KTH ROYAL INSTITUTE
OF TECHNOLOGY

Utilizing Industrial Waste Heat for Power Generation Using sCO_2 Cycles

Björn Thorsson, Hady Soliman, Silvia Trevisan, Rafael Guedez

Table of Content

EGI & HPT at KTH

KTH Royal Institute of Technology

- 18 Master programmes in Engineering
- More than 13,000 active students and 5,000 employees

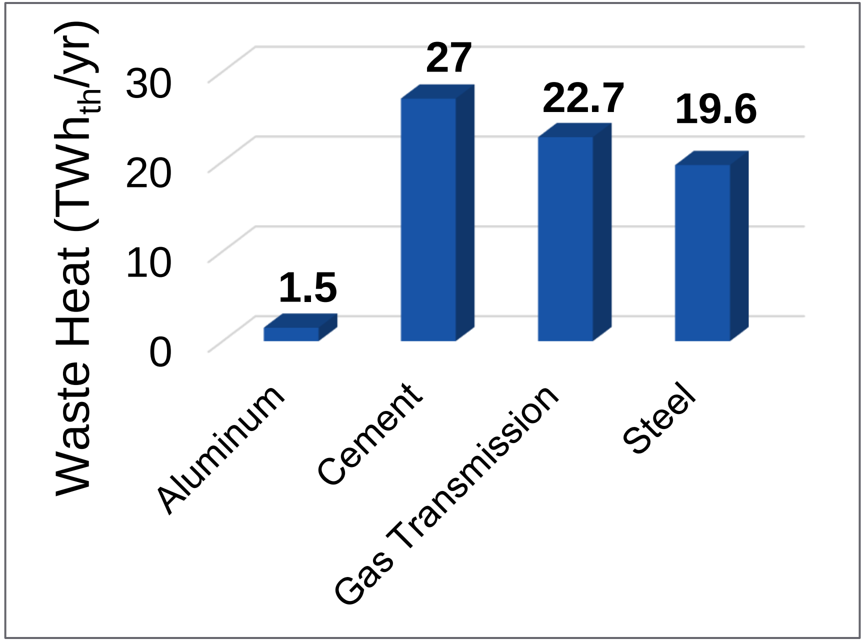
Energy Department – Heat and Power Technology

- Centralized & Distributed Renewable Energy Systems
- Thermal Process & Heat Transfer
- Turbomachinery & Propulsion

https://www.energy.kth.se/heat-and-power-technology

Motivations

- Power and Industry sectors account for:
  - 60% of global CO_2 emissions (1).
  - 61% of global Primary Energy Consumption (2)
- 72% of global PEC is lost as waste heat (3)
- EU has waste heat of 300 TWh/year (4)
  - 54% of Sweden's TPES (5)
- Conventional methods have efficiencies between 15-30%



70.8 TWh$_{th}$/yr

Objectives

1. **Identify industries** whose techno-economic performance might be enhanced by the introduction of sCO_2 based waste heat recovery units.

