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Coal-Based Power Plants of the Future: Electricity and Ammonia Polygeneration Cost Results Report

Submitted To:

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1. Concept Background

Team AST developed a coal-based power system for application in the evolving bulk power system. Specifically, the design is a polygeneration plant for the co-production of electricity and ammonia from coal in a flexible system that can adapt to complex and shifting realities inherent in a modern electrical grid with significant renewable penetration. At a high level, the plant consists of two gasifier trains, a power island and two ammonia loops.

The general business philosophy of the polygeneration design centers on offering multiple potential revenue streams, including (1) commercial electricity available for sale to the grid, (2) salable ancillary services (e.g., capacity markets, frequency stability, voltage regulation, etc.), (3) and NH_3 for commercial delivery at or near retail (as opposed to wholesale) prices. By combining these three different revenue streams in a polygeneration facility that offers high operational flexibility, it is possible to modulate plant operations on a very short time scale to meet emerging market signals and opportunities. This ability to correctly match production to market demand will allow for optimization of plant profitability.

While the plant has the flexibility to operate at a multitude of operating points, the edges of the overall operating range are currently described by five specific operation modes, as seen in Exhibit 1-1:

Exhibit 1-1. Summary of Operating Modes

Operating Point	Net Export Power	Ammonia Production	Gasifier Operation	GT Operation	ST Operation	Ammonia Loop Operation
Balanced Generation, 3 GT's	48 MW	600 MTPD	100% of Capacity	Three Turbines @ 67% Capacity	Primary ST @ 86% load	Both Trains @ 100% Capacity
Balanced Generation, 2 GT's	51 MW	600 MTPD	100% of Capacity	Two Turbines @ 100% Capacity	Primary ST @ 91% Load	Both Trains @ 100% Capacity
Net Zero Power	0 MW	600 MTPD	66% of Capacity	One Turbine at 67% Capacity	Primary ST @ 40% Load	Both Trains @ 100% Capacity
High Electricity Production	82 MW	380 MTPD	100% of Capacity	Three Turbines @ 100% Capacity	Primary ST @ 88% Load	Both Trains @ 63% Capacity
Max Electricity Production	112 MW	59 MTPD	100% of Capacity	Three Turbines @ 100% Capacity	Primary ST @ 100% Load, Secondary ST @ 85% Load	Both Trains @ 10% Capacity

These operating modes define an operating window that provides the flexibility to modulate ammonia and net electricity production to meet market demand while enabling the two gasifier trains to operate at ~65% of capacity even in the absence of net electricity demand by the grid. This will allow the plant owner to choose operating points to maximize profitability while reducing the potential of being forced into outage by curtailed market demand.

The intent is to operate the polygeneration facility at a high service factor more typical of a chemical production facility rather than what would be normally expected from a pure, fossil fuel-based electricity generation facility that is subjected to forced curtailment. A number of design decisions have been made to support this goal. Multiple gasifier trains have been selected to provide the ability to run one train in conjunction with utilization of stored syngas (if required) while another train is shut down for maintenance. Additionally, if service is required to either the ammonia loop or power island, it can be performed at time when high demand is predicted for the alternative plant production capacity (i.e., if ammonia loop maintenance is required, it can be scheduled during a time of predicted high net energy demand, reducing the overall turndown for the plant as a whole).

The ability to perform opportunistic maintenance as described above, as well as the ability to match plant output to market demand, should support a service factor closer to the 96% metric achievable by chemical production facilities. However, it should be noted that the standard electrical generation service metric does not have as clear of a meaning for a polygeneration plant with multiple, viable operating points.

At the reference *Balanced Production, 3 GT's* operating point, ~71,000 kg/hr of as-received, Illinois #6 coal will be dried in a fluidized bed before passing to two SES U-Gas gasifiers, which will produce ~172,000 kg/hr of raw syngas. After passing through a water-gas shift reactor and various syngas cleaning and emission control technologies[1], the clean syngas will be nominally distributed to the ammonia train and power block. This *Balanced Production* syngas disposition will support net power generation of 48 MW and ammonia generation of 600 MTPD.

As detailed above in Exhibit 1-1, the 600 MTPD represents the maximum ammonia production for this plant. By shifting to the *High Electricity Production* operating mode, it is possible to increase net power generation to 82 MW while reducing ammonia production to ~380 MTPD. This net power export can be further increased to 112 MW, as seen in the *Max Electricity Production* operating point. This 112 MW net power export relies on a deep turndown of the ammonia trains (both trains operating at 10% of maximum capacity).

To maximize cross-comparison against existing studies, and to maintain compliance with the site characteristics and conditions provided by the awarded contract, general siting characteristics and air composition will be adopted in accordance with those found in the June 2019 release of National Energy and Technology Laboratory's (NETL's) *Quality Guideline for Energy System Studies: Process Modeling Design Parameters*[2]. The general and specific siting characteristics are provided in the Design Basis report. These characteristics, and the business philosophy described above, will be combined with the Class 4 capital cost estimates contained below to develop a forthcoming assessment of commercial viability for inclusion in the final report.

2. Cost Estimating Methodology[3]

The cost estimates contained in this document are consistent with approved NETL methodologies,

[1] Details on ammonia removal, mercury removal, acid gas removal, CO_2 compression and drying, sulfur recovery, and tail gas treatment can be found in *Performance Analysis Report*.
[2] These exhibits correspond with Site Conditions found in the June 2019 release of NETL's *Quality Guideline for Energy System Studies: Process Modeling Design Parameters*. However, some differences do exist. In these instances, this report has defaulted to the values in the latest QGESS document.
[3] This section is largely repeated verbatim from the 2019 version of NETL's *Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity."* Changes have been made, were appropriate, to ensure relevance and accuracy with the polygeneration design.

as defined in the 2019 revision of the QGESS document *Cost Estimation Methodology for NETL Assessment of Power Plant Performance.* Multiple individual members of the AST Team are well versed in these approaches through their experience serving as Program Managers overseeing past process and cost engineering work for NETL. Additionally, the applied methodology draws on Worley's past experience serving as the EPC supporting NETL strategic analysis functions.

Worley has applied their experience, combined with both (1) vendor cost estimates for component technologies and (2) scaling and estimation practices considered to be industry standard to develop and certify a Class 4 capital cost estimate as defined by the Association for the Advancement of Cost Engineering International (AACE).

The individual unit operations and operating sections of the defined polygeneration plant are sufficiently mature to eliminate the need to integrate technologies requiring a high level of new research and development (R&D). However, there is some uncertainty associated with the initial, complex integrations of technologies in a commercial application. It is possible that the integration component may result in higher costs, however this cost variation will be within the cost range as expected for a Class 4 cost estimate.

While these cost estimates represent the best abstract estimate at the current level of engineering, actual reported project costs for the polygeneration design are also expected to deviate from the cost estimates in this report due to differences in real-world implementation (e.g., project- and site-specific considerations) that may impact construction costs. The reported cost uncertainty does not capture changes to site characteristics or added infrastructure costs that would be incurred from changing the design basis of the project.

External supporting innovations (e.g., improvements in ammonia synthesis and pre-combustion capture technology, as mentioned in the Pre-FEED study's technology gap analysis) are expected to result in design and operational improvements for future generations of this polygeneration technology platform (beyond the current scope), resulting in lower costs than those estimated here.

