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USING POWER LCAT TO EXPLORE BRAYTON CYCLE ECONOMICS

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August 19, 2014

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Introduction

- Goal of the Sandia/NETL Power Systems Life Cycle Analysis Tool (Power LCAT) is to show the economic and environmental tradeoffs associated with various electricity generation options.
- Electricity production costs are estimated using a levelized cost of energy (LCOE) approach. LCOE calculations estimate the per unit ($/kWh) cost of production over the economic lifetime of the technology.
  - LCOE includes consideration of the the capital costs, associated financing costs, O&M, fuel costs, and any externality costs (such as CO2) and calculates a per unit production cost.
  - The LCOE is often used as an economic measure of energy costs as it allows for comparison of technologies with different capital and operating costs, construction times, and plant load factors.
- Power LCAT publically available on the NETL website

Introduction (continued)

- Goal of this presentation is to provide a preliminary economic analysis of supercritical CO2 Closed Brayton Cycle (CBC) Demonstration plant

Economic assumptions for CBC

- Estimated cost of $35.35 million for plant built to deliver electricity to grid.
  - $3535 $/kW installed capital cost
  - Assume O&M 4% of capital = 141 $/kW (very high!)
  - Natural gas as fuel. Efficiency of 40.2% = heat rate of 8488 Btu/kWh.
    - Assume natural gas cost of 5.19 $/MMBtu (AEO, 2014. Estimate for 2020, delivered) .
- Financial assumptions:
  - 50%/50% Debt/Equity split; Debt finance rate @ 4.5%, Equity rate @ 12.5% (WACC = 7.4%)
  - 30 year plant life, 20 year depreciation, 37.6% effective tax rate

Estimates for other plants

- Estimates for other plants taken from DOE's *Annual Energy Outlook 2014 (AEO 214)*
- AEO estimates are summarized on next page
- For sake of comparison with CBC, included:

1. Supercritical Pulverized Coal with and without CCS
2. Advanced Combined Cycle Natural Gas
3. Advanced nuclear
4. Onshore wind

