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SIMULTANEOUS OPTIMIZATION OF CYCLE AND HEAT EXCHANGER PARAMETERS FOR WASTE HEAT TO POWER CONVERSION AT ALUMINIUM PLANTS

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Outline

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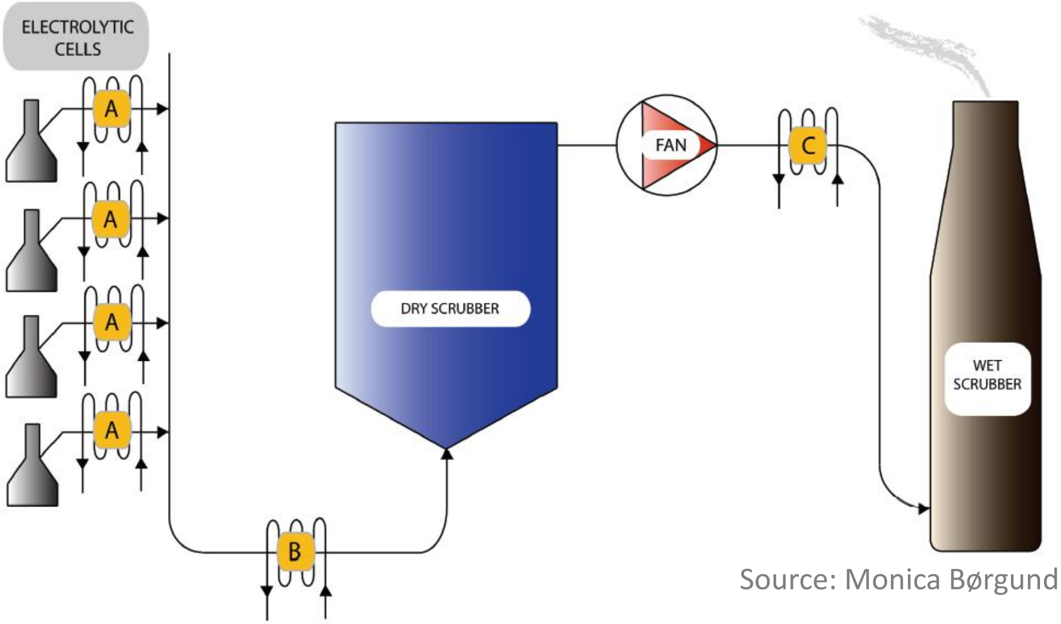
- Objective
- Methodology
- Case definition
- Case results
- Summary

Introduction

- Aluminum production generates vast amount of heat (cells flushed with air for cooling and to remove contaminants)
- In Norway, smelting plants are installed in remote places
- Growing focus on conversion of heat to electricity
- One interesting heat source in an aluminum smelter is the pot gas



Source: Monica Børgund

Introduction

- Challenges:
  - Power production from low temperature heat sources is impeded by high investment cost and poor efficiency.
  - Waste heat recovery is a thermal- and economic problem
  - Optimization of both profitability and performance is needed

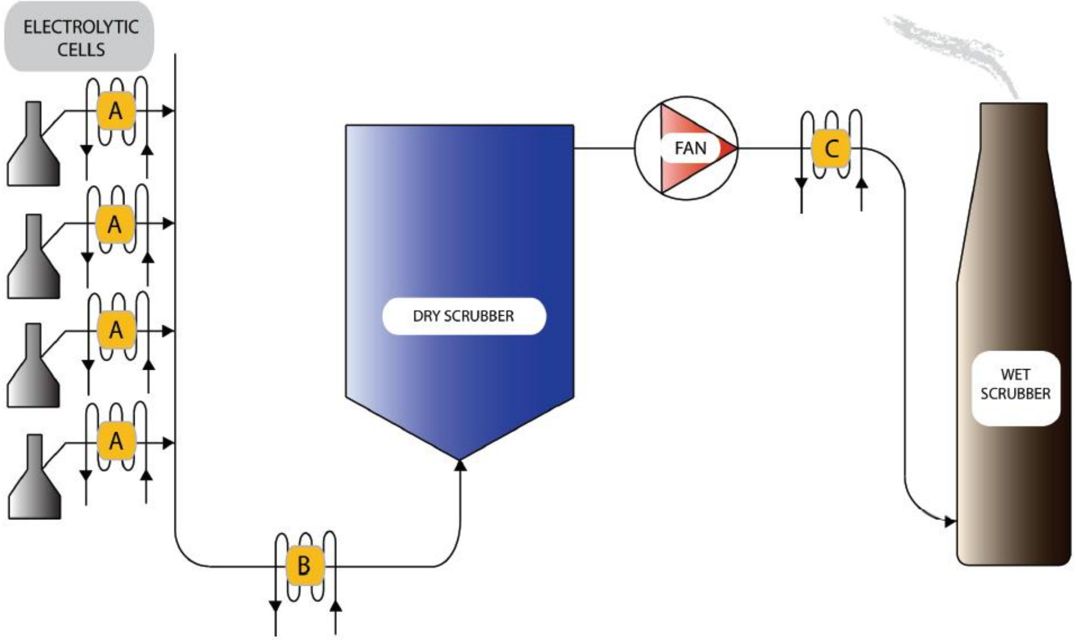
Objective

- Compare cycles for power production from low temperature waste heat
  - Working fluids
  - Cycle configurations
  - Impact of boundary conditions and limitations
- Basis for comparison
  - Performance AND cost
  - Optimal heat recovery – how much heat to take out

