

**Economic Analysis
For
Conceptual Design of Oxygen-Based PC Boiler**

Topical Report

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Task 5

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ABSTRACT

The objective of the economic analysis is to prepare a budgetary estimate of capital and operating costs of the O₂-fired PC power plant as well as for the equivalent conventional PC-fired power plant. Capital and operating costs of conventional steam generation, steam heating, and power generation equipment are estimated based on Foster Wheeler's extensive experience and database. Capital and operating costs of equipment, such as oxygen separation and CO₂ liquefaction, are based on vendor supplied data and FW process plant experience. The levelized cost of electricity is determined for both the air-fired and O₂-fired power plants as well as the CO₂ mitigation cost. An economic comparison between the O₂-fired PC and other alternate technologies is presented.

Table of Contents

ABSTRACT.....	3
1.0 Introduction	6
2.0 Executive Summary	7
3.0 Experimental	8
4.0 Results and Discussion	9
4.1 Main Assumptions	9
4.2 Plant Cost Basis	9
4.3 Total Plant Investment (TPI)	13
4.4 Total Capital Requirement (TCR)	13
4.5 Operating Costs And Expenses.....	14
4.6 Cost Of Electricity (COE)	15
4.7 Comparison with Other Technologies.....	16
5.0 Conclusion	25
6.0 References.....	26
7.0 List of Acronyms and Abbreviations	27

List of Tables

Table 1 – Coal Properties	11
Table 2 – Oxygen-Fired PC Plant Capital Cost Estimate.....	12
Table 3 - Operating, Maintenance and Fuel Costs for the O ₂ PC and the Air-fired Reference	18
Table 4 - Estimate Basis/Financial Criteria for Revenue Requirement Calculations: Air-fired Reference Plant	19
Table 5 - Estimate Basis/Financial Criteria for Revenue Requirement Calculations: O ₂ -fired Reference Plant	20
Table 6 - Capital Investment and Revenue Requirement Summary: Air-fired Reference Plant	21
Table 7 - Capital Investment and Revenue Requirement Summary: O ₂ -fired Plant	22

List of Figures

Figure 1 - Comparison of Levelized Cost of Electricity Among Alternative Technologies (O ₂ PC with 65% CF).....	23
Figure 2 - Comparison of Mitigation Costs Among Alternative Technologies (O ₂ PC with 65% CF)	23
Figure 3 - Comparison of Levelized Cost of Electricity Among Alternative Technologies (O ₂ PC with 85% CF).....	24
Figure 4 - Comparison of Mitigation Costs Among Alternative Technologies (O ₂ PC with 85% CF)	24

1.0 Introduction

This report describes the results and conclusions of Task 5, economic analysis of the Conceptual Design of Oxygen-Based PC Boiler study. The objective of the Conceptual Design of Oxygen-Based PC Boiler study is to develop a conceptual pulverized coal (PC)-fired power plant, which facilitates the practical capture of carbon dioxide capture for subsequent sequestration. The economic analysis is based on the results of the system analysis and design task (Task 2) and the furnace design and analysis task (Task 4). The basis of the economic analysis is conventional air-fired power plant that Foster Wheeler is currently designing and constructing.

2.0 Executive Summary

The objective of the Conceptual Design of Oxygen-Based PC Boiler study is to develop a conceptual pulverized coal-fired power plant, which facilitates the practical capture of carbon dioxide capture for subsequent sequestration. The objective of the economic analysis is to prepare a budgetary estimate of capital and operating costs of the O₂-fired PC power plant as well as for the equivalent conventional PC-fired power plant.

The reference plant applied is a subcritical pressure, natural circulation boiler firing high-volatile bituminous coal generating 450 MWe. A conventional air-fired case was simulated as the comparison basis.

The economic analysis was carried out based on the EPRI Technical Assessment Guide (TAG) methodology. Plant capital costs were compiled under the Code of Accounts developed by EPRI. The estimate basis is 2004 dollars, 20-year life, and 85% capacity factor.

The major changes to the reference plant were redesigned boiler, SCR system removal, FGD removal, ASU addition, and CO₂ compression addition. The estimated cost of the reference plant is \$585,000,000 (1300 \$/kW) and of the O₂-fired plant is \$668,673,700 (2106 \$/kW).

The levelized cost of electricity (COE) was calculated for both the reference plant and the O₂-fired plant. The COE value is made up of contributions from the capital cost, operating and maintenance costs, consumables, and fuel costs. The levelized COE was calculated to be 4.61 ¢/kWh for the reference plant and to be 6.41¢/kWh for the O₂ PC plant. The CO₂ mitigation cost (MC) of the O₂-PC plant was calculated at 21.4 \$/tonne.

Compared to the COE of the O₂ PC, the COE for the other technologies is 45% higher for Air PC, 40% higher for NGCC, and 6% higher for IGCC. Compared to the MC of the O₂ PC, the MC for the other technologies is 250% higher for NGCC, 160% higher for Air PC, and 17% higher for IGCC.

3.0 Experimental

This work performed for this report was performed utilizing computer program simulations. No experimental equipment was used.

4.0 Results and Discussion

4.1 Main Assumptions

The economic analysis was carried out based on the EPRI Technical Assessment Guide (TAG) methodology. Plant capital costs were compiled under the Code of Accounts developed by EPRI and used in references [1] and [2].

The estimate basis and major assumptions are listed below:

- Total plant costs are estimated in January 2004 dollars.
- Plant book life is 20 years.
- The net power output for the reference PC plant (without CO₂ sequestration) is 450 MWe and for the O₂ PC plant (with sequestration) is 327 MWe.
- Capacity factor is 85%. The plant will operate at 100% load at 85% of the time.
- Cost of electricity (COE) was determined on a levelized constant dollar basis.
- Average annual ambient air conditions for material balances, thermal efficiencies and other performance related parameters are at a dry bulb temperature of 60 deg. F and an air pressure of 14.7 psia.
- The coal is Illinois #6 coal (see Table 1 for analysis).
- Terms used are consistent with the EPRI TAG.

