100 MWe COAL-FIRED DIRECT INJECTION CARBON ENGINE (DICE) COMPOUND REHEAT COMBINED CYCLE (CRCC) WITH 90 PERCENT POST-COMBUSTION CO_2 CAPTURE

VOLUME V: COST RESULTS REPORT

U. S. Department of Energy (DOE)

Contract No. 89243319CFE000025, Coal-Based Power Plants of the Future

By

Nexant, Inc

and

Bechtel Power and Infrastructure

Table of Contents

Tables in Report

Figures in Report

Section 1 Capital Cost Estimate

1.1 COST ESTIMATION METHODOLOGY

Capital costs for the small-modular DICE CRCC plant (nominally a 100 MW "power block" but less than 100 MW with post-combustion capture for this introductory variant) were derived based on the following methodology:

- Capital costs for the coal beneficiation system were estimated by Sedgman and presented as a turnkey subcontract cost in this report. The capital cost estimate is reflective of the facility fully designed, supplied, fabricated and delivered to site, constructed and commissioned in accordance with the coal beneficiation plant scope of work detailed in the pre-FEED performance results study. For this study phase, Sedgman has utilized its historical cost information for procurement, fabrication and installation pricing and rate and this information will be validated in future study phases.

  Sedgman's bulk material and labor cost estimating procedures are based on quantity take-offs and construction rates respectively. The Sedgman in-house cost estimating database for the development, design and construction of coal handling and preparation plants and associated mine infrastructure is comprehensive and is continuously being updated.

- The costs for certain specialized, commercial equipment associated with the DICE CRCC plant, such as the air compressor, hot gas combustor, hot gas expander and the various generator equipment, were estimated and verified with budgetary quotes from equipment vendors. These were then developed up to the total plant cost level, which includes bulk material, labor, and construction indirect costs based on historical factors for similar equipment type. Costs associated with common equipment types (pumps, heat exchangers) were estimated using commercial cost estimation software (Aspen In-Plant Cost Estimator, Thermoflow PEACE)
- Post combustion capture (PCC) plant cost was determined via a bottoms-up cost estimate based on major equipment sizing and using past quotes from equipment vendors or cost curves derived from commercial cost estimate software
- DICE CRCC balance of plant (BOP) systems were estimated via a bottoms-up cost estimate based on major equipment sizing and developed to total plant cost level using historical factors
- The DICE CRCC solids handling systems (coal handling and ash handling) were scaled via capacity factor, using appropriate scaling parameters and capacity factoring exponents stated in NETL's Quality Guidelines for Energy System Studies (QGESS) Cost Scaling Report

Table 1-1 shows the methodology used to estimate the costs for each of the major accounts and subaccounts of the DICE CRCC plant.

Table 1-1
100 MWe DICE CRCC Cost Accounts and Estimation Methodology

Acct No.	Item/Description	Cost Estimate Methodology
1	COAL HANDLING	Included in Sedgman scope
2	COAL & SORBENT PREP & FEED	
2.1	Coial Receiving, Conveying & Crushing	Each area estimated as turnkey subcontract cost based on Sedgman's in-house estimation database
2.2	Grinding	
2.3	Flotation	
2.4	Product Dewatering	
2.5	Product Slurry Storage	
2.6	Tailings Dewatering	
2.7	BOP and Reagents	
3	FEEDWATER & MISC BOP SYSTEMS	
3.1	Feedwater System	Included in HRSG cost
3.2	Deaerator, Water Treatment & Tanks	Bottoms-up, major equipment factored estimate
3.3	Service Water Systems	Bottoms-up estimate, includes service water pumps and headers
3.4	Natural Gas Pipeline	Bottoms-up estimate based on inch-mile of pipeline; pipeline used is 6" ID, 10 mile length
3.5	Waste Treatment Equipment	Bottoms-up estimate, includes waste water discharge pumps, tanks, and headers
3.6	Plant Instrument Air System	High-level estimate based on plant and instrument air consumption
3.7	Fire Protection System	Bottoms up estimate based on fire water requirement
3.8	Miscellaneous Pumps and Tanks	Bottoms-up cost estimate
4	DICE GT	
4.1	DICE and Generator (5)	Per MAN, equipment engines of this type are between $6 and $7 million
4.2	Air Compressor	Equipment cost quoted by Siemens Dresser-Rand
4.3	Hot Gas Expander + Generator (1)	Equipment cost quoted by Siemens Dresser-Rand
4.4	MRC Preheater	Estimated from Thermoflow PEACE
4.5	Fin-Fan Air Cooler	Estimated from Thermoflow PEACE
4.9	DICE-GT Foundation	Bulk foundation material and labor factored from DICE GT equipment costs
5	FLUE GAS CLEANUP	
5.1	Caustic scrubber/direct contact cooler	Sulzer quote for packing/internals and literature
5.2	Third-Stage Separator	Quote from UOP Honeywell
5B	CO2 REMOVAL & COMPRESSION	
5B.1	MEA CO2 Capture	Nexant bottoms-up cost estimate
5B.2	CO2 Compression & Drying	Nexant bottoms-up cost estimate
5B.9	CO2 Capture & Compression Foundation	Bulk foundation material and labor factored from CO2 capture and compressions equipment costs
7	HRSG, DUCTING & STACK	
7.1	Heat Recovery Steam Generator (w/ SCR)	Nooter & Eriksen bid for TC-RHT GTCC
7.2	Ductwork	From layout using other CCS cost estimates as guide
7.9	HRSG, Duct & Stack Foundations	Bulk foundation material and labor factored from HRSG equipment costs
8	STEAM TURBINE GENERATOR	
8.1	Steam TG & Accessories	Siemens Industrial bid
8.2	Condenser & Auxiliaries	Thermoflow PEACE
8.3	Steam Piping	From layout using other Bechtel power projects as guide
8.9	TG Foundations	Bulk foundation material and labor factored from steam turbine equipment costs
9	COOLING WATER SYSTEM	
9.1	Cooling Towers	Quote from Cooling Tower Depot
9.2	Circulating Water Pumps	Bottoms-up cost estimate based on pump sizing
9.3	Circ. Water Piping	Estimate based on underground CW piping length
9.4	Make-up Water System	Bottoms-up estimate, includes makeup water pump, filter, and headers
9.9	Circ. Water System Foundations	Bulk foundation material and labor factored from cooling water/cooling tower equipment costs

Table 1-1 (cont'd)
100 MWe DICE CRCC Cost Accounts and Estimation Methodology

Acct No.	Item/Description	Cost Estimate Methodology
10	ASH/SPENT SORBENT HANDLING SYS	
10.6	Ash Storage Silos	Scaled via QGESS capacity factoring using Low Rank Coal Baseline Report as reference
10.7	Ash Transport & Feed Equipment	
10.9	Ash/Spent Sorbent Foundation	
11	ACCESSORY ELECTRIC PLANT	
11.1	Electical Equipment	Bottoms-up cost estimate based on electrical single-line
11.2	Transmission Lines and Switchyards	
11.9	Electrical Bulks and Foundations	
12	INSTRUMENTATION & CONTROL	
12.1	DICE GT-CRCC Control Equipment	Factored from DICE GT-CRCC equipment costs
12.2	PCC Control Equipment	Factored from CO2 capture and compression equipment costs
13	IMPROVEMENTS TO SITE	
13.1	DICE GT-CRCC Sitework	Factored from DICE GT-CRCC equipment costs
13.2	PCC Sitework	Factored from CO2 capture and compression equipment costs
14	BUILDINGS & STRUCTURES	
14.1	DICE Area	Factored from DICE GT equipment costs
14.2	Steam Turbine Building	Factored from steam turbine equipment costs
14.3	Administration Building	Based on labor position requirements
14.4	Circulating Water Pumphouse	Factored from cooling water associated equipment costs
14.5	Water Treatment Buildings	Based on rough square footage requirements
14.6	Machine Shop	
14.7	Warehouse	
14.8	Other Buildings & Structures	
14.9	Waste Treating Building & Structures	

1.2 CAPITAL COST ESTIMATE

1.2.1 Total Plant Cost (TPC)

Table 1-2 provides a breakdown of the DICE CRCC total plant cost (TPC), in 2018 dollars, reported in a similar format, with similar code of accounts as the NETL baseline reference cases for combustion-based coal and natural gas-fired power plants.

The estimated TPC for the small, modular (nominal 100 MW "block") DICE CRCC plant is $422.4 million (MM), or $5,419/kW-net,

Table 1-3 presents the breakdown of the additional costs required to develop the TPC to total overnight cost (TOC), per the assumptions used in the NETL coal and natural gas baseline power plant cases. The resulting TOC, at $525 MM, or $6,732/kW-net is used for the calculation of the levelized cost of electricity (LCOE).

