GREENING A CEMENT PLANT USING sCO_2 POWER CYCLE

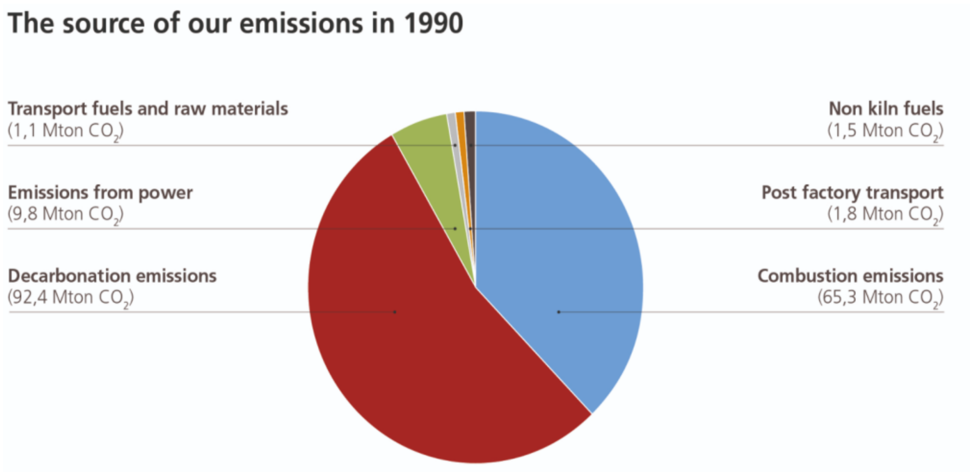
Ladislav Vesely, Prabu Thangavel, S. Gopinathan, Otakar Frybort, Ganesan Subbaraman, Jayanta Kapat

Center for Advanced Turbomachinery and Energy Research (CATER), University of Central Florida
PSG college of technology, Peelamedu, Coimbatore, India
Research Centre Řež, Husinec, Czech Republic

The 4th European sCO_2 Conference for Energy Systems
March 22-26, 2021, Prague, Czech Republic

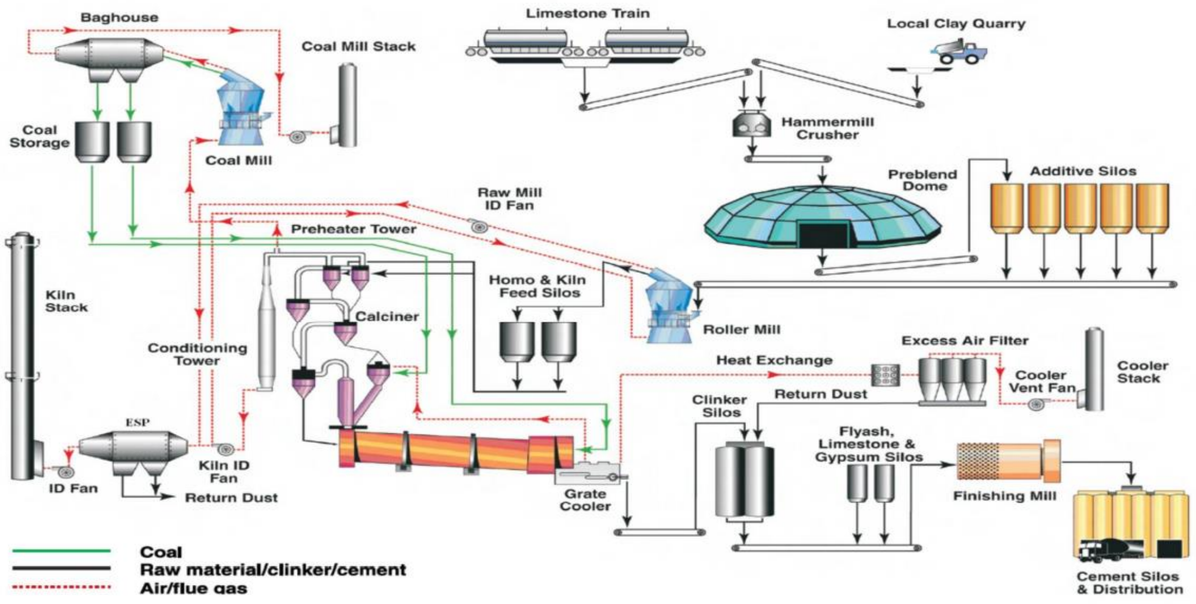
Topics

- Introduction
- Sources of waste heat and Available Potential
- Supercritical CO2 Power Generation Cycle Selection
- Scope and Novelty of the work
- Mechanism of Waste Management Through Coprocessing In Cement Kiln
- Plant Description
- Mechanism of Waste Management Through Coprocessing In Cement Kiln
- ACC Madukkarai plant Layout showing Available Heat Potential
- sCO2 System Design
- Demo plant unit operating parameters
- T-S diagram of the sCO2 demo plant unit RESULT ANALYSIS
- Comparison of Demo and Commercial Units
- Results
- Conclusions & Recommendations



Introduction

- Cement production is an energy-intensive process.
- Cement production requires raw materials to be heated to 1650°C.
- Thermal energy only accounts for approximately 35% of the cement industry's CO_2 emissions.
- Based on GNR (Getting the Numbers Right) data for the year 2010, the European average thermal energy needed to produce a tone of clinker is 3,733 MJ.
- Exhaust gases from kiln operations can reach up to 600 °C. – Potential heat source for waste heat recovery systems
  - Supercritical Carbon dioxide (sCO_2) power.
  - Due to the compactness of the sCO_2 turbomachinery, the equipment can also be retrofitted in existing plants.
- Improving the energy efficiency of a cement plant will dramatically improve its bottom line.
  - Waste Heat Recovery systems are the key for transfer current cement plants to greening cement plants



