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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CO_2 Emission

- Challenges with CO_2 emission is more than global warming!

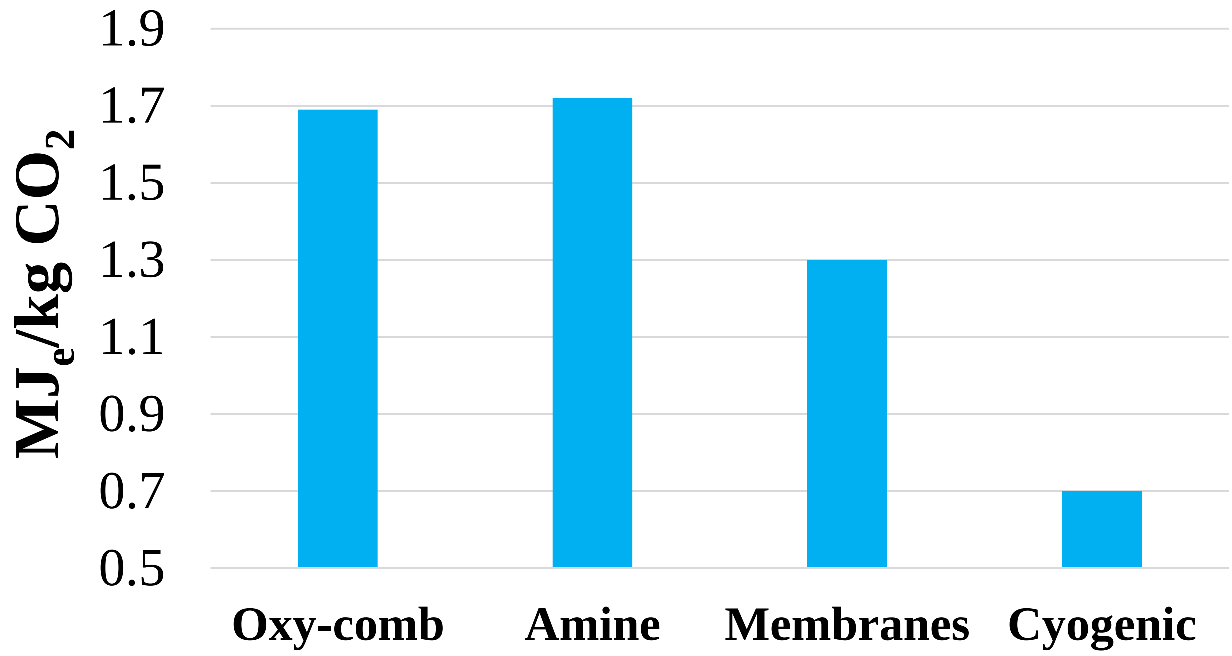
- According to Environmental Protection Agency (EPA):
  - ✓ Harm to agriculture and forests
  - ✓ Increased potential for enhanced spread of some waterborne and pest-related diseases
  - ✓ Species extinctions and ecosystem damage

