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DICE-Gas Turbine Compound Reheat Combined Cycle

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BECHTEL – Carbon Capture Experience

Highlights

- With 60 years of experience in the oil, gas, and chemical production and refining industry, we have become experts in acid gas treating and removal systems that use amines or physical solvents
- We have built more than 40 amine-based CO_2/H_2S removal systems for liquefied natural gas (LNG) plants, gas processing plants, and petroleum refineries
- We provided engineering, procurement, and construction management (EPCM) services for the 630 MW Edwardsport integrated gasification combined cycle (IGCC) project, the first US IGCC in a decade, with pre-combustion carbon capture readiness

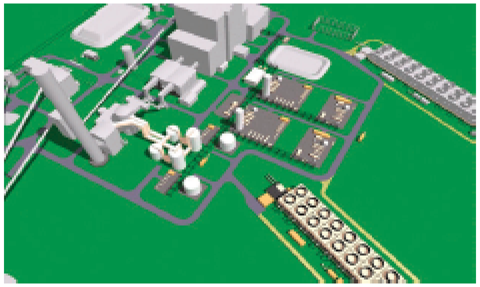
Key Projects

Kårstø Carbon Capture Facility

Overview: Bechtel performed conceptual and front-end engineering and design (FEED) work for a CO_2 capture facility in Kårstø, Norway. The facility is designed to capture CO_2 from a new 420 MW combined-cycle power plant.

European Test Centre Mongstad

Overview: Bechtel performed FEED work for a CO_2 capture pilot plant in Mongstad, Norway, in 2008. The work centered on removing CO_2 emissions from power generation and oil refinery facilities and included design basis; process equipment and physical arrangement; environmental, safety, and health evaluation; and methodology for construction, startup, operation, and testing programs.



Electric Power Research Institute

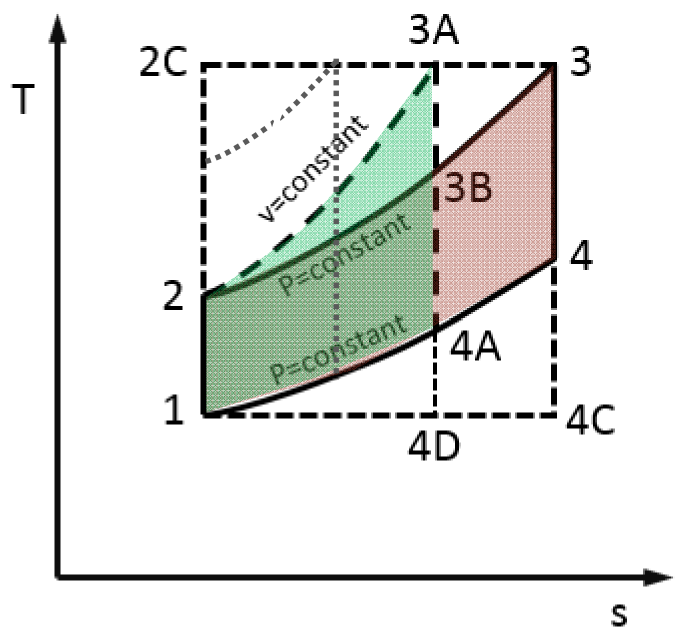
Overview: Nexant/Bechtel is helping the Electric Power Research Institute (EPRI) conduct engineering and economic assessments of technologies and processes for capturing CO_2 and other emissions from coal-fired power plants. Along with finding ways to improve plant performance, this valuable work identifies the best approaches to retrofit existing plants with CO_2 capture technologies.

