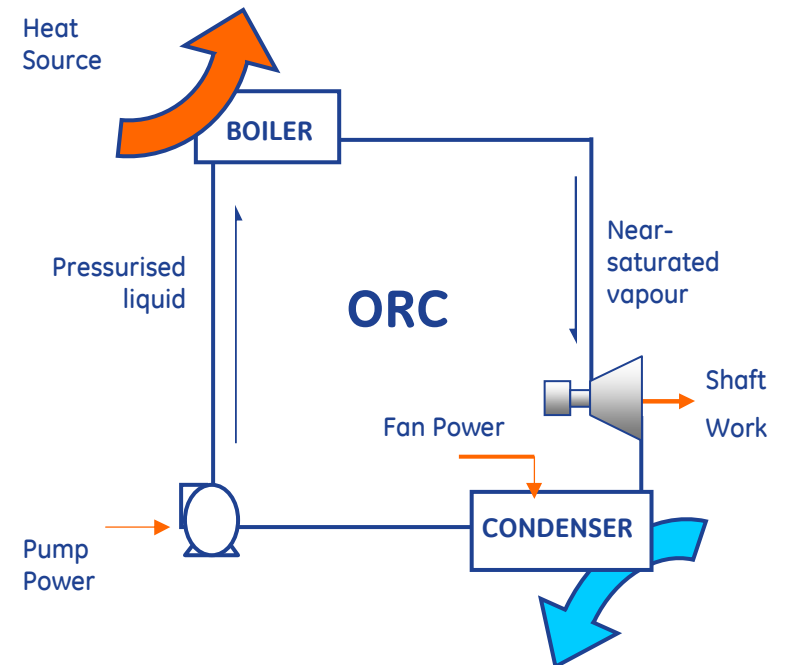
Features

- Robust, simple system
- Mature, well known components
- Only low temperatures required
- On-site operators not required

Technology Status

- Conventional ORCs successfully in operation for many years
- CAPEX: ~ 2000 – 6000 \$/kW, f (kW, temp, site etc.)

Advantaged technology for small and low T applications



ORC Efficiency

Carnot efficiency

- Theoretical maximum
- Increases with increasing ΔT

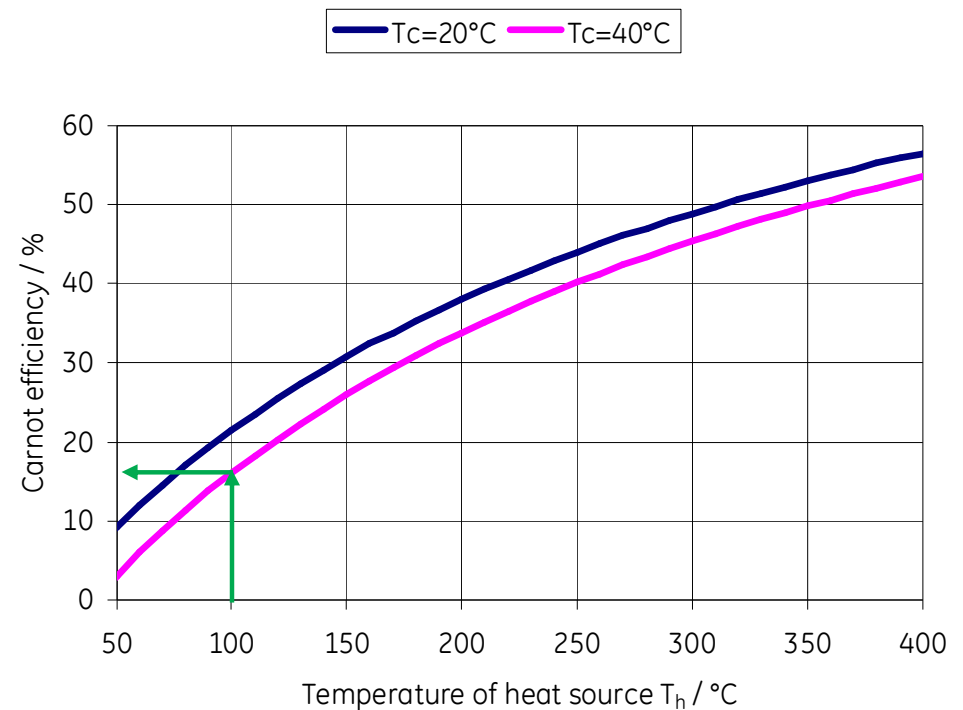
Real efficiency

- Process always has losses
- 30 – 50% of Carnot

Potential improvements

- Reduce losses
- Increase max. temperature (risk: fluid decomposition)
- Optimize cold cycle end (increased cost)

