SYSTEMS STUDY METHODOLOGY

SYSTEMS ANALYSES OF ADVANCED BRAYTON CYCLES

FOR

HIGH EFFICIENCY ZERO EMISSION PLANTS

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Task 1.1 - Set Systems Study Methodology

Introduction

This document provides an explanation of the systems study procedure to be used to evolve the conceptual IGCC plant design. It is the intent to adhere to the "Quality Guidelines for Energy System Studies" established by the DOE / NETL wherever possible.

This systems study procedure explains the rationale or approach for choosing:

- site conditions and feedstock characteristics
- advanced technology projections
- design basis, plant size and configuration
- executing material and energy balances including labeling streams and indicating stream compositions and conditions.

The procedure provides an explanation of the methodology or approach for:

- building up the cost elements to estimate each plant unit cost (e.g., gasification, cleanup, power generation, heat recovery, etc.)
- estimating direct costs to reasonable level of detail [i.e., bare equipment (where required), total direct and total indirect, general facilities, home office overhead and fee, contingencies, royalties, start-up working capital, spare parts, initial catalyst and chemicals and land].

The procedure also explains how:

- unit plant costs will be collected to determine a total plant capital construction cost
- annual plant operating costs will be estimated
- financial analysis strategy (considering current tax laws for private plant construction) to establish the minimum required plant product selling price for amortizing capital costs and operating the plant.

And finally, the procedure for third party validation of the study is addressed.

Process Design Procedure

Site Conditions and Feedstock Characteristics

Site Conditions

Table 1 summarizes the site conditions to be used in this systems analysis study.

Coal

Pittsburgh No. 8 coal will be utilized for this study. Table 2 shows its ultimate, proximate, and sulfur analyses (as provided by NETL / DOE) along with that of Illinois No. 6 coal (taken from the "Quality Guidelines for Energy System Studies") which will be utilized for sensitivity analysis.

Natural Gas

The composition shown in Table 3 taken from the "Quality Guidelines for Energy System Studies," which is based on the mean of over 6,800 samples of pipeline quality natural gas taken in 26 major metropolitan areas of the United States will be used.

Limestone

Limestone if required (e.g., as a flux) having the composition shown in Table 4 (taken from the "Quality Guidelines for Energy System Studies") will be utilized.

Table 1: Site Conditions

Dry Bulb Temperature	15^o C[1]
Relative Humidity	60%[1]
Elevation	sea level[1]
Air Composition by Volume	
O_2	20.74%
N_2	77.338%
CO_2	0.002%
H_2O	0.99%
Ar	0.93%
Plant Make-up Water	Fresh Water
Plant Heat Rejection	Mechanical Draft Cooling Towers
Plant Site	Level Greenfield without any Piling Requirement

[1] International Standards Organization (ISO) conditions.

Table 2: Coal Analysis

Rank	Medium-volatile Bituminous		High-volatile Bituminous	
Seam	Pittsburgh No. 8		Illinois #6 (Herrin)	
Sample Location	PA		St. Clair Co., IL	
PROXIMATE ANALYSIS	As Received	Dry	As Received	Dry
Moisture	5.83	0	7.97	0
Ash	9.65	10.25	14.25	15.48
Volatile Matter	34.87	37.03	36.86	40.05
Sulfur	2.89	3.07	4.45	4.83
Fixed Carbon (BD)	46.76	49.65	36.47	39.64
HHV				
kJ/kg	28959	30806	25584	27798
Btu/lb	12450	13244	10999	11951
ULTIMATE ANALYSIS				
Moisture	5.83	0	7.97	0
Carbon	69.50	73.79	60.41	65.65
Hydrogen	4.53	4.81	3.89	4.23
Nitrogen	1.21	1.29	1.07	1.16
Chlorine	-	-	0.05	0.05
Sulfur	2.89	3.07	4.45	4.83
Ash	9.95	10.57	14.25	15.48
Oxygen	6.09	6.47	7.91	8.60
SULFUR SPECIES				
Pyritic	-	-	--	2.81
Sulfate	-	-	--	0.01
Organic	-	-	--	2.01

Notes: (1) Data reproduced/derived from Argonne National Laboratory, premium coal sample analytical data, (2) HHV (gross) measured experimentally; LHV (net) derived from the corresponding HHVs.