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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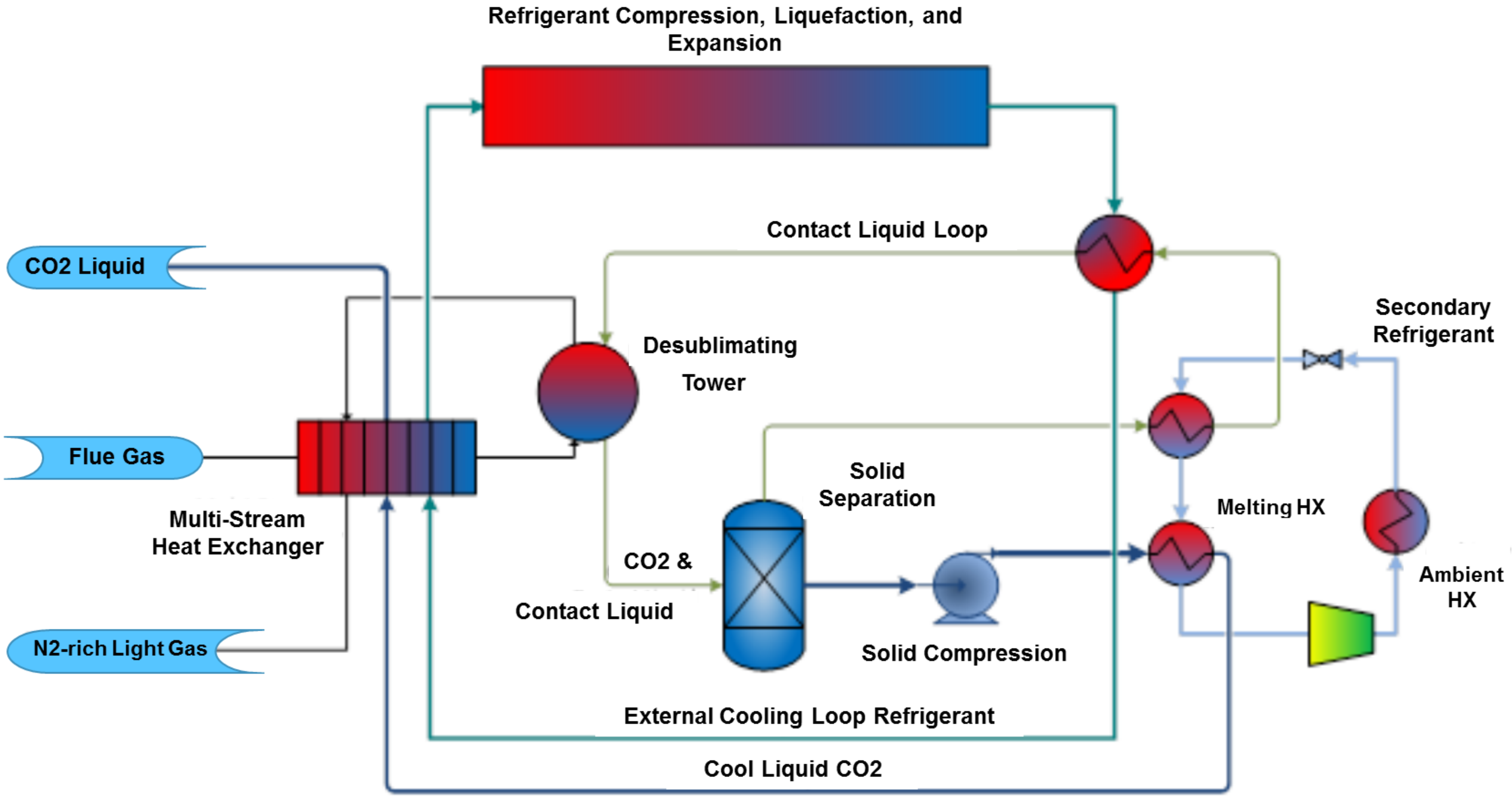
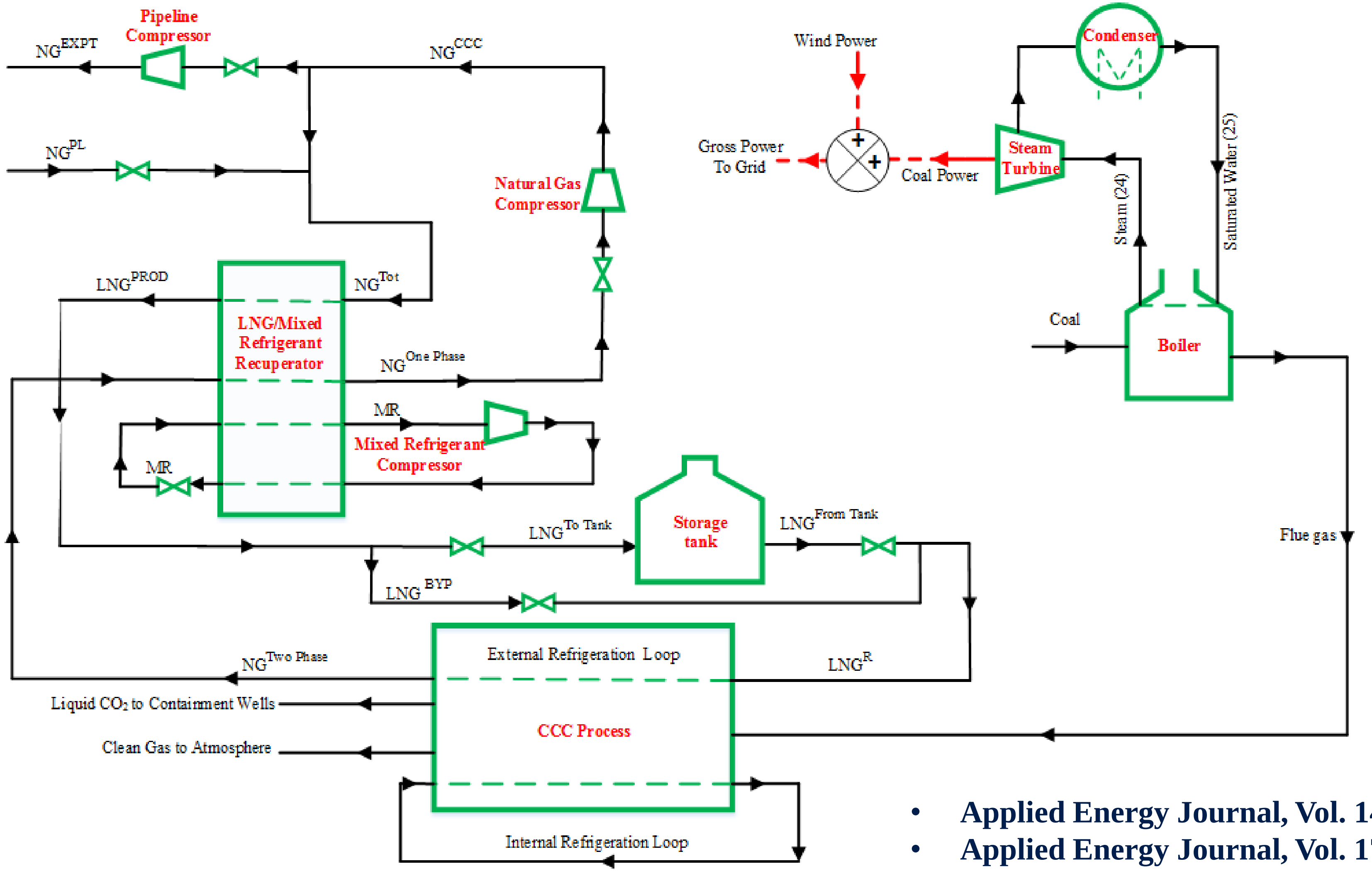
Cryogenic Carbon Capture (CCC)



