The Potential of Waste Heat Recovery from Industry in Europe – an ORC Perspective

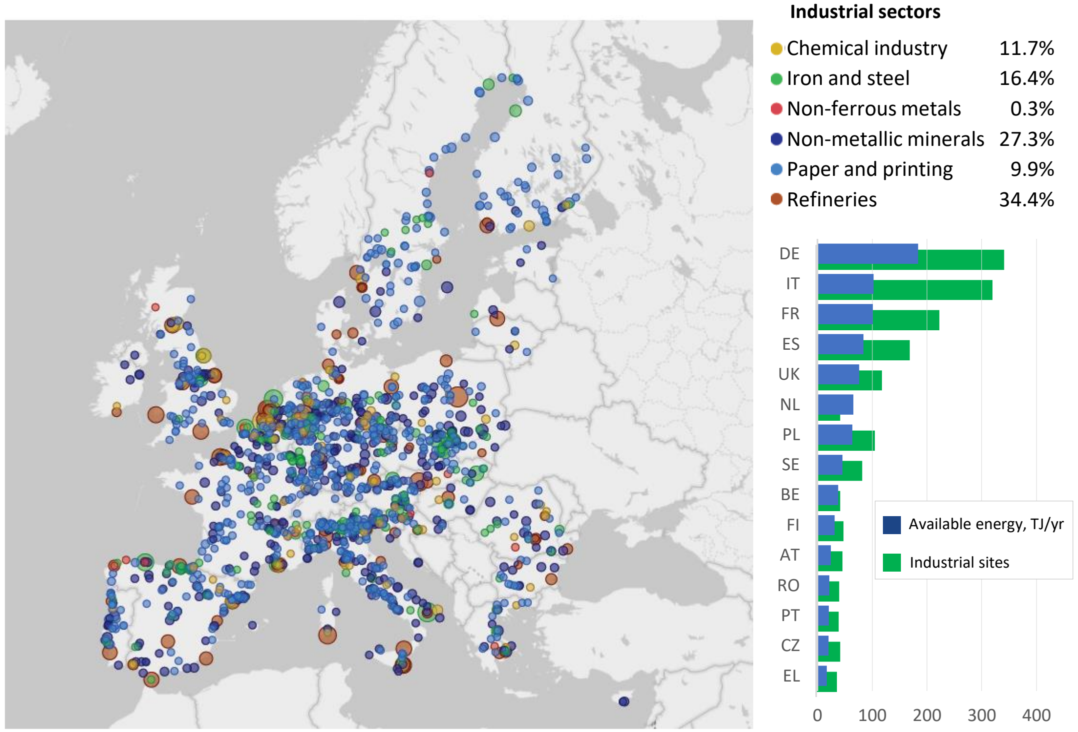
Dr.-Ing. Christoph Wieland
Prof. Dr.-Ing. Hartmut Spliethoff
Chair of Energy Systems

28th of July 2022

12th Energy Colloquium of the Munich Institute of Integrated Materials, Energy and Process Engineering (MEP)

Outline

1. Waste Heat Potential from Energy Intensive Industries



Temperature range of waste thermal energy / °C

	<100	100 – 200	200 – 300	300 – 400	400 – 500	500 – 600	600 – 1000	>1000	TWh/a
Iron and Steel									73.0
Non-metallic minerals									91.2
Clinker*									
Glass*									
Non ferrous metals (Primary aluminum*)									32.3
Chemical and Petrochemical									141.7
Pulp, Paper and Printing*									125.5
Others									263.0
Refinery*									
Food and Beverages									115.2
Gas and Diesel Engines									2013.5

- ▶ Enormous waste heat is available all over Europe
- ▶ Temperature levels of available waste heat is sector specific
- ▶ Technical potential in Europe for electricty from waste heat is about 150 TWh/a

Source [1]

1. Waste Heat Potential from Energy Intensive Industries

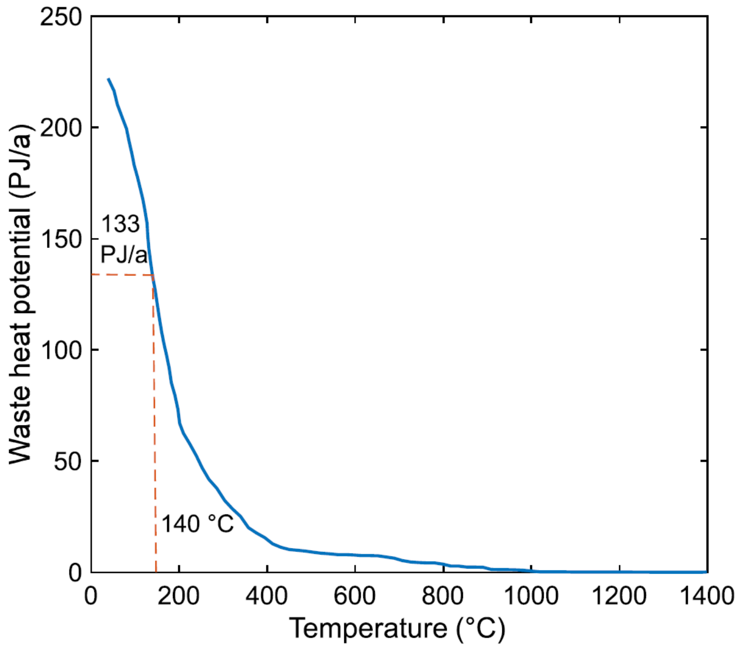
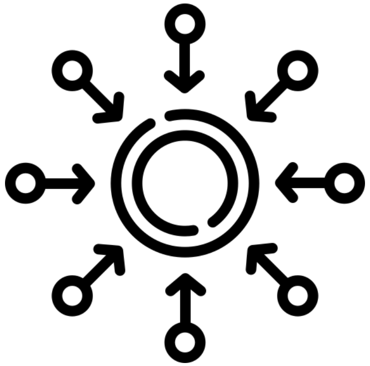


Fig. 1. Cumulative distribution of the IWH as a function of the temperature from Brückner et al. [33].