2.1 Capital Costs[4]

Exhibit 2-1, provides an overview of the five capital cost levels included within this report: BEC, EPCC, TPC, and TOC are "overnight" costs, expressed in December 2018 dollars. TASC is expressed in mixed, current-year dollars over the assumed five-year capital expenditure period for the polygeneration design. The following definitions have been adopted in accordance with the definitions found in the 2019 version of NETL's *Quality Guideline for Energy System Studies: Cost Estimation Methodology for NETL Assessment of Power Plant Performance:*

> <u>Bare Erected Cost</u> (BEC) comprises the cost of process equipment, on-site facilities and infrastructure that support the plant (e.g., shops, offices, labs, road), and the direct and indirect labor required for its construction and/or installation. Equipment cost estimates are frequently developed for each plant or plant component using in-house database and conceptual estimating models for specific technologies and may differ from values generated by other software packages such as Aspentech's Aspen Economic Analyzer.
>
> <u>Engineering, Procurement, and Construction Cost</u> (EPCC) comprises the BEC plus the cost of

[4] The cost level definitions and graphic appearing in Exhibit 2-1 are a reproduction of those found in *Section 2.1: Level of Capital Costs* in the June 2019 release of NETL's *Quality Guideline for Energy System Studies: Cost Estimation Methodology for NETL Assessment of Power Plant Performance* (National Energy Technology Laboratory, "Quality Guidelines for Energy System Studies: Cost Estimation Methodology for NETL Assessment of Power Plant Performance," U.S. Department of Energy, Pittsburgh, PA, 2019.)

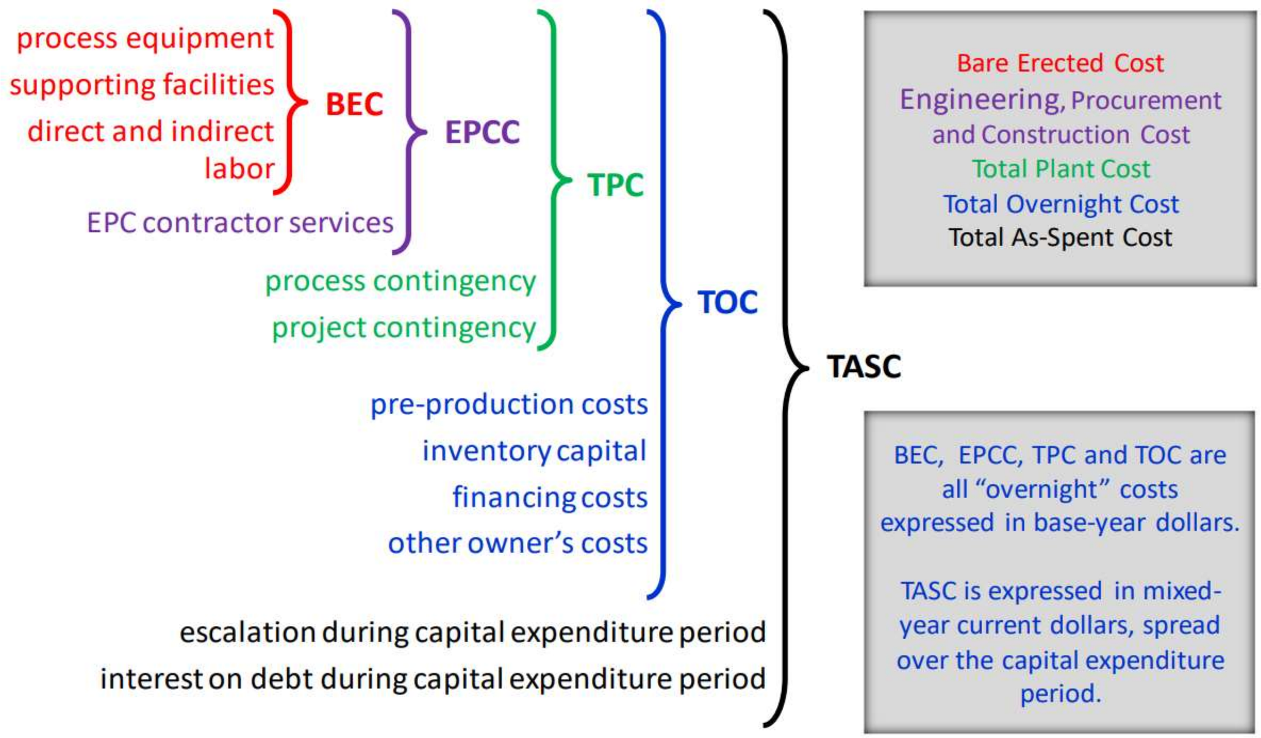
services provided by the EPC contractor. The EPC services include detailed design, contractor permitting (i.e., those permits that individual contractors must obtain to perform their scopes of work, as opposed to project permitting, which is not included here), and project/construction management costs.

Total Plant Cost (TPC) comprises the EPCC cost plus project and process contingencies.

Total Overnight Capital (TOC) comprises the TPC plus all other "overnight" costs, including owner's costs. TOC is an overnight cost, expressed in base-year dollars and as such does not include escalation during construction or construction financing costs.

Total As-Spent Capital (TASC) comprises the sum of all capital expenditures as they are incurred during the capital expenditure period for construction including their escalation. TASC also includes interest during construction, comprised of interest on debt and a return on equity (ROE). TASC is expressed in mixed, current-year dollars over the capital expenditure period.

Exhibit 2-1. Capital Cost Levels and Their Elements[5]



2.1.1 Cost Estimate Basis and Classification

Worley used a combination of: (1) in-house database and estimating models, (2) commercial software packages, and (3) scaling based on applying QGESS methodologies to existing NETL reports to develop TPC and operation and maintenance (O&M) costs for the relevant operating modes. Additional discussion and details can be found in *Section 3*.

[5] This graphic is a reproduction of one found in existing NETL literature (National Energy Technology Laboratory, "Quality Guidelines for Energy System Studies: Specification for Selected Feedstocks," U.S. Department of Energy, Pittsburgh, PA, 2019) in accordance with fair-use standards.

2.1.2 System Code-of-Accounts

As with NETL's *Baseline* reports[6], a process/system-oriented code of accounts is used to group relevant costs into logical subaccounts. This approach ensures that all components of a given process or unit operation are logically grouped together.

2.1.3 Estimate Scope

The estimates represent the polygeneration plant deployed on a generic site located in the Midwest. The limit of the plant includes the total facility including feedstock receiving and water supply system, ending at the high voltage side of the main power transformers.

CO_2 transport and storage (T&S) costs are not considered in the reported capital or O&M costs.

2.1.4 Capital Cost Assumptions[7]

Worley developed the capital cost estimates for the polygeneration plant using the company's in-house database, commercial software packages, and relevant QGESS scaling methodologies. This database and approach are maintained by Worley as part of a commercial design base of experience for similar equipment in the company's range of power and chemical process projects. A reference bottom-up estimate for each major component provides the basis for the estimating models.

Other key estimate considerations include the following:

- Labor costs are based on Midwest, Merit Shop. The estimating models are based on a U.S. Gulf Coast location and the labor cost has been factored to a Midwest location. Labor cost data were sourced from recent projects and Worley in-house references/cost databases.
- The estimates are based on a competitive bidding environment, with adequate skilled craft labor available locally.
- Labor is based on a 50-hour work-week (5-10s). No additional incentives such as per-diem allowances or bonuses have been included to attract craft labor.
- While not included at this time, labor incentives may ultimately be required to attract and retain skilled labor depending on the amount of competing work in the region, and the availability of skilled craft in the area at the time the projects proceed to construction.
- The estimates are based on a greenfield site.
- The site is considered to be Seismic Zone 1, relatively level, and free from hazardous materials, archeological artifacts, or excessive rock. Soil conditions are considered adequate for spread footing foundations. The soil bearing capability is assumed adequate

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[6] National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity," U.S. Department of Energy, Pittsburgh, PA, 2019.

[7] These are standard assumptions used by Worley for capital cost assumptions. As such they match the assumptions which appear in previous NETL documents on which they have worked, including the previous NETL *Baseline* reports. The text in this section closely mirrors what can be found in Revision 2b of Volume 1b (*National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Plants Volume 1b: Bituminous Coal (IGCC) to Electricity, Revision 2b – Year Dollar Update" U.S. Department of Energy, Pittsburgh, PA, 2015.*). The only notable exception is the update in the engineering/construction management costs from 8-10% to 15% to reflect prevailing Baseline assumptions.

such that piling is not needed to support the foundation loads.

