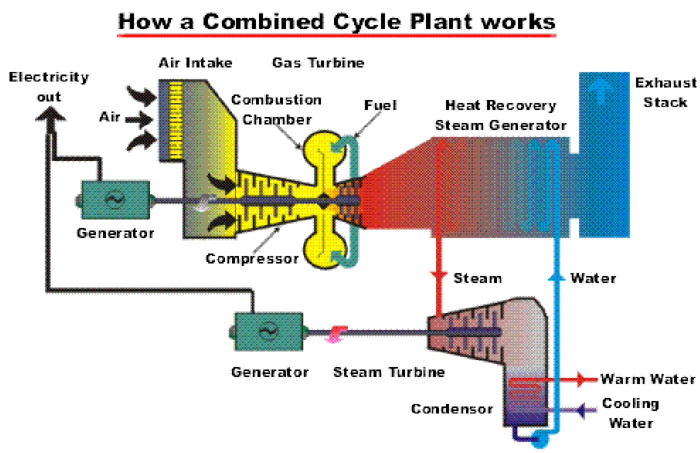
# NATURAL GAS

## DESCRIPTION

The two most common types of fossil-fueled power plants being constructed in the United States are simple-cycle and combined-cycle gas turbines (CCGT), both primarily powered by natural gas.

Simple-cycle gas turbines are essentially jet engines. The engine burns gas and the thrust rotates a drive shaft that is coupled to a generator which produces electricity. Simple-cycle gas turbines are used as peaking generators because their efficiency (around 30%) is not high enough to provide economical baseload generation. Much of the fuel energy ends up being wasted as thermal energy in the hot exhaust gases from the combustion process.

CCGT plants operate in two stages. The first stage is the same as a simple-cycle gas turbine. In the second stage, a heat recovery steam generator uses the hot exhaust of the turbine to create steam that drives a second generator. By using heat that would have been wasted through the exhaust stack in a simple-cycle plant, CCGT plants can achieve efficiencies of up to 60%.




Natural gas plants produce about half of the carbon that coal-fired plants produce.

## COST

Construction cost of CCGT would be in the range of $1 to $1.2 million/MW. The all-in estimate for energy from CCGT would be in the $70/MWh range for the next decade, depending on the cost of natural gas.

## CAPACITY FACTOR

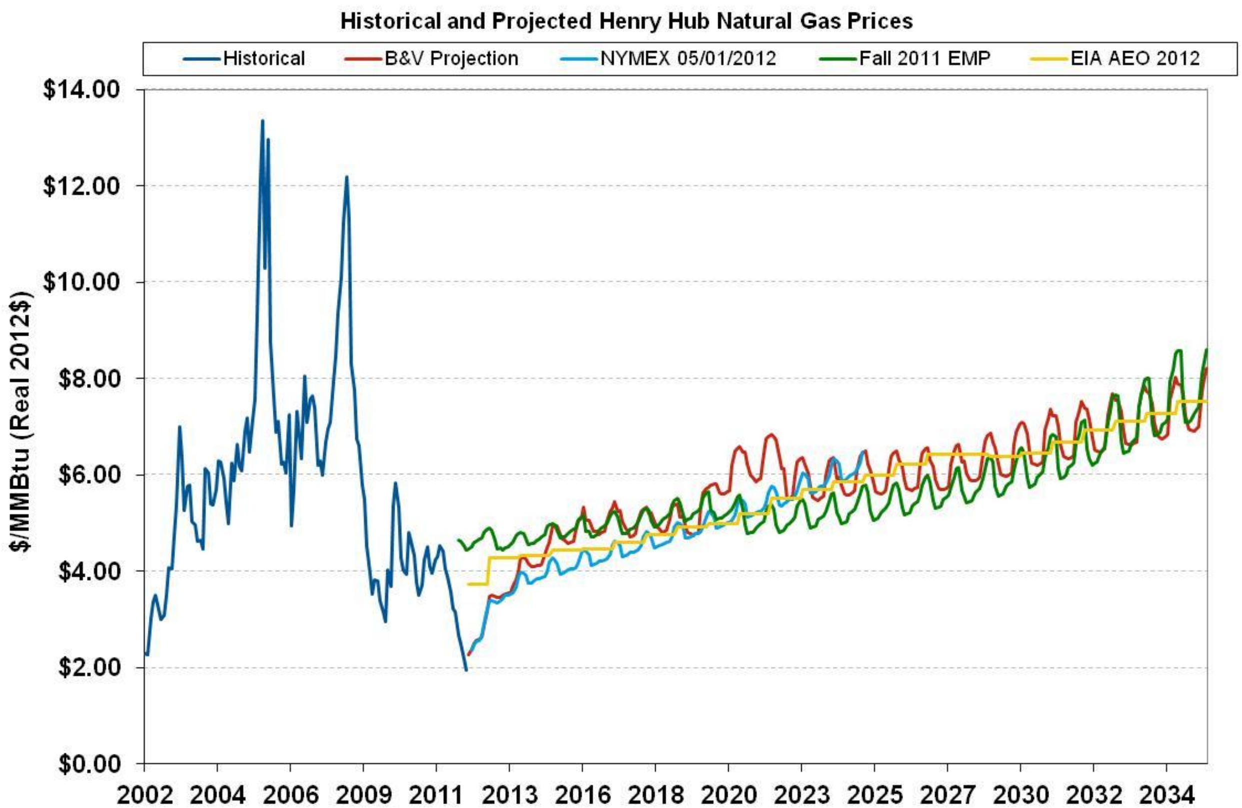
Typical capacity factor for a CCGT in the desert southwest is around 55%, although that is driven largely by economic factors. CCGT plants are capable of generating about 90% of the time.

## TIME TO PERMIT AND CONSTRUCT

Assuming control of the underlying land, permitting and construction time for CCGT is less than three years.

## NOTES

Reliance on natural gas will likely cause energy costs to vary greatly from year to year due to the inherent volatility of the natural gas market. The chart below, developed for CAP by Black & Veatch, shows actual natural gas prices over the past decade and various projections for the next two decades. Just as the price spikes of the past decade were not predicted, it is unlikely that prices over the next two decades will be as stable as this chart suggests.



