CARBON CAPTURE AND STORAGE

4/25/2021

INTRODUCTION

Concerns about global climatic change has initiated efforts to develop the technology of "Carbon Capture and Storage," also called "Carbon Capture and Sequestration," CCS. The technology targets CO_2 from coal-fired power plants, cement manufacturing, natural gas production, petroleum refining and other major polluting industrial processes.

One approach is to liquefy the CO_2 gas and inject it into deep saline water aquifers and depleted gas and oil fields below the water table at a depth greater than 800 meters and up to 1,000 meters or 3,280 feet. Saline water aquifers are permeable geological formations saturated with a salty brine with a cap rock that separates it from the surface potable groundwater. It is fortunate that CO_2 is readily soluble in brines. Brines mixed with CO_2 possess a higher density than the surrounding brine making them less likely to migrate upward out of the saline aquifer.

The separation of carbon emissions for underground storage reduces a power plant overall thermal efficiency. Coal power plants have a thermal efficiency of about 44 percent, which CO_2 separation, liquefaction and pumping reduces it to about 34 percent.

Figure 1. The Schwarze Pumpe power plant at Sprenberg, Germany. First plant storing CO_2 deep underground in saline aquifers. Source: der Spiegel.

Another approach is to inject the pressurized gas into porous formations underground such as sandstone formations or depleted natural gas fields. Other approaches such as incorporation in the process of cement manufacturing and algae growing have been proposed [1].

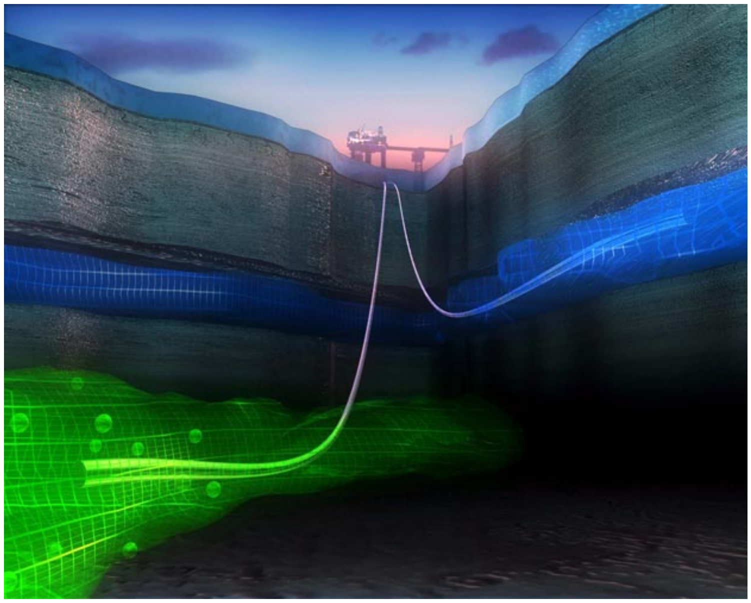

Figure 2. Concurrent production of natural gas and storage of CO_2 in a gas field. Source: StatoilHydro.

Figure 3. One million tons of CO_2 emissions per year from natural gas production are stored in a sandstone deposit 800 meters under the North Sea at the Sleipner gas field off the Norwegian coast. Source: StatoilHydro.

The magnitudes of production of CO_2 from different hydrocarbon fuels per unit of energy produced and per unit of mass of fuel burned are listed in Table 1.

Table 1. Carbon dioxide Emissions from different sources per unit of energy produced and per unit of fuel mass burned. Coal is the highest emitter of CO_2 per unit of energy produced.

Source	[kg CO_2 / GJ energy]	[kg CO_2 / kg fuel]
Gasoline	73.0	3.20
Diesel, Light Fuel Oil	74.0	3.16
Heavy Fuel Oil	78.0	3.15
Natural Gas, methane	56.9	2.74
Coal	95.0	2.33, steam coal 2.52, other

In the USA, China, India, and Russia, coal remains the cheapest and most preferred fuel for electricity production. More than 11 trillion tons of carbon are embedded in the Earth crust. Humanity can only allow 0.3 trillion tons of them to be released into the Earth's atmosphere up to the year 2100; otherwise climatic change will become irreversible.

The nations that rely on coal for power production are reluctant to participate in a United Nations (UN) climate change agreement unless they can assume that they can continue to use coal and dispose of the CO_2 it generates into the atmosphere.

Coal will remain indispensable in the long term for affordable electrical power generation. Without CO_2 capture and storage or sequestration, the days of cheap, coal-based power would be numbered.

ENVIRONMENTAL RULES AND ECONOMICS

The USA Environmental Protection Agency (EPA) proposed a new carbon pollution rule that encourages the use of natural gas in power production and discourages the use of coal-fired power plants. The rule sets limits on emissions of CO_2 from new power plants in line with emissions rates from modern, combined-cycle natural gas plants but far lower than anything existing operational coal-fired plant can achieve [2,3].

A National Academy of Science's report on America's energy future estimates that one would need a price on carbon emissions of well in excess of $50 per ton to make a coal plant with CCS cost competitive with a combined cycle natural gas plant without CCS. Carbon emissions in the European Union were trading in 2012 at the $9–10 per metric tonne level. A higher price is needed to make CCS more economically viable than the purchase of polluting industries of carbon credits [2].

Under the European Union's emissions trading program, companies pay fees for each ton of CO_2 that they release into the atmosphere. The E.on Group in Germany estimates that the total annual cost of these emissions fees, currently at €1 billion or $1.4 billion, will rise to €20 billion or $28 billion by 2020. Pipelines and storage sites would be costly, but they would permanently relieve the electrical utility companies from the burden of CO_2 emissions trading. The environmentalist groups counter that the money should be dedicated into renewable energy projects instead.

CO_2 STORAGE CAPACITY

The coal power production industry in the USA is committing itself to the technology of Carbon Capture and Storage (CCS). Six of the 15 coal-fired plants currently holding permits have incorporated into their business plans the provision to capture the CO_2 from burning coal and storing the CO_2 emissions.