PROCESS FLOW DIAGRAM OF CEMENT PLANT

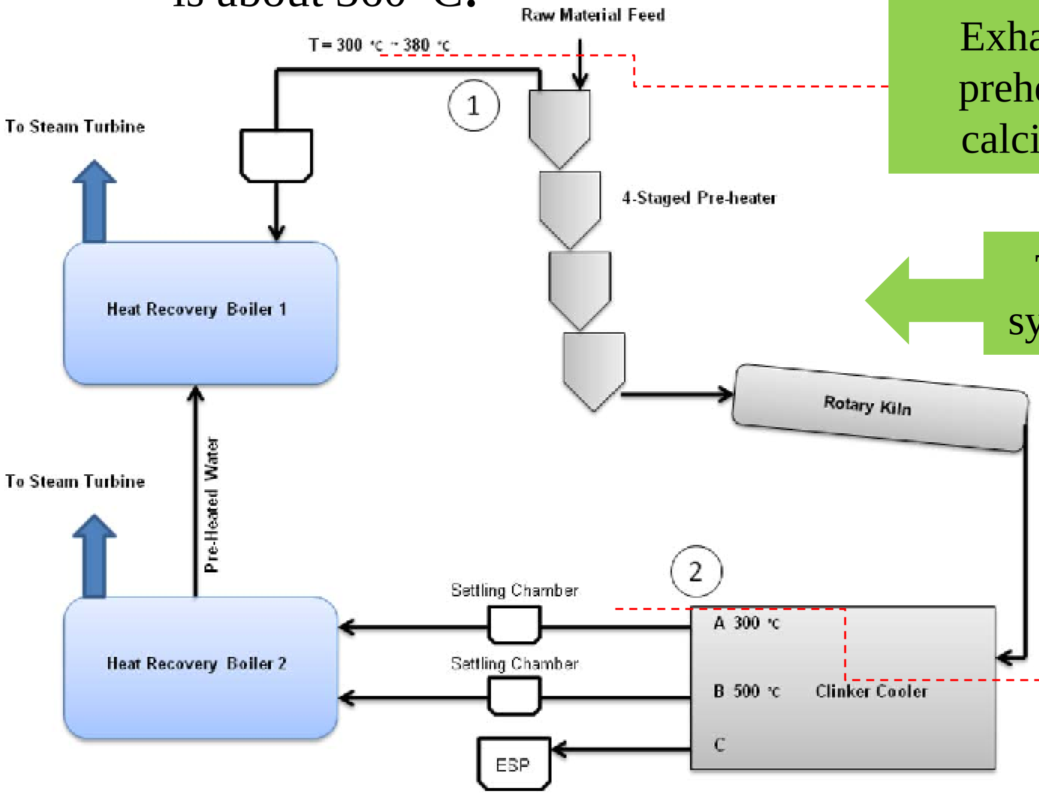
Sources of Waste Heat and Available Potential

- Exhaust gases from the rotary kiln:
  - The temperature range for gases after going through a preheater is around 380◦C.
- Hot air waste from clinker cooler:
  - The average temperature range for hot air from grate cooler is about 360◦C.

Source taken from A. Amiri and M. R. Vaseghi, "Waste Heat Recovery Power Generation Systems for Cement Production Process," in IEEE Transactions on Industry Applications, vol. 51, no. 1, pp. 13-19, Jan.-Feb. 2015.

Source	Energy Consumption MJ / yr	Avg. Exhaust Temp. ° C	Waste Heat 25 ° C MJ / yr	Waste Heat 150 ° C MJ / yr	Carnot Efficiency %	Work Potential MJ / yr
Wet Kiln	103	340	20	10	50	11
Dry Kiln						
No Preheater	85	450	22	14	60	13
Preheater	72	340	15	7	50	7
Precalciner	151	340	32	16	50	16
Total	**411**		**89**	**47**		**47**

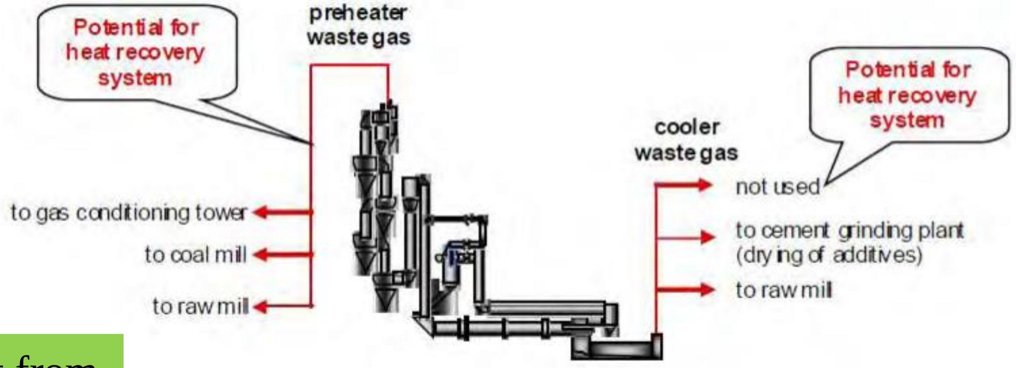
Uncovered waste heat and work potential from exhaust gases in cement kilns



Exhaust gases after preheating and pre-calcining (point 1)

