Coupling amine storage tanks in coal fired power plants with renewable electricity generation

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Motivation

- An amine-based Carbon Capture and Storage system CCS, consists of two main elements: an absorber where CO_2 is removed, and a regenerator where CO_2 is released and the original solvent - mono-ethanol amine (MEA) - is recovered
- Approximately 55% of the CCS energy penalty is due to the steam consumption of the regenerator and 35% is due to the compression of the captured CO_2 for transport to the storage site
- In a "CCS with Amine Storage“ system the quantity of CO_2 captured remains the same as in a conventional amine-based system, but unlike in conventional CCS setups, the stripping of the CO_2-rich amine solution and compression of the CO_2 only occur during “off-peak” hours, when the cost of energy use is comparatively low
- The CO_2-rich amine solution that is not stripped down during times of high energy cost is temporarily stored in a tank. An additional regenerated amine storage tank is required to supply regenerated amine to the absorber when the regenerator is turned off
- A renewable source can provide electricity and/or steam for solvent regeneration and compression so that the original power output of the coal plant does not change and can be sold at peak hours
- The amine storage tanks allow the use of renewable energy when it is available. In this way the integration cost of renewable energy can be reduced.

Objectives

1. **Explore whether the benefits of amine-storage from price arbitrage in US electricity markets outweigh its capital costs**
2. **Find a threshold for the capital cost of a source of renewable power so that the economic benefits of the whole CCS storage system with renewable generation outweigh its cost**

METHOD

P_k: K[th] lowest electricity hourly price of the day ($/kWh)

$$\text{m-th Daily Price Differential}: DPD_m = \sum_{k=24-m+1}^{24} \frac{P_k}{m} - \sum_{k=1}^{24-m} \frac{P_k}{24-m}$$

E: CCS Energy use that can be differed with storage system (kWh/hour).

H_s: Number of hours the system operates in storage mode (hours/day). Same as Capacity of the storage system.

CF: Capacity factor of coal plant.

$CC^S_{H_s}$: Annualized Capital Cost of Storage with H_s capacity ($)

A storage system with capacity H_s is cost effective if:

$$DPD_{H_s} > \frac{CC^s_{H_s}}{E \times 365 \times H_s \times CF}$$

METHOD CONT'D

$$\text{m-th Daily Low Price Sum}: DLS_m = \sum_{k=1}^{24-m} P_k$$

$CC^R_{H_s}$: Annualized Capital Cost of Renewable Generator that supplies all the power for regeneration and compression in a system with H_s hours of rich amine storage

A storage system of capacity H_s with renewable energy for regeneration and compression is cost effective if:

$$CC^R_{H_s} \leq 365 \times E \times \left(DPD_{H_s} \times H_s \times CF + DLS_{H_s}\right) - CC^S_{H_s}$$

RESULTS

Capital Cost of Storage

MEA Inventory and **storage tank**

- MEA cost: 630 – 711 $/m^3
- Circulation rate: 15-19 m^3/hour/MW
- MEA inventory: circulation rate * H_s

For 500MW plant with H_s = 1, upper estimate:
MEA: $6.7M, stainless steel tank: $3.3M

Oversized CCS components

- Most of the components (excluding the absorber) need to be scaled up in capacity by *24/(24-H_s)*

For a retrofit plant with 303MW-net (NETL study), H_s=1,cost = $15.8M . H_s=4, cost = $67.1M
For a new supercritical plant with 512MW –net, H_s=1, cost = $89.1M. H_s=4, cost $163.9M

Required Daily Price Differential for a storage-only retrofit plant

Required DPD ($/MWh)

Capacity Factor	Hs=1	Hs=4
1	41.20	43.73
0.95	43.36	46.04
0.9	45.77	48.59
0.85	48.47	51.45
0.8	51.49	54.67