4.2 Plant Cost Basis

The total plant cost (TPC), also referred to as the plant capital cost is comprised of the following elements:

1. Bare erected plant cost.
2. Overheads and fee for engineering and home office.
3. Project and process contingencies.

The O₂-fired PC plant capital costs were derived in comparison to a recently constructed Foster Wheeler reference plant, which is an existing subcritical pressure, natural circulation PC plant.

The major changes to the reference plant were:

- Redesigned boiler (boiler size, and heat transfer surface) (see Ref. 3)
- Air pre-heater removed
- Added new flue gas-to-recycle gas heat exchanger
- Reduced size of FD and ID boiler fans
- Reduced weight of primary and secondary oxidant ductwork
- Removed plant selective catalytic NO_x reduction (SCR) system
- Removed plant flue gas desulfurization (FGD) system
- Replaced full size plant stack with start-up stack
- Added air separation unit
- Added CO₂ compression and dehydration unit

For the modified components, the plant capital costs were calculated as cost differentials by the Foster Wheeler estimating department. These cost differentials were then added to the base cost of the reference plant.

For the new components costs were either obtained from vendor quotes and/or determined by the Foster Wheeler estimating department as follows:

- The ASU cost was obtained from Air Products and Chemicals Inc.
- The CO₂ compression and de-hydration system costs were developed using internal data from a Foster Wheeler commercial project. This price was compared to a recent estimate by Nexant Inc. (Ref. 4) for confirmation.
- The flue gas-to-recycle gas heat exchanger cost was estimated by Foster Wheeler based on internal cost data for similar units.

Allowance for engineering and home office overheads and fee of 6% of the bare erected cost was added for the new components. The “bare erected cost” is the installed cost of the equipment and systems that make up the plant.

For the new plant items, project contingencies were added to account for the uncertainty based on the level of detail currently available (or lacking) in the design. Consistent with EPRI Technical Assessment Guide (TAG), a 15% (of bare erected cost) project contingency was used for the CO₂ compression and de-hydration system, and a 5% project contingency was used for the ASU. No process contingencies were applied, since the components of the new systems (e.g. compressors, knock-out pots, etc.) are well-developed technologies.

Table 2 shows the capital cost worksheet for the O₂ fired PC plant. As the table shows, a total plant cost of \$668,673,700.00, or 2106 \$/kW was calculated.

Table 1 – Coal Properties

Illinois No. 6 Coal		
C	%	63.75%
H	%	4.50%
O	%	6.88%
N	%	1.25%
Cl	%	0.29%
S	%	2.51%
Ash	%	9.70%
H ₂ O	%	11.12%
Total	%	100.00%
LHV	Btu/lb	11,283
HHV	Btu/lb	11,631

Table 2 – Oxygen-Fired PC Plant Capital Cost Estimate

Base Plant: Air-Fired subcritical pressure, natural circulation PC

Base Plant Output: 450 MWe, net

Base Plant "As bid" cost: \$ 585,000,000.00 Includes contingencies and EPC costs

Cost differences in converting air-fired PC to the oxygen-fired PC configuration:

Item	Description of change	Bare erected cost	Eng'g CM HO & Fee	Contingencies		Total Plant Cost
				Process	Project	
Boiler	Furnace panels change from carbon steel to alloy steel	\$ 600,000.00	Incl. As bid	\$ -	\$ -	\$ 600,000.00
	Less HRA surface needed	\$ (306,000.00)	Incl. As bid	\$ -	\$ -	\$ (306,000.00)
	Smaller economizer	\$ (600,000.00)	Incl. As bid	\$ -	\$ -	\$ (600,000.00)
	Air pre-heater not required	\$ (4,600,000.00)	Incl. As bid	\$ -	\$ -	\$ (4,600,000.00)
	New Flue-gas/recycle gas heat exchanger	\$ 6,000,000.00	Incl. As bid	\$ -	\$ -	\$ 6,000,000.00
	Less oxidant and gas ductwork	\$ (1,000,000.00)	Incl. As bid	\$ -	\$ -	\$ (1,000,000.00)
	SCR system not required	\$ (6,400,000.00)	Incl. As bid	\$ -	\$ -	\$ (6,400,000.00)
	Smaller FD and ID boiler fans	\$ (2,200,000.00)	Incl. As bid	\$ -	\$ -	\$ (2,200,000.00)
	Less boiler structural steel (smaller boiler)	\$ (2,000,000.00)	Incl. As bid	\$ -	\$ -	\$ (2,000,000.00)
BOP	FGD sytem not required	\$ (56,000,000.00)	Incl. As bid	\$ -	\$ -	\$ (56,000,000.00)
	Full size stack replaced by small, start-up stack	\$ (6,000,000.00)	Incl. As bid	\$ -	\$ -	\$ (6,000,000.00)
ASU	Air separation unit added	\$ 116,970,000.00	\$ 7,018,200.00	\$ -	\$ 5,848,500.00	\$ 129,836,700.00
CO2 System	CO2 compression and dehydration unit added	\$ 38,300,000.00	\$ 2,298,000.00	\$ -	\$ 5,745,000.00	\$ 46,343,000.00
Total difference:		\$ 82,764,000.00	\$ 9,316,200.00	\$ -	\$ 11,593,500.00	\$ 103,673,700.00

O2 PC Plant Cost: \$ 688,673,700.00 2,106 \$/kW

O2 PC Plant net output: 327 MW

4.3 Total Plant Investment (TPI)

To determine the total investment required at the date of start-up, the TPC is escalated by the average interest rate over the construction period. Unlike the TPC, which assumes instantaneous construction, TPI ensures that escalation of construction costs and allowance for funds used during construction is properly taken into account. The construction period was estimated to be 4 years. Assuming uniform cash flow over the construction period, the TPI was calculated as follows:

$$TPI = TPC [1+i_{avg}]$$

Where

$$\begin{aligned} i_{avg} &= \text{Average interest rate over construction period} \\ &= (\text{Interest rate})(\text{Construction Period in Years})/2 = 10\% \end{aligned}$$

The annual interest rate was taken as 5%.