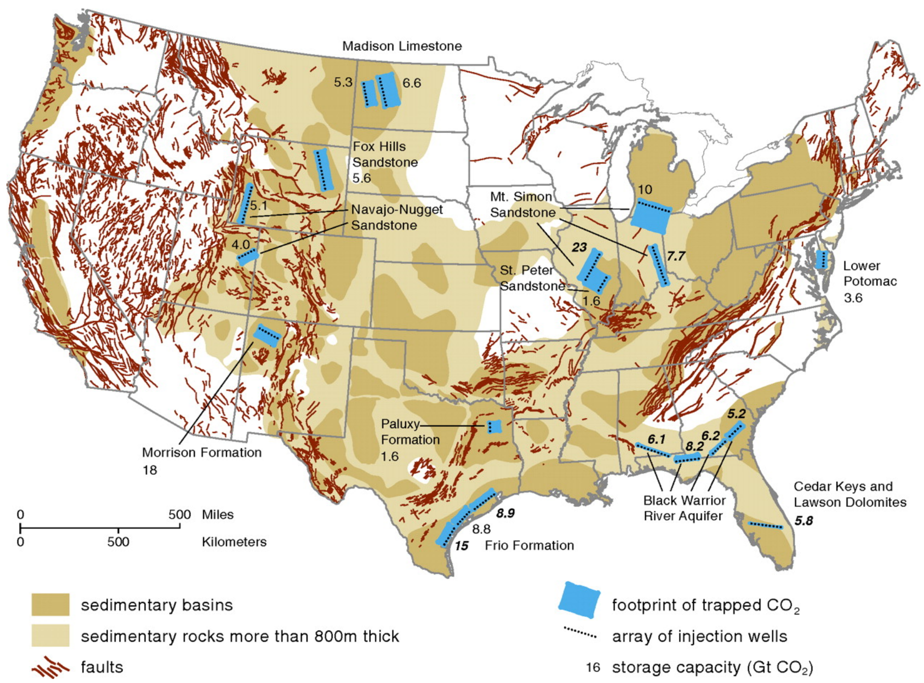

Figure 4. The locations of 11 large capacity saline aquifers and their storage capacities for an injection period of 100 years [3].

The storage capacity estimates of saline aquifer storage in the USA vary over a large range; from 5 billion metric tons of CO_2 to 20,000 billion metric tons. The USA produces about 5.7 billion metric tons of CO_2 per year of which about 2.2 billion metric tons comes from electric power plants [3]. The upper estimate provides storage for 20,000 / 2.2 = 9,090 years, whereas the lower estimate provides storage for just 5 / 2.2 = 2.3 years. The later estimate would not justify the investment in the needed infrastructure for the implementation of CCS.

Michael Szulczewski of the Massachusetts Institute of Technology and colleagues attempted to provide a more definitive answer to the storage capacity question [3]. They considered the storage capacity of 11 large saline aquifers in the USA. They used a detailed fluid dynamics model to simulate the injection, flow, and subsequent trapping of the CO_2 in each of the 11 aquifers. They report that two critical factors that determine an aquifer's viability to store CO_2. The first is the aquifer's overall capacity, and the second is the rate at which the aquifer can take up the CO_2 without discharging part of it back out

[2, 3]. The study estimates that the capacity of the considered 11 saline aquifers can stabilize emissions at the current rates for period of 100 years [2, 3].

PHOTOSYNTHESIS ENHANCEMENT

CO_2 has been beneficially used as a photosynthesis process enhancer. In Holland, natural gas as methane, CH_4 was once burned to enhance plant growth in greenhouses.

About 400,000 tons / year of waste CO_2 from oil refineries is now directed to about 500 Netherland greenhouses claiming a 30 percent growth rate enhancement in the treated plants.

CARBON SEQUESTRATION IN CEMENT MANUFACTURE

Current cement manufacturing releases 800 kg CO_2 / ton of cement produced, both from burning fossil fuels and from the process of baking the limestone or calcium carbonate used in cement production. The retort process operates at a temperature of 1,400 ^oC and in the process the concrete industry produces more than 2 billion tons of cement worldwide each year. It releases 5 percent of the CO_2 emitted worldwide, making it the third-largest single producer of the greenhouse gas.

The industry's large carbon footprint is a result of energy-intensive production processes, which include temperatures of 1,450 ^oC or 2,642 ^oF to bake the raw materials and the use of electric motors to pulverize the resulting cement bricks.

Limestone as calcium carbonate used in the cement production process can be replaced with a magnesium silicate mineral, serpentine, baked at a lower temperature of 700 ^oC and resulting in magnesium oxide, MgO. The MgO can then be reacted with CO_2 to make a magnesium carbonate based cement.

A net 50 kg CO_2 / ton of cement can be absorbed in the process. The concern here is the availability of the serpentine ores.

ARTIFICIAL CORAL FORMATION

The Calera Company built a prototype plant on a site next to a gas-fired power plant in Moss Landing, California. It is studying ways to siphon off a portion of the CO_2 released by the plant and conduct it through sea water from the nearby Pacific Ocean.

When CO_2 is combined with the Mg and Ca dissolved in sea water, the resulting substance is cement. The same process happens in corals in nature when they grow.

This reaction with seawater would benefit the climate, because the CO_2 from emissions would be incorporated into the carbonate. Heat from the power plant would then be used to dry the separated mud-like substance.

One ton of this type of cement removes about 1/2 a ton of CO_2 from the atmosphere.

CARBON STORAGE IN ALGAE

Some algae species offer about 8 percent enhanced sunlight capture compared with about just 1 percent for land-based plants. Both natural and genetically modified strains are under consideration.

Algae often produce oils that can be harvested and directly used as fuels. The use of closed bioreactors offers the advantage of avoiding contaminating the process by wild algae strains but entails a high capital cost. The use of open ponds entails a lower capital cost but suffers from wild strains contamination limiting the process efficiency.

We suggest that replacing the considered batch industrial process in bioreactors by a continuous cascading process could lead to a reduction of the capital cost while avoiding contamination.

At a Hawaii proposed test site, waste CO_2 from power plants would be used to enhance algae growth, with the produced algae products then used to fuel the power plant for a net zero carbon emission process. Since Hawaii already has a high imported energy cost, the local production of fuel would offer an economical incentive.

In an interesting twist, the algae would be initially grown in bioreactors then transferred to open ponds for a quick finishing process.

PHOTOCHEMICAL PROCESSING

The photochemical conversion of CO_2 and H_2O to methanol is studied at the Helios Research Center in California [1]. In this process, cadmium nanorods emit electrons which are captured by a catalyst which helps to split H_2O into O_2 and H_2.

Other catalyst-coated nanorods react with the CO_2 generating CO. The H_2 then passes through a membrane and reacts with CO to generate methanol as a hydrocarbon fuel.

OTHER APPROACHES

Other approaches are currently being developed to sequester CO_2. The Planktos Company, based in California, has come up with the idea of using giant tankers to add iron dust to the world's oceans, restoring the behavior of wind-borne dust, which diminishes with global warming, and stimulating algae growth. The CO_2 captured in the algae would sink into the depths when the plants die. A large-scale test near the Galapagos Islands failed due to insufficient funding.

Submerging tree trunks deep into the oceans and, along with them, the CO_2 captured in the wood fiber could provide employment for one million forestry workers.

There is a possibility of pumping CO_2 into coal seams. This would lead to the release of methane gas CH_4, which could be captured and used as a fuel.

Carbon dioxide from power plants would have to be captured and sequestered in a highly compressed form. However, this costs energy. A coal power plant, for instance, would lose about 10 percent of its efficiency.

CO_2 can be used as a chemical feedstock, for instance in the manufacture of plastics. It can be reacted with water and waste heat to produce methane, CH_4.

Pressurized CO_2 is a potential coolant for High Temperature Gas-cooled Reactors as an alternative to He which would be a better coolant, but is depleted and is in short supply.

SCHWARZE PUMPE PILOT PLANT

A German pilot program for testing the safety and usefulness of pumping CO_2 emissions underground has been implemented at a remote spot in the German state of Brandenburg as the Schwarze Pumpe coal power station near Spremberg.

