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Feasibility study of selected technology and industry

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Authors		
Author(s) Name	Organisation	E-mail address
Monika Nikolaisen	SINTEF Energy Research	Monika.Nikolaisen@sintef.no

Abstract

Representative current and near-future aluminium industry heat sources are defined and evaluated for heat-to-power conversion. Indirect organic Rankine cycles, with and without recuperator, are optimized to give maximum power output from a "current" case and a "near-future" case. The analysis demonstrates that performance is strongly dependent on total heat exchanger area, or "system size". For selected values of total area, the maximum annual electric output from the current case is 26 GWh, and the corresponding value for the near-future case is 40 GWh, representing an improvement of 53 %. Energy efficiencies are 11.5 % and 12.8 %, respectively. Theoretical efficiencies (net power to maximum theoretical net power) better illustrate exploited heat source potential, and are 46.8 % and 48.6 %, respectively. Recuperated ORCs improve net power by 4-5 %, but potentially up to 13 %, depending on heat exchanger size.

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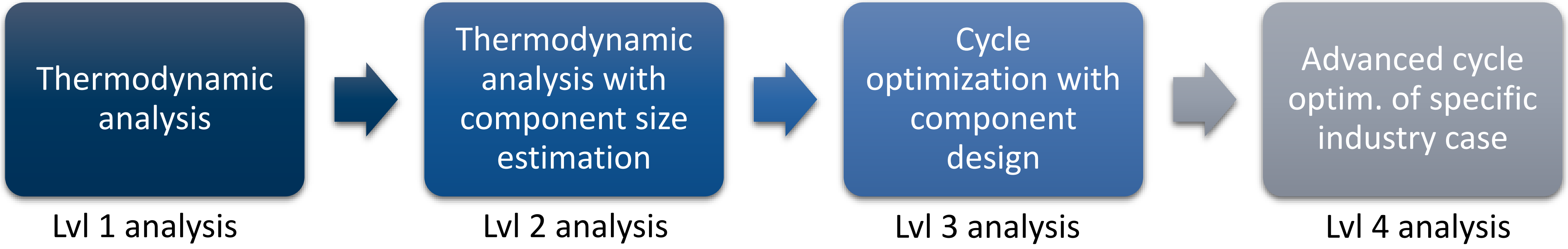
FEASIBILITY STUDY OF SELECTED TECHNOLOGY AND INDUSTRY PROCESS

14.12.17

Monika Nikolaisen

Introduction

- Feasibility study of selected combinations of heat-to-power technologies and industry processes
- Technology selected to match industry case parameters
- Evaluation of technologies and power potential from present and future scenarios
- "Level 2-analysis": Thermodynamic analysis with *heat exchanger size estimation*



Industry cases (per 2017/12)

Focus in this document:

- Aluminium case
  - Pot gas as heat source – "Current" and "near-future" scenarios
  - Rankine cycles using pure hydrocarbons as working fluids (ORC)

Future work:

- Mo industry park
  - Excess recovered heat (combination with export to disctrict heating, seasonal variations)
- Ferro-manganese case
  - To be defined (higher temperature, intermittent source)
- Ferro-silicon case
  - To be defined (higher temperature)

Aluminium case 2017

- Representative aluminium cases
  - "Current" case
  - "Near-future" case
- Results
  - Cases evaluated at given total HX areas
  - All KPIs (except heat source utilization) increase from "current" to "near-future" case & by adding recuperator
  - Annual electric output **26 GWh** in "current" case
  - Annual electric output **40 GWh** in "near-future" case

Case parameters		Unit	Current case	Near-future case
Heat source	Fluid	-	Air	Air
	Inlet temperature	°C	126.2	143.7
	Outlet temperature	°C	>=80	>=80
	Mass flow	Nm^3/h	1 500 000	1 500 000
	Pressure	bar	1	1
	Minimum inlet temp. of indirect fluid in WHRU	°C	60	60
Heat sink	Fluid	-	Water	Water
	Inlet temperature	°C	7	7
	Outlet temperature	°C	Calculated	Calculated
	Mass flow	kg/s	Calculated	Calculated
	Pressure drop	bar	1	1
Core process	Technology	-	Indirect ORC	Indirect ORC
	Working fluid	-	Propane	Isobutane
	Indirect fluid	-	Water	Water