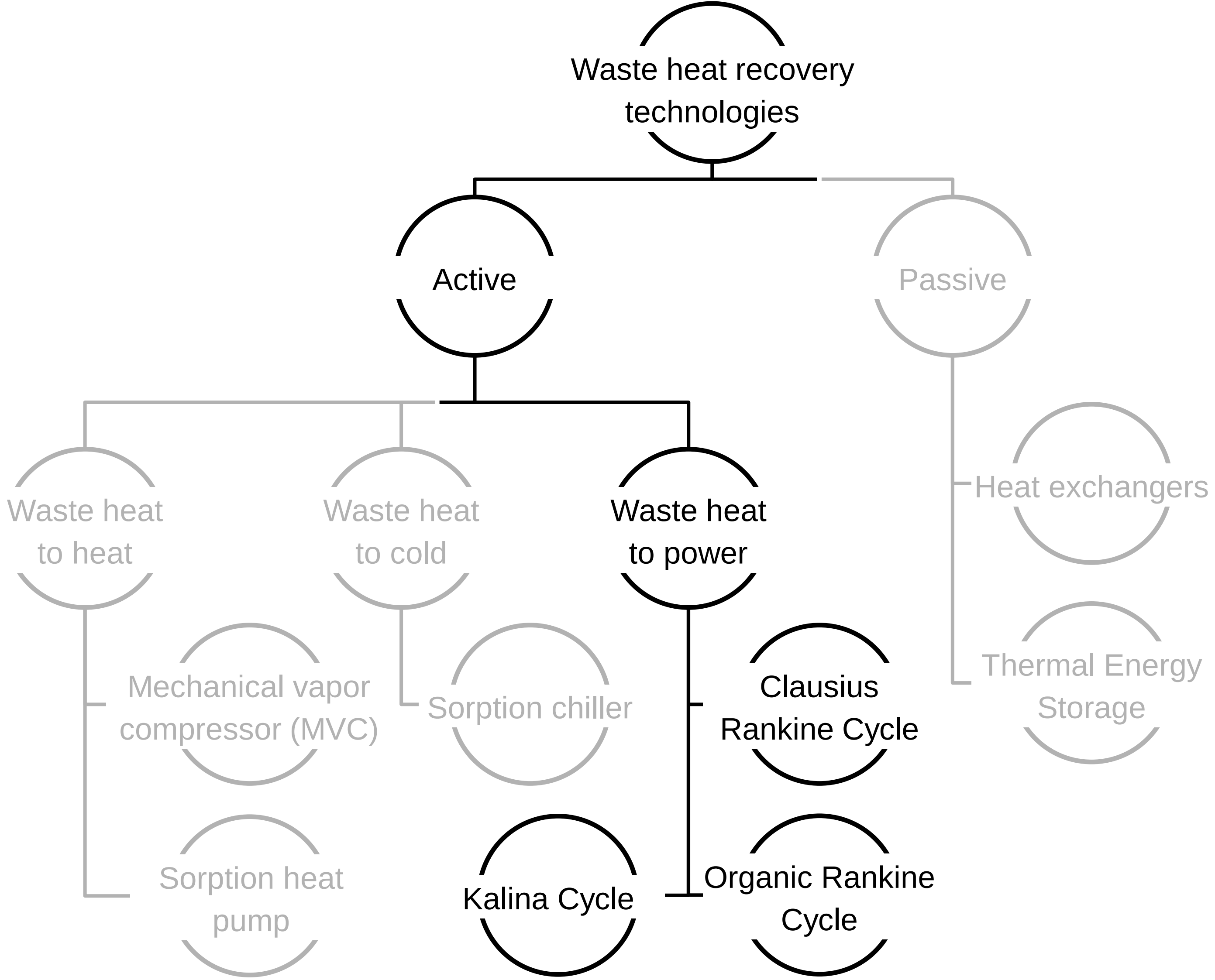
Source [2]



- Not all of the available waste heat is easy to use
- Temperature levels can be challenging low and distributed heat sources are difficult to be harvested

Outline

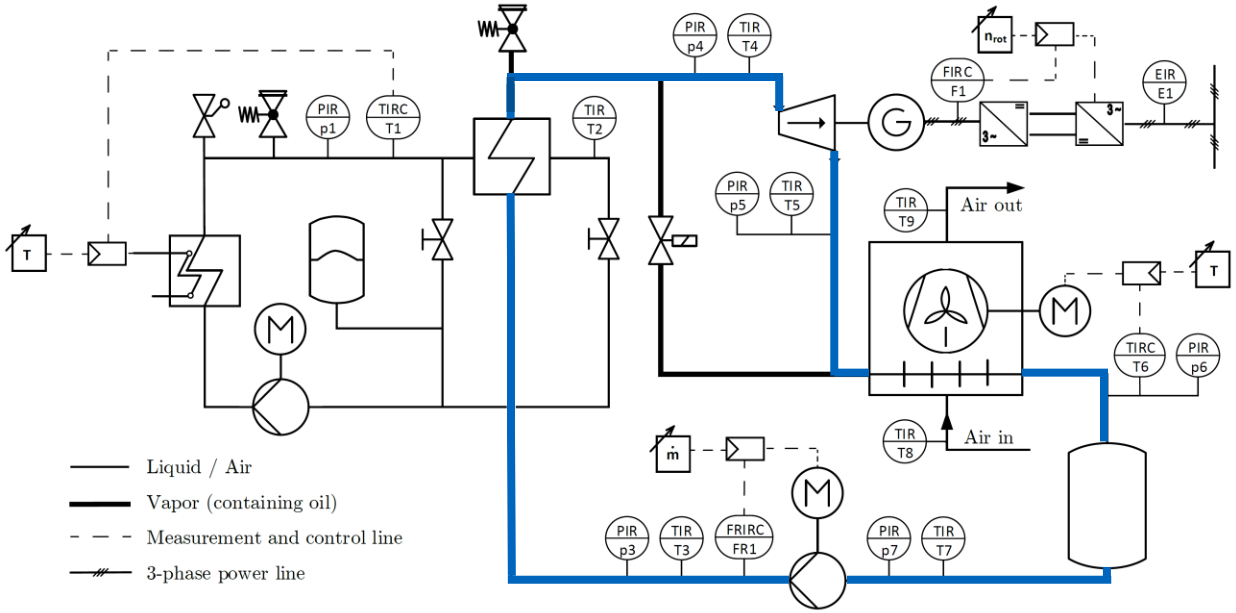
1. Waste Heat Potential in Europe
2. Waste Heat Utilisation and Organic Rankine Cycles
3. Example 1: Steel Industry
4. Challenges for Investments
5. Example 2: Cement and Glass
6. ORC Market Overview
7. Summary and Conclusion



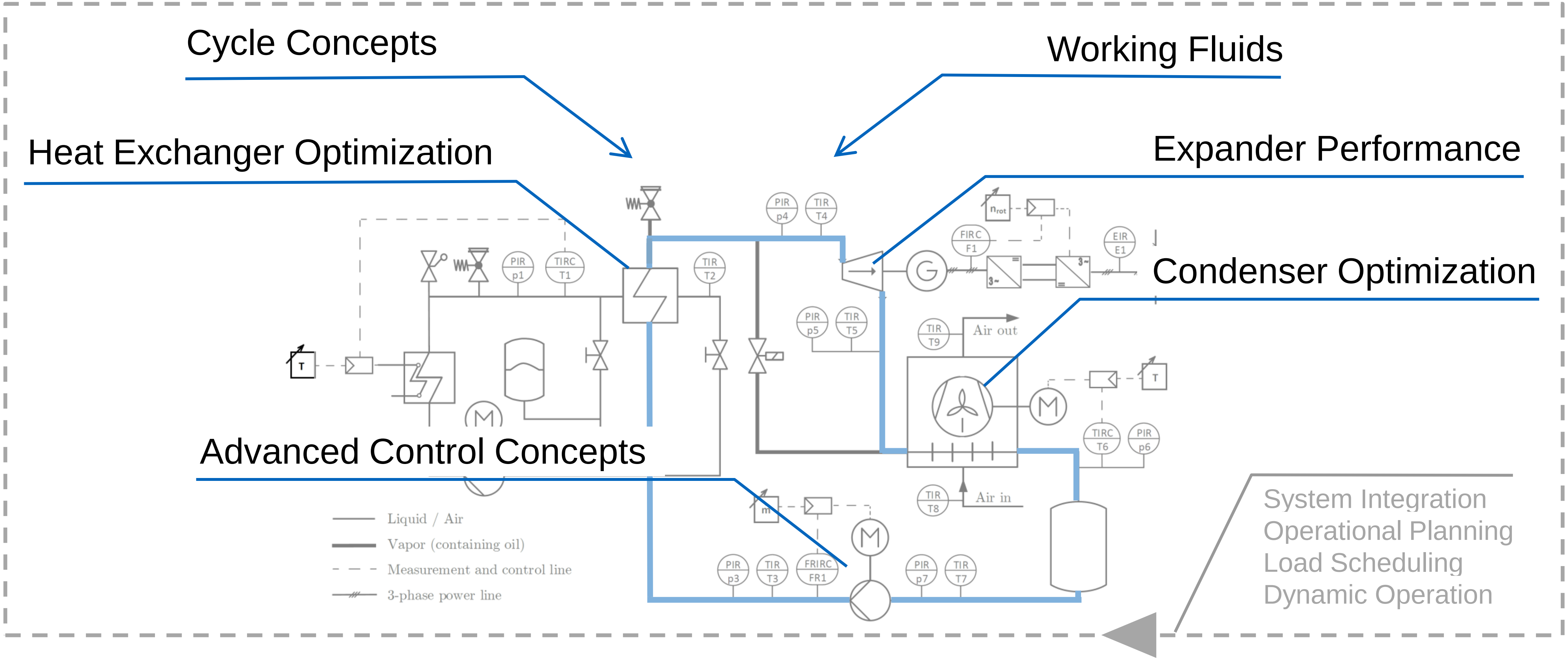
- Clausius Rankine Cycle T > 200 °C (State-of-the-art)
- ORC & Kalina T > 120 °C (State-of-the-art)