The Swedish power supplier Vattenfall built the €70 million pilot program to demonstrate how CO_2 emissions from coal plants can be captured and pumped underground.

The power plant being used to test the project's feasibility is 350 kilometers or 217 miles away from the CO_2 storage site. The CO_2 is liquefied and hauled in refrigerated trucks to the sequestration site. Vattenfall plans to pump 100,000 tons of CO_2 from the Schwarze Pumpe site into a nearly depleted deposit of natural gas in Saxony-Anhalt.

Power plant technology is still in the development stages. The current pilot program has an output of barely 30 MWe. In 2015, Vattenfall wants to open two model power stations in Germany and Denmark. In contrast to the current project, these will produce meaningful quantities of electricity.

This technology only works in new, purpose-built power stations. Refitting old ones is not a possibility. Vatenfall's competitor RWE has announced that it will build a 450 MWe model CCS power plant in Hürth, nine kilometers southwest of Cologne, Germany. CCS will only be viable in the marketplace with power stations that produce upwards of 1,000 MWe, which is difficult given that CCS plants are currently much less efficient than traditional plants.

The storage technology is still being tested. Estimates vary between 1,000-10,000 years when it comes to the question of how long the gas must remain in the ground to have any positive effect on the climate.

It is unclear exactly how CO_2 can be transported before storage. The construction of CO_2 pipelines would likely run into considerable political and public opposition.

Environmental groups, such as the consortium of 99 organizations called the “Climate Alliance,” complain that the development costs for the new technology are too high and charge that the CCS projects are meant to help climate-harming coal-fired power plants maintain a foothold in the energy mix.

Figure 5. Liquefied CO_2 hauling truck received at the Schwarze Pumpe power plant at Sprenberg, Germany, the first plant storing CO_2 deep underground in a saline aquifer. Source: Reuters.

FUTUREGEN PROJECT

Overview

The FutureGen 2.0 project was hoped to be the USA's first near-zero emissions coal-fuelled power plant. It was initiated as part of President Bill Clinton's administration "Vision 21" program. It was conceived during the President George W. Bush administration with hopes to demonstrate at a commercial level the feasibility of clean coal technology. It had its ups and down as an ambitious and expensive project and the government's $1 billion commitment was cancelled in early 2015 by the President Barack Obama administration, which incidentally has pledged $1 billion for advanced coal projects in China.

The USA Department of Energy (DOE) on January 16, 2014 had issued a favorable 25-page "record of decision" for the $1.68 billion plan that would refit a coal-fired power plant in Meredosia in western Illinois. The project would have removed carbon dioxide from the coal and store it underground in an injection site in Morgan county in Illinois. The DOE suggested that the project planners had addressed USA Environmental Protection Agency (EPA) concerns raised about potential air pollution and other matters. The DOE provided $1 billion to the project, with the rest of the money coming from the FutureGen Alliance, a group of coal companies that formed to work on the project.

The project sought to obtain a permit to store the CO_2 gas and to finalize its end of the financing. FutureGen was first proposed in 2003 by President George W. Bush administration. Initially, it would have involved building a new power plant in Mattoon in eastern Illinois. The Energy Department shelved that project but under President Barack Obama the project was moved to Meredosia, Illinois.

A stumbling block was that the project depended on supplemental private financial commitments. Some local residents have raised concerns about pollution and other potential impacts. The Sierra Club filed suit in December 2013 to try to tighten pollution controls, and filed a legal challenge in December 2014 to stop the project on the basis that it would affect negatively the development of renewable technologies.

FutureGen 1.0

FutureGen was an industry alliance aimed at demonstrating clean coal technology in the USA. Originally, a plan was intended to create a facility at the city of Mattoon, Illinois, to store CO_2 in an underground porous formation. The project faced years of arguments about environmental concerns, siting hurdles and cost-cutting measures and was eventually rejected by the USA Department of Energy (USDOE) in 2008.

FutureGen 2.0

The FutureGen 2.0 project replaced FutureGen 1.0 with a plan is to consider an existing largely idle 200 MWe Ameren coal power plant at the city of Meredosia, Illinois and retrofit it. The project would be located in northeast Morgan County. A pipeline would convey the generated CO_2 from the retrofitted coal power plant to an injection site 25 miles west of Springfield, Illinois. The project is slated to go online in 2015.

The cost was reduced from an original $1.8 billion to $1.3 billion that would be financed through the USA government providing $1 billion in Federal Stimulus funds, the FutureGen Alliance supplying $250 million, and the Ameren utility, Babcok &Wilcox and Air Liquide Process and Construction spending $150 million to redesign and retrofit the ageing plant to test a modern clean burning oxy-combustion process.

The project would be the world's first coal-fired power plant to capture carbon at a rate greater than 90 percent and be fully integrated with a pipeline and a CO_2 storage hub.

The project covered about 1,000 acres as a buffer zone of underground CO_2 storage rights. Like in the original Mattoon site, it laid above the Mt. Simon sandstone formation, which is considered ideal for CO_2 storage. The Mattoon site would have required injection at 7,000-8,000 feet of depth. Morgan County allowed sequestration at 4,000 of depth, reducing the drilling costs.

Other alternative sites were 75-130 miles from Meredosia. At $1.5-2.0 million per mile in pipeline construction costs, a 32 miles Morgan County line offered key savings.

The project would have provided 150-175 permanent technical and research jobs to run the plant and 1,000 jobs for its construction. Fifty jobs would be created at the retrofitted Ameren coal power plant. The site included a crafts training center at Jacksonville to prepare workers in welding and iron work and electricians to handle the retrofitting of existing coal power plants to meet Environmental Protection Agency (EPA) emission guidelines.

MEREDOSIA COAL PLANT FUTUREGEN 2.0 ALLIANCE

INTRODUCTION

The FutureGen 2.0 Alliance was a first-of-its-kind, near-zero emissions coal-fueled power plant. In cooperation with the USA Department Of Energy (USDOE), the FutureGen 2.0 project partners would have upgraded one out of 4 units of the 70-year old mothballed power plant at Meredosia, Illinois with Oxy-Combustion technology to capture approximately 1.3 million tonnes of CO_2 each year; more than 90 percent of the plant's carbon emissions.

Other emissions such as NOx and SOx would be reduced to low levels. Using conventional pipeline technology, the CO_2 would be liquefied, pumped over long distance and stored underground in the proposed Mount Simon aquifer. The top of the Mount Simon aquifer slopes from the Wisconsin dome toward Michigan and Illinois. This aquifer, representing the lower part of the Cambrian-Ordovician aquifer system, is buried to depths of 2,000 to 3,500 feet below sea level. The configuration of the tops of the overlying Ironton-Galesville and St. Peter-Prairie du Chien-Jordan aquifers are similar to that of the Mount Simon aquifer. Only the deeply buried parts of the aquifer system contain saline water.