4.4 Total Capital Requirement (TCR)

The TCR includes all capital required to complete the project. TCR is the sum of TPI, pre-paid royalties, pre-production (start-up) costs, inventory capital, and land cost:

- Royalties costs are assumed inapplicable to the CO₂ hybrid plant
- Pre-production costs cover operator training, equipment checkout, major changes in plant equipment, extra maintenance, and inefficient use of fuel and other materials during start-up. They are estimated as follows:
 - 1 month of fixed operating costs, operating and maintenance labor, administrative and support labor, and maintenance materials.
 - 1 month of variable operating costs at full capacity (excluding fuel) – includes chemicals, water, and other consumables and waste disposal charges.
 - 25% of full capacity fuel cost for 1 month – covers inefficient operation that occurs during the start-up period.
 - 2% of TPI – covers expected changes and modifications to equipment that will be needed to bring the plant up to full capacity.
- Inventory capital is the capital required for initial inventories of fuel and other consumables, which are capitalized and included in the inventory capital account. Fuel and other consumables inventory (except water) are based on full-capacity operation for 15 days. An allowance of ½ percent of the TPC equipment cost is included for spare parts.

- Initial catalyst and chemical charge covers the initial cost of any catalysts or chemicals that are contained in the process equipment, but not in storage. In this study, this small charge was included with the equipment capital costs and is a part of the TPC.
- Land cost is based on 60 acres at \$10,000/acre.

The TPI and the TCR cost components are shown on Table 6 and Table 7.

4.5 Operating Costs And Expenses

Operating costs were expressed in terms of the following categories:

- Operating Labor
- Maintenance Cost
 - Maintenance labor
 - Maintenance materials
- Administrative and Support Labor
- Consumables
- Fuel Cost

These values were calculated in consistence with EPRI TAG methodology. All costs were based on a first year basis with January 2004 dollars. The first year costs do not include start-up expenses, which are included in the TCR.

The cost categories listed above are calculated, on a dollars per year basis, as follows:

- Operating labor is calculated by multiplying the number of operating personnel with the average annual (burdened) compensation per person.
- Maintenance costs are estimated to be 2% of the TPC and are divided into maintenance labor and maintenance materials
 - Maintenance labor is estimated to be 40% of the total maintenance cost
 - Maintenance materials are estimated to be 60% of the total maintenance cost
- Administrative and support labor is estimated to be equal to 25% of the sum of operating and maintenance labor.
- Consumables are feedstock and disposal costs calculated from the annual usage at 100% load and 85% capacity factor. The costs is expressed in year 2004 dollars and levelized over 20 years on constant dollar basis.

- Fuel cost is calculated based on the assumed net cost for delivered coal, which is \$1.14/MMBtu [5]. Fuel cost is determined on a first year basis and levelized over 20 years on a constant dollar basis. The calculation of first year fuel costs is done as follows:

$$\text{Fuel (tons/day)} = \frac{(\text{Plant Heat Rate}) \times (\text{net capacity in kW}) \times 24 \text{ hr/day}}{\text{HHV} \times 2000 \text{ lb/ton}}$$

$$\text{Fuel Unit Cost (\$/ton)} = \text{HHV} \times 2000 \text{ lb/ton} \times (\text{Fuel Cost in \$/MMBtu}) \times 10^6$$

$$\text{Fuel Cost (1}^{\text{st}} \text{ year)} = \text{Fuel (tons/day)} \times \text{Fuel Unit Cost (\$/ton)} \times 365 \text{ day/yr} \times 0.85 \text{ (CF)}$$

The operating and maintenance costs, excluding fuel and consumables, are combined and divided into two components: 1) Fixed O&M, which is independent of power generation, and 2) Variable O&M, which is proportional to power generation. These are calculated as follows:

$$\text{Fixed O\&M (\$/yr)} = \text{Oper. Labor} + \text{Maint. Labor} + \text{Adm. and Support Labor}$$

$$\text{Fixed O\&M (\$/kW-yr)} = \frac{\text{Fixed O\&M (\$/year)}}{\text{Net Power (kW)}}$$

$$\text{Variable O\&M (\$/yr)} = \text{Maintenance Materials}$$

$$\text{Variable O\&M (¢/kWh)} = \frac{\text{Variable O\&M (\$/yr)}}{\text{Net Power (kW)} \times \text{CF} \times 8760}$$

Where, CF is the plant capacity factor and 8760 is the total number of hours in one year.

The operating and maintenance costs for the O₂-fired PC and the air-fired reference plant are shown on Table 3. The “total production cost” shown at the bottom of the table expresses the charge of operating and maintaining the baseline plant (including fuel and consumable costs) in terms of cents per kilowatt-hour.