Source: modified from [3]

2. The Organic Rankine Cycle Technology

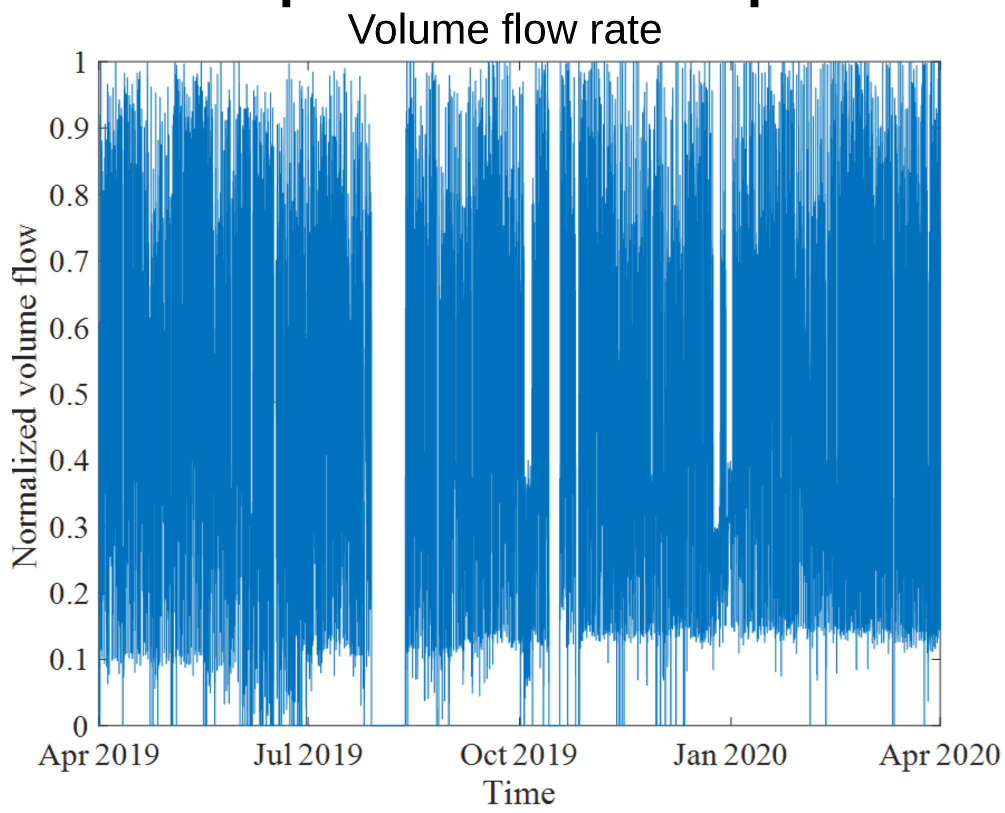


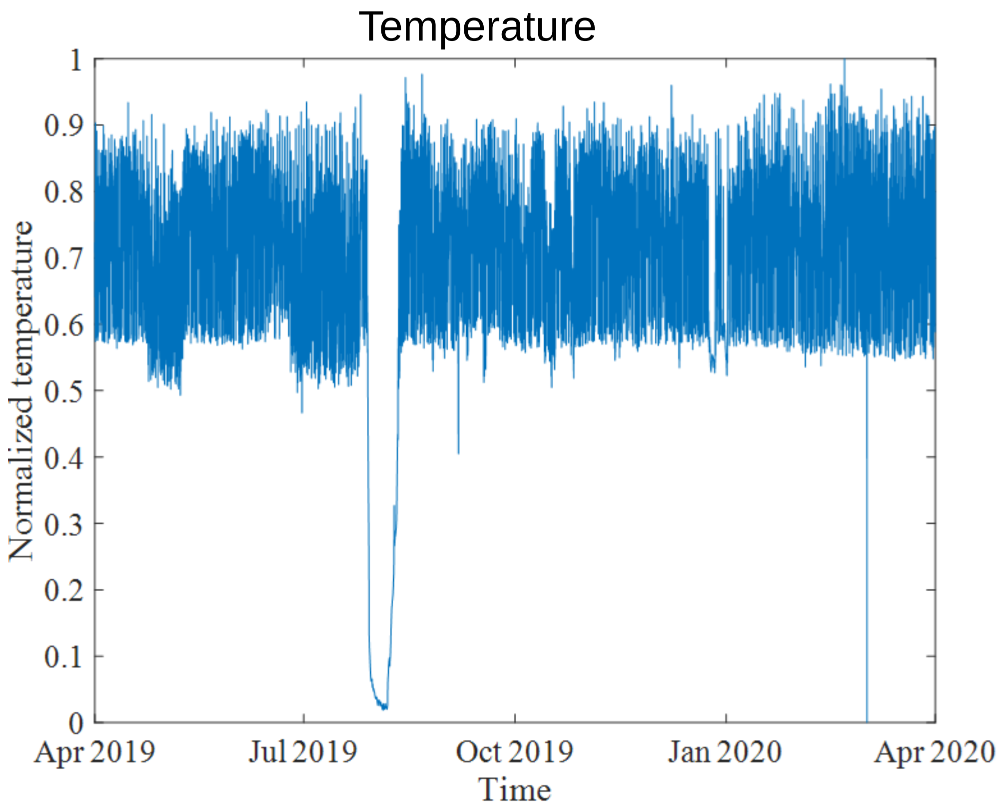
… and its Research Challenges



Outline

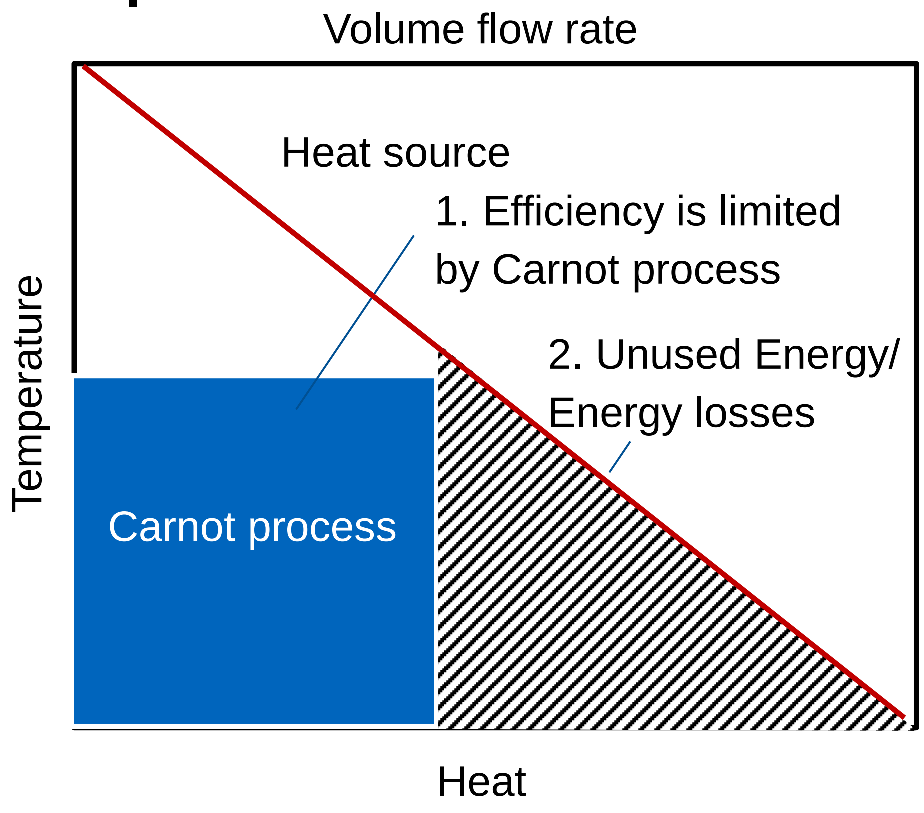
3. Example 1: Steel plant

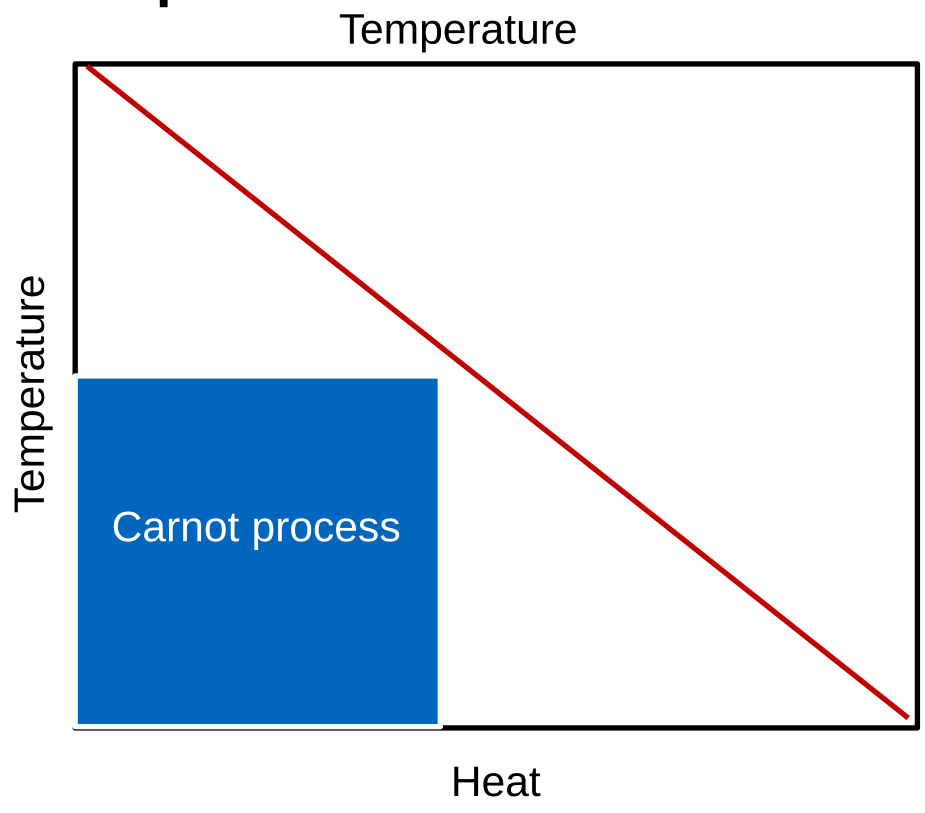




- Fluctuations in volume flow rate are significant