Service - Administrative Law Judge Ruling

Notice given that the Administrative Law Judges direct Ameren Transmission Company of Illinois ("ATXI") to respond to the following questions regarding the scope of its Illinois Rivers Project at issue in this docket: 1) Why is the construction of a 345 kilovolt ("kV") transmission line between Sidney and Rising, Illinois part of the Illinois Rivers Project? Please explain why the construction of this transmission line can not be considered on a standalone basis in a separate docket. In order to reduce the number of issues to be resolved under the shortened statutory deadline, would ATXI be willing to withdraw the Sidney to Rising portion of its Illinois Rivers Project? If not, please explain why. 2) Why is the construction of a 345 kV transmission line between Ipava and Meredosia, Illinois part of the Illinois Rivers Project? Please explain why the construction of this transmission line can not be considered on a standalone basis in a separate docket. In order to reduce the number of issues to be resolved under the shortened statutory deadline, would ATXI be willing to withdraw the Ipava to Meredosia portion of its Illinois Rivers Project? If not, please explain why. ATXI's response to each of these questions must be filed by December 19, 2012. Notice also given that the Administrative Law Judges have granted the following motion and petitions to intervene: 1) Petition to Intervene of Gregory and Theresa Pearce (filed December 3, 2012); 2) Petition to Intervene of The Nature Conservancy (filed December 3, 2012); 3) Petition to Intervene of Wind on the Wires (filed December 3, 2012); 4) Petition to Intervene of The Village of Mt. Zion (filed December 3, 2012); and 5) Clark County Preservation Committee's Motion for Leave to Amend Petition to Intervene (filed December 7, 2012). Notice served electronically to parties.

12-0598 · 12/12/2012

Figure 6. Illinois Commerce Commission's Administrative Law Judge Ruling asking questions about the connection between what was introduced as a wind power transmission project; the "Illinois Rivers Project," to the mothballed Meredosia's plant FutureGen-2.0 coal power plant by the Ameren Transmission Company of Illinois (ATXI), a one-employee electrical transmission venture established by the Ameren utility from the state of Missouri.

Before commencing full-scale operations, the storage site would have been the subject of an extensive environmental review conducted by DOE in compliance with the National Environmental Policy Act (NEPA). The site would have to be fully permitted by the Illinois Environmental Protection Agency to assure its safety and provide the opportunity for community input.

MEREDOSIA COAL AND FUEL OIL PLANT

Ameren Corporation's 429 MWe 70-year-old Meredosia generating station was among the largest employers in Morgan County, Illinois, a rural area two-hours of driving north of St. Louis, Missouri on the east bank of the Illinois River, Illinois. It was considered by critics to be "an energy dinosaur in an age of wind farms and green jobs."

According to Jeffrey Tomich from the Saint-Louis Post-Dispatch: "Two of Meredosia's four generating units were mothballed because they were too inefficient. A third unit sits idle most of the time. Ameren tried to sell the aging plant last year but couldn't find a buyer. And dozens of workers were laid off — the product of the recession and reduced electricity demand."

Figure 7. Meredosia 4-units, 3-coal and one-fuel oil, 70-year-old mothballed plant. The oil unit was meant to be restarted for the FutureGen-2.0 Alliance $1.65 billion, shovel-ready, financial stimulus, clean-coal project. Source: Google Maps.

The mothballed plant was selected as the centerpiece of the USA government's revamped FutureGen 2.0 program to demonstrate the potential of capturing greenhouse gas emissions from coal-fired power plants. There were no guarantees that the project will advance further than the first version of FutureGen 1,0, which was scrapped after eight years of political wrangling and rising costs.

There are about 600 coal-fired power plants in the USA, generating 40-50 percent of the nation's electricity. On average, those plants are more than 30 years old and represent about 40 percent of USA greenhouse gas emissions. Smaller coal plants like Meredosia would likely be shuttered if the government follows through with plans to a regulate CO_2. Larger, newer coal-fired generating plants will be a significant part of the nation's electricity mix for decades to come.

FutureGen 2,0 was not the Energy Department's only investment in Carbon Capture and Storage (CCS) technology. In July 2010, the administration of President Barack Obama approved a $417 million tax credit for Tenaska Inc.'s $3.5 billion clean-coal power plant in Taylorville, 90 miles east of Meredosia.

Under the restructured FutureGen 2.0 program, the federal government was committing $1 billion in stimulus funds. Construction was scheduled to begin in 2012 and the 200-MWe unit was supposed to begin generating electricity by the third quarter of 2016.

The USA War Production Board halted work at Meredosia in 1942, a year after construction began, and re-directed the plant's turbo-generator and other materials to Russia, an ally of the USA during World War II. The plant began generating electricity in 1948, and doubled its capacity the following year. Central Illinois Public Service Company, then the plant's owner, added another coal-fired generator in 1960 and added an oil-fired unit in 1975.

The FutureGen 2.0 project was supposed to utilize only the plant's youngest unit, which sits idle most of the time. Even as crude oil prices well off their high of $140 a barrel, fuel was so expensive that it was rarely profitable enough to operate.

The project involved replacing Meredosia's oil-fired steam generator unit with a coal boiler that uses oxygen instead of air during combustion. The result is an emissions stream of nearly pure CO_2 that can be captured and stored. The OxyCombustion technology was developed by Ameren's partners, Babcock & Wilcox and Air Liquide, and has been tested at a Babcock & Wilcox's research plant at Alliance, Ohio.

Plans called for capturing 90 percent of the FutureGen's 2.0 CO_2 emissions, or about 1.3 million tons annually. The gas would be compressed to a liquid state, transported via pipeline and buried thousands of feet underground at a yet-to-be-chosen site in Southern Illinois, possibly the Mt. Simon sandstone and saline water geological structure. The many technical, political and economic challenges made opponents skeptical that FutureGen 2.0 will advance beyond the research and a concept study stages.