2. Propose a series of **sCO_2 cycle layouts integration**

3. Evaluate the **techno-economic performance** of the proposed layout integrated in the identified industries

Methodology

Industry Analysis

- EU Production capacity
- Available heat streams and waste heat

Model Development

- Design of sCO_2 layout
- MATLAB model development

Techno-economic Optimization

- Economic Analysis
- System optimization

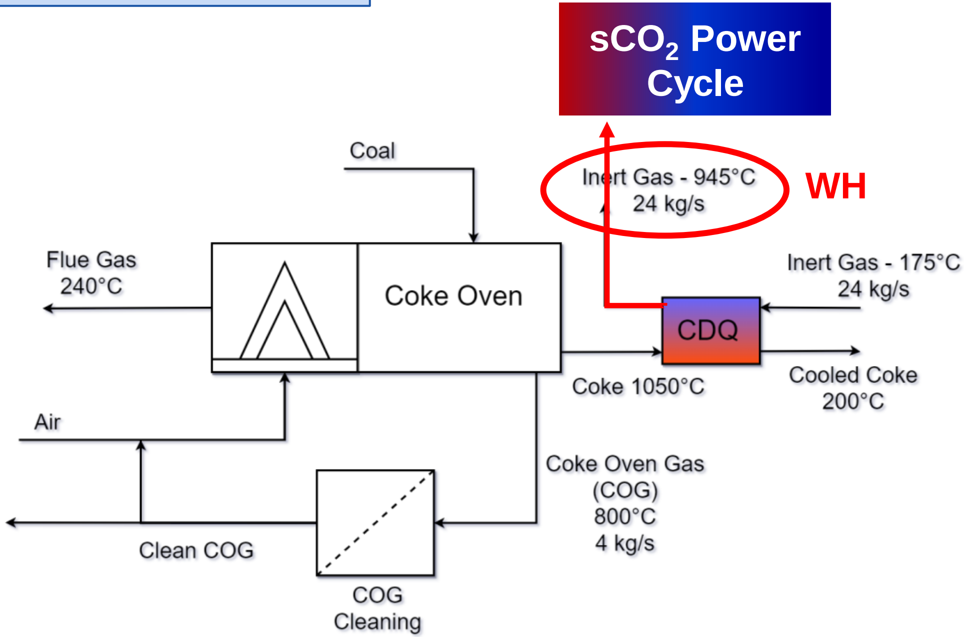
Results Analysis

- Thermal & environmental KPIs
- Sensitivity Analyses

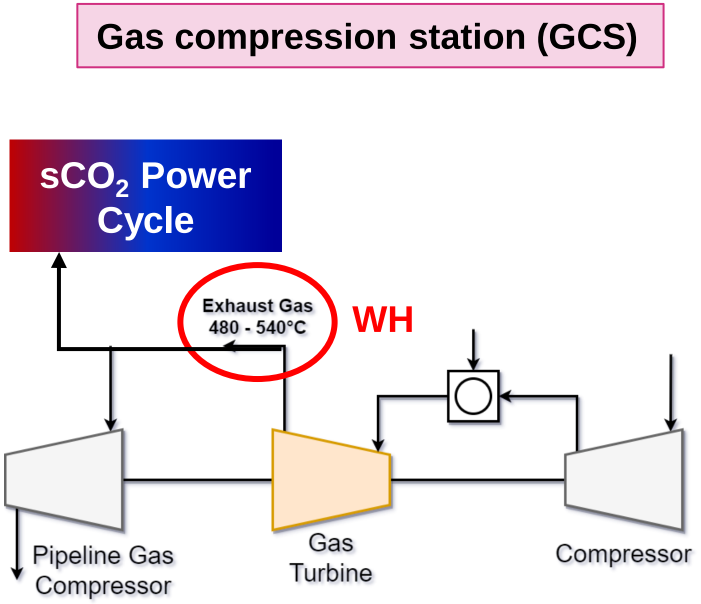
Industry Current Main Layouts & sCO_2 Integration

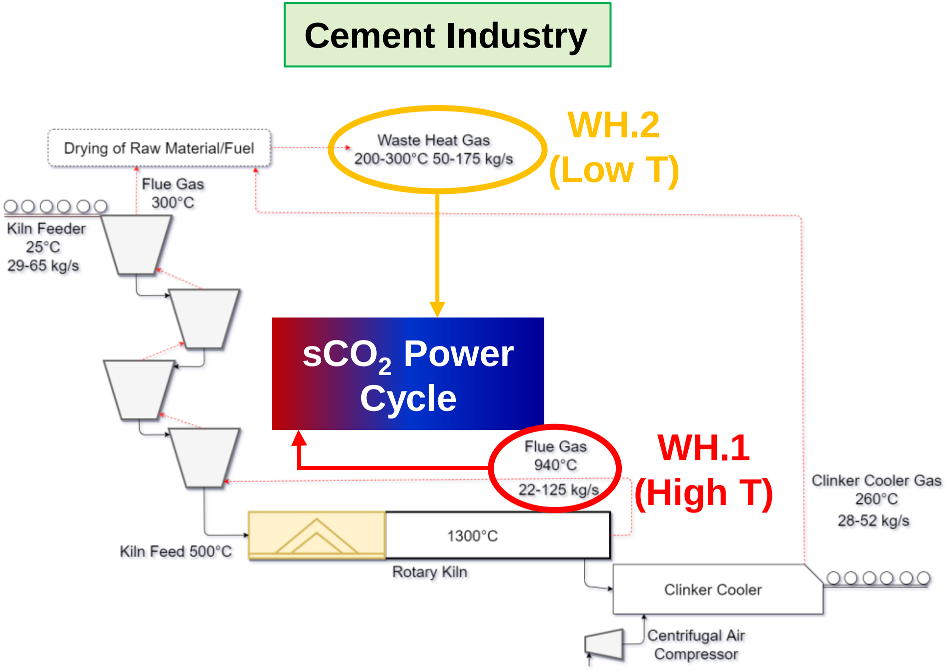
Coke dry quenching (CDQ)