Table 3: Natural Gas Composition

Component	Volume Percentage	
Methane, CH_4	93.1	
Ethane, C_2H_6	3.2	
Propane, C_3H_8	0.7	
n-Butane, C_4H_{10}	0.4	
Carbon Dioxide, CO_2	1.0	
Nitrogen, N_2	1.6	
	LHV	**HHV**
MJ/scm	34.71	38.46
Btu/scf	932	1032

Notes:

1. The reference data reported the mean volume percentage of higher hydrocarbons (C_4 +) to be 0.4%. For simplicity, the above composition represents all the higher hydrocarbons as *n*-butane (C_4H_{10}).
2. The reference data reported the mean volume percentage of CO_2 and N_2 (combined) to be 2.6%. The above composition assumes that the mean volume percentage of CO_2 is 1.0%, with the balance (1.6%) being N_2.
3. LHV = lower heating value; HHV = higher heating value

Table 4: Greer Limestone Analysis

Component	Dry Basis %
Calcium Carbonate, $CaCO_3$	80.40
Magnesium Carbonate, $MgCO_3$	3.50
Silica, SiO_2	10.32
Aluminum Oxide, Al_2O_3	3.16
Iron Oxide, Fe_2O_3	1.24
Sodium Oxide, Na_2O	0.23
Potassium Oxide, K_2O	0.72
Balance	0.43

Advanced Technology Projections

Some of the technological advances being made or being investigated to improve the Brayton cycle include the following:

- Rotor inlet temperature of 1700ºC (3100ºF) or higher which would require the development and use of advanced materials including advanced thermal barrier coatings and turbine cooling techniques including closed loop steam cooling.

- High blade metal temperature in the neighborhood of ~1040ºC (1900ºF) while limiting coolant amount would again require the development and use of the advanced materials including advanced thermal barrier coatings.

- Cycle changes such as air humidification, inlet air fogging, in-situ reheat, intercooling, and chemical recuperation (in case of a natural gas for H2 coproduction).

- Improvements to the aerodynamic and mechanical design such as pressure gain combustion, improved compressor (such as that being developed by Ramgen) and / or turbine isentropic efficiencies.

- Cavity or trapped vortex combustor (such as that being developed by Ramgen).

- High pressure ratio compressor (greater than 30 to take full advantage of higher firing temperature).

- Catalytic combustors (such as that being developed by PCI).

Other technological advances being made or being investigated that could be incorporated in an advanced technology plant include the following:

- Oxy combustion systems (such as that being developed by CES).

- Compressor designs for use in the air separation unit or the CO2 compression unit (such as those being evolved by Ramgen and by SwRI).

As an example, it may be possible in an IGCC plant to utilize the cavity or trapped vortex combustor in the gas turbine to limit the combustor diluent addition to a value which optimizes the overall plant thermal efficiency while minimizing the NOx emissions. Next, with oxy combustion where it is possible to capture the CO2 from the turbine exhaust (partial) condenser, shifting of the syngas prior to combustion is not required. A gasification system such as the E-Gas gasifier would be more suitable to such applications.

A myriad of gas turbine based cycles have been proposed in the past but the majority of these cycles have been for natural gas applications. Thus, it is important to identify only those cycles that have a potential for success in coal based gasification plants also and the following lists the initial activities included in this task to select promising cycles for inclusion in the systems analysis:

- Based on a literature search, identify gas turbine based cycles that have a potential for high efficiency.

- Conduct brainstorming sessions in order to identify those gas turbine based cycles that have a potential to meet the objectives of this program. Improvements to these cycles as well as the evolution of new cycle configurations by synergistically combining aspects of other cycles will also be brainstormed.

After the selection of the advanced cycles, a narrative accompanying the recommended cycles as well as the integration scheme with the remainder of the plant for each of the cases will be made to the COR. Upon COR approval, UCIrvine will proceed with detailed systems analysis and design for these cases. Three or more systems studies will be conducted in the second year which integrate these advanced technologies upon mutual agreement of UCIrvine and COR (the exact number of cases dependent upon funding availability).

Design Criteria, Configuration and Plant Size

Table 5 summarizes the design criteria for the Cases 1.1 through 2.0 as defined in the following.