- Engineering and Construction Management are estimated based on Worley's historical experience in designing and building power and chemical process projects. The cost of 15% of BEC is representative of Worley's historical engineering/construction management costs for similar plant types. These costs consist of all home office engineering and procurement services as well as field construction management costs. Site staffing generally includes construction manager, resident engineer, scheduler, and personnel for project controls, document control, materials management, site safety, and field inspection.

2.1.5 Price Fluctuations

All historic vendor and reference quotes have been updated and adjusted to December 2018 dollars to account for any relevant price fluctuations to equipment and/or materials. Relevant price indices were used as needed for these adjustments.

2.1.6 Process Contingency

Notable process contingencies were applied as follows:

- Gasifiers and Syngas Coolers: 15%
- Two-Stage Selexol: 20%
- Mercury Removal: 5%
- CTG: 10%
- Instrumentation and Controls: 5%

2.1.7 Owner's Costs

There are three main categories for owner's costs: pre-production costs, inventory capital, and other costs. Pre-production costs are intended to move a given plant through significant completion toward commercial operation.

2.2 Operation and Maintenance Costs[8]

Operating costs and related maintenance expenses (O&M) relate to charges associated with operating and maintaining the plant throughout its expected life, including:

- Operating labor
- Maintenance – material and labor
- Administrative and support labor
- Consumables

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[8] [8]These are standard assumptions used by Worley for Operation and Maintenance Costs. As such, they match the assumptions which appear in previous NETL documents on which they have worked, including the previous NETL *Baseline* reports. The text in this section very closely mirrors what can be found in Revision 2b of Volume 1b (*National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Plants Volume 1b: Bituminous Coal (IGCC) to Electricity, Revision 2b – Year Dollar Update" U.S. Department of Energy, Pittsburgh, PA, 2015.*). Notable exceptions include a change in the Operating Labor rate from $39.70/hour to $38.50/hour in *Section 2.2.1* and explicit definition of the waste disposal rates in *Section 2.2.5*.

- Feedstock
- Waste disposal
- Co-product or by-product credit (that is, a negative cost for any by-products sold)

O&M costs can be divided into both "fixed" and "variable" costs.

2.2.1 Operating Labor

Operating labor cost was determined based on the number of operators required for the polygeneration plant with an average base labor rate used to determine annual cost is $38.50/hour and an associated labor burden of 30% relative to the base labor rate.

2.2.2 Maintenance Material and Labor

Maintenance cost is based on the maintenance costs in relation to the initial capital costs. Due to the aggressive cycling and ramping that this plant is expected to be subjected to, an *additional* 10% maintenance adder has been applied to account for protentional extra wear on the equipment.

2.2.3 Administrative and Support Labor

Labor administration and overhead charges are assessed at a rate of 25% of the burdened O&M labor.

2.2.4 Consumables

Consumable costs, including plant feedstock, were determined on the using relevant consumption rates, unit costs, and plant capacity factors. Required consumable quantities are based on previously developed energy and mass balances for the polygeneration plant.[9] The quantities for initial fills and daily consumables were calculated on a 100 percent operating capacity basis at the *Balanced Generation, 3 GT's* operating point.[10]

2.2.5 Waste Disposal

The approach for estimating waste quantities and disposal costs is similar to consumables, with hazardous waste disposal rates of $80.00/ton and non-hazardous waste disposal rates of $38.00/ton.

2.2.6 Co-Products and By-Products

No financial credit was taken to offset costs based on the potential salable value or relevant by-products when calculating system costs. However, as the plant is a polygeneration facility, sensitivity to ammonia prices was examined in Section 3.

3. Cost Estimates

Applying the previously discussed cost methodologies results in the BEC and TPC seen in Exhibit 3-1. Exhibit 3-2 shows the owner's costs, TOC, and TASC. Exhibit's 3-3 through 3-9 examine the O&M costs for the polygeneration plant.

It should be noted that no costs in Exhibits 3-1 through 3-9 are reported on a per kilowatt (or

[9] Please refer to the *Performance Analysis* report for the relevant energy and mass balances.
[10] The *Balanced Generation, 3 GT's* operating point represents the maximum values for initial fills and consumables of the five defined operating points.

megawatt) basis due to the inherent design and operating characteristics of a polygeneration plant. There is not a clear kilowatt basis for a system that operates across a broad, adaptive window that includes cogeneration of salable products (e.g., ammonia). Furthermore, the metric has no meaning when there are capital components (such as the ammonia loop) that are not related to electricity generation.

Additional discussion of this decision, as well as the inherent problems of applying a per kilowatt (or per megawatt) metric to a polygeneration plant, is presented following Exhibit 3-11.

The cost estimates for the major sub-systems came from three primary sources:

- Worley in-house data and cost modeling database
- *Aspen Capital Cost Estimator* based on the relevant sized equipment list
- Scaling based on the 2019 *Baseline* report, which represents detailed bottoms-up estimates of cost accounts done by qualified firms such as Worley Group and Black and Veatch providing site support services to NETL

In some cases, data points from multiple sources were combined to generate the final reported estimate.

Exhibit 3-1 Polygeneration Capital Plant Cost Details

AST Coal First Polygeneration Plant								Estimate Type:		Class 4
								Cost Base:		Dec 2018
Item No.	Description	Equipment Cost	Material Cost	Labor		Bare Erected Cost	Eng'g CM H.O & Fee	Contingencies		Total Plant Cost
				Direct	Indirect			Process	Project	$/1000
	1	**Coal Handling**								
1.1	Coal Receive & Unload	$492	$0	$237	$0	$730	$109	$0	$168	$1,007
1.2	Coal Stackout & Reclaim	$1,609	$0	$384	$0	$1,994	$299	$0	$459	$2,751
1.3	Coal Conveyors & Yd Crush	$15,351	$0	$3,907	$0	$19,258	$2,889	$0	$4,429	$26,575
1.4	Other Coal Handling	$2,391	$0	$538	$0	$2,929	$439	$0	$674	$4,042
1.5	Sorbent Receive & Unload	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.6	Sorbent Stackout & Reclaim	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.7	Sorbent Conveyors	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.8	Other Sorbent Handling	$0	$0	$0	$0	$0	$0	$0	$0	$0
1.9	Coal & Sorbent Hnd. Foundations	$0	$43	$113	$0	$156	$23	$0	$36	$215
	SUBTOTAL 1.	**$19,843**	**$43**	**$5,179**	**$0**	**$25,066**	**$3,760**	**$0**	**$5,765**	**$34,591**
	2	**Coal & Sorbent Prep and Feed**								
2.1a	Coal Crushing	$376	$23	$54	$0	$453	$68	$0	$104	$625
2.1b	Coal Drying	$9,922	$1,984	$3,382	$0	$15,289	$2,293	$535	$3,623	$21,741
2.2	Prepared Coal Storage & Feed	$2,311	$555	$357	$0	$3,224	$484	$0	$741	$4,448
2.3	Dry Coal Injection System	$2,950	$34	$270	$0	$3,254	$488	$0	$748	$4,491
2.4	Misc. Coal Prep & Feed	$228	$167	$491	$0	$886	$133	$0	$204	$1,223
2.4a	Dryer Vent Booster Compressor & Accessories	$5,511	$473	$1,066	$0	$7,050	$1,057	$0	$1,621	$9,729
2.5	Sorbent Prep Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.6	Sorbent Storage & Feed	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.7	Sorbent Injection System	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.8	Booster Air Supply System	$0	$0	$0	$0	$0	$0	$0	$0	$0
2.9	Coal & Sorbent Feed Foundation	$0	$555	$477	$0	$1,032	$155	$0	$237	$1,424
	SUBTOTAL 2.	**$21,299**	**$3,792**	**$6,097**	**$0**	**$31,188**	**$4,678**	**$535**	**$7,280**	**$43,681**
	3	**Feedwater and Misc. BOP Systems**								
3.1	Feedwater System	$1,994	$3,541	$2,071	$0	$7,606	$1,141	$0	$1,749	$10,496