4.6 Cost Of Electricity (COE)

The COE value is made up of contributions from the capital cost (called the carrying charge), operating and maintenance costs, consumables, and fuel costs. The following relationship is used to calculate COE from these cost components:

$$\text{COE} = \text{LCC} + \text{LFOM} \times 100 / (8760 \times \text{CF}) + \text{LVOM} + \text{LCM} + \text{LFC}$$

LCC = Levelized carrying charge, ¢/kWh

LFOM = Levelized fixed O&M, \$/kW-yr
 LVOM = Levelized variable O&M, ¢/kWh
 LCM = Levelized consumables, ¢/kWh
 LFC = Levelized fuel costs, ¢/kWh
 CF = plant capacity factor (0.85)

The basis for calculating the capital investment and revenue requirements for the reference plant and the O₂ PC are given in Table 4 and Table 5, respectively. The capital investment and revenue requirements summary is given in Table 6 for the reference plant without CO₂ sequestration and in Table 7 for the O₂ PC.

As Table 6 and Table 7 show, the levelized COE for 85% capacity factor was calculated at 4.61 ¢/kWh without CO₂ sequestration and at 6.41¢/kWh with CO₂ sequestration.

4.7 Comparison with Other Technologies

An economic comparison was performed between the O₂ PC and other competing CO₂ removal technologies. For comparison the following alternate technologies were chosen:

Air PC: Supercritical PC plant with post-combustion CO₂ mitigation (Ref [1] case 7A).
 NGCC: Natural Gas Combined Cycle with post combustion (Ref [1] case 1A).
 IGCC: Integrated Gasification Combined Cycle with pre-combustion CO₂ mitigation (Ref. [2] case 3E).

The economics of these technologies were compared with the O₂ PC using both the levelized cost of electricity and the CO₂ mitigation cost as indexes. The CO₂ mitigation cost (MC) shows the cost impact, in dollars per tonne of CO₂ that would otherwise be emitted, of a configuration that allows CO₂ capture relative to the reference plant.

The MC is calculated as follows:

$$MC = \frac{COE_{\text{with removal}} - COE_{\text{reference}}}{E_{\text{reference}} - E_{\text{with removal}}} \times 0.01 \text{ \$/}\text{¢}$$

COE = Cost of electricity in ¢/kWh
 E = CO₂ emission in tonnes/kWh

The COE and MC for the Air PC, NGCC, and IGCC were obtained from Ref. 1 and Ref. 2. Since the economic analysis of Ref. 1 and Ref. 2 were made in 2000

two adjustments were necessary so that the values can be compared to the results of the current O₂ PC economic analysis:

1. A constant inflation rate of 2% was assumed between 2000 and 2004.
2. The 2000 natural gas fuel price was replaced with the 2004 natural gas fuel price (fuel price increase is 118%).

Since the analyses of Ref. 1 and Ref. 2 were assumed at a 65% capacity factor, Figure 1 and Figure 2 present a comparison of the COE and MC using a 65% capacity factor for the O₂ PC. Compared to the COE of the O₂ PC, the COE for the other technologies is 17% higher for Air PC, 15% higher for NGCC, and 14% lower for IGCC. Compared to the MC of the O₂ PC, the MC for the other technologies is 170% higher for NGCC, 100% higher for Air PC, and 9% lower for IGCC.

Since the O₂ PC uses reliable long-proven technology it is expected that the capacity factor of the O₂ PC will be close to 85%. Consequently Figure 3 and Figure 4 present a comparison of the COE and MC using an 85% capacity factor for the O₂ PC. Compared to the COE of the O₂ PC, the COE for the other technologies is 45% higher for Air PC, 40% higher for NGCC, and 6% higher for IGCC. Compared to the MC of the O₂ PC, the MC for the other technologies is 250% higher for NGCC, 160% higher for Air PC, and 17% higher for IGCC.

Note that the air-fired post combustion capture PC plant data used in Figure 1 to Figure 4 is for a supercritical unit whereas the O₂ PC plant operates at subcritical pressure. It is expected that the economic cost (COE and MC) of a supercritical O₂ PC will be lower than a subcritical O₂ PC.

Table 3 - Operating, Maintenance and Fuel Costs for the O₂ PC and the Air-fired Reference

1) With CO₂ Sequestration (O₂ PC)

Plant Net Power = 326 MW
Capacity Factor 85%

Operating and Maintenance Costs

		Unit Cost	\$/year	\$/KW-yr
Operating labor	60 people	\$90,000.00	\$5,400,000.00	\$16.56
Maintenance Cost	2% of TPC			
Maintenance Labor (40%)			\$5,509,389.60	\$16.90
Maintenance Materials (60%)			\$8,264,084.40	\$25.35
Administrative Support and Labor	25 % of O&M Labor		\$2,727,347.40	\$8.37

Consumable Operating Costs (Except Fuel)

		Unit Cost	\$/year	c/KWh
Water	8080 kgals/day	\$0.80	\$2,005,411	0.070
Water Chemicals	19553 lbs/day	\$0.16	\$970,619	0.034
Limestone				
Start-up Fuel	5 starts/year		\$50,000.00	0.002
Startup Electricity	6300 MWh/yr	\$30	\$189,000.00	0.007
Ash disposal	18.26 ton/hr	\$10	\$1,359,639.60	0.048
Other Chemicals			\$330,000.00	0.012
				0.160

<u>Fuel Cost (2004 Dollars)</u>	Heat Rate =	11,411 Btu/kWh		
		Unit Cost	\$/year	c/KWh
	3720.11 MMBtus/hr	\$1.14	\$31,577,905	1.301

Total Production Cost 2.36 c/kWh

2) Without CO₂ Sequestration (Air-fired reference)

Plant Net Power = 417 MW
Capacity Factor 85%

Operating and Maintenance Costs

		Unit Cost	\$/year	\$/KW-yr
Operating labor	56 people	\$90,000.00	\$5,040,000.00	\$15.46
Maintenance Cost	2% of TPC			
Maintenance Labor (40%)			\$4,680,000.00	\$14.36
Maintenance Materials (60%)			\$7,020,000.00	\$21.53
Administrative Support and Labor	25 % of O&M Labor		\$2,430,000.00	\$7.45