- Temperature fluctuations only between 60%-90% of the maximum temperature

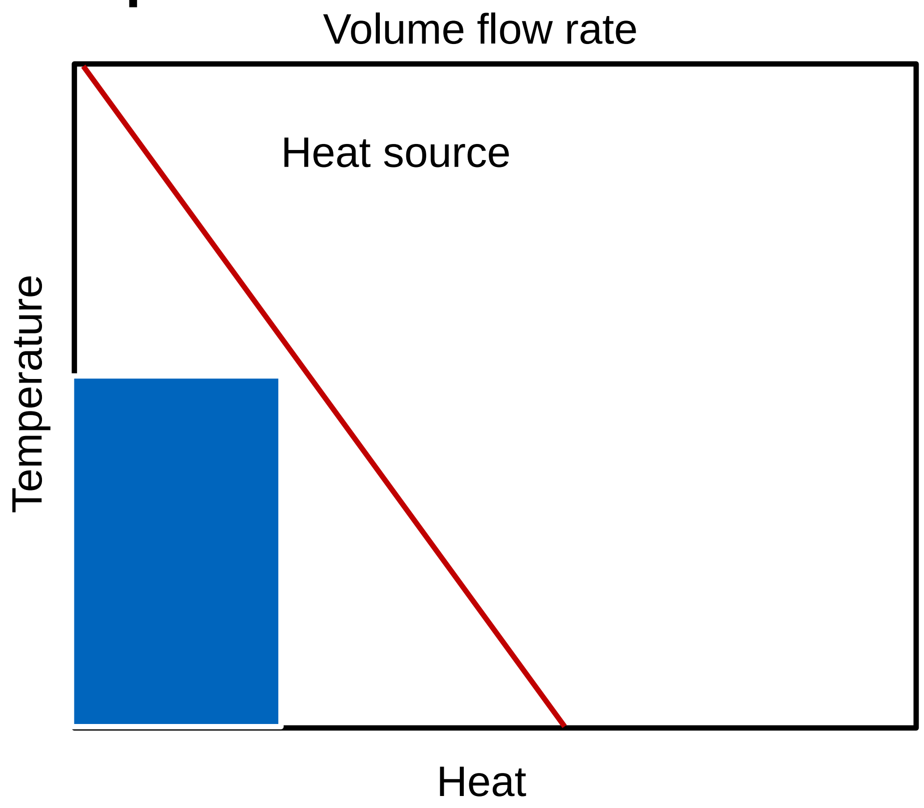
3. Impact of Volume Flow and Temperature

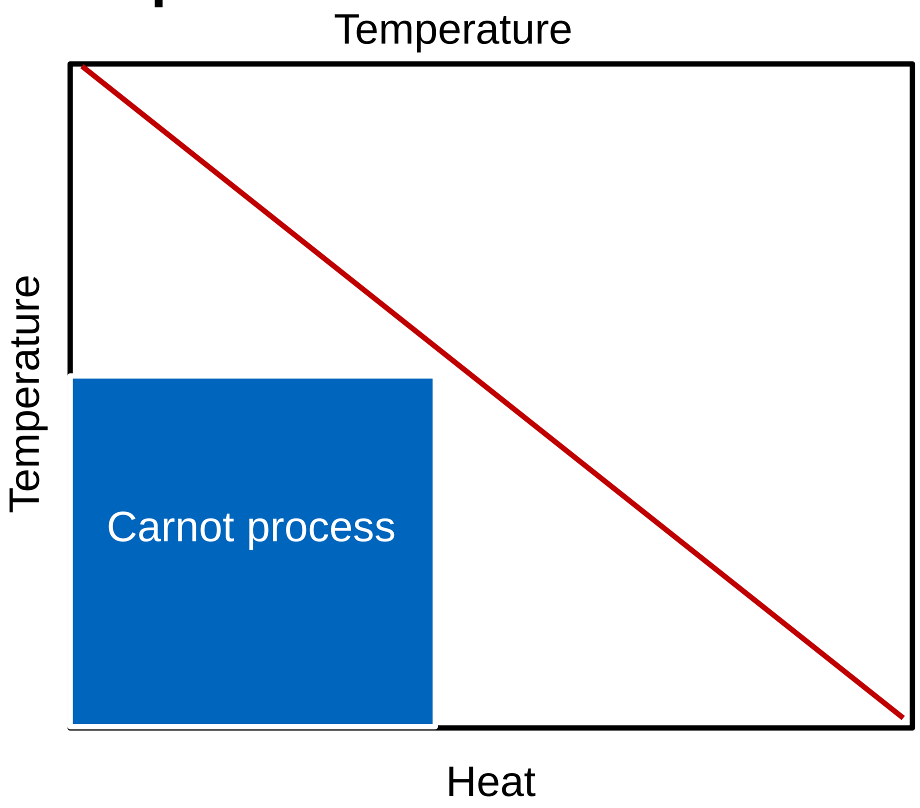




- Usually waste heat is sensible in nature → $Q \sim T$
- Pinch-point limits heat transfer to Carnot cycle

