Hybrid Gas Coal Combustion System with Energy Storage

DOE Phase I STTR Project (DE-SC0020863)

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Envergex LLC
Sturbridge, MA

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Background

Work conducted as part of ongoing DOE Phase 1 STTR project

Team (Envergex LLC, University of North Dakota, Microbeam Technologies)

- Evaluate energy storage options
- Develop software tools utilizing the IDAES modeling platform that can evaluate multiple technologies, determine optimum size and integration w/ energy producer, operating strategy, capital and operating costs and net present value of option
- Variable load and power prices and future projections over life of asset
- Energy storage options presented today
  - Flexible CO_2 capture
  - Batteries

Software Development Goals

– Development of software that describes
    - Functionality, operation and performance of energy storage systems (current and emerging)
    - Integration with energy generators and grid
    - Associated capital and operating costs

– Modeling impact of future demand profiles and pricing scenarios on viability of these capital investments

– Predictive models of Day-Ahead hourly energy prices

Software Methodology

- Step 1: Inputs
  - Base plant design and process information (coal-fired boiler, gas turbine)
  - Hourly load/dispatch profile
  - Hourly Locational Marginal Pricing (LMP) data
- Step 2: Energy storage and CO_2 capture option process selection
- Step 3: Exercise process models of power plant, CO_2 capture, energy storage systems
  - Material balances
  - Energy balances
  - Sizing and capital costs
- Step 4: Establish integration options (material, energy-steam/power) between power plant, CO_2 capture plant, and energy storage systems
- Step 5: Hourly revenue and cost calculations
- Step 6: Pro forma economic evaluation
- Step 7: Identify key input variables, why, and quantify economic benefit

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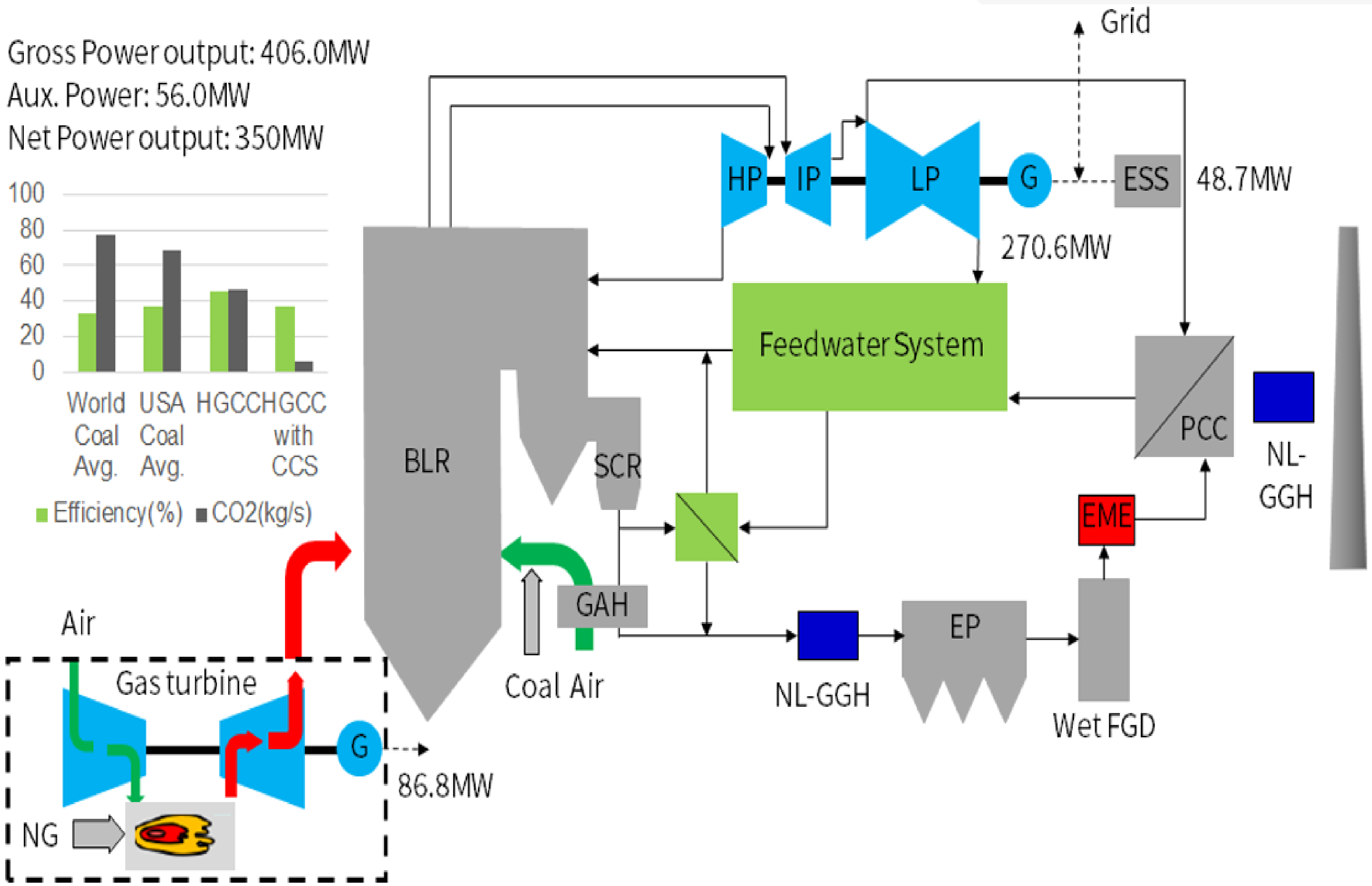
Case Study: Energy Storage integration with Hybrid Gas Coal Combustion (HGCC) Concept