Direct Injection Carbon Engine (DICE) + Gas Turbine (GT) Compound Reheat Combined Cycle

A **Combined Cycle Power Plant** comprising

- A multiplicity of coal-fired reciprocating internal combustion engines (RICE), which is commonly referred to by the acronym DICE (Direct Injection Carbon Engine);
- A natural gas-fired gas turbine (turbine and combustor);
- A heat recovery steam generator (HRSG);
- A steam turbine generator;
- An integrally-geared and intercooled centrifugal air compressor

One-Slide Thermodynamics



Order of Decreasing Efficiency

{1-2C-3-4C-1} Carnot Cycle

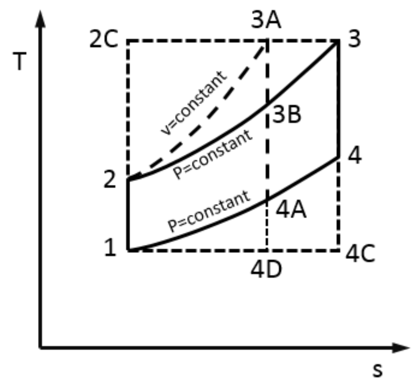
{1-2-3A-3B-4-1} Turbocompound Reheat

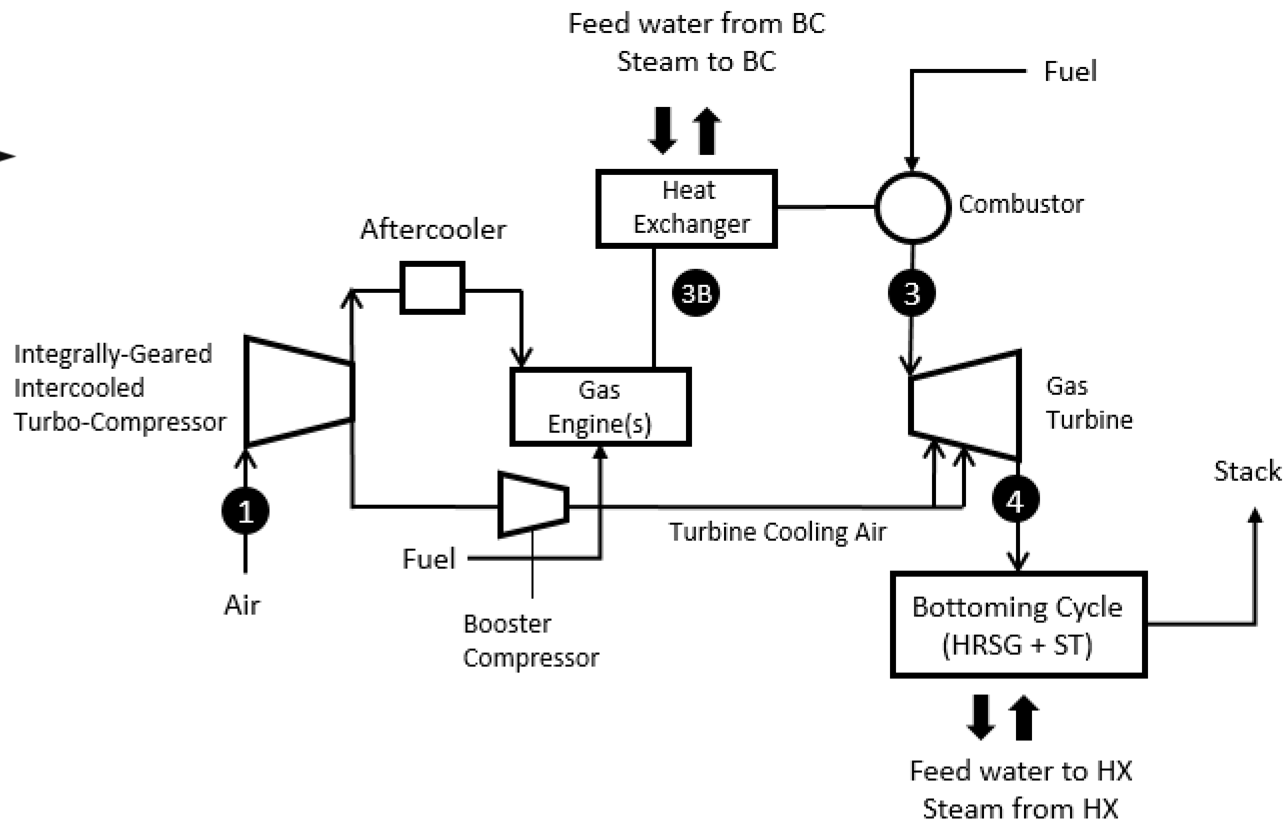
{1-2-3A-$A-1} Atkinson Cycle

{1-2-3-4-1} Brayton (Gas Turbine) Cycle

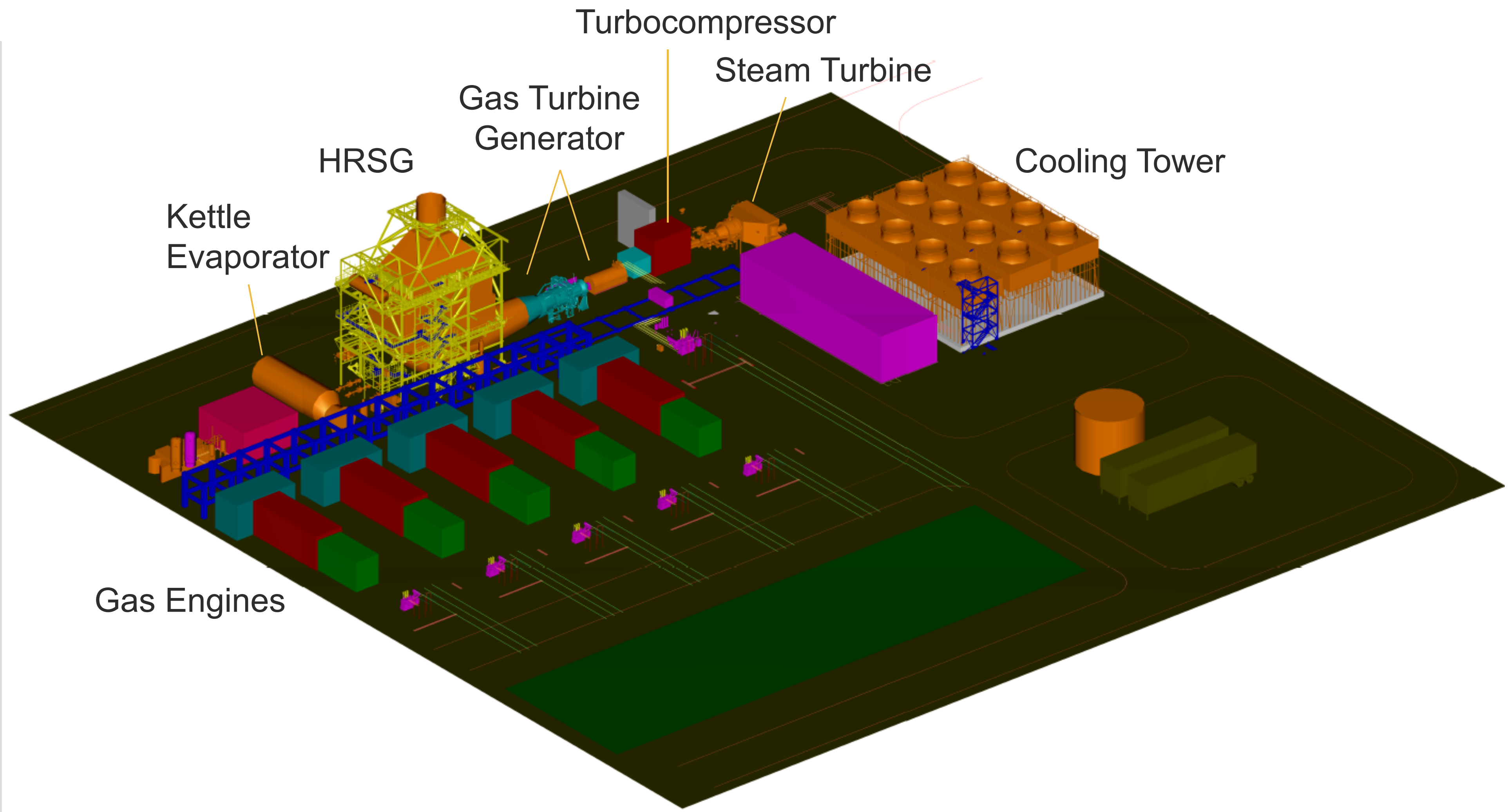
Two Major Cycle Improvements in One:
- Constant Volume Heat Addition (Combustion)
- Reheat