AST Coal First Polygeneration Plant							Estimate Type:		Class 4
							Cost Base:		Dec 2018
Item No.	Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost	Eng'g CM H.O & Fee	Contingencies Process	Contingencies Project	Total Plant Cost $/1000
3.2	Water Makeup & Pretreating	$320	$33	$195	$0	$548	$82	$0	$189	$819
3.3	Other Feedwater Subsystems	$1,549	$541	$656	$0	$2,746	$412	$0	$632	$3,790
3.4	Service Water Systems	$189	$372	$1,429	$0	$1,989	$298	$0	$686	$2,974
3.5	Other Boiler Plant Systems	$3,271	$1,360	$3,201	$0	$7,832	$1,175	$0	$1,801	$10,808
3.6	FO Supply Sys & Nat Gas	$267	$505	$522	$0	$1,295	$194	$0	$298	$1,787
3.7	Waste Treatment Equipment	$416	$0	$298	$0	$713	$107	$0	$246	$1,067
3.8	Misc. Power Plant Equipment	$910	$121	$547	$0	$1,578	$237	$0	$544	$2,359
	SUBTOTAL 3.	**$8,915**	**$6,473**	**$8,919**	**$0**	**$24,306**	**$3,646**	**$0**	**$6,146**	**$34,098**
	4	**Gasifier and Accessories**								
4.1	Gasifier, Syngas Cooler & Auxiliaries (U-Gas)	$40,045	$23,625	$33,868	$0	$97,538	$14,631	$14,631	$19,020	$145,819
4.2	Syngas Cooling	w/4.1	w/ 4.1	w/ 4.1	$0	$0	$0	$0	$0	$0
4.3	ASU/Oxidant Compression	$23,731	$15,188	$26,199	$0	$65,117	$9,768	$0	$0	$74,885
4.4	LT Heat Recovery & FG Saturation	$0	$0	$0	$0	$0	$0	$0	$0	$0
4.5	Misc. Gasification Equip.	$173	$321	$664	$0	$1,159	$174	$0	$0	$1,333
4.6	Flare Stack System	$343	$193	$108	$0	$643	$96	$0	$148	$887
4.8	Major Component Rigging	w/ 4.1	w/ 4.1	w/ 4.1	$0	$0	$0	$0	$0	$0
4.9	Gasification Foundations	w/ 4.1	w/ 4.1	w/ 4.1	$0	$0	$0	$0	$0	$0
	SUBTOTAL 4.	**$64,292**	**$39,327**	**$60,838**	**$0**	**$164,457**	**$24,669**	**$14,631**	**$19,168**	**$222,924**
	5A	**Gas Cleanup and Piping**								
5A.1	Double Stage Selexol	$65,792	$0	$27,586	$0	$93,379	$14,007	$18,676	$25,212	$151,274
5A.2	Elemental Sulfur Plant	$23,075	$4,498	$29,566	$0	$57,139	$8,571	$0	$13,142	$78,852
5A.3	Mercury Removal	$317	$0	$240	$0	$557	$84	$28	$134	$802
5A.4	Shift Reactors	$3,741	$2,859	$3,225	$0	$9,824	$1,474	$0	$0	$11,298
5A.5	Particulate Removal	w/4.1	$0	w/4.1	$0	$0	$0	$0	$0	$0
5A.6	Blowback Gas Systems	$343	$193	$108	$0	$643	$96	$0	$0	$739

AST Coal First Polygeneration Plant								Estimate Type:		Class 4
								Cost Base:		Dec 2018
Item No.	Description	Equipment Cost	Material Cost	Labor		Bare Erected Cost	Eng'g CM H.O & Fee	Contingencies		Total Plant Cost
				Direct	Indirect			Process	Project	$/1000
5A.7	Fuel Gas Piping	$0	$380	$249	$0	$629	$94	$0	$145	$868
5A.8	Gas Cooling	$10,413	$2,355	$4,481	$0	$17,250	$2,587	$0	$3,967	$23,805
5A.9	Sour Water Stripper	$2,394	$1,745	$3,060	$0	$7,199	$1,080	$0	$1,656	$9,935
5A.10	Sulfur Storage	$2,651	$272	$1,238	$0	$4,161	$624	$0	$957	$5,743
5A.11	Syngas Storage	$0	$5,152	$8,872	$0	$14,023	$2,104	$0	$3,225	$19,352
5A.12	Process Interconnects	$0	$10,000	$24,000	$0	$34,000	$5,100	$0	$7,820	$46,920
5A.13	HGCU Foundations	$0	$214	$144	$0	$358	$54	$0	$124	$536
	SUBTOTAL 5A.	**$108,727**	**$27,668**	**$102,769**	**$0**	**$239,164**	**$35,875**	**$18,704**	**$56,382**	**$350,124**
	5B	**CO_2 Compression**								
5B.1	CO2 Removal System	$0	$0	$0	$0	$0	$0	$0	$0	$0
5B.2	CO2 Compression & Drying	$13,822	$1,802	$3,468	$0	$19,092	$2,864	$0	$4,391	$26,347
5B.3	CO2 Transport & Storage	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 5B.	**$13,822**	**$1,802**	**$3,468**	**$0**	**$19,092**	**$2,864**	**$0**	**$4,391**	**$26,347**
	5C	**Ammonia Production**								
5C.1	Ammonia Plant	$71,045	$19,563	$13,157	$0	$103,764	$15,565	$0	$23,866	$143,195
5C.2	Ammonia Storage & Loadout	$7,466	$2,146	$12,576	$0	$22,188	$3,328	$0	$5,103	$30,619
	SUBTOTAL 5C.	**$78,510**	**$21,709**	**$25,733**	**$0**	**$125,952**	**$18,893**	**$0**	**$28,969**	**$173,813**
	6	**Combustion Turbine and Accessories**								
6.1	Combustion Turbine Generator	$33,945	$0	$1,929	$0	$35,874	$5,381	$3,587	$4,484	$49,327
6.2	Combustion Turbine Auxiliaries	$1,796	$429	$813	$0	$3,038	$456	$0	$0	$3,494
6.3	Compressed Air Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0
6.9	Combustion Turbine Foundations	$0	$601	$760	$0	$1,360	$204	$0	$469	$2,034
	SUBTOTAL 6.	**$35,741**	**$1,029**	**$3,502**	**$0**	**$40,273**	**$6,041**	**$3,587**	**$4,954**	**$54,855**
	7	**Heat Recovery Steam Generator (HRSG), Ducting, and Stack**								
7.1	HRSG	$14,400	$0	$5,623	$0	$20,023	$3,003	$0	$2,303	$25,329
7.2	Selective Catalytic Reduction (SCR) System	w/7.1	w/7.1	w/7.1	$0	$0	$0	$0	$0	$0
7.3	Ductwork	$0	$1,123	$845	$0	$1,967	$295	$0	$453	$2,715