- Coal First concept combines a coal boiler and gas turbine
- Indirect Firing (pulverized coal storage) => Lower min. load
- Model in IDAES platform
- Model will be capable to study ES integration with coal only, gas only, and combined options



https://netl.doe.gov/project-information?p=89243319CFE000017

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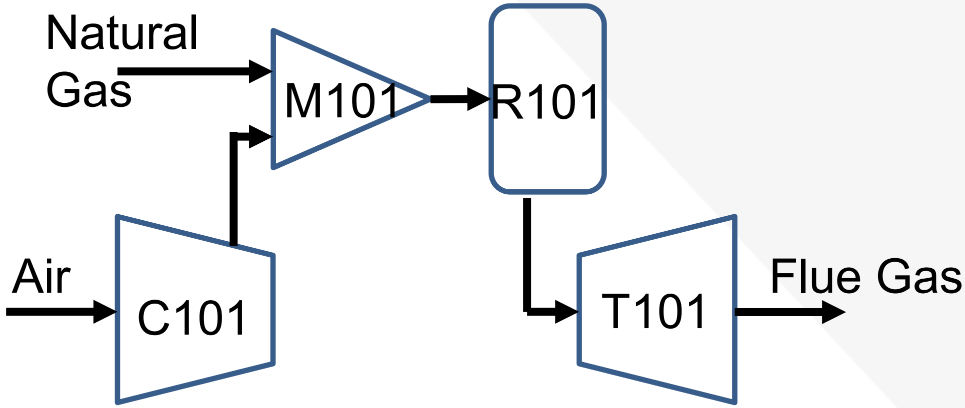
IDAES

https://github.com/IDAES

- Process modeling tool
- Pyomo optimization capabilities
- Contains detailed coal boiler and steam turbine models
- Built a gas turbine model from IDAES generic unit operation models