Schematic Diagram





Conceptual Layout



Modifications (RICE → DICE)

High Back Pressure

- Different intake valve cam shape (because of delayed intake valve close timing);
- Modification to gaskets, head bolts and the exhaust manifold (because of increased peak cylinder pressure);
- Modifications to the pre-chamber design (for this particular engine).

Firing Coal-Water Slurry

- Dual fuel system, i.e.
  - CWS direct injector in place of diesel injector in each cylinder,
  - Addition of diesel pilot direct injector for each cylinder;
- Hardened cylinders and pistons – needed for abrasion due to ash content in fuel and unburned fuel;
- New piston rings – same as above;
- New exhaust valves and seats – same as above;
- New crank bearing – needed to account for possible ash carryover into oil.

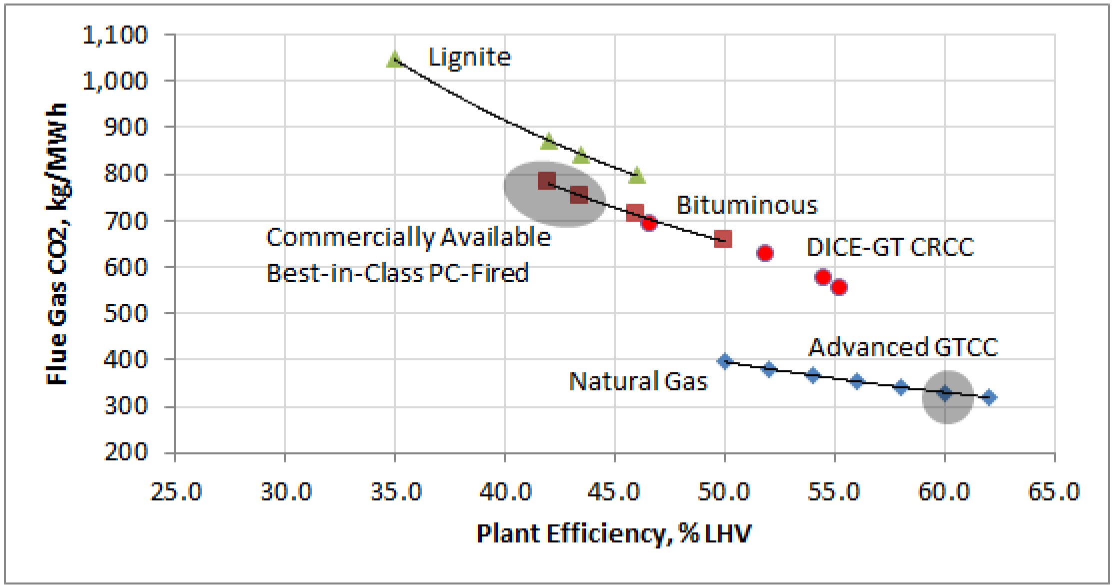
DICE Performance

		State-Of-the-Art	Vintage Diesel
Intake Valve Close Timing	CA deg	501	537
Boost Pressure	bar	5	5
Exhaust Pressure	bar	6	8
Exhaust Temperature	C	667.4	624.3
Exhaust Gas Flow	kg/s	16.22	28.8
Exhaust O2	%(v)	9.47	7.75
Peak Cylinder Pressure	bar	149	133
Peak Cylinder Temperature	C	1426	1252
BTE	**%**	**40.33**	**31.06**
Brake HP	kW	9,686	14,772
BMEP	bar	22	20.1
Heat Rejection to Coolant	kWth	2,688	9,665