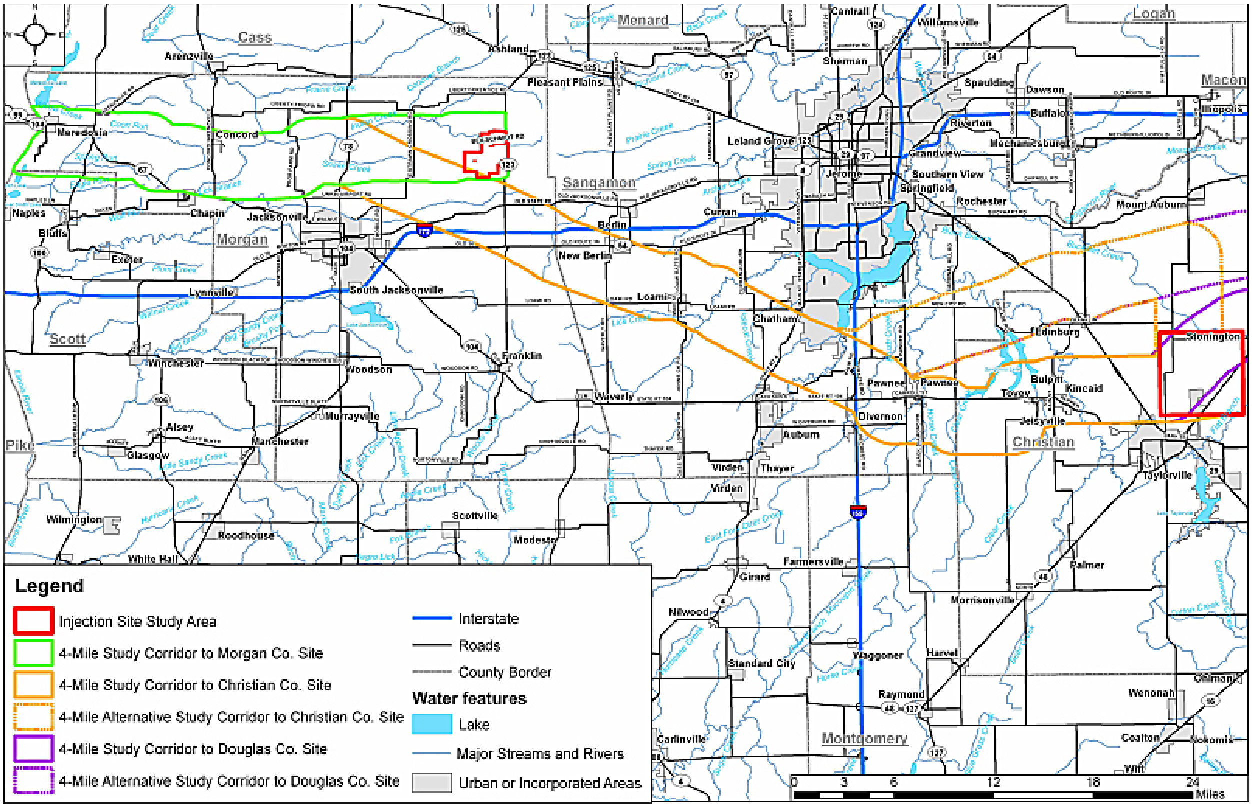

Figure 8. Merodosia coal plant FutureGen 2.0 Alliance International Alliance project 4-mile wide corridors for CO_2 pipelines and Power lines by Springfield, Taylorville, New Berlin and Jacksonville, Illinois from Morgan, Cass counties to Christian and Douglas Counties. Meredosia lies in the upper left side of the map.

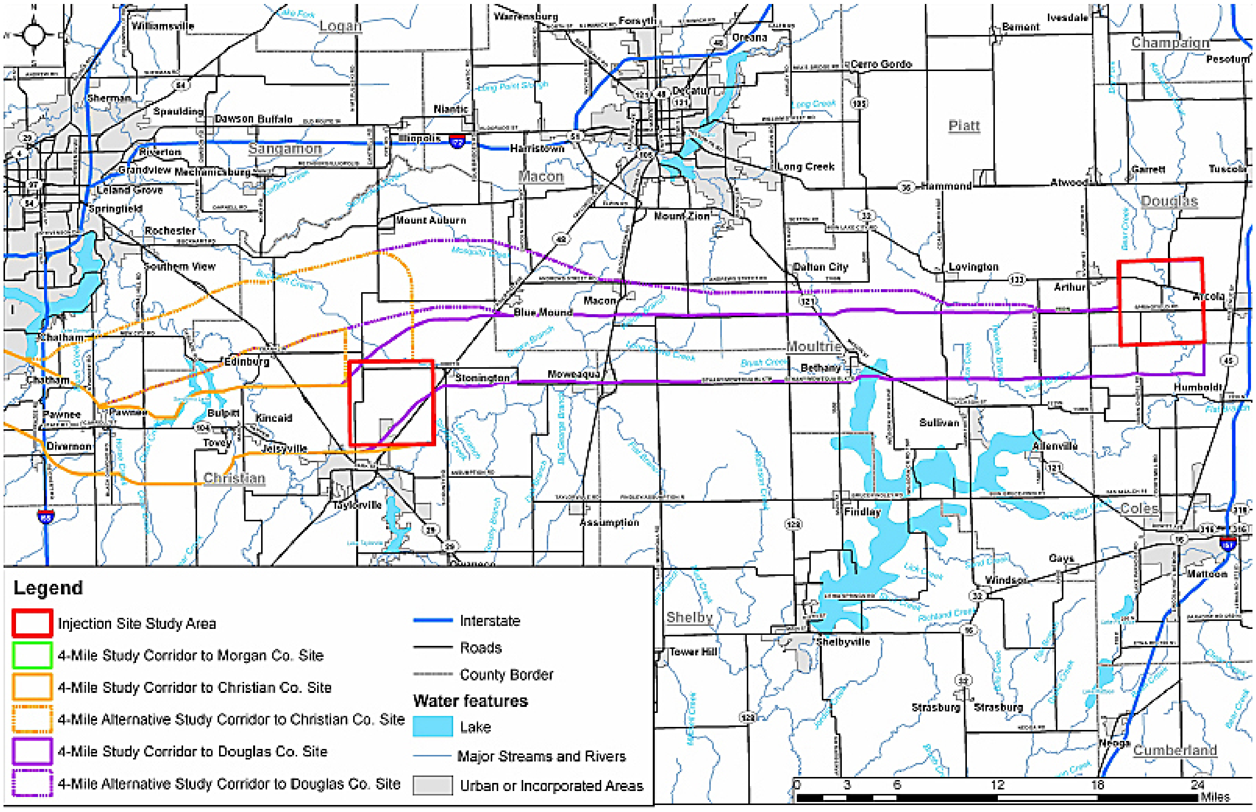

Figure 9. An earlier FutureGen 1.0 clean coal project from Meredosia to the city of Mattoon in Coles County, Illinois, failed to materialize for environmental, political and economic considerations and was replaced by the FutureGen 2.0 project by an International Alliance.

FUTUREGEN INDUSTRIAL ALLIANCE

The FutureGen Industrial Alliance, Inc. was structured as a non-profit section (501(c)(3)) organization composed of:

1. **Xstrata Coal**: is the world's largest exporter of thermal coal and the fifth largest producer of hard coking coal, producing both hard coking coal and semi-soft coal. Headquartered in Sydney, Australia, Xstrata Coal Pty Limited has interests in over 30 operating coal mines throughout Australia, South Africa and Colombia. Thermal coal is used in power generation, while coking coal is used mainly in the production of steel and other industrial applications. Xstrata Coal Pty Limited is the second largest of the commodity businesses within Xstrata plc, a major global diversified mining group, listed on the London and Swiss stock exchanges with around 40,000 employees worldwide.

2. **Peabody Energy**: is the world's largest private-sector coal company, with 2008 sales of 256 million tons and $6.6 billion in revenues. Its coal products fuel 10 percent of all USA electricity generation and 2 percent of worldwide electricity generation. Peabody Energy has diverse national and international coal and energy operations.

3. Joy Global Inc.: is a worldwide leader in high-productivity mining solutions. Through its businesses – P&H Mining Equipment and Joy Mining Machinery – the Company manufactures and markets original equipment and aftermarket parts and services for both the underground and above-ground mining industries and certain industrial applications. Joy Global's products and related services are used extensively for the mining of coal, copper, iron ore, oil sands, gold and other mineral resources. Facilities and equipment service centers span six continents and more than twenty distinct countries.

