IPRO 302

CO_2 Mitigation: A Techno-Economic Assessment

Midterm Report

Instructor: Professor Don Chmielewski

Sponsor: Sargent & Lundy

Team:
John Enverga
Jarrod Godfrey
Ellen Kloppenborg
Martin Kolodziej
Da Hye Lee
Asma Mustafa
Miri Park
Vernell Robinson
George Vrana

Illinois Institute of Technology

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1.0. Revised Objectives

A. Current Objectives

The objective of this IPRO is to research and compile information on potential future CO_2 environmental regulations, current CO_2 mitigation technology, and CO_2 sequestration techniques. In addition to this, research will be conducted to find the chemical processes associated with each technology. The results will include an analysis of the items listed above as well as a high-level technical and economic comparison of the CO_2 mitigation technologies.

B. Changes

No changes were made to this objective.

2.0. Results to Date

A. Current Data Results

The team has met with Sargent & Lundy to discuss their expectations and learn background information about the subject of CO_2 mitigation. IPRO 302 additionally watched the movie, What's Up With the Weather, in order to learn more about the subject of global warming. A team structure was created, and students have met in both large and smaller groups for discussion about the project. IPRO 302 representatives were sent to both the ethics and project management workshops. The Seven Layers of Integrity was read by team members and used to create the code of ethics. The project plan and midterm presentation were also completed by the team. In addition, the goal of gathering pertinent information on CO_2 mitigation technology, sequestration technologies and economic comparisons of various techniques has been achieved.

Our research includes information from three different subjects: integrated gasification combined cycles (IGCC), pulverized coal-fired plants (PC) and sequestration technologies. In addition to these, we have also found information on current and future regulations regarding CO_2 emissions.

Integrated Gasification Combined Cycles (IGCC)

IGCC power plants differ from standard PC plants, providing much cleaner energy with reduced emissions. Within the gasification stage of the plant, synthetic gas is produced by breaking down coal with the aid of heat, pressure, pure oxygen and water. Since most of the particulate can be captured in this phase, it produces clean gas which in turn lowers CO_2 emissions. The synthetic gas is then used to power the turbine-generator set. Excess heat is also captured throughout the plant creating steam to power a second generator.

Membrane Separation Technology

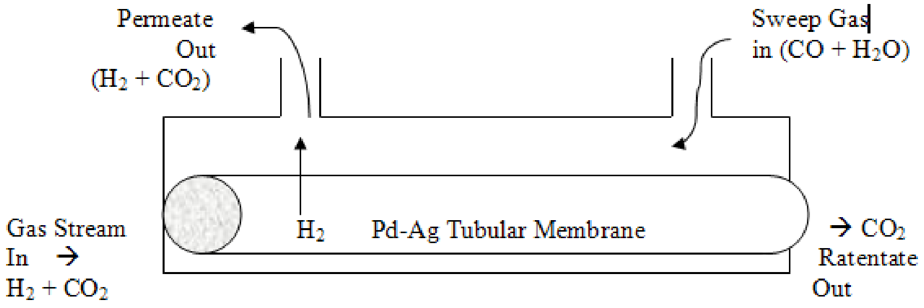
A new technology that is still in its early stages of applicability to IGCC is membrane separation. Membrane separation has advantages over liquid-gas absorption technologies: clean operation, smaller size, simplicity in operation and maintenance, and compatibility with different plant designs. Other studies have suggested that efficiency can be increased and costs reduced to physical absorption by using the membrane technology. However, these studies are based on a technology that is still in its preliminary stages.

Polymer-based membranes have properties that can reduce CO_2 to fifty-percent purity; however, the efficiency notably decreases when CO_2 purity requirements rise. Polymeric membrane technology also has several other limitations including limited selectivity, poor flux in comparison to other membrane materials. The stability of polymers is affected by high temperature, making it not feasible for plants with high temperature gas limitations. Although ceramic membranes could be used in high temperatures, this would require higher initial capital costs.

