Integrated gasification combined cycle

From Wikipedia, the free encyclopedia

An **integrated gasification combined cycle** (**IGCC**) is a technology that uses a high pressure gasifier to turn coal and other carbon based fuels into pressurized gas—synthesis gas (syngas). It can then remove impurities from the syngas prior to the power generation cycle. Some of these pollutants, such as sulfur, can be turned into re-usable byproducts through the Claus process. This results in lower emissions of sulfur dioxide, particulates, mercury, and in some cases carbon dioxide. With additional process equipment, a water-gas shift reaction can increase gasification efficiency and reduce carbon monoxide emissions by converting it to carbon dioxide. The resulting carbon dioxide from the shift reaction can be separated, compressed, and stored through sequestration. Excess heat from the primary combustion and syngas fired generation is then passed to a steam cycle, similar to a combined cycle gas turbine. This process results in improved thermodynamic efficiency compared to conventional pulverized coal combustion.

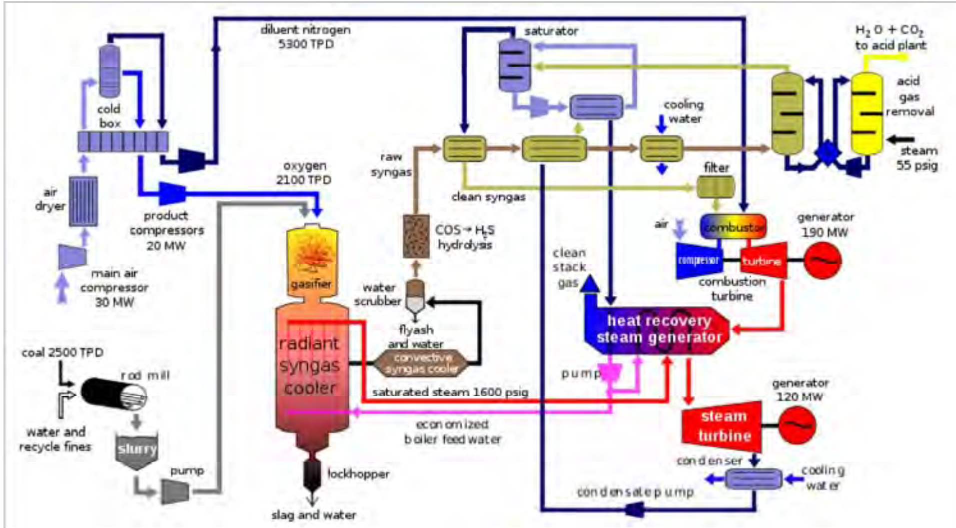
Contents

Significance

Coal can be found in abundance in the USA and many other countries and its price has remained relatively constant in recent years. Of the traditional fossil fuels - oil, coal, and natural gas - coal is used as a feedstock for 40% of global electricity generation. Fossil fuel consumption and its contribution to large-scale, detrimental environmental changes is becoming a pressing issue, especially in light of the Paris Agreement. In particular, coal contains more CO_2 per BTU than oil or natural gas and is responsible for 43% of CO_2 emissions from fuel combustion. Thus, the lower emissions that IGCC technology allows through gasification and pre-combustion carbon capture is crucial to addressing aforementioned concerns.[1]

Operations

Below is a schematic flow diagram of an IGCC plant:



Block diagram of IGCC power plant, which utilizes the HRSG

The gasification process can produce syngas from a wide variety of carbon-containing feedstocks, such as high-sulfur coal, heavy petroleum residues and biomass.

The plant is called *integrated* because (1) the syngas produced in the gasification section is used as fuel for the gas turbine in the combined cycle, and (2) steam produced by the syngas coolers in the gasification section is used by the steam turbine in the combined cycle. In this example the syngas produced is used as fuel in a gas turbine which produces electrical power. In a normal combined cycle, so-called "waste heat" from the gas turbine exhaust is used in a Heat Recovery Steam Generator (HRSG) to make steam for the steam turbine cycle. An IGCC plant improves the overall process efficiency by adding the higher-temperature steam produced by the gasification process to the steam turbine cycle. This steam is then used in steam turbines to produce additional electrical power.

IGCC plants are advantageous in comparison to conventional coal power plants due to their high thermal efficiency, low non-carbon greenhouse gas emissions and capability to process low grade coal. The key disadvantage is the amount of CO2 released without pre-combustion capture.[2]

Process overview

- The solid coal is gasified to produce syngas, or synthetic gas. Syngas is synthesized by gasifying coal in a closed pressurized reactor with a shortage of oxygen. The shortage of oxygen ensures that coal is broken down by the heat and pressure as opposed to burning completely. The chemical reaction between coal and oxygen produces a product that is a mixture of carbon and hydrogen, or syngas. $C_xH_y + (x/2)O_2 \rightarrow (x)CO_2 + (y/2)H_2$
- The heat from the production of syngas is used to produce steam from cooling water which is then used for steam turbine electricity production.
- The syngas must go through a pre-combustion separation process to remove CO_2 and other impurities to produce a more purified fuel. Three steps are necessary for the separation of impurities:[3]

1. Water-gas-shift reaction. The reaction that occurs in a water-gas-shift reactor is $CO + H_2O \rightleftharpoons CO_2 + H_2$. This produces a syngas with a higher composition of hydrogen fuel which is more efficient for burning later in combustion.
2. Physical separation process. This can be done through various mechanisms such as absorption, adsorption or membrane separation.
3. Drying, compression and storage/shipping.

- The resulting syngas fuels a combustion turbine that produces electricity. At this stage the syngas is fairly pure H_2.

Benefits and drawbacks

A major drawback of using coal as a fuel source is the emission of carbon dioxide and other pollutants, including sulfur dioxide, nitrogen oxide, mercury, and particulates. Almost all coal-fired power plants use pulverized coal combustion, which grinds the coal to increase the surface area, burns it to make steam, and runs the steam through a turbine to generate electricity. Pulverized coal plants can only capture carbon dioxide after combustion when it is diluted and harder to separate. In comparison, gasification in IGCC allows for separation and capture of the concentrated and pressurized carbon dioxide before combustion. Syngas cleanup includes filters to remove bulk particulates, scrubbing to remove fine particulates, and solid absorbents for mercury removal. Additionally, hydrogen gas is used as fuel, which produces no pollutants under combustion.[4]

IGCC also consumes less water than traditional pulverized coal plants. In a pulverized coal plant, coal is burned to produce steam, which is then used to create electricity using a steam turbine. Then steam exhaust must then be condensed with cooling water, and water is lost by evaporation. In IGCC, water consumption is reduced by combustion in a gas turbine, which uses the generated heat to expand air and drive the turbine. Steam is only used to capture the heat from the combustion turbine exhaust for use in a secondary steam turbine. Currently, the major drawback is the high capital cost compared to other forms of power production. To become an economically viable source of energy, gasification-based plants must become comparable to pulverized coal and natural gas plants in terms of capital costs.

Installations

The DOE Clean Coal Demonstration Project[5] helped construct 3 IGCC plants: Edwarsport Power Station in Edwardsport, Indiana, Polk Power Station in Tampa, Florida (online 1996), and Pinon Pine in Reno, Nevada. In the Reno demonstration project, researchers found that then-current IGCC technology would not work more than 300 feet (100m) above sea level.[6] The DOE report in reference 3 however makes no mention of any altitude effect, and most of the problems were associated with the solid waste extraction system. The Wabash River and Polk Power stations are currently operating, following resolution of demonstration start-up problems, but the Piñon Pine project encountered significant problems and was abandoned.

The US DOE's Clean Coal Power Initiative (CCPI Phase 2) selected the Kemper Project as one of two projects to demonstrate the feasibility of low emission coal-fired power plants. Mississippi Power began construction on the Kemper Project in Kemper County, Mississippi, in 2010 and is poised to begin operation in 2016, though there have been many delays.[7] In March, the projected date was further pushed back from early 2016 to August 31, 2016, adding $110 million to the total and putting the project 3 years behind schedule. The electrical plant is a flagship Carbon Capture and Storage (CCS) project that burns lignite coal and utilizes pre-combustion IGCC technology with a projected 65% emission capture rate.[8]

The first generation of IGCC plants polluted less than contemporary coal-based technology, but also polluted water; for example, the Wabash River Plant was out of compliance with its water permit during 1998–2001[9] because it emitted arsenic, selenium and cyanide. The Wabash River Generating Station is now wholly owned and operated by the Wabash River Power Association.

IGCC is now touted as *capture ready* and could potentially be used to capture and store carbon dioxide.[10][11] (See FutureGen) Poland's Kędzierzyn will soon host a Zero-Emission Power & Chemical Plant that combines coal gasification technology with Carbon Capture & Storage (CCS). This installation had been planned, but there has been no information about it since 2009. Other operating IGCC plants in existence around the world are the Alexander (formerly Buggenum) in the Netherlands, Puertollano in Spain, and JGC in Japan.

The Texas Clean Energy project plans to build a 400 MW IGCC facility that will incorporate carbon capture, utilization and storage (CCUS) technology. The project will be the first coal power plant in the United States to combine IGCC and 90% carbon capture and storage. Commercial operation is due to start in 2018.[12]

There are several advantages and disadvantages when compared to conventional post combustion carbon capture and various variations [13]

Cost and reliability

A key issue in implementing IGCC is its high capital cost, which prevents it from competing with other power plant technologies. Currently, ordinary pulverized coal plants are the lowest cost power plant option. The advantage of IGCC comes from the ease of retrofitting existing power plants that could offset the high capital cost. In a 2007 model, IGCC with CCS is the lowest-cost system in all cases. This model estimated IGCC with CCS to cost 71.9 $US2005/MWh compared to pulverized coal with CCS that cost 88 $US2005/MWh and natural gas combined cycle with CCS that cost 80.6 $US2005/MWh. The cost of electricity value estimated was noticeable sensitive to the price of natural gas and the inclusion of carbon storage and transport costs.[14]

The potential benefit of retrofitting has so far, not offset the cost of IGCC with carbon capture technology. A 2013 report by the U.S. Energy Information Administration demonstrates that the overnight cost of IGCC with CCS has increased 19% since 2010. Amongst the three power plant types, pulverized coal with CCS has an overnight capital cost of $5,227 (2012 dollars)/kW, IGCC with CCS has an overnight capital cost of $6,599 (2012 dollars)/kW, and natural gas combined cycle with CCS has an overnight capital cost of $2,095 (2012 dollars)/kW. Pulverized coal and NGCC costs did not change significantly since 2010. The report further relates that the 19% increase in IGCC cost is due to recent information from IGCC projects that have gone over budget and cost more than expected.[15]

Recent testimony in regulatory proceedings show the cost of IGCC to be twice that predicted by Goddell, from $96 to 104/MWhr.[16][17] That's before addition of carbon capture and sequestration (sequestration has been a mature technology at both Weyburn in Canada (for enhanced oil recovery) and Sleipner in the North Sea at a commercial scale for the past ten years)—capture at a 90% rate is expected to have a $30/MWh additional cost.[18]

Wabash River was down repeatedly for long stretches due to gasifier problems. The gasifier problems have not been remedied—subsequent projects, such as Excelsior's Mesaba Project, have a third gasifier and train built in. However, the past year has seen Wabash River running reliably, with availability comparable to or better than other technologies.

The Polk County IGCC has design problems. First, the project was initially shut down because of corrosion in the slurry pipeline that fed slurried coal from the rail cars into the gasifier. A new coating for the pipe was developed. Second, the thermocoupler was replaced in less than two years; an indication that the gasifier had problems with a variety of feedstocks; from bituminous to sub-bituminous coal. The gasifier was designed to also handle lower rank lignites. Third, unplanned down time on the gasifier because of refractory liner problems, and those problems were expensive to repair. The gasifier was originally designed in Italy to be half the size of what was built at Polk. Newer ceramic materials may assist in improving gasifier performance and longevity. Understanding the operating problems of the current IGCC plant is necessary to improve the design for the IGCC plant of the future. (Polk IGCC Power Plant, http://www.clean-energy.us/projects/polk_florida.html.) Keim, K., 2009, IGCC A Project on Sustainability Management Systems for Plant Re-Design and Re-Image. This is an unpublished paper from Harvard University)

General Electric is currently designing an IGCC model plant that should introduce greater reliability. GE's model features advanced turbines optimized for the coal syngas. Eastman's industrial gasification plant in Kingsport, TN uses a GE Energy solid-fed gasifier. Eastman, a fortune 500 company, built the facility in 1983 without any state or federal subsidies and turns a profit.[19][20]

There are several refinery-based IGCC plants in Europe that have demonstrated good availability (90-95%) after initial shakedown periods. Several factors help this performance:

1. None of these facilities use advanced technology (*F* type) gas turbines.
2. All refinery-based plants use refinery residues, rather than coal, as the feedstock. This eliminates coal handling and coal preparation equipment and its problems. Also, there is a much lower level of ash produced in the gasifier, which reduces cleanup and downtime in its gas cooling and cleaning stages.
3. These non-utility plants have recognized the need to treat the gasification system as an up-front chemical processing plant, and have reorganized their operating staff accordingly.

Another IGCC success story has been the 250 MW Buggenum plant in The Netherlands. It also has good availability. This coal-based IGCC plant currently uses about 30% biomass as a supplemental feedstock. The owner, NUON, is paid an incentive fee by the government to use the biomass. NUON has constructed a 1,311 MW IGCC plant in the Netherlands, comprising three 437 MW STEG units. The Nuon Magnum IGCC power plant was commissioned in 2011, and was officially opened in June 2013. Mitsubishi Heavy Industries has been awarded to construct the power plant.[21] Following a deal with environmental organizations, NUON has been prohibited from using the Magnum plant to burn coal and biomass, until 2020. Because of high gas prices in the Netherlands, two of the three units are currently offline, whilst the third unit sees only low usage levels. The relatively low 59% efficiency of the Magnum plant means that more efficient CCGT plants (such as the Hemweg 9 plant) are preferred to provide (backup) power.

A new generation of IGCC-based coal-fired power plants has been proposed, although none is yet under construction. Projects are being developed by AEP, Duke Energy, and Southern Company in the US, and in Europe by ZAK/PKE, Centrica (UK), E.ON and RWE (both Germany) and NUON (Netherlands). In Minnesota, the state's Dept. of Commerce analysis found IGCC to have the highest cost, with an emissions profile not significantly better than pulverized coal. In Delaware, the Delmarva and state consultant analysis had essentially the same results.

The high cost of IGCC is the biggest obstacle to its integration in the power market; however, most energy executives recognize that carbon regulation is coming soon. Bills requiring carbon reduction are being proposed again both the House and the Senate, and with the Democratic majority it seems likely that with the next President there will be a greater push for carbon regulation. The Supreme Court decision requiring the EPA to regulate carbon (Commonwealth of Massachusetts et al. v. Environmental Protection Agency et al.)[20] also speaks to the likelihood of future carbon regulations coming sooner, rather than later. With carbon capture, the cost of electricity from an IGCC plant would increase approximately 33%. For a natural gas CC, the increase is approximately 46%. For a pulverized coal plant, the increase is approximately 57%.[22] This potential for less expensive carbon capture makes IGCC an attractive choice for keeping low cost coal an available fuel source in a carbon constrained world. However, the industry needs a lot more experience to reduce the risk premium. IGCC with CCS requires some sort of mandate, higher carbon market price, or regulatory framework to properly incentivize the industry.[23]

In Japan, electric power companies, in conjunction with Mitsubishi Heavy Industries has been operating a 200 t/d IGCC pilot plant since the early '90s. In September 2007, they started up a 250 MW demo plant in Nakoso. It runs on air-blown (not oxygen) dry feed coal only. It burns PRB coal with an unburned carbon content ratio of <0.1% and no detected leaching of trace elements. It employs not only *F* type turbines but *G* type as well. (see gasification.org link below)

Next generation IGCC plants with CO_2 capture technology will be expected to have higher thermal efficiency and to hold the cost down because of simplified systems compared to conventional IGCC. The main feature is that instead of using oxygen and nitrogen to gasify coal, they use oxygen and CO_2. The main advantage is that it is possible to improve the performance of cold gas efficiency and to reduce the unburned carbon (char).

As a reference for powerplant efficiency:

- With Frame E gas turbine, 30bar quench gas cooling, Cold Temperature Gas Cleaning and 2 level HRSC it is possible to achieve around 38% energy efficiency.
- With Frame F gas turbine, 60 bar quench gasifier, Cold Temperature Gas Cleaning and 3 level+RH HRSC it is possible to achieve around 45% energy efficiency.
- Latest development of Frame G gas turbines, ASU air integration, High temperature desulfurization may shift up performance even further.[24]

The CO_2 extracted from gas turbine exhaust gas is utilized in this system. Using a closed gas turbine system capable of capturing the CO_2 by direct compression and liquefication obviates the need for a separation and capture system.[25]

CO_2 capture in IGCC

Pre-combustion CO_2 removal is much easier than CO_2 removal from flue gas in post-combustion capture due to the very high concentration of CO_2 after the water-gas-shift reaction. During pre-combustion in IGCC, the partial pressure of CO_2 is nearly 1000 times higher than in post-combustion flue gas.[26] Due to the high concentration of CO_2 pre-combustion, physical solvents, such as Selexol and Rectisol, are preferred for the removal of CO_2 vs that of chemical solvents. Physical solvents work by absorbing the acid gases without the need of a chemical reaction as in traditional amine based solvents. The solvent can then be regenerated, and the CO_2 desorbed, by reducing the pressure. The biggest obstacle with physical solvents is the need for the syngas to be cooled before separation and reheated afterwards for combustion. This requires energy and decreases overall plant efficiency.[26]

Testing

National and international test codes are used to standardize the procedures and definitions used to test IGCC Power Plants. Selection of the test code to be used is an agreement between the purchaser and the manufacturer, and has some significance to the design of the plant and associated systems. In the United States, The American Society of Mechanical Engineers published the

Performance Test Code for IGCC Power Generation Plants (PTC 47) in 2006 which provides procedures for the determination of quantity and quality of fuel gas by its flow rate, temperature, pressure, composition, heating valve, and its content of contaminants.[27]

IGCC emission controversy

In 2007, the New York State Attorney General's office demanded full disclosure of "financial risks from greenhouse gases" to the shareholders of electric power companies proposing the development of IGCC coal-fired power plants. "Any one of the several new or likely regulatory initiatives for CO_2 emissions from power plants - including state carbon controls, EPA's regulations under the Clean Air Act, or the enactment of federal global warming legislation - would add a significant cost to carbon-intensive coal generation";[28] U.S. Senator Hillary Clinton from New York has proposed that this full risk disclosure be required of all publicly traded power companies nationwide.[29] This honest disclosure has begun to reduce investor interest in all types of existing-technology coal-fired power plant development, including IGCC.

Senator Harry Reid (Majority Leader of the 2007/2008 U.S. Senate) told the 2007 Clean Energy Summit that he will do everything he can to stop construction of proposed new IGCC coal-fired electric power plants in Nevada. Reid wants Nevada utility companies to invest in solar energy, wind energy and geothermal energy instead of coal technologies. Reid stated that global warming is a reality, and just one proposed coal-fired plant would contribute to it by burning seven million tons of coal a year. The long-term healthcare costs would be far too high, he claimed (no source attributed). "I'm going to do everything I can to stop these plants.", he said. "There is no clean coal technology. There is cleaner coal technology, but there is no clean coal technology."[30]

One of the most efficient ways to treat the H_2S gas from an IGCC plant is by converting it into sulphuric acid in a wet gas sulphuric acid process wsa process. However, the majority of the H_2S treating plants utilize the modified Claus process, as the sulphur market infrastructure and the transportation costs of sulphuric acid versus sulphur are in favour of sulphur production.

See also

- Relative cost of electricity generated by different sources
- Environmental impact of the coal industry
- Integrated Gasification Fuel Cell Cycle

References

1. Padurean, Anamaria (5 July 2011). "Pre-combustion carbon dioxide capture by gas–liquid absorption for Integrated Gasification Combined Cycle power plants" (PDF). *International Journal of Greenhouse Gas Control*. **7**: 1–11. doi:10.1016/j.ijggc.2011.12.007. Retrieved 28 April 2016.
2. Padurean, Anamaria (5 July 2011). "Pre-combustion carbon dioxide capture by gas–liquid absorption for Integrated Gasification Combined Cycle power plants" (PDF). *International Journal of Greenhouse Gas Control*. **7**: 1. doi:10.1016/j.ijggc.2011.12.007. Retrieved 28 April 2016.
3. Stephens, Jennie C. (May 2, 2005). "Coupling CO_2 Capture and Storage with Coal Gasification: Defining "Sequestration-Ready" IGCC" (PDF). *Energy Technology Innovation Project, Harvard University*. Retrieved 1 May 2016.
4. "Syngas Composition for IGCC". *National Energy Technology Laboratory*. US Department of Energy. Retrieved 30 April 2016.
5. "Clean Coal Research | Department of Energy". *www.fossil.energy.gov*. Retrieved 2016-05-27.
6. Source: Joe Lucas, Executive Director of Americans for Balanced Energy Choices, as interviewed on NPR's Science Friday, Friday May 12, 2006
7. Schlissel, David. "The Kemper IGCC Project: Cost and Schedule Risks." (PDF). The Institute for Energy Economics and Financial Analysi.
8. "Kemper County IGCC Fact Sheet: Carbon Dioxide Capture and Storage Project". *Caron Capture & Sequestration Technologies @ MIT*. MIT. Retrieved 28 April 2016.
9. Wabash (August 2000). "Wabash River Coal Gasification Repowering Project Final Technical Report" (PDF). *Work performed under Cooperative Agreement DE-FC21-92MC29310*. The U.S. Department of Energy / Office of Fossil Energy / National Energy Technology Laboratory / Morgantown, West Virginia. Retrieved 2008-06-30. "As a result, process waste water arising from use of the current feedstock, remains out of permit compliance due to elevated levels of arsenic, selenium and cyanide. To rectify these concerns, plant personnel have been working on several potential equipment modifications and treatment alternatives to bring the discharge back into compliance. Wabash River is currently obligated to resolve this issue by September 2001. [p. ES-6] Elevated levels of selenium, cyanide and arsenic in the waste water have caused the process waste water to be out of permit compliance. Daily maximum values, though not indicated in the table above, were routinely exceeded for selenium and cyanide, and only occasionally for arsenic. [p. 6-14, Table 6.1L]"
10. El Gemayel, Jimmy. "Simulation of the integration of a bitumen upgrading facility and an IGCC process with carbon capture". FUEL Journal. Retrieved 2014-01-30.
11. "Products & Services". Gepower.com. Retrieved 2013-10-13.
12. *Texas Clean Energy Project (TCEP)*
13. Fred, Dr. "Integrated Gasification Combined Cycle (IGCC) for Carbon Capture & Storage | Claverton Group". Claverton-energy.com. Retrieved 2013-10-13.

14. Rubin, Edward (26 April 2007). "Cost and performance of fossil fuel power plants with CO2 capture and storage" (PDF). *Energy Policy*. **34**: 4444–4454. Retrieved 5 May 2016.
15. "Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants". *U.S. Energy Information Adminsitration*. U.S. Energy Information Administration. Retrieved 5 May 2016.
16. Testimony of Dr. Elion Amit, Minnesota Dept. of Commerce.
17. "State of Minnesota : Office of the Attorney General" (PDF). Mncoalgasplant.com. Retrieved 2013-10-13.
18. [1] (http://www.prajhipurity.net/?p=list&t=insightnote&sp=1&f=sectors,ccs/publish,Yes/&sort=2&ic
19. Goodell, Jeff. "Big Coal." New York, Houghton Mifflin. 2006
20. "Eastman Chemical Company - The results of insight™". Eastman.com. Retrieved 2013-10-13.
21. [2] (http://www.nuon.com/about-nuon/Innovative-projects/magnum.jsp) Archived (https://web.archive.org/web/20081015025223/http://www.nuon.co nuon/Innovative-projects/magnum.jsp) October 15, 2008, at the Wayback Machine.
22. Rubin, Edward (26 April 2007). "Cost and performance of fossil fuel power plants with CO2 capture and storage" (PDF). *Energy Policy*. **34**: 4444–4454. Retrieved 5 May 2016.
23. "Costs and Challenges of CCS". *Clear Air Task Force*. Retrieved 5 May 2016.
24. Analisi Termodinamica di cicli Igcc avanzati, G.Lozza P.Chiesa, Politecnico di Milano, ati2000 conference proceedings
25. Inumaru, Jun - senior research scientist, Central Research Institute of Electric Power Industry (CRIEPI)(Japan) G8 Energy Ministerial Meeting Symposium, Nikkei Weekly.
26. Davidson, Robert (December 2011). "Pre-combustion capture of CO2 in IGCC plants". *Profiles-IEA Clean Coal Centre*. Retrieved 1 May 2016.
27. "Archived copy". Archived from the original on 2016-03-04. Retrieved 2013-11-19.
28. [3] (http://www.marketwire.com/mw/rel_us_print.jsp?id=776699)
29. [4] (http://www.hillaryclinton.com/files/pdf/poweringamericasfuture.p Archived (https://web.archive.org/web/20080124001602/http://www.hillary January 24, 2008, at the Wayback Machine.
30. [5] (http://publicutilities.utah.gov/news/cleanenergysummitreidoppose Archived (https://web.archive.org/web/20110721072632/http://publicutilitie July 21, 2011, at the Wayback Machine.

External links

- Huntstown: Ireland's most efficient power plant (http://www.powergeneration.siemens.com/en/press/pg200303017e/index.cfm) @ Siemens Power Generation website
- Natural Gas Combined-cycle Gas Turbine Power Plants (http://www.westgov.org/wieb/electric/Transmission%20Protocol/SSG-WI/pnw_5pp_02.pdf) Northwest Power Planning Council, New Resource Characterization for the Fifth Power Plan, August 2002
- Combined cycle solar power (http://www.ingenia.org.uk/ingenia/articles.aspx?index=244&print=true)

Categories: Thermodynamic cycles | Chemical processes | Power station technology | Energy conversion