Integration of Solar Energy with Carbon Capture: An ongoing collaboration

Laboratory for Energy and Nano Science, Masdar Institute Abu Dhabi
School of Chemical and Biomolecular Engineering, University of Sydney, Sydney, Australia
M. Chiesa & A. Abbas

- Local and Global Challenges
- The Solar-Assisted Post-Combustion Carbon Capture concept
- Direct Solvent Regeneration Through Solar Thermal Energy
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Perspectives on renewable energy in Europe

Lower Climate Gas Emission by 2020...
A Global Challenge

Observed changes.

Range for 19 model simulations using natural forcing.

Range for 51 model simulations using natural and human forcing

IPCC Fourth Assessment Report: Climate Change 2007
About 550 billion tons of carbon stored in the Arctic tundra & frozen soils (SCOPE 2004).

Reference: Bindschadler et al.
Lower Climate Gas Emission by 2020...
Need for a policy to manage the risk

Compared with NO POLICY

What would we buy with STABILIZATION of CO₂ at 550 ppm?

A NEW WHEEL with lower odds of EXTREMES

http://web.mit.edu/globalchange/

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Australia and UAE have a high CO₂ footprint

2008 CO₂ emission per capita
Qatar (1st 53.5), UAE (3rd 34.6), Bahrain (5th 29), Kuwait (7th 27), Australia (11th 18.9), USA (12th 17.5), Saudi Arabia (13th 17.2)
http://data.worldbank.org/indicator/EN.ATM.CO2E.PC/countries

For Australia the problem is mainly related to power generation

The UAE will increase its oil production from 2.8 to 3.5 Mb/day maintaining the same production time horizon.

This implies an increase recovery factor from the UAE onshore fields.

CO₂ is currently one of the available solutions although new innovative solutions are needed.
Australia and UAE have abundant solar resources
Australia and UAE have abundant solar resources.
PCC is one of the promising technologies for reducing CO₂ emissions from existing fossil-fuel power plants due to ease of retrofitting.

A significant obstacle in widely deploying this technology is the power plant output reduction (Output Power Penalty – OPP) due to the energy intensive CO₂ separation process.
It relies on a strong and successful academic sector:

- 6 universities among the 100 best in the world
- A strong and highly visible research center

Solving the problems taking into account of the local boundary condition and achieve innovative solutions that can provide a competitive advantage
Solar-Assisted Post-combustion Carbon Capture: An ongoing collaboration

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Solar Assisted Post-combustion Carbon Capture (SPCC)

Thermal energy for regeneration comes from the steam cycle by extracting high quality steam from the turbines. Solar energy can be used to fully or partially provide the solvent regeneration energy.
Formulates the SPCC operational parameters and region-dependent variables into expected costs and revenues, to assess the expected revenue stream.

The net revenue from a power plant fitted with an SPCC would consist of the generated electricity sold at price $p_{elec}$ (from which the following costs are subtracted: fuel, solar plant, CO$_2$ pumping and storage cost, and the carbon costs incurred from the CO$_2$ that is actually released.)

$$R = \int E_{elec}(t, SF(t)) \cdot p_{elec}(t)\, dt - \int FF(t) \cdot p_{fuel}(t)\, dt - P_{solar}(A, TS) - P_{MEA}(CR) - \int E_{elec}(t, SF(t)) \cdot F_{CO2} \cdot CR(t) \cdot p_{stor} \, dt - \int E_{elec}(t, SF(t)) \cdot F_{CO2} \cdot [1 - CR(t)] \cdot p_{CO2}(t)\, dt$$

Techno-economic analysis for different combinations of operational parameters of the SPCC under region dependent boundary conditions is needed.

If the decision to retrofit a solvent-based PCC system is already taken on the merits of reducing carbon emissions impacts, it is possible to evaluate the decision on whether or not that unit should be solar-assisted by comparing the following two cases:

- **Case A:** A PCC plant which continuously bleeds steam from the turbine circuit for solvent regeneration.
- **Case B:** An SPCC plant which uses both solar energy and turbine circuit steam for solvent regeneration, switching between them as necessary in real-time.
The conceptual baseline plant for our case is a typical pulverized coal-fired power plant with a 300MWe capacity operating in NSW, Australia.

The auxiliary consumption of the plant is 17.1MWe and hence the net generation capacity is 282.9MWe, and the net electrical efficiency is 30.0%. The plant emits 256 ton/h of CO2, which is equivalent to 0.906 kg/kW he.

After adding the PCC unit, the net power output drops to 227.9MWe. This is due to the OPP (37.9MWe) and the PCC auxiliary consumption (17.2MWe), thus the net electrical efficiency drops to 24%.