Table 5: Design Criteria

Location	Midwest U.S.
Steam Cycle	Subcritical to match Syngas Cooler where Utilized
ASU-GT Integration	Air-Nitrogen Partial-Integration
Power-To-Hydrogen Ratio	20:1
CO_2 Removal	90% of Carbon in Coal less Carbon in Slag

The following cases will be developed during the first year of the program:

- *CASE 1.1: IGCC with H2 Coproduction and CO2 Capture (utilizing GE type Gasifiers with Radiant and Convective Syngas Coolers.* Overall plant design will be consistent with the configuration per the DOE/NETL Draft Interim Study report provided by Wimer (including using Pittsburgh No. 8 coal and single GE 7FB gas turbine which sets the size of the plant). Sensitivity studies may include implication of using Illinois No. 6 coal, plant without CO2 recovery, improved subystems, or other depending on availability of resources. As a minimum, the reports due upon completion of the study will suggest sensitivity study work for future work.

- *CASE 1.2: IGCC with H2 Coproduction and CO2 Capture (UCIrvine Configuration).* This case consists of an alternate configuration to that in Case 1.1 based on UCIrvine's prior experience to show possible improvements over Case 1.1. Changes may include type of syngas cooling (e.g., total quench heat recovery) but the power block technology will remain the same as Case 1.1. Again Pittsburgh No. 8 coal will be utilized and the plant will consist of a single GE 7FB gas turbine which sets the size of the plant. Sensitivity studies may include implication of using Illinois No. 6 coal, plant without CO2 recovery, or other depending on availability of resources. As a minimum, the reports due upon completion of the study will suggest sensitivity study work for future work.

- *CASE 1.3: Natural Gas Plant.* A natural gas based power plant coproducing H2 and capturing CO2 while utilizing the same gas turbine technology as in Cases 1.1 and 1.2, i.e., the GE 7FB gas turbine. The plant will consist f a single gas turbine. The ratio of the exported H2 to net electric power generated, and the CO2 emissions on a net electric power basis will be held the same as in Case 1.2. This case will provide a basis for comparing the economics of coproducing H2 in a carbon constrained world from natural gas versus coal.

- *Case 2.0: IGCC with H2 Coproduction and CO2 Capture (UCIrvine Configuration).* This case will be similar to Case 1.2 but will utilize a single GE 7H gas turbine. Again, sensitivity studies may include implication of using Illinois No. 6 coal, plant without CO2 recovery, or other depending on availability of resources. As a minimum, the reports due upon completion of the study will suggest sensitivity study work for future work. The reasons for including this advanced case are as follows: It is expected that the Case 1.0 technology (with the GE 7FB gas turbine) will be outdated in another 5 years and will be replaced by this Case 2.0 technology. Inclusion of Case 2.0 in this study will provide a good basis for comparing the other advanced technologies (to be studied under Case 3.0 described in the following) since a comparison of technologies to be available during the same time frame will be facilitated and would be quantifying the incentives if any, for developing the Case 3.0 technologies (hardware wise). Furthermore, the "add-on technologies" such as the POx cycle (i.e., cycles that would add on to a combined cycle) may not show the same improvement in efficiency in a Case 2.0 type IGCC as they would in a Case 1.0 type IGCC since the gas turbine firing temperature and especially the pressure ratio effect the resulting efficiency improvement.

During the second year of this program, advanced technology cases will be developed; some of these technologies were discussed previously under "Advanced Technology Projections."

Material and Energy Balances

The material and energy balances will be developed utilizing predictive computer simulation techniques. The primary heat and mass balance code will be APSAT. Appendix A provides its description and capabilities. The Aspen Plus® simulator may also be used for selected cases. THERMOFLEX which is a Thermoflow suite product will be utilized primarily in developing the performance for the steam cooled the H technology gas turbine on syngas. Appendix B provides descriptions and capabilities of the Thermoflow suite of products to be used in this study.

The following specific modeling guidelines will be applied to the overall energy system:

- Process models will generate sufficient information to generate a property table of the streams entering and leaving the process unit.

- Heat loss, blowdown amount, pressure drop, mechanical efficiency, auxiliary and miscellaneous power and cooling water requirements will be taken into account for each piece of equipment or plant section.

- All major streams appearing in a flow diagram will be labeled with an accompanying table that will provide stream compositions, flowrates and conditions of pressure and temperature.

- Overall performance summaries will be developed showing the power generation by each equipment and the power consumed by the plant.

Specifications for Unique Equipment and Plant Units

Duty / functional specifications will be developed where necessary for unique equipment and plant units and provided to third parties such as the equipment / process developers or vendors in order to more accurately estimate their costs.

Cost Estimating Procedure

In general, cost engineering will be done in accordance with the recognized methods and standards that are promulgated by groups such as the Association for the Advancement of Cost Engineering (AACE).