Table 1. Updated estimates of power plant capital and operating costs

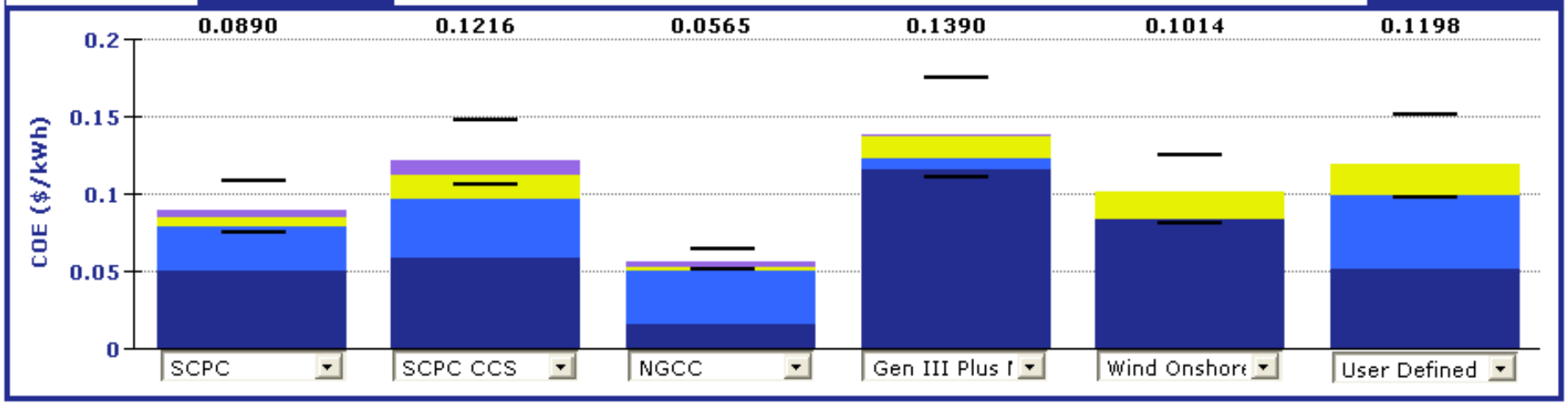
	Plant Characteristics		Plant Costs (2012$)			
	Nominal Capacity (MW)	Heat Rate (Btu/kWh)	Overnight Capital Cost ($/kW)	Fixed O&M Cost ($/kW-yr)	Variable O&M Cost ($/MWh)	NEMS Input
Coal						
Single Unit Advanced PC	650	8,800	$3,246	$37.80	$4.47	N
Dual Unit Advanced PC	1,300	8,800	$2,934	$31.18	$4.47	Y
Single Unit Advanced PC with CCS	650	12,000	$5,227	$80.53	$9.51	Y
Dual Unit Advanced PC with CCS	1,300	12,000	$4,724	$66.43	$9.51	N
Single Unit IGCC	600	8,700	$4,400	$62.25	$7.22	N
Dual Unit IGCC	1,200	8,700	$3,784	$51.39	$7.22	Y
Single Unit IGCC with CCS	520	10,700	$6,599	$72.83	$8.45	N
Natural Gas						
Conventional CC	620	7,050	$917	$13.17	$3.60	Y
Advanced CC	400	6,430	$1,023	$15.37	$3.27	Y
Advanced CC with CCS	340	7,525	$2,095	$31.79	$6.78	Y
Conventional CT	85	10,850	$973	$7.34	$15.45	Y
Advanced CT	210	9,750	$676	$7.04	$10.37	Y
Fuel Cells	10	9,500	$7,108	$0.00	$43.00	Y
Uranium						
Dual Unit Nuclear	2,234	N/A	$5,530	$93.28	$2.14	Y
Biomass						
Biomass CC	20	12,350	$8,180	$356.07	$17.49	N
Biomass BFB	50	13,500	$4,114	$105.63	$5.26	Y
Wind						
Onshore Wind	100	N/A	$2,213	$39.55	$0.00	Y
Offshore Wind	400	N/A	$6,230	$74.00	$0.00	Y
Solar						
Solar Thermal	100	N/A	$5,067	$67.26	$0.00	Y
Photovoltaic	20	N/A	$4,183	$27.75	$0.00	N
Photovoltaic	150	N/A	$3,873	$24.69	$0.00	Y
Geothermal						
Geothermal – Dual Flash	50	N/A	$6,243	$132.00	$0.00	N
Geothermal – Binary	50	N/A	$4,362	$100.00	$0.00	N
Municipal Solid Waste						
Municipal Solid Waste	50	18,000	$8,312	$392.82	$8.75	N
Hydroelectric						
Conventional Hydroelectric	500	N/A	$2,936	$14.13	$0.00	N
Pumped Storage	250	N/A	$5,288	$18.00	$0.00	N

Results

- Next slide shows main output from Power LCAT updated to the *AEO 2014* assumptions. These are for *new* plants.
- Last column shows preliminary estimates using Sandia estimates of the cost for constructing a small CBC plant with wet cooling.
- Important points:
  - Natural gas combined cycle (NGCC) is the low cost option (5.65 cents/kWh)
  - Supercritical pulverized coal (SCPC) is 8.9 cents/kWh.
  - Nuclear estimated at 13.90 cents/kWh
  - The CBC plant is 11.98 cents/kWh; note this is the first plant and costs can be expected to decrease (discussed later)
  - Note: All of the comparison plants are much larger than the CBC option included here.

NETL Production Analysis | Environmental Performance | Costs vs Emissions | Sensitivity Analysis | Sandia National Laboratories

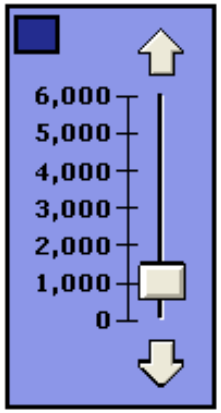
Graph | Table | Master Sheet



IGCC | SCPC | NGCC | EXPC | USCPC | GEN III+ Nuclear | EXNUC | WIND | USER DEFINED

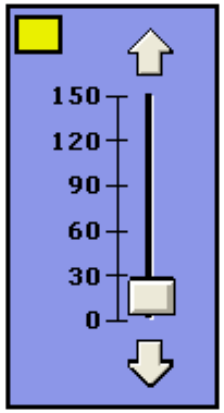
With CCS | Without CCS

CAPITAL COST



1,023.00 $/kW

FIXED O&M



15.3700 $/kW

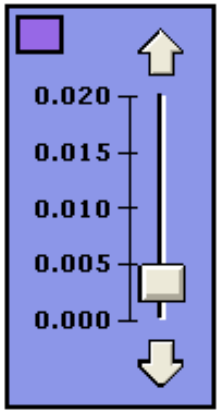
Technical | Finance

Capacity Factor	90 %
Transmission Loss	7 %
Plant Life	30 yrs
Heat Rate	6,430 Btu/kWh
CO2 Capture	0%

