DECARBONIZATION OF INDUSTRIAL PROCESSES AND DIGITALIZATION

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CONTENT

• Industrial Sectors

• Decarbonization Technologies

• Heat Pumps: steam and drying

• Digitalization: method for decarbonization

• Final Statements
Decarbonization = decarb. Electricity + decarb. Heat + decarb. feedstock

Many technologies already available
INDUSTRIAL SECTORS

• Pulp & Paper: drying with steam and gas firing, milling

• Chemical Industry: steam for heating and drying, cooling, feedstock

• Food: steam/hot water for heating, drying, cooling

• Iron & Steel: redox reaction (blast furnace), arc furnace, gas for metal forming

• Cement: burning, milling

• Non-ferrous metals: burning, steam for Bayer process, electrolysis
TECHNOLOGY OPTIONS & INFLUENCING FACTORS TO DECARBONIZE YOUR PROCESS

Technology options
- Thermal, electrical and chemical storage
- Direct electrification: electric arc, electric boiler, etc.
- Heat pumps + steam recompression
- H₂ gas engines & turbines
- Hydrogen (some processes require methane)
- Geothermal, deep storage (gas, heat).

Influencing factors
- Temporality of processes: Seasonal, continuity
- Process temperatures: $T < 200 \, ^\circ\text{C} < T$
- Process atmosphere: $\text{H}_2\text{O}, \text{O}_2, \text{N}_2$, etc.
- Load profiles
- Energy prices and CO₂ price
- Existing facilities: load ramps
- Plant inventory: replacement investments
- Technology costs
- Infrastructure stock: electricity, gas, district heating, costs
- Geography & Topography
FOCUS

- Heat Pump Technologies
  - General
  - Steam
  - Drying

- Thermal storages
  - Bayer Process

- Geogenic emissions & CCU vs. CCS
Who is familiar with heat pump technologies?
Industrial Heat Pumps
INDUSTRIAL HEAT DEMAND IN THE EU

EU 28:

~ 1950 TWh of process heating in industry

~ 30% of process heat at up to 200°C

BASICS OF INDUSTRIAL HEAT PUMPS
CLOSED LOOP HEAT PUMP

Source: https://www.ait.ac.at/fileadmin/mc/energy/News_Artikel/2020-07-10_whitepaper_IHP_A4.pdf
BASICS OF INDUSTRIAL HEAT PUMPS

Boundary conditions: temperature lift = 70K; isentropic efficiency = 0.7
Steam generation without fossil fuels
Closed loop steam generating heat pumps

- up to 160°C steam
- up to 90°C heat source
- up to 150°C steam
direct expansion cycles

REFRIGERANT / WORKING FLUID
synthetic and natural
low GWP

Industrial process

Condenser
Flash tank
Feed water

Evaporator
Steam supply

Expansion valve

Screw / Piston compressor

27/07/2022
28.07.2022
TYPES OF STEAM GENERATING HEAT PUMPS

Open loop steam generating = MVR

Combination of types
MARKET OUTLOOK
IMPACT ON EU LEVEL – GENERAL

• Based on energy audit data
• Limited to max. 200°C supply temperature
• Limited to max. 100°C temperature lift
• Also sizes in sense of heating capacity of industrial heat pumps

Fig. 11. Distribution of heating capacity (<30 MW) for the cumulative heating capacity of heat pump units which make up the EU28 industrial heat pump market.
MARKET OUTLOOK
IMPACT ON EU LEVEL – GENERAL

Estimated reduction of CO2 emissions

Current energy system
37,3 mio t/year

Fully decarbonized electricity system
52,6 mio t/year

Estimated necessary investments
4.6 to 11.5 billion €

Shares per sector:
- Paper: 1.5%
- Food: 33.0%
- Chemistry: 40.5%
- Refinery: 25.0%

Marina A. et al: An estimation of the European industrial heat pump market potential; Renewable and Sustainable Energy Reviews; Volume 139, April 2021, 110545
MARKET OUTLOOK
IMPACT ON EU LEVEL – STEAM GENERATION

Current energy system

Low pressures steam (<150°C)
significant share of

Future heat pump market - about
3,5 to 8,6 billion €

Reduction of CO2 emissions - about
21 to 35 mio t/year

[Image: Marina A. et al: An estimation of the European industrial heat pump market potential; Renewable and Sustainable Energy Reviews; Volume 139, April 2021, 110545]
ACKNOWLEDGEMENT

• H2020 project Bamboo (GA No. 820771)

• development of technologies for the valorization of waste streams and electrical flexibility

• 4 demonstrations in resource and energy intensive industries (steel, petrochemical, mineral, paper)

• heat pump steam generator for 5 bara steam

In BAMBOO EDF and AIT are working with various partners to increase the use of industrial heat pumps with a focus on steam generation.

Partners: CIRCE, TU Braunschweig, AIT, IKERLAN, CERTH, EI-JKU, N-SIDE, Turboden, AMT Kältetechnik, Électricité de France, RINA Consulting, COSMO TECH, ARCELOR MITTAL, TUPRAS, Grecian Magnesite, UPM, SIDENOR, Magnesitas Navarras, ICONS
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Drying without fossil fuels
CONVENTIONELL VS. HEAT PUMP
PRELIMINARY PROJECT ON BRICK DRYING

Supply air = Recirculation air

Drying chamber

Exhaust air

Burner

Recirculation air

Supply air

Drying air

Drying chamber

Hot media cycle

Heat pump

Cold media cycle

https://energieforschung.at/projekt/effiziente-trocknung-mit-kompressionswaermepumpen/
Closed loop heat pumps