Capital Costs

Plant capital cost estimates will reflect full turnkey outlays. The costs for each major subsystem involved in the estimate will be developed from known costs for a similar system or a factored analysis based on equipment costs. These two types of methodologies will be employed depending upon the type of unit and availability of data.

Capacity Factored Estimates

These type of estimates are based on multiplying the cost of a unit for which the direct construction costs are known by the ratio of the new unit's capacity to the capacity of the known unit. Capacity ratios are adjusted by an exponent chosen on the basis of the unit type. The costs are adjusted for design differences, location and time frame.

Equipment Cost Factored Estimates

These type of estimates for each mechanical equipment item are developed utilizing ICARUS which is an Aspen Suite product, and PEACE which is a Thermoflow Suite product for the power block equipment. The bare equipment cost as well as the various other costs such as piping, instrumentation, foundations etc. are also estimated by these software. These costs will be checked against the AACE Recommended Practice No. 16R-90, "Conducting Technical and Economic Evaluations in the Process and Utility Industries" and necessary adjustments will be made to the estimates.

The methodology to be utilized for each of the Process and General Facility Units in the plant are listed in Table 6.

Contingency

The plant capital cost will be broken down by each major plant section, with both a process contingency and a project contingency applied to each.

Process Contingency. Process contingency is designed to compensate for uncertainty in cost estimates caused by performance uncertainties associated with the development status of a technology. A process contingency to each plant section will be applied based on its technology status (at the time the cost estimate is prepared), according to the AACE standards listed in Table 7. Each process contingency will account for the cost uncertainty arising from the use of new technology in the plant section to which it is applied.

Project Contingency. Project contingency is designed to compensate for uncertainty in cost estimates caused by an incomplete technical definition. Project contingencies as listed in the NETL/DOE "Quality Guidelines for Energy System Studies" are shown in Table 8 based on the five levels of the AACE classification of estimates. Table 9 lists these classifications along with a range of expected accuracy and the level of definition that is needed per class. The level of definition provides some indication of the expected accuracy of the estimate. The cost estimates developed in this system studies will fall under Class 4.

Based on the NETL/DOE "Quality Guidelines for Energy System Studies," a 40% contingency would be required for cost estimates developed in this study which would be excessive. Instead, the AACE recommended 25% contingency will be applied on the sum of: the total plant cost, the home office overhead and fee, and the process contingency.

Table 6: Cost Estimation Methodology for Each Plant Section

Plant Section	Technique
Coal Receiving and Conveying, Grinding and Slurry Preparation	Unit Capacity Factored
Air Separation	Unit Capacity Factored
Claus Plant Oxygen (ITM)	Unit Capacity Factored
Gasification, High Temperature Gas Cooling and Scrubbing	Unit Capacity Factored
Shift, Low Temperature Gas Cooling and Cleanup	Equipment Cost Factored
Desulfurization and CO_2 Capture	Equipment Cost Factored
Sulfur Recovery and Tail Gas Treating	Unit Capacity Factored
CO_2 Compression, Dehydration and Pumping	Equipment Cost Factored
H_2 Separation (PSA) and Tail Gas compression	Equipment Cost Factored
Humidification (Syngas and /or N2)	Equipment Cost Factored
Power Generation	Equipment Cost Factored
General Facilities (Each Subsystem)	Unit Capacity Factored

Table 7: AACE Standards for Process Contingency

Technology Status	Process Contingency
New Concept with Limited Data	40% +
Concept with Bench-Scale Data	30-70%
Small Pilot Plant Data	20-30%
Full-Size Modules have been Operated	5-20%
Process is used Commercially	0-10%

Table 8: Standards for Project Contingency

Design Stage	Level of Project Definition (% of complete definition)	AACE Estimate Class	Project Contingency
Concept Screening	0 - 2	5	50%
Feasibility Study	1 - 15	4	40%
Budget Authorization	10 - 40	3	30%
Project Control	30 - 70	2	15%
Bid Check	50 - 100	1	5%

Table 9: Expected Accuracy of Five Estimate Classes

AACE Estimate Class	Expected Accuracy	Level of Project Definition (% of complete definition)
5	+50% to -30%	0 – 2
4	+30% to -15%	1 – 15
3	+20% to -10%	10 – 40
2	+15% to -5%	30 – 70
1	+5% to -5%	50 – 100

Conceptual Equipment or Equipment Under Developed

The basis of all major equipment items when estimating the capital cost of equipment that is conceptual or under development will be identified in the report. The status of the equipment under development will be discussed. A sensitivity analysis can be performed around the major equipment costs if required.