IDAES Gas Turbine Model Output

	Compressed Air	Air Fuel Mix	Turbine Inlet	Turbine Outlet
flow_mol_phase_comp ('Vap', 'co2')	1.0000e-07	0.0060561	0.31016	0.31016
flow_mol_phase_comp ('Vap', 'water')	1.0000e-07	2.0000e-07	0.59580	0.59580
flow_mol_phase_comp ('Vap', 'methane')	1.0000e-07	0.27930	1.0000e-08	1.0000e-08
flow_mol_phase_comp ('Vap', 'nitrogen')	5.7800	5.7851	5.7851	5.7851
flow_mol_phase_comp ('Vap', 'oxygen')	1.5560	1.5560	0.95400	0.95400
flow_mol_phase_comp ('Vap', 'ethane')	1.0000e-07	0.012400	1.0000e-08	1.0000e-08
flow_mol_phase_comp ('Vap', 'argon')	0.074100	0.074100	0.074100	0.074100
temperature	685.63	663.44	1560.1	930.69
pressure	1.6000e+06	1.6000e+06	1.6000e+06	1.0200e+05

```
==========================================================================================
Ambient Air Temperature =  288 K
Compressor Power =  88.0 MW
Turbine Power =  173.2 MW
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Gas Turbine Power =  85.2 MW
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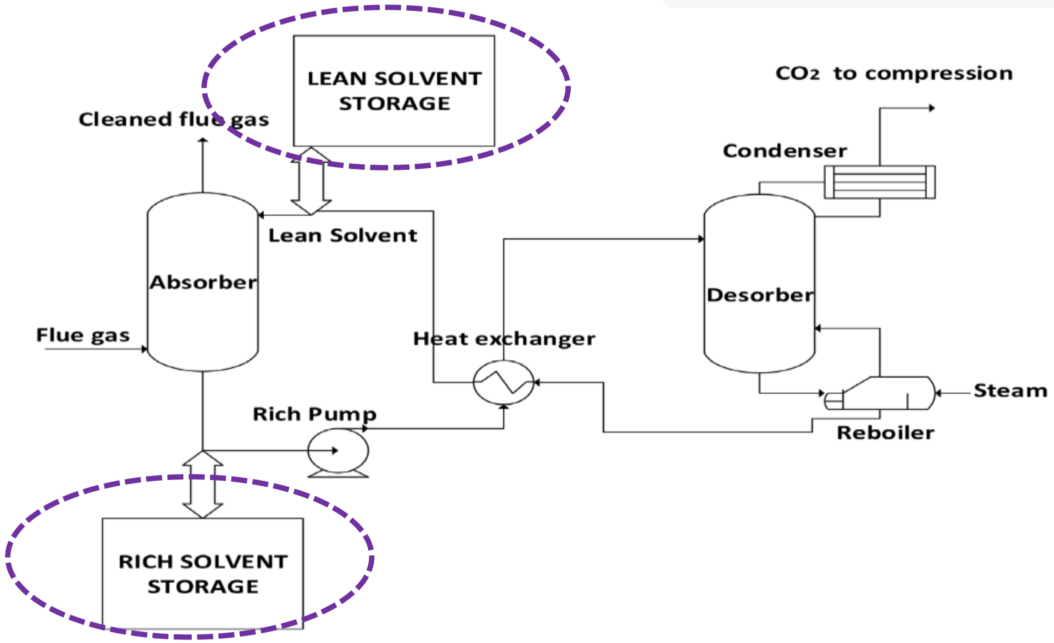
CO_2 Capture Systems Under Evaluation

- Solvents/Sorbents – flexible regeneration
  - Matched to expected capacity factor
  - Solvent/Sorbent storage could enable smaller CO_2 capture plant