DICE-GT CRCC Performance

Gas Engine Technology		SOA	Vintage	SOA	SOA
Steam Conditions		1,400 psig - 955° F		1,400 psig – 1,020° F	
Gas Turbine TIT	° F	1,750	1,850	2,200	2,000
Gas Turbine PR		8	8	10	10
Gas Turbine (1x)	MWe	45.4	50.3	65.9	60.2
Gas Engines (5x)	MWe	47.9	39.9	47.9	47.9
Steam Turbine (1x)	MWe	19.7	20.8	31.6	26.1
Total Gross Output	MWe	113.0	111.0	145.5	134.3
Auxiliary Power	MWe	17.2	14.3	20.8	19.9
Gas Engine Fuel Consumption	MWth	129.9	142.6	132.0	132.0
Gas Turbine Fuel Consumption	MWth	54.5	64.9	93.8	77.8
	% of total	29.5%	31.3%	41.5%	37.1%
Net Output	**MWe**	**95.8**	**96.7**	**124.8**	**114.4**
Net Plant Efficiency	**%**	**51.94**	**46.60**	**55.25**	**54.52**
Stack CO_2	%(v)	11.92	12.51	11.64	11.44
	lb/MWh	1,378	1,522	1,214	1,261

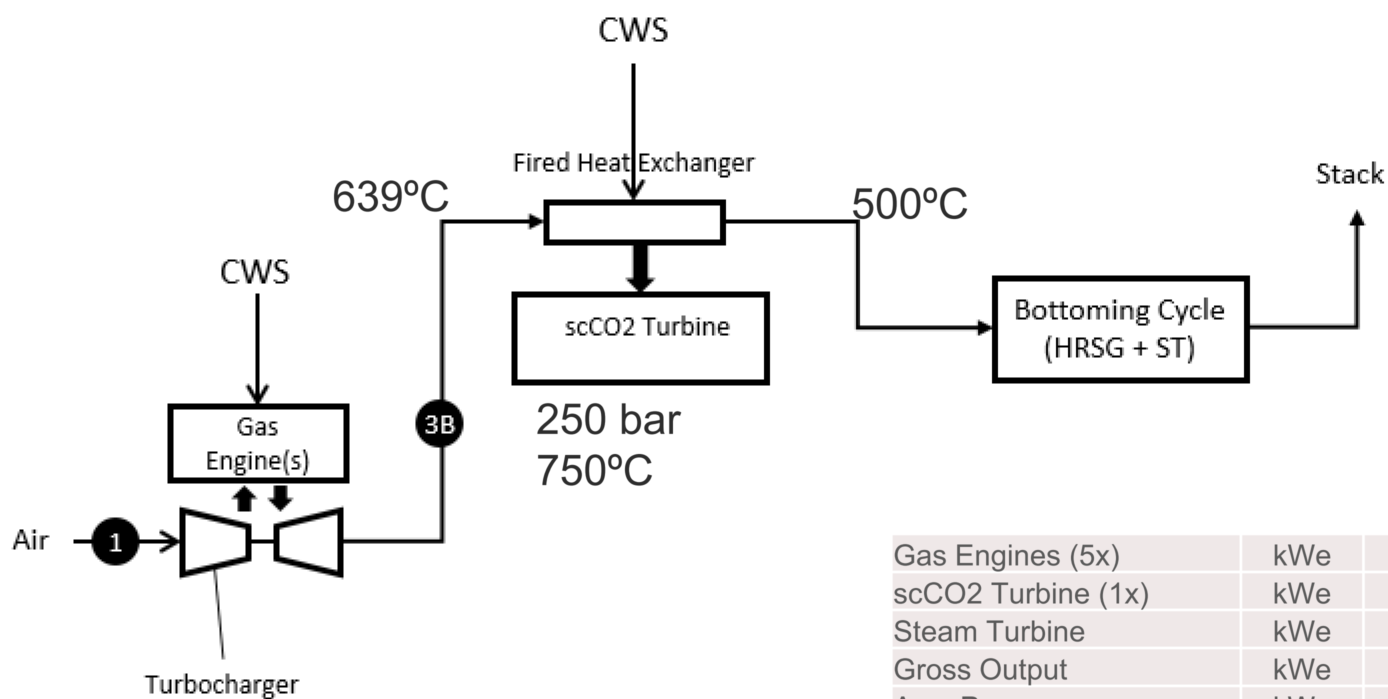
Better Than Current/Future PC Technology