An Overview of Combined Cycle Power Plant (on photo Magnolia Energy, 900MW CCPT)

Abstract

The Combined Cycle Power Plant or ***combined cycle gas turbine***, a gas turbine generator generates electricity and waste heat is used to make steam to generate additional electricity via a steam turbine. The gas turbine is one of the most efficient one for the conversion of gas fuels to mechanical power or electricity. The use of distillate liquid fuels, usually diesel, is also common as alternate fuels.

More recently, as simple cycle efficiencies have improved and as natural gas prices have fallen, gas turbines have been more widely adopted for base load power generation, especially in combined cycle mode, where waste heat is recovered in waste heat boilers, and the steam used to produce additional electricity.

This system is known as a ***Combined Cycle***. The basic principle of the Combined Cycle is simple: burning gas in a gas turbine (GT) produces not only power – which can be converted to electric power by a coupled generator – but also fairly hot exhaust gases.

Routing these gases through a water-cooled heat exchanger produces steam, which can be turned into electric power with a coupled steam turbine and generator.

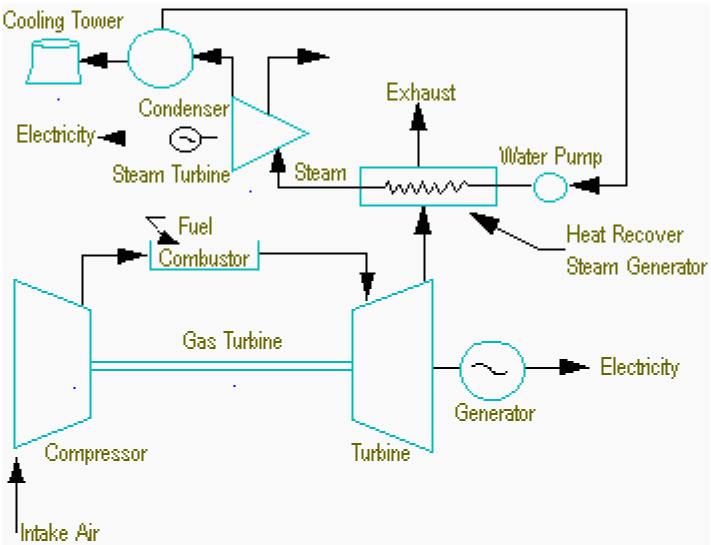



Figure - Combined cycle power plant scheme

This type of power plant is being installed in increasing numbers round the world where there is access to substantial quantities of natural gas.

A Combined Cycle Power Plant produces high power outputs at high efficiencies (up to 55%) and with low emissions. In a Conventional power plant we are getting *33% electricity only* and remaining 67% *as waste*.

By using combined cycle power plant we are getting ***68% electricity***.

It is also possible to use the ***steam from the boiler for heating purposes*** so such power plants can operate to deliver electricity alone or in combined heat and power (CHP) mode.

## Mechanism

Combined cycle power plant as in name suggests, it combines existing gas and steam technologies into one unit, yielding significant improvements in thermal efficiency over conventional steam plant. In a CCGT plant the thermal efficiency is extended to approximately 50-60 per cent, by piping the exhaust gas from the gas turbine into a heat recovery steam generator.

However the heat recovered in this process is sufficient to drive a steam turbine with an electrical output of approximately 50 per cent of the gas turbine generator.

The gas turbine and steam turbine are coupled to a single generator. For startup, or '***open cycle***' operation of the gas turbine alone, the steam turbine can be disconnected using a hydraulic clutch. In terms of overall investment a single-shaft system is typically about 5 per cent lower in cost, with its operating simplicity typically leading to higher reliability.

## Working principle of CCTG plant

First step is the same as the simple cycle gas turbine plant. An open circuit gas turbine has a compressor, a combustor and a turbine. For this type of cycle the input temperature to turbine is very high. The output temperature of flue gases is also very high.

This is therefore high enough to provide heat for a second cycle which uses steam as the working medium i.e. thermal power station.

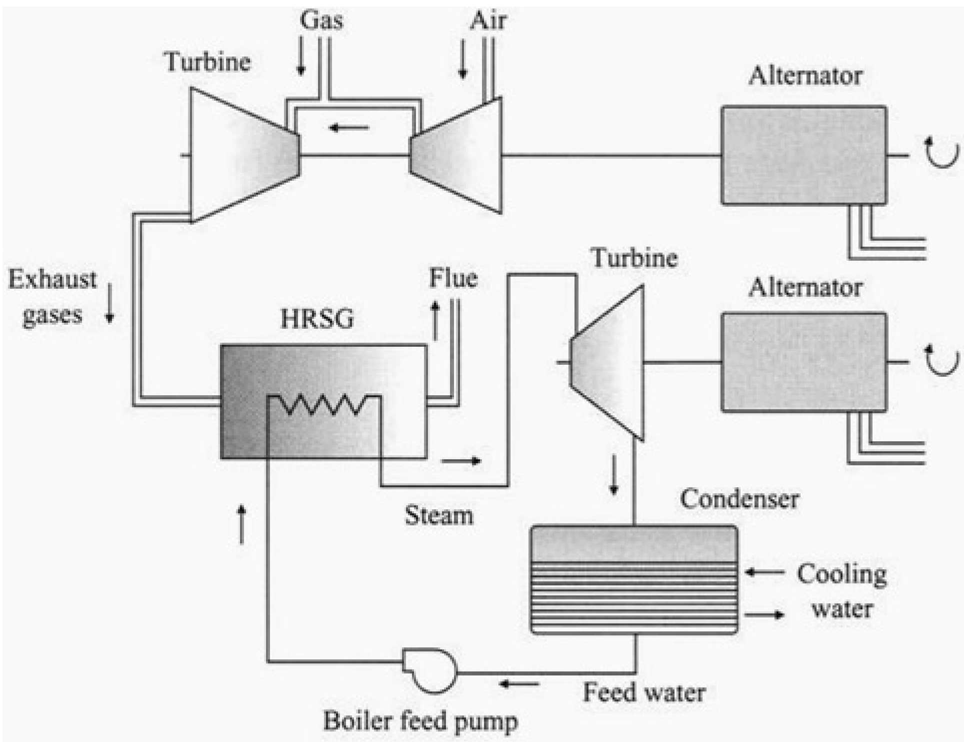



Figure - Working principle of combined cycle gas turbine (CCTG) plant

### Air Inlet

This air is drawn though the large air inlet section where it is cleaned cooled and controlled. Heavy-duty gas turbines are able to operate successfully in a wide variety of climates and environments due to inlet air filtration systems that are specifically designed to suit the plant location.