  - Peak demand: store rich solvent/sorbent, decrease stripping duty, more steam to turbine
  - Low electrical demand: regenerate stored solvent/sorbent
  - Low electricity demand: increase stripping intensity – lower lean loadings, increase capture
- Oxy-fired processes
- New ARPA-E project – Flexible sorbent CO_2 capture



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Power plant Data for evaluation

Unit ID	UC-1	UC-2	UC-3	Units
Unit Size (Gross)	450	470	687	MW
Shut downs <6 hours	7	0	0	/year
Shutdowns 6-11 hours	2	0	0	/year
Shutdowns 23-72 hours	3	1	0	/year
Extended Outages (>72 hours)	2	4	2	/year
Extended Outage Hours	2610	1684	672	hours/year
Total Hours Off	2811	1712	672	hours/year
Hours at Low Load (<60%)	1265	164	3008	hours/year
Hours at Medium Loads (60-90%)	1520	773	1980	hours/year
Hours at High load (>90%)	3164	6111	3100	hours/year
Total Hours	5949	7048	8088	hours/year
Total Generation (Gross)	2183	3151	3694	GWh/year
Capacity Factor	55.4%	76.5%	61.4%	--
Capacity Factor (excl. Extended Outages)	78.9%	94.8%	66.5%	--
CO2 Emissions	2.26	3.00	2.84	MMt/year

*Source EPA Air Markets Program https://ampd.epa.gov/ampd/

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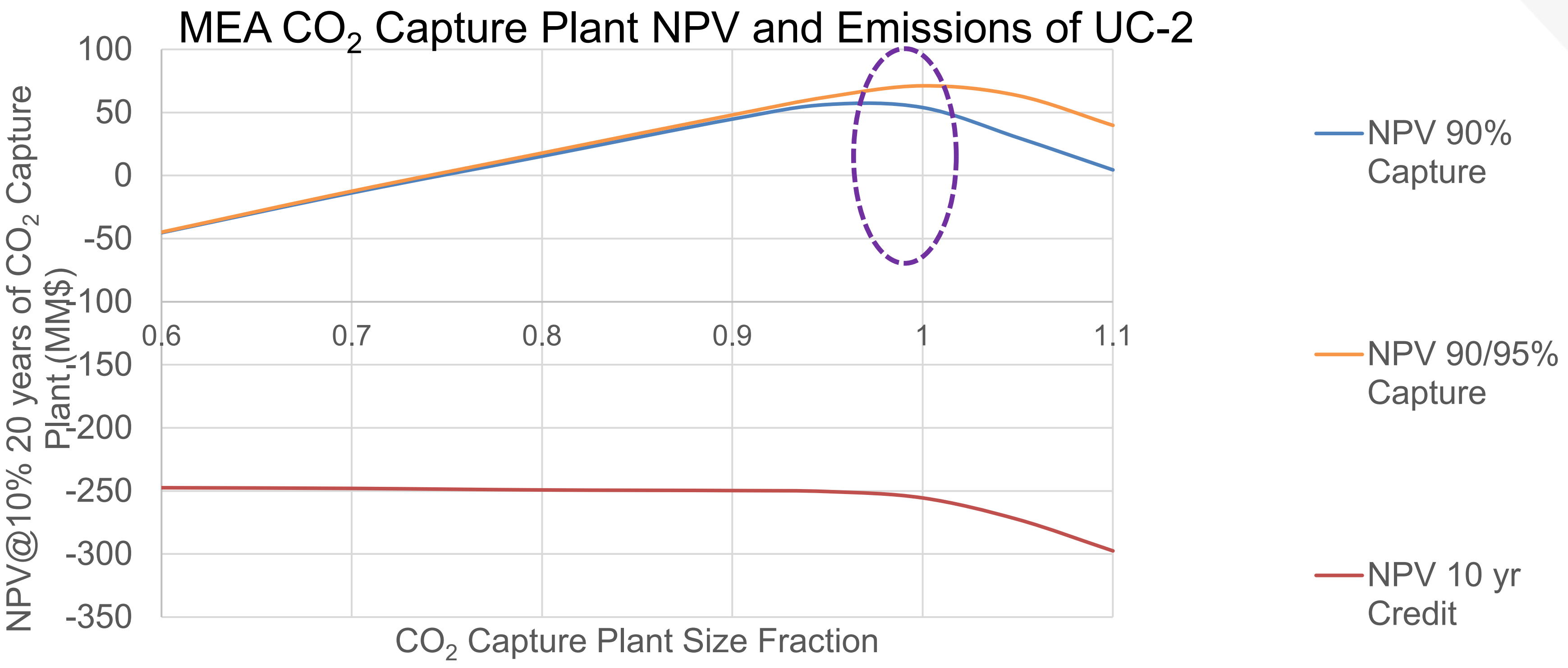