The retrofitted plant emits 25.6 ton/h of CO2 regeneration for a CR of 90% and CO2 purity of 99% is estimated to be 200MWth (3.12 GJ/tones CO2).

Solar Assisted Post-combustion Carbon Capture (SPCC)

Relation between solar field size and solar fraction SF for a 300MWe coal fired power plant with capacity factor of 85% and 90% CR.

Relation between SF and Thermal Storage TS in Full Load Hours FLD. The curve shows TS required to achieve the corresponding SF.
Solar Assisted Post-combustion Carbon Capture (SPCC)

Net annual benefits of SPCC for different solar collector costs (100–600 $/m2) and varying boundary conditions; carbon prices (0–0.2 $/kgCO2) and Electricity Price Increments (EP_{inc}) (0–0.2 $/kWh).

Net annual benefits of SPCC for different solar collector costs (100–600 $/m²) and varying boundary conditions; carbon prices (0–0.2 $/kg CO₂) and Electricity Price Increments (EP_{inc}) (0–0.2 $/kW h).

Net annual benefits of SPCC for different solar collector costs (100–600 $/m2) and varying boundary conditions; carbon prices (0–0.2 $/kgCO2) and Electricity Price Increments (EP$_{inc}$) (0–0.2 $/kW h).

Net annual benefits of SPCC for varying turbine isentropic efficiency (and hence varying OPP).
Solar Assisted Post-combustion Carbon Capture (SPCC)

PCC: Post-combustion Carbon Capture

- Solar Collector Technology
- Financial Incentives
- Location

Heat Integration

Without

With

PCC
Solar Field
Power Plant
The yield of the solar field depends on its locations.

Average daily solar exposure
Annual

Locations of areas included in study (highlighted).
Solar Assisted Post-combustion Carbon Capture (SPCC)

Solar Collector Technologies

- Flat Plate Collector (FPC)
- Evacuated Tube Collector (ETC)
- Compound Parabolic Collector (CPC)
- Linear Fresnel Collector (LFC)
- Parabolic Trough Collector (PTC)

Financial Incentives

- Subsidy
- Carbon Tax/Credits
- Renewable Energy Certificates

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Solar Assisted Post-combustion Carbon Capture (SPCC)

Comparison of solar collector technologies with and without heat integration for Sydney.

Comparison of financial incentives for the four locations under the conservative carbon price scenario.

Current Carbon Price
$23/tonne-CO2 (ETC-scenario)

Comparison of financial incentives for the four locations under the current carbon price scenario.

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Direct Solar Regeneration of Solvent

Exhaust gas

Leak solvent cooler

Absorber

Flue gas

Rich/Lean heat exchanger

Hot Rich Liquid

CO₂ for compression

CO₂ knock out drum
Heat Transfer Steps (Losses) in Indirect Solvent Regeneration Through Solar Energy

1. Heating Working Fluid (WF)
2. Generation of steam
3. Heating reboiler for steam generation inside desorber
4. The steam mixes with the rich solvent and passes its latent heat to the solvent for reverse reaction and breaking the bonds.
Schematic of a coal-fired power plant with retrofitted PCC
Day Operation of Direct Solar Regenerator

Exhaust gas

Lean solvent cooler

Lean Solvent storage (if required)

Hot Rich Liquid

Solar thermal collector

CO₂ For compression

N modules of solar thermal collectors

CO₂ knock out drum

Absorber

Flue gas

Rich/Lean heat exchanger

Rich Solvent storage (if required)
Night Operation of Direct Solar Regenerator

Exhaust gas

Lean solvent cooler

Absorber

Flue gas

Hot Rich Liquid

Lean Solvent storage (if required)

Rich Solvent storage (if required)

Solar thermal collector

CO₂

For compression

CO₂ knock out drum

N modules of solar thermal collectors

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Case Study: Solar Collector Area Requirement for 660MW Coal-Fired Power Plant

Above: Relation between solar fraction and a) solar collector area; b) annual economic benefit

The relationship between solar collector area and carbon capture capacity
Relative Performance of Proposed Direct Solar Regeneration Method

- Conventional method
- The proposed method

Annual economic benefit (Scaled 0-100)

Solar collector area (m²)

2.64x10^6 m²
• Solar-assisted Post-combustion Carbon Capture (SPCC) is not feasible at current carbon price (it is feasible when a 5% per annum increase in price is assumed OR if REC are allowed)
  – SPCC would require a lower carbon price to breakeven than conventional PCC.

• Non-concentrating evacuated tube collectors are most feasible for a plant with heat integration.

• Parabolic trough collectors most feasible without heat integration.

• Renewable Energy Certificates (REC) provide highest benefit.
  – Policy proposed to allow REC for SPCC plants

• Direct regeneration of solvent through solar thermal energy is more economically feasible than SPCC.