4. Consol Energy: is the largest producer of high-Btu bituminous coal in the USA, the largest exporter of USA coal, and one of the largest USA producers of coal bed methane. Consol Energy also operates one of the largest private coal research organizations in the USA. Under a grant from the USDOE, Consol is conducting a $9 million investigation of sequestering CO_2 in coal seams. Coal seams are a possible formation for FutureGen 2.0 sequestration, making Consol's technical experience relevant to the project.

5. AngloAmerican PLC: is one of the world's largest mining companies, is headquartered in the UK and listed on the London, UK, and the Johannesburg, South Africa, stock exchanges. Its portfolio of mining businesses spans precious metals and minerals in which it is a global leader in both platinum and diamonds; base metals – copper and nickel; and bulk commodities iron ore, metallurgical coal and thermal coal. The company's mining operations and pipeline of projects are located in Southern Africa, South America, Australia, North America and Asia.

6. Alpha Natural Resources: is one of the USA's main coal suppliers with coal production capacity of greater than 120 million tons a year. Alpha Natural Resources is the nation's leading supplier and exporter of metallurgical coal used in the steel-making process and is a major supplier of thermal coal to electric utilities and manufacturing industries across the country. The company, through its affiliates, employs approximately 14,000 people and operates approximately 150 mines and 33 coal preparation facilities in Appalachia and the Powder River Basin.

MOUNT SIMON AQUIFER

The top of the Mount Simon sandstone aquifer slopes from the Wisconsin dome toward Michigan and Illinois. This aquifer, representing the lower part of the Cambrian-Ordovician aquifer system, is buried to depths of 2,000 to 3,500 feet below sea level. The configuration of the tops of the overlying Ironton-Galesville and St. Peter-Prairie du Chien-Jordan aquifers are similar to that of the Mount Simon aquifer. The aquifer is primarily a fresh water aquifer. Only the deeply buried parts of the aquifer system contain saline water.

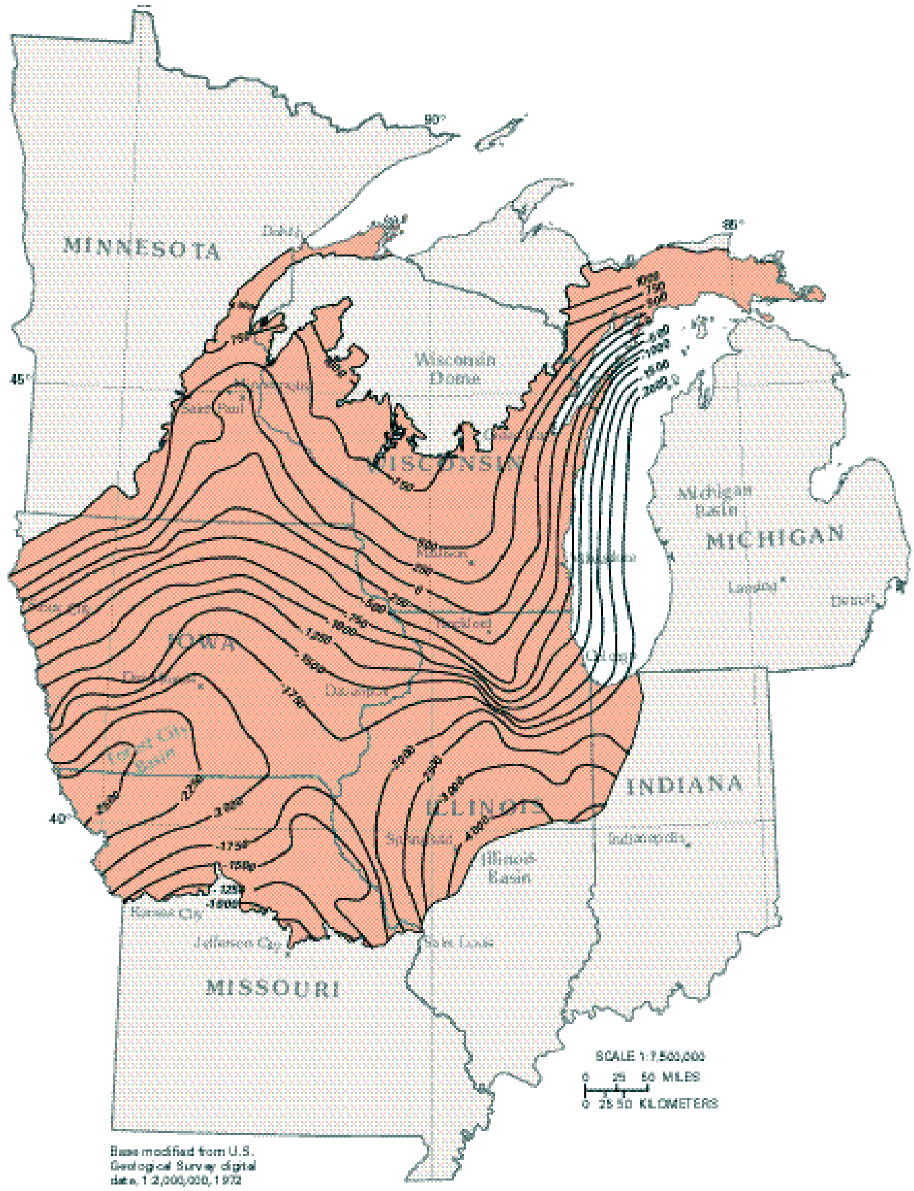

Figure 10. Extent of the Mount Simon aquifer proposed for the CO_2 Carbon Sequestration and Storage (CSS) associated with the Meredosia coal project. Source: USA Geological Survey.

Fresh water withdrawals from the Cambrian-Ordovician aquifer system, primarily for industrial use in Milwaukee, Wisconsin, and Chicago, Illinois, caused declines in water levels of more than 375 feet in Milwaukee and more than 800 feet in Chicago from 1864 to 1980.