AST Coal First Polygeneration Plant							Estimate Type:			Class 4
							Cost Base:			Dec 2018
Item No.	Description	Equipment Cost	Material Cost	Labor		Bare Erected Cost	Eng'g CM H.O & Fee	Contingencies		Total Plant Cost
				Direct	Indirect			Process	Project	$/1000
7.4	Stack	$915	$1,304	$3,889	$0	$6,108	$916	$0	$702	$7,727
7.9	HRSG, Duct & Stack Foundations	$0	$324	$356	$0	$680	$102	$0	$234	$1,016
	SUBTOTAL 7.	**$15,315**	**$2,750**	**$10,712**	**$0**	**$28,778**	**$4,317**	**$0**	**$3,692**	**$36,787**
	8	**Steam Turbine Generator**								
8.1	Steam TG & Accessories	$18,150	$0	$3,101	$0	$21,251	$3,188	$0	$2,444	$26,883
8.2	Turbine Plant Auxiliaries	$262	$0	$665	$0	$928	$139	$0	$107	$1,173
8.3	Condenser & Auxiliaries	$2,016	$1,048	$1,808	$0	$4,872	$731	$0	$560	$6,164
8.4	Steam Piping	$10,354	$0	$4,642	$0	$14,996	$2,249	$0	$4,311	$21,557
8.9	TG Foundations	$0	$189	$365	$0	$554	$83	$0	$191	$828
	SUBTOTAL 8.	**$30,782**	**$1,237**	**$10,582**	**$0**	**$42,601**	**$6,390**	**$0**	**$7,613**	**$56,605**
	9	**Cooling Water System**								
9.1	Cooling Towers	$2,090	$0	$810	$0	$2,900	$435	$0	$500	$3,835
9.2	Circulating Water Pumps	$803	$0	$44	$0	$848	$127	$0	$146	$1,121
9.3	Circ. Water System Auxiliaries	$87	$0	$14	$0	$101	$15	$0	$17	$133
9.4	Circ. Water Piping	$0	$3,946	$1,042	$0	$4,988	$748	$0	$1,147	$6,884
9.5	Make-up Water System	$215	$0	$325	$0	$540	$81	$0	$124	$745
9.6	Component Cooling Water Sys	$446	$533	$404	$0	$1,383	$207	$0	$318	$1,909
9.9	Circ. Water System Foundations	$0	$1,505	$2,926	$0	$4,431	$665	$0	$1,529	$6,625
	SUBTOTAL 9.	**$3,641**	**$5,985**	**$5,565**	**$0**	**$15,191**	**$2,279**	**$0**	**$3,782**	**$21,251**
	10	**Ash/Spent Sorbent Handling Systems**								
10.1	Slag Dewatering & Cooling	$725	$0	$355	$0	$1,080	$162	$0	$124	$1,367
10.2	Gasifier Ash Depressurization	$1,096	$0	$537	$0	$1,633	$245	$0	$282	$2,160
10.3	Cleanup Ash Depressurization	$492	$0	$241	$0	$733	$110	$0	$126	$969
10.4	High Temperature Ash Piping	$0	$0	$0	$0	$0	$0	$0	$0	$0

AST Coal First Polygeneration Plant								Estimate Type:		Class 4
								Cost Base:		Dec 2018
Item No.	Description	Equipment Cost	Material Cost	Labor		Bare Erected Cost	Eng'g CM H.O & Fee	Contingencies		Total Plant Cost
				Direct	Indirect			Process	Project	$/1000
10.5	Other Ash Rec. Equipment	$0	$0	$0	$0	$0	$0	$0	$0	$0
10.6	Ash Storage Silos	$1,104	$0	$1,193	$0	$2,297	$345	$0	$396	$3,038
10.7	Ash Transport/Feed Equip.	$425	$0	$99	$0	$524	$79	$0	$90	$693
10.8	Misc. Ash Handling Equip.	$61	$75	$22	$0	$158	$24	$0	$27	$209
10.9	Ash/Spent Sorbent Foundation	$0	$431	$573	$0	$1,004	$151	$0	$346	$1,501
	SUBTOTAL 10.	**$3,903**	**$506**	**$3,020**	**$0**	**$7,429**	**$1,114**	**$0**	**$1,393**	**$9,936**
	11	**Accessory Electric Plant**								
11.1	Generator Equipment	$556	$0	$661	$0	$1,217	$183	$0	$140	$1,539
11.2	Station Service Equipment	$3,359	$0	$364	$0	$3,722	$558	$0	$428	$4,709
11.3	Switchgear & Motor Control	$5,986	$0	$1,358	$0	$7,344	$1,102	$0	$1,267	$9,712
11.4	Conduit & Cable Tray	$0	$3,403	$11,439	$0	$14,842	$2,226	$0	$4,267	$21,336
11.5	Wire & Cable	$0	$5,921	$4,353	$0	$10,274	$1,541	$0	$2,954	$14,769
11.6	Protective Equipment	$0	$878	$3,976	$0	$4,854	$728	$0	$837	$6,419
11.7	Standby Equipment	$146	$0	$177	$0	$323	$48	$0	$56	$427
11.8	Main Power Transformers	$9,374	$0	$85	$0	$9,459	$1,419	$0	$1,632	$12,509
11.9	Electrical Foundations	$0	$94	$279	$0	$373	$56	$0	$129	$558
	SUBTOTAL 11.	**$19,421**	**$10,295**	**$22,692**	**$0**	**$52,408**	**$7,861**	**$0**	**$11,709**	**$71,979**
	12	**Instrumentation and Control**								
12.1	IGCC Control Equipment	$0	$0	$395	$0	$395	$59	$20	$71	$545
12.2	Combustion Turbine Control	$0	$0	$0	$0	$0	$0	$0	$0	$0
12.3	Steam Turbine Control	$0	$0	$0	$0	$0	$0	$0	$0	$0
12.4	Other Major Component Control	$1,399	$0	$1,163	$0	$2,562	$384	$128	$461	$3,535
12.5	Signal Processing Equipment	w/12.7	$0	w/12.7	$0	$0	$0	$0	$0	$0
12.6	Control Boards, Panels & Racks	$322	$0	$257	$0	$578	$87	$29	$139	$833
12.7	Computer & Accessories	$7,462	$0	$297	$0	$7,760	$1,164	$388	$931	$10,243
12.8	Instrument Wiring & Tubing	$0	$2,900	$6,634	$0	$9,535	$1,430	$477	$2,860	$14,302

AST Coal First Polygeneration Plant							Estimate Type: / Cost Base:			Class 4 / Dec 2018
Item No.	Description	Equipment Cost	Material Cost	Labor		Bare Erected Cost	Eng'g CM H.O & Fee	Contingencies		Total Plant Cost
				Direct	Indirect			Process	Project	$/1000
12.9	Other I & C Equipment	$4,988	$0	$3,015	$0	$8,004	$1,201	$400	$1,441	$11,045
	SUBTOTAL 12.	**$14,171**	**$2,900**	**$11,762**	**$0**	**$28,834**	**$4,325**	**$1,442**	**$5,903**	**$40,504**
	13	**Improvements to Site**								
13.1	Site Preparation	$0	$141	$3,630	$0	$3,771	$566	$0	$1,301	$5,638
13.2	Site Improvements	$0	$2,513	$4,014	$0	$6,527	$979	$0	$2,252	$9,759
13.3	Site Facilities	$4,504	$0	$5,712	$0	$10,216	$1,532	$0	$3,524	$15,273
	SUBTOTAL 13.	**$4,504**	**$2,655**	**$13,356**	**$0**	**$20,514**	**$3,077**	**$0**	**$7,077**	**$30,669**
	12	**Building and Structures**								
14.1	Combustion Turbine Area	$0	$202	$123	$0	$326	$49	$0	$75	$449
14.2	Steam Turbine Building	$0	$1,678	$2,579	$0	$4,257	$639	$0	$734	$5,630
14.3	Administration Building	$0	$1,190	$931	$0	$2,120	$318	$0	$366	$2,804
14.4	Circulation Water Pumphouse	$0	$149	$85	$0	$234	$35	$0	$40	$309
14.5	Water Treatment Buildings	$0	$271	$285	$0	$556	$83	$0	$96	$735
14.6	Machine Shop	$0	$629	$464	$0	$1,093	$164	$0	$189	$1,446
14.7	Warehouse	$0	$1,016	$707	$0	$1,723	$258	$0	$297	$2,279
14.8	Other Buildings & Structures	$0	$608	$511	$0	$1,119	$168	$0	$257	$1,545
14.9	Waste Treating Building & Str.	$0	$1,228	$2,532	$0	$3,760	$564	$0	$865	$5,189
	SUBTOTAL 14.	**$0**	**$6,972**	**$8,216**	**$0**	**$15,188**	**$2,278**	**$0**	**$2,919**	**$20,386**
	TOTAL COST	**$442,887**	**$135,144**	**$302,411**	**$0**	**$880,441**	**$132,066**	**$38,899**	**$177,144**	**$1,228,550**

Estimates related to syngas storage capacity used a syngas storage capacity of 1,000 m^3. The design basis for the storage capacity was motivated by the desire to ease transitions between plant operating points, as well as assisting in handling process upsets (i.e. syngas to be diverted to storage while the gasifier is backdown in event of an issue with the PSA or ammonia train). These transition needs set the capacity requirement, primarily by evaluating the lag in the transition time of the ammonia loop relative to the gasifier trains and the power island. The capacity selected will provide 40 minutes of storage which is sufficient to handle the most drastic operating point transition, and this storage time can be extended to 60 – 80 minutes by performing other operational adjustments during the transition period.