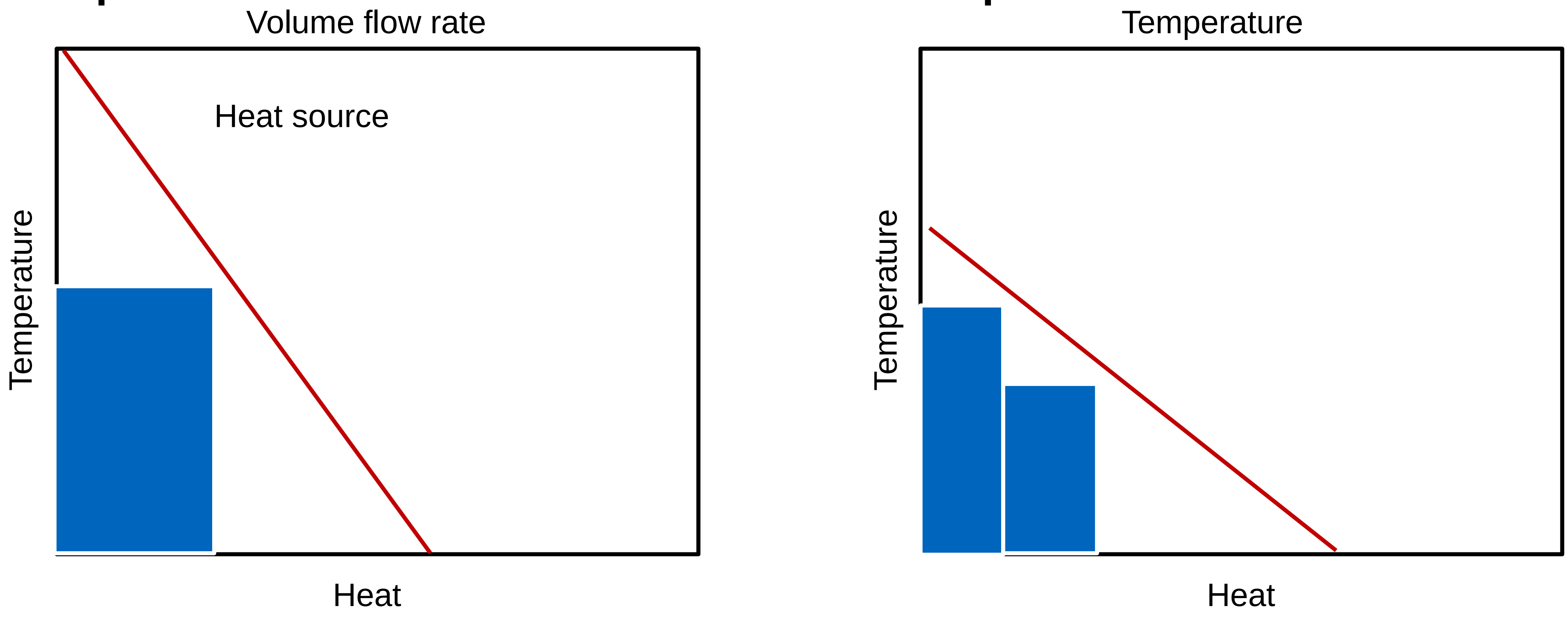
3. Impact of Volume Flow and Temperature





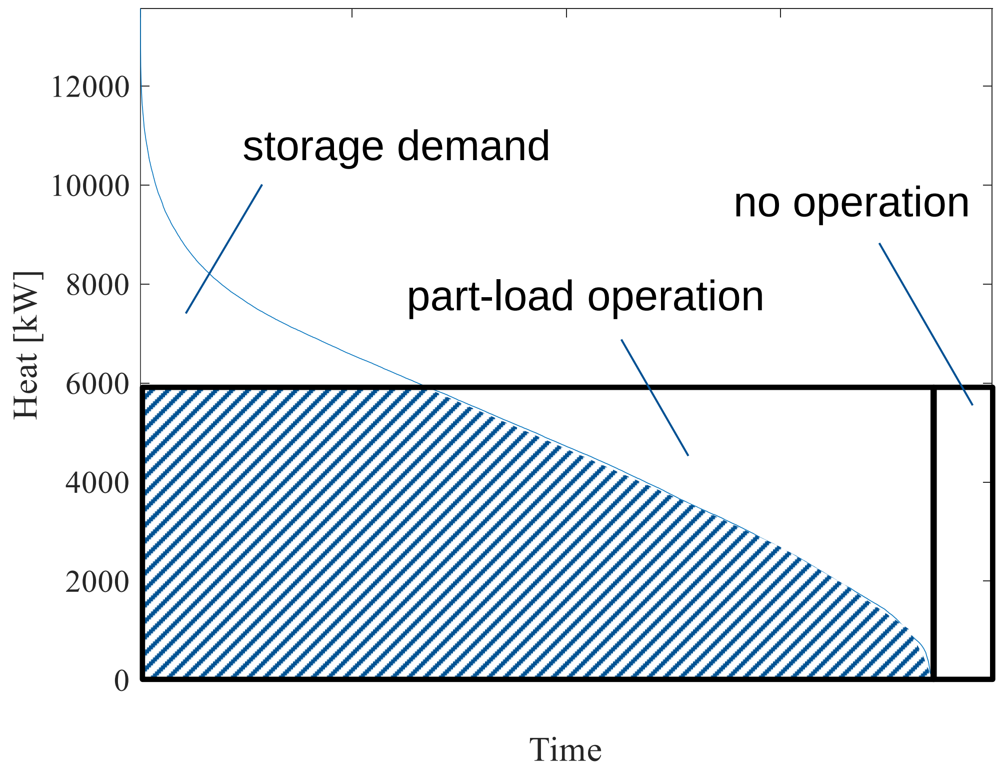
- Part load operation, as available heat is reduced
- Temperature/pressure of ORC is maintained → Efficiency remains constant

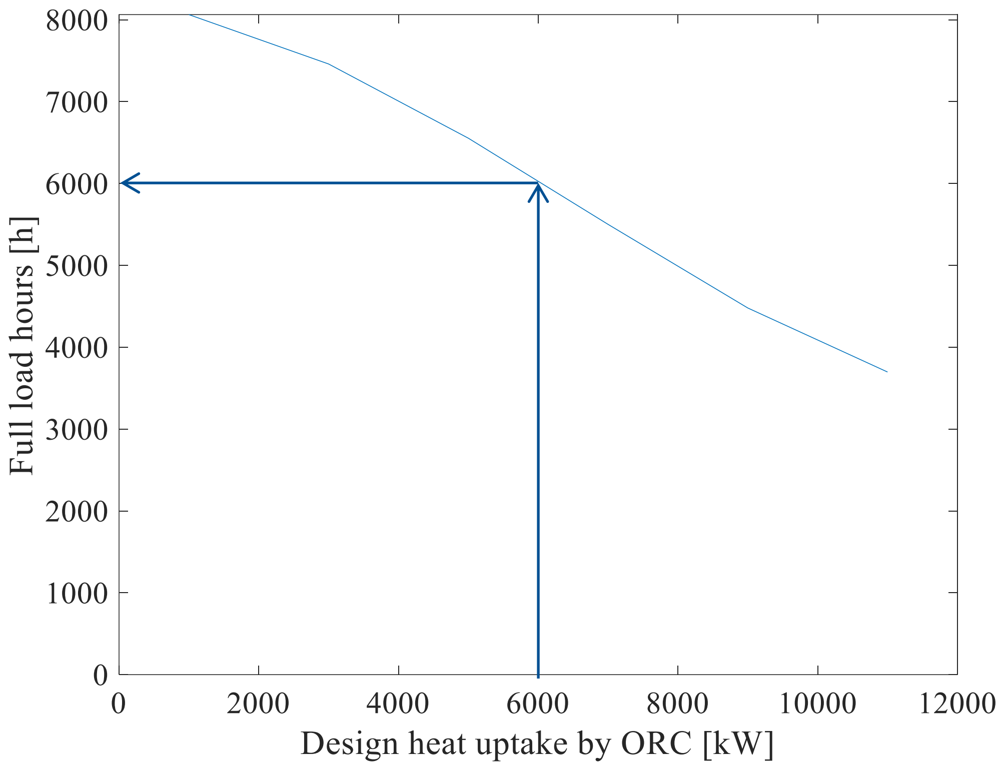
3. Impact of Volume Flow and Temperature