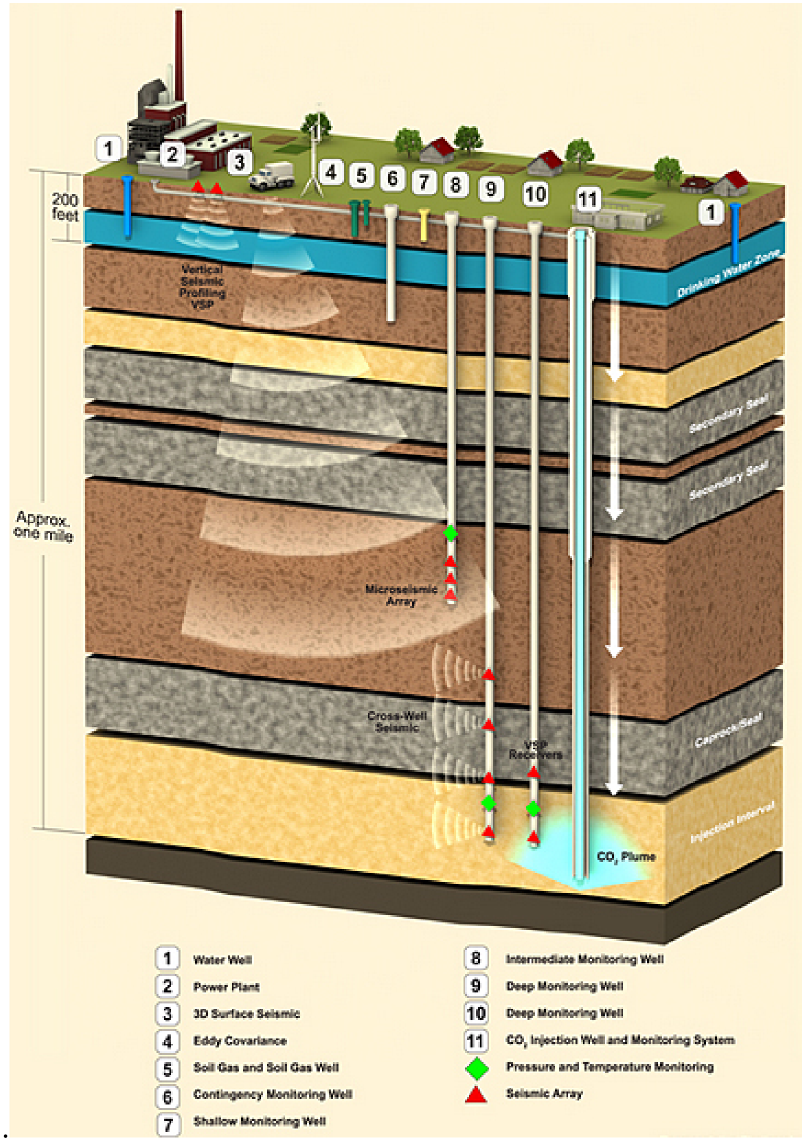

Figure 11. Idealized parallel layers of ground excluding flow patterns, fissures, cracks and geological faults structures conceptual diagram of CO_2 Carbon Sequestration and Storage (CCS) in the Mount Simon sandstone aquifer for the Meredosia coal plant FutureGen 2.0 Alliance project. Source: FutureGen 2.0.

Many of the wells in the Chicago-Milwaukee area obtain water from all three aquifers of the aquifer system. The declines extended outward for more than 70 miles from the pumping centers in 1980. Movement of water in the aquifers was changed from the natural flow direction (eastward toward the Michigan Basin) to radial flow toward the pumping centers. Beginning in the early 1980's, withdrawals from the Cambrian-Ordovician aquifer system decreased as some users switched to Lake Michigan as a source of fresh water supply. Water levels in the aquifer system had begun to rise by 1985 as a result of the decreased withdrawals.

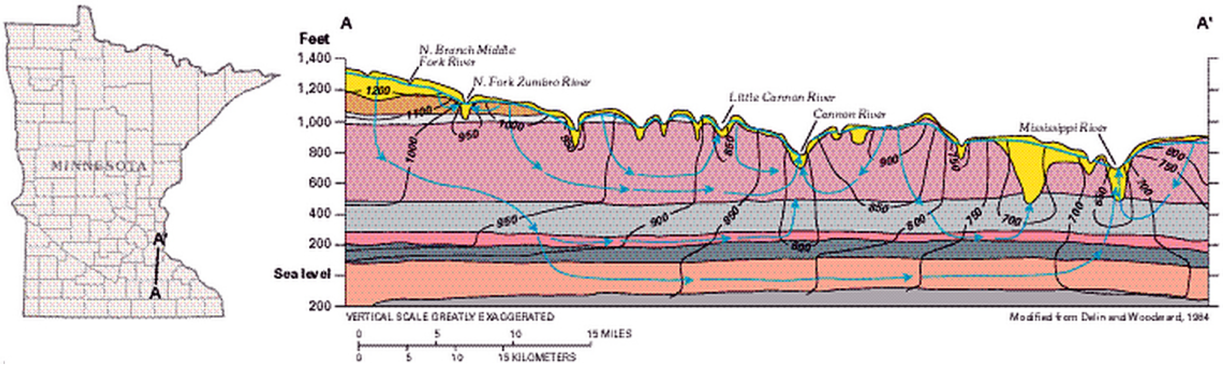

Figure 12. Water flow downward then horizontally in aquifers toward stream and river systems. The flow of water from the Mount Simon aquifer along the A-A' cross-section is shown to eventually flow into the Mississippi River. Source: USA Geological Survey.

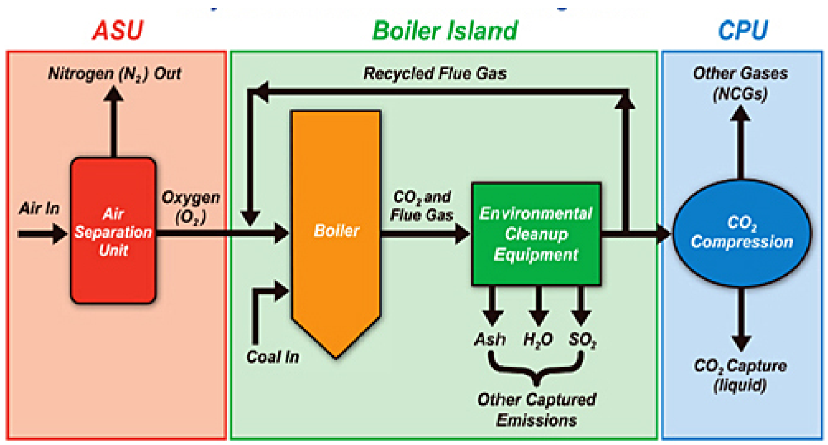

Figure 13. Proposed Oxy-Combustion coal technology for the Meredosia FutureGen 2.0 project.