Table 1-2
100 MWe Nominal DICE CRCC Capital Cost Breakdown

DICE CRCC w/ CO2 Capture Total Plant Cost Details (Jun 2018 Basis)

5x1x1x1 100 MW DICE CRCC PLANT WITH 30 WT% MEA CO2 CAPTURE

Cost Basis: 2018 ($x1000)
Plant Size: 78 MWe, net

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sub Contract	Bare Erected Cost $	Eng'g CM H.O & Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL HANDLING			incl in Coal Beneficiation Scope								
2	COAL BENEFICIATION											
2.1	Coal Receiving, Conveying & Crushing	$0	$0	$0	$0	$4,648	$4,648	$1,118	$937	$577	$7,280	
2.2	Grinding	$0	$0	$0	$0	$16,159	$16,159	$3,887	$3,257	$2,005	$25,308	
2.3	Flotation	$0	$0	$0	$0	$4,050	$4,050	$974	$816	$502	$6,343	
2.4	Product Dewatering	$0	$0	$0	$0	$4,705	$4,705	$1,132	$948	$584	$7,369	
2.5	Product Slurry Storage	$0	$0	$0	$0	$2,838	$2,838	$683	$572	$352	$4,445	
2.6	Tailings Dewatering	$0	$0	$0	$0	$1,997	$1,997	$480	$403	$248	$3,128	
2.7	BOP and Reagents	$0	$0	$0	$0	$5,383	$5,383	$1,295	$1,085	$668	$8,431	
	SUBTOTAL 2.	**$0**	**$0**	**$0**	**$0**	**$39,780**	**$39,780**	**$9,568**	**$8,019**	**$4,935**	**$62,302**	**$799**
3	FEEDWATER & MISC BOP SYSTEMS											
3.1	Feedwater System			incl w/ HRSG			$0	$0	$0	$0	$0	
3.2	Deaerator, Tanks and Water Treatment	$145	$425	$133	$0	$0	$703	$70	$0	$155	$928	
3.4	Service Water Systems	$71	$83	$137	$0	$0	$290	$29	$0	$64	$383	
3.6	Natural Gas Pipeline	$0	$9,076	$0	$0	$0	$9,076	$908	$0	$1,497	$11,481	
3.7	Waste Treatment Equipment	$196	$220	$330	$0	$0	$747	$75	$0	$164	$986	
3.8	Plant and Instrument Air System	$911	$902	$720	$0	$0	$2,533	$253	$0	$418	$3,204	
3.8	Fire Protection System	$150	$179	$237	$0	$0	$565	$57	$0	$93	$715	
3.9	Misc Pumps and Tanks	$500	$607	$773	$0	$0	$1,880	$188	$0	$310	$2,378	
	SUBTOTAL 3.	**$1,973**	**$11,491**	**$2,329**	**$0**	**$0**	**$15,794**	**$1,579**	**$0**	**$2,702**	**$20,075**	**$258**
4	DICE-GT SYSTEMS											
4.1	DICE and Generator (5)	$30,000	$4,500	$5,400	$0	$0	$39,900	$3,990	$8,778	$7,900	$60,568	
4.2	Air Compressor	$8,300	$3,633	$4,259	$0	$0	$16,192	$1,619	$0	$2,672	$20,483	
4.3	Combustor, Expander and Generator	$17,000	$837	$1,274	$0	$0	$19,111	$1,911	$0	$3,153	$24,175	
4.4	MRC Preheater	$150	$130	$133	$0	$0	$413	$41	$0	$68	$522	
4.5	Fin-Fan Air Cooler	$1,000	$867	$884	$0	$0	$2,751	$275	$0	$454	$3,479	
4.9	DICE-GT Foundation	$0	$2,469	$4,805	$0	$0	$7,274	$727	$0	$1,200	$9,202	
	SUBTOTAL 4.	**$56,450**	**$12,435**	**$16,755**	**$0**	**$0**	**$85,640**	**$8,564**	**$8,778**	**$15,447**	**$118,429**	**$1,519**
5	FLUE GAS CLEANUP											
5.1	Direct Contact Cooler	$1,275	$1,284	$1,325	$0	$0	$3,884	$388	$0	$427	$4,700	
5.3	Third Stage Separator	$6,000	$4,916	$5,426	$0	$0	$16,342	$1,634	$0	$1,798	$19,774	
5.3	Flue Gas Cleanup Foundation	$0	$575	$1,120	$0	$0	$1,695	$169	$0	$186	$2,051	
	SUBTOTAL 5.	**$7,275**	**$6,775**	**$7,871**	**$0**	**$0**	**$21,921**	**$2,192**	**$0**	**$2,411**	**$26,525**	**$340**
5B	CO2 REMOVAL & COMPRESSION											
5B.1	CO2 Removal System	$12,984	$5,838	$11,595	$0	$0	$30,416	$3,042	$0	$5,019	$38,476	
5B.2	CO2 Compression & Drying	$11,061	$4,060	$5,175	$0	$0	$20,296	$2,030	$0	$3,349	$25,674	
5B.3	CO2 Removal & Compression Foundation	$0	$877	$1,417	$0	$0	$2,294	$229	$0	$378	$2,902	
	SUBTOTAL 5B.	**$24,044**	**$10,775**	**$18,186**	**$0**	**$0**	**$53,006**	**$5,301**	**$0**	**$8,746**	**$67,052**	**$860**
7	HRSG, DUCTING & STACK											
7.1	Heat Recovery Steam Generator (w/ SCR)	$6,000	$2,775	$6,018	$0	$0	$14,792	$1,479	$0	$2,441	$18,712	
7.2	Deaerator			incl in 3.2			$0	$0	$0	$0	$0	
7.3	Ductwork	$1,675	$0	$0	$0	$0	$1,675	$168	$0	$276	$2,119	
7.9	HRSG & Duct Foundations	$0	$297	$679	$0	$0	$976	$98	$0	$215	$1,288	
	SUBTOTAL 7.	**$7,675**	**$3,072**	**$6,696**	**$0**	**$0**	**$17,443**	**$1,744**	**$0**	**$2,932**	**$22,119**	**$284**

Table 1-2 (cont'd)
100 MWe Nominal DICE CRCC Capital Cost Breakdown

DICE CRCC w/ CO2 Capture Total Plant Cost Details (Jun 2018 Basis)

5x1x1x1 100 MW DICE CRCC PLANT WITH 30 WT% MEA CO2 CAPTURE

Cost Basis: 2018 ($x1000)
Plant Size: 78 MWe, net

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sub Contract	Bare Erected Cost $	Eng'g CM H.O & Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
8	STEAM TURBINE GENERATOR											
8.1	Steam Turbine & Accessories	$4,850	$421	$741	$0	$0	$6,013	$601	$0	$661	$7,275	
8.2	Steam Turbine Condenser	$400	$347	$354	$0	$0	$1,100	$110	$0	$121	$1,331	
8.4	Steam Piping	$0	$4,500	$6,667	$0	$0	$11,167	$1,117	$0	$1,843	$14,126	
8.9	Steam Turbine Foundations	$0	$329	$640	$0	$0	$969	$97	$0	$213	$1,280	
	SUBTOTAL 8.	**$5,250**	**$5,597**	**$8,402**	**$0**	**$0**	**$19,249**	**$1,925**	**$0**	**$2,838**	**$24,012**	**$308**
9	COOLING WATER SYSTEM											
9.1	Cooling Towers	$2,216	$346	$943	$0	$0	$3,504	$350	$0	$385	$4,240	
9.2	Circulating Water Pumps	$1,204	$1,387	$1,570	$0	$0	$4,161	$416	$0	$458	$5,035	
9.4	Circ. Water Piping	$1,075	$596	$2,632	$0	$0	$4,303	$430	$0	$710	$5,444	
9.5	Make-up Water System	$951	$591	$813	$0	$0	$2,355	$236	$0	$389	$2,979	
9.9	Circ. Water System Foundations	$0	$767	$1,491	$0	$0	$2,258	$226	$0	$497	$2,980	
	SUBTOTAL 9.	**$5,446**	**$3,688**	**$7,449**	**$0**	**$0**	**$16,582**	**$1,658**	**$0**	**$2,439**	**$20,679**	**$265**
10	ASH/SPENT SORBENT HANDLING SYS											
10.6	Ash Storage Silos	$95	$0	$290	$0	$0	$385	$38	$0	$42	$465	
10.7	Ash Transport & Feed Equipment	$847	$0	$839	$0	$0	$1,686	$169	$0	$185	$2,040	
10.9	Ash/Spent Sorbent Foundation	$0	$29	$35	$0	$0	$64	$6	$0	$14	$85	
	SUBTOTAL 10.	**$942**	**$29**	**$1,165**	**$0**	**$0**	**$2,135**	**$214**	**$0**	**$242**	**$2,591**	**$33**
11	ACCESSORY ELECTRIC PLANT											
11.1	Electrical Equipment	$13,175	$0	$1,867	$0	$0	$15,042	$1,504	$0	$1,158	$17,704	
11.2	Transmission Lines and Switchyards	$6,300	$0	$0	$0	$0	$6,300	$630	$0	$485	$7,415	
11.9	Electrical Bulks and Foundations	$0	$3,000	$6,133	$0	$0	$9,133	$913	$0	$2,009	$12,056	
	SUBTOTAL 11.	**$19,475**	**$3,000**	**$8,000**	**$0**	**$0**	**$30,475**	**$3,048**	**$0**	**$3,653**	**$37,175**	**$477**
12	INSTRUMENTATION & CONTROL											
12.1	DICE-GT CRCC Control Equipment	$0	$5,000	$3,706	$0	$0	$8,706	$871	$0	$1,436	$11,013	
12.2	PCC Control Equipment	$0	$1,751	$758	$0	$0	$2,509	$251	$0	$414	$3,173	
	SUBTOTAL 12.	**$0**	**$6,751**	**$4,463**	**$0**	**$0**	**$11,214**	**$1,121**	**$0**	**$1,850**	**$14,186**	**$182**