Since CO_2 purity is lower in a single stage of separation, examination of multiple stages were conducted. Studies of low temperature separation with polymeric membranes in combination with high temperature separation with ceramic membranes proved that the technology was feasible, but the result was an energy change between eight and fourteen percent depending on the staging and pressure.

Other studies have been performed to show efficiency of metallic based membranes. Studies showed that these membranes are 1.7 percent more efficient then industry standard absorption plants such as Selexol or Pressure Swing Absorption (PSA); other economic aspects were not considered in these studies. Metallic membrane technology does have its disadvantages, such as the high cost due to the metallic film and reduced H_2 permeation and selectivity due to deactivation of the metal by H_2S. An exciting notion of this technology is reducing the overall stage from two stages involving carbon separation and the water-gas shift and absorption-stripping into one smaller stage of membrane reactor (MR) technology. Since plants can save costs by removing a large absorption unit, the higher material costs involved in MR technology will be offset. It should be noted that metallic membrane technology also requires additional heat exchanges to provide a sweep-gas stream of precise temperature that produces an optimal reaction.

As you can see from the diagram, a thin tubular membrane of Pd-Ag alloy filled with a packed catalyst is enclosed in another steel tubular frame. The entry and exit ports located on the tubular frame let in sweep gas and let out permeate gas. Steam and CO are primarily in the sweep gas phase, and mostly hydrogen and CO_2 are in the permeating gas phase.



Counter-flow Membrane Reactor

The water-gas shift reaction and CO_2 separation are obtained through the palladium-based reactor. Hot steam and carbon monoxide, which make up sweep gas, are compressed to 11.5 bar, then fed into the outer steel tube where the water-gas shift (WGS) reaction is applied. Once the WGS process has been applied, hydrogen, carbon dioxide and steam are left. The water content is then removed through a condensation stage, and heat energy is transformed into more incoming sweep gas through a exchange stage. Cooler dry gas is fed into the inner Pd-Ag tubular membrane where H_2 gas diffuses through the membrane in turn, leaving CO_2. CO_2 is further filtered through the tubular membrane with a packed catalyst. The hydrogen can be permeated across the membrane by increasing the sweep gas and further enhanced by optimizing the partial pressure profiles in the reactor. Disadvantages still exist within the design, including the greater reduction of net power from 9.4 percent to 12.5 percent, which occurs because thermal power is need to produce steam from the cycle in order to use sweep gas, which lowers steam efficiency. Yet another disadvantage is the need for higher compression in order to liquefy CO_2 from the membrane reactor. After calculating everything that is needed to run a proficient palladium membrane system, it would cost around $61.20/MWh versus $54-$79/MWh for basic IGCC systems.

Hot solids gasifier with CO_2 removal

Gasifier technologies are now available that produce hydrogen while removing CO_2. These apparatuses can be applied to modern day power plants that utilize fossil fuels, biomass, petroleum coke, and any other carbon fuel that produces hydrogen for power generation. Such devices induce chemical process loops that go through several stages of oxidizing and endothermic reactions, transforming into different molecules, and eventually stripping CO_2 and producing hydrogen.

Future Plans for Implementation of IGCC

Although there are only two operational IGCC power plants in use in the United States today, there are future plans to invest in this technology. The U.S Department of Energy is investing one billion dollars in order to run a future generation program that aims to build and test IGCC plant technologies for the next 10 years. A near-term goal for IGCC is the construction of a 275MW demonstration and validation plant by 2008. The capital cost is $1000/KW and zero HHV emission is targeted. A midterm goal is to design a commercial plant with efficiency of 60% designed by. This plant would include CO_2 sequestration, producing hydrogen at a wholesale price of $4/million BTU. A long term goal is the design of a commercial plant by 2015 for fuel cell gas turbine hybrid. This plant would have a capital cost of 850/KW, run at 65% efficiency, produce zero emissions, and contain a sequestration option.