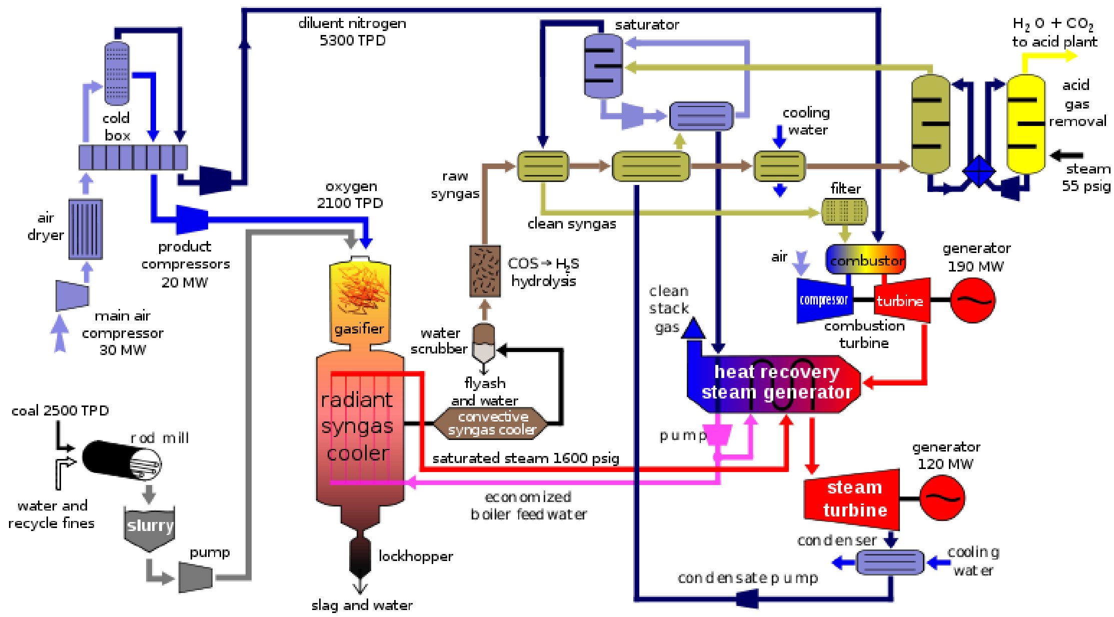

Figure 14. Integrated Gasification Combined Cycle (IGCC) flow diagram. Production of Syngas is associated with a gas turbine and a steam turbine.

PROJECT DEVELOPMENTS

The USA Department Of Energy (USDOE) in September 2010 announced agreements with Ameren Corporation and the FutureGen Industrial Alliance that formally committed $1 billion in Stimulus Program funding to revive the FutureGen project. The centerpiece of the new FutureGen is the idled oil-fired unit at Ameren's Meredosia coal plant in western Illinois that would be re-engineered to run on coal.

The revised FutureGen project still had a long way to go, and would not be complete until at least late 2016, when it was cancelled in early 2015. The agreement with the DOE paved the way for the partners, Babcock & Wilcox and Air Liquide, to begin research and development work on the conversion of Meredosia. The first step would have been the determination whether the project is commercially and technically viable. If so, the Illinois Legislature would have passed legislation to recover the costs of the project from the electrical consumers. Only then would the company's board authorize construction.

The DOE and FutureGen Industrial Alliance were tasked with choosing a site in Illinois for the CO_2 storage and building a pipeline that would move than 1 million tons of captured CO_2 per year from the Meredosia plant. The Mt. Simon sandstone and saline water geological formation is a leading candidate for the injection site.

Ameren Corporation, fearing financial commitment and loss, and emphasizing the more profitable power transmission business over power production, pulled out of the FutureGen 2.0 project in spite of the Federal Government committing $1 billion to the project. St. Louis, Missouri-based Ameren negotiated an option to sell portions of its Meredosia plant in Morgan County, Illinois, to the FutureGen Alliance, an international consortium of mining companies and other utilities that committed themselves to see the project through to completion.

The FutureGen project was a venture conceived by the President George W. Bush’s administration. It remains the nation's most visible effort to develop a next-generation coal-fueled power plant where most CO_2 emissions would be captured and pumped underground.

Some skeptics have dubbed the project NeverGen. The Ameren Company withdrew from the project and tried to sell its interest in the Meredosia plant to the remaining project partners. Initial plans were scrapped in 2008 with a failed implementation at the city of Mattoon, Illinois amid rising costs and political bickering. Supporters, meanwhile, say carbon capture technology is a necessity if the country is to ever address global warming.

FutureGen was revived with Ameren's 70-year-old Meredosia plant as the centerpiece. Congress approved $1 billion in Recovery Act funds to support the effort. Ameren was charged with re-powering one of the aging plant's four generating units to enable the capture of most CO_2 emissions.

The original estimate for the power plant work was $730 million. But projected costs jumped 50 percent to $1.1 billion, bringing the total project cost to $1.65 billion. The remainder of fund, or $550 million, is set aside for construction of a CO_2 pipeline and permanent underground storage.

Ameren, to pare costs, offered buyouts to 715 employees at its Missouri utility and administrative support units. It took steps to reduce capital expenditures, and announced plans to shutter two power plants, including Meredosia. The company would not participate in FutureGen, but pledged to help obtain environmental permits and maintain the plant so that it can be used after operations ceased on December 31, 2010.

Plans for FutureGen called for the rarely used oil-fired unit, out of four at the plant to be re-powered with Oxy-Combustion technology, which involves burning coal in oxygen instead of air. The result would be an emissions stream of nearly pure CO_2. About 90 percent of the CO_2 emissions, or about 1.3 million tons annually, would be captured. It would then be compressed to a liquid, transported via pipeline and buried thousands of feet underground. The estimated completion date was later pushed back to 2016 and then the project cancelled in early 2015. Even that was an ambitious target because this will be the first time that Oxy-Combustion technology is used on a commercial scale.

DISCUSSION

Grass root movements have been protesting against the choice of their communities for carbon capture and storage pilot plants in different parts of Germany, as well as at Mattoon, Illinois in the USA, citing their economical viabilities.

Figure 15. Protest against CCS at the town of Flensburg, State of Schleswig-Holstein, Germany. Photo: DPA.

A pilot plant in Germany plans to inject liquid CO_2 into the ground at a depth of 2,000 meters or 6,560 feet. The best bedrock for this storage technique is thought to be porous sandstone with concentrated salt water. The objective is to study how much salt water the CO_2 displaces, how it distributes itself and whether it would stay down there.

For an impact on climate and to keep the stored CO_2 safely away from the biosphere, it must remain underground for at least 10,000 years.

The water companies are afraid that the CO_2 could push salt water and possibly contaminants to the surface and that the groundwater could become contaminated.

The benefits of the storage technology are under intensive debate as the climate change it is alleviating. In Germany, a plan exists to phase out coal-fired electricity generation by 2040.

The saline aquifers into which the CO_2 gas is to be pumped are separated from the fresh water aquifers higher up by multiple massive impermeable rock layers that keep both the saline waters and the CO_2 separate from the fresh groundwater near the surface.

A 2005 report from the United Nations climate change body, the Intergovernmental Panel on Climate Change (IPCC), suggests:

> "Leakage of CO_2 could potentially degrade the quality of groundwater, damage some hydrocarbon or mineral resources, and have lethal effects on plants and sub-soil animals. Avoiding or mitigating these impacts will require careful site selection, effective regulatory oversight, an appropriate monitoring program that provides early warning that the storage site is not functioning as anticipated and implementation of remediation methods to stop or control CO_2 releases."

Depleted natural gas fields appear to be the most promising possibility for storage sites. Their geological make-up suggests that they have the ability to contain the stored gases for thousands of years. Oil fields have similar benefits but are too small to make a significant contribution to CO_2 storage. Deep saline aquifers have the highest potential storage capacity, but are still largely unexplored.

The environmental groups counter that CO_2 storage will hinder investments in clean energies. The Greenpeace organization argues that the technology behind CCS is still in its infancy and points out that it will not be viable to incorporate into power plants for 15-20 years, which is too late to protect the Earth's climate.

Another alternative is to inject to inject CO_2 deep into the ocean floor while extracting methane at the same time. The CO_2 would become liquefied because of the high pressure at great water depths. Such a technology still needs to be developed. However, underground storage can be implemented immediately.

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