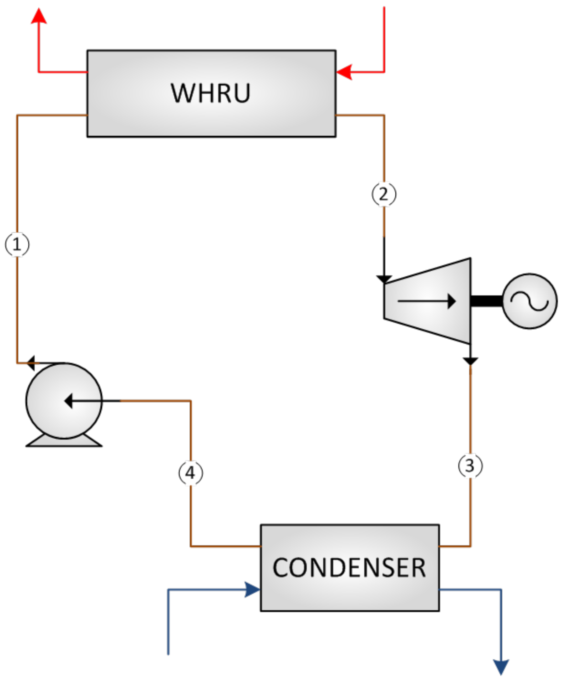
Results	KPI				
	W_{net} [MW]	GWh el/yr	η_B [%]	η_q [%]	η_e [%]
Current case	2.79	24.4	44.3	100	10.9
Current case w/rec	2.95	25.8	46.8	98.7	11.5
Near-future case	4.33	38.0	46.7	100	12.3
Near-future case w/rec	4.51	39.5	48.6	97.9	12.8

Selected technologies

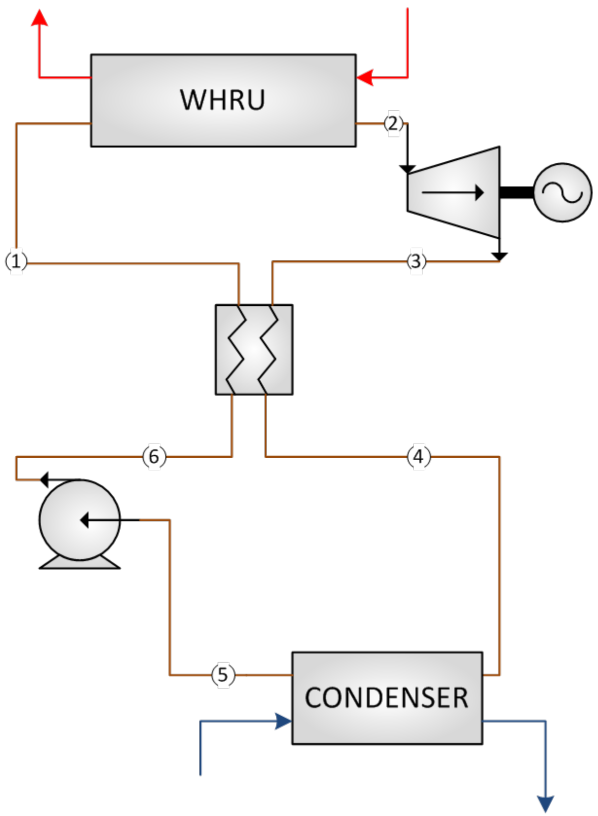
- Technologies selected to match case parameters
  - Low-to-medium temperature heat sources
    - ➢ ORC is the most suitable technology
  - Lower limit on heat source outlet temperature
    - ➢ Recuperator improves performance
  - Non-direct heat exchange with exhaust gas desirable in aluminium case
    - ➢ Indirect cycle decouples source from ORC
- Basic, recuperated and indirect ORC studied