Develop a methodology for simultaneous optimization of cycle operation and critical component design

Special Al smelter frame conditions

- Dry scrubber for particle removal requires very high fan work, extracting heat pre scrubber reduce pressure drop -> net power gain (20-50%) of Rankine cycle net power output
- Must avoid pot gas condensation in HRHE



Case definition

- Pot gas from aluminium cells as heat source
  - *Limited*, *sensible* and in *gas phase*

- Requires large Heat Recovery Heat Exchanger (HRHE)
  - Major cost
  - Large impact on system performance
  - Non-linear relation between HRHE size and heat recovery

→ Optimize cycle operation and **HRHE geometry**

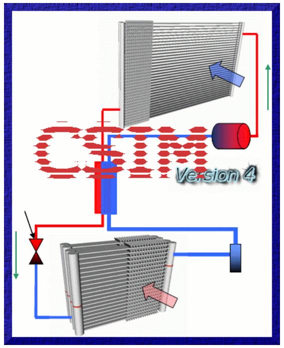
Methodology – Focus on HRHE design

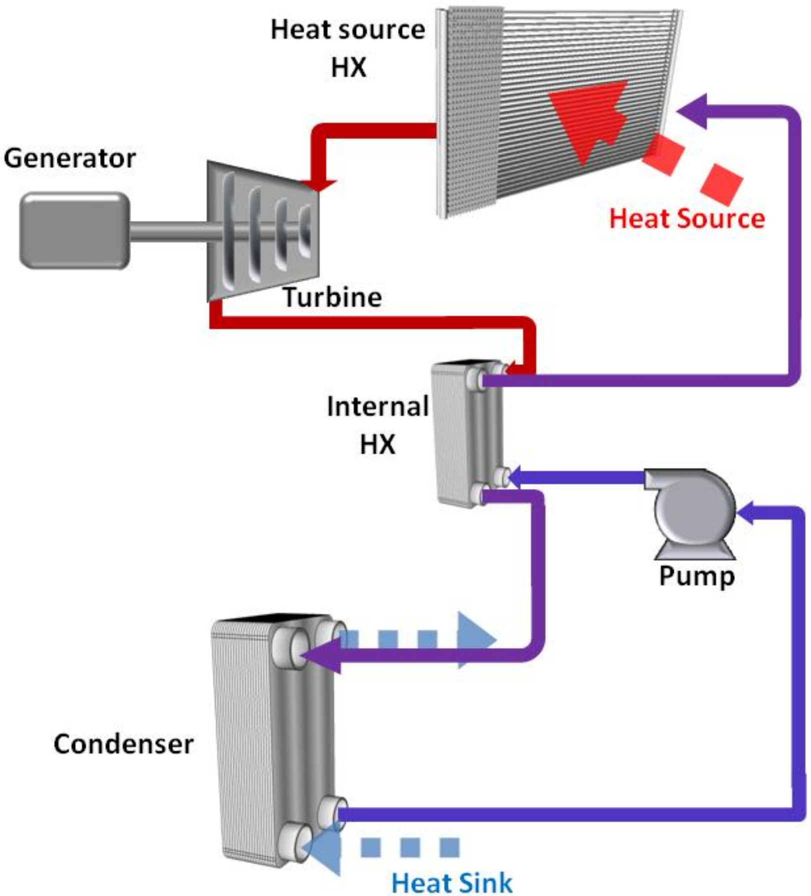
- HRHE design – many factors to consider
  - Boundary conditions, operation range
  - Structural, durability, maintenance
  - Thermodynamics of heat source and working fluid
  - Performance (on- and off design)
  - Cost

=> Type, geometry and configuration

- Simple component/system models fall short
- Advanced models can take into account more of these factors