Under normal conditions the inlet system has the capability to process the air by removing contaminants to levels below those that are harmful to the compressor and turbine.

### Turbine Cycle

The air which is purified then compressed and mixed with natural gas and ignited, which causes it to expand. The pressure created from the expansion spins the turbine blades, which are attached to a shaft and a generator, creating electricity.

In second step the heat of the gas turbine's exhaust is used to generate steam by passing it through a heat recovery steam generator (HRSG) with a live steam temperature ***between 420 and 580 °C***.

### Heat Recovery Steam Generator

In Heat Recovery Steam Generator highly purified water flows in tubes and the hot gases passes a around that and thus producing steam .The steam then rotates the steam turbine and coupled generator to produce Electricity. The hot gases leave the HRSG at around 140 degrees centigrade and are discharged into the atmosphere.

The steam condensing and water system is the same as in the steam power plant.

## Typical Size and Configuration of CCGT Plants

The combined-cycle system includes ***single-shaft*** and ***multi-shaft configurations***. The single-shaft system consists of one gas turbine, one steam turbine, one generator and one Heat Recovery Steam Generator (HRSG), with the gas turbine and steam turbine coupled to the single generator on a single shaft.

Multi-shaft systems have one or more gas turbine-generators and HRSGs that supply steam through a common header to a separate single steam turbine-generator. In terms of overall investment a multi-shaft system is about 5% higher in costs.

The ***primary disadvantage*** of multiple stage combined cycle power plant is that the number of steam turbines, condensers and condensate systems-and perhaps the cooling towers and circulating water systems increases to match the number of gas turbines.

### Efficiency of CCGT Plant

Roughly the steam turbine cycle produces ***one third of the power*** and gas turbine cycle produces ***two thirds of the power output*** of the CCPP. By combining both gas and steam cycles, high input temperatures and low output temperatures can be achieved. The efficiency of the cycles adds, because they are powered by the same fuel source.

To increase the power system efficiency, it is necessary to optimize the HRSG, which serves as the critical link between the gas turbine cycle and the steam turbine cycle with the objective of increasing the steam turbine output. HRSG performance has a large impact on the overall performance of the combined cycle power plant.

The electric efficiency of a combined cycle power station may be as high as 58 percent when operating new and at continuous output which are ideal conditions. As with single cycle thermal units, combined cycle units may also deliver low temperature heat energy for industrial processes, district heating and other uses. This is called cogeneration and such power plants are often referred to as a Combined Heat and Power (CHP) plant.

The efficiency of CCPT is increased by Supplementary Firing and Blade Cooling. Supplementary firing is arranged at HRSG and in gas turbine a part of the compressed air flow bypasses and is used to cool the turbine blades. It is necessary to use part of the exhaust energy through gas to gas recuperation. Recuperation can further increase the plant efficiency, especially when gas turbine is operated under partial load.

## Fuels for CCPT Plants

The turbines used in Combined Cycle Plants are commonly fuelled with natural gas and it is more versatile than coal or oil and can be used in 90% of energy applications. Combined cycle plants are usually powered by natural gas, although fuel oil, synthesis gas or other fuels can be used.

## Emissions Control

***Selective Catalytic Reduction (SCR):***

- To control the emissions in the exhaust gas so that it remains within permitted levels as it enters the atmosphere, the exhaust gas passes through two catalysts located in the HRSG.
- One catalyst controls Carbon Monoxide (CO) emissions and the other catalyst controls Oxides of Nitrogen, (NOx) emissions. Aqueous Ammonia – In addition to the SCR, Aqueous Ammonia (a mixture of 22% ammonia and 78% water) is injected into system to even further reduce levels of NOx.

## Fuel efficiency

In conventional power plants turbines have a fuel conversion efficiency of ***33%***which means ***two thirds*** of the fuel burned to drive the turbine off. The turbines in combined cycle power plant have a fuel conversion efficiency of ***50% or more***, which means they burn about half amount of fuel as a conventional plant to generate same amount of electricity.

## Commercial availability

Combined cycle units are commercially available from suppliers anywhere in the world. They are easily manufactured, shipped and transported.

## Abundant fuel sources

The turbines used in combined cycle plants are fuelled with natural gas, which is more versatile than a coal or oil and can be used in 90% of energy publications. To meet the energy demand now a day's plants are not only using natural gas but also using other alternatives like bio gas derived from agriculture.

# Demerits

1. The gas turbine can only use Natural gas or high grade oils like diesel fuel.
2. Because of this the combined cycle can be operated only in locations where these fuels are available and cost effective.

Published by Electrical Engineering Portal

http://electrical-engineering-portal.com/an-overview-of-combined-cycle-power-plant

# Harquahala Generating Facility

# Facility Characteristics, Operating Costs and Permitting Overview

2013

# Harquahala Facility Characteristics

**Harquahala Generation Costs (All-In)**

| | Nat Gas ($/MMBtu) | Dispatch Cost ($/ MWH) | Start Fuel ($/ MWH) | Fixed O&M ($/ MWH) | Capital ($/ MWH) | All-In Cost ($/ MWH) |
|---|---|---|---|---|---|---|
| 2012 | $ 3.07 | $ 25.14 | $ 0.25 | $ 2.40 | $ 5.83 | **$ 33.61** |
| 2013 | $ 3.61 | $ 28.89 | $ 0.29 | $ 2.42 | $ 5.83 | **$ 37.43** |
| 2014 | $ 4.05 | $ 31.95 | $ 0.32 | $ 2.45 | $ 5.83 | **$ 40.55** |
| 2015-2019 | $ 4.65 | $ 36.12 | $ 0.37 | $ 2.47 | $ 5.83 | **$ 44.79** |