- Part load operation, as available heat is reduced
- Temperature/pressure of ORC is reduced or waste heat utilisation is reduced

3. Example 1: Steel plant





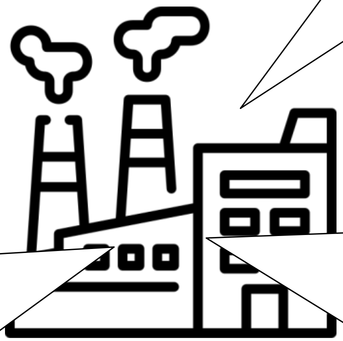
- ▶ Waste heat amount is up to 12 MW
- ▶ Reasonable full load hours can be achieved

Outline

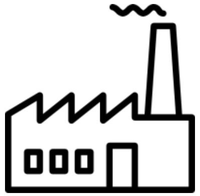
Challenges for Investments

- ▶ Security of supply
  - → Seamless commissioning and operation
  - → Simple and easy installation only outside battery limit

- ▶ Retrofitting to the existing asset has
  - → Space constraint
  - → Decentral distributed waste heat sources are hard to capture



Quelle: Flaticon.com



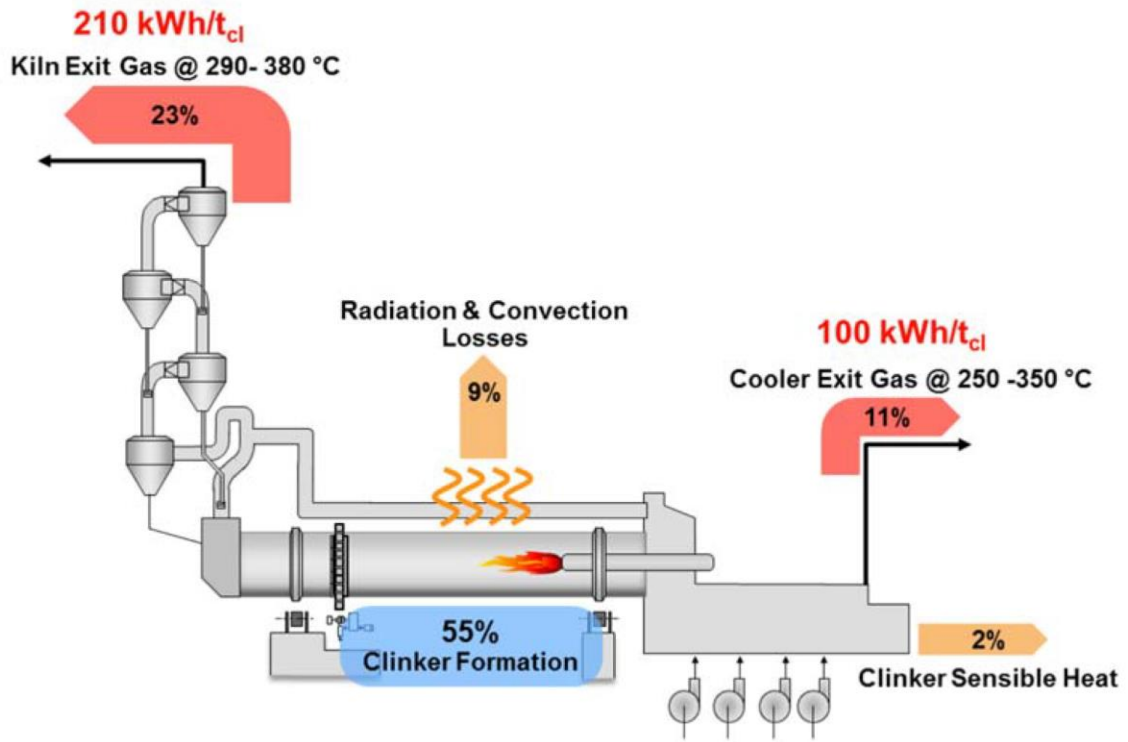
- ▶ Industry usually focuses only on their core-process
- ▶ Likelihood that existing assets cannot commit to long-term operation

- ▶ Typical pay-back periods are in the range of 3-5 years vs. >>10 years in the energy sector
  - → Low specific investment costs
  - → Modularity, flexibility and “second life” approaches are selling points

Source: [4]

Outline

Example: Cement and Glass



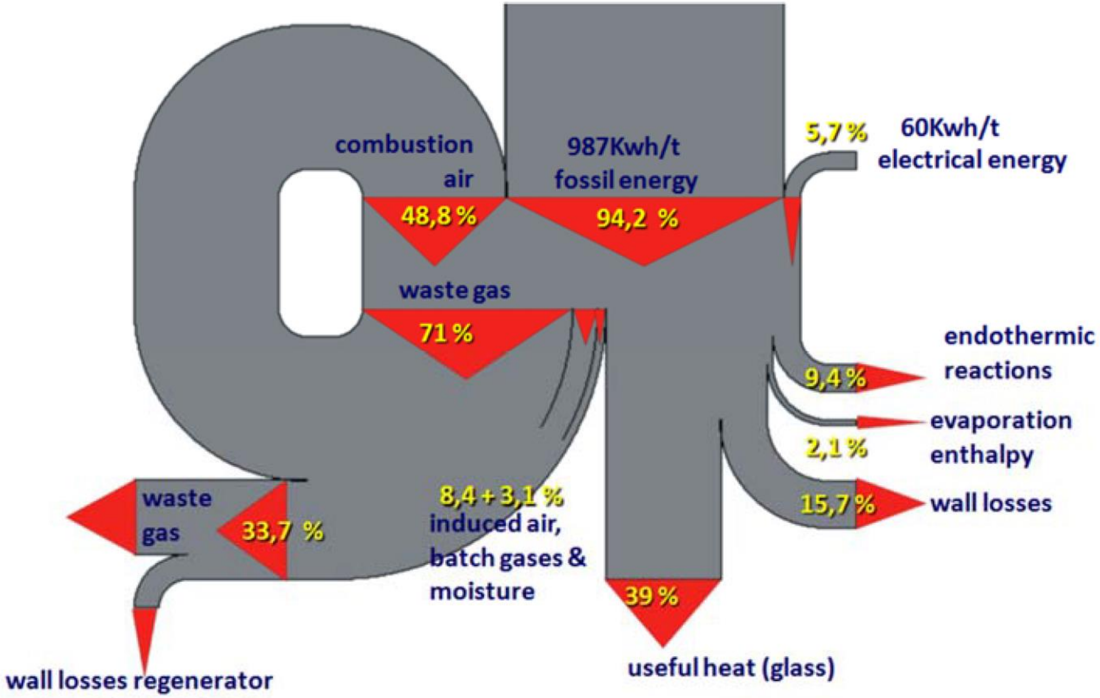


Figure 3: Energy flowchart of a typical fired glass furnace

Source: [5]