Typical heat recovery system in a cement plant

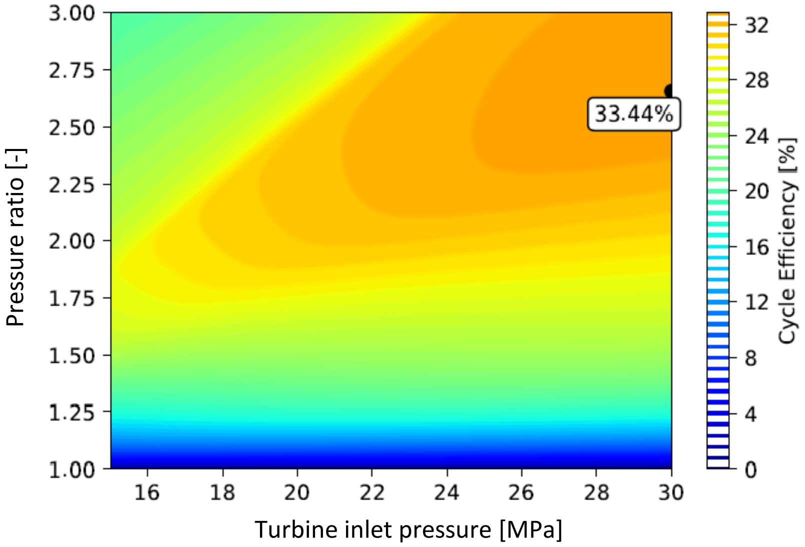
Potential recovery heat from clinker cooler (point 2).



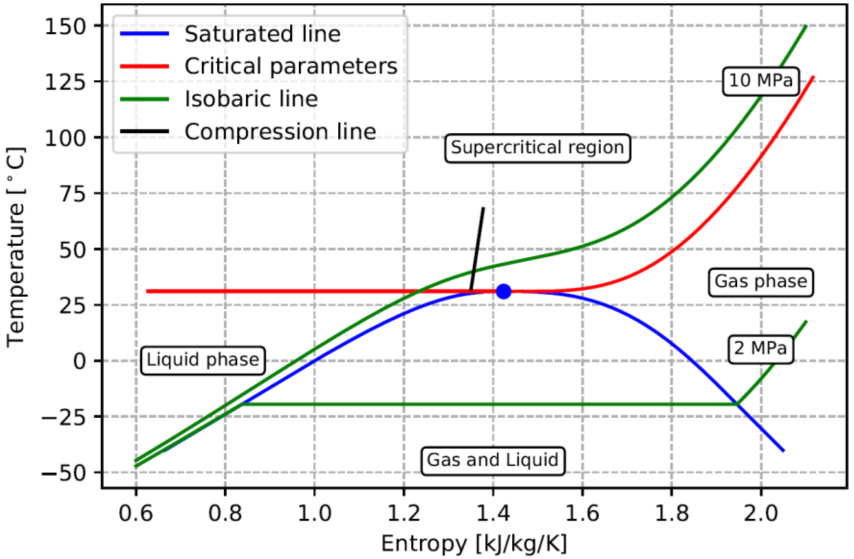
Supercritical CO_2 Power Generation Cycle Selection

- The Supercritical CO_2 (sCO_2) power cycle is a relatively new concept with high efficiency.
- The main reason for the interest of the sCO_2 power cycle is its theoretical and practical promise of compactness, high efficiency, and wide-range-applicability.
- The sCO_2 power cycle can be used for majority of heat sources, which are used in energy conversion systems
- The main applications:
    - waste heat recovery systems
    - solar power plants
    - geothermal power plants
    - fossil power plants
    - nuclear power plants

Application	Power [MWe]	Operation Temperature [°C]	Operation Pressure [MPa]
Nuclear	10-300	350-700	20-35
Fossil fuel (syngas, natural gas, coal)	300-600	550-1500	15-35
Geothermal	10 - 50	100-300	15
Concentrating solar power	10 - 100	500 - 1000	35
Waste heat recovery	1 - 10	200 - 650	15- 35



L. Vesely, "Study of power cycle with supercritical CO2," Dept. Energy Eng., Czech Tech. Univ. Prague, Prague, Czechia, Tech. Rep., 2018.

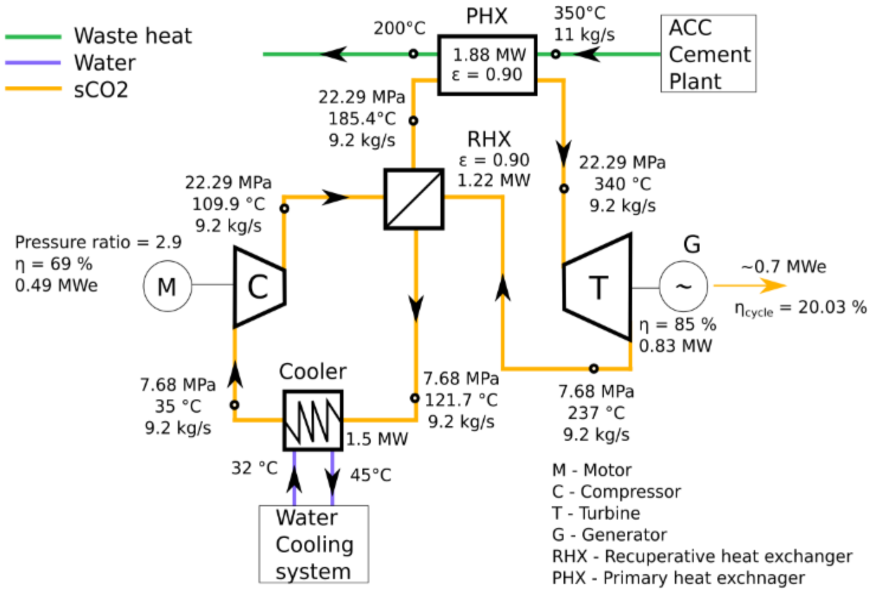


- <u>The waste heat recovery system considered for the current study is in the range of 1 to 10 MWe, with the operating temperature between 200 to 600 °C.</u>