Selected technologies

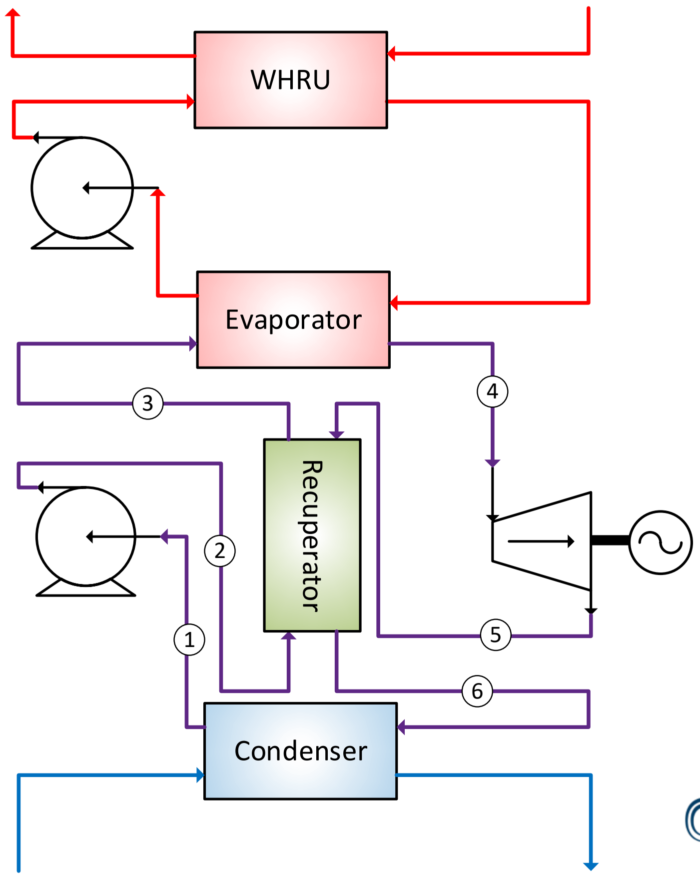
Basic ORC



Recuperated ORC



Indirect ORC (with or w/o recuperator)



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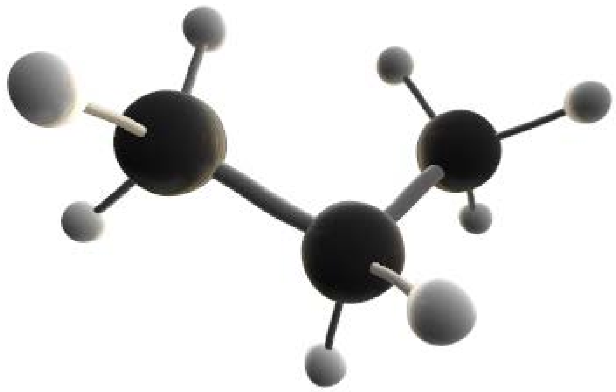
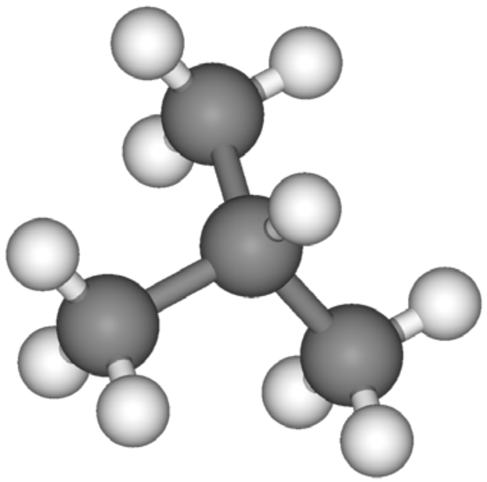
Working fluid selection

- Natural organic working fluids with low global warming potential
- Working fluids selected based on COPRO deliverable D2_2017.2
  - T ~ 120 °C -> Propane is optimal working fluid (current case)
  - T ~ 150 °C -> Isobutane is optimal working fluid (near-future case)