https://www.eng.nipponsteel.com/english/whatwedo/steelplants/ironmaking/coke_dry_quenching/



Industry Current Main Layouts & sCO_2 Integration

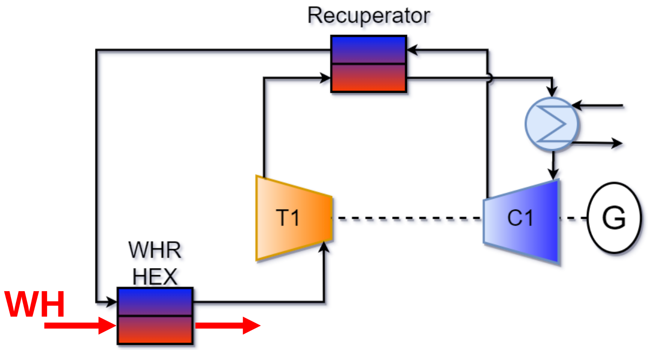




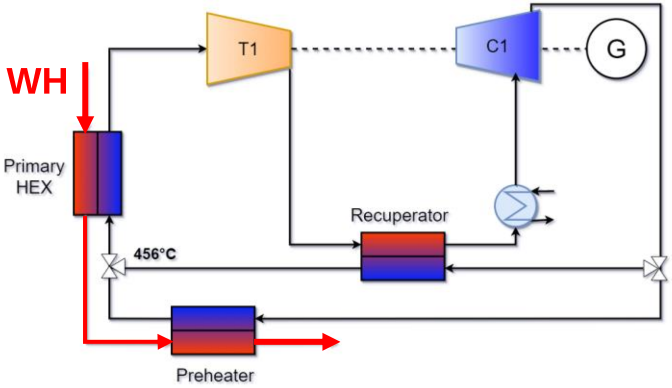
Studied Cycle Configurations

1. **Simple Recuperated Brayton Cycle**
2. Recompression Cycle
3. Combined Cycle with Brayton
4. Combined Cycle with Recompression
5. **Preheating**
6. Dual Recuperated

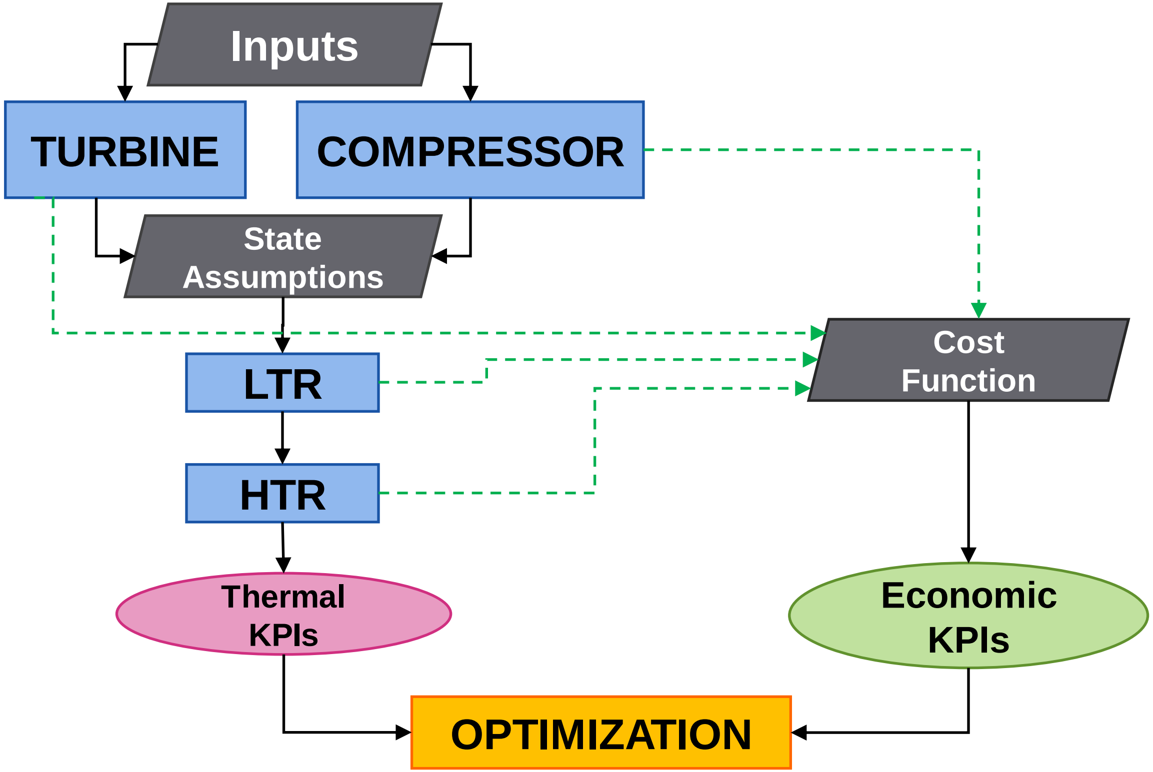
Simple Recuperated Brayton



Preheating



Modelling



Parameter (as from (6,7))	**Value**
Turbine Isentropic Eff., %	93
Compressor Isentropic Eff., %	89
Generator Eff., %	98
Pressure losses HEX, %	1
Downtime, %	15
Project lifetime, years	25
Nominal Discount, %	6
Electricity price, €/MWh	65

Key Performance Indicators

Net Present Value (NPV) $= \sum_{t=0}^{n} \frac{el_{price} \times E_t - costs}{(1+i)^n}$

$$LCOE = \frac{sum\ of\ costs\ over\ lifetime}{sum\ of\ power\ generated} = \frac{\sum_{t=0}^{n} \frac{\text{Costs}}{(1+\text{i})^{\text{t}}}}{\sum_{t=0}^{n} \frac{E_t}{(1+\text{i})^{\text{t}}}}$$

Thermal Efficiency $= \frac{Electrical\ energy\ produced}{Required\ Thermal\ power} = \frac{\dot{P}_e}{\dot{Q}_{th}}$

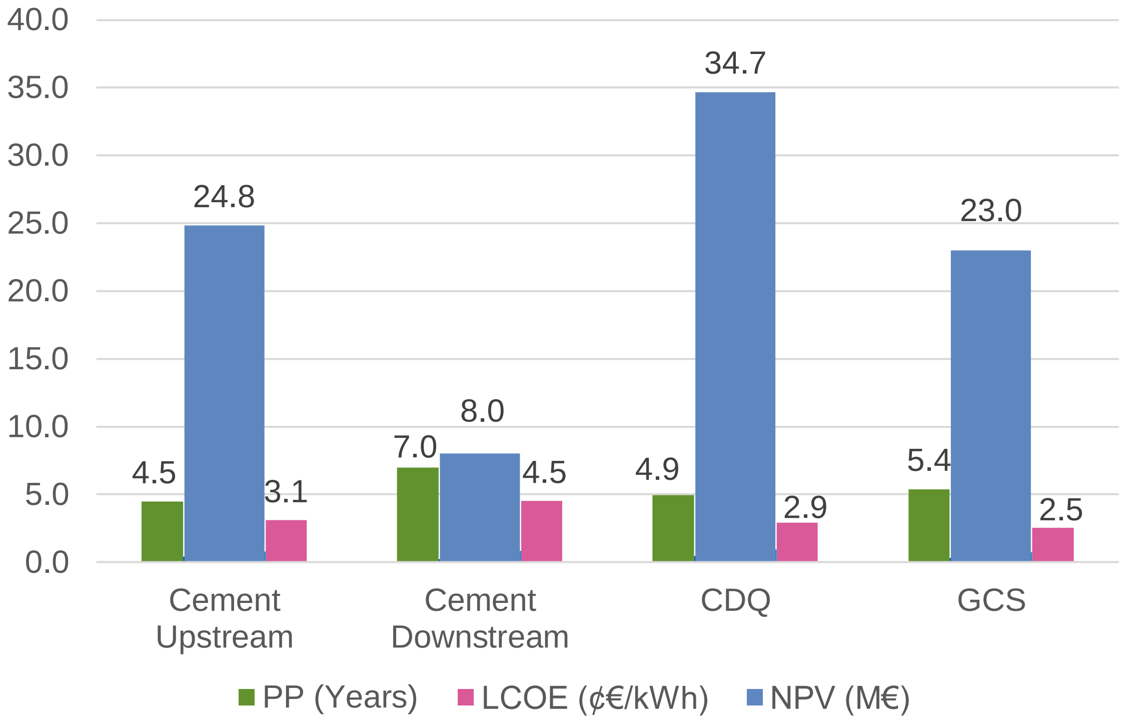
Payback Period $= \frac{Capital\ Cost}{Annual\ Cashflow}$

Waste Heat Utilized $= \frac{Exploited\ WH}{Total\ WH} = \frac{\dot{Q}_{WHEX}}{\dot{Q}_{exhaust}}$

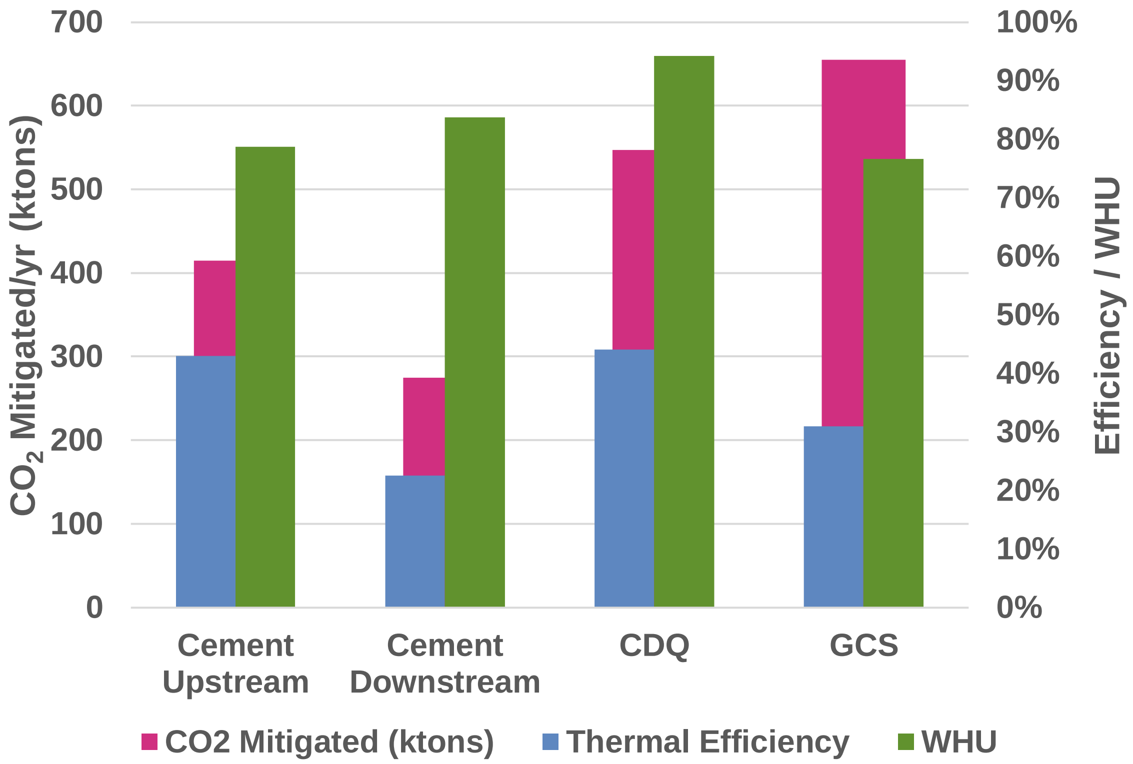
CO_2 Mitigated $= E_t \times EU_{Emission\ Factor}$

Results.1

Industry	Config.	Net Power Output [MW]
Cement Upstream	SRBC	9.4
Cement Downstream	SRBC	5.5
CDQ	Preheating	10.9
GCS	Preheating	13

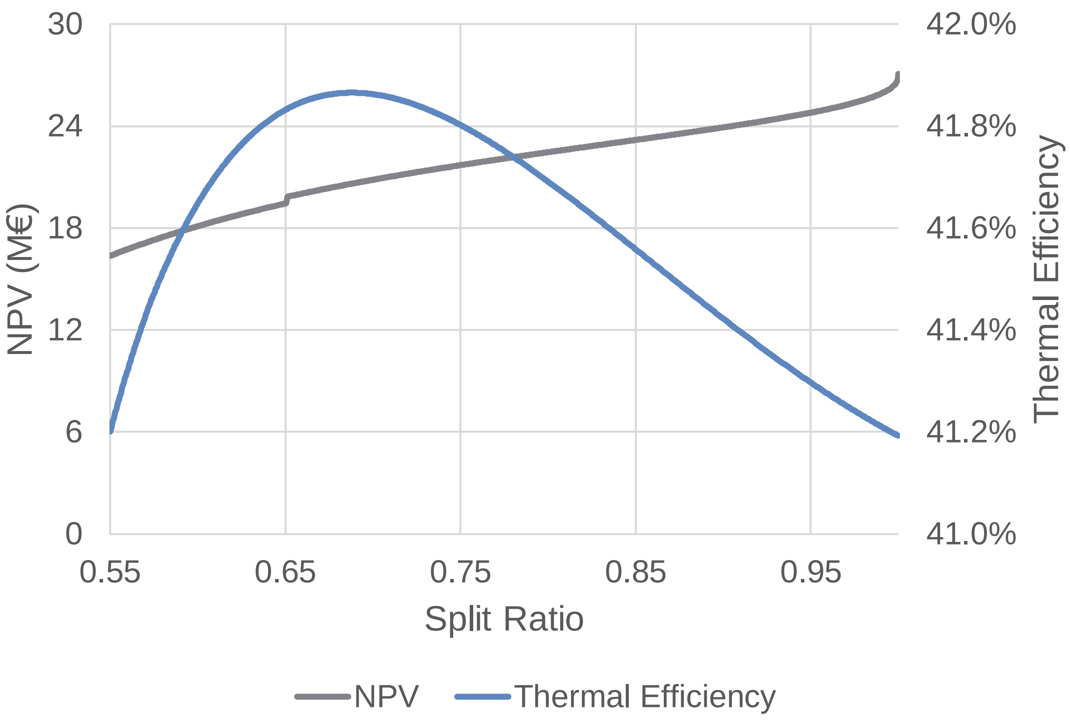


Results.2



700
600
500
400
300
200
100
0
CO2 Mitigated/yr (ktons)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Efficiency / WHU
Cement Upstream
Cement Downstream
CDQ
GCS
CO2 Mitigated (ktons)
Thermal Efficiency
WHU