Table 1-2 (cont'd)
100 MWe Nominal DICE CRCC Capital Cost Breakdown

DICE CRCC w/ CO2 Capture Total Plant Cost Details (Jun 2018 Basis)

5x1x1x1 100 MW DICE CRCC PLANT WITH 30 WT% MEA CO2 CAPTURE

Cost Basis 2018 ($x1000)
Plant Size 78 MWe, net

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sub Contract	Bare Erected Cost $	Eng'g CM H.O & Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
13	IMPROVEMENTS TO SITE											
13.1	DICE GT-CRCC Sitework	$0	$623	$1,360	$0	$0	$1,983	$198	$0	$436	$2,617	
13.2	PCC Sitework	$0	$682	$1,472	$0	$0	$2,154	$215	$0	$474	$2,843	
	SUBTOTAL 13.	**$0**	**$1,305**	**$2,832**	**$0**	**$0**	**$4,137**	**$414**	**$0**	**$910**	**$5,460**	**$70**
14	BUILDINGS & STRUCTURES											
14.1	DICE-GT Building	$0	$370	$0	$0	$0	$370	$37	$0	$61	$468	
14.2	Steam Turbine Building	$0	$216	$0	$0	$0	$216	$22	$0	$36	$273	
14.3	Administration Building	$0	$252	$0	$0	$0	$252	$25	$0	$42	$319	
14.4	Circulating Water Pumphouse	$0	$120	$0	$0	$0	$120	$12	$0	$20	$152	
14.5	Water Treatment Buildings	$0	$180	$0	$0	$0	$180	$18	$0	$30	$228	
14.7	Warehouse	$0	$211	$0	$0	$0	$211	$21	$0	$35	$267	
14.9	Waste Treating Building & Structures	$0	$59	$0	$0	$0	$59	$6	$0	$10	$75	
	SUBTOTAL 14.	**$0**	**$1,409**	**$0**	**$0**	**$0**	**$1,409**	**$141**	**$0**	**$232**	**$1,782**	**$23**
	CALCULATED TOTAL COST	**$128,530**	**$66,327**	**$84,147**	**$0**	**$44,485**	**$323,489**	**$38,600**	**$17,745**	**$49,921**	**$422,387**	**$5,419**

Table 1-3
100 MWe DICE CRCC Total Overnight Cost Breakdown

Description	$/1,000	$/kW
Preproduction Costs		
6 Months All Labor	$6,197	$79
1 Month Maintenance Materials	$388	$5
1 Month Non-Fuel Consumables	$878	$11
1 Month Waste Disposal	$2,388	$31
25% of 1 Months Fuel Cost at 100% CF	$712	$9
2% of TPC	$8,448	$108
Total	**$19,010**	**$244**
Inventory Capital		
60-day supply of fuel at 100% CF	$4,130	$53
60-day supply of non-fuel consumables at 100% CF	$1,242	$16
0.5% of TPC (spare parts)	$2,112	$27
Total	**$7,484**	**$96**
Other Costs		
Initial Cost for Catalyst and Chemicals	$782	$10
Land	$300	$4
Other Owner's Cost	$63,358	$813
Financing Costs	$11,404	$146
Total Overnight Costs (TOC)	**$524,724**	**$6,732**

Section 2 Plant Operating Costs

2.1 FUEL SPECIFICATIONS

2.1.1 PRB Coal

The design fuel for the DICE CRCC is low-sulfur sub-bituminous Montana Rosebud Powder River Basin (PRB) coal, with an as-received heating value of 8,564 Btu/lb HHV (8,252 Btu/lb LHV).

Based on the QGESS Cost Estimation Methodology for NETL Assessments of Power Plant Performance document, the levelized fuel price for PRB coal delivered to the U.S. Midwest is $38.21/ton.

2.1.2 Beneficiated Coal Yield

The raw coal has an ash content of 11.03 percent by weight (wt%) on a dry basis, and needs to be micronized and de-ashed to an appropriate level in order to protect the moving parts of the engine that are exposed to either the micronized coal-water fuel or the solid particulate products of combustion which contain both ash and traces of unburned coal.

The DICE CRCC conceptual design utilizes physical beneficiation to remove the minerals and sulfate/pyritic sulfur in the PRB coal. Sedgman's physical beneficiation process, as described in the Performance Results Report, reduces the ash content to about 2 wt% on a dry basis, which is considered suitable for combustion in DICE. On a mass basis, the yield of beneficiated coal product to raw coal feed is 47.5 percent.

2.1.3 Natural Gas Price

Based on the most recent DOE Bituminous Baseline Report (rev 4, 2019), the current levelized natural gas price is $4.19/GJ ($4.42/MMBtu) on an HHV basis, delivered to the Midwest, and reported in 2018 U.S. dollars.

In its reference Midwestern NGCC case, DOE assumes that the natural gas feed is delivered to the power plant via a 10-mile long underground, carbon steel gas pipeline. The DICE CRCC plant in this conceptual design accounts for the cost associated with the same pipeline length but for a smaller diameter (6 inch-piping) due to the much smaller natural gas demand.

2.1.4 Diesel Price

Based on EIA data, the average annual wholesale price for U.S. No.2 diesel is $2.12/gallon. For this study, a price of $2.50/gallon of No.2 diesel is assumed to account for transportation costs to the DICE CRCC plant. Since the real escalation rate is assumed to be zero percent, all real dollar amounts stay the same as in the base year, 2018, and thus the levelized cost of fuel is the same as the estimated 2018 cost at $2.50/gallon.

2.2 OPERATING COST

Table 2-1 presents a breakdown of the nominal 100 MWe DICE CRCC fixed and variable operating costs related to operations and maintenance (O&M) of the facility, including the cost of fuel, in 2018 dollars, based on the performance of the plant as presented in the Pre-FEED Performance Results Report.

It is notable that the low recovery of beneficiated product from processing PRB coal, at less than 50 percent, results in a large consumption of the PRB coal feed. Additionally, it generates a significant quantity of coal tailings slurry that needs to be disposed of. While these tailings still contain significant heating value, there appears to be no commercial or non-monetary disposal methods for the tailings slurry. A conventional wet disposal method is proposed and a $38/ton disposal cost was used in the cost estimate, as referenced from the DOE Bituminous Baseline Report.

This disposal cost is considered conservative, since the tailings contain significant heating value, as much as the product itself, albeit with higher ash content and in the form of a slurry. Its quality can be comparable to that of lignite coals found in the Gulf Coast region, which have heating values as low as 4,000 Btu/lb, and moisture contents as high as 55 percent). It could therefore be potentially useful as a fuel for slurry-based gasification or for combustion after suitable processing (e.g. briquetting). Additionally, research has shown that such wastes can be used as a material for filling abandoned workings in mines or to seal surface stockpiles. Post-flotation wastes from beneficiation of coking coals with calorific value more than 5,000 kJ/kg can be used as fuel for the production of building construction ceramics, and after further beneficiation as an additive to energy fuel.

A sensitivity analysis is conducted in a later section which assumed a disposal cost ranging from -$10/ton to $38/ton. The former assumes that the tailings are a useful byproduct with a free on board (FOB) price of $10/ton, or about $1.4/MMBtu. The latter, as used in this base case analysis, simply assumes that there is no market for this product, and it must be disposed of at the full-on disposal cost of $38/ton.

Table 2-1
100 MWe Nominal DICE CRCC Annual Operating Cost Breakdown

INITIAL & ANNUAL O&M EXPENSES

Case:	DICE GT-CRCC		
Plant Size (MWe)	**78**		
Primary/Secondary Fuel:	**Wyoming PRB**	**Fuel Cost ($/MMBtu):**	
Design/Construction	3 years	**Book Life (yrs):**	20
		Cost Base	Dec-18
Capacity Factor (%)	85	**CO2 Captured (TPD)**	1857

OPERATING & MAINTENANCE LABOR

Operating Labor

Operating Labor Rate (base):	$38.50	$/hr
Operating Labor Burden:	30.0	% of base
Labor Overhead Charge	25.0	% of labor

	per Shift
Coal Beneficiation Plant Operating Labor Requirements	**per Shift**
Skilled Operator	1.0
Operator	5.0
Foreman	1.0
Lab Tech's etc	1.3
DICE GT-CRCC Operating Labor Requirements	**per Shift**
Skilled Operator	2.0
Operator	4.3
Foreman	1.0
Lab Tech's etc	1.0
TOTAL Operating Jobs	**16.6**

	Annual Cost $	$/kW-net
Annual Operating Labor Cost	$7,278,071	$93.37
Maintenance Labor Cost	$2,636,417	$33.82
Administration & Support Labor	$2,478,622	$31.80
Property Taxes and Insurance	$8,447,741	$108.37
TOTAL FIXED OPERATING COSTS	**$20,840,851**	**$267.36**