Assuming:
- E=118MWh;
- Capital Charge Factor = 11.28%

Observed average DPD

		2007 Hs=1	2007 Hs=4	2008 Hs=1	2008 Hs=4
NYISO	CAPITL Zone	$ 24.63	$ 22.11	$ 27.92	$ 24.82
	CENTRL Zone	$ 21.94	$ 20.08	$ 25.20	$ 22.45
	DUNWOD Zone	$ 33.54	$ 30.37	$ 40.43	$ 36.98
	GENESE Zone	$ 21.42	$ 19.64	$ 24.49	$ 21.78
	WEST Zone	$ 20.20	$ 18.47	$ 21.26	$ 18.99
	HUD VL Zone	$ 28.58	$ 27.22	$ 36.86	$ 33.58
	LONGIL Zone	$ 43.33	$ 38.08	$ 44.91	$ 40.94
	MHK VL Zone	$ 22.73	$ 20.85	$ 26.02	$ 23.23
	MILLWD Zone	$ 33.45	$ 30.29	$ 40.06	$ 36.65
	N.Y.C. Zone	$ 33.79	$ 30.64	$ 39.81	$ 37.53
	NORTH Zone	$ 21.18	$ 19.35	$ 23.45	$ 20.76
Midwest ISO	Cinergy Hub	$ 37.28	$ 33.45	$ 39.05	$ 35.47
	FE Hub	$ 37.55	$ 33.56	$ 38.76	$ 35.24
	Illinois Hub	$ 37.55	$ 33.77	$ 37.77	$ 34.63
	MichiganHub	$ 38.88	$ 34.50	$ 40.54	$ 36.77
	Minnesota Hub	$ 47.42	$ 41.85	$ 42.44	$ 38.78
NEISO	Connecticut Zone	$ 26.35	$ 24.55	$ 30.77	$ 28.08
	Maine Zone	$ 19.99	$ 17.48	$ 22.63	$ 20.10
	NE MassBost Zone	$ 21.85	$ 19.14	$ 24.65	$ 22.30
	New Hampshire Zone	$ 21.10	$ 18.80	$ 24.23	$ 21.82
	Rhode Island Zone	$ 20.90	$ 18.51	$ 24.37	$ 21.92
	SE MASS Zone	$ 19.85	$ 18.82	$ 26.16	$ 23.95
	WC MASS Zone	$ 22.09	$ 19.78	$ 25.43	$ 22.96
	Vermont Zone	$ 22.46	$ 20.22	$ 24.98	$ 22.63

		2007 Hs=1	2007 Hs=4	2008 Hs=1	2008 Hs=4
NEISO	Connecticut Zone	$ 26.35	$ 24.55	$ 30.77	$ 28.08
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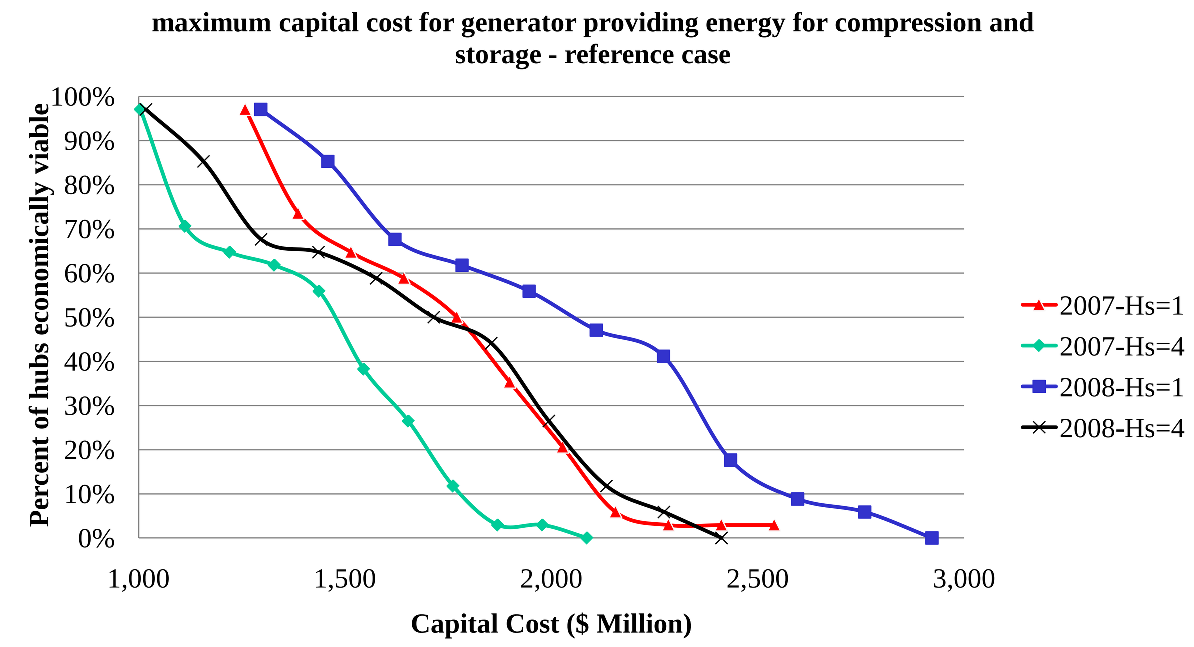
	Rhode Island Zone	$ 20.90	$ 18.51	$ 24.37	$ 21.92
	SE MASS Zone	$ 19.85	$ 18.82	$ 26.16	$ 23.95
	WC MASS Zone	$ 22.09	$ 19.78	$ 25.43	$ 22.96
	Vermont Zone	$ 22.46	$ 20.22	$ 24.98	$ 22.63
PJM	AEP GEN HUB	$ 29.75	$ 28.20	$ 31.04	$ 29.87
	AEP-DAYTON HUB	$ 31.19	$ 29.72	$ 32.78	$ 31.71
	CHICAGO GEN HUB	$ 31.13	$ 29.64	$ 33.43	$ 32.51
	CHICAGO HUB	$ 31.13	$ 29.64	$ 34.14	$ 33.22
	DOMINION HUB	$ 32.94	$ 31.24	$ 36.52	$ 34.82
	EASTERN HUB	$ 36.37	$ 34.10	$ 45.21	$ 41.41
	N ILLINOIS HUB	$ 31.38	$ 29.89	$ 33.75	$ 32.84
	NEW JERSEY HUB	$ 35.99	$ 33.72	$ 42.91	$ 39.61
	OHIO HUB	$ 31.09	$ 29.58	$ 32.89	$ 31.81
	WEST INT HUB	$ 29.13	$ 27.63	$ 31.55	$ 30.58
	WESTERN HUB	$ 32.37	$ 31.04	$ 40.13	$ 37.82