Consumable Operating Costs (Except Fuel)

		Unit Cost	\$/year	c/KWh
Water	7906 kgals/day	\$0.80	\$1,962,269	0.054
Water Chemicals	19133 lbs/day	\$0.16	\$949,738	0.026
Limestone	432 tons/day	\$15	\$2,010,420	0.055
Start-up Fuel	5 starts/year		\$50,000.00	0.001
Startup Electricity	6300 MWh/yr	\$30	\$189,000.00	0.005
Ash disposal	52.43 ton/hr	\$10	\$3,903,937.80	0.107
				0.248

<u>Fuel Cost (2004 Dollars)</u>	Heat Rate =	9,302 Btu/kWh		
		Unit Cost	\$/year	c/KWh
	3878.96 MMBtus/hr	\$1.14	\$32,926,353	1.060

Total Production Cost 2.10 c/kWh

**Table 4 - Estimate Basis/Financial Criteria for Revenue Requirement
Calculations: Air-fired Reference Plant**

GENERAL DATA/CHARACTERISTICS

Plant Type:	Air-fired Subcritical PC		
Plant Size:	450 MW, net		
Location:	Sea Level, Middletown USA		
Fuel: Primary/Secondary	Illinois #6	--	
Energy from Primary/Secondary Fuels:	9,302 Btu/kWh	--	Btu/kWh
Levelized Capacity Factor / Preproduction (equivalent months):	85%		1 months
Capital Cost Year Dollars (Reference Year Dollars):	2004 (January)		
Delivered Cost of Primary/Secondary Fuel:	1.14 \$/MBtu	--	\$/MBtu
Design/ Construction Period:	4 years		
Plant Start-up Date (1st year Dollars):	2008 (January)		
Land Area/Unit Cost:	60 acres		\$10,000 / Acre

FINANCIAL CRITERIA

Project Book Life:	20 years		
Book Salvage Value:	-	%	
Project Tax Life:	20 years		
Tax Depreciation Method:	Accel. Based on ACRS Class		
Inflation Rate	2.0 %		
Property Tax Rate:	1.0 %		
Insurance Tax Rate:	1.0 %		
Federal Income Tax Rate:	34.0 %		
State Income Tax Rate:	4.2 %		
Investment Tax Credit/% Eligible	-	%	-
Economic Basis:	Over Book	Constant Dollars	
Capital Structure	<u>% of Total</u>	<u>Cost(%)</u>	
Common Equity	40	12	
Preferred Stock	0	8.5	
Debt	60	7	
Weighted Cost of Capital: (after tax)		7.456%	

**Table 5 - Estimate Basis/Financial Criteria for Revenue Requirement
Calculations: O₂-fired Reference Plant**

GENERAL DATA/CHARACTERISTICS

Plant Type:	Oxygen Fired Subcritical PC
Plant Size:	327 MW, net
Location:	Sea Level, Middletown USA
Fuel: Primary/Secondary	Illinois #6 --
Energy from Primary/Secondary Fuels:	11,411 Btu/kWh -- Btu/kWh
Levelized Capacity Factor / Preproduction (equivalent months):	85% 1 months
Capital Cost Year Dollars (Reference Year Dollars):	2004 (January)
Delivered Cost of Primary/Secondary Fuel:	1.14 \$/MBtu -- \$/MBtu
Design/ Construction Period:	4 years
Plant Start-up Date (1st year Dollars):	2008 (January)
Land Area/Unit Cost:	60 acres \$10,000 / Acre

FINANCIAL CRITERIA

Project Book Life:	20 years
Book Salvage Value:	- %
Project Tax Life:	20 years
Tax Depreciation Method:	Accel. Based on ACRS Class
Inflation Rate:	2.0 %
Property Tax Rate:	1.0 %
Insurance Tax Rate:	1.0 %
Federal Income Tax Rate:	34.0 %
State Income Tax Rate:	4.2 %
Investment Tax Credit/% Eligible	- % - %
Economic Basis:	Over Book Constant Dollars
Capital Structure	<u>% of Total</u> <u>Cost(%)</u>
Common Equity	40 12
Preferred Stock	0 8.5
Debt	60 7
Weighted Cost of Capital: (after tax)	7.456%

Table 6 - Capital Investment and Revenue Requirement Summary: Air-fired Reference Plant

Case:	Subcritical PC Plant		
Plant size:	417 MW net	Net Cycle Efficiency:	36.68%
Primary/Secondary Fuel (type):	Illinois #6	Net Plant Heat Rate (NPHR):	9,302 (Btu/kWh)
Design/Construction:	4 (years)	Cost:	1.14 (\$/MMBtu)
TPC (Plant Cost) Year:	2004 (July)	Book Life:	20 (years)
Capacity Factor:	85% (%)	TPI Year:	2004 (July)
		CO2 Removed:	(tons/year)

CAPITAL INVESTMENT	\$x1000	\$/kW
Process Capital and Facilities	585,000	1,402.9
Engineering Adder (Incl. C.M., H.O., and Fee)	-	-
Process Contingency Adder	-	-
Project Contingency Adder	-	-
TOTAL PLANT COST (TPC)	\$ 585,000	1,402.9
TOTAL CASH EXPENDED	\$ 585,000	
AFDC	\$ 58,500	
TOTAL PLANT INVESTMENT (TPI)	\$ 643,500	

Royalty Allowance	
Preproduction Cost	\$16,012
Inventory Capital	\$3,544
Initial Chemicals and Catalysts (w/equip)	
Land Cost	\$600