VARIABLE OPERATING COSTS

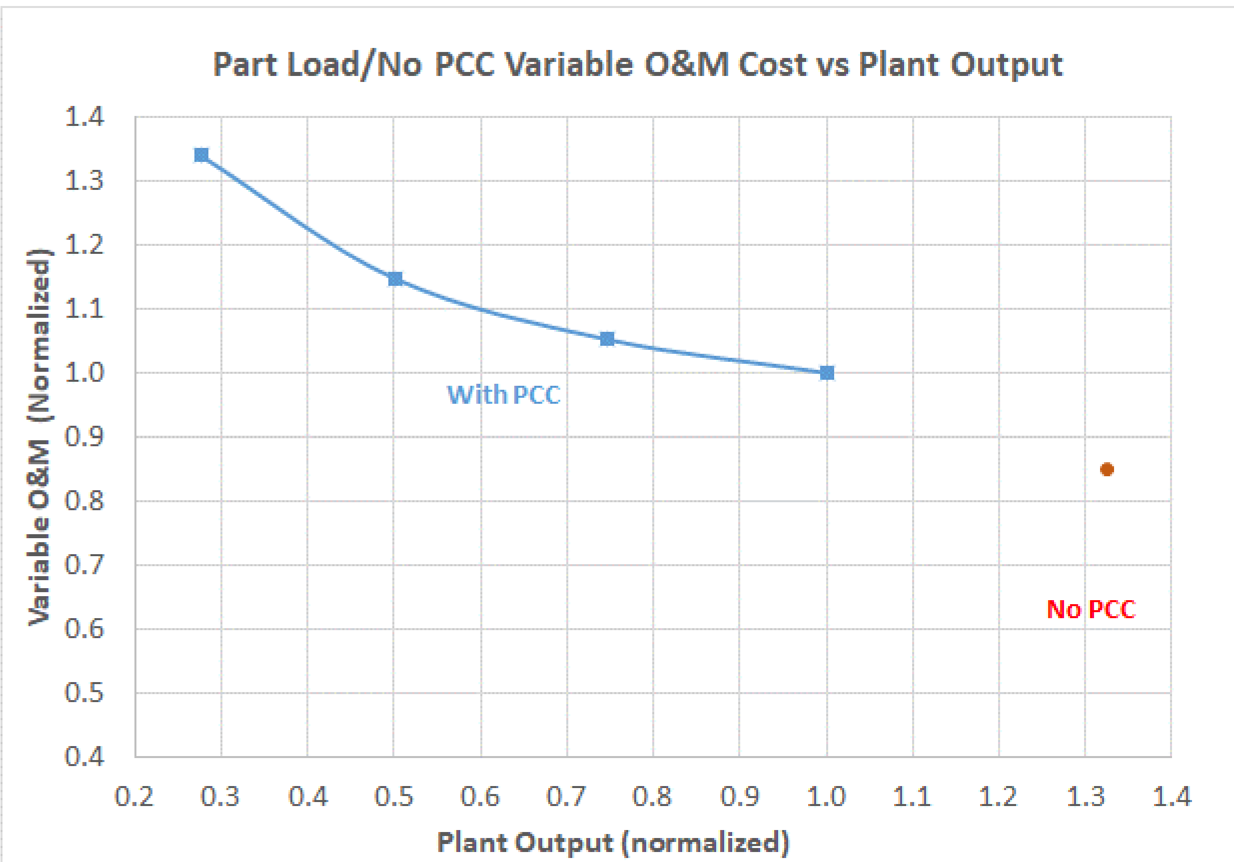
	Consumption Initial	Consumption /Day	Unit Cost	Initial Fill Cost	$	$/MWh-net
DICE GT-CRCC Plant Maintenance Material Cost					**$3,954,626**	**$6.81**
Coal Beneficiation Plant Maintenance Cost					**$2,043,113**	**$3.52**
Water(/1000 gallons)	0	902	1.90	**$0**	**$531,901**	**$0.92**
Chemicals						
MU & WT Chem (ton)	0	3.87	550.00	$0	$660,221	$1.14
MIBC Frother (ton)	0	1.1	4082	$0	$1,332,000	$2.29
Collector (diesel) (gal)	0	315	2.50	$0	$244,386	$0.42
Flocculant (ton)	0	0.2	2948.38	$0	$168,350	$0.29
Lube Oil for DICE					$468,979	$0.81
SCR Catalyst (ft2)	0	0.43	150.00	$0	$19,815	$0.03
Ammonia (19% NH3) (ton)	0	0.18	300.00	$0	$16,615	$0.03
NaOH (tons)		16.3	300.00	$0	$1,515,531	$2.61
Carbon (Mercury Removal) (ton)	0	0.1	1600.00	$0	$64,871	$0.11
MEA Solvent (ton)	279	3.8	2721.80	$759,280	$3,208,156	$5.53
Corrosion Inhibitor				$0	$339,454	$0.58
MEA Reclaimer Additive (ton)		3.8	181	$0	$212,436	$0.37
Lean Amine Carbon Filter Package (lb)	6723	242	1.2	$8,336	$93,113	$0.16
Pre- and Post- Cartridge Filter (ea)	2	0.04	6964	$13,928	$77,784	$0.13
Subtotal Chemicals				**$781,544**	**$8,421,712**	**$14.51**
Waste Disposal:						
Coal Beneficiation Slurry Reject	0	2054	38.00	$0	$24,213,934	$41.72
Fly Ash (ton)	0	12.1	38.00	$0	$143,069	$0.25
PCC Thermal Reclaimer Waste	0	3.8	38.00	$0	$44,492	$0.08
Subtotal Waste Disposal				**$0**	**$24,401,495**	**$42.04**
TOTAL VARIABLE OPERATING COSTS				**$781,544**	**$39,352,846**	**$67.80**
FUEL COSTS						
PRB Coal (ton)	**0**	**1786**	**38.21**	**$0**	**$21,170,246**	**$36.47**
Diesel (gal)	**0**	**238**	**2.50**	**$0**	**$184,471**	**$0.32**
Natural Gas (MMBtu)	**0**	**5743**	**4.42**	**$0**	**$7,875,770**	**$13.57**
TOTAL FUEL COSTS				**$0**	**$29,230,487**	**$50.36**
TOTAL VARIABLE OPERATING + FUEL COSTS					**$68,583,333**	**$118.16**

2.3 OPERATION & MAINTENANCE (O&M) COSTS AT TURNDOWN (PART LOAD) CONDITIONS

The variable O&M costs associated with the plant part load operating conditions are shown in Figure 2-1. These costs include the consumables (water, chemicals and catalysts), waste disposal, and fuel costs, while excluding fixed O&M costs associated with operating and maintenance labor costs, as well as maintenance material costs. These are reported on a normalized basis. For reference purposes, the variable operating cost associated with the base case of 5 DICE with PCC is $100.7/MWh.

The horizontal axis indicates the part load variable O&M cost expressed as a fraction of the full load (5 DICE, with PCC) net output, and is based on an operational range of two DICE through the maximum of all five DICE. The right-most point on the graph shows the variable O&M cost of the plant when the PCC is not in service and steam is routed to a condensing turbine to generate additional power instead of the PCC reboiler.

Figure 2-1
DICE CRCC Part Load Variable O&M Costs



Section 3 Estimated Levelized Cost of Electricity and Sensitivity Analysis

3.1 DESIGN LEVELIZED COST OF ELECTRICITY (LCOE)

Based on the overall performance, TOC, and annual operating cost of the 100 MWe DICE CRCC plant, its levelized cost of electricity (LCOE) was estimated to be $223.9/MWh. The LCOE was estimated based on the methodology established in the previously submitted Design Basis Report. The parameters used in estimating the LCOE are summarized in Table 3-1.

Table 3-1
LCOE Parameters and Cost Breakdown

Plant	**DICE CRCC**
Size	**78 MWe**
Capacity Factor (CF)	**85%**
Years of Construction	**3**
Total As-Spent Cost/Total Overnight Cost Ratio	**1.093**
Fixed Charge Rate (FCR)	**0.0707**
Total Overnight Cost (TOC), $MM	525
Total As-Spent Cost (TASC), $MM	574
Fixed Operating Cost, $MM/yr	20.8
Variable Operating Cost @ 100% CF, $MM/yr	46.3
Fuel Cost @ 100% CF, $MM/yr	34.4
Annual 1000 MWh (100% CF)	683
LCOE (excl. CO_2 T&S), $/MWh	**223.9**
LCOE Breakdown, $/MWh	
Fuel (incl. coal beneficiation)	50.4
Variable O&M	67.8
Fixed O&M	35.9
Capital Charges	69.9
Total LCOE, $/MWh	**223.9**

Note: 3 year construction for DICE CRCC is consistent with NGCC construction period assumption as used by NETL in its reference reports. TASC/TOC ratio used for LCOE evaluation for such 3-year capital projects is 0.0707

3.2 LCOE OF POTENTIAL VARIANTS

3.2.1 No Post-Combustion Capture

Implementing post-combustion capture (PCC) to the DICE CRCC system imposes a significant penalty on its efficiency, capital cost, and operating cost, thereby resulting in a high LCOE. A parametric scenario without PCC was evaluated to quantify the performance and cost impact. For this parametric case, exhaust steam from the main steam turbine that would have been diverted to the PCC is sent to a condensing turbine to produce more power, resulting in greater power generation from the steam cycle. As shown in the Performance Results Report of this pre-FEED study, eliminating PCC results in a 35 percent increase in net power generation. The calculated efficiency of this case is 39.9 percent on an LHV basis (37.7 percent HHV).