DryFiciency: Industrial Heat Pump


AIT Austrian Institute of Technology
Closed loop HP

Compressor adaptation to high temperatures applications

Viking Heat Engines AS
Piston compressor

Lubricant by Fuchs Schmierstoffe GmbH
Providing sufficient viscosity for the compressors, compatibility with OpteonMZ, chemically stable

Bitzer Kühlmaschinenbau GmbH
Screw compressor

up to 160°C

Heat supply for industrial drying

Condenser

about 80°C

Industrial heat source

Evaporator

Wienerberger AG & Agrana Stärke GmbH

Expansion valve

OpteonMZ as refrigerant by Chemours
non flammable, non explosive, non toxic, low GWP
Overview on COP

Environmental impact: End energy and CO₂ emission reduction

Comparison to a natural gas burner (90% efficiency, 8400 h/a)

CO₂ emissions natural gas: 271 g/kWh

CO₂ emissions electricity: 258 g/kWh
Outlook

- Assume that 50% of all drying processes in Europe are equipped with a DryFiciency heat pump
- Replace natural gas burners
- Impact on end energy consumption, primary energy and CO2 emissions
Actual status

Integration HTWP and TS

Heating capacity 50 kW
Source temperature 60 °C
Sink temperatures (i/o) 100/130 °C
Condensation temperature 127 °C
Evaporation temperature 55 °C
Digitalization – Methods for Decarbonization
1. Heat storage to overcome the mismatch between availability of fluctuating renewable electric power (solar-electric and wind) and industrial electricity or heat demand.
2. Heat storage to overcome the mismatch between availability of renewable thermal energy (solar-thermal, geothermal) and industrial heat demand.
3. Cold storage to overcome the mismatch between availability of fluctuating renewable electric power (solar-electric and wind) and cold demand.
4. Heat storage to improve the recovery of waste heat from industrial batch processes, to increase industrial process energy efficiency.
5. Heat storage to store waste heat for district heating applications.
6. Heat / cold storage to deliver back-up heating / cooling in industrial processes.
7. Peak-shaving
System changes are triggered by events, e.g. end of life of use.
ECONOMIC DESIGN OF DECARBONISED STEAM GENERATION – IN A NUTSHELL

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ECONOMIC DESIGN OF A DECARBONISED STEAM GENERATION

- Steam demand
- Varying energy prices
- Steam generation
  - Electric boiler
  - High temperature-HP
- Storage technologies
  - Ruths, latent, concrete, molten salt
ECONOMIC DESIGN OF A DECARBONISED STEAM GENERATION

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MILP/MILQ - Optimisation
- Cost functions
- Energy demand
- Energy prices
Cooperation of Sintef and AIT as spin-off project in the HighEFF framework

Project Team (alphabetical order):
- Anton Beck (AIT)
- Alexis Sevault (SINTEF)
- Gerwin Drexler-Schmid (AIT)
- Michael Schöny (AIT)
- Hanne Kauko (SINTEF)

Links
- HighEFF (sintef.no)
- Paper in Applied Sciences
DIGITALISATION - WHAT IS NEEDED?

• Monitoring of all major electricity consumers on hourly basis

• Monitoring of major energy
  • Input
  • Utilization
  • Waste heats
  • On hourly basis
Decarbonization Example: Pharmaceutics
• Intermittent production (various batch processes)
• Small-scale industry (< 10 MW steam)
• Limited area for PV / Solar thermal available

• Current energy supply units
  • Gas boiler for steam production
  • Electricity powered refrigeration system (excess heat potentials)

• Electricity price: 10 c/kWh, fixed
• Gas price: 8 c/kWh, fixed
DEMAND:
STEAM AND COOLING

![Chart showing steam and cooling demand over an annual course.]
100% CO₂-reduction

Heat load / power (kW)

One year (hours)

Energy (GWh)

- excess heat
- district heating
- electricity purchase
- PV

sum

28.07.2022
Carbonates - Calcination
CARBONATES, GEOGENIC EMISSIONS

- Cement: \( \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \)
- Magnesium: \( \text{MgCO}_3 \rightarrow \text{MgO} + \text{CO}_2 \)

- CCU shifts direct emissions (scope 1) to indirect emissions (scope 3)
- 80% of current Austrian plastics demand could be covered with \( \text{CO}_2 \) emissions from cement industry, at a current recycling rate of only 8%
- Possible future recycling rate 80% would lead to an 60% overproduction
- Use CCS for geogenic emissions (trees)
Conclusio
Approx. 50% of primary energy can be saved, sometimes more, sometimes less.

- Decrease process temperature if possible – rethink the process.
- Increase cooling temperatures.
- Use heat recovery!
- Avoid to burn stuff!
- Look at the whole system! – Every investment must be puzzle piece for an 100% decarbonized systems.
NEFI PROJECT MAP

Geographical distribution of projects and industrial sites

FURTHER INFORMATION:
www.nefi.at/projects

BC4I – Biochar for industry
Clean Energy for Tourism – Load Management in the field of power grids
DSM_OPT - Demand Side Management: Operation Optimization of Industrial Energy Systems
EDCSPPROOF – Process flexibility and efficiency in the food industry
EDDY – Enhanced drying in the agricultural commodity and food industry
ENVIOTCAST – environmentally friendly casting
GmundenHTLink – High temperature waste heat utilization in the cement industry
Heat Highway – Interregional heat transfer networks
HyStEPs – Hybrid steam storage in the steel industry
Industrial Microgrid – Energy exchange between industrial companies
Industry4redispach
LEAP – Low Pressure Steam Heat pump
Oxysteel – Energy efficiency through oxygen input in steel production
SANBA – low temperature waste heat utilization from food industry
SBM_IND – demand-oriented and network-related marketing of industrial flexibility potentials
TCP_to_Industry – Thermal cracking process for energy recovery to industry
THANK YOU!

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