There are many ways being studied to enhance the performance of IGCC. One project plans to enhance the performance of the IGCC by developing the F-class gas turbine to run on synthetic (syn) gas. Another aims to produce syn gas composed of H_2 and CO. A reaction of the syn gas and steam will produce additional amounts of H_2 and CO_2 for capture and storage. The initial target is to capture 90% with the goal of raising the target to 100%.

Taxco conducted a study to determine whether one IGCC plant can be used to lower emissions with and without CO_2 capturing. Their results found that 75% of carbon dioxide can be removed without using capturing mode. With capturing mode, most of the CO will be converted to CO_2 and an equal amount of H_2. Another study was made to estimate the cost of modifying the

Taxco power from non-capture mode to the full capture mode. The cost was estimated at five million dollars.

Pulverized Coal-Fired Power Plants

For pulverized coal-fired (PC) power plants, there are several technologies being developed to remove the carbon dioxide before it reaches the stack. Existing power plants can be retrofitted with these systems, which is a big advantage for them.

Amine Removal

One of the more popular technologies uses amines to remove the carbon dioxide from the flue gas. Amines are bases and react with the carbon dioxide, an acid, to form a water soluble salt. This takes place in an absorption column at low temperatures. The carbon dioxide and amine reaction is reversed in a stripper column through the use of high temperatures. After the CO_2 is released from the amine, the amine solution is cooled, cleaned and recycled.

There are various amines being used for this process, which can have primary, secondary, or tertiary structures. Primary and secondary amines are faster than tertiary amines at removing carbon dioxide, but have the capacity to absorb CO_2 at the ratio of a half mole of CO_2 per mole of amine. Tertiary amines are capable of absorbing up to one mole of CO_2 per mole of amine and require less energy to regenerate after the reaction. This amount of energy is very important, since up to seventy percent of the total operating costs in a carbon dioxide capture plant can come from the energy needed to regenerate the amine. Monoethanolamine (MEA) and diethanolamine (DEA) are the most commonly used primary and secondary amines, and methanol diethanolamine (MDEA) is the tertiary amine that is found most frequently. Testing has been done on other amines, including ethyl ethanolamine (EEA), ethylene diamine (EDA), and diethyl monoethanolamine (DMEA), as well as combinations of primary/secondary amines and tertiary amines to see if they would be better at CO_2 removal than the currently used reactants. One study found EDA to be very promising, since it was faster and could absorb more CO_2 than MEA. EEA and DMEA also may work well for this process. The combination of MEA and MDEA lowered the amount of CO_2 that was absorbed, and the same amount of energy was found to be needed for regeneration of the amine. This result is believed to be due to the harsh environmental conditions in a coal-fired power plant. The conditions in the power plant, particularly the sulfur compounds that form, can also cause the amines to degrade. MEA was found to degrade at 0.5 mole percent per day. Degradation rates were even higher in the combined MEA and MDEA reaction.

Another technology uses an aqueous solution that contains two parts MDEA to one part 2-(2-aminoethoxy)ethanol to remove carbon dioxide and hydrogen sulfide. This reaction occurs in the range of 10 °C and 100 °C, generally between 60 °C and 80 °C. Pressures range from 0 psig to 150 psig. One issue with this process is the need for regeneration or replacement of the solution, as 2-(2-aminoethoxy)ethanol usually converts slowly to bis-(2-hydroxyethoxyethyl)urea when contacted with acid gas impurities. Technology has been developed to minimize this reaction, though, so that a regeneration unit is not needed.

Other Processes

Powerspan has developed another technology to remove carbon dioxide from a pulverized coal-fired power plant. Their ECO2 process uses an ammonia bicarbonate solution instead of an amine. This is advantageous, because ammonia can absorb more carbon dioxide than MEA, requires less energy for regeneration, costs less, and has lower equipment corrosion rates. After the absorption of CO_2 by the ammonia bicarbonate, the solution is regenerated and ammonia and carbon dioxide are released. The ammonia is recycled and the CO_2 is further prepared for storage. This reaction has been tested at 130 °F with a gas residence time of four to five seconds. With these conditions, carbon dioxide removal has been 90%. Pilