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2012 Plant of the Year: AES Coal-Hybrid Plant in Chile



AES Gener's Angamos Power Plant Earns *POWER's* Highest Honor



AES Gener recently completed construction of twin coal-fired, 260-MW units in the electricity-starved desert of northern Chile that may serve as models for future hybrid-fossil plant designs. For meeting an aggressive construction schedule, integrating a 20-MW battery energy storage system, embracing desalination, using the first-of-its-kind seawater cooling tower in South America, and employing innovative financing methods, the AES Gener Angamos plant has earned *POWER's* 2012 Plant of the Year Award.

By Dr. Robert Peltier, PE

Courtesy: AES Corp

AES Gener S.A. is a Chilean publicly listed power generation company that has invested heavily in the future of the Chilean economy. The sixth and seventh most recent units to enter service as part of AES Gener's \$3 billion, 1,638-MW power plant expansion plan were the two units at the Angamos Power Plant (Angamos) on the Pacific coast of northern Chile. Before examining the unique design features of this coal-hybrid plant, it's useful to look at the Chilean electricity industry and the important role that independent power producers (IPPs) play in the country's economy.

AES Gener, 71% owned by U.S.-based AES Corp., is the second-largest electricity generating company in Chile. Pension funds (14%) and public investors (15%) hold the remaining stock. AES, based in Arlington, Va., is one of the largest global power companies. It operates 13 utilities and 121 generation facilities in 28 countries.

The Chilean government contracts with AES Gener for the supply of electricity in

two principal markets: the Central Interconnected System (SIC) and the Greater Northern Interconnected System (SING) in Chile. These separate regions were formed with the privatization of the Chilean electricity sector in the 1980s, when all generation, transmission, and distribution systems were turned over to private ownership. AES Gener, one of the largest IPPs in Chile, operates 16 power plants in the country, accounting for 3,821 MW of capacity—2,241 MW in the SIC and 1,465 MW in the SING.

AES Gener enjoys a 22% share of the Chilean electricity market based on installed capacity. In the SING, where electricity consumption is dominated by mining (90%), the company's market share is approximately 32%. Mining interests represent about half of the country's industrial infrastructure. In the SIC, which covers over 92% of Chile's population, including the densely populated Santiago metropolitan area, the company's market share is 19%. As of March 15, 2012, AES

Gener's market capitalization was approximately \$5 billion.

In Chile, AES Gener's diverse generation portfolio—consisting of hydroelectric, coal, gas, diesel, and biomass facilities—allows it to flexibly and reliably operate under a variety of market and hydrological conditions. The company's power plants are located near the principal electricity consumption centers, including Santiago, Valparaiso, and Antofagasta, extending from Antofagasta in the north to Concepción in south-central Chile.

Shifting Fuel Mix

The availability of low-cost natural gas from Argentina delivered via pipelines built across the Andes Mountains in the late 1990s prompted construction of five combined cycle plants that were used to provide baseload generation to the SING. In 2004, Argentina began to curtail gas deliveries to Chile. The interruptions became increasingly severe over the next several years until gas deliveries were essentially

halted in 2007. Dual-fuel combustion turbines allowed generators to switch to more-expensive fuel oil and continue to operate, but at much higher market prices.

The mines in northern Chile, which produce about 35% of the world's copper, were struggling to find enough electricity to support current operations at the time—never mind support aggressive expansion plans to meet the rapidly rising global demand for copper. Mining in Chile, though very competitive globally, requires significant electricity, particularly for pumping water to the mines, which are located in arid desert areas.

In sum, the loss of natural gas supplies and rising demand for power by the mines made construction of a new coal-fired power plant complex a necessity. AES Gener set out to build a new, two-unit coal plant, and so much more.

An International Project

In August 2008, AES Gener, through its subsidiary Empresa Eléctrica Angamos S.A., began construction on the greenfield, two-unit 520-MW (470-MWnet) Angamos Power Plant (Figure 1). A critical part of the project was construction of the 140-kilometer (km) Angamos-Laber-

into transmission line and expansion of the Laberinto and Nueva Zaldívar substations, which were necessary for startup of the plant's transmission system. When completed in late 2011, the \$1.3 billion

Angamos plant was the first power plant constructed in the SING in more than 10 years. Table 1 lists key project milestones.

The expected average generation of the plant is 3,500 GWh/year. Its primary cus-

Table 1. Key milestones for the AES Angamos project. *Source: AES Corp.*

Project milestones	Date
Contract signed	Oct. 17, 2007
Limited Notice to Proceed 1, 2	Dec. 20, 2007
Limited Notice to Proceed 3	Dec. 30, 2007
EPC contract commencement date	Apr. 4, 2008
Boiler drum lift (Unit 1)	July 2009
Boiler drum lift (Unit 2)	Nov. 2009
Receive backfeed power	Jan. 2010
Initial firing (Unit 1)	Oct. 2010
Initial firing (Unit 2)	Mar. 2011
First synchronization (Unit 1)	Dec. 2010
First synchronization (Unit 2)	June 2011
Substantial completion (Unit 1)	Apr. 2011
Substantial completion (Unit 2)	Oct. 2011
Commercial operation	Unit 1: Apr. 11, 2011
	Unit 2: Oct. 10, 2011

Table 2. Key Angamos performance parameters. *Source: AES Corp.*

Parameter	Details	
Net single unit output	230.7 MW guarantee. Test: Unit 1, 242.8 MW; Unit 2, 244.1 MW	
Net plant heat rate (HHV)	10,478 Btu/kWh guarantee. Test: Unit 1, 9,849; Unit 2, 9,941	
Turbine throttle conditions	2,220.6 psig/1,049 F main steam 573 psig/1,049F reheat steam	
Fuel	Pulverized coal facility using blended coals: Bituminous (min. 54%) and subbituminous (max. 46%)	
Emissions	NO _x	500 mg/Nm ³
	SO ₂	200 mg/Nm ³
	PM10 (filterable)	50 mg/Nm ³
Boiler	Type	Subcritical
	Steam pressure	2,220.6 psig
	Steam temperature	1,049F
	Maximum continuous rating	741.4 tons/hr
Turbine	Rating	270 MWh
	Type	Single-flow high-pressure turbine, double-flow intermediate-pressure (reheat) turbine, four flow low-pressure condensing turbines
	Rotational speed	3,000 rpm
	Condenser vacuum	2.3 inches HgA
	Feedwater heaters	6 stages of feedwater heating, including deaerator
	Generator	Voltage
Capacity		330 MVA @ 0.85 PF
Boiler feed pump configuration	3 x 50%-sized pumps	
Cooling water system	Seawater cooling towers	
Water pretreatment system	Desalinated water plant for service water; demineralized water plant for boiler feedwater makeup	

1. Treasure in the desert. AES Gener recently completed construction of the \$1.3 billion, two-unit, 520-MW Angamos Power Plant in the desert of northern Chile. Located near the ocean, the plant features a water desalination plant and seawater cooling towers. The coal-hybrid plant includes 20 MW of electricity storage to stabilize local grid operations. *Courtesy: AES*



tomers are BHP Billiton of Australia subsidiaries Minera Escondida and Minera Spence—both large copper mines. A long-term power purchase agreement was essential for obtaining long-term financing for the project, which is discussed later.

South Korea's POSCO Engineering & Construction Co., Ltd. (POSCO) was the engineering, procurement, and construction (EPC) contractor. Doosan Heavy Industries

2. Clean air was a priority. A full complement of air quality control system (AQCS) equipment—an electrostatic precipitator, fabric filter, and spray dryer absorber for removing SO₂ from the stack gas—was included on both units. It was the first use of this AQCS in South America. *Courtesy: AES*



3. Ocean cooling. The desert location of the Angamos plant did not allow using potable water for the cooling tower. Instead, a seawater cooling tower was used, which runs at about two cycles of concentration. *Courtesy: AES Corp.*



& Construction supplied the two coal-fired steam boilers outfitted with low-NO_x burners, and Italian manufacturer Ansaldo Energia provided the steam turbines and the two 350-MVA air-cooled generators. (See Table 2 for key performance characteristics of the project.)

Other key components—such as the coal and ash-handling systems and air quality control system (AQCS), including electrostatic precipitators (ESP) and fabric filter (to remove particulates from the flue gas) and spray dryer absorber flue gas scrubber (to remove 95% of the SO₂)—were supplied by POSCO Plantec and other South Korean manufacturers. The AQCS used was the first of its kind in South America and was designed to meet the latest emissions standards, published in Chile in June 2010 (Figure 2).

POSCO received the notice to proceed for construction of the plant on Apr. 7, 2008.

Earlier, on Oct. 17, 2007, AES Gener had signed a turnkey EPC contract with POSCO valued at \$870 million. Although POSCO started engineering the project at contract signing, actual construction at the site did not begin until June 2008. The groundbreaking ceremony was held on August 27, 2008, with more than 150 participating, including Energy Minister of Chile Marcelo Tokman, Korean Ambassador to Chile Lim Chang-Soon, POSCO E&C CEO Han Soo-Yang, AES Gener Chairman Andres Gluski, and President Felipe Creron. “Angamos coal-fired power station with a generation capacity of a large scale will contribute to Chile’s economic growth,” said Soo-Yang in his congratulatory speech.

Unit 1 was first synchronized to the SING grid on Dec. 21, 2010, and entered commercial service in April 2011, approximately two weeks ahead of the scheduled completion date. The second unit entered commercial service in October 2011, also several weeks ahead of schedule. This represents a significant achievement, especially given that a magnitude 8.8 on the Richter scale earthquake hit southern Chile in February 2010 and delayed construction by about a month because 70% of the workers lived in the affected area. Even so, POSCO completed both units early and earned a \$7 million schedule bonus. In addition, unit performance tests found that the net output of both units was about 5% higher and the heat rate about 6% lower than the contract guarantee.

During the inauguration of Unit 1 in August 2011, the subsecretary of energy of Chile said, “This project meets the three basic conditions of energy policies with

which we work in our country since it is competitive, it gives energy supply security and meets the highest environmental standards. Angamos complies with all environmental standards promulgated by President Sebastián Piñera last February and meets the requirements of Latin-American and are at the same level of the European Union in terms of exigency.”

Unique Design Features

Fuel supply represented a special challenge because coal deliveries for Angamos are made by sea through a dry bulk terminal that was constructed in Mejillones, north of Angamos Port. Construction of the port coal-handling facilities was completed in January 2011. Bituminous and subbituminous coal, purchased on the global market, is transported to the plant’s transfer tower, from which it is distributed across the coal pile. The port’s solids-handling capacity is 1,500 metric tons (mt)/hour. It can receive cargoes up to 80,000 mt and has unloading rates between 17,000 and 20,000 mt/day.

Ash collected from the ESP hoppers is conveyed to a silo, where it is stored. The ash is then removed by truck and deposited in a special landfill or used in the construction industry as raw material for cement.

Although Angamos is located on the Pacific coast of northern Chile, 55 km north of Antofagasta and 1,300 km north of Santiago, it is situated in the 1,000 km-long Atacama Desert, the driest desert in the world, according to NASA. Annual rainfall in this desert is less than 0.004 inches, and some areas have gone hundreds of years with no rainfall. That makes water supply a major concern.

The Angamos plant is the first of its kind in South America to use seawater cooling towers (Figure 3). About 6,000 cubic meters/hour of seawater are supplied from a seawater makeup pumping station with siphon and submarine discharge pipe. This pumping station also supplies seawater to the thermal vapor compression (TVC) desalination plants to produce boiler makeup water, firewater, potable water, service water, and water for other facility uses.