Methodology implementation



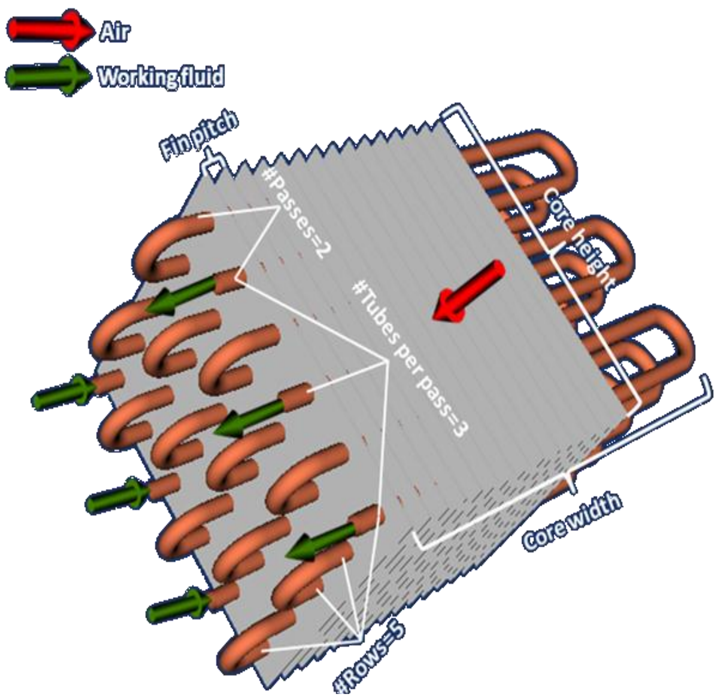


- In-house tool for circuit simulation and optimization – CSIM
- Verified vs. laboratory experiments
- Advanced component models
  - HX: Discretized in elements, "Stream evolution method"
  - Local correlation-based calculation of HTC and ∂P
- Charge inventory
- Multi-parameter optimization
  - Including HX-geometry parameters

Case definition - Parameters

Heat Exchanger Parameters	
Type	Fixed
Tube material	Fixed
Fin material	Fixed
Fin thickness	Fixed
Fin pitch	Automatic
Tube inner diameter	Automatic
Tube outer diameter	Automatic
Core depth	Automatic
Core height	Manual
Core width	Manual
No. of tubes per row	Manual
No. of tube rows	Manual

Cycle Parameters	
High side pressure	Automatic
Working fluid pump speed	Automatic
Temperature approach recup	Fixed



Case definition

Boundary Conditions / Constraints	
Heat source mass flow	500kg/s
Heat source temperature	125°C
Min. fin pitch	8 mm
Min. tube pitch	2 tube diameters
Min. tube inner diameter	5 mm
Condensation temperature	20°C
Pump is. efficiency	70%
Expander is. efficiency	80%
Working fluid HRHE inlet	min. 40°C
Heat source temperature	min. 70°C
Max. pressure R134a	25bar
Max. pressure CO2	140bar

1-stage Rankine cycles

- R134a and CO_2
- Recooperated to avoid pot gas condensation

Minimize **specific system cost**

- Any cost function possible
- Here analyzing impact of HRHE design => cost: **[kg_{HRHE}/kWe]**

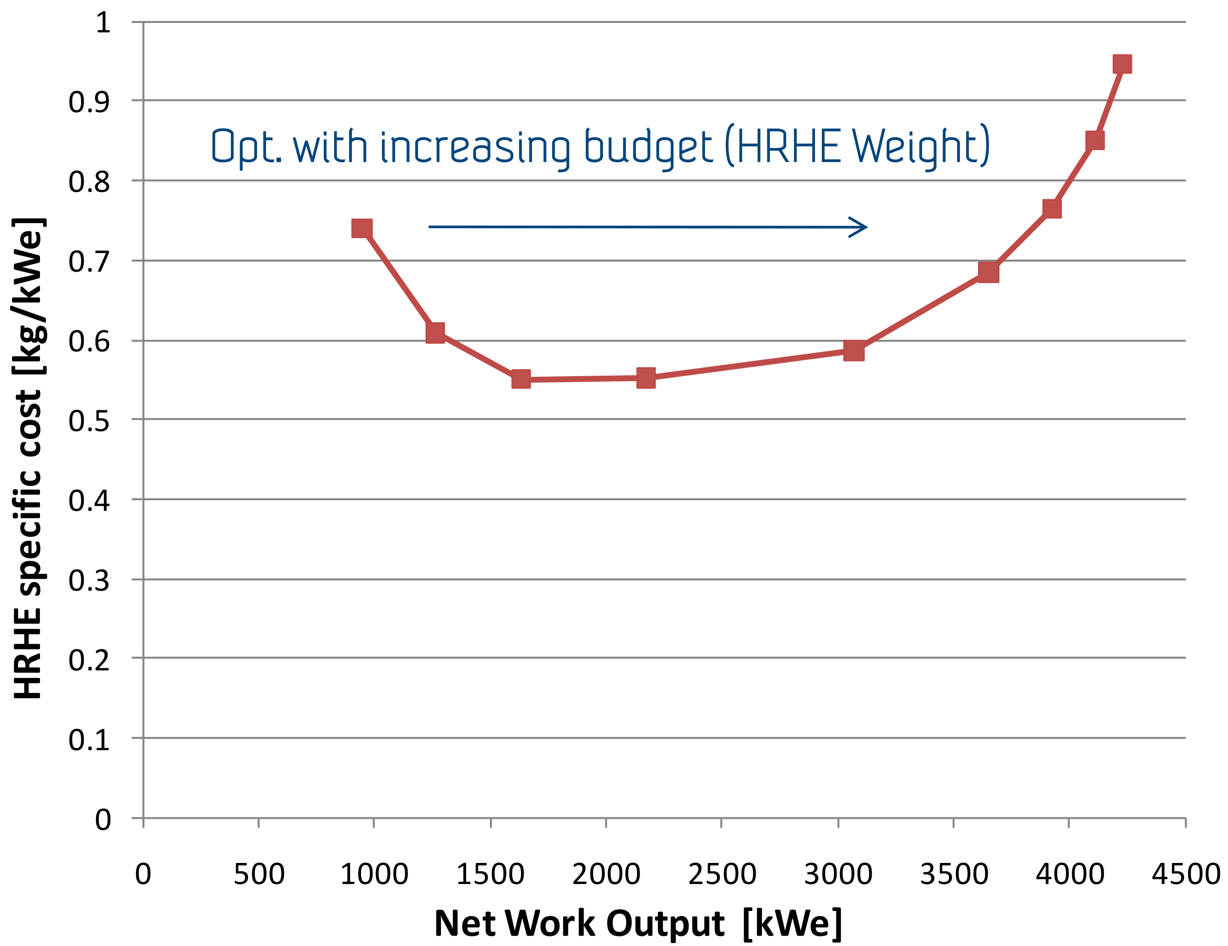
Demo. case results – single configuration

For one set of "manual" variables:

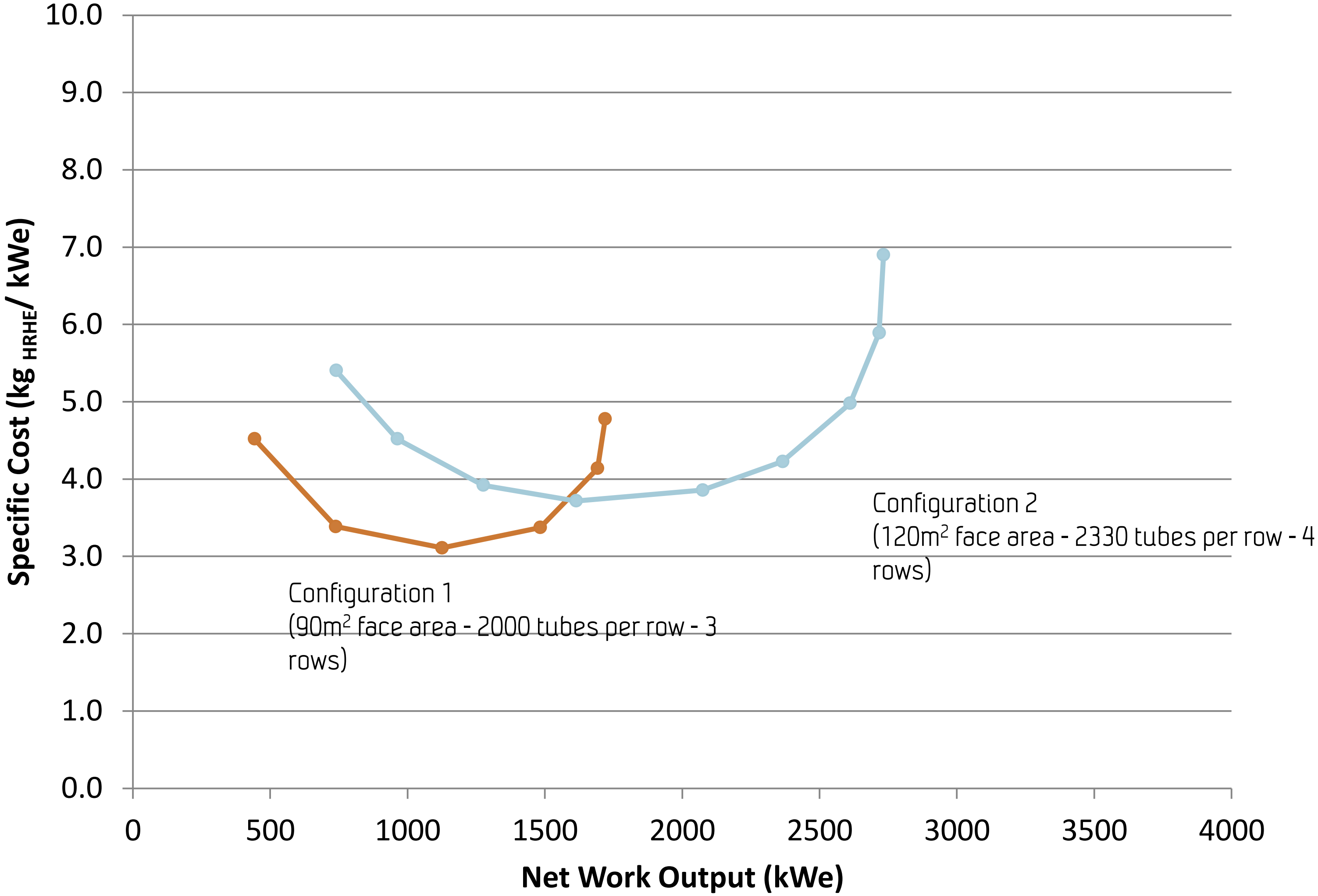
- Number of tubes
- Number of rows
- HRHE width
- HRHE height

Optimized variables in each point:

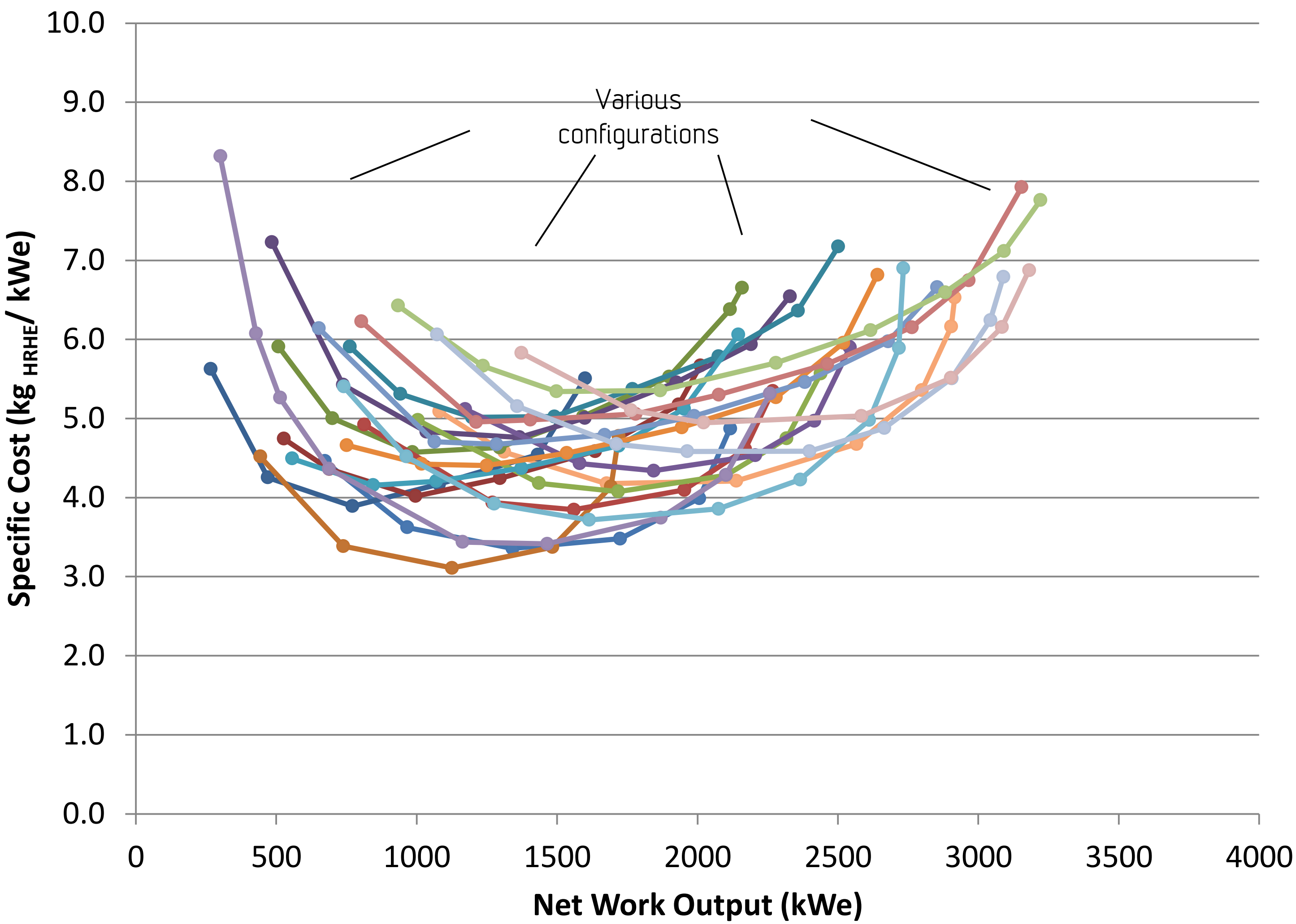
- Tube diameter
- Fin pitch
- HRHE depth
- Cycle pressure
- Cycle mass flow