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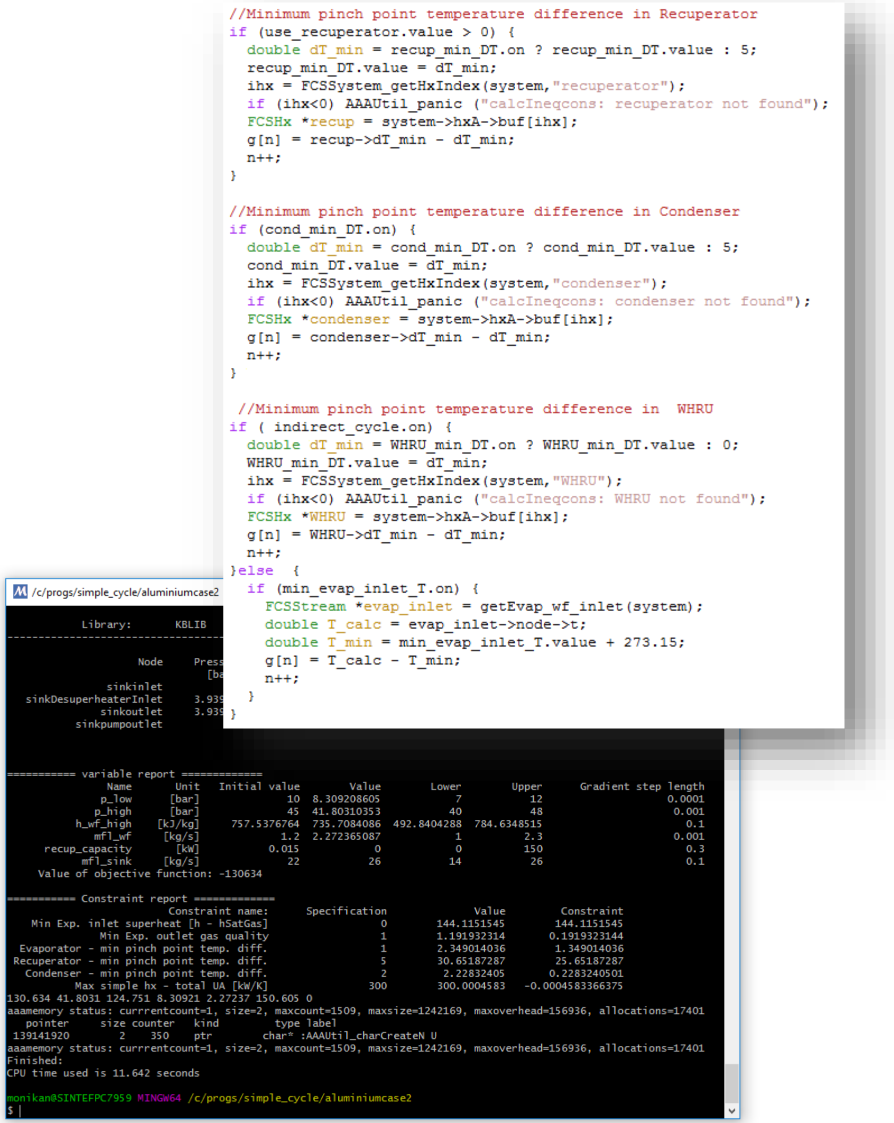
Sources: https://commons.wikimedia.org/wiki/File:Propane_Molecule_3D_X.jpg, https://commons.wikimedia.org/wiki/Isobutane#/media/File:Isobutane2.png

Process optimization

- In-house numerical framework used for process optimization
- "Level 2"-analysis
  - Net power maximised for a given value of total heat exchanger area
  - Heat transfer coefficients estimated to account for different evaporator, condenser, WHRU and recuperator heat transfer performance



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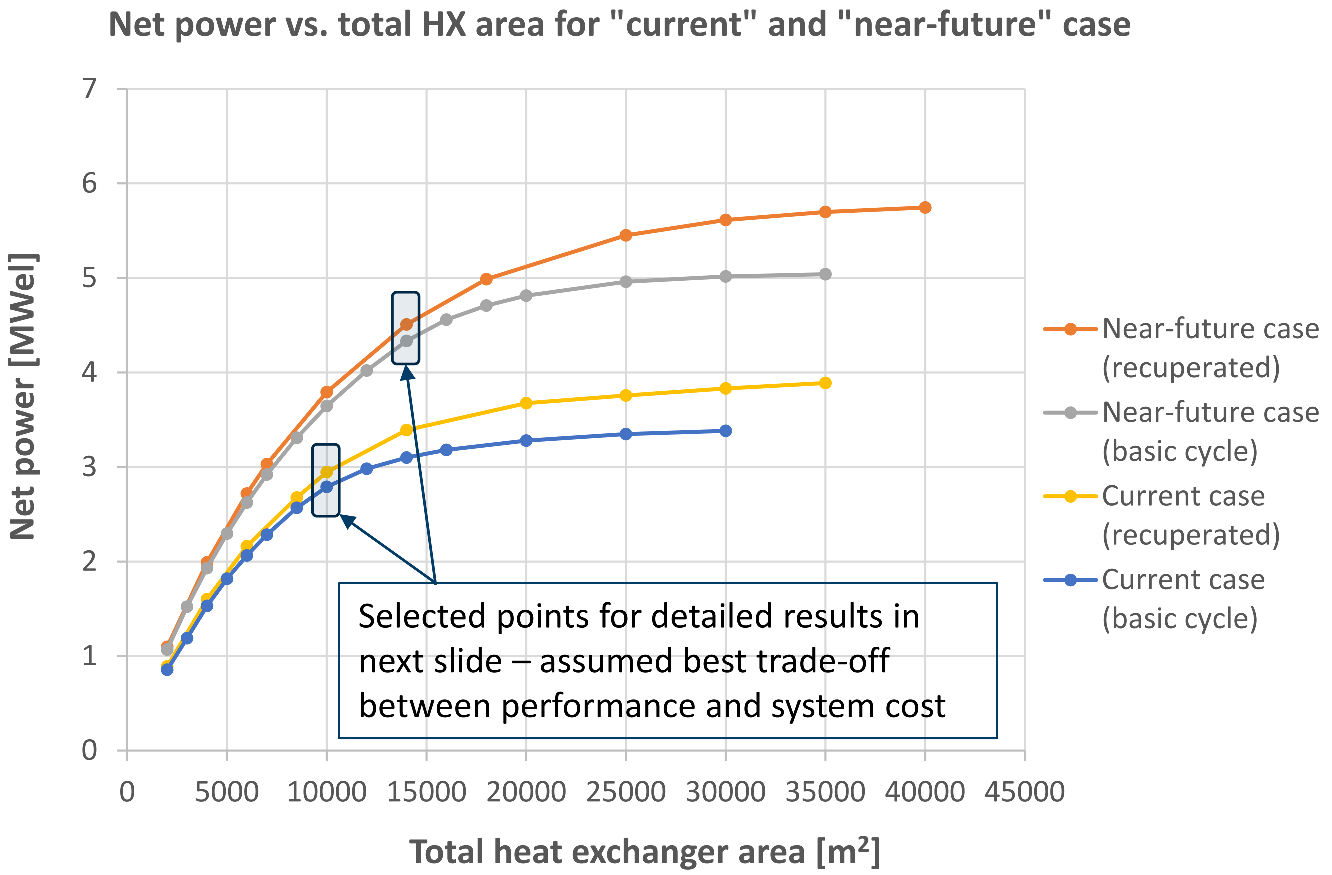
Results for Aluminium cases