TOTAL CAPITAL REQUIREMENT (TCR) \$ 663,656

OPERATING & MAINTENANCE COSTS (1999 DOLLARS)	\$x1000	\$/kW-yr
Operating Labor	5,040	12.1
Maintenance Labor	4,680	11.2
Maintenance Materials	7,020	16.8
Administrative Support and Labor	2,430	5.8

TOTAL OPERATION & MAINTENANCE \$ 19,170 46.0

FIXED O & M 29.14 \$/kW-yr

VARIABLE O & M 0.23 c/kWh

CONSUMABLE OPERATING COSTS less Fuel (1999 DOLLARS)	\$x1000	c/kWh
Water	1962	0.05
Chemicals	2960	0.08
Other Consumables	239	0.01
Waste Disposal	3904	0.11
TOTAL CONSUMABLE OPERATING COST	\$ 9,065	0.25

FUEL COST (1999 Dollars) \$ 32,926 1.06

Levelized (Over Book Life \$)

PRODUCTION COST SUMMARY	c/kWh
Fixed O&M	0.39
Variable O&M	0.23
Consumables	0.25
By-product Credit	0
Fuel	1.06
TOTAL PRODUCTION COST	1.93

LEVELIZED CARRYING CHARGES (Capital) 2.68

LEVELIZED (Over Book Life) BUSBAR COST OF POWER 4.61

Table 7 - Capital Investment and Revenue Requirement Summary: O₂-fired Plant

Case:	Oxygen Fired Subcritical PC Plant		
Plant size:	326 MW net	Net Cycle Efficiency:	29.90%
Primary/Secondary Fuel (type):	Illinois #6	Net Plant Heat Rate (NPHR):	11,411 (Btu/kWh)
Design/Construction:	4 (years)	Cost:	1.14 (\$/MMBtu)
TPC (Plant Cost) Year:	2004 (July)	Book Life:	20 (years)
Capacity Factor:	85% (%)	TPI Year:	2004 (July)
		CO2 Removed:	3,652,640 (tons/year)

<u>CAPITAL INVESTMENT</u>	<u>\$x1000</u>	<u>\$/kW</u>
Process Capital and Facilities	667,764	2,048.4
Engineering Adder (Incl. C.M., H.O., and Fee)	9,316	28.6
Process Contingency Adder	-	-
Project Contingency Adder	11,594	35.6
 TOTAL PLANT COST (TPC)	\$ 688,674	2,112.5
TOTAL CASH EXPENDED	\$ 688,674	
AFDC	\$ 68,867	
TOTAL PLANT INVESTMENT (TPI)	\$ 757,541	
 Royalty Allowance		
Preproduction Cost	\$18,268	
Inventory Capital	\$3,718	
Initial Chemicals and Catalysts (w/equip)		
Land Cost	\$600	
 TOTAL CAPITAL REQUIREMENT (TCR)	\$ 780,128	

<u>OPERATING & MAINTENANCE COSTS (1999 DOLLARS)</u>	<u>\$x1000</u>	<u>\$/kW-yr</u>
Operating Labor	5,400	16.6
Maintenance Labor	5,509	16.9
Maintenance Materials	8,264	25.3
Administrative Support and Labor	2,727	8.4
 TOTAL OPERATION & MAINTENANCE	\$ 21,901	67.2
 FIXED O & M		41.83 \$/kW-yr
 VARIABLE O & M		0.34 c/kWh

<u>CONSUMABLE OPERATING COSTS less Fuel (1999 DOLLARS)</u>	<u>\$x1000</u>	<u>c/kWh</u>
Water	2005	0.07
Chemicals	1301	0.05
Other Consumables	239	0.01
Waste Disposal	1360	0.05
 TOTAL CONSUMABLE OPERATING COST	\$ 4,905	0.17

<u>FUEL COST (1999 Dollars)</u>	\$ 31,578	1.30
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<u>PRODUCTION COST SUMMARY</u>	<u>Levelized (Over Book Life \$)</u>	<u>\$/tonne CO2 avoided</u>	<u>c/kWh</u>
Fixed O&M	2.03		0.56
Variable O&M	1.36		0.34
Consumables	(0.91)		0.17
By-product Credit	-		-
Fuel	2.86		1.30
TOTAL PRODUCTION COST	5.34		2.37

<u>LEVELIZED CARRYING CHARGES (Capital)</u>	16.08	4.03
<u>LEVELIZED (Over Book Life) BUSBAR COST OF POWER</u>	21.42	6.41

Figure 1 - Comparison of Levelized Cost of Electricity Among Alternative Technologies (O₂ PC with 65% CF)