Amenable to Post-Combustion Capture

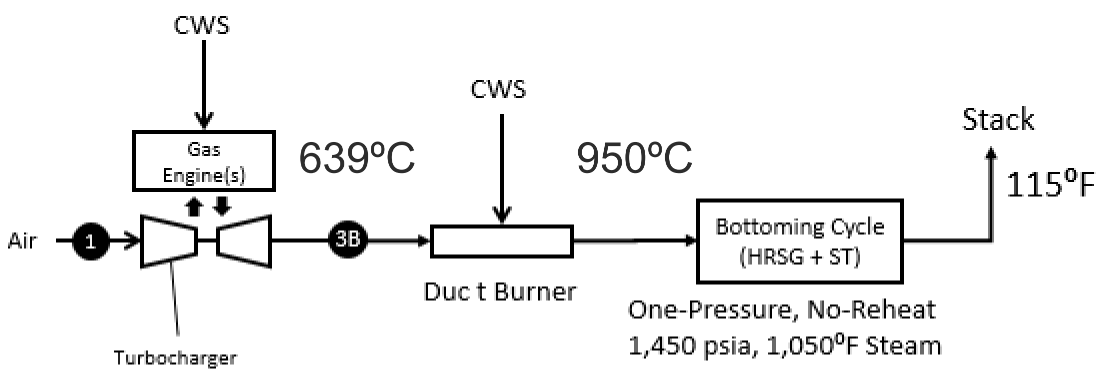
Gas Engine Technology		SOA
Nominal Fuel Split (Coal-NG)	%-%	70-30
Gas Turbine (1x)	MWe	73.5
Gas Engines (10x)	MWe	87.2
Steam Turbine (1x)	MWe	10.7
Total Gross Output	MWe	171.3
Auxiliary Power	MWe	40.7
Net Output	MWe	130.6
HRSG Stack CO_2	lb/s (% by vol.)	67.72 (11.94)
Plant Stack CO_2	lb/s	6.772
Net Plant Efficiency	**% LHV**	**38.36**
	% HHV	**35.76**

100% Coal-Fired – scCO2 Closed Cycle Turbine



Gas Engines (5x)	kWe	47,698
scCO2 Turbine (1x)	kWe	15,205
Steam Turbine	kWe	10,024
Gross Output	kWe	72,927
Aux. Power	kWe	541
Net Output	kWe	72,386
Heat Input	kWth	142,479
Net Efficiency		50.80%
CO2 Emissions	lb/MWh	1,633

100% Coal-Fired – High-Fired Single-Pressure Steam Cycle



Gas Engines (5x)	kWe	47,698
scCO2 Turbine (1x)	kWe	0
Steam Turbine	kWe	28,329
Gross Output	kWe	76,027
Aux. Power	kWe	780
Net Output	kWe	75,247
Heat Input	kWth	142,410
Net Efficiency		52.84%
CO2 Emissions	lb/MWh	1,564