Jensen, PhD Dissertation, Brigham Young University, 2015



- **Applied Energy Journal, Vol. 149 (2015), pp. 354–366**
- **Applied Energy Journal, Vol. 172 (2016), pp 66–79**
- **American Control Conference (ACC), 2015**

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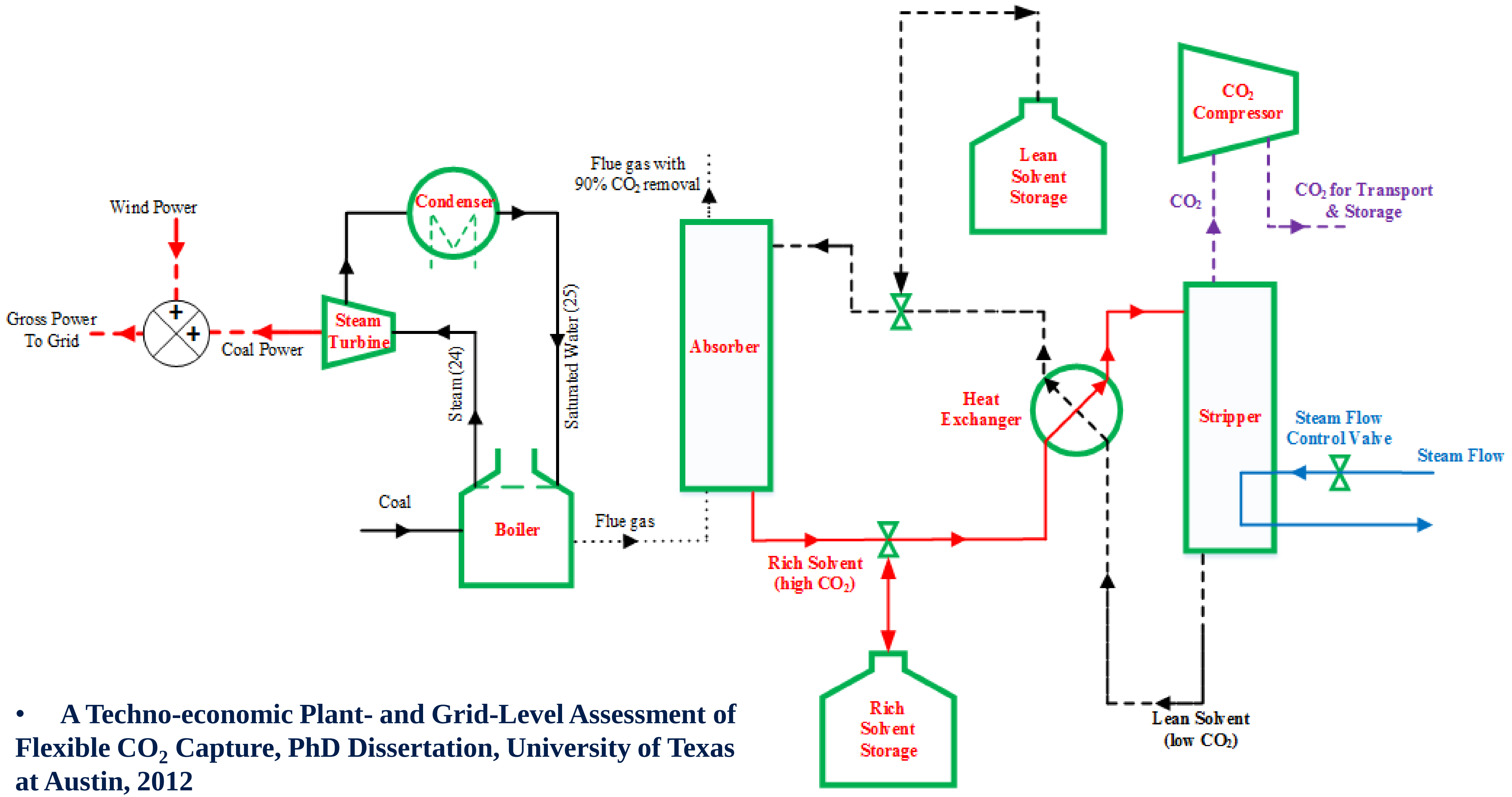
Integrated System of Power Generation & Chemical Absorption



- 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:

$$Oper.\,Cost^{CCC} = \sum (C^{Cap.\,Energy} + C^{Fuel} + C^{NG\,Net} + C^{CO_2\,Emission} + C^{O\&M,b} + C^{O\&M,CCC} + C^{imbal})T$$

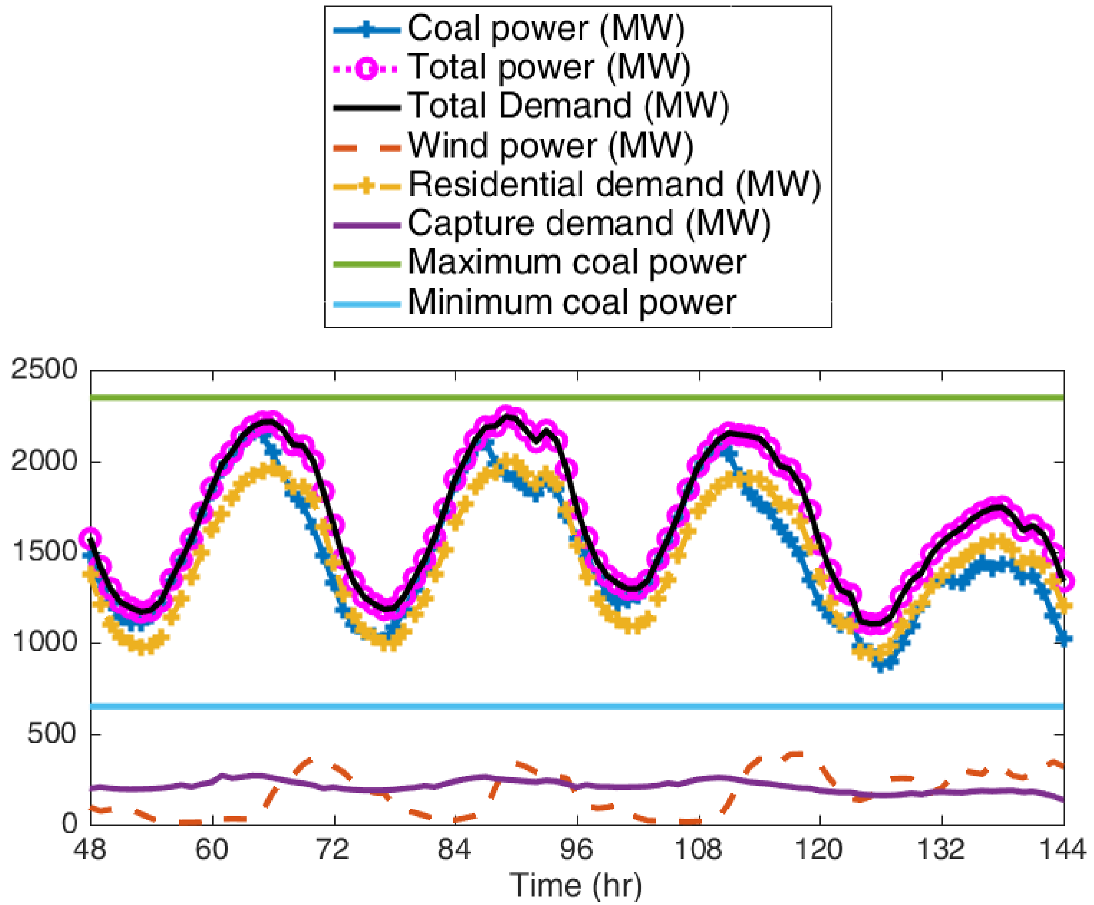
- Amine cost function:

$$Oper.\,Cost^{Chem.Abs.} = \sum (C^{Cap.\,Energy} + C^{Fuel} + C^{CO_2\,Emission} + C^{O\&M,b} + C^{Solv.} + C^{Caus.} + C^{Waste} + C^{Wat.} + C^{Trans.} + C^{Cap.\,Ramp} + C^{imbal})T$$