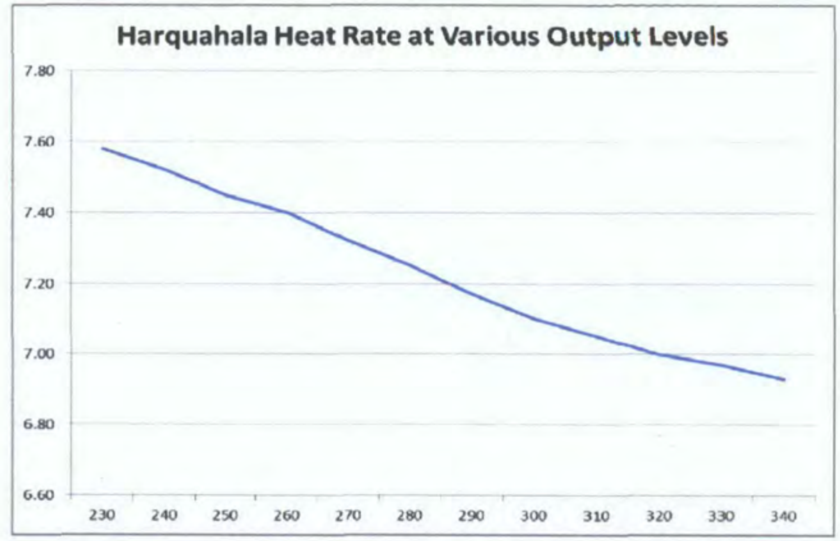
Notes: Heat Rate: 6,950 (Baseload Operations)

VOM: $ 3.80 (per MWH)

Project Cost Calculated at Recently Disclosed Acquisition of Mesquite by SRP

Project Amortized over 25 Years at 5.5%

Property Tax is approximately $5.9M per Year (equivalent of $0.75 per MWH)




- Configuration: Three Independent Units ( 1 CTx 1 HRSG x 1 ST)
- Minimum Generation per Power Block: 180 MW
- Maximum Generation per Power Block: 330 (Summer); 345 (Winter)
- All-In cost assumes an 85% capacity factor. Actual availability is anticipated to be in excess of 92%. Opportunity for lower total cost may be available due to optimization of ramping and dispatch versus the wholesale market.
- Operations could include a divided interest in each power block with shared cost for the common facilities and general facility management.

# CCGT versus Coal Cost (Current and Future)

| Regional Generation Cost | | | | | | |
|---|---|---|---|---|---|---|
| | Typical CCGT (Natural Gas) ($/ MWH) | Apache (Coal) ($/ MWH) | Cholla (Coal) ($/ MWH) | Four Corners (Coal) ($/ MWH) | Navajo (Coal) ($/ MWH) | San Juan (Coal) ($/ MWH) |
| 2013 | $ 37.43 | $ 39.20 | $ 42.00 | $ 50.00 | $ 44.60 | $ 59.80 |
| 2019 | $ 47.55 | $ 55.45 | $ 47.15 | $ 67.50 | $ 55.70 | $ 74.00 |

Notes: CCGT cost in the SW based on recent comps and atual operating costs.
CCGT assumes existing forw ard natural gas prices for 2013 and 2019.
Coal costs based on publicly available data w ith 2% esclation and no emissions offset cost.
Total cost may fluctuate somew hat amongst various ow ners.
Coal emissions upgrades cost based on publicly release cost estimates for compliance w ith EPA requiremenets, implemented by 2019.

# Environmental, Health and Safety

## Key Permits

| Permit | Permitting Agency | Status / Date Obtained | Permit Number |
|---|---|---|---|
| Title V | MCAQD | Received Dec 2011<br>Expires Dec 2016 | V99-015 |
| NPDES | EPA | None Required | NA |
| Aquifer Protection | ADEQ | July 2010 | P-104190 |
| Storm Water | ADEQ | Exempt | AZM-SG-10680 |
| Special Use | Maricopa County | Nov 2000 | Z2000-049 |

Water Consumption: 280 gallons per MWH

## Permitted and Operating Emission Levels

**Harquahala Permit Emissions Limits**

| | Annual (Tons) | Daily (Lbs/ Hour) |
|---|---|---|
| NOx | 108 | 25 |
| CO | 192 | 37 |
| S02 | 23 | 5.8 |
| PM-10 | 97 | 24 |
| PM-2.5 | 97 | 24 |
| VOC | 34 | 7.8 |

Annual Limits include emissions during Start-up
Additional Stack Limits of 2.5 PPMVD for Nox and 10 PPMVD for CO
Each Pow er Block is equipped w ith NOx and CO selective catalyst reduction
Facility meets BACT for NOx control.
Facility has no regional haze or mercury emissions issues
Facility maintains continous emissions monitoring and conducts annual source testing

## Environmental & Safety Performance Metrics

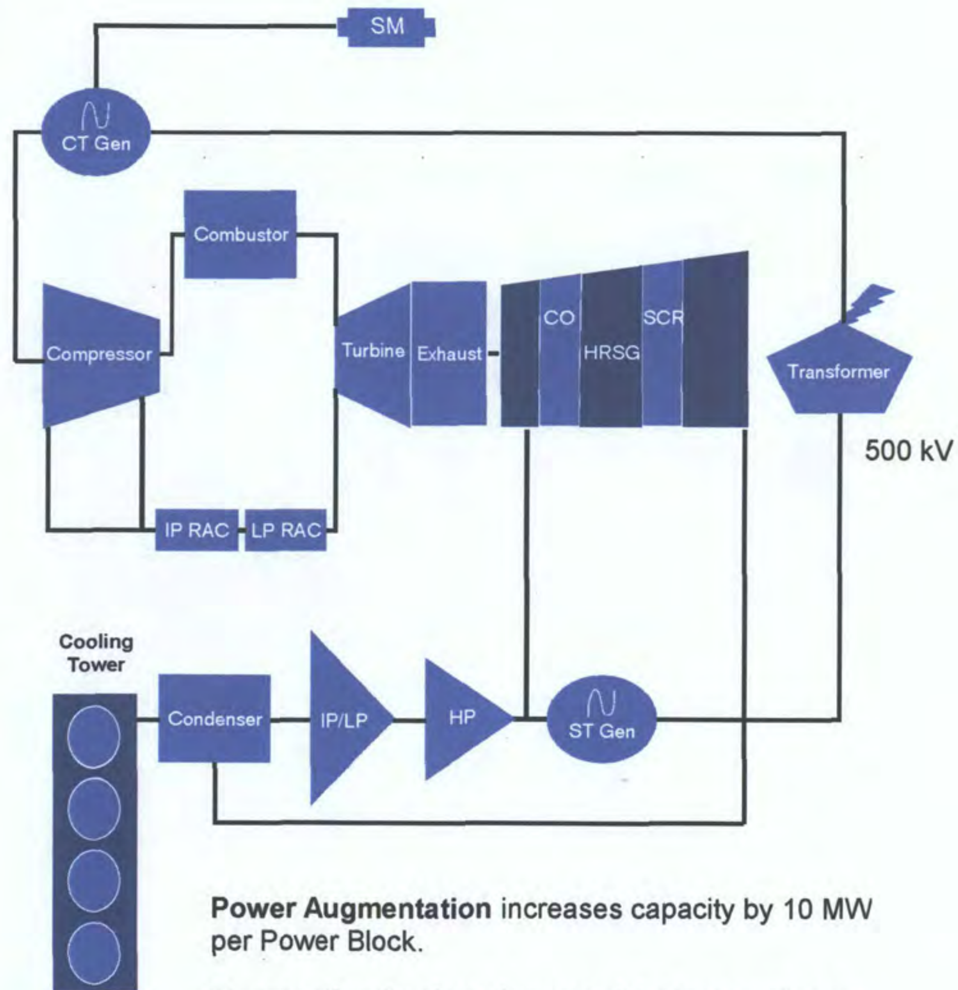
| | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|
| Notices of Violation | 0 | 0 | 0 | 1 | 0 |
| Environmental Exceedances | 0 | 1 | 0 | 0 | 0 |
| Lost-Time Accidents | 0 | 0 | 0 | 0 | 0 |
| Occupational Safety and Health Administration ("OSHA") Recordable Incidents | 0 | 0 | 0 | 0 | 0 |

# Equipment Summary and Process Overview

## Equipment Description

| Equipment | Manufacturer | Description |
|---|---|---|
| **Combustion Turbine** | Siemens | 501G CTs (each at 240 MW) equipped with DLN combustors, hydrogen-cooled generators, power augmentation ("PAG" offering additional 12 MW per turbine) and inlet evaporative cooling |
| **Heat Recovery Steam Generator** | NEM | Natural circulation HRSGs equipped with a SCR system and a CO catalyst |
| **Steam Turbine** | Siemens | The two-casing STs (each at 120 MW), HP combined LP/IP, axial exhaust, condensing reheat |
| **GSU Transformer** | Toshiba | One generator step-up per train |
| **Condenser** | Alstom | Dual two pass circulating water condenser with titanium tubing |
| **Cooling Tower** | PSI | Two, nine-cell, mechanical draft cooling towers with one extra cell per tower for redundancy |
| **Boiler Feed Pump** | Ingersoll Flowserve | One per train, one spare motor and pump included in inventory |
| **DCS System** | Siemens | T3000 |
| **Gas Compressor** | Tran Am | Reciprocating; available as contingency, have not been needed for operations |

## Process Overview




**Power Augmentation** increases capacity by 10 MW per Power Block.

**Evaporative Coolers** decrease inlet temperature to 85 degrees on a peak summer day, thus limiting any net generation degradation.

# Harquahala Generating Facility

# Sundevil Power Facility

# Harquahala Generating Facility

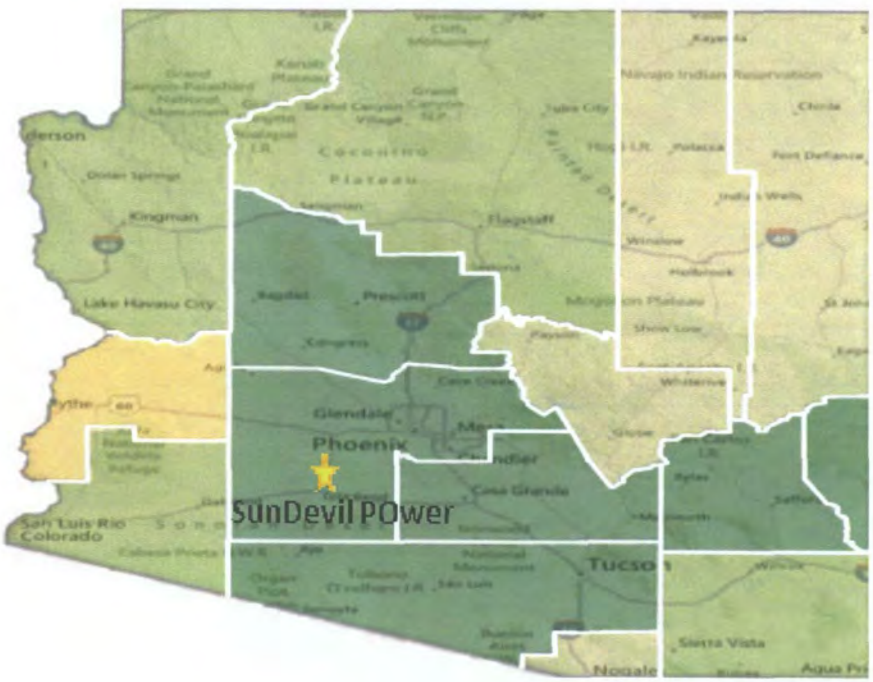

| | |
|---|---|
| **Location:** | Tonopah, AZ |
| **Nominal Capacity:** | 1,092 MW |
| **COD:** | September 2004 |
| **Heat Rate:** | 6,975 Btu/kWh[1] |
| **NERC Region:** | WECC (AZ-NM-SNV) |
| **Pricing Point:** | Palo Verde |
| **Fuel:** | Natural Gas |
| **Gas Interconnection:** | El Paso (South Mainline) |
| **Electric Interconnection:** | Harquahala Substation<br>Hassayampa Switchyard |
| **Facility Type:** | Combined-Cycle |
| **Configuration:** | Three independent units (1 CT x 1 HRSG x 1 ST) |
| **Key Equipment:** | 3 Siemens 501G CTs<br>3 NEM HRSGs<br>3 Siemens STs |
| **Site:** | 640-acre parcel; 556 undeveloped acres<br>Additional remote undeveloped parcel of 240 acres |
| **O&M Provider:** | NAES Corporation (34 on-site personnel) |
| **Energy Manager:** | Twin Eagle |

# Harquahala Facility Attributes



| | | |
|---|---|---|
| **Capital Investment to meet Best in Class Expectations** | 1 | Replacement of SCR catalyst and air compressors |
| | 2 | Collaborative coordination with Siemens to enhance efficiency and reliability, including combustion and generator inspections |
| | 3 | Installation of electric turning gear on all steam turbines, upgraded DCS system and replacement of instrumentation for enhanced automation |
| | 4 | Enhanced procedures and vibration monitoring programs enhanced reliability |
| **Strategic Benefits** | 5 | Cooling technology and sustainable water access provides competitive advantage |
| | 6 | Interconnection access to Arizona, Nevada and California markets via Palo Verde |
| | 7 | Third party O&M services (NAES) and Siemens LTSA |
| **Flexibility & Development Potential** | 8 | Highly reliable and efficient operations, including ability to add low turn-down capability |
| | 9 | Expansion opportunities including additional thermal capacity and solar development |

# Sundevil Power Generating Facility




| | |
|---|---|
| **Location:** | Gila Bend, AZ |
| **Nominal Capacity:** | 1,072 MW |
| **COD:** | August 2003 |
| **Heat Rate:** | 7,100 Btu/kWh[1] |
| **NERC Region:** | WECC (AZ-NM-SNV) |
| **Pricing Point:** | Palo Verde |
| **Fuel:** | Natural Gas |
| **Gas Interconnection:** | El Paso (South Mainline)<br>Transwestern (Phoenix Lateral) |
| **Electric Interconnection:** | Gila River –Panda 230 / 500 kV with firm transmission to Jojoba |
| **Facility Type:** | Combined-Cycle |
| **Configuration:** | Two 2x1 Power Blocks (2 CT x 2 HRSG x 1 ST) |
| **Key Equipment:** | 4 GE 7FA CTs<br>4 Alstom HRSGs<br>2 GE D11STs |
| **Site:** | 1,100 acre site. Site can be expanded and developed for solar or thermal generation |
| **O&M Provider:** | Wood Group (56 on-site personnel) |
| **Energy Manager:** | EDF Trading North America |

# Sundevil Facility Attributes



| | | |
|---|---|---|
| Capital Investment to meet Best in Class Expectations | 1 | Major maintenance on combustion turbines (HGP) completed in 2013 |
| | 2 | Restoration of fogger system for enhanced net output, including erosion resistant RO blades |
| | 3 | Maintenance of HRSG valves and baffles to maximize thermal efficiency |
| | 4 | Implemented NIST traceable valve and instrument calibration program for all instruments as well as extensive predictive and preventative maintenance measures |
| Strategic Benefits | 5 | Cooling technology and sustainable water access provides competitive advantage |
| | 6 | Interconnection access to Arizona, Nevada and California markets |
| | 7 | Third party O&M services (Wood Group) and defined operating procedures |
| Flexibility & Development Potential | 8 | Quick ramping capability with highly reliable and efficient operations |
| | 9 | Expansion opportunities including additional thermal capacity and solar development |

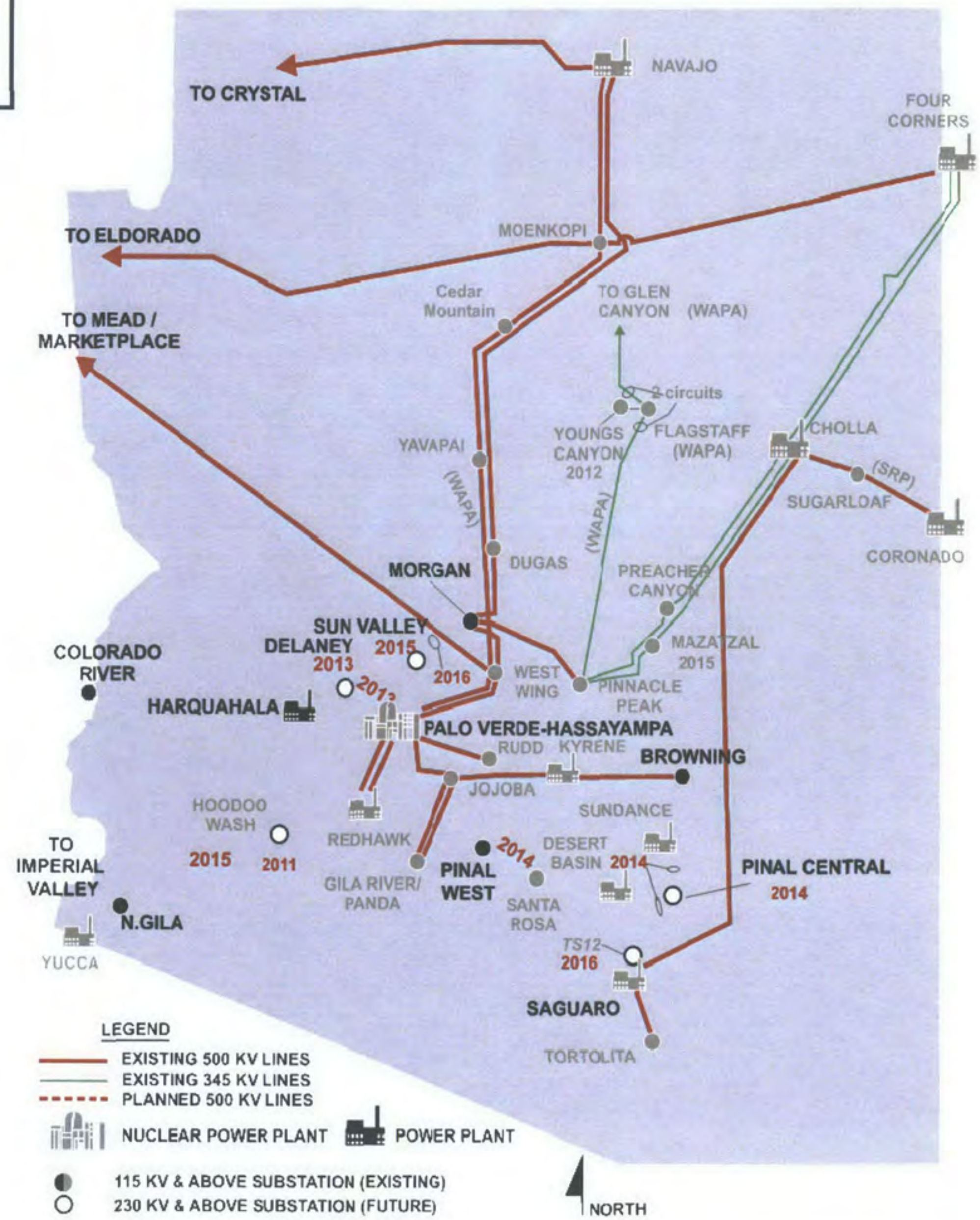
## Transmission capacity to Arizona, Nevada and California load centers via Palo Verde

### Transmission to Arizona Load Centers

| Project | MW | In-Service Date | Load Center Access |
|---|---|---|---|
| Delaney – Sun Valley – Morgan | 1,000 | June 2016 | Sun Valley / Delaney |
| Hassayampa – Pinal West #2, and Pinal West – Pinal Central – Browning | 1,400 | TBD | Phoenix Metro Area |
| Hassayampa – North Gila #2 | 1,200 | May 2015 | Sun Valley |
| Palo Verde – Saguaro | TBD | TBD | Greater Tucson Area |

### Transmission to California/Nevada

| Project | MW | In-Service Date | Market Access |
|---|---|---|---|
| Palo Verde – Devers #2 (California section) in combination with Delaney – Colorado River | TBD | TBD | California, Nevada via SMRT[1] |
| North Gila – Imperial Valley #2 in combination with Hassayampa – North Gila #2 | 1,200 | January 2017 | California, Nevada via SMRT[1] |



# Demonstrated Best-in-Class Operations



**Harquahala's operations have been recognized as best-in-class by several industry publications**

**•Key Awards**

✓ **Combined Cycle Journal 2011 Best of the Best Practice Award - Improved Plant Communication Document Control with SharePoint**

✓ **Combined Cycle Journal 2011 Best of the Best Practice Award - Initiatives and Procedures to Improve Operating Reliability**

✓ **Combined Cycle Journal 2009 Best of the Best Practice Award - Vibration Monitoring Programs Safeguards Critical Rotating Equipment**

✓ **2008 NAES Power Plant Operations Safety Award**

**•SAIC Commentary**

- **"Siemens has a structured program to identify new issues; quantify the magnitude of risks associated with such issues; and ultimately to establish a root cause for each issue, sufficient to develop and implement a validated solution across the W501G CT fleet"**
- **"NAES has an established training and qualifications program for the Facility. In addition to the training programs, safety and environmental programs are in place to prepare staff to deal with environmental and safety issues that may arise during operation of the Facility"**

Source: SAIC Independent Engineer's Report

- **Proven technology, focus on automation and disciplined standard operating procedures, complimented by OEM parts, maintenance and service agreements ensure the long-term viability of the units**
- **Sundevil voluntarily participates in GE parts and services agreements**
- **Harquahala participates in OEM (Siemens) LTSA**

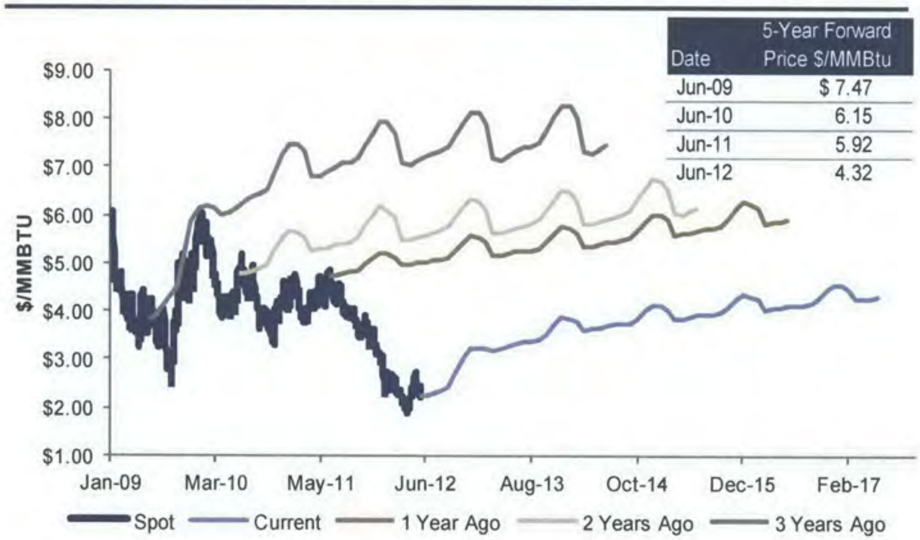
# Proven Technology to meet Portfolio Requirements



## Clean, efficient natural gas generation provides a low-cost sustainable resource to compliment the generation portfolio

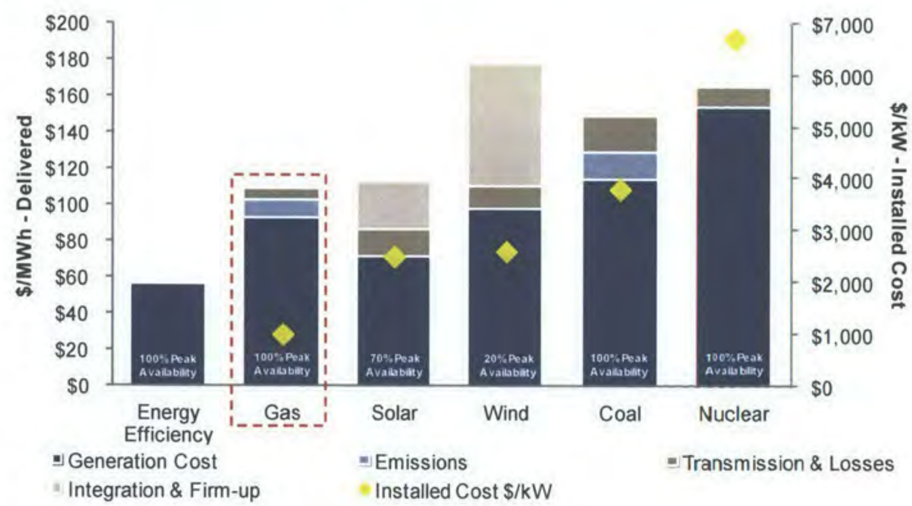
- The abundance of new gas supply in the US, complimented by shale resources, has had pronounced implications, both near-term and long-term for the power generation sector
  - Increases economic dispatch capacity factors due to low marginal cost
  - Promotes a sustainable cost competitive fuel source with lower forward implied price volatility
  - Provides a clear "all-in" delivered-cost advantage, especially when considering emissions costs
  - Enhances dispatch flexibility and ability to adapt to market conditions
- Analysis demonstrates that efficient combined cycle natural gas generation provides the lowest delivered and installed cost among new-build alternatives, with the exception of energy efficiency

### Evolution of Natural Gas Forward Curves




Source: Bloomberg (June 2012)

### APS Technology Cost Comparison



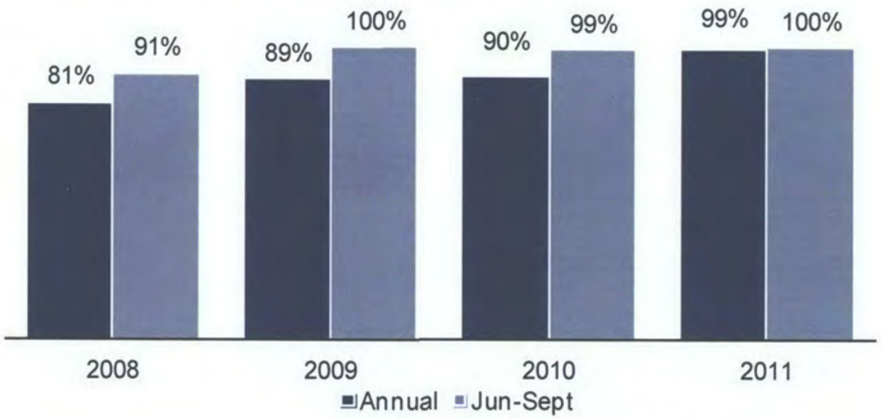

Source: Arizona Public Service Company 2012 IRP

# Highly Reliable & Efficient Operations

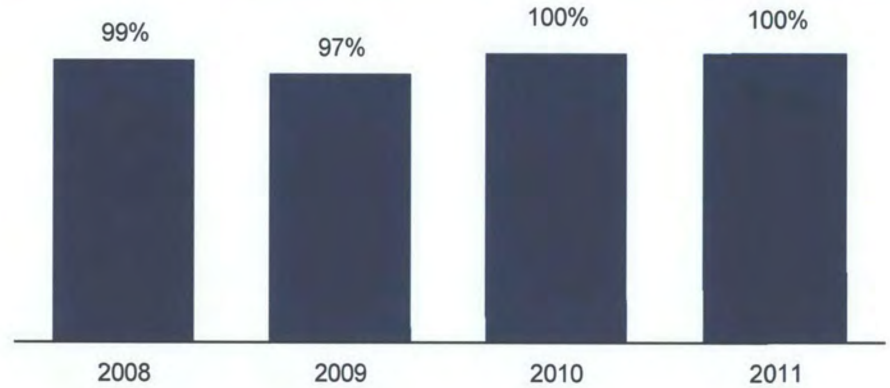


**Focus on "In Market Availability" performance supported by substantial reliability and efficiency investments.**

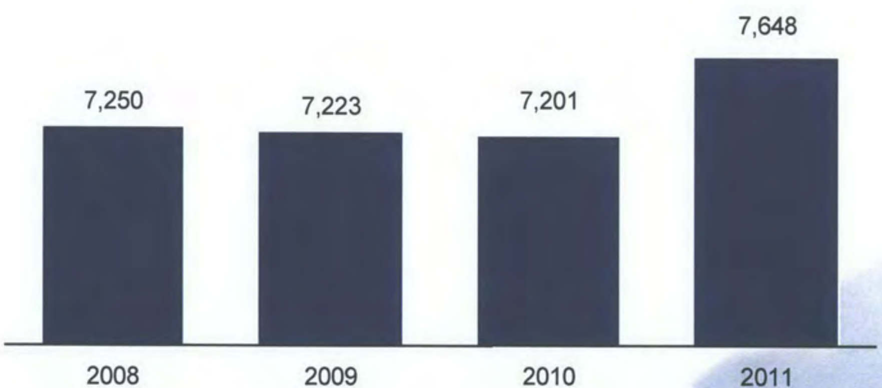
## •Availability Factors



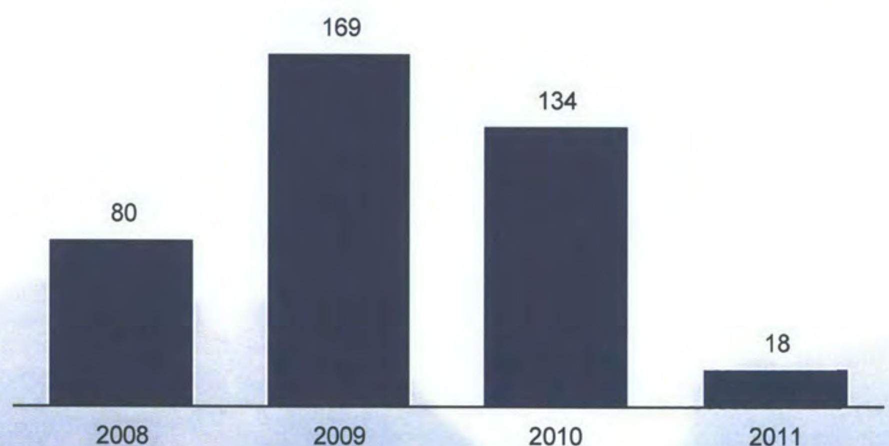

## •Annual Reliability Factors




## •Realized Heat Rate (Btu/kWh)[1]




## •Operating Hours per Start (Hours/Start)




Source: Company

•[1] All hours heat rate includes start fuel and the impact of electrical losses.