Exhibit 3-2 reports the TOC and TASC using the pre-production and inventory capital requirements required to operate across the whole operating window as strategically desired. As previously noted, the Owner's Costs are based on assumptions found in NETL's *Quality Guideline for Energy System Studies: Cost Estimation Methodology for NETL Assessment of Power Plant Performance*[11].

[11] The cost estimation contained in this report assumes:

- A Debt/Equity split of 55%/45%
- Real current dollar cost of debt of 2.94%
- Real current dollar cost of equity of 7.84%
- A total weighted average cost of capital of 5.14%
- A 5 year capital expenditure period, with a distribution of total overnight capital over the capital expenditure period (before escalation) of: 10%, 30%, 25%, 20%, 15%

Please refer to Exhibits 2-4, 3-1, 3-2, and 3-11 in the referenced QGESS document for additional details and assumptions (National Energy Technology Laboratory, "Quality Guidelines for Energy System Studies: Cost Estimation Methodology for NETL Assessment of Power Plant Performance," U.S. Department of Energy, Pittsburgh, PA, 2019.).

Exhibit 3-2 Polygeneration Owner's Costs

Description	Balanced, 3 GT's $/1,000
Pre-Production	
6 Months All Labor	$12,090
1 Month Maintenance Materials	$1,492
1 Month Non-Feedstock Consumables	$132
1 Month Waste Disposal	$197
25% of 1 Month's Feedstock at 100% CF	$740
2% of TPC	$24,571
Total Pre-production	**$39,222**
Inventory Capital	
60 Day Supply Feedstock & Consumables at 100% CF	$6,095
0.5% of TPC (spare parts)	$6,143
Total Inventory Capital	**$12,238**
Other Costs	
Initial Cost for Catalysts & Chemicals	$10,456
Land	$900
Financing Costs	$33,171
Other Owner's Costs	$184,282
Total Other Costs	**$228,809**
Total Overnight Cost (TOC)	**$1,508,818**
TASC Multiplier (IOU, 35 year)	1.154
Total As-Spent Cost (TASC)	**$1,741,177**

Exhibit 3-3 represents the fixed *annual* operating and maintenance costs. These are operating and maintenance costs which are independent of operational choices (i.e. the distribution of time spent in various portions of the operating window defined by the five operating points).

Exhibit 3-3 Polygeneration Fixed O&M Costs

Operating Point: All Cases	AST Coal First Polygeneration Plant			Cost Base:	Dec 2018
				Capacity Factor	100
Operating and Maintenance Labor					
Operating Labor				Operating Labor Requirements per Shift	
Operating Labor Rate (base):		38.50	$/hour	Skilled Operator:	4
Operating Labor Burden		30.00	% of base	Operator:	11
Labor O-H Charge Rate		25.00	% of Labor	Foreman:	2
				Lab Techs, etc:	3
				Total:	20
Fixed Operating Costs					
					Annual Cost
					($)
Annual Operating Labor Cost					$8,768,760
Maintenance Labor Cost					$10,575,577
Administrative & Support Labor					$4,836,084
Property Taxes and Insurance					$24,570,995
TOTAL FIXED OPERATING COSTS					**$48,751,416**

Exhibit 3-4 presents a summary of the Fixed O&M costs on an *hourly* basis, the Variable O&M costs (defined again on an hourly basis) and hourly Feedstock costs for each of the five defined operating points.[12]

One key takeaway from this summary table is that the total O&M costs are primarily driven by the operating capacity of the gasifier. As long as it is operating at 100% capacity, the total O&M, including Feedstock, costs will be ~$12,200 per hour. If the gasifier is turned down (e.g., the *Zero Net Power* case operates the gasifier at 66% capacity), then one starts to see meaningful reduction in the total O&M cost.

[12] Representing Hourly Costs ($/hr) is a deviation from the Annual Costs approach commonly seen in the *Baseline Reports*. This decision is meant to more accurately reflect the expected real-world operating conditions of this polygeneration plant. While the *Baseline Reports'* approach of selecting a single operating point (e.g., max net export power generation) and assuming the plant operates at that point for the entire year at a set capacity factor (e.g., 80% in the 2019 revision of *Volume 1*) is sensible for evaluating a traditional PC, NGCC, or IGCC power plant, it is a poor metric for a polygeneration design that is specifically designed to frequently and rapidly vary the amount of net power and cogeneration product (i.e. ammonia) produced in order to meet market demand.

Exhibit 3-4 Summary of Hourly Polygeneration O&M and Feedstock Costs

Cost Component	Balanced, 3 GT's	Balanced, 2 GT's	Zero Net Power	High Elec Prod	Max Elec Prod
Fixed O&M ($/hr)	**$5,565**	**$5,565**	**$5,565**	**$5,565**	**$5,565**
Variable O&M ($/hr)	**$2,545**	**$2,556**	**$2,409**	**$2,552**	**$2,543**
Maintenance Material Cost ($/hr)	$2,044	$2,044	$2,044	$2,044	$2,044
Water ($/hr)	$50	$63	$38	$64	$74
Chemicals ($/hr)	$180	$179	$148	$173	$154
Waste Disposal ($/hr)	$270	$270	$179	$270	$270
By-Products and Emissions ($/hr)	$0	$0	$0	$0	$0
Feedstock ($/hr)	**$4,059**	**$4,059**	**$2,680**	**$4,059**	**$4,059**
Total:	**$12,169**	**$12,180**	**$10,654**	**$12,176**	**$12,167**

Exhibit's 3-5 through 3-9 present the detailed breakdown of the Variable O&M and Feedstock costs that are summarized in Exhibit 3-4. The analysis focuses on the December 2018 Dollars per hour since the hours spent in various portions of the operating window are not known a priori. These per hour cost vectors are a key input to AST's investment analysis which uses a reduced form model for the evaluating the profit potential for this polygeneration platform at the five defined operating points.

Exhibit 3-5 Variable Polygeneration O&M and Feedstock Costs for *Balanced, 3 GT's* Operating Point

Operating Point	Bal, 3 GT	AST Coal First Polygeneration Plant		Cost Base:	Dec 2018
Electrical Generation (MW, net)	48				
Variable Operating Costs					
					($)/hr
Maintenance Material:					$2,044.46
Consumables					
	Initial Fill	Per Hour	Per Unit	Initial Fill Cost	
Water (gal/1000)	-	26.3910	$1.90	**$0**	**$50.14**
MU & WT Chem. (ton)	-	0.0197	$550.00	$0	$10.81
Carbon (Mercury Removal) (ton)	73	0.0042	$12,000.00	$873,031	$50.27
Water Gas Shift Catalyst (ft^3)	3,320	0.0636	$480.00	$1,593,398	$30.51
Selexol Solution (gal)	118,613	0.6868	$38.00	$4,507,304	$26.10
SCR Catalyst (ft^3)	w/ equip	0.0886	$48.00	$0	$4.25
Ammonia (19% NH_3) (ton)	95	0.0562	$300.00	$28,440	$16.87
Ammonia Synthesis Catalyst (ft^3)	1,766	0.0202	$1,956.00	$3,453,774	$39.44
Claus Catalyst (ft^3)	w/ equip	0.0403	$48.00	$0	$1.93
Subtotal:			$550.00	**$10,455,946**	**$180.18**
Waste Disposal					
Spent Mercury Catalyst (ton)		0.0042	$80.00	$0	$0.34
Water Gas Shift Catalyst (ft^3)		0.0636	$2.50	$0	$0.16
Selexol Solution		0.6868	$0.35	$0	$0.24
SCR Catalyst (ft^3)		0.0886	$3.10	$0	$0.27
Ammonia Synthesis Catalyst (ft^3)		0.0202	$16.00	$0	$0.32
Claus Catalyst (ft^3)		0.0011	$2.00	$0	$0.00
Slag (ton)		7.0713	$38.00	$0	$268.71
Subtotal:		0.0042	$80.00	**$0**	**$270.04**
By-Products Disposal					
Sulfur (ton)		1.9842	$0.00	$0	$0
Ammonia (ton)		27.5000	$0.00	$0	$0
Subtotal:				**$0**	**$0**
Variable Operating Costs Total:				**$10,455,946**	**$2,544.83**
Feedstock Cost					
Illinois #6 (ton)		78.1142	$51.96	**$0**	**$4,058.82**