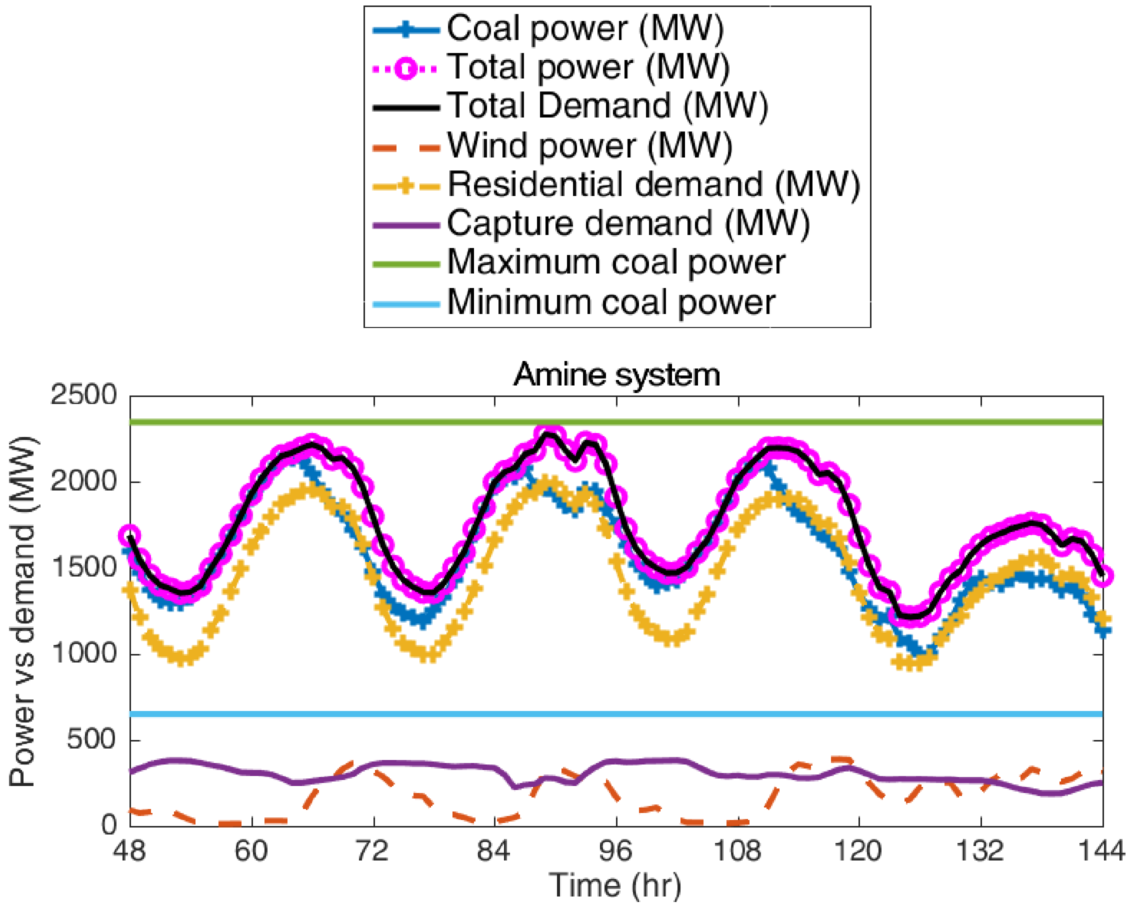
- Both systems were modeled in GAMS and solved on NEOS servers using KNITRO solver

Power vs. Demand

CCC



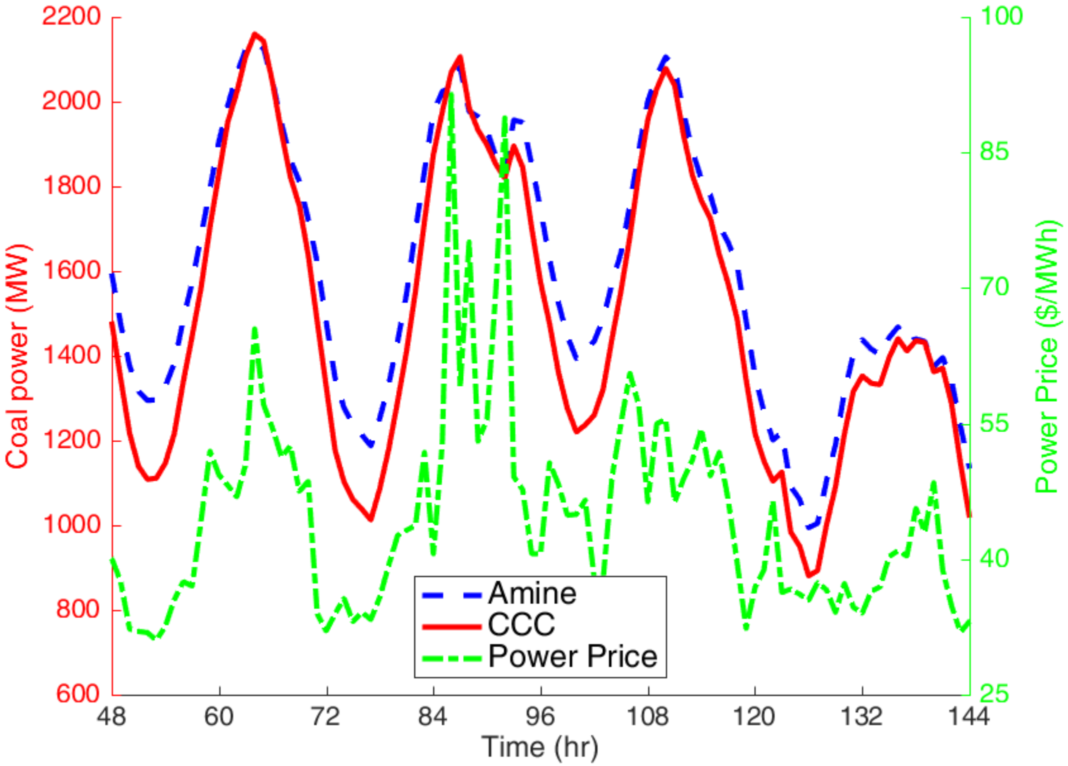
Amine



- ➢ Both systems meet the total electricity demand
- ➢ 100% utilization of the wind power