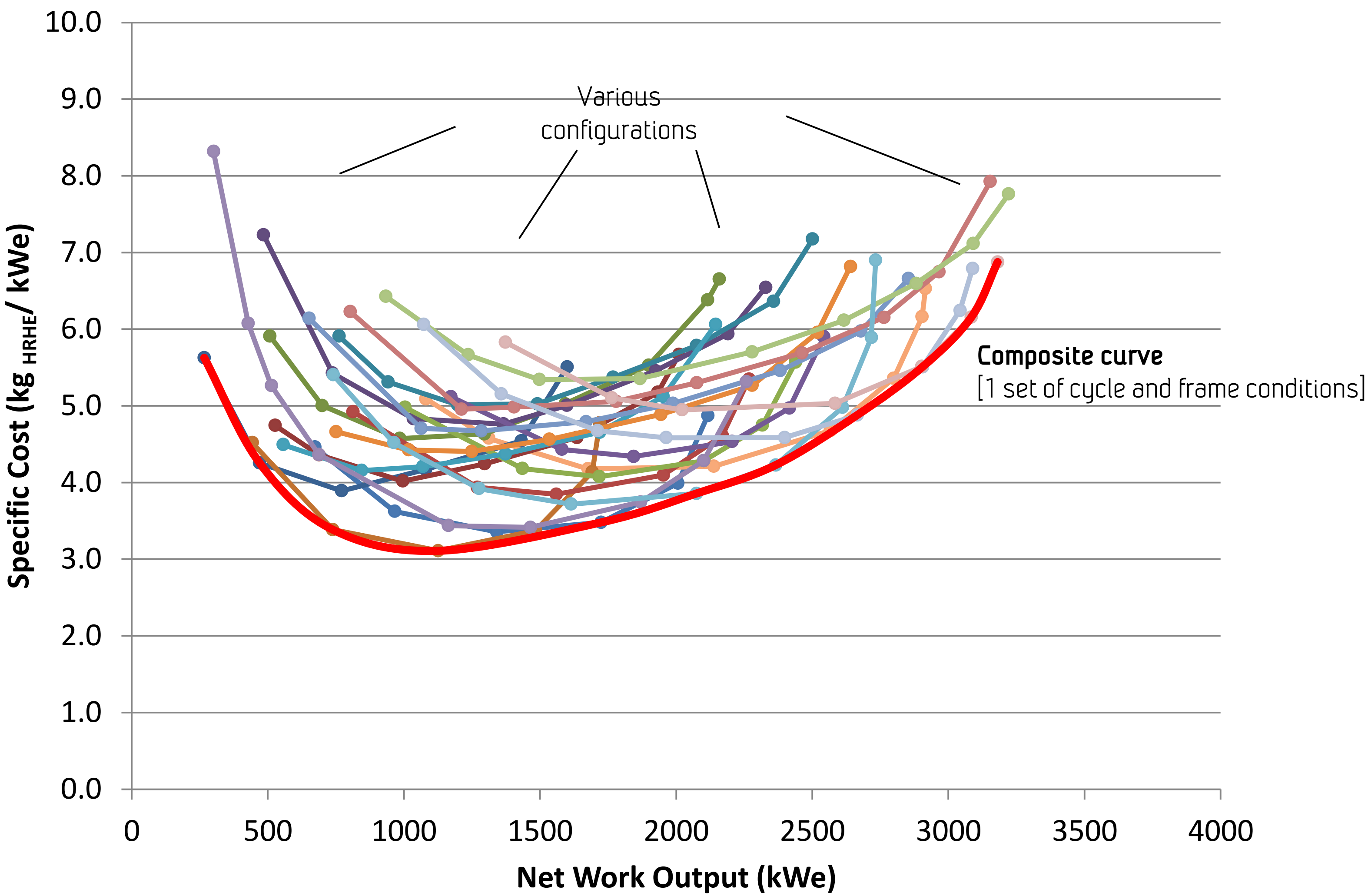
Case results- Forming composite curves



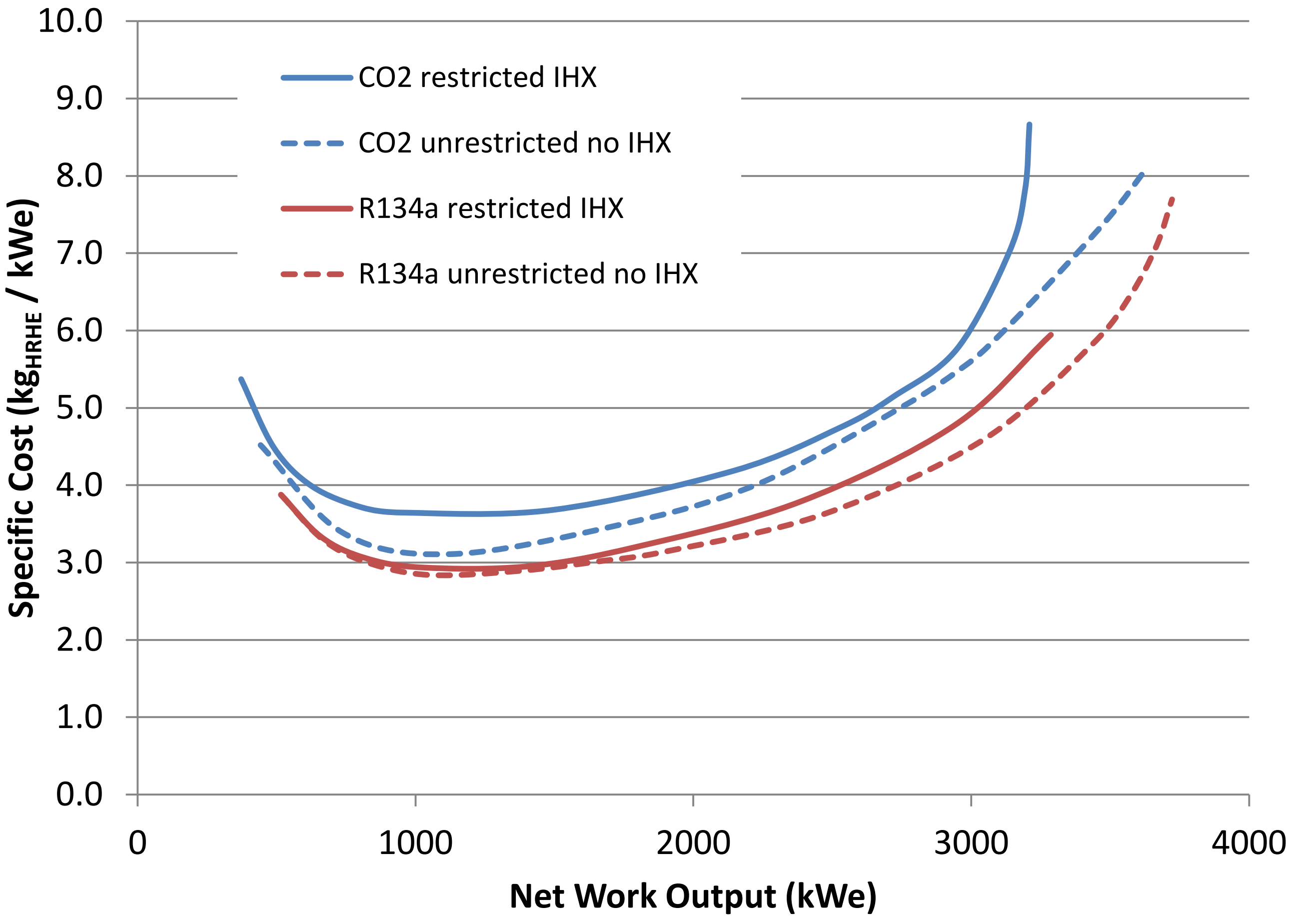
Case results- Forming composite curves