Exhibit 3-6 Variable Polygeneration O&M and Feedstock Costs for *Balanced, 2 GT's* Operating Point

Operating Point	Bal, 2 GT	AST Coal First Polygeneration Plant		Cost Base:	Dec 2018
Electrical Generation (MW, net)	51				
Variable Operating Costs					
					($)/hr
Maintenance Material:					**$2,044.46**
Consumables					
	Initial Fill	Per Hour	Per Unit	Initial Fill Cost	
Water (gal/1000)	-	33.1202	$1.90	**$0**	**$62.93**
MU & WT Chem. (ton)	-	0.0247	$550.00	$0	$13.57
Carbon (Mercury Removal) (ton)	73	0.0042	$12,000.00	$873,031	$50.27
Water Gas Shift Catalyst (ft^3)	3,320	0.0636	$480.00	$1,593,398	$30.51
Selexol Solution (gal)	118,613	0.6868	$38.00	$4,507,304	$26.10
SCR Catalyst (ft^3)	w/ equip	0.0812	$48.00	$0	$3.90
Ammonia (19% NH_3) (ton)	95	0.0430	$300.00	$28,440	$12.90
Ammonia Synthesis Catalyst (ft^3)	1,766	0.0202	$1,956.00	$3,453,774	$39.44
Claus Catalyst (ft^3)	w/ equip	0.0403	$48.00	$0	$1.93
Subtotal:				**$10,455,946**	**$178.61**
Waste Disposal					
Spent Mercury Catalyst (ton)		0.0042	$80.00	$0	$0.34
Water Gas Shift Catalyst (ft^3)		0.0636	$2.50	$0	$0.16
Selexol Solution		0.6868	$0.35	$0	$0.24
SCR Catalyst (ft^3)		0.0812	$3.10	$0	$0.25
Ammonia Synthesis Catalyst (ft^3)		0.0202	$16.00	$0	$0.32
Claus Catalyst (ft^3)		0.0011	$2.00	$0	$0.00
Slag (ton)		7.0713	$38.00	$0	$268.71
Subtotal:				**$0**	**$270.02**
By-Products Disposal					
Sulfur (ton)		1.9842	$0.00	$0	$0
Ammonia (ton)		27.5000	$0.00	$0	$0
Subtotal:				**$0**	**$0**
Variable Operating Costs Total:				**$10,455,946**	**$2,556.02**
Feedstock Cost					
Illinois #6 (ton)		78.1142	$51.96	**$0**	**$4,058.82**

Exhibit 3-7 Variable Polygeneration O&M and Feedstock Costs for *Zero Net Power* Operating Point

Operating Point	Zero Net Power	AST Coal First Polygeneration Plant		Cost Base:	Dec 2018
Electrical Generation (MW, net)	**0**				
Variable Operating Costs					
					($)/hr
Maintenance Material:					**$2,044.46**
Consumables					
	Initial Fill	Per Hour	Per Unit	Initial Fill Cost	
Water (gal/1000)	-	19.9075	$1.90	**$0**	**$37.82**
MU & WT Chem. (ton)	-	0.0148	$550.00	$0	$8.15
Carbon (Mercury Removal) (ton)	73	0.0030	$12,000.00	$873,031	$35.71
Water Gas Shift Catalyst (ft^3)	3,320	0.0636	$480.00	$1,593,398	$30.51
Selexol Solution (gal)	118,613	0.6868	$38.00	$4,507,304	$26.10
SCR Catalyst (ft^3)	w/ equip	0.0290	$48.00	$0	$1.39
Ammonia (19% NH_3) (ton)	95	0.0187	$300.00	$28,440	$5.62
Ammonia Synthesis Catalyst (ft^3)	1,766	0.0202	$1,956.00	$3,453,774	$39.44
Claus Catalyst (ft^3)	w/ equip	0.0268	$48.00	$0	$1.29
Subtotal:				**$10,455,946**	**$148.22**
Waste Disposal					
Spent Mercury Catalyst (ton)		0.0030	$80.00	$0	$0.24
Water Gas Shift Catalyst (ft^3)		0.0636	$2.50	$0	$0.16
Selexol Solution		0.6868	$0.35	$0	$0.24
SCR Catalyst (ft^3)		0.0290	$3.10	$0	$0.09
Ammonia Synthesis Catalyst (ft^3)		0.0202	$16.00	$0	$0.32
Claus Catalyst (ft^3)		0.0008	$2.00	$0	$0.00
Slag (ton)		4.6727	$38.00	$0	$177.56
Subtotal:				**$0**	**$178.61**
By-Products Disposal					
Sulfur (ton)		1.3228	$0.00	$0	$0
Ammonia (ton)		27.5000	$0.00	$0	$0
Subtotal:				**$0**	**$0**
Variable Operating Costs Total:				**$10,455,946**	**$2,409.12**
Feedstock Cost					
Illinois #6 (ton)		51.5815	$51.96	**$0**	**$2,680.17**

Exhibit 3-8 Variable Polygeneration O&M and Feedstock Costs for *High Electricity Production* Operating Point

Operating Point	High Elec Prod	AST Coal First Polygeneration Plant		Cost Base:	Dec 2018
Electrical Generation (MW, net)	82				
Variable Operating Costs					
					($)/hr
Maintenance Material:					**$2,044.46**
Consumables					
	Initial Fill	Per Hour	Per Unit	Initial Fill Cost	
Water (gal/1000)	-	33.8956	$1.90	**$0**	**$64.40**
MU & WT Chem. (ton)	-	0.0252	$550.00	$0	$13.88
Carbon (Mercury Removal) (ton)	73	0.0042	$12,000.00	$873,031	$50.27
Water Gas Shift Catalyst (ft^3)	3,320	0.0636	$480.00	$1,593,398	$30.51
Selexol Solution (gal)	118,613	0.6868	$38.00	$4,507,304	$26.10
SCR Catalyst (ft^3)	w/ equip	0.1218	$48.00	$0	$5.85
Ammonia (19% NH_3) (ton)	95	0.0661	$300.00	$28,440	$19.84
Ammonia Synthesis Catalyst (ft^3)	1,766	0.0128	$1,956.00	$3,453,774	$25.01
Claus Catalyst (ft^3)	w/ equip	0.0403	$48.00	$0	$1.93
Subtotal:				**$10,455,946**	**$173.39**
Waste Disposal					
Spent Mercury Catalyst (ton)		0.0042	$80.00	$0	$0.34
Water Gas Shift Catalyst (ft^3)		0.0636	$2.50	$0	$0.16
Selexol Solution		0.6868	$0.35	$0	$0.24
SCR Catalyst (ft^3)		0.1218	$3.10	$0	$0.38
Ammonia Synthesis Catalyst (ft^3)		0.0128	$16.00	$0	$0.20
Claus Catalyst (ft^3)		0.0011	$2.00	$0	$0.00
Slag (ton)		7.0713	$38.00	$0	$268.71
Subtotal:				**$0**	**$270.03**
By-Products Disposal					
Sulfur (ton)		1.9842	$0.00	$0	$0
Ammonia (ton)		17.4350	$0.00	$0	$0
Subtotal:				**$0**	**$0**
Variable Operating Costs Total:				**$10,455,946**	**$2,552.28**
Feedstock Cost					
Illinois #6 (ton)		78.1142	$51.96	**$0**	**$4,058.82**

Exhibit 3-9 Variable Polygeneration O&M and Feedstock Costs for *Max Electricity Production* Operating Point