Economic Analysis

The Electric Power Research Institute (EPRI) Technical Assessment Guide (TAG) methodology will be used in assessing overall economic performance.

Capital Costs

The costs associated with capital expenditures are those costs associated with purchase, siting, and startup of working equipment. The costs will be broken down into three areas: total plant cost, total plant investment, and total capital requirement.

Total Plant Cost (TPC)

This cost will include the following:

- Process Plant Cost (PPC)—Plant section subtotal
- Engineering fees—10% of PPC unless turn-key unit
- Process Contingency—Plant-section dependent as discussed previously
- Project Contingency

The PPC consists of the following:

- Direct Costs
- Subcontract Supply / Erection Costs and Lump Sum Turnkey Costs
- Indirect Costs
- Home Office Costs

The components of the PPC are discussed individually in the following paragraphs.

Direct Costs. Direct costs consist of:

- Total Direct Material
    - o Delivered equipment costs
    - o Installation material
- Total Direct Labor
    - o Labor for handling and placing bare equipment
    - o Associated Installation labor

Handling and placing equipment costs consist of costs associated with unloading, uncrating and physically placing the equipment at its final resting place, mechanical connection alignment, storage, inspection, etc. The installation material and labor components consist of the following items: foundations, structures, buildings, piping, instrumentation, insulation, electrical, painting, and miscellaneous.

Subcontract Supply / Erection Costs and Lump Sum Turnkey Costs. Subcontract supply and erection costs include equipment and materials furnished by the local subcontractors such as buildings, field fabricated tanks, field fabricated vessels, cooling towers, coal and limestone storage and handling systems, water treating systems, etc.

These costs also include all installation labor, indirect costs, and overhead and profit of the subcontractors.

Lump sum turnkey package costs cover certain areas of the plant that are assumed to be built on a turnkey basis where a single firm provides all of the engineering, material and construction services required to build a certain area of the plant. An example of a plant section that is supplied on such a basis is the air separation unit.

Indirect Costs. Indirect costs are those costs which do not become a final part of the installation but which are required for the orderly completion of the installation and include indirect field labor, construction support and supplies, cleanup, labor benefits, payroll taxes and insurance, construction camp and equipment and tools.

Home Office Costs. Home office costs include the following areas:

- Engineering, design and procurement work-hours, and labor costs
- Office expenses such as computer costs, reproduction and communication costs, and travel
- Office burdens, benefits, and overhead costs and fee.

As stated previously, these costs will be estimated utilizing the AACE Recommended Practice No. 16R-90 and compared to those developed by ICARUS and PEACE and appropriate adjustments will be made.

Total Plant Investment (TPI)

This cost consists of adding to the TPC an interest and inflation-adjustment factor (dependent on construction interest rate, inflation rate, and construction time frame) multiplied by the TPC.

Total Capital Requirement (TCR)

This cost consists of adding to the TPI the following:

- Prepaid Royalties—0.5% of Direct and Indirect Costs of Process Units
- Initial Catalyst and Chemical Inventory—30 day inventory
- Startup Costs and Other Pre-production Costs
    - One month of fixed operating and maintenance costs
    - Two months of consumable costs excluding fuel cost (calculated at full capacity)
    - One month of fuel inefficiency (25% excess fuel at full capacity).
    - Two percent of TPC
- Spare Parts—0.5% of TPC
- Working Capital
    - Two months of consumable costs excluding fuel cost (calculated at full capacity).
    - Two month supply fuel at full capacity
    - Three months of operating and maintenance labor costs
    - Spare parts inventory at 0.5% of the TPC
    - A contingency of 25% of the total of the above four items

- Land

Operating and Maintenance Costs

The annual operation and maintenance costs are divided into fixed and variable cost components. Description of the basis and computations for these cost components are given in the following. A capacity factor of 85% will be assumed.

Fixed Operating Costs

The fixed operating costs are essentially independent of the plant capacity factor and are composed of the following charges:

- Operating labor
- Maintenance costs
- Overhead charges

These items are discussed below.

<u>Operating Labor</u> – The average number of operating positions per shift is computed. An average labor rate per person-hour is used which includes payroll burdens. A typical operating labor cost calculation (in units of $/yr) is given below:

(OJ) (ALR) (8760 hr/year)

where "OJ" is the average number of operating positions per shift for a given plant and "ALR" is the hourly labor rate including payroll burden. The EPRI TAG value on a $ per hr basis will be utilized.