Example: Cement and Glass

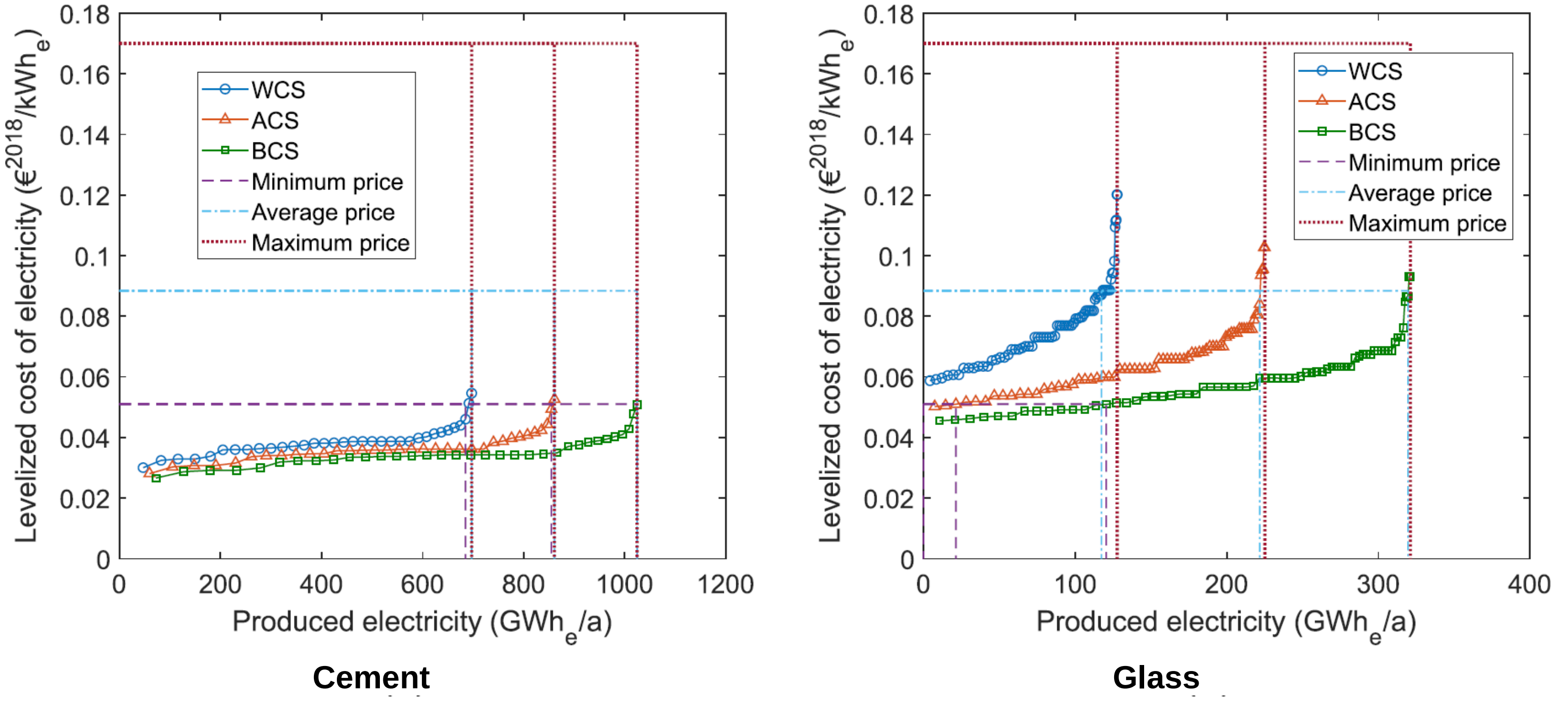
Item	M.U.	Cement – Clinker Cooler
Source of data		Holcim
Plant size	t/d	5,000
	t/h	208
Type of fuel/source	Ambient air	
Exhaust gas flow rate	Nm^3/h	125,000
Exhaust gas temperature	°C	330
Exhaust gas composition	N_2	78
	O_2	20
	H_2O	2
	CO_2	0
Exhaust gas specific heat capacity	kJ/kg K	1.06
Exhaust gas density	kg/Nm^3	1.28
Exhaust gas cooled down to	°C	120
Thermal power available	kWt	9,900
Gross ORC efficiency	20%	
Ambient air	°C	20
ORC Gross electric power output	kWe	1,950
ORC auxiliary consumptions	10%	
Net electric power output (estimated)	kWe	1,715

Item	M.U.	Glass - Container glass
Source of data	Vidrala	
Plant size	t/d	440
Type of fuel/source	Natural gas	
Exhaust gas flow rate	Nm^3/h	43,000
Exhaust gas temperature	°C	380
Exhaust gas composition	N_2	68
	O_2	7
	H_2O	15
	CO_2	10
Exhaust gas specific heat capacity	kJ/kg K	1.15
Exhaust gas density	kg/Nm^3	1.27
Exhaust gas cooled down to	°C	200
Thermal power available	kWt	3,130
Ambient air	°C	20
Gross electric efficiency	20%	
Net electric efficiency	18%	
ORC Gross electric power output	kWe	630
Net electric power output (estimated)	kWe	565

Source: [5]

LCOE for Cement and Glass

BCS: best-case scenario
ACS: average-case scenario
WCS: worst-case scenario



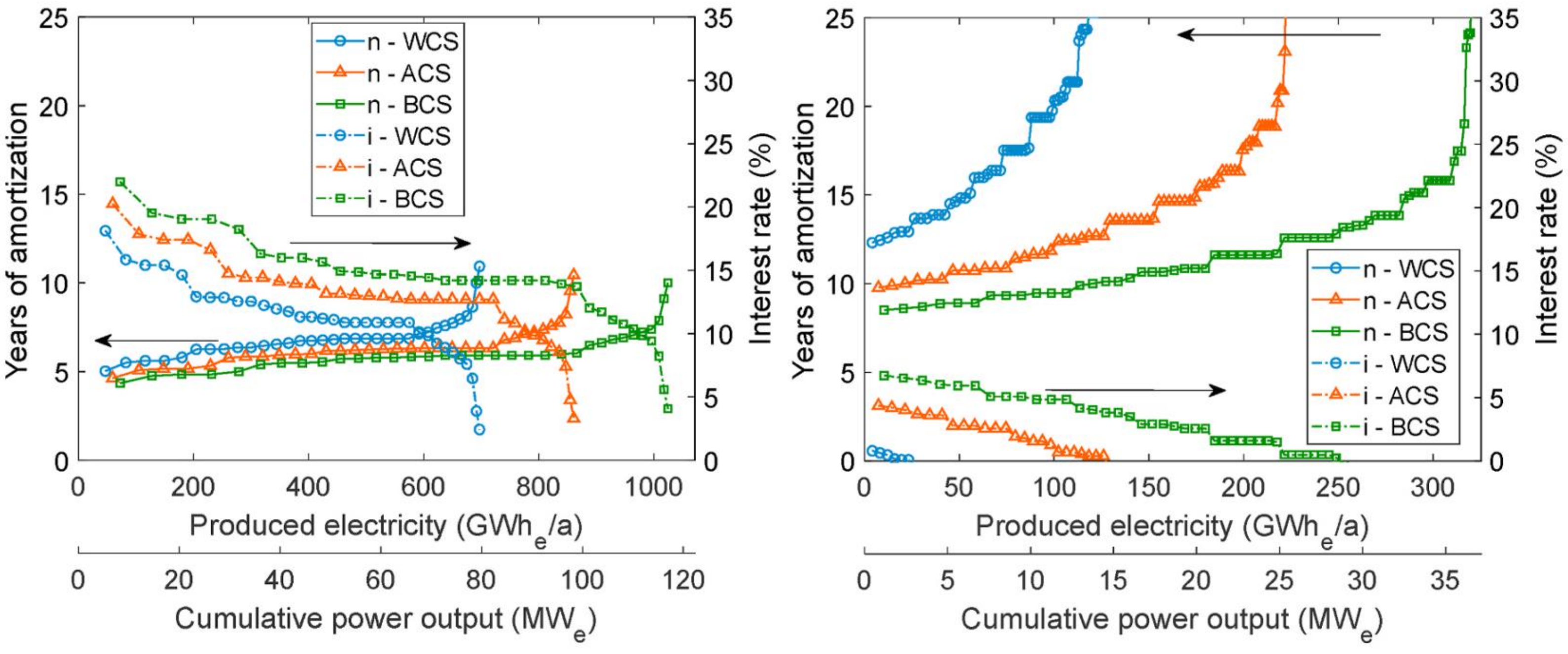
Source: [2]

Fig. 10. Economic potential for production with i = 4%, n = 10 years: (a) cement; (b) glass.