Carnot efficiency: $\eta_c = 1 - \frac{T_c}{T_h}$



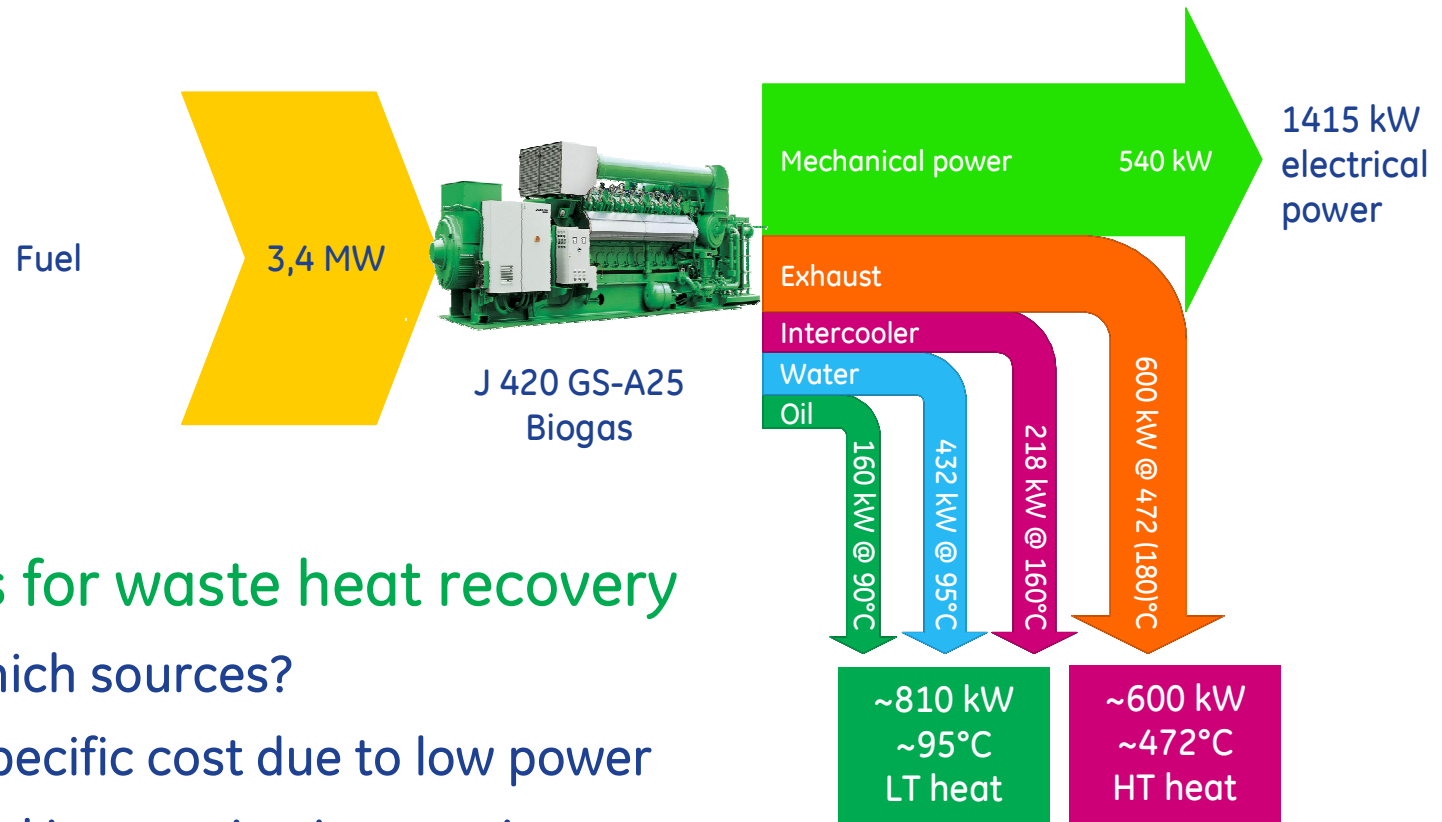
Waste Heat Recovery

Example: ORC for Reciprocating Engines



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Gas Engine Heat Sources



Challenges for waste heat recovery

- Use which sources?
- High specific cost due to low power
- Thermal integration into engine

Two heat sources with different temperature level

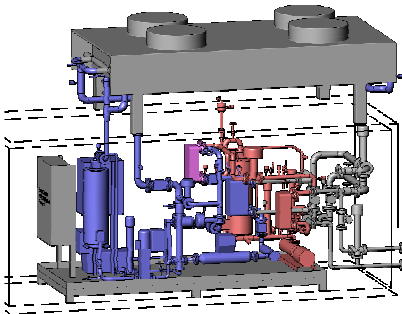


Example: GE Jenbacher Recipr WHR

Reciprocating engine



+



Containerised ORC

		“Medium”	“Large”
Specifications	Engine power	1 – 1,5 MW	3 MW
	Fuel	Biogas, landfill, NG	Natural Gas
	ORC power boost	110 - 140 kW	300 - 370 kW
	Efficiency increase	> 4% pts	> 5% pts

ORC: Bottoming cycle for reciprocating engines

GRC Waste Heat Recovery Focus



Reciprocating Engines

- Customer prototype installation Q1/2010
- Approx. 5% pts efficiency boost
- Potential for 50%+ efficient engine



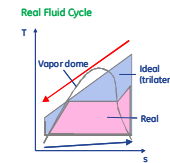
Industrial Gas Turbines

- GE O&G ORegen™ cycle developed
- ORC adds approx. 20% power to GT
- Ecomagination certified



Industrial Waste Heat

- Collaboration with industry (e.g. utilities, cement, refineries etc.)
- Identification of new WHR opportunities & markets



Discovery

- Development of high efficient cycles
- New fluids identification
- CAPEX optimized components
- Simulation & experiments

Key to low \$/kW: New cycles & integration into heat source



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Thank you.



Acknowledgement:
Project is partly funded by the Bavarian Ministry for
Economy, Infrastructure, Traffic and Technology