Case results- Forming composite curves



Case results – effect of boundary conditions



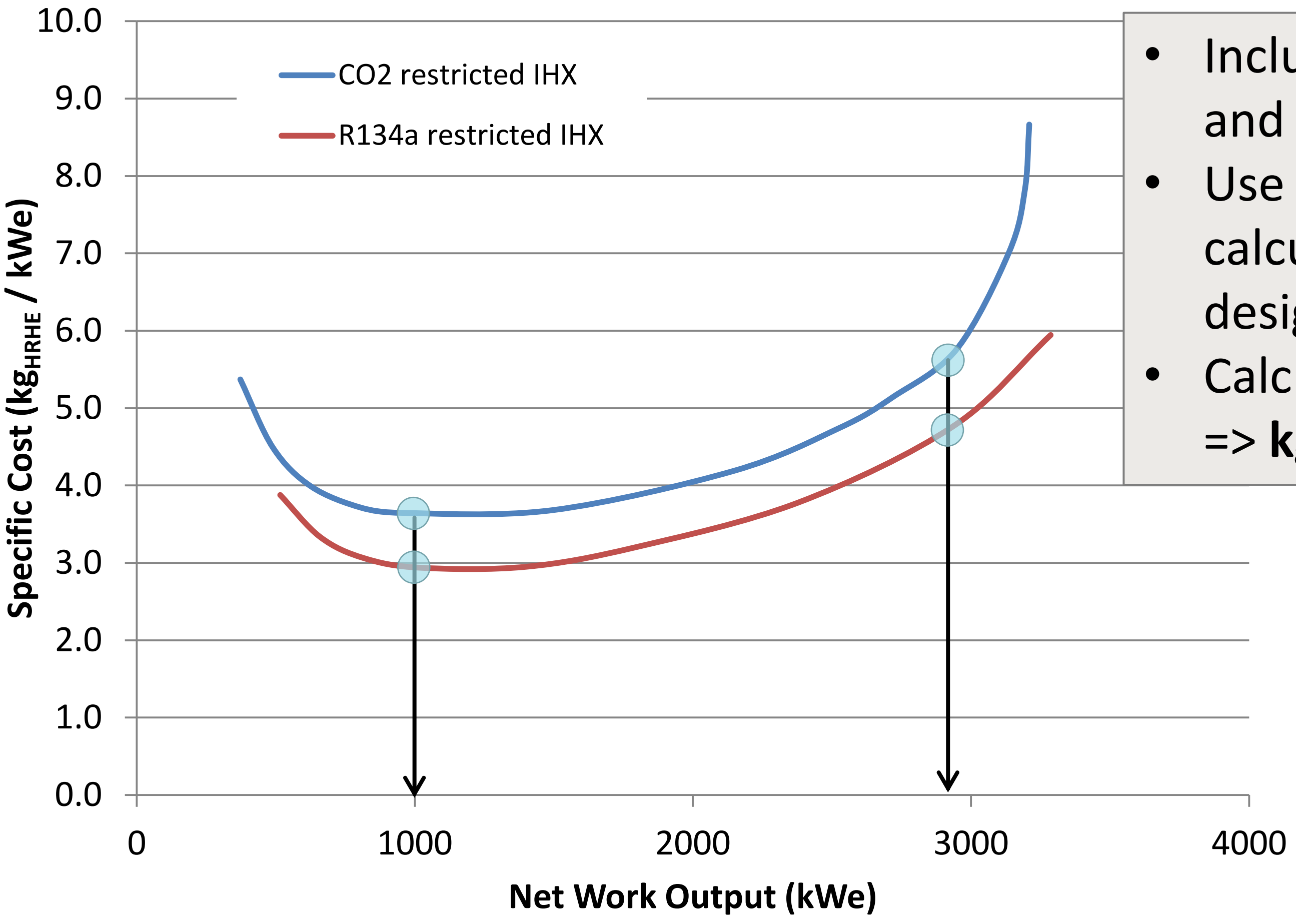
"Restricted":