Demineralized water is produced by a multiple-effect distillation system as well as with the TVC unit. Desalinated water is next treated in a new demineralization plant using electro-deionization units to produce boiler-quality makeup water. Given the arid location, this water system is cost-effective and sustainable for a plant located close to the ocean.

A containerized portable reverse osmosis plant was shipped from South Korea to provide potable water during construction.

Table 3. Major contractors and equipment suppliers to the Angamos project. *Source: AES Corp.*

What	Who
Plant engineering and design	Hyundai Engineering Co., Ltd.
Plant construction	Sigdo Koppers S.A.
Steam generator	Doosan Heavy Industries Co., Ltd.
Steam generator erection	Ansaldo Energia/Sigdo Koppers S.A.
Steam turbine generators	Ansaldo Energia
BESS battery supplier	A123
Cooling tower	Hamon Korea
Fabric filter	STX
Material handling	Baekdoo
Semi-dry flue gas desulfurization	Gia Niro/STX
Distributed control system	Emerson Korea Inc.
Sootblowers, furnace wall cleaning	Doosan HHI
Condensers	Bumwoo Eng. Co., Ltd.
Feedwater heaters	Bumwoo Eng. Co., Ltd.
Condensate pumps	Hyundai Heavy Industries Co., Ltd.
Boiler feedwater pumps	Hyundai Heavy Industries Co., Ltd.
Fuel handling	Posco Machinery & Engineering Co., Ltd.
Auxiliary transformers	Hyundai Heavy Industries Co., Ltd.
Large power transformers	Hyundai Heavy Industries Co., Ltd.
Dry ash handling	Baekdoo Industry Machinery Co., Ltd.
Wet ash handling	Baekdoo Industry Machinery Co., Ltd.
Limestone preparation	Niro/STX
Water systems	GTF/GE

4. Battery storage lockers. Inside the Angamos BESS are about one million advanced lithium-ion battery cells, divided between 10 2-MW battery containers and five 4-MW power controls containers—plus the power electronics to manage the system operation. *Courtesy: AES Corp.*



Table 3 lists the major contributors to the success of Angamos.

Because Chile is seismically active, the plant was designed to withstand a medium-intensity earthquake without tripping the plant offline. Should a severe earthquake occur, the plant design includes features that will minimize the length of a forced outage.

Buy the BESS

In close proximity to the Angamos plant, a 20-MW high-efficiency lithium-ion battery energy storage system (BESS) was installed. The advanced reserve capacity provided by the BESS enables Angamos to generate an additional 20 MW—that would otherwise be tied up to maintain the plant’s grid spinning reserve—for up to 15 minutes virtually any time of the year. (Spinning reserve is used during an unexpected transmission loss, the failure of a power generator, or another accident that might otherwise necessitate reducing power to customers.) This “hybrid” part of the plant allows the plant to reduce the mandated spinning reserve, thus allowing the plant to operate at increased load. The BESS increases generation from the Angamos plant by 4%, or about 130 GWh each year. The BESS entered commercial service in May 2012 (Figure 4).

The Angamos project built on the success of an initial partnership between AES Gener and AES Energy Storage, both subsidiaries of AES Corp., to develop and install a 12-MW BESS associated with AES Gener’s Norgener power plant, also in the SING, 172 km from Angamos, in only 15 months.

“As one of the largest power generators in Chile, we’re consistently looking for ways to unlock [the] value of our existing plants while maintaining grid reliability and flexibility,” said Felipe Ceron, CEO of AES Gener. “Since 2009, we’ve been working with AES Energy Storage to free up generating capacity at our Norgener plant by employing a battery-based installation to meet the power system’s obligations for spinning reserve. That project has been in commercial operation for nearly three years, and we’re now applying the service on a larger scale with Angamos.”