<u>Fixed Maintenance Costs</u> – Maintenance costs will be estimated as a percentage of the installed unit installed cost of the facilities including contingency (see Table 10).

The system-by-system annual maintenance cost factors are divided into fixed and variable maintenance costs (65% and 35% respectively). The fixed maintenance costs are then divided into labor and materials (40% and 60%, respectively).

<u>Overhead Charges</u> – The only overhead charge to be included in a power plant is a charge for administrative and support labor, which is taken as 30% of the operating and maintenance labor.

Table 10: Maintenance Cost Factors

Plant Section	Annual Cost as a % of Installed Plant Section Cost
Coal Receiving and Conveying, Grinding and Slurry Preparation	3.0
Air Separation	2.0
Claus plant oxygen (ITM)	4.5
Gasification, High Temperature Gas Cooling and Scrubbing	4.5
Shift, Low Temperature Gas Cooling and Cleanup	2.0
Desulfurization and CO_2 Capture	2.0
Sulfur Recovery and Tail Gas Treating	2.0
CO_2 Compression, Dehydration and Pumping	2.0
H_2 Separation (PSA) and Tail Gas compression	2.0
Humidification (Syngas and /or N2)	2.0
Power Generation	3.0
General Facilities	3.0

Variable Operating Costs

The variable operating costs are composed of the following charges:

Fuel Cost – Coal cost consistent with the analysis shown in Table 2 will be utilized. EPRI TAG values on a $ per MMBtu (HHV) will be utilized for the coal and natural gas.

Raw Water – Raw water acquisition cost will be accounted for by utilizing the EPRI TAG value on a $ per gal basis. Treating costs and pumping costs will accounted for in the operating and maintenance charges.

Catalyst and Chemicals and Other Consumables – The catalyst, chemicals, and other consumable costs will estimated based on annualized consumption rates.

Disposal Costs – Disposal of slag from the gasification process and any spent catalyst / sorbents will be accounted for while taking into account the type of disposal requirements. For example, the spent carbon bed used for the capture of Hg will be treated as a hazardous waste. Disposal costs will be accounted for the sludge and granular solids (vitrified form) utilizing the EPRI TAG values on a $ per ST basis depending on the form.

Variable Maintenance Labor and Materials – Costs are 35% of total maintenance cost of the plant. The variable cost is divided into labor and materials (40% and 60%, respectively).

Byproduct Credits—Credit for Salable Materials

Byproduct sales will be fully described and referenced as follows:

- Material description
- Amount per unit time
- Market price per unit amount.

Economic Analysis

Table 11 summarizes the basis for the economic analysis. Since these advanced plants will be high-risk projects, the financial structure in Table 12 will be utilized. The tenth-year levelized dollar cost of electricity will be utilized since it is an accepted practice that balances the offset of capital in early years versus fuel cost in later years. These criteria are consistent with DOE / NETL's "Quality Guidelines for Energy System Studies" except that the tax depreciation method will consist of the Modified Accelerated Cost Recovery System while the DOE / NETL's Quality Guidelines suggest the previous Accelerated Cost Recovery System.

Table 11: Financial Structure for High-Risk Projects

Project Life	20 years
Book Life	20 years
Tax Life	20 years
Federal and State Income Tax Rate	38%
Tax Depreciation Method	Modified Accelerated Cost Recovery System
Investment Tax Credit	0.00%
Construction Interest Rate	Construction period at 11.2%
Financial Structure	Constant dollars
Inflation Rate	3.00%
Real Escalation Rates	
Coal	0.5% over inflation, Energy Information Administration (EIA) 2003
Natural Gas	0.3% over inflation, low growth case, EIA 2003
	0.6% over inflation, high growth case, EIA 2003
O&M	0% over inflation

Table 12: Financial Structure for High-Risk Projects

Type of Security	% of Total	Current Dollar		Constant Dollar	
		Cost %	Return %	Cost %	Return %
Debt	45	9.0	4.1	5.8	2.6
Preferred Stock	10	8.5	0.9	5.3	0.5
Common Stock	45	12.0	5.4	8.7	3.9
Discount Rate (Cost of Capital)			**10.3**		**7.1**

Third Party Validation

The flow diagrams and stream summaries along with the overall performance summaries as described previously will form the basis for a third party validation if the DOE so chooses. The plant cost estimates will be broken down by major process units so that a third party may be able to assess the reasonableness of the cost estimate while the study basis and assumptions will be clearly identified.