3.2.2 Centralized Coal Beneficiation Plant

For a small, modular power plant such as the DICE CRCC (< 100 MW for this introductory variant), the performance and cost estimates presented in previous reports suggest that it makes no economic sense to install a coal beneficiation plant on-site, analogous to building a crude oil refinery on-site at every gas station. For the modular DICE CRCC plant to be feasible, there must be multiples of such power plants, each receiving fuel from a centralized coal beneficiation plant, thereby taking advantage of the economies-of-scale benefits that the large central beneficiation plant possesses.

A parametric case was run to denote the ideal future deployment of the DICE CRCC technology. This case utilizes a centralized coal beneficiation plant which distributes beneficiated coal to the multiple small-scale DICE CRCC power plants in operation. The performance of this plant was presented in the Performance Results Report, which was estimated by eliminating all auxiliary loads and utilities associated with the coal beneficiation plant. The gross power remains the same as the on-site beneficiation case but the auxiliary power is reduced by about 10.5 percent or 5 MW. The net power increases similarly by 5 MW, or a 7 percent increase. The estimated efficiency for this case is 32.7 percent LHV (31.0 percent HHV).

3.2.3 LCOE Estimates of Variants

Table 3-2 presents the summary comparison of the capital costs, operating costs, and LCOE breakdown of the DICE CRCC plant with and without PCC, and the envisioned "ideal" DICE plant that receives coal feed from a centralized coal beneficiation plant.

Table 3-2
Performance and LCOE Summary Comparison for DICE CRCC Parametric Cases

Plant	DICE CRCC No PCC	DICE CRCC with PCC (on-site beneficiation)	Ideal DICE CRCC with PCC (centralized beneficiation)
Size	**105 MWe**	**78 MWe**	**83 MWe**
Plant Efficiency, LHV	**39.9%**	**30.8%**	**32.7%**
Plant Efficiency, HHV	**37.7%**	**29.1%**	**31.0%**
Capacity Factor (CF)	**85%**	**85%**	**85%**
Total Overnight Cost (TOC), $MM	433	525	450
TOC, $/kW	4,123	6,732	5,558
Total As-Spent Cost (TASC), $MM	474	573	492
Fixed Operating Cost, $MM/yr	17.6	20.8	15.2
Variable Operating Cost @ 100% CF, $MM/yr	40.8	46.3	13.4
Fuel Cost @ 100% CF, $MM/yr	35.8	34.4	33.7
Annual 1000 MWh (100% CF)	921	683	726
LCOE (excl. CO_2 T&S), $/MWh	**148.6**	**223.9**	**145.7**
LCOE Breakdown, $/MWh			
Fuel (incl. coal beneficiation)	38.9	50.4	46.4
Variable O&M	44.4	67.8	18.4
Fixed O&M	22.5	35.9	24.6
Capital Charges	42.8	69.9	56.4
Total LCOE, $/MWh	**148.6**	**223.9**	**145.7**

For the case without PCC, the capital costs and operating costs associated with the PCC were eliminated in the parametric cost analysis. The resulting TOC is about 18 percent lower at $433MM. The fixed operating cost is about 15 percent lower while the variable operating cost is 12 percent lower, primarily because the amine make-up requirement, the largest PCC variable cost contributor, has been eliminated. Fuel cost is slightly higher due to the higher natural gas consumption requirement in the supplementary fired HRSG in order to raise the steam quality such that it is suitable for the condensing turbine downstream of the HRSG.

The DICE CRCC plant without PCC has an LCOE of $148.6/MWh, or 66 percent of the same plant with PCC. Essentially, adding the PCC plant to capture 90 percent of the CO_2 in the DICE CRCC flue gas increases its cost of electricity by 50 percent.

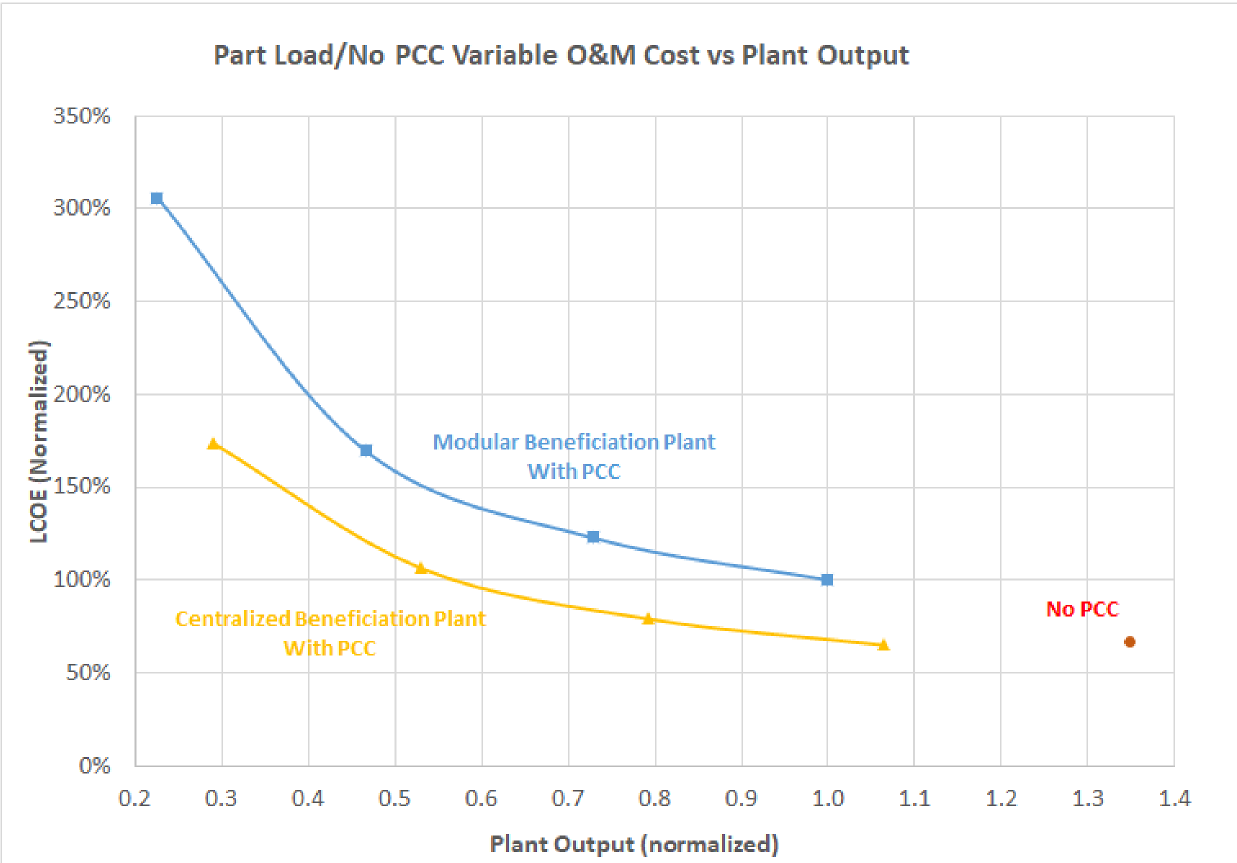
For the ideal DICE CRCC plant, the capital and operating costs associated with the modular coal beneficiation plant were eliminated in the analysis. The resulting TOC is 14 percent lower at $450MM. Fixed operating cost is about 27 percent lower due to the much lower staffing requirement as a result of eliminating the labor-intensive on-site beneficiation plant. In terms of fuel cost, the beneficiated coal cost was estimated to be $4.3/MMBtu, in line with CSIRO's estimates from **DICEnet** literature, and the resulting fuel cost, at $33.7MM/yr, is about 2 percent lower than the base case. Additionally, the variable operating cost is significantly reduced as there are no reject tailings to dispose of on-site since the plant uses beneficiated coal directly. Elimination of the tailings slurry waste disposal operating cost results in a 71 percent reduction in variable operating cost.

The ideal DICE CRCC plant using coal received from a centralized beneficiation plant and with 90 percent CO_2 capture has a more reasonable LCOE of $145.7/MWh, or about 65 percent of the base case plant with on-site beneficiation.

3.3 LCOE AT TURNDOWN CONDITIONS

The LCOEs associated with the plant part load operating conditions are reported on a normalized basis in Figure 3-1 and includes the estimated part load conditions for a DICE CRCC plant receiving coal from a centralized coal beneficiation facility.

Figure 3-1
DICE CRCC Part Load LCOE



3.4 REFERENCE SUPERCRITICAL PC PLANT LCOE

For reference purposes, the cost and performance estimates of a conventional 650 MWe supercritical pulverized coal (SC PC) plant with CO_2 capture (Case B12B) from the most recent NETL Bituminous Baseline Report (BBR rev4) are shown in Table 3-3.