AES Energy Storage worked with AES Gener throughout design, development, and installation of the Angamos BESS. Both entities worked with the CDEC-SING operator and other partners to configure the Angamos BESS to meet performance requirements of the electrical system operator and enable it to respond autonomously within established parameters. The BESS

features system monitoring, SCADA, and integration with other operational systems. A123 Systems supplied the lithium-ion batteries for the project. ABB provided the power controls modules.

People First

Angamos is a significant contributor to the development of Chile's energy sector and the entire country. It also benefited the region by creating more than 3,000 jobs during the construction phase. Hiring local manpower was a priority, and some of the workers are staying with the company as plant operators.

To integrate the project with the local community, the company has developed a cooperation agreement with municipal schools to align students' capabilities with project needs. In addition, as part of the company's social responsibility program, it committed to enhancing the infrastructure of the Municipal Sport Center to improve the quality of life.

AES Gener maintains strict environmental and safety standards at its operations. Maintaining a workplace free of safety incidents was a remarkable challenge for a project that took around 14 million man-hours in a multicultural environment. The project recorded no fatalities and achieved 5 million man-hours without a lost-time accident and without a fatality. The achievement of that milestone demonstrated the strength of the programs and culture at the construction facility, such as proactive AES actions that include safety walks and work activity observations. The development of 10 Safety Management System action plans and completing each of them was a strong indication

of the company's dedication to continuous safety improvement. Making the construction safety requirements a priority and the routine identification of workplace hazards was certainly a key to the milestone achievement.

Awards and Honors

AES Gener was named international recipient of the 85th Annual Edison Electric Institute's Edison Award on June 4, 2012, the electric utility industry's most prestigious honor, for its "distinguished leadership, innovation and contribution to the advancement of the electric industry for the benefit of all."

"AES Gener made the completion of the Angamos coal-fired power plant one of its highest priorities, and in doing so, illustrated the kind of contributions our industry is capable of making to customers," EEI President Thomas R. Kuhn said during the presentation.

"We are very proud of AES Gener for winning this prestigious award. The Angamos project combines low-cost, reliable power with our innovative lithium-ion batteries to increase available capacity and efficiency," said Andres Gluski, president and CEO of AES. "By delivering innovative projects such as Angamos, AES helps meet a growing demand for affordable energy in the markets we serve."

Financing the \$1.3 billion Angamos plant represented a significant challenge, as the process was initiated in 2008 and closed in the midst of the international financial crisis. However, a syndication of international banks, reassured by the financial strength of AES Gener, the EPC

contractor, and the oft-takers, allowed AES Gener to secure nearly \$1 billion under a 72/28 debt-to-equity project finance structure just months after the debt market meltdown in September 2008. Notably, \$675 million was guaranteed by Korea Export Insurance Corp. Financing also was guaranteed by two long-term contracts: with Minera Escondida, for 340 MW for 18 years, and with Minera Spence, for 90 MW for 15 years.

The Angamos project was also recognized as the Best Deal of the Year by *LatinFinance*, *Project Finance International*, and *Infrastructure Journal* in 2008.

Environmental Concerns

AES Gener, in partnership with several companies in the nearby city of Mejillones, formed the "Fundación para la Sustentabilidad del Gaviotín Chico" (Foundation for Sustainability of the Small Tern) with the aim of instituting measures that will preserve bird migration. It was the first time in Chile that the public and private companies joined together to contribute to the conservation of an ecosystem affected by the development of large infrastructure projects.

The foundation has found that the population of Gaviotín Chico has remained stable in the area of Mejillones, where the birds have found new nesting sites. With input from specialists working for this organization, companies and private citizens better understand the life cycle and migratory patterns of this bird species and have taken concrete actions to control the hazards that might affect them. ■

—**Dr. Robert Peltier, PE** is *POWER's* editor-in-chief.

