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• Based in Gothenburg, Sweden’s west coast
• Conducts research and education in technology and natural science
• Offers education in engineering, natural sciences, shipping and architecture
• 10,000 students and 3400 employees
• Founded in 1829
Transformative change for deep decarbonization of industrial systems
The role of Industrial symbiosis

"Industrial symbiosis systems collectively optimize material and energy use at efficiencies beyond those achievable by any individual process alone”

Key message
Advanced detailed planning and a wide system perspective are necessary in order to harness symbiosis benefits when implementing deep decarbonization measures
A structured approach to maximizing energy symbiosis in industrial facilities

- Improved unit operations
- Control systems
- Housekeeping
- Advanced heat recovery concepts
- Transformative changes of process design and/or energy supply

Process integration for Advanced heat recovery:
- Recover heat from one process to be reused in another (within one plant or adopting a site-wide approach)
The importance of upfront design for energy symbiosis. The case of energy integration opportunities in the chemical cluster in Stenungsund, Sweden

- Total heating requirements: 442 MW of which
  - 320 MW heat recovery
  - 122 MW from boilers fired with purchased fuels

- The heating requirements covered by fired boilers can theoretically be reduced to 0 MW by efficient heat exchanging between all plants at the site (potential energy symbiosis benefits: 27% savings)

Achieving the full potential retroactively is complicated and highly expensive.

When implementing transformative changes in industrial processes, important to allocate sufficient resources during initial planning stage so as to identify opportunities for energy symbiosis.

- Sweden’s largest chemical cluster
- GHG emissions ~1 Mt/a (6th largest point source)
- Fossil feedstock ~20 TWh/a (4th largest consumer)
- Built in 1960s without consideration for interplant energy efficiency
Energy market conditions including policy instruments (background conditions) will be very different in the future. Energy symbiosis projects should be assessed for a range of scenarios.

Innovative design for industrial symbiosis:
- Clustering in Eco-industrial parks
- Deliver excess heat to a regional heating network or other off-site heat sink
Energy supply mix
Swedish district heating sector

- Other 0.26 TWh (2019)
- Peat 0.67 TWh (2019)
- Renewables 22.0 TWh (2019)
- Energy recovery 30.0 TWh of which industrial excess heat 4.6 TWh (2019)
- Fossil fuels 1.96 TWh (2019)

CO₂ intensity g/kWh

Energy recovery 30.0 TWh of which industrial excess heat 4.6 TWh (2019)
Context and challenge

Swedish climate targets

<table>
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<th>Historical emissions</th>
<th>Climate target</th>
<th>Climate targets in the Climate Policy Framework</th>
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<td>Sweden’s emissions in total</td>
<td>-26% 1990-2017</td>
<td>Net-zero by 2045 Max 15 percentage points supplementary measures</td>
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| Emissions from sectors outside the EU ETS | -30% 1990-2017 | -40% by 2020 Max 13 percentage points supplementary measures | -63% by 2030 Max 8 percentage points supplementary measures | -75% by 2040 Max 2 percentage points supplementary measures |

| Emissions from domestic transportation | -19% 2010-2017 Excl. domestic aviation | -70% by 2030 Compared to 2010 |

How can the benefits of delivering industrial excess heat to a district heating network be assessed if all sectors involved (heating sector, power sector and industry sector) are aiming for zero emissions by 2045?
Regional energy symbiosis: exporting excess process heat to a district heating system

- Up to 150 MW of excess heat suitable for district heating available after energy efficiency measures within the cluster
- Not profitable to build a heat pipeline today but attractive for a range of scenarios for 2030 and beyond
In-depth inventory of available excess heat and estimation of capital costs to collect the heat (*energy and cost targeting*)
Requires early decommissioning of NGCC CHP plant (261 MW_{el}, 294 MW_{h})

Candidate solutions

- Green gas fuel to CHP
- Seasonal heat storage
- New Bio-CHP plant
- Or increased supply of industrial excess heat
Ex-ante comparison of investment options using energy market scenarios

**Key question** for district heating operator: Which heat supply option will generate most revenue and has greatest potential for CO₂ emissions abatement in the future?

**Solution**: construct scenarios with possible consistent combinations of future energy prices, policy instruments and energy market description.

**Challenge 1**: energy prices, energy market policy instruments as well as the carbon intensity of energy carriers in the surrounding system will change over time.

**Challenge 2**: how will availability of biomass change over time?
Conclusions – GHG emissions reduction

- The climate benefit of increased usage of industrial excess heat depends on the future development of the background energy system.
- Excess heat from Stenungsund could facilitate Göteborg Energi’s goal to become fossil-free by 2025-2030.
- Investing in a Bio-CHP unit is preferable as long as reference power generation is fossil-based and biomass is not a limited resource (current situation).
- In a future situation with fossil-free electricity and limited biomass availability, maximum recovery of excess heat from Stenungsund could reduce GHG emissions by approx. 200 kton/a (2% of the current regional emissions, 20% of the petrochem complex emissions).
Possible future game changer: CCS versus district heating?

- Competition for heat
- Heat integration

- Decarbonisation
- Decarbonisation & climate services

Industrial excess heat

CCS

District heating

CHP plants

Sweden: A lot of biomass / biogenic waste
Example: CO\textsubscript{2} capture from HPU at a modern refinery
Heat req: 52 MW
Results: HPU - 52 MW supply

Obj fct: minimize annual costs

All economically attractive excess heat is used for CCS. HPU accounts for ~40% of refinery CO₂ emissions.
Assessing Industrial Symbiosis Concepts: the Importance of System Boundaries

Combining expansion in pulp capacity with production of sustainable biofuels – Techno-economic and greenhouse gas emissions assessment of drop-in fuels from black liquor part-streams

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Pulp production and recovery cycle – black liquor treatment often a bottleneck
Comparing candidate biorefinery concepts

Lignin separation and upgrading to diesel and petrol

Black liquor gasification combined with methanol-to-gasoline (MTG)

Summary: Industrial symbiosis and deep decarbonization

Plan early and adopt a wide system perspective in order to harness symbiosis benefits when implementing deep decarbonization measures.

Commit expert resources at the early-planning stage. Draw system boundaries carefully so as to identify potential symbiosis effects as early as possible.

Adopt a long-term perspective: what is not profitable today may well become attractive later on. Explore and assess symbiosis options for a wide range of scenarios.