- ▶Cement case: All the investigated scenarios can use the available waste heat economically
- ▶Glass case: Bigger challenges. As waste heat recovery is more complex, electricity prices are higher

LCOE for Cement and Glass

BCS: best-case scenario
ACS: average-case scenario
WCS: worst-case scenario



Cement **Glass**

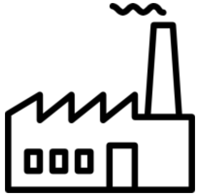
Source: [2]

Fig. 14. Boundaries for economic feasibility of WHR-ORC from: (a) cement and (b) glass.

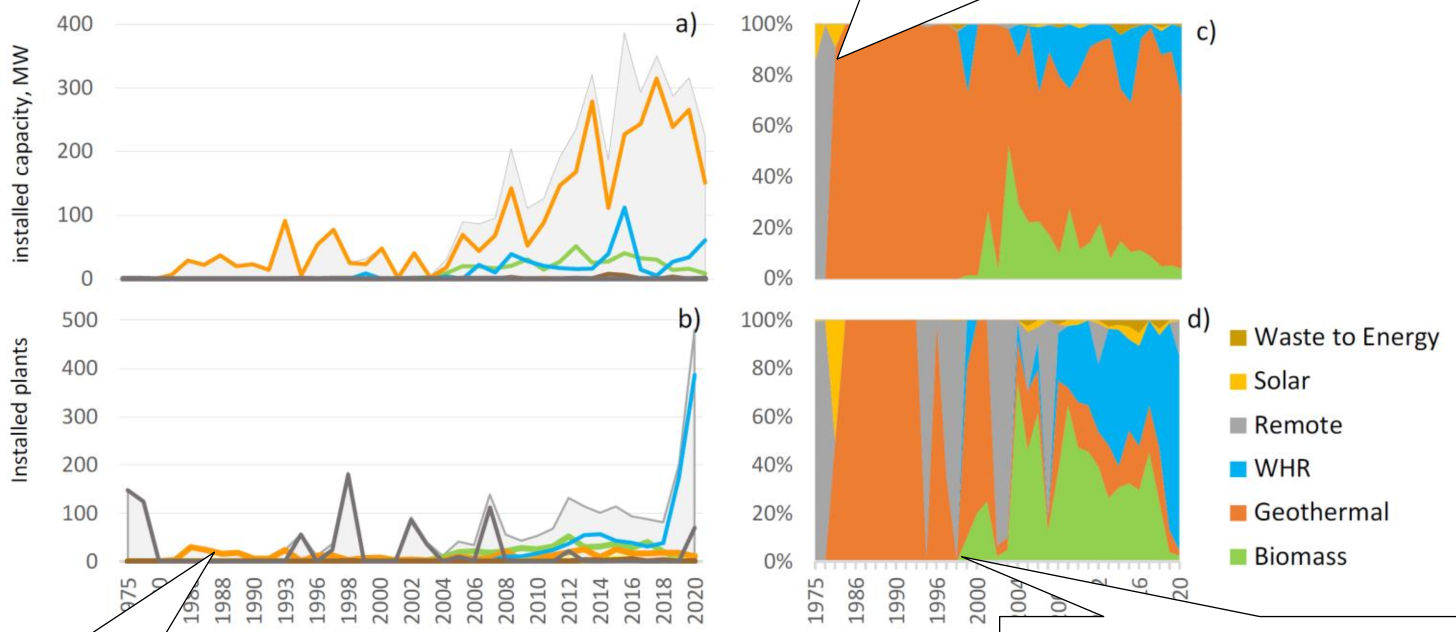
- Cement case: Payback periods are between 4-10 years. Interest rates between 4-15%
- Glass case: Payback periods are between 8-25 years. Interest rates between <0-5%

Outline

ORC Market Overview



- ▶ More than 2600 plants
- ▶ More than 4 GWe installed capacity



...re 1: Historical trend of ORC installed capacity (a) and inst... applications and relative share by year (c...

- ▶ 30 manufacturers
- ▶ Global market

- ▶ Rapidly growing market in Waste Heat Recovery

Source: [7], flaticon.com

Outline

7. Summary and Conclusion

- Waste heat recovery is abundantly available and for free.

- For optimal operation, part load should be achieved at constant temperature.

- Investment decisions need to be facilitated.
  - By incentives
  - By technological progress

- ORC technology is a mature technology, with a lot of successful plants in the field.

- Despite the above challenges, there are already today quite a number of commercially successful references.

Energy Sources for Energy Intensive Industry

Table 1
Sector and key factors for estimating flue gas properties.

	Sector	Process	Primary fuel	Non-energy-related CO_2
Power	Power generation	Boiler	Coal, oil, natural gas	
		Combined cycle	Natural gas	
Industry	Cement	Clinker production	Coal	✓
	Iron and steel	Boiler	Steel process gas	
	Refineries	Furnace	Oil	
	Ethylene	Furnace	Oil	
	Glass	Furnace	Natural gas	
	Ammonia	Hydrogen production	Natural gas	✓

Table 2
Categorization of CO_2 sources by combinations of the primary fuel inputs and combustion technologies.

	Boiler/Furnace	Combined cycle	Clinker production	Hydrogen production
Coal	Coal		CP	
Oil	Oil			
NG	NG	NG-CC		HP
SPG	SPG			
Non-energy-related CO_2			✓	✓

NG: natural gas, SPG: steel process gas, CP: clinker production, HP: hydrogen production. Note: CO_2 sources emitting non-energy-related CO_2 are identified apart from other combustion technologies.

- Basic industry uses abundant amount of fossil fuels
- The future needs a change in paradigm towards sustainable energy carriers

Source: [6]

References

[1] Astolfi, M, van Buijtenen, J, Casella, F, Colonna, P., Karellas, S, Öhman, H, Sanchez, D, Wieland, C.: Thermal Energy Harvesting - the Path to Tapping into a Large CO2-free European Power Source, (2022) https://kcorc.org/en/committees/thermal-energy-harvesting-advocacy-group/

[2] Pili, R, García Martínez, L, Wieland, C, Spliethoff, H: Techno-economic potential of waste heat recovery from German energy-intensive industry with Organic Rankine Cycle technology, Renewable and Sustainable Energy Reviews, 134 (2020), 110324

[3] Brückner, S; Liu, S; Miro, L; Radspieler, M; Cabeza, LF; Lävemann, E: „Industrial waste heat recovery technologies: an economic analysis of heat trans-formation technologies“, Applied Energy, 151, 2015

[4] Wieland, C, Schifflechner, C, Dawo, F, Astolfi, M: The Organic Rankine Cycle Power Systems Market: Report on Recent Developments and Future Perspectives, submitted to Applied Thermal Engineering.

[5] Faraci, E.: Tasio Project Deliverable 8.4 Adaptability and replicability of the developed technology (2018)

[6] Caillat, S: Burners in the steel industry: utilization of by-product combustion gases in reheating furnaces and annealing lines, Energy Procedia, 120 (2017), 20-27

[7] Wieland, C, Dawo, F, Schifflechner, C, Astolfi, M: Market report on organic Rankine cycle power systems: recent developments and outlook, 6th International Seminar on ORC Power Systems, 2021

The Potential of Waste Heat Recovery from Industry in Europe – an ORC Perspective

Dr.-Ing. Christoph Wieland
wieland@tum.de