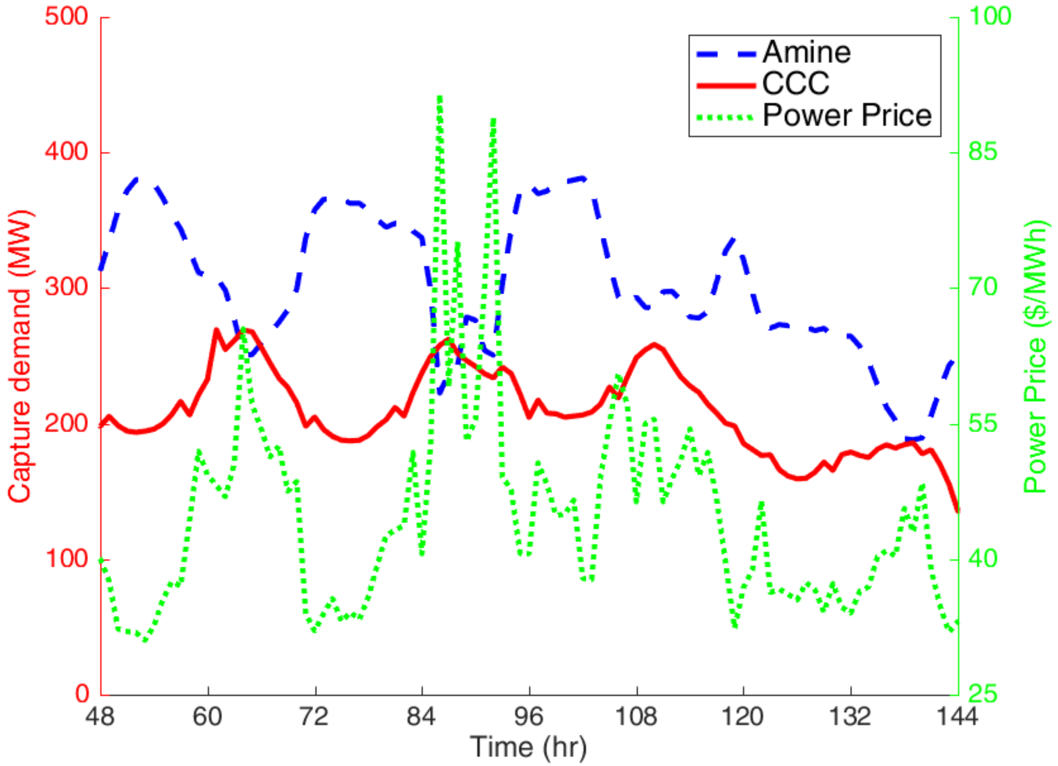
PRISM

Coal Power Generation



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

Capture Power Demand

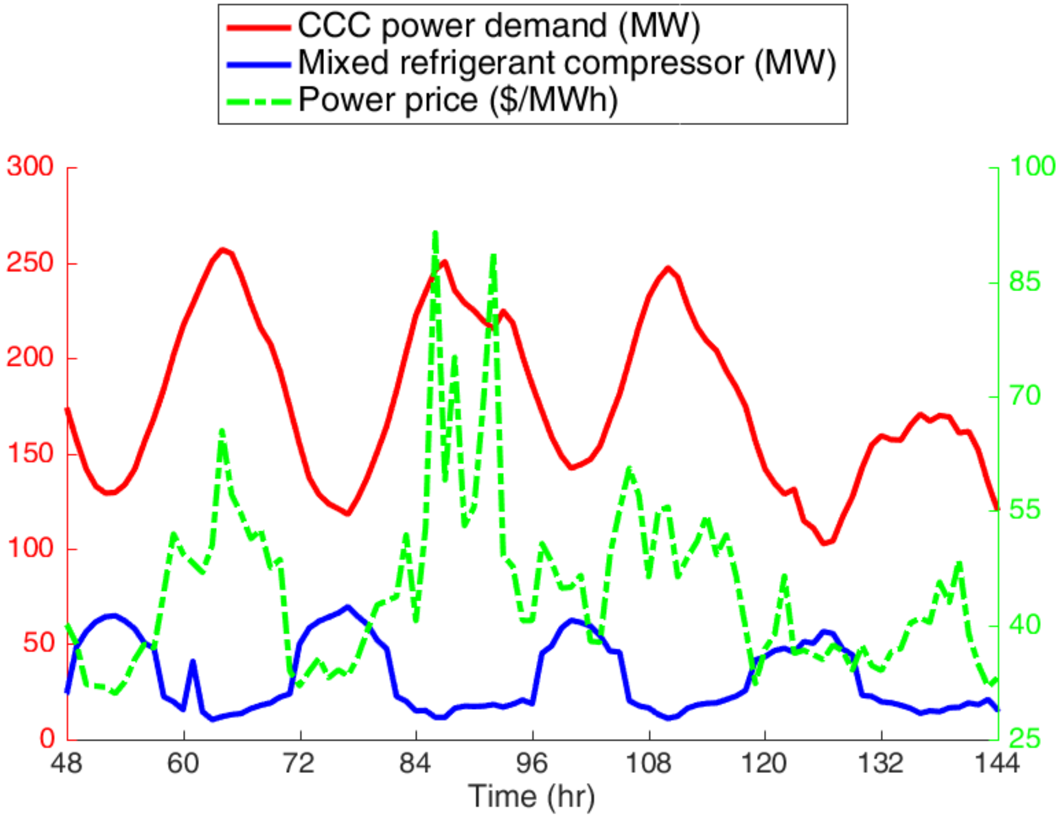


$$\frac{\text{Total Capture Demand (CCC)}}{\text{Total Capture Demand (Amine)}} = 0.69$$