Table 3-3
Reference NETL 650 MWe SC PC Plant Performance and Cost Summary

Plant	SC PC (NETL)
Size	**650 MWe**
Gross Power Production, MWe	**770**
Total Auxiliaries, MWe	**120**
Net Efficiency, HHV	**31.5%**
, LHV	**32.7%**
Capacity Factor (CF)	**85%**
Years of Construction	**5**
Total As-Spent Cost/Total Overnight Cost Ratio	**1.154**
Fixed Charge Rate (FCR)	**0.0707**
Total Overnight Cost (TOC), $MM	3,023
TOC, $/kW	4,654
Total As-Spent Cost (TASC), $MM	5,372
Fixed Operating Cost, $MM/yr	78.1
Variable Operating Cost @ 100% CF, $MM/yr	79.7
Fuel Cost @ 100% CF, $MM/yr	137.3
Annual 1000 MWh (100% CF)	5,694
LCOE (excl. CO_2 T&S), $/MWh	**105.3**
LCOE Breakdown, $/MWh	
Fuel (incl. coal beneficiation)	24.1
Variable O&M	14.0
Fixed O&M	16.1
Capital Charges	51.0
Total LCOE, $/MWh	**105.3**

While the base case DICE CRCC plant has almost double the LCOE of that of a conventional 650 MW SC PC with CO_2 capture, it utilizes the modular coal beneficiation plant, oft-repeated in this report to be not cost-competitive. With the centralized beneficiation plant variant, the DICE CRCC plant's LCOE is reduced to $145.7/MWh. While still almost 40 percent higher than the SC PC plant, it is important to note that the SC PC plant's LCOE is for a base-loaded, 650 MWe plant, with huge economy-of-scale benefits compared to that of the modular DICE CRCC plant.

A comparable modular SC PC plant generating 78 MW net was estimated based on the performance and cost estimates for the reference plant and the results are shown in Table 3-4. The TOC for this modular 78 MWe plant was estimated by scaling the costs using a capacity factor exponent of 0.7 to arrive at 3,023 x $(78/650)^{0.7}$ = $685 million. The same exponent of 0.7 was used to calculate the modular plant's fixed operating cost.

Variable and fuel costs were estimated by pro-rating the consumptions for 78 MW of net power generation, assuming that the plant net efficiency remains the same, while maintaining the same unit costs. The resulting LCOE of this plant is $164.9/MWh, which is 13 percent higher than the DICE CRCC plant burning beneficiated coal from a centralized facility.

Table 3-4
Scaled Modular 78 MWe SC PC Plant Performance and Cost Summary

Plant	Modular SC PC
Size	**78 MWe**
Net Efficiency, HHV	**31.5%**
, LHV	**32.7%**
Capacity Factor (CF)	**85%**
Years of Construction	**5**
Total As-Spent Cost/Total Overnight Cost Ratio	**1.154**
Fixed Charge Rate (FCR)	**0.0707**
Total Overnight Cost (TOC), $MM	685
TOC, $/kW	8,786
Total As-Spent Cost (TASC), $MM	791
Fixed Operating Cost, $MM/yr	17.7
Variable Operating Cost @ 100% CF, $MM/yr	9.6
Fuel Cost @ 100% CF, $MM/yr	16.5
Annual 1000 MWh (100% CF)	683
LCOE (excl. CO_2 T&S), $/MWh	**164.9**
LCOE Breakdown, $/MWh	
Fuel (incl. coal beneficiation)	24.1
Variable O&M	14.0
Fixed O&M	30.4
Capital Charges	96.3
Total LCOE, $/MWh	**164.9**

3.5 SENSITIVITY ANALYSIS

3.5.1 Coal Beneficiation Yield

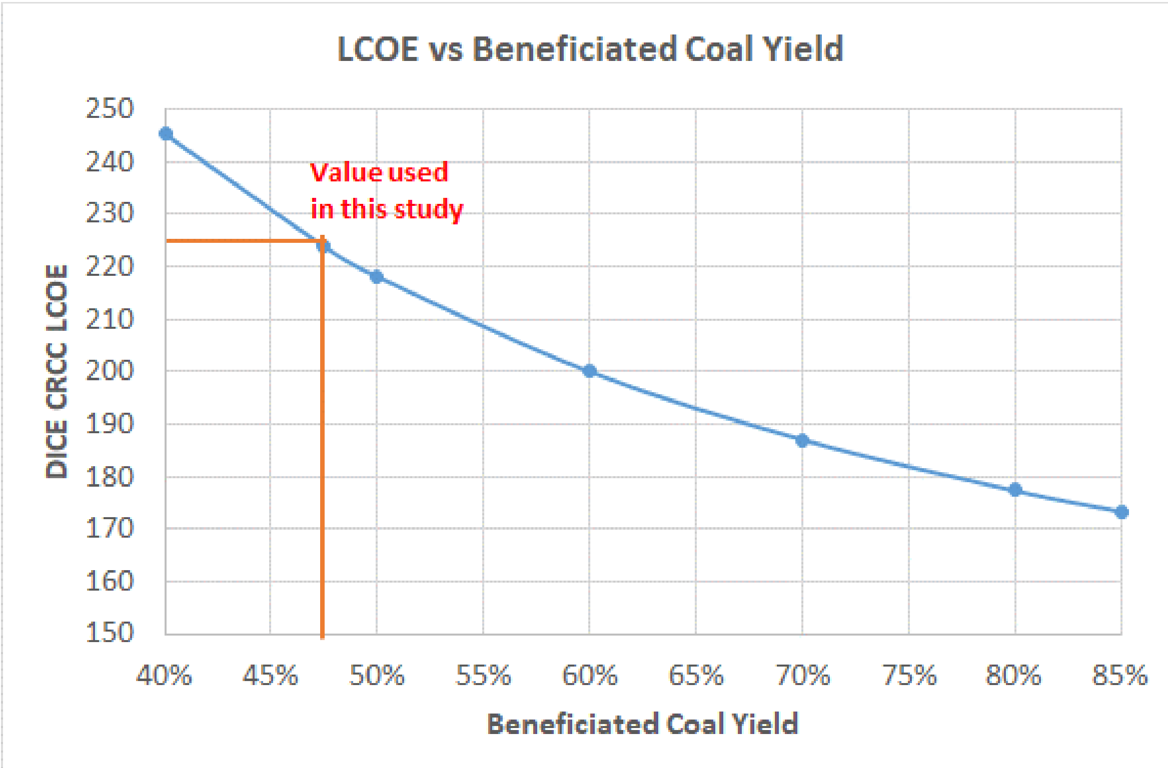
Based on Section 2.1.2, the beneficiated coal product yield from the as-received PRB coal is only 47.5 percent on a mass basis. Sedgman, the coal beneficiation process OEM, has indicated that its experience with low rank bituminous coal with high inherent moisture levels such as PRB shows that they are not amenable to upgrading with conventional coal flotation reagents, due to the high inherent moisture rendering the coal particle surface hydrophilic. It can thus be concluded that the design PRB coal used in this study was not an ideal choice for the beneficiation process.

Additionally, beneficiated product yield is inversely proportionate to its ash target. The relatively low ash target of 2 percent thus renders its low yield based on Sedgman's experience. A more ideal choice would therefore be a hydrophobic coal such as a bituminous coal with low inherent moisture and low ash content. Nevertheless, Sedgman acknowledged that the stated product recovery rate was on the conservative end and the actual yield could potentially be higher.

A sensitivity analysis was conducted to determine the impact of the coal beneficiation yield on the DICE CRCC plant LCOE, with a product recovery rate ranging from 40 percent to 85 percent. The high end of the recovery rate can be justified by using a coal that is more amenable to upgrading as well as a more developed DICE that can potentially tolerate higher ash beneficiated coal.

Figure 3-2 illustrates the relationship between the DICE CRCC plant LCOE and coal beneficiation yield. The effect of a larger beneficiation yield is twofold. First, a higher recovery rate leads to less as-received coal feed required for the process, resulting in a lower fuel cost. Second, the tailings reject rate is also reduced since more of the coal is recovered as product, thus reducing the waste disposal cost. At the most optimistic recovery rate of 85 percent beneficiated coal product yield, the plant LCOE is estimated to be $173/MWh.

Figure 3-2
Plant LCOE vs Beneficiated Coal Yield



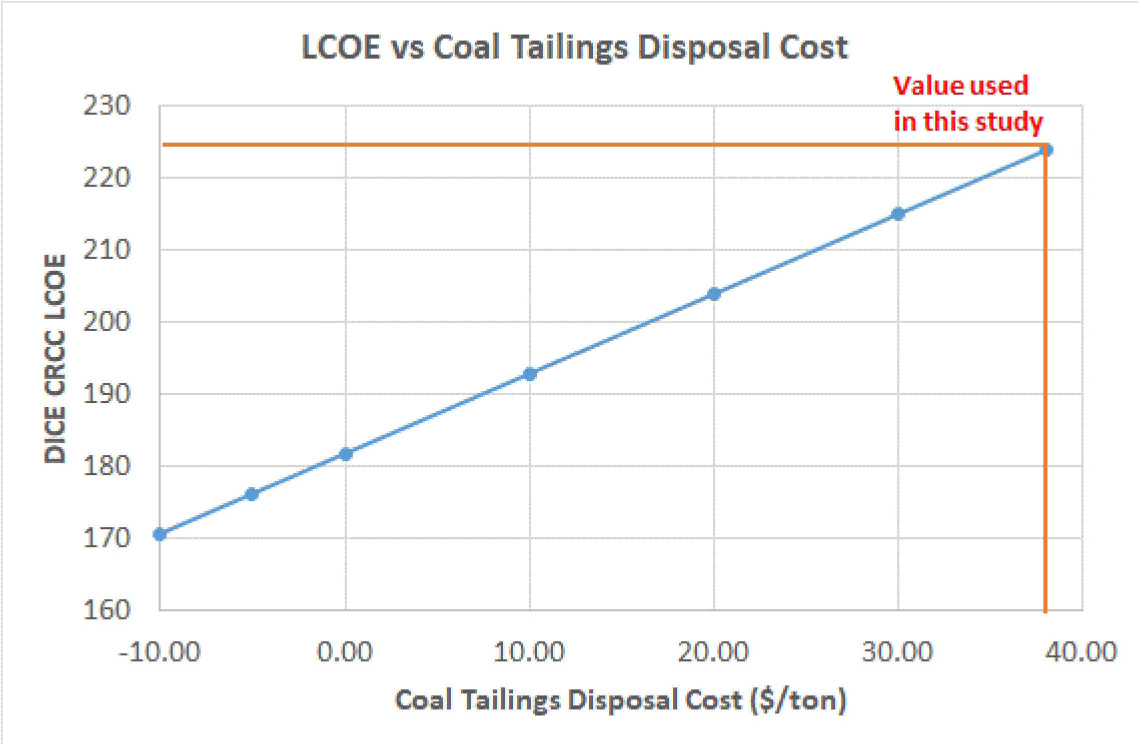
3.5.2 Beneficiation Process Reject Disposal