hubs where storage-only is economic are highlighted

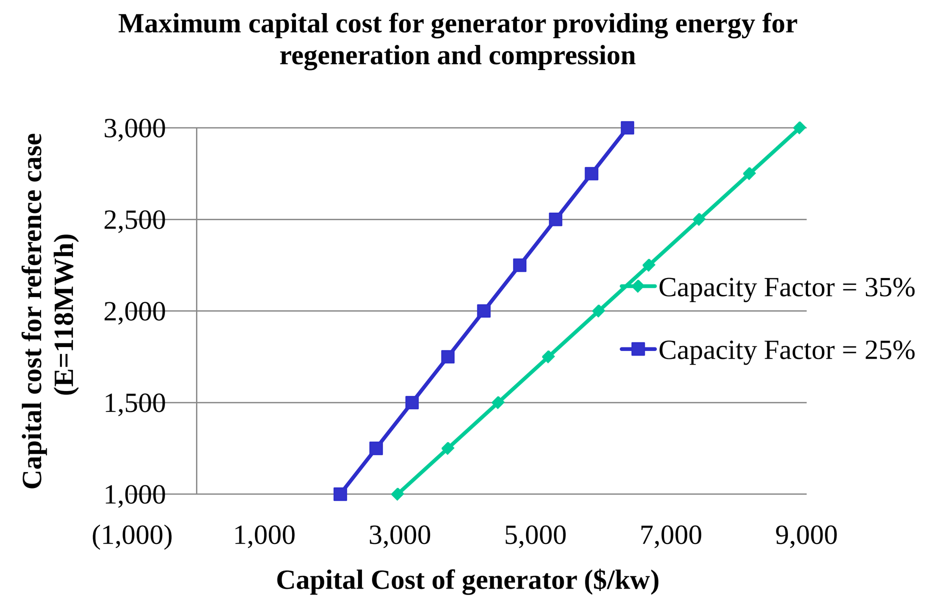
RESULTS CONT'D

Finding a threshold for the Capital Cost of a generator supplying energy for regeneration and compression

The figure below shows the maximum capital cost of a generator supplying an average of 118MWh per hour, for a CCS plant with 1 and 4 hours of amine storage, according to electricity prices observed in 35 hubs during 2007 and 2008.



Assuming the least favorable electricity prices observed, and a capacity factor of 25% the threshold for the capital cost of a generator providing energy for amine regeneration and compression is 2,912 $/kw for a system with 1 hour of storage and 2,127 $/kw for a system with 4 hours of storage:



CONCLUSIONS AND WORK IN PROGRESS

-The economic benefits of price arbitrage allowed by amine storage do not outweigh its costs, but integration with a renewable source is economically viable

-Research is underway to explore the optimal configuration of a system that combines amine storage with electrical power and/or steam from wind and thermal solar. Montecarlo simulation of wind speeds and electricity prices for a case study show system is likely to be profitable

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