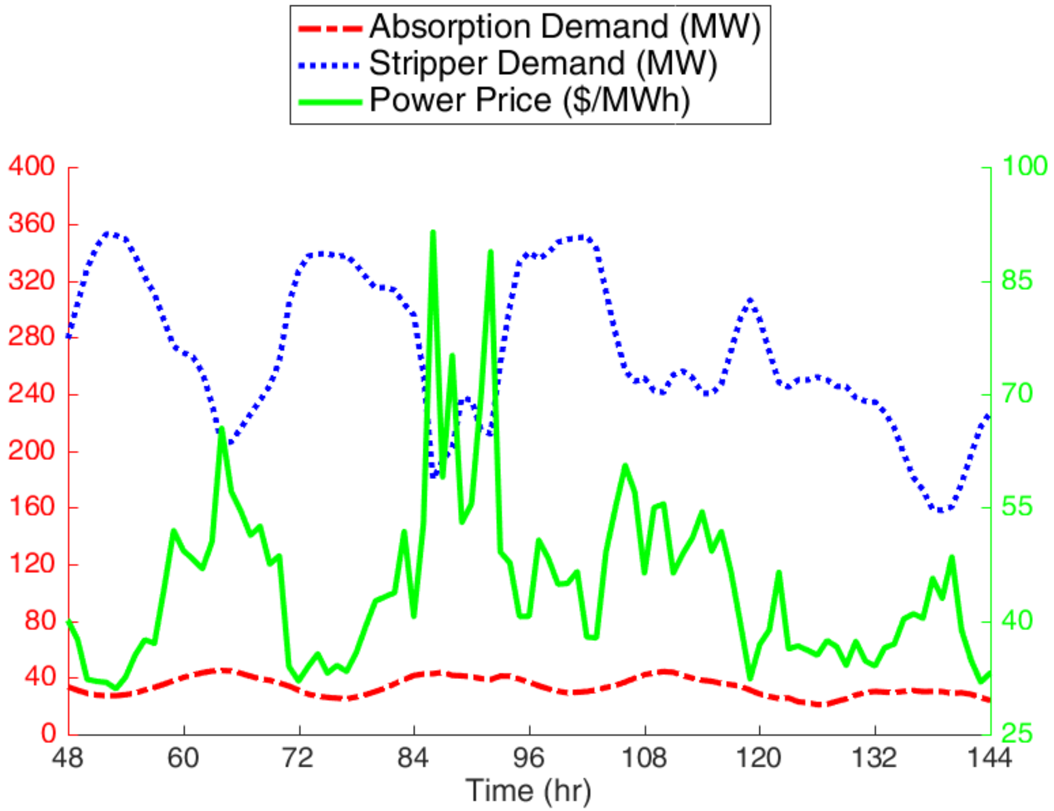
$$\frac{\text{Capture Demand per } co_2 \text{ Captured (CCC)}}{\text{Capture Demand per } co_2 \text{ Captured (Amine)}} = 0.73$$