The current study assumes that the coal tailings from the beneficiation process have no market value and have to be disposed at the full-on disposal cost of $38/ton. However, the tailings still contain significant heating value, as much as the product itself, albeit with higher ash content and in the form of a slurry. Its quality is actually comparable to that of lignite coals found in the Gulf Coast region, which have heating values as low as 4,000 Btu/lb, and moisture contents as high as 55 percent). It could therefore be potentially useful as a fuel for slurry-based gasification or for combustion after suitable processing (e.g. briquetting). Additionally, research has shown that such wastes can be used as a material for filling abandoned workings in mines or to seal surface stockpiles. Post-flotation wastes from beneficiation of coking coals with calorific value more than 5,000 kJ/kg can be used as fuel for the production of building construction ceramics, and after further beneficiation as an additive to energy fuel.

For this sensitivity analysis, a disposal cost range of -$10/ton to $38/ton was used. The former assumes that the tailings are a marketable byproduct with a free on board (FOB) price of $10/ton, or about $1.4/MMBtu. The latter simply assumes that there is no market for this product, and it must be disposed of at the full-on disposal cost of $38/ton per the base case.

Figure 3-3 depicts how the DICE CRCC plant LCOE varies with the coal beneficiation tailings disposal cost. Due to the large quantity of rejects generated by the coal beneficiation plant, the LCOE is sensitive to the disposal cost, ranging from $169/MWh when the tailings are considered most valuable to $222/MWh when they have no value and the full disposal cost has to be paid.

Figure 3-3
Plant LCOE vs Coal Tailings Disposal Cost

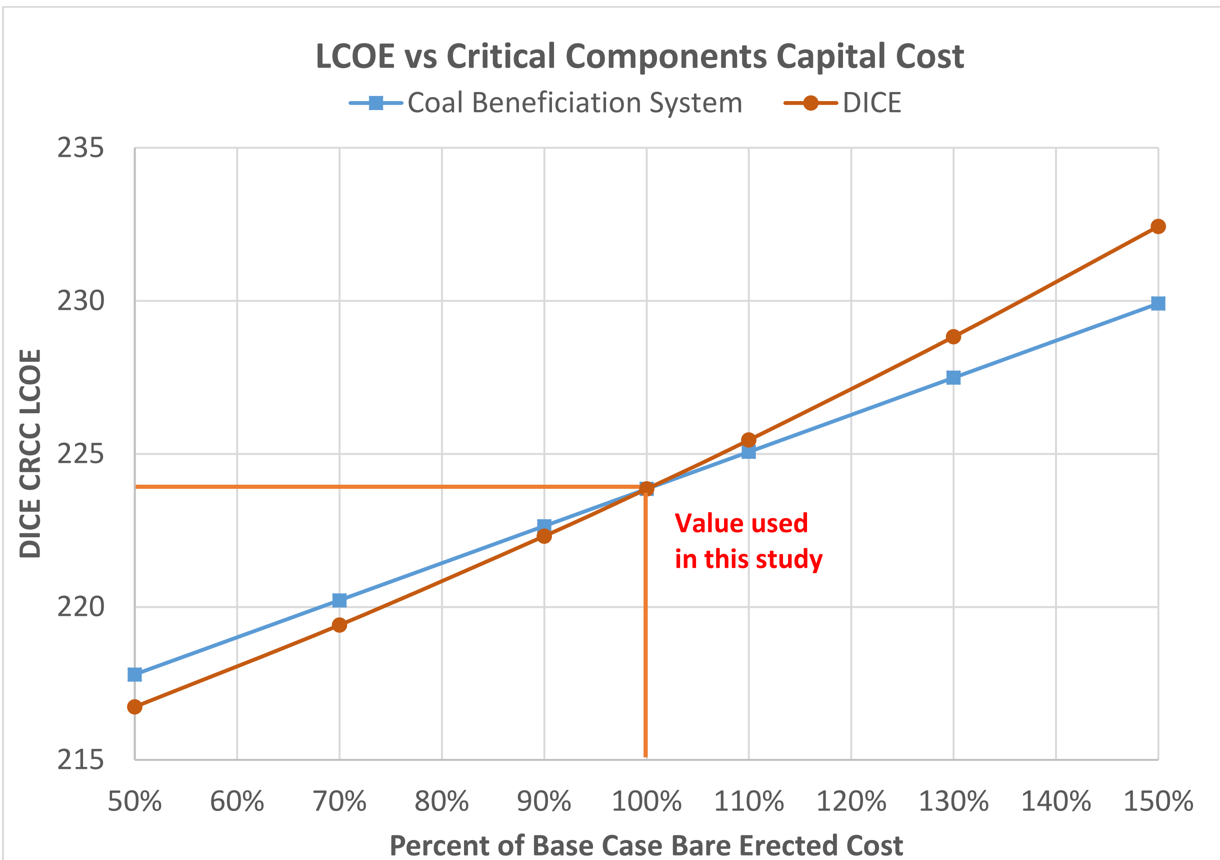


3.5.3 DICE and Coal Beneficiation Plant Capital Cost

The two components considered most critical to the DICE CRCC plant's success are the DICE itself and the coal beneficiation plant. A sensitivity analysis was therefore conducted to determine the variation of the plant's LCOE on the capital costs of these components. A range of +/- 50 percent from the baseline cost estimate was assumed for both systems and the results are shown in Figure 3-4.

From Figure 3-4, it can be concluded that the capital cost variation for both the DICE and coal beneficiation plant causes similar impacts on the LCOE. This is not surprising since, as shown in Table 1-2, the DICE and coal beneficiation plants have similar costs at around $60 MM on a total plant cost basis.

Figure 3-4
Plant LCOE vs Coal Beneficiation Plant and DICE Bare Erected Cost



3.5.4 Equivalent Beneficiated Coal Cost

As described in Section 3.2.2, there is no economic sense in installing a coal beneficiation plant on-site at every modular DICE CRCC power plant. This is somewhat analogous to appending an oil refinery to each fuel oil-fired power generation facility (they rarely exist anymore, at least in the developed world, but makes the point). For the modular DICE CRCC plant to be feasible, there must be multiples of such power plants, each receiving fuel from a centralized coal beneficiation plant to take advantage of its inherent economies-of-scale advantages.

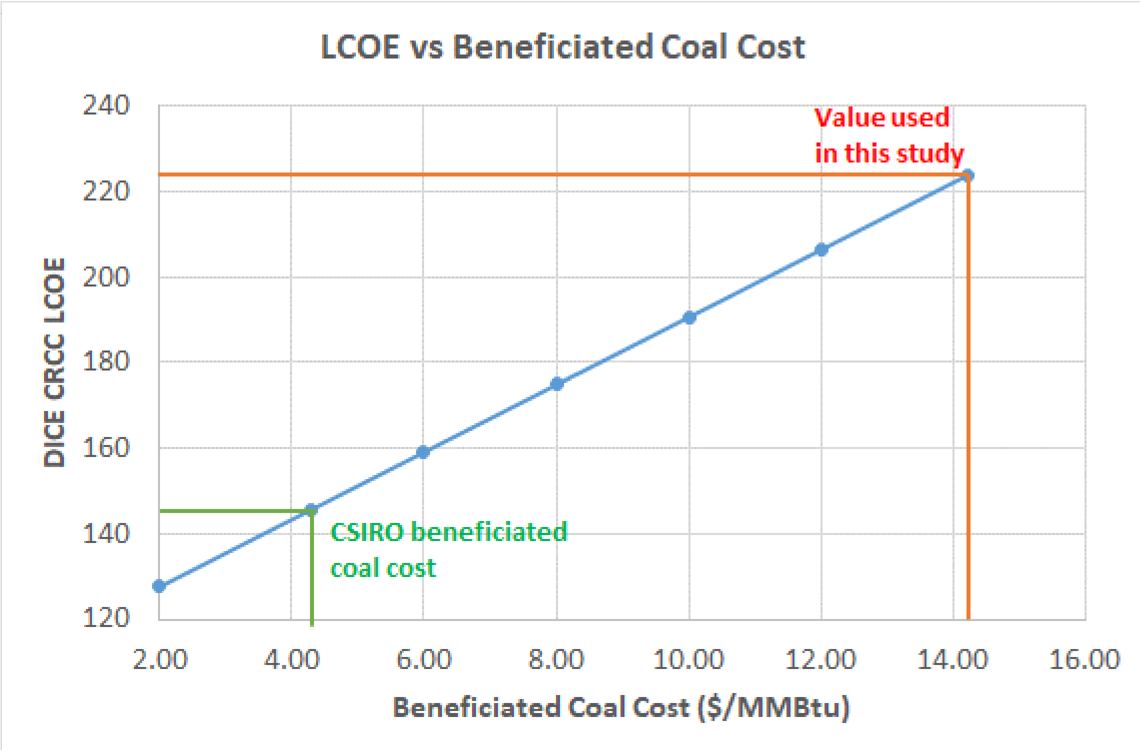
For the base case, an "equivalent beneficiated coal cost" was determined on a $/ton basis. This was calculated by eliminating all auxiliary power and capital and operating costs associated with the on-site coal beneficiation plant. After removing all coal beneficiation related costs and utilities, the coal cost was back-calculated on a "net-back" basis to arrive at the original LCOE of $223.9/MWh. This equivalent beneficiated coal cost was calculated to be $14.2 per MMBtu (HHV), compared to the original PRB coal price of $2.23 per MMBtu (HHV) based on the $38.2/ton cost. This represents a more than 6-fold increase in coal cost due to the modular, economically disadvantaged coal beneficiation plant.

