Comparison in Dynamic Response of Energy-Storing Cryogenic and Chemical Absorption Carbon Capture Systems to Electricity Demand

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Outline

- Background
- Cryogenic Carbon Capture
- Chemical Absorption
- Modeling Basis & Results
- Conclusion
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➢ Background

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CO₂ Emission

➢ Challenges with CO₂ emission is more than global warming!

➢ According to Environmental Protection Agency (EPA):
  ✓ Harm to agriculture and forests
  ✓ Increased potential for enhanced spread of some waterborne and pest-related diseases
  ✓ Species extinctions and ecosystem damage
EIA Annual Energy Outlook of 2017

- Power sector will remain one of the major CO$_2$ emitting sources in the US
  - 26% contribution in 2015
  - 23% contribution in 2050 with Clean Power Plan (CPP) regulations (26% without CPP)

- Continuing dependence of the US power sector to fossil fuels
  - 70% dependence in 2015
  - 56% dependence in 2050 with CPP (62% without CPP)

- CO$_2$ capture and sequestration technology will cover 19% of the total CO$_2$ reductions by 2050
Carbon Capture Technologies

- Oxy-combustion (1.69 MJ$_e$/kg CO$_2$)
- Chemical and Physical Absorption (1.72 MJ$_e$/kg CO$_2$)
- Membranes (1.3 MJ$_e$/kg CO$_2$)
- Cryogenic Carbon Capture (0.7 MJ$_e$/kg CO$_2$)
Objectives

- Compare the dynamic performance of a coal-fired power plant equipped with cryogenic carbon capture and amine-based chemical absorption
- Volatile wind, electricity prices, and residential demand
- Both capture schemes are enabled with storage systems
- 90% carbon capture rate for both systems
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Integrated System of Power Generation and CCC

- American Control Conference (ACC), 2015
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Integrated System of Power Generation & Chemical Absorption

- A Techno-economic Plant- and Grid-Level Assessment of Flexible CO$_2$ Capture, PhD Dissertation, University of Texas at Austin, 2012
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Comparison Basis

- 300 MW/hr ramping rate in the coal-fueled power plant
- Similar residential electricity demand, energy price, and wind power profiles
- Negligible CO\(_2\) compression cost for the CCC (compression in liquid form)
- $9.69/ton CO\(_2\) compression cost for amine (compression in gas form)
- Similar storage capacity
- Penalty applied for CO\(_2\) emissions in both systems
Minimization of Total Operating Cost

- CCC cost function:

\[
\text{Oper. Cost}^{\text{CCC}} = \sum (C^{\text{Cap. Energy}} + C^{\text{Fuel}} + C^{\text{NG Net}} + C^{\text{CO}_2 \text{ Emission}} + C^{O&M,b} + C^{O&M,CCC} + C^{\text{imbal}})T
\]

- Amine cost function:

\[
\text{Oper. Cost}^{\text{Chem.Abs.}} = \sum (C^{\text{Cap. Energy}} + C^{\text{Fuel}} + C^{\text{CO}_2 \text{ Emission}} + C^{O&M,b} + C^{\text{Solv.}} + C^{\text{Caus.}}
+ C^{\text{Waste}} + C^{\text{Wat.}} + C^{\text{Trans.}} + C^{\text{Cap. Ramp}} + C^{\text{imbal}})T
\]

- Both systems were modeled in GAMS and solved on NEOS servers using KNITRO solver
- Both systems meet the total electricity demand
- 100% utilization of the wind power
Coal Power Generation and Capture Power Demand

Coal Power Generation

Capture Power Demand

\[
\frac{\text{Total Coal Power (CCC)}}{\text{Total Coal Power (Amine)}} = 0.94
\]

\[
\frac{\text{Capture Demand per CO}_2 \text{ Captured (CCC)}}{\text{Capture Demand per CO}_2 \text{ Captured (Amine)}} = 0.69, \quad 0.73
\]

November 2, 2017
Capture Demand Components

**CCC**

- Continuous CO$_2$ capture
- Reduction in electricity demand of mixed refrigerant compressor (CCC system) and stripping operation (amine system) during periods with expensive electricity price
- Transfer of saved energy to the power grid, resulting in more grid stability

**Amine**

- Absorption Demand (MW)
- Stripper Demand (MW)
- Power Price ($/MWh)
Storage vs. Time

LNG Level in Tank (CCC)
- Refrigerant storage during periods with cheap electricity price and refrigerant retrieval when electricity is expensive

CO₂ Captured vs. Stripped (Amine)
- Reduction in CO₂ stripping load during periods with expensive electricity price and increase in stripping load when electricity is cheap
Lower operational cost for the CCC process

\[
\frac{\text{Total Operating Cost (CCC)}}{\text{Total Operating Cost (Amine)}} = 0.83
\]

\[
\frac{\text{Operating Cost per } CO_2 \text{ Captured (CCC)}}{\text{Operating Cost per } CO_2 \text{ Captured (Amine)}} = 0.88
\]
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Both systems are able to meet the total electricity demand with a CO$_2$ removal rate of 99%

Large-scale energy storage improves the power grid stability by empowering load management of the capture processes

CCC requires 27% lower energy and costs 12% lower than amine-based chemical absorption to capture the same level of CO$_2$ (over 4 days)
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