Appendix A - Advanced Power Systems Analysis Tool (APSAT)

Existing models for analysis of systems such as power plants may be divided into two types (1) those developed for simulating chemical process plants (e.g. commercially available Hysis, Aspen, Pro II) and (2) those developed for simulating power plants (e.g. commercially available ThermoFlex and GATE/Cycle). Models in the first category have the capability for predicting the performance of typical process equipment and the thermodynamic properties of non-ideal systems but do not include the proper models for power cycle equipment such as gas turbines, steam turbines and fuel cells. The models in the second category have the capability of modeling gas and steam turbines in detail but do not handle rigorously the modeling of process equipment such as gasifiers or partial oxidation units, shift reactors and humidifiers which are playing an important role in IGCC plant designs, nor the properties of non-ideal gases except for pure steam.

Non-ideal gas behavior is quite important in thermodynamic analyses, as there are many processes where such behavior is critical. Two examples of where non-ideal properties for a gas stream need to be accounted for are: (1) predicting the Joule-Thompson cooling of natural gas when its pressure is reduced from typical pipeline pressure to the pressure required by say a heavy frame gas turbine which typically operates at a pressure-ratio in the neighborhood of 15, and (2) the recovery and compression of the carbon dioxide to supercritical pressures (which is typically required for sequestration with greenhouse gas emissions becoming a more global concern). Predicting the saturated vapor content of water vapor in a gas stream at high pressure, which is important in determining the correct heat release curve for syngas cooling, also requires the proper accounting of the non-ideal behavior of the vapor phase.

After years of piecing together the chemical process models with the power plant models, it was obvious that an overall fuel-in to kW-out simulation capability was needed especially in complex multi working fluid/multi power generating component cycles that are becoming more attractive. Beginning in 1997 development began on Advanced Power Systems Analysis Tool (APSAT). This modeling system is based on more than 30 years of process industry and power plant experience with gasification licensors and process/power plant engineering firms. APSAT is a C-based (C++) simulation tool that runs on a PC. Components are described in a series of modules (e.g., see below) and the thermodynamic and flow properties from one module feeds into the following module(s). A series of balances (Q, ω, T, P, H, etc.) are calculated and convergence obtained. Molar properties are tracked for each stream. APSAT has been successfully used in a number of studies for the DOE and other energy industry members. It is an organic modeling capability and additional modules are added as new technology requires.
The following table lists the major modules available in APSAT along with brief descriptions. Note that each of these modules consist of a number of subroutines that calculate the thermodynamic and flow system parameters that are then sent along to the next module.

List of Modules in APSAT

Module Name	Description
Combine	Combines two streams adiabatically to give the mixture temperature at pressure equal to the lower of the two streams being combined
Combust	Calculates effluent composition & conditions for a combustor with specified gloss and pressure drop
CombustT	Calculates effluent composition & conditions & heat release for a combustor with given outlet temperature and pressure drop
Compress	Calculates the power and outlet temperature of a compressor for a given outlet pressure (the isentropic efficiency may either be specified or can be calculated by module)
Controller	Adjusts variable upstream to make desired variable match target value (while simulating a flowsheet with iterations to satisfy a specified design criteria)
COSHyd	Adiabatic COS hydrolysis reactor to calculate effluent composition and conditions
Deaer	Calculates the effluent conditions from & heat required by a boiler feed water deaerator
Decant	Decanter to separate a solid from water for a specified moisture content in separated solid
ExchQ	Calculates outlet temperature for a specified heat duty and pressure drop
ExchT	Calculates heat duty for a specified outlet temperature and pressure drop
Expand	Calculates the power and outlet temperature of a gas expander for a given outlet pressure (the isentropic efficiency may either be specified or can be calculated by module)
GTcalib	Calibrates gas turbine (for use in below Gas Turbine modules)
GasTurb	Gas turbine of geometry same as that specified in GTcalib
GTcombEXP	Combustor/Expander of a gas turbine consistent with GTcalib (used in configuring a new cycle)
GTcomp	Compressor of a gas turbine consistent with GTcalib (used in configuring a new cycle)
GTsplit	Splits for cooling air of gas turbine consistent with that specified in Gtcalib. Cooling air is taken just upstream of combustor specified in GTcombEXP. (used in configuring a new cycle)