Based on CSIRO's research involving Australian coals, it has been suggested that the cost of beneficiated coal is about AUD 6/GJ (USD 4.3/MMBtu), so a cost of USD 14.2/MMBtu of beneficiated coal in the baseline case is therefore unrealistically high.

A sensitivity analysis was conducted to determine the impact of the beneficiated coal cost on the DICE CRCC plant LCOE, using a range of beneficiated coal costs from $2/MMBtu (essentially no associated beneficiation costs) to the current calculated value of $14.2/MMBtu.

Figure 3-5 plots the variation of LCOE against beneficiated coal cost. Clearly, this cost has an extremely large impact on the economic performance of the DICE CRCC plant. With the modular beneficiation plant resulting in a cost of $14.2/MMBtu of beneficiated coal, the baseline plant's LCOE stands at $223.9/MWh. However, if this cost was reduced to $4.3/MMBtu per CSIRO's estimates, with a path toward achieving this via a centralized beneficiation plant, then the LCOE could be reduced to a much more reasonable $145.7/MWh.

Figure 3-5
Plant LCOE vs Beneficiated Coal Cost

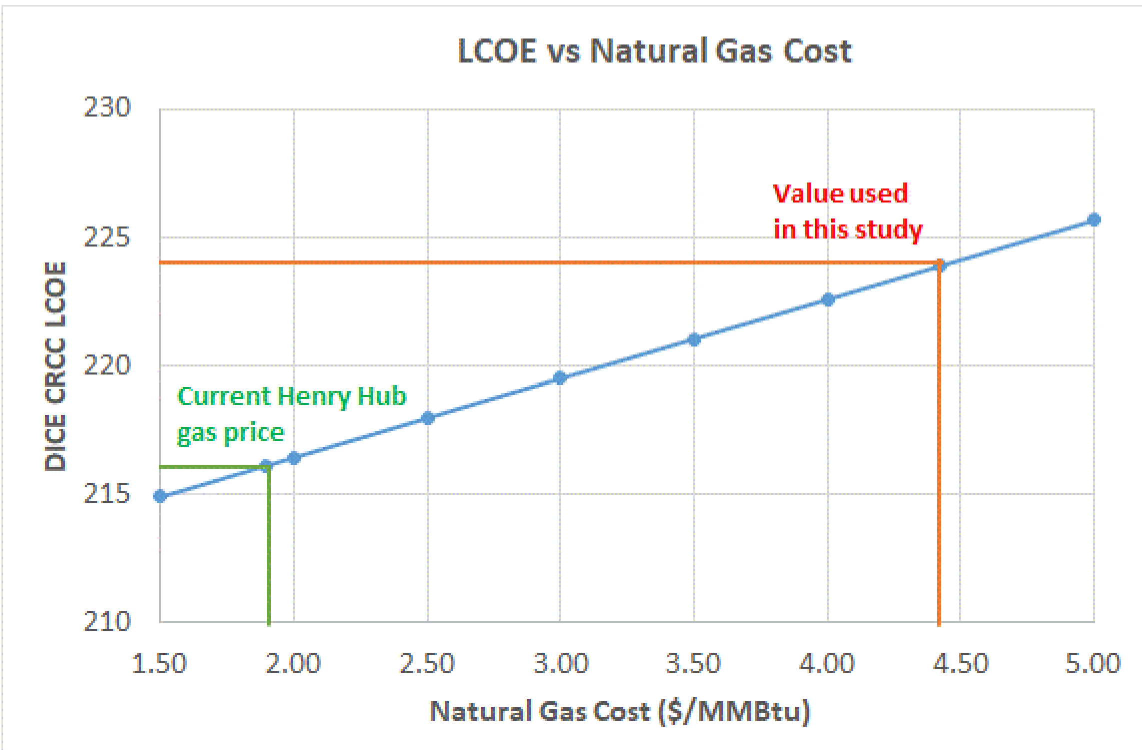


3.5.5 Gas Pricing

For this study, a levelized natural gas price of $4.42/MMBtu (HHV) for delivery to the Midwest was used in the operating cost analysis, which is consistent with that used in the most recent DOE Bituminous Baseline Report (rev 4, 2019). Natural gas delivered to power plants in the Midwest was estimated to be about the same price as those delivered to the Texas area, based on DOE's most recent QGESS Fuel Pricing document. However, it is noted that current Henry Hub gas prices is only about $1.9/MMBtu, so the assumed cost of $4.42/MMBtu (HHV) may be too high.

A sensitivity analysis on gas pricing is therefore conducted to determine its impact on the DICE-GT CRCC LCOE, using a range of $1.5/MMBtu to $5/MMBtu. At the current Henry Hub natural gas pricing of $1.9/MMBtu (HHV)[1], the estimated LCOE is reduced to $216/MWh.

Figure 3-6
Plant LCOE vs Natural Gas Cost

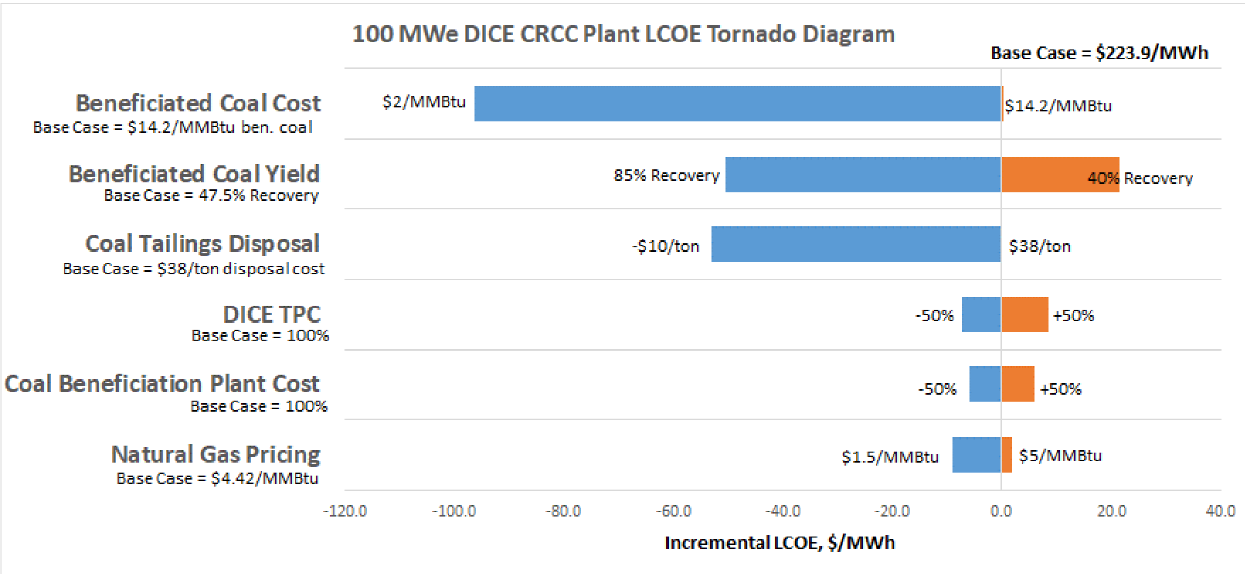


[1] Henry Hub Natural Gas Spot Price was 1.89 USD/MMBtu for Mar 17 2020 https://ycharts.com/indicators/henry_hub_natural_gas_spot_price.

3.5.6 Tornado Chart

Figure 3-7 depicts the tornado chart that provides both a ranking and measure of magnitude of the impact that each of the parameters described above has on the LCOE. It is clear from this figure that the LCOE is most sensitive to the performance and cost of the coal beneficiation plant. It would therefore be most beneficial to the DICE CRCC technology if there was a centralized coal beneficiation plant with maximum economy-of-scale that also maximizes the yield of the beneficiation process (which simultaneously minimizes the tailings to be disposed of), thus reducing the beneficiated coal cost to be delivered to the modular DICE CRCC plant.

Figure 3-7
LCOE Tornado Chart



.