Operating Point	Max Elec Prod	AST Coal First Polygeneration Plant		Cost Base:	Dec 2018
Electrical Generation (MW, net)	112				
Variable Operating Costs					
					($)/hr
Maintenance Material:					$2,044.46
Consumables					
	Initial Fill	Per Hour	Per Unit	Initial Fill Cost	
Water (gal/1000)	-	39.1546	$1.90	**$0**	**$74.39**
MU & WT Chem. (ton)	-	0.0292	$550.00	$0	$16.04
Carbon (Mercury Removal) (ton)	73	0.0042	$12,000.00	$873,031	$50.27
Water Gas Shift Catalyst (ft^3)	3,320	0.0636	$480.00	$1,593,398	$30.51
Selexol Solution (gal)	118,613	0.6868	$38.00	$4,507,304	$26.10
SCR Catalyst (ft^3)	w/ equip	0.1218	$48.00	$0	$5.85
Ammonia (19% NH_3) (ton)	95	0.0650	$300.00	$28,440	$19.51
Ammonia Synthesis Catalyst (ft^3)	1,766	0.0020	$1,956.00	$3,453,774	$3.87
Claus Catalyst (ft^3)	w/ equip	0.0403	$48.00	$0	$1.93
Subtotal:				**$10,455,946**	**$154.08**
Waste Disposal					
Spent Mercury Catalyst (ton)		0.0042	$80.00	$0	$0.34
Water Gas Shift Catalyst (ft^3)		0.0636	$2.50	$0	$0.16
Selexol Solution		0.6868	$0.35	$0	$0.24
SCR Catalyst (ft^3)		0.1218	$3.10	$0	$0.38
Ammonia Synthesis Catalyst (ft^3)		0.0020	$16.00	$0	$0.03
Claus Catalyst (ft^3)		0.0011	$2.00	$0	$0.00
Slag (ton)		7.0713	$38.00	$0	$268.71
Subtotal:				**$0**	**$269.86**
By-Products and Emissions					
Sulfur (ton)		1.9842	$0.00	$0	$0
Ammonia (ton)		17.4350	$0.00	$0	$0
Subtotal:				**$0**	**$0**
Variable Operating Costs Total:				**$10,455,946**	**$2,542.78**
Feedstock Cost					
Illinois #6 (ton)		78.1142	$51.96	**$0**	**$4,058.82**

Exhibit 3-10 represents the calculated required first-year cost of electricity (COE) in dollars per MWh required at the five representative operating points based on the previously discussed financial assumptions and cost estimates and accounting for revenue obtained through the sale of ammonia produced by the polygeneration plant.[13] It should be noted that the exhibit below does not reflect additional revenue for any potential CO_2 sales prices and emissions penalties, profit from sale of sulfur, etc.

[13] It is appropriate to present the required first-year COE in Exhibits 3-10 through 3-12 in terms of $/MWh-net (in contrast to the approach adopted for Exhibits 3-4 through 3-9) as the results presented in these exhibits take into account the financial value that can be provided by the ammonia production aspect of the polygeneration plant. Additional discussion on this point can be seen following Exhibit 3-12.

The first year COE estimate was evaluated over the range from the current ammonia retail cost ($551/ton, representing the "high end" estimate) and the current United States Gulf Coast (USGC) ammonia contract price ($195/ton, representing the "low end" estimate). The retail price represents a reasonable upper bound estimate on potential ammonia revenue (i.e., full capture of the distributed ammonia production advantage), whereas the USGC contract price represents a current reasonable lower bound estimate, for this stage of evaluation, on the potential ammonia revenue (i.e., no capture of the distributed ammonia production advantage). An intermediate choice, such as 75% of the retail price, is a more plausible basis for evaluation. In practice, the plant would most likely capture a different level of locational advantage based on the geographical distribution of customers relative to the specific plant siting.

Exhibit 3-10 First Year COE ($/MWh-net) at Five Defined Operating Points for Various Ammonia Price Sensitivities

Balanced Gen, 3 GT's	Balanced Gen, 2 GT's	Zero Net Power	High Electricity Production	Max Electricity Production	NH_3 Revenue ($/ton)	
$245	$234	N/A	$213	$227	$551	Full Retail Ammonia Price w/o Distribution Costs
$323	$308	N/A	$243	$231	$473	75% of Retail
$401	$383	N/A	$272	$234	$276	50% of Retail
$448	$427	N/A	$290	$236	$195	Current U.S. Gulf Coast Delivery; No locational Advantage

A breakdown of these first year COE's across previously discussed cost components is presented in Exhibit 3-11 using the "75% of Retail" price point for ammonia.

Exhibit 3-11 First Year COE ($/MWh-net) Breakdown with Ammonia Price Set at 75% of Retail

First Year COE Component	Balanced, 3 GT's	Balanced, 2 GT's	Zero Net Power	High Elec Prod	Max Elec Prod	Percentage[14]
Capital	$302	$288	N/A	$179	$130	54%
Fixed O&M	$120	$114	N/A	$71	$52	22%
Variable O&M	$53	$50	N/A	$31	$23	9%
Feedstock	$84	$80	N/A	$50	$36	15%
Total (Excluding Ammonia Revenue)	**$559**	**$532**	**N/A**	**$331**	**$241**	N/A
Ammonia Revenue	$235	$224	N/A	$88	$10	N/A
Total (Including Ammonia Revenue)	**$323**	**$308**	**N/A**	**$243**	**$231**	N/A

Exhibit 3-12 provides an alternative representation on the information contained in Exhibit 3-11. Rather than including "Ammonia Revenue" as a separate line item, it has been pro-rated and included as a credit in each of the other cost components. For example, 54% of the $235 "Ammonia Revenue" in the *Balanced, 3 GT's* case was applied as a credit to reduce the First Year COE of the "Capital" cost component, 22% of the $235 "Ammonia Revenue" was applied as a credit to the "Fixed O&M" cost component, etc.

[14] This represents the percent of each cost component relative to the *Total (Excluding Ammonia Revenue)*. While the percentage was not exact across all five operating points, the variance fell within the bounds of round-off error (e.g., Capital Cost percentages ranged from 54.12% to 54.15%).

Exhibit 3-12 First Year COE ($/MWh-net) Breakdown with Pro-Rated Ammonia Revenue

First Year COE Component	Balanced, 3 GT's	Balanced, 2 GT's	Zero Net Power	High Elec Prod	Max Elec Prod	Percentage
Capital	$175	$167	N/A	$132	$125	54%
Fixed O&M	$69	$66	N/A	$52	$49	22%
Variable O&M	$30	$29	N/A	$23	$22	9%
Feedstock	$49	$46	N/A	$36	$35	15%
Total	**$323**	**$308**	**N/A**	**$243**	**$231**	N/A

It is important to note the impact of including the pro-rated ammonia revenues to the various cost components. For example, the *Capital* cost component at the *Balanced, 3 GT's* operating point is $302/MWh-net without ammonia revenue considered (Exhibit 3-11). However, when the pro-rated ammonia revenue is included (Exhibit 3-12), the *Capital* cost component is reduced to $175/MWh-net.

This large change in the apparent *Capital* cost component (as well as similar comparisons between Exhibits 3-11 and 3-12) should provide justification for the previous decision to forego inclusion of metric based on a net export power (e.g., $/MWh-net) in Exhibits 3-4 to 3-9.

The COE metric is inherently challenging for use in comparing a polygeneration plant to other power producing facilities. For example, a cursory glance may make it appear that the *Max Electricity Production* representative operating point is superior to the other four at ammonia prices at "75% of Retail" and below, but realistically this is simply a construct of the calculation. In this operating mode, while the gasifier and power island are being fully utilized to capacity, there is capital cost for the ammonia loop which is not being fully utilized. Similarly, in the *Balanced* representative operating modes the power island capital equipment is not being run to capacity (hence higher COE, as capital costs are being spread among fewer MWh), but the ammonia loop is being run to capacity (hence no idle capacity or capital costs in the ammonia loop). Since COE fails to adequately capture or evaluate the value of the multiple product, multiple operating point polygeneration facility, a multivariate financial analysis is necessary to support the technology platform and future project decisions.