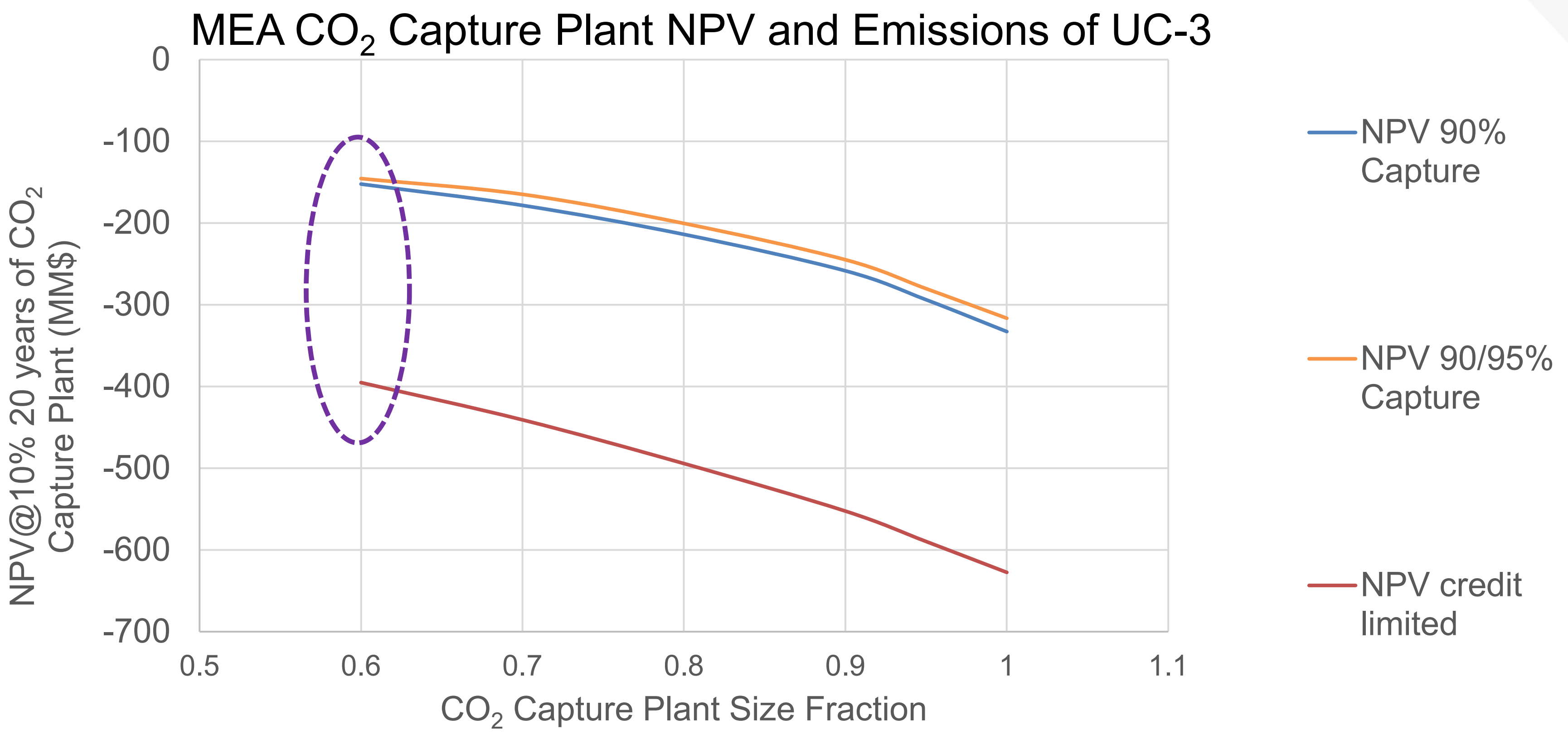
Effect of Capture Plant Size



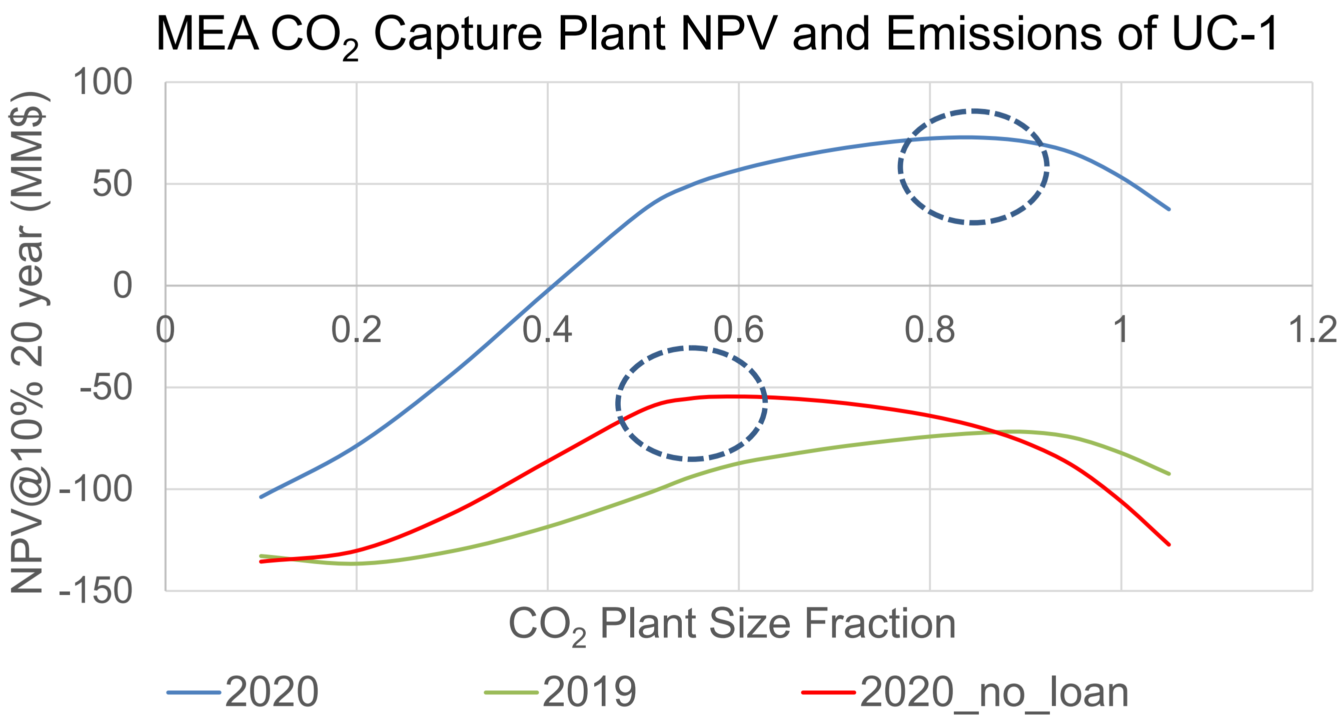
- High capacity factor case, and credit of $50 / ton CO_2
- Increased capture (95% vs 90%) at low loads increases NPV and shifts maximum to larger CO_2 capture plant size

Effect of Capture Plant Size



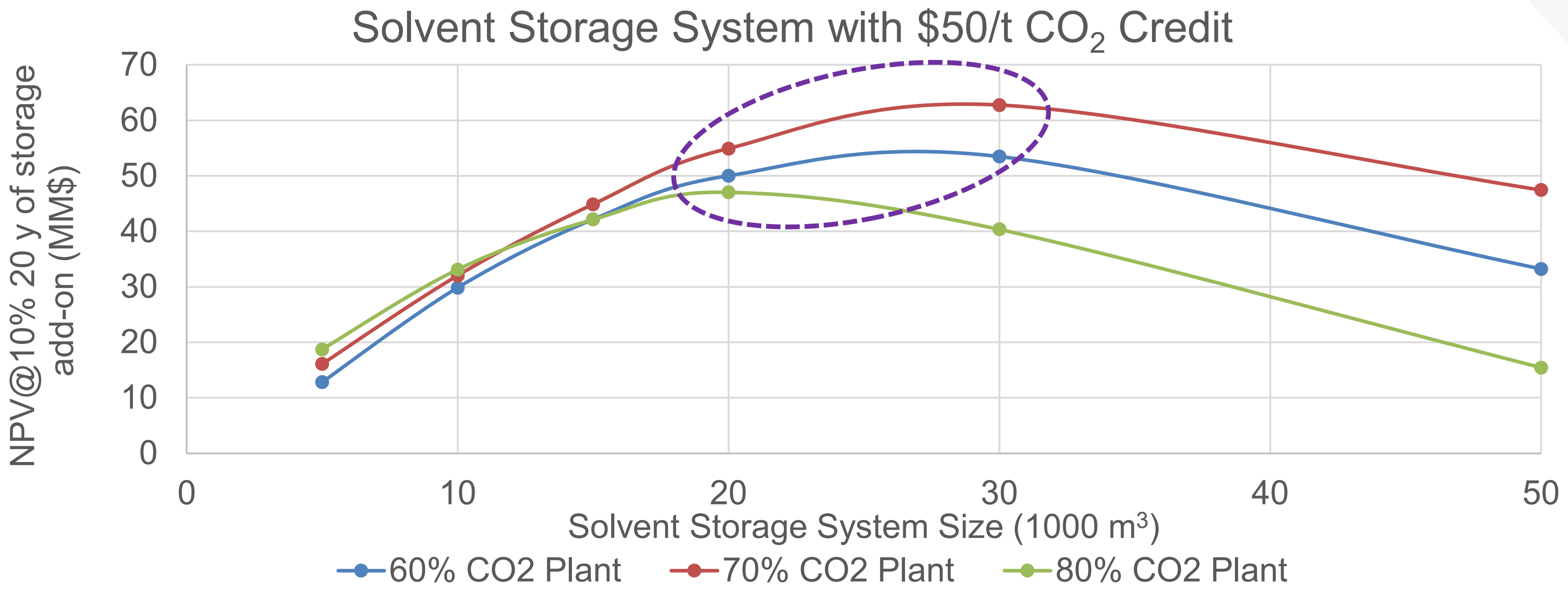
- Full Size CO_2 capture not economical for 60% capacity factor power plant ($50/ ton CO_2)
- Increased capture at low loads increases NPV

Example CO_2 Capture Plant Evaluation Result



- Highest capacity factor offers best economic case (2019 vs 2020)
- Access to financing increases economic viability

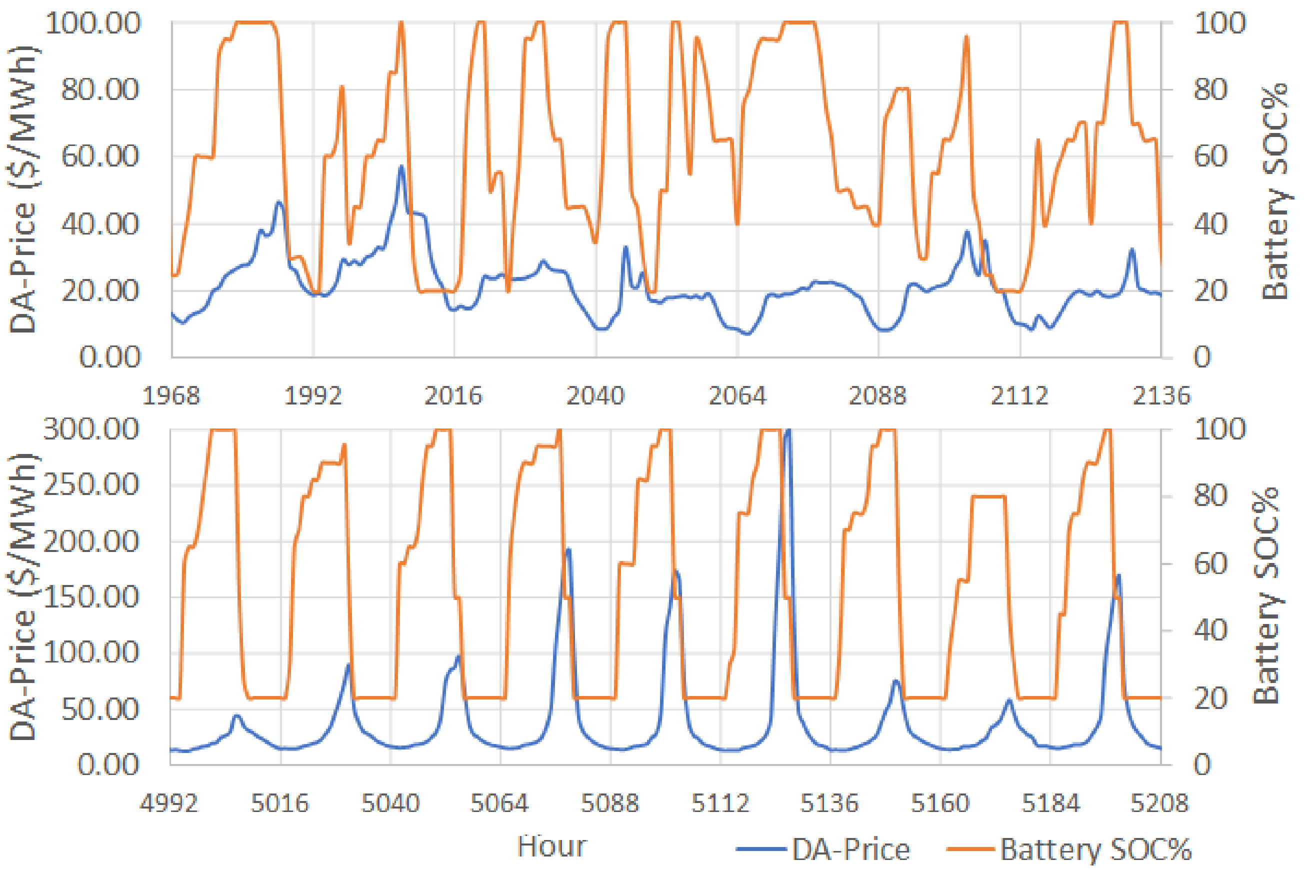
Optimized Solvent Storage Capacity



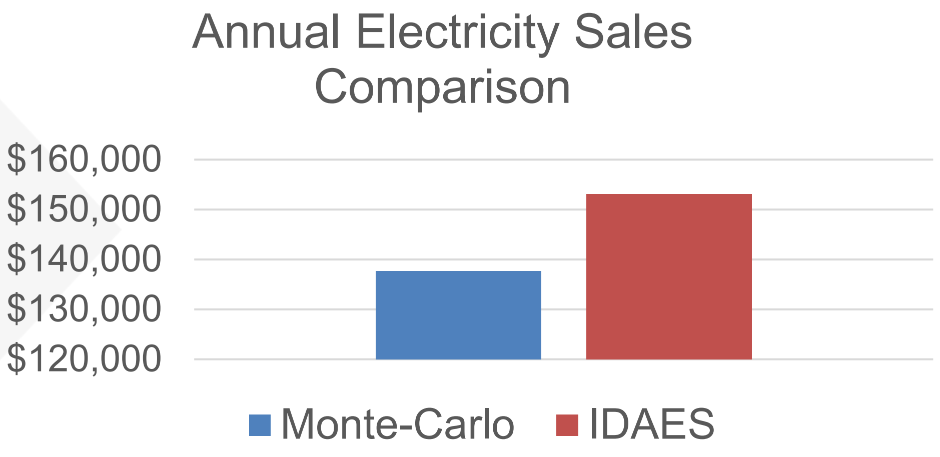
- 20,000 - 30,000 m^3 optimum value for UC-3
- CO_2 plant size balance: need opportunities to accumulate and deplete rich solvent
- More frequent load changes has greater benefit of solvent storage (more opportunities)

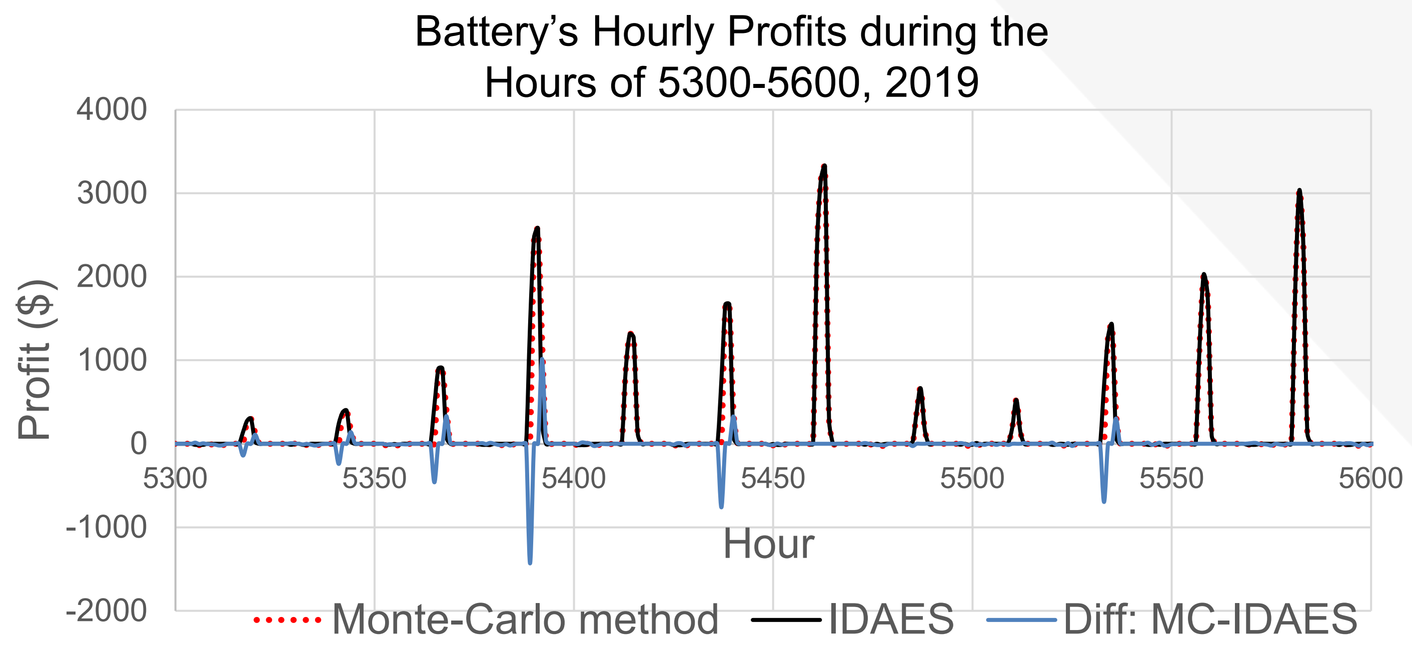
Battery Evaluation

- Battery specification inputs: efficiencies, capacity, discharge limit
- Grid data inputs: day-ahead electricity and frequency regulation services hourly pricing