HPstmTurb	Calculates the power and outlet temperature of a steam turbine – HP section (the isentropic efficiency may either be specified or as a default, it is calculated using the Spencer-Cotton Correlations)
Humid	Calculates gas & water streams leaving a Humidifier or Dehumidifier (composition of gas as well as flowrate, temperature & pressure) by solving simultaneous heat and mass transfer equations using nodal analysis.
IPstmTurb	Calculates the power and outlet temperature of a steam turbine – IP section (the isentropic efficiency may either be specified or as a default, it is calculated using the Spencer-Cotton Correlations)
LPstmTurb	Calculates the power and outlet temperature of a steam turbine – condensing section (the isentropic efficiency may either be specified or as a default, it is calculated using the Spencer-Cotton Correlations)
Membrane	Calculates the outlet streams while taking into account the partial pressure gradients
Pipe	Calculates outlet conditions for specified pressure and temperature drops
Pox	Calculates adiabatic POX effluent composition and conditions
PoxH2	Calculates adiabatic H2 POX effluent composition and conditions
PoxH2Temp	Calculates H2 POX effluent composition and conditions & qloss for a given outlet temperature
PoxTemp	Calculates POX effluent composition and conditions & heat loss for a given outlet temperature
Pump	Calculates power required and outlet temperature for a pump for a given discharge pressure and isentropic efficiency
Recycler	Iterates till two streams match or their temperatures maintain a specified delta T
Reform	Calculates reformer effluent composition and conditions and absorbed duty
Results	Shows results with stream composition, temperature and pressure, elemental flow rates (for quick check of the elemental balance), energy and exergy contents (for cycle analysis), physical properties (for equipment specs), overall plant thermal efficiency.
SatStmHP	Calculates energy (enthalpy above 60 deg F) of saturated steam/BFW mixture for given pressure
SatStmHT	Calculates energy (enthalpy above 60 deg F) of saturated steam/BFW mixture for given temperature
Separate	Separates water condensate & liquid/solid from a stream

SepComp	Removes a specific vapor component (by %) from a stream
Shift	Adiabatic shift reactor to calculate effluent composition and conditions
ShiftTemp	Non-adiabatic shift reactor to calculate effluent composition and conditions & duty in shift reaction for a specified outlet temperature
SOFC	Performance (depleted fuel and oxidant composition and conditions and power) and sizing of Solid Oxide Fuel Cell
SplitFlo	Splits a stream into two streams for a given kg/s (or lb/s)
SplitPer	Splits a stream into two streams for a given % Split
SteamGenM	Steam generator (calculates steam produced, blowdown, heat duty for a specified steam pressure and BFW flowrate)
SteamGenQ	Steam generator (calculates steam generated, blowdown, BFW required for a specified heat duty and pressure)
SteamCon	Steam consumer (calculates steam required, condensate produced for specified heat duty and pressure)
Substitute	Substitutes or duplicates a stream
Valve	Calculates outlet conditions including any phase change for a specified pressure drop

Appendix B – THERMOFLEX AND PEACE

Included in the Thermoflow suite of products are:

- THERMOFLEX program
- PEACE program.

THERMOFLEX is a modular program with a graphical interface that allows one to assemble a model from icons representing over a hundred different components. The program covers both design and off-design simulation, and models various types of power plants, including gas turbines, combined cycles, conventional steam cycles, and repowering. An advanced gas turbine such as the closed loop steam cooled H technology machine may be "assembled" in THERMOFLEX by combining a compressor module, a combustor module and cooled turbine modules. The engine assembled for natural gas may then be operated in off-design mode on syngas.

PEACE (Plant Engineering and Construction Estimator) module generates equipment designs and cost and labor estimates along with each heat balance produced by THERMOFLEX. The assumptions used to create the physical design and dimensions of components, such as boilers and condensers, may be defined by the user, or left to the program's own automated logic. This provides the flexibility for knowledgeable users to mimic actual designs created by specific vendors, while providing the convenience of automated equipment design logic for the casual user. PEACE also includes detailed pipe sizing procedures for all main steam and water pipes, as well as convenient pump sizing and specification routines.

The cost estimates generated by PEACE are "bottom-up", adding the costs of the various components. The cost and field-labor hours of each component are derived from models that take into account the component's features, materials, rating, size and weight. These models have been extensively calibrated by actual equipment data. This approach is in contrast to "top-down" cost estimating procedures, which start with the cost of the system and break-it down according to rules of thumb.