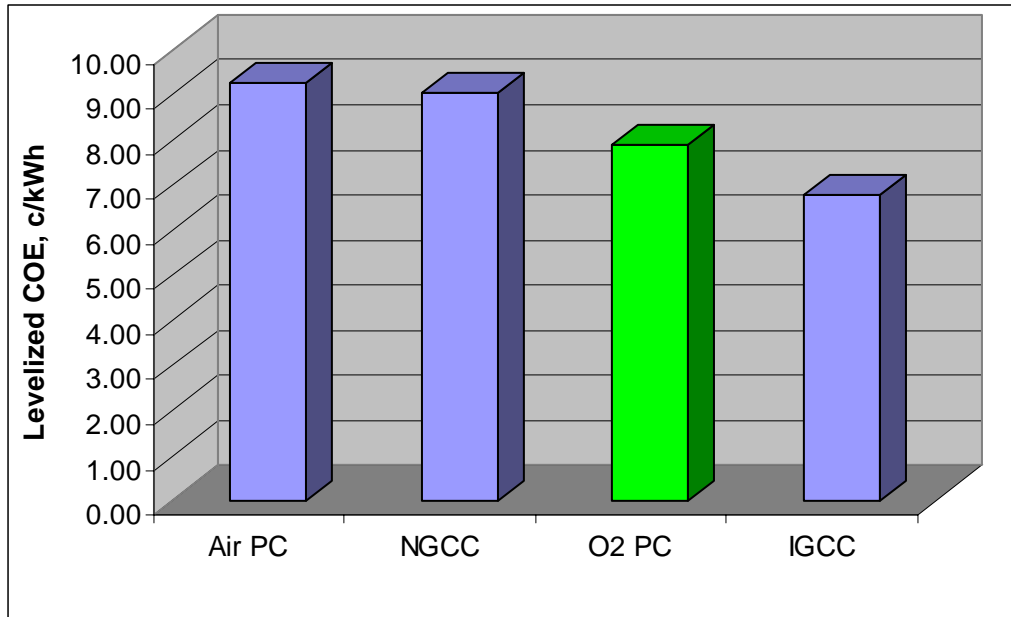


Figure 2 - Comparison of Mitigation Costs Among Alternative Technologies (O₂ PC with 65% CF)

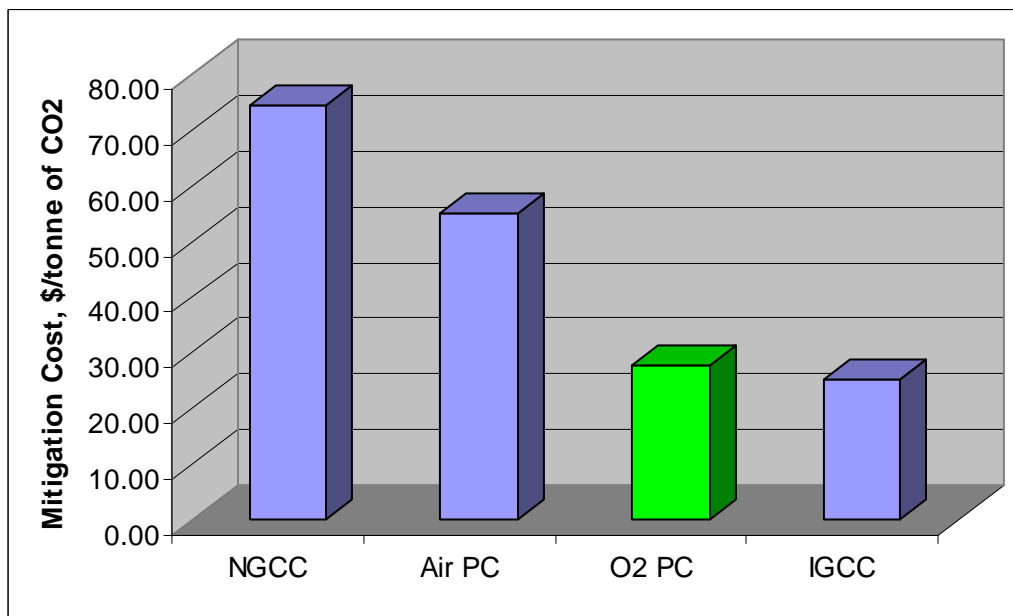


Figure 3 - Comparison of Levelized Cost of Electricity Among Alternative Technologies (O₂ PC with 85% CF)

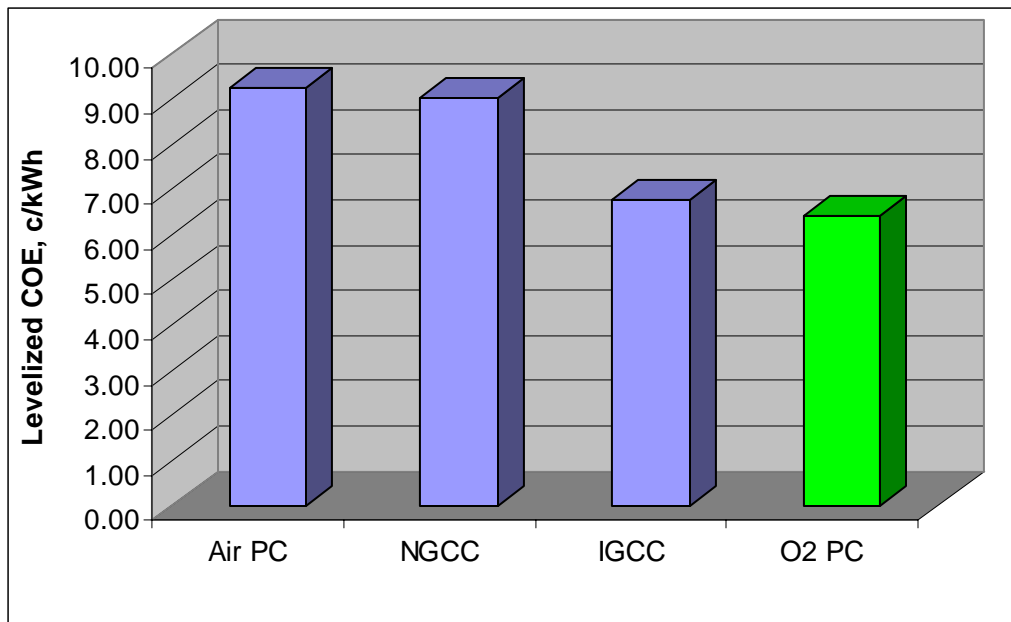
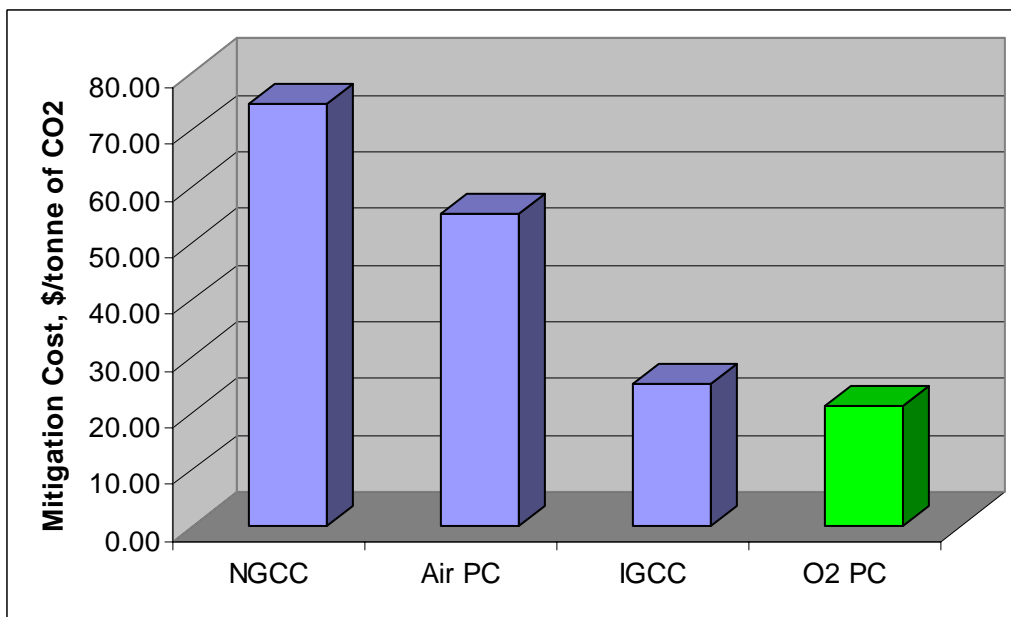