Capture Demand Components

CCC



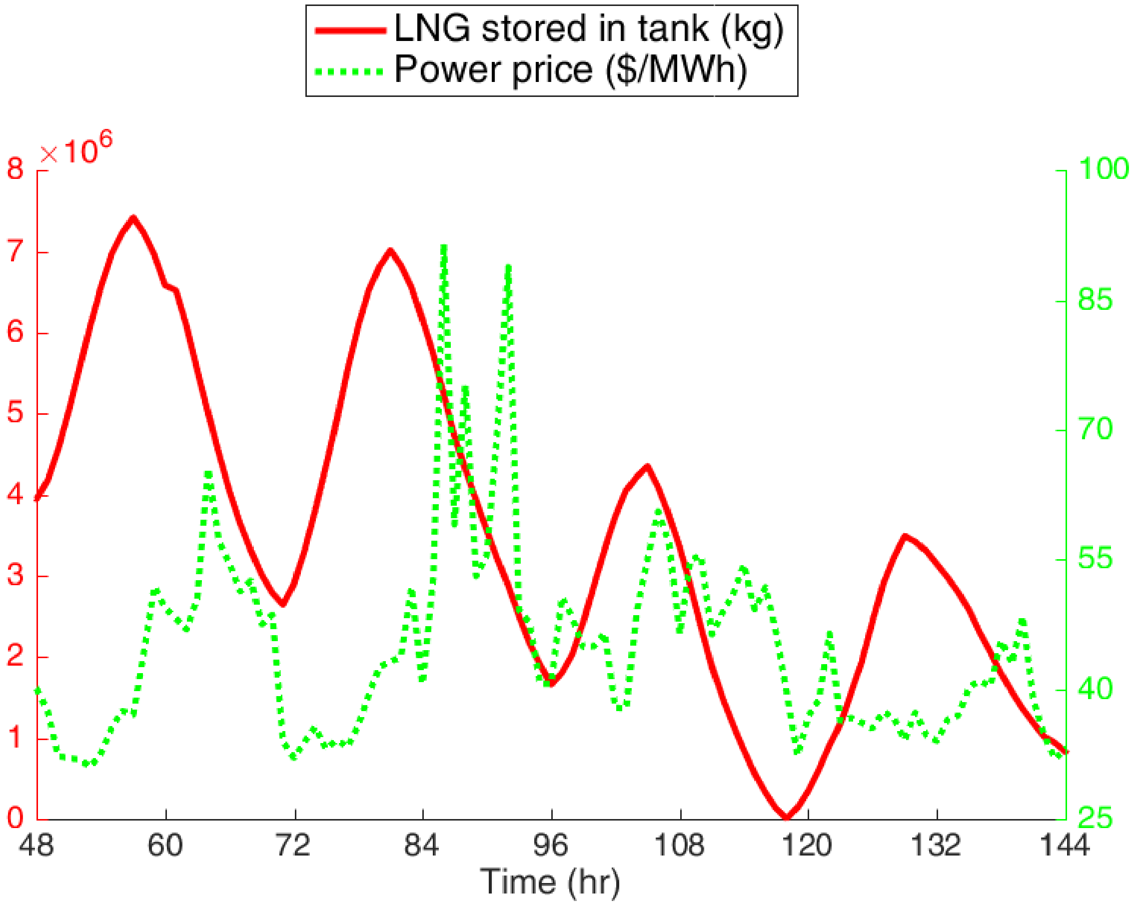
Amine



- 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

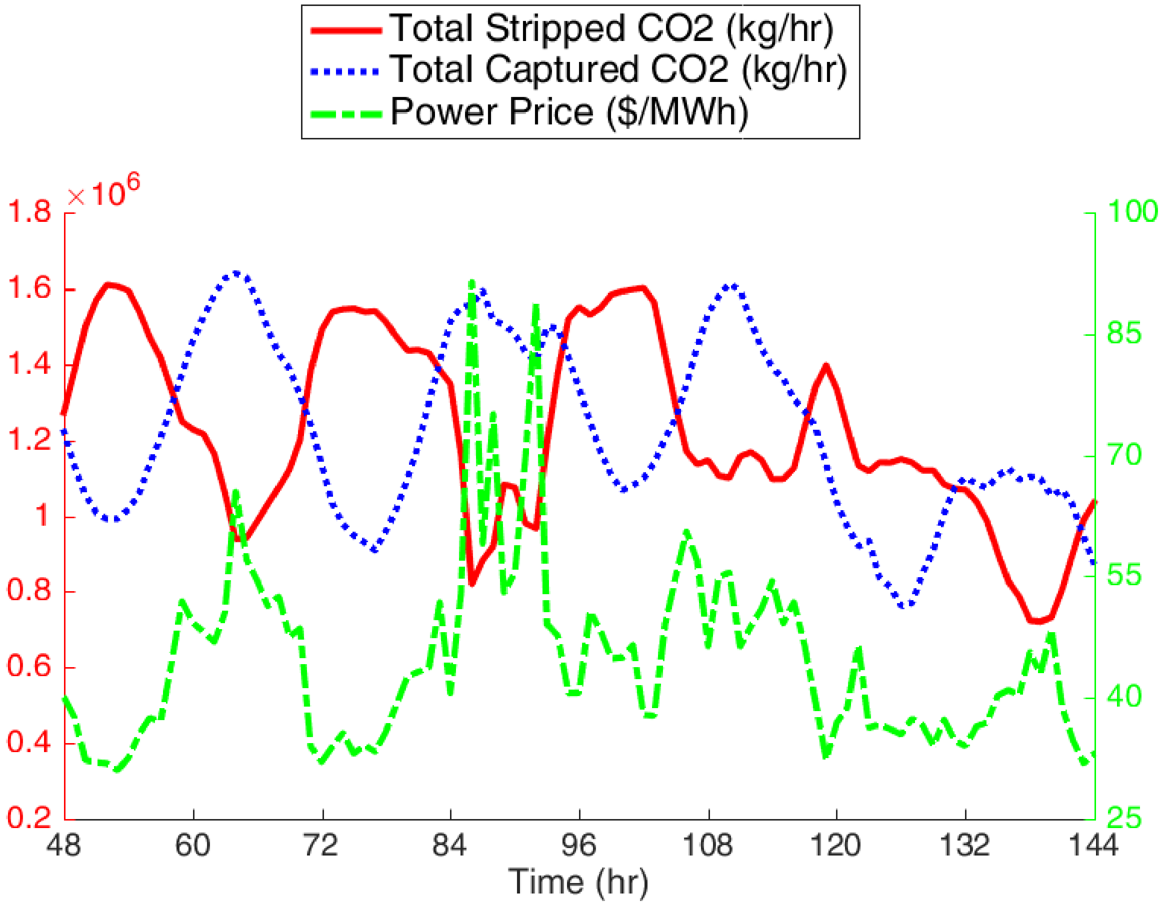
Storage vs. Time

LNG Level in Tank (CCC)



- Refrigerant storage during periods with cheap electricity price and refrigerant retrieval when electricity is expensive

CO_2 Captured vs. Stripped (Amine)



- Reduction in CO_2 stripping load during periods with expensive electricity price and increase in stripping load when electricity is cheap

Operating Costs

- 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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Conclusion

- 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)

Acknowledgements

- Sustainable Energy Solutions (SES)

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