Scope and Novelty of the Work

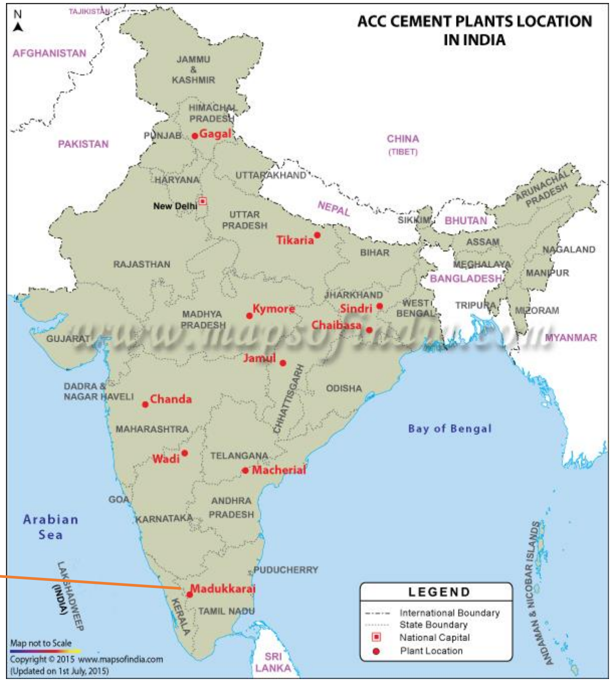
- The work determines the feasibility of deploying a SCO_2 power cycle to recover waste heat from different extraction points.
- This is the first-ever case study done for retrofitting sCO_2 power conversion equipment in an existing cement plant.
  - This assessment indicates opportunities for a Demo plant to extract 700 kWe (Turbine power output) while minimally disturbing plant operations.
- The study is expected to provide data for a larger, 8MWe (net) sCO_2-derived power at higher turbine inlet temperatures and with potentially increased MSW (Municipal Solid Waste) use.
  - The study supports deploying a low-temperature, smaller-scale demo to obtain scale-up and techno-economics data.

  - Deployment of the larger sCO_2 system could lead to partially or fully replacing the second coal boiler, leading to further "greening" of the plant and to a potentially attractive pay-back period.
  - Additional use of MSW (Municipal Solid Waste) may lead to the design and operating conditions with lower CO2 emissions, replacement of the existing (second) coal boiler, and a desired pay-back period for the operator while lowering the landfill burden to neighboring communities, all leading to further "greening" cement production.



Plant Description

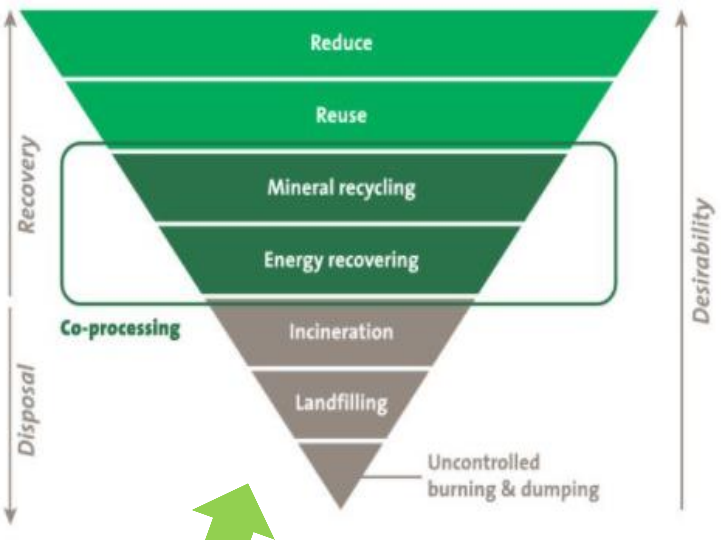
- ACC Madukkarai plant produces 1.18 million tonnes of cement per year.
  - The plant, located in India, using renewable power to offset some coal use, and uses Municipal Solid Waste (MSW) to augment the caloric needs of the kiln.
- The plant is equipped with a Geo cycle which uses the municipal waste as a heat source for combustion that reduces the coal requirement of the cement plant, the required additional heat can be tapped from the Geo cycle.
- The plant unlike other Cement plants, the raw material is in slurry form and hence the complete exhaust gas from the preheater is used to dry the raw material
  - The ACC Madukkarai plant feeds the kiln in slurry form, the heat requirement is comparatively more to remove the water content comparing with the modern plants. Due to this additional process, the Madukarrai plant utilizes the waste heat for heating the slurry.



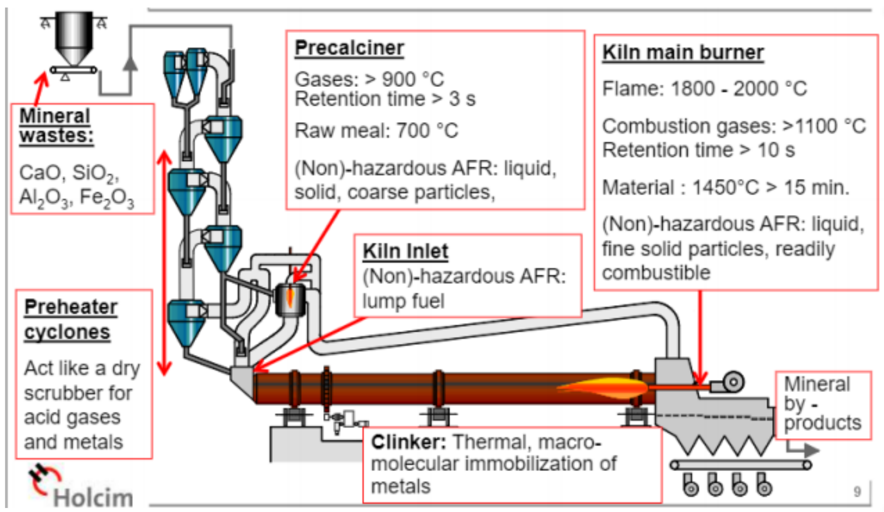
Mechanism of Waste Management Through Coprocessing In Cement Kiln

- The organic constituents are completely destroyed due to:
  - High temperatures,
  - Long residence time
  - Oxidizing conditions in the cement kiln.