Results.3



30
24
18
12
6
0
NPV (M€)
42.0%
41.8%
41.6%
41.4%
41.2%
41.0%
Thermal Efficiency
0.55
0.65
0.75
0.85
0.95
Split Ratio
NPV
Thermal Efficiency

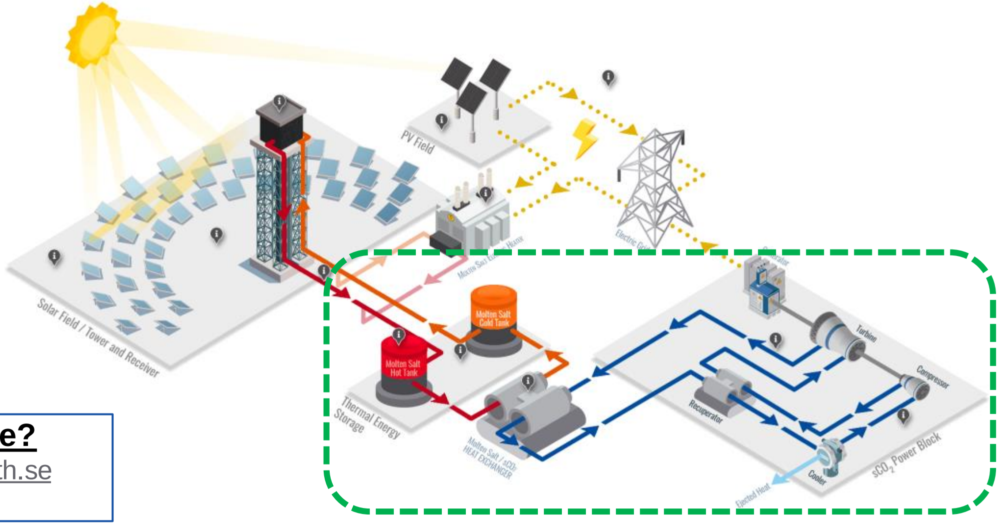
Conclusions

1. **Preheating Cycle** is best suited for waste heat recovery applications
2. **Thermal efficiencies** are limited to **40%** for financial feasibility
3. **CDQ Industry** most promising for a demo site
4. **LCoE** of about **3c€/kWh** can be attained

SOLARsCO2OL project

- Develop a **first of a kind MW scale sCO_2 – CSP integration** demonstration
- **Increase flexibility and efficiency** of CSP plants
- **Reduce CSP LCoE** below 10 c€/kWh
- **Components development** (turbomachinery, heat exchangers and MS electrical heaters)

https://www.solarsco2ol.eu/



Curious? Do you want to know more?
Dr. Rafael Guedez - rafael.guedez@energy.kth.se
Silvia Trevisan – trevisan@kth.se

KTH ROYAL INSTITUTE
OF TECHNOLOGY

Thank you!

Questions??

Björn Thorsson, Hady Soliman, Silvia Trevisan, Rafael Guedez

Dr. Rafael Guedez - rafael.guedez@energy.kth.se
Silvia Trevisan – trevisan@kth.se

References

1. Lead (n.d.), ‘Sources of co2’, CARBON DIOXIDE CAPTURE AND STORAGE p. 75.
2. https://www.eia.gov/totalenergy/data/browser/
3. Forman, Clemens, et al. "Estimating the global waste heat potential." Renewable and Sustainable Energy Reviews 57 (2016): 1568-1579.
4. Papapetrou, Michael, et al. "Industrial waste heat: Estimation of the technically available resource in the EU per industrial sector, temperature level and country." Applied Thermal Engineering 138 (2018): 207-216.
5. http://energimyndigheten.a-w2m.se/FolderContents.mvc/Download?ResourceId=174155
6. S. Trevisan, R. Guédez, B. Laumert, Thermo-economic optimization of an air driven supercritical CO2 Brayton power cycle for concentrating solar power plant with packed bed thermal energy storage, Sol. Energy. 211 (2020) 1373–1391. https://doi.org/10.1016/j.solener.2020.10.069.
7. BMWi (2017), ‘Zahlen und fakten energiedaten-nationale und internationale entwicklung’.