- Considered Capacity to power ratio of 4 and 2 (1 MW / 4 MWh and 1 MW / 2MWh batteries)
- Method: IDAES model of Pyomo variables and constraints
- Monte Carlo simulation for comparison
- Output: Best case battery dispatch and profits (full knowledge of upcoming prices)



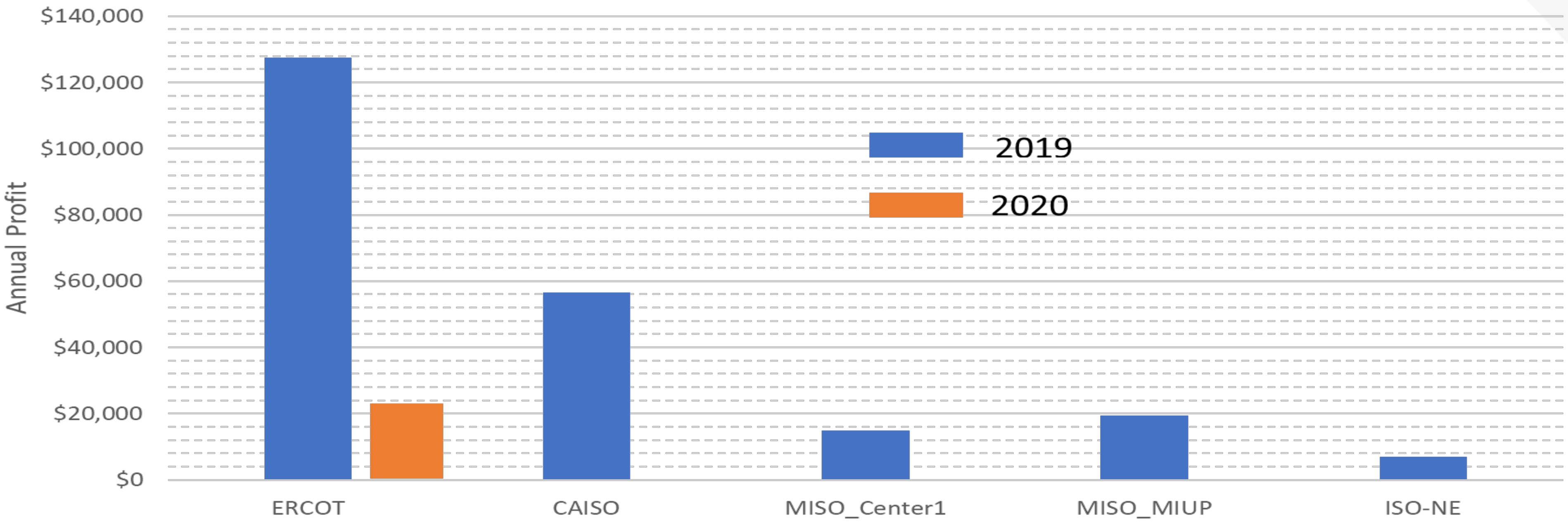
Battery Profits Calculation Method Comparison Totals





- IDAES captures additional profit from earlier discharge during peak pricing (+$15,400)
- Monte-Carlo CPU time: ~20 minutes
- IDAES CPU time: ~5 seconds

Battery Profits at Different Locations



- Locational dependence
- Battery is more profitable in areas with highly variable prices
- ERCOT has substantially higher profits in 2019 due to several peak demand/supply constraint events

Battery Profitability Estimate

- Li-ion Battery on ERCOT grid in 2019
- Capital investment assumption of $300/kWh
- Assumed 10 year lifetime (~5000 cycles) and same profits per year
- Energy arbitrage alone has negative NPV
- Participation in ancillary services markets case has positive NPV (frequency regulation)

	DA-only 2 MWh	DA-only 4 MWh	DA-AS 2 MWh	DA-AS 4 MWh
Capital Investment	$0.60	$1.2	$0.60	$1.2
Annual Profit	$0.07	$0.11	$0.31	$0.44
NPV@10% 10 year	-$0.16	-$0.50	$1.3	$1.5

(million dollars)