- Maximised net power vs. total HX area for "current" and "near-future" case
  - Basic and recuperated ORC compared (both indirect)
- Power increases with total HX area, or "total system cost"
- Pinch causes stagnation in net power
- Higher potential in near-future case
  - Up to 48 % higher net power than current case for same total HX area
- Higher potential with recuperated ORC
  - Up to 13 % more net power for same total HX area in both cases



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Selected, detailed results for Aluminium cases

Results	KPI					Total heat exchanger area and pinch points				
	W_{net} [MW]	GWh el/yr	η_B [%]	η_q [%]	η_e [%]	Area [m^2]	$\Delta T_{min,cond}$ [°C]	$\Delta T_{min,evap}$ [°C]	$\Delta T_{min,WHRU}$ [°C]	$\Delta T_{min,rec}$ [°C]
Current case	2.79	24.4	44.3	100	10.9	10E3	3.3	1.4	16	-
Current case w/rec	2.95	25.8	46.8	98.7	11.5	10E3	3.8	1.6	14	3.5
Near-future case	4.33	38.0	46.7	100	12.3	14E3	3.4	2.3	19	-
Near-future case w/rec	4.51	39.5	48.6	97.9	12.8	14E3	3.4	1.7	15	5.0

KPI	Definition
Net power, W_{net}	Expander work minus working fluid pump work and heat sink pump work
Net annual electric output, GWh-el/yr	Total amount of electricity produced with continuout operation during one year
Exergy efficiency, η_B	Fraction of net power to the maximum theoretical power (when cooling heat source to lower temperature limit)
Heat source utilization, η_q	Fraction of transferred heat to maximum available heat in heat source (cooling heat source to lower temperature limit)
Energy efficiency, η_e	Fraction of net power to maximum available heat in heat source (cooling heat source to lower temperature limit)

- KPIs given for selected values of total HX area
- "Near-future" case evaluated at a higher total HX area due to larger heat content in source
- All KPIs (except heat source utilization) increase from "current" to "near-future" case & by adding recuperator
- Recuperated "near-future" case has 53.0 % higher annual electric output than recuperated "current" case, and 1.8 % higher theoretical efficiency
- Adding recuperator improves theoretical efficiency by ~ 2% and net power by 4-5 %, and at the same time requires less heat input
- Energy efficiencies relatively low, ~ 11-13 %. Exergy efficiencies better illustrate exploited potential, ~ 44-49 %.
- Pressure drop not considered, and would yield lower levels of net power if included

Conclusion

Case parameters		Unit	Current case	Near-future case
Heat source	Fluid	-	Air	Air
	Inlet temperature	°C	126.2	143.7
	Mass flow	Nm^3/h	1 500 000	1 500 000

- Significant potential for aluminium cases
  - Net power varies with total heat exchanger area
- Results for "current case", 10000 m^2
  - Maximum annual electric output of 26 GWh
- Results for "near-future" case, 14000 m^2
  - Maximum annual electric output of 40 GWh
- 53 % improvement in potential annual electric output by upgrading heat source from 126°C to 144°C (current vs. near-future)
- Recuperator improves annual electric output by up to 13 %

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