- T_{min} Heat source: 70°C
- HRHE inlet T_{min} : 40°C

"Unrestricted":

- No IHX
- Free T_{min} Heat source
- Free HRHE inlet T_{min}

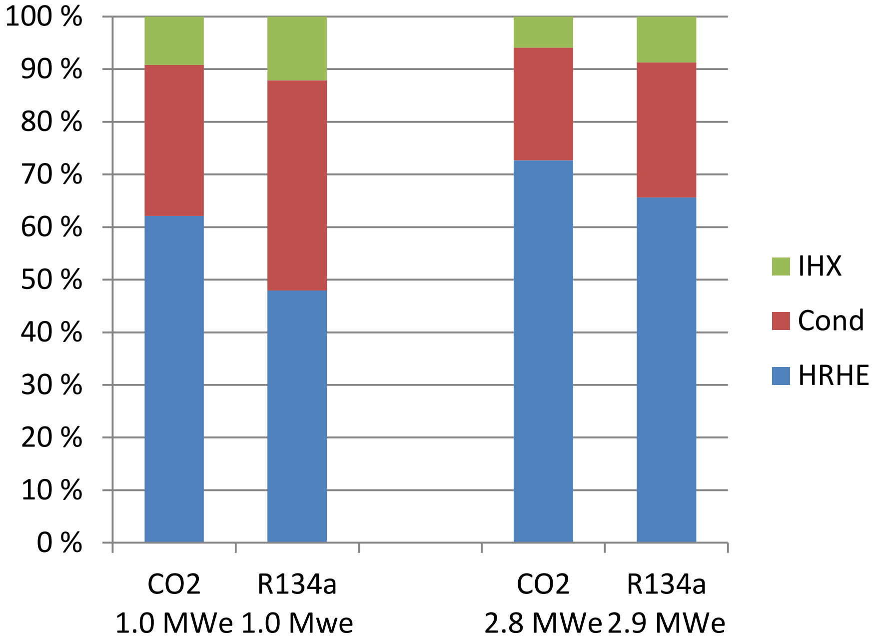
Case results – Analysis of results



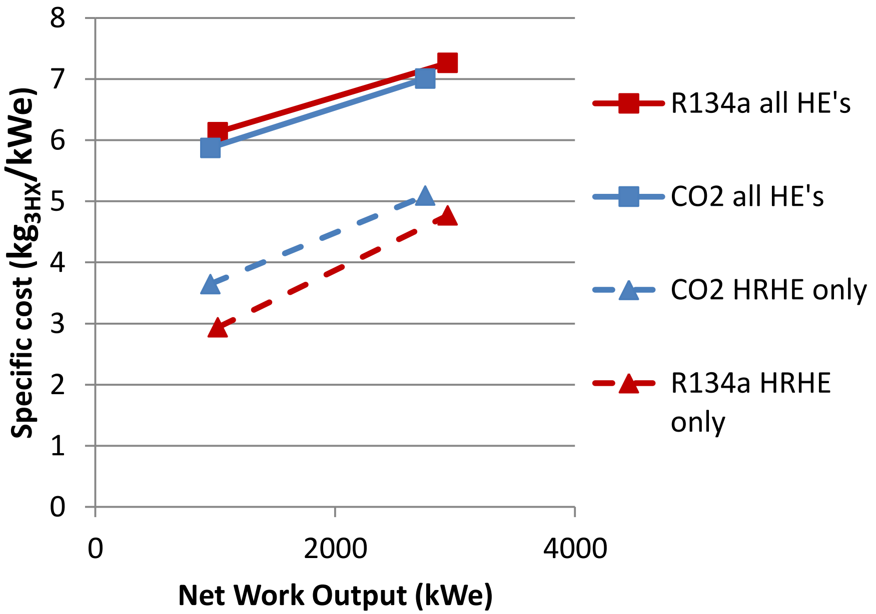
- Include cost of **condenser** and **recooperator**
- Use seperate design tool to calculate weight for two design points
- Calculate new specific cost: => $\mathbf{kg_{3HX}/kWe}$

Case results – Heat exchanger weight

- Relative weight of heat exchangers in system – analysis of presumptions
- Identifies HRHE as major "cost"



- **Other HX's should be included in full optimization**
  - Distribute "budget" on all heat exchangers
  - Large impact on resulting cost and comparison



Summary

- Tools and methodology has been developed
  - Component models based on **real geometry**
  - Prediction of physical **system behavior**
  - Optimizing any **cost function**
- Preliminary results from aluminium smelter case
  - Analysis of complex boundary conditions
  - Comparing HRHE design, cycles and working fluids
- Case show importance of considering the total system
- Work continues to implement optimization including all important components
- Aim to define total system cost functions in €

Thank you for your attention!

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