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Grid Forecasting – Work in Progress

- Goal is to predict the Day Ahead Energy Market hourly prices of the up coming days (~ next 7 days)
- Experimenting with machine learning approaches to produce hourly price predictions
- Incorporate expected changes to supply side (e.g. wind power) over time horizon on electricity pricing
- Provide real time information to best operate units
- Improve algorithm to project future prices given historical data and weather forecasts
- Long term (5-10 years) forecast scenarios to be included in Phase II work

Time-frame	Data Set Used
Very short term	Last 24 hours prices
Short term	Previous 24-48 hours prices
Weekday/Month/Year	One-hot encoded
- Regional Load - Renewable Generation - Ancillary Services Requirements - Outage Schedule - Weather	Latest forecast data released by ISO and weather forecasts

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LSTM

- Long Short Term Memory(LSTM) – a recurrent neural network (RNN) well suited for sequence learning
- 2019 Day-ahead LMP data - 70% to train, 20% to validate, 10% to test
- Features
  - LMP
  - Weekday/weekend
  - Hour
- Sliding window using previous 168 hours to predict the next 24 hours

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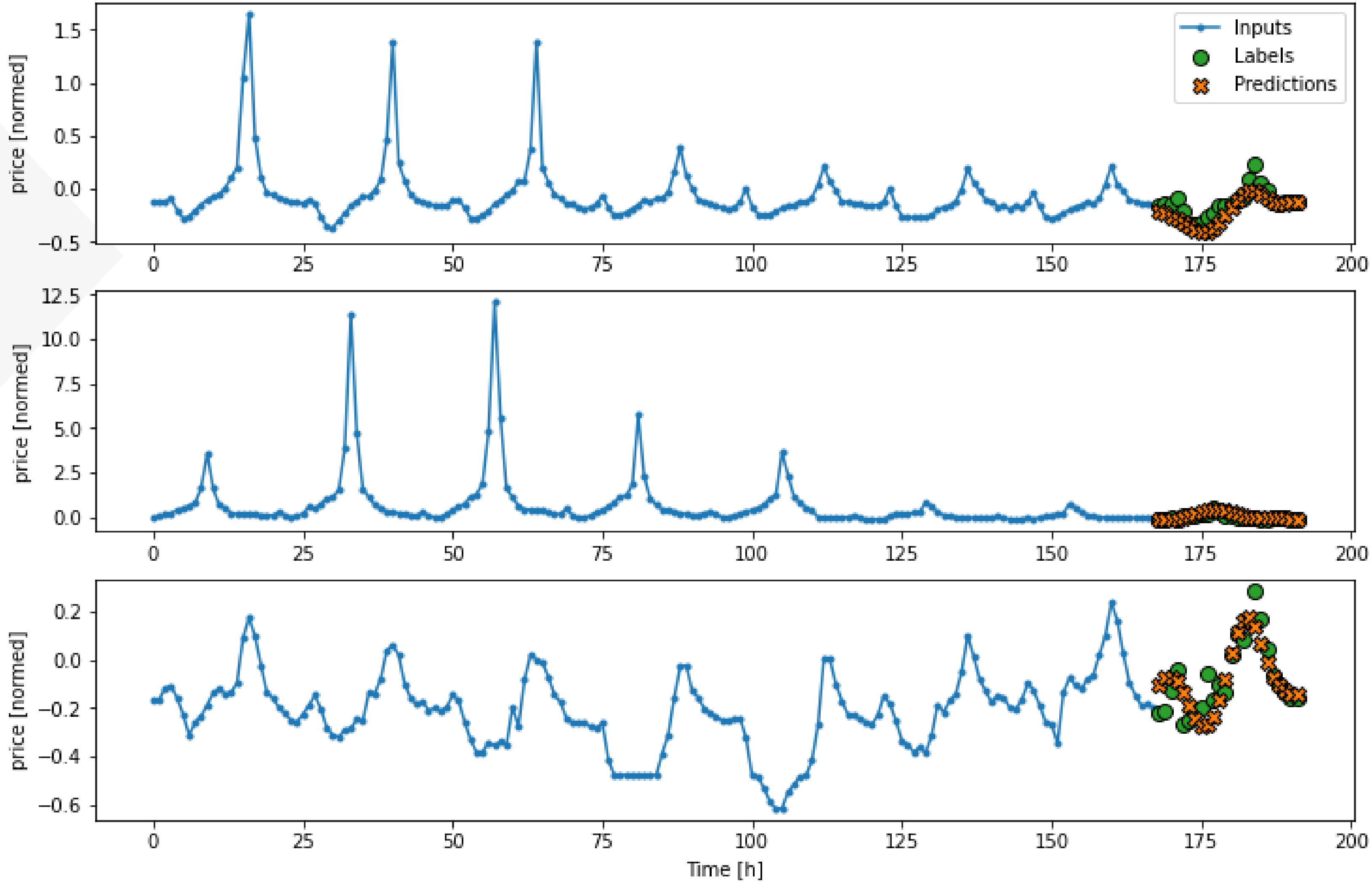
Day Ahead Market Forecasting Results



Results from three of our predictions of day ahead prices on the CAISO grid

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Summary

- Flexible CO_2 Capture Assessment
  - Capital cost largest influence
  - Size CO_2 capture plant to match power plant capacity factor
  - Cycling plants can benefit from solvent storage
- Batteries Assessment
  - Arbitrage alone not economically viable
  - Inclusion of ancillary services may make a battery economically viable
- Day-Ahead Market Forecasting
  - Needed for energy storage decision making (when to charge/discharge)
  - Investigating machine learning approaches

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Next Steps

- Day-ahead forecasting
  - Incorporate weather data into the model.
- Investigate Liquid air energy storage
  - Provides battery-like storage and an oxygen source
  - Integrate with oxy-combustion generators

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Contact Information

Srivats Srinivasachar

Envergex LLC

Email: srivats.srinivasachar@envergex.com

Phone: (508) 347-2933

Mobile: (508) 479-3784

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