NG Fuel Source Assumption

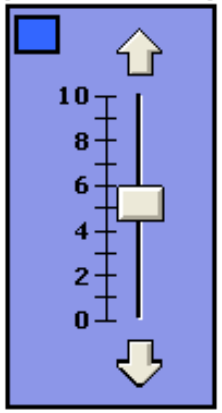
- NGCC with domestic NG
- NGCC with imported LNG

VARIABLE O&M



0.0033 $/kWh

FUEL COST (NATURAL GAS)



5.19 $/MMBtu

Important points, continued

- Note that cost breakdowns are color-coded so can easily see the likely sensitivities.
  - For NGCC, fuel costs (and hence efficiency) are key.
  - For SCPC and nuclear, capital costs are very important.
  - For CBC, results sensitive to capital, feedstock, and O&M! As efficiency improves, feedstock costs will be less important. O&M may be high as is currently based on 4% of total capital costs/year (common engineering economics assumption).
- Note that sliders make it easy to find break even points for comparing competitiveness of various options.
- Horizontal black lines indicate uncertainty regarding estimates.
  - For non-CBC technologies, uncertainty based on ranges provided by NETL
  - For CBC, assumed capital costs could be +/- 50%; O&M could be +/- 30%.

Next steps for CBC Economic Analysis

- Initial economic estimates are for a small, first generation CBC facility with wet cooling, max pressure of 20 MPa, 550 deg C unit.
- Efficiency: 40.2%
  - This is much lower than for assumed by AEO for the new NGCC (53%).
  - As higher temperatures achieved in CBC, efficiency will increase.
- Under what conditions might the CBC be able to compete with the AEO reference NGCC?
  - Dry cooling option makes possible in areas where new NGCC could not be located.
  - NEED: similar initial estimates for CBC with dry cooling.
  - What happens to economics as size scaled up? Can capital costs be sharply reduced as economies of scale are achieved?

Next steps (continued)

- Assumptions to DOE's *Annual Energy Outlook* also useful.
- Chart on next page shows assumptions about cost component of each new plant.
- For example, the HRSG for new combined cycle plants is 40% of the estimated cost (30% turbine, 30% balance of plant).
  - Can we use this information to make educated estimates of larger plant economics?
- DOE estimates also incorporate learning factors to drive down costs over time; we can follow similar approach.

From *AEO 2014*

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Table 8.4. Component cost weights for new technologies

Technology	Pulverized Coal	Combus-tion Turbine-conven-tional	Combus-tion Turbine-advanced	HRSG	Gasifier	Carbon Capture/ Seques-tration	Balance of Plant-IGCC	Balance of Plant-Turbine	Balance of Plant-Combined Cycle	Fuel Prep Biomass
Integrated Coal-Gasification Comb Cycle (IGCC)	0%	0%	15%	20%	41%	0%	24%	0%	0%	0%
IGCCwith carbon sequestration	0%	0%	10%	15%	30%	30%	15%	0%	0%	0%
Conv Gas/Oil Comb Cycle	0%	30%	0%	40%	0%	0%	0%	0%	30%	0%
Adv Gas/Oil Comb Cycle (CC)	0%	0%	30%	40%	0%	0%	0%	0%	30%	0%
Adv CC with carbon sequestration	0%	0%	20%	25%	0%	40%	0%	0%	15%	0%
Conv Comb Turbine	0%	50%	0%	0%	0%	0%	0%	50%	0%	0%
Adv Comb Turbine	0%	0%	50%	0%	0%	0%	0%	50%	0%	0%
Biomass	50%	0%	0%	0%	0%	0%	0%	0%	0%	50%

Note: All unlisted technologies have a 100% weight with the corresponding component. Components are not broken out for all technologies unless there is overlap with other technologies.
HRSG = Heat Recovery Steam Generator.
Source: Market-Based Advanced Coal Power Systems, May 1999, DOE/FE-0400.

Next steps (continued)

- Discuss these results with Brayton cycle team.
- Show presentation to relevant industry stakeholders to gather feedback.
- Use feedback to refine estimates.
- Use final estimates to derive market outlook over time using a market diffusion model approach (s-shaped diffusion).