Figure 4 - Comparison of Mitigation Costs Among Alternative Technologies (O₂ PC with 85% CF)



5.0 Conclusion

To assure continued U.S. power generation from its abundant domestic coal resources, new coal combustion technologies must be developed to meet future emissions standards, especially CO₂ sequestration. Current conventional coal-fired boiler plants burn coal using 15-20% excess air producing a flue gas, which is only approximately 15% CO₂. Consequently, CO₂ sequestration requires non-condensable gases stripping, which is both expensive and highly power-consumptive. Several different technologies for concentrating the CO₂ by removing the non-condensable gases have been proposed including amine-based absorption and membrane gas absorption. However, these techniques require substantial energy, typically from low-pressure steam.

A new boiler is presented where the combustion air is separated into O₂ and N₂ and the boiler uses the O₂, mixed with recycled flue gas, to combust the coal. The products of combustion are thus only CO₂ and water vapor. The water vapor is easily condensed, yielding a pure CO₂ stream ready for sequestration. The CO₂ effluent is in a liquid form and is piped from the plant to the sequestration site. The combustion facility is thus truly a zero emission stackless plant.

The levelized cost of electricity (COE) was calculated to be 4.61 ¢/kWh for the reference air-fired plant and to be 6.41¢/kWh for the O₂ PC plant. The CO₂ mitigation cost (MC) of the O₂-PC plant was calculated at 21.4 \$/tonne.

Compared to the COE of the O₂ PC, the COE for the other technologies is 45% higher for Air PC, 40% higher for NGCC, and 6% higher for IGCC. Compared to the MC of the O₂ PC, the MC for the other technologies is 250% higher for NGCC, 160% higher for Air PC, and 17% higher for IGCC.

It is expected that the COE and MC of the O₂ PC will be reduced by the incorporation of new lower power-consuming air separation techniques, such as membrane separation and more advanced steam cycles such as supercritical and ultra-supercritical. In DOE contract, DE-FC26-04NT42207, FW will conduct a study to improve the efficiency and cost-effectiveness of the O₂-based PC power plant through the incorporation of a high-temperature supercritical steam cycle and advanced O₂ separation techniques.

6.0 References

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2. *Updated Cost and Performance Estimates For Fossil Fuel Power Plants with CO₂ Removal*, EPRI, Palo Alto, CA, U.S. Department of Energy – Office of Fossil Energy, Germantown, MD and U.S. Department of Energy/NETL, Pittsburgh, PA: 2002. 1004483.
3. Seltzer, Andrew, “Furnace and Heat Recovery Area Design and Analysis for Conceptual Design of Oxygen-Based PC Boiler” Task 4 Topical Report, January 2005, DE-FC26-03NT41736.
4. Gerard N. Choi, et al., “Cost Efficient Amine Plant Design for Post Combustion CO₂ Capture from Power Plant Flue Gas”, DOE/NETL 3rd Annual Conference on Carbon Sequestration, Alexandria, VA, May 3-6, 2004
5. Energy Information Administration/Electric Power Monthly, October 2004

7.0 List of Acronyms and Abbreviations

ASU	Air separation unit
CF	Capacity Factor
COE	Cost of Electricity
E	Emission of CO ₂
EPRI	Electric Power Research Institute
FD	Forced draft
FGD	Flue gas de-sulfurization reactor
HHV	Higher heating value
ID	Induced draft
IGCC	Integrated gasification combined cycle
LCC	Levelized Carrying Charge
LCM	Levelized Consumables
LFC	Levelized Fuel Costs
LFOM	Levelized Fixed O&M
LHV	Lower heating value
LVOM	Levelized Variable O&M
MC	Mitigation Cost (CO ₂)
NGCC	Natural gas combined cycle
NO _x	Nitrogen oxides
O&M	Operation and Maintenance
PC	Pulverized coal
SCR	Selective catalytic reactor
TCR	Total Capital Requirement
TPC	Total Plant Cost
TPI	Total Plant Investment