- Acid gases such as HCL and SO_2 are absorbed and neutralized by the freshly formed lime and other alkaline materials within the kiln.
- The inorganic constituents react with the raw materials while heavy metal become immobilized in clinker matrix



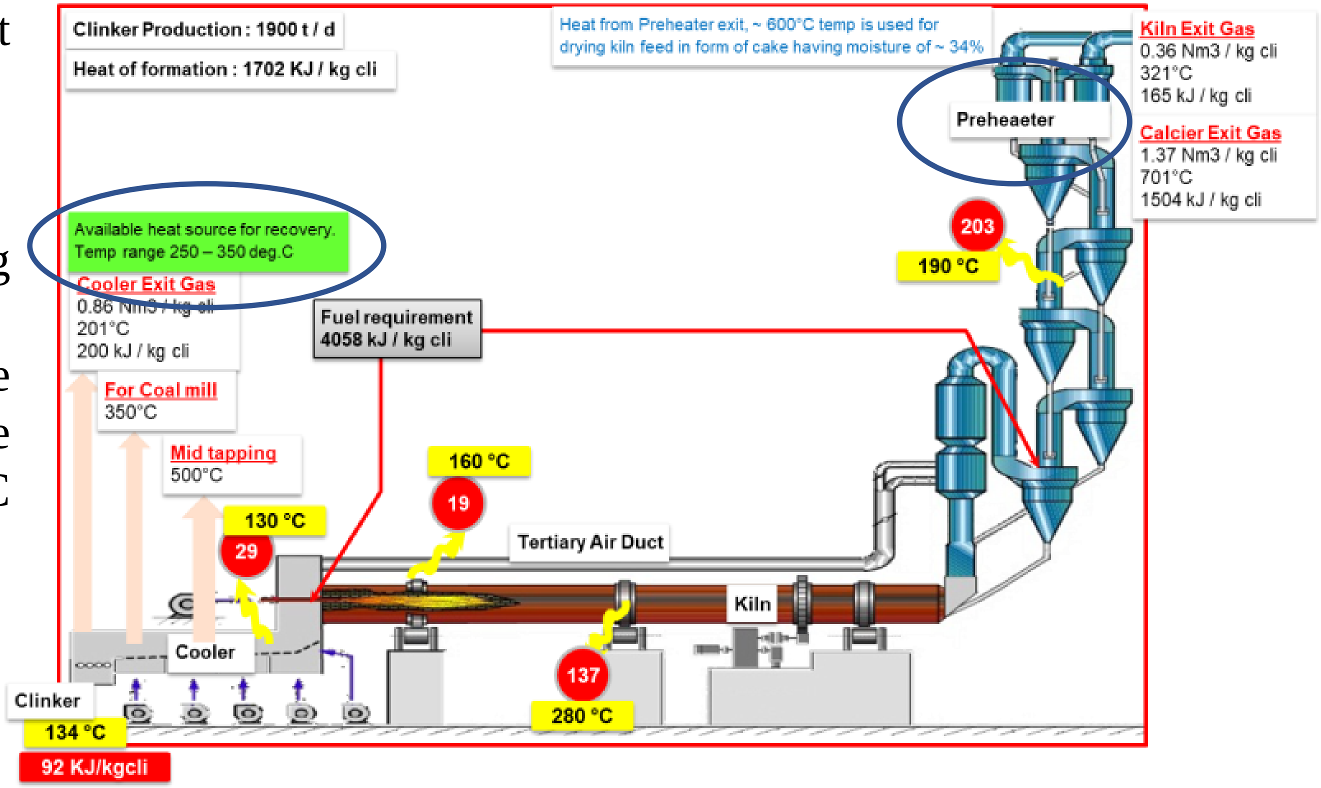
Waste Management Hierarchy

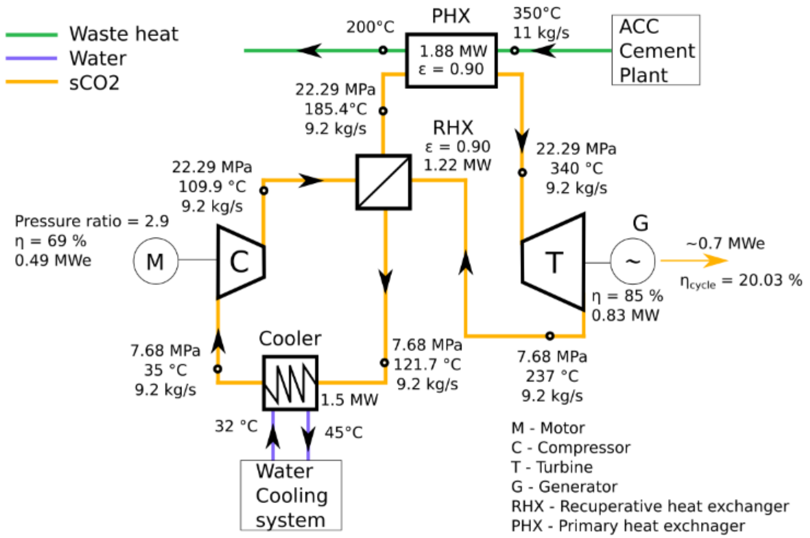


- Organic constituents are completely destroyed into CO2 and water.
- Chlorine, Fluorine, or sulfur acids are neutralized by the alkaline materials within the kiln.
- The inorganic constituents including heavy metals react with the raw materials and become part of the clinker matrix.

ACC Madukkarai plant Layout - Available Heat Potential

- The hot, dust-laden exhaust gases from the cement plant can be tapped from two sources
  a. Clinker cooler
  b. Preheater.
- Waste heat recovery can be operated at different heating levels range from 200 to 600 °C.
- The tertiary air duct and the cooler blowers can be managed for the hot air recovery of the plant and the temperature availability is varying from 500 °C to 201 °C at different tapping points.





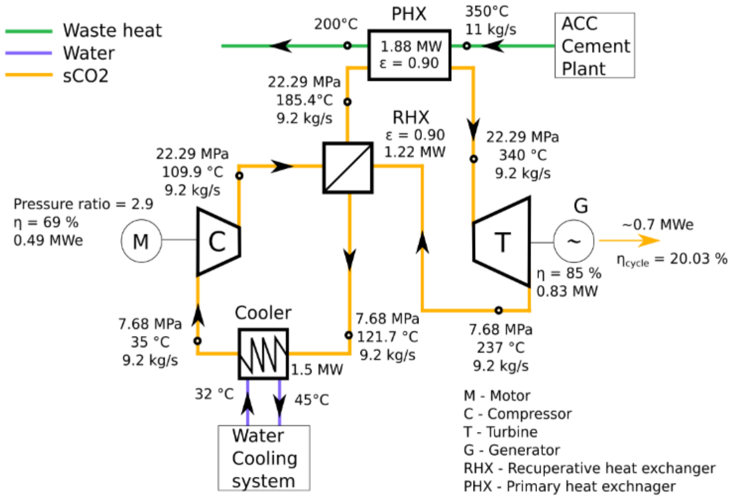
Cooler exit gas	201	°C
Coal mill	250 - 350	
Preheater	600	

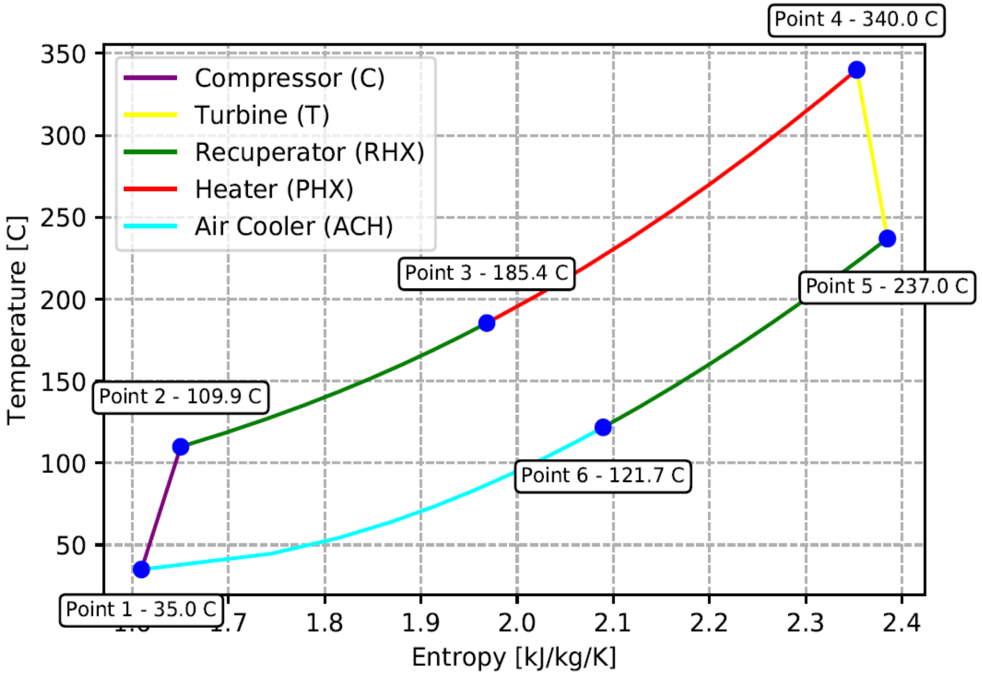
Demo Plant Unit Operating Parameters

- The heat source for the SCO_2 demo plant unit is from Clinker cooler with outlet temperature 350 °C.
- The sCO2 demo plant unit is designed as a compact system to provide data that can utilized to design commercial units with 8 MWe of net power output.
  - The cooling system is designed as water-cooling system with an inlet temperature of 32 °C.
  - The pressure ratio is 2.9
  - Compressor outlet pressure is 22.29 MPa
  - Required heat input from the heat source is 1.88 MWth with the sCO_2 flow rate of 9.2 kg/s.
  - The cooling power is 1.5 MWth.

Flow rate	9.2	kg/s
Cycle efficiency	20.03	%
Compressor mechanical power	0.46	MW
Added heat	1.88	
Removed heat	1.5	
Regenerative heat	1.22	
Turbine power output	0.7	MWe

Compressor inlet temperature	35	°C
Turbine efficiency	85	%
Compressor efficiency	69	
Recuperator effectiveness	90	



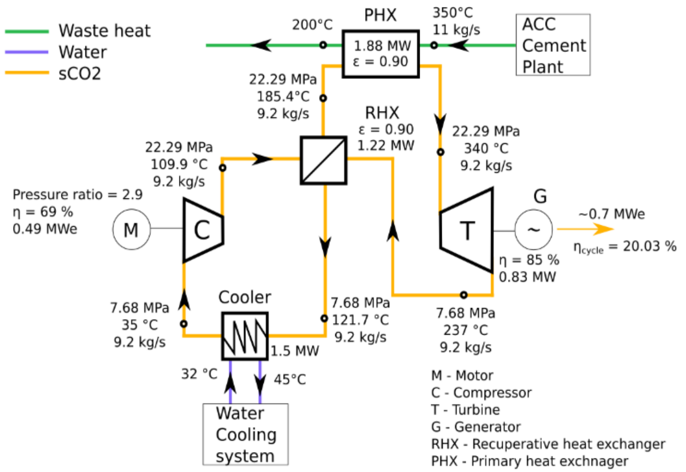


Comparison of DEMO and Commercial Units

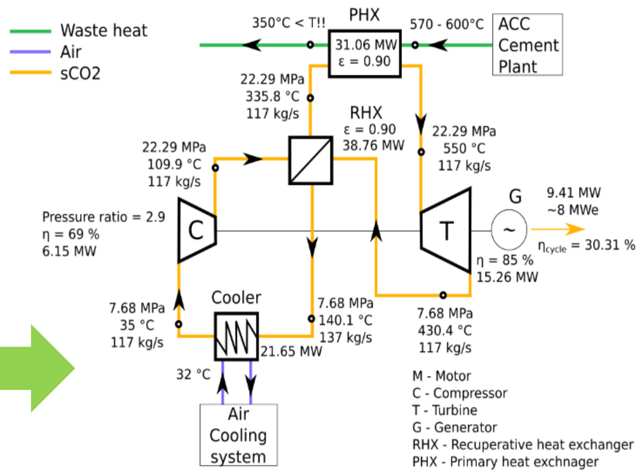
Modifications were done to Reduce Complexity

- <u>Electrical motor-driven compressor:</u>
  - 0.7 MWe generator will be driven by sCO_2 turbine and sCO_2 compressor
- <u>Water-cooled heat exchanger</u>
  - Commercial (8 MWe) system is planned to be designed with air-cooled heat exchanger.
- From the data obtained simple sCO_2 Brayton cycle can be scaled up from the sCO_2 demo unit to commercial units in the same configuration.

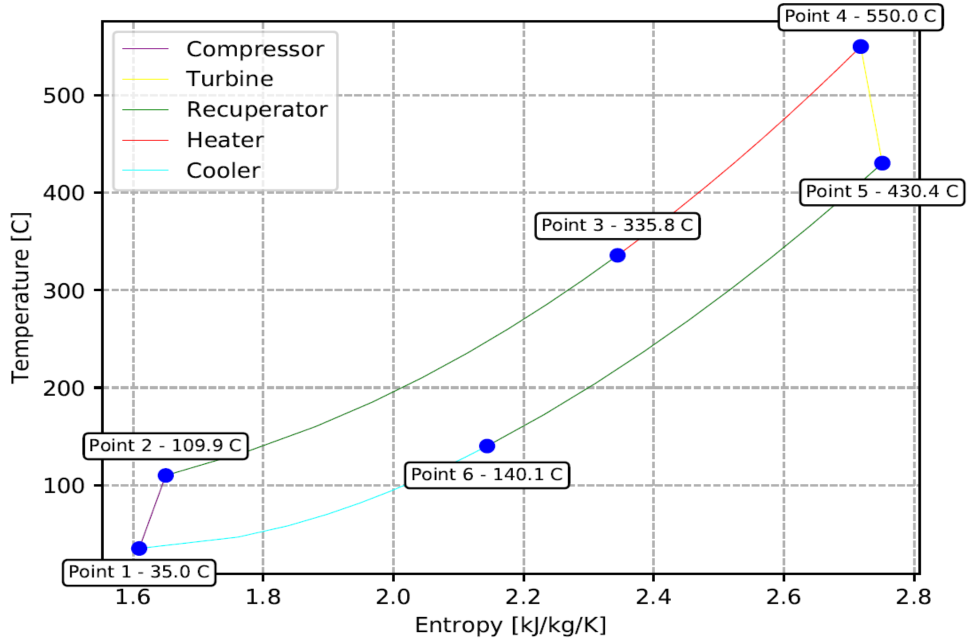
Flow rate	117	kg/s
Cycle efficiency	30.31	%
Turbine mechanical power	15.29	MW
Compressor mechanical power	6.15	
Added heat	31.06	
Removed heat	21.65	
Reg heat	38.76	
Net power	8	MWe



DEMO unit

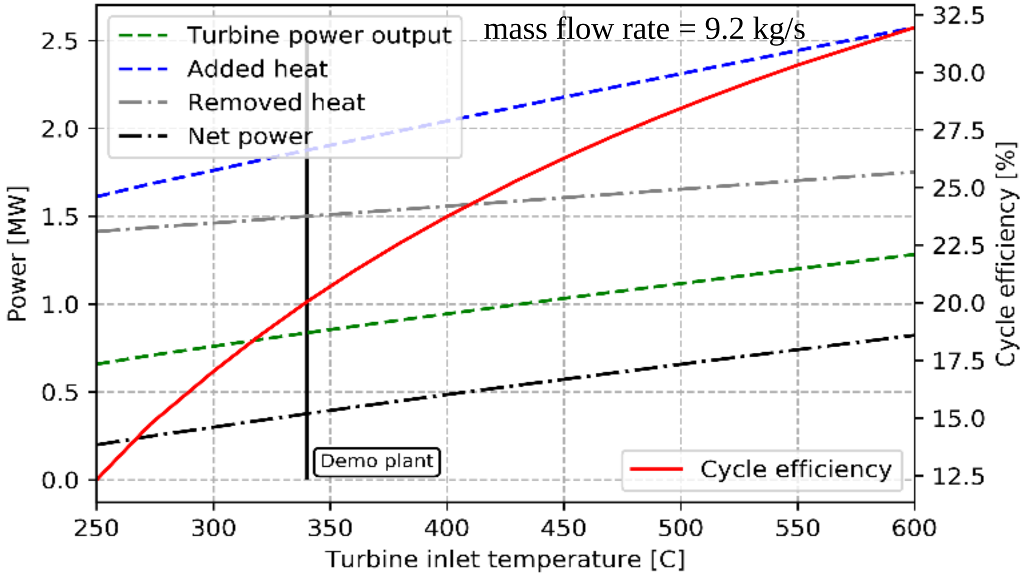


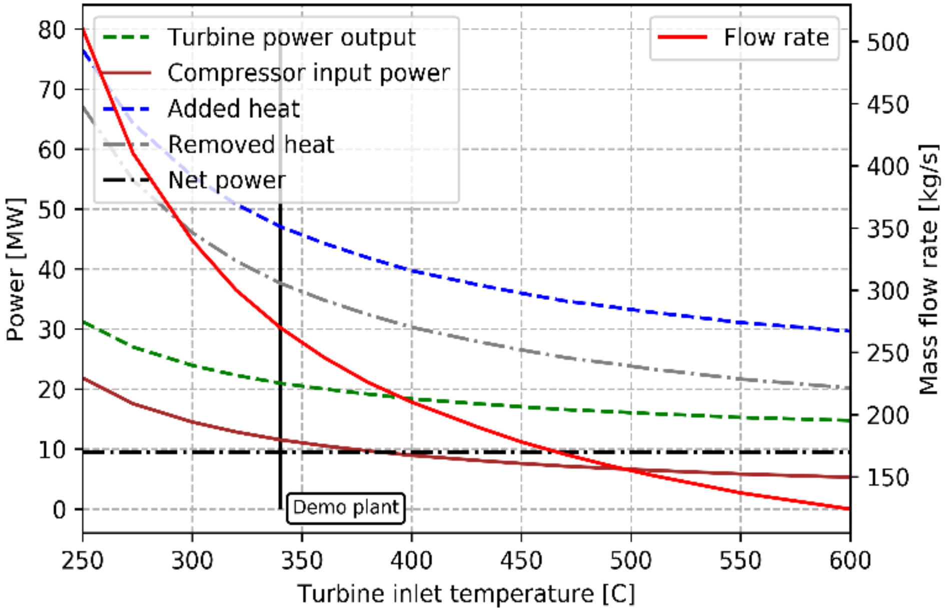
Commercial unit

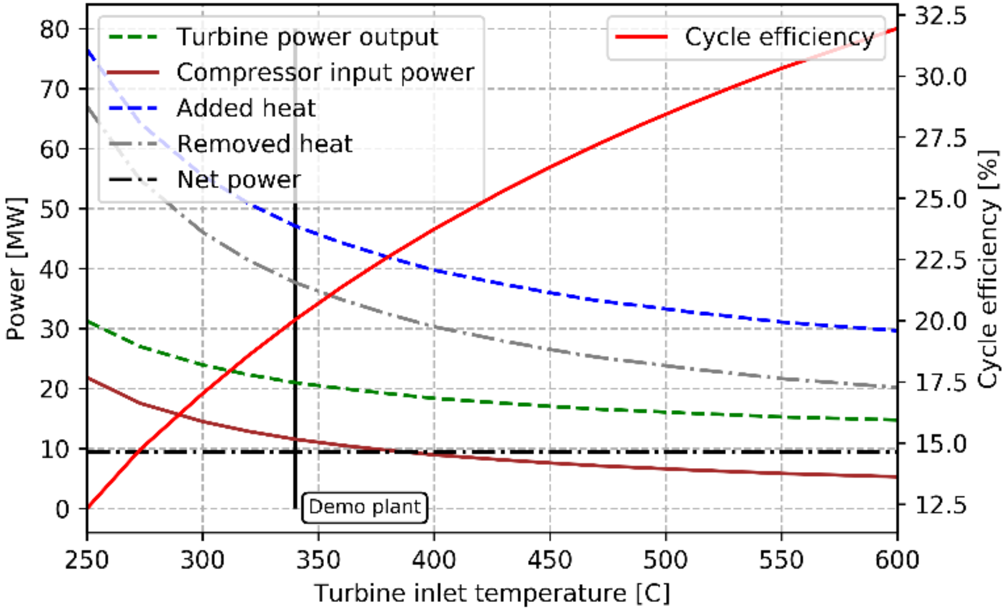


Effect of the different Turbine Inlet Temperature Under Various Conditions

- The sCO_2 demo plant unit is planned to operate at 340°C and the corresponding turbine power output is around 0.8 MWth with the cycle efficiency is 20.03%.
  - As the temperature increases, the heat power required as input decreases which explains the performance improvement at the higher temperatures (red line).
  - The thermal input is lower for the constant output with the rise in temperature from 250 °C to 550 °C.
  - Net power is dependent on the compressor and turbine power.
  - The compressor power is decreased too and because the compressor is operated near the critical point of the CO_2, the required compressor power is lower.







Conclusions & Recommendations

- This study focused on retrofitting of an existing cement plant in order to make it green.

- Consideration of all other sources of waste heat, as well as use of locally-sourced municipal solid waste, can increase the exergy-content of the total waste heat at a higher temperature and can lead to larger net electrical output at a higher overall cycle efficiency.
- For a completely new design, an overall design optimization that considers both cement production and waste heat recovery in an integrated fashion is necessary

- The cycle optimization could lead to a maximum overall waste-heat-to-electricity efficiency of 30.3% for a net power output of 8 MWe and a turbine inlet temperature of 550 °C.
  - Simple Brayton sCO_2 power cycle

- The cement plant heat source can be used for many different cycle layouts and with a combination of Hydrogen systems can lead to the high-efficiency green cement plant.

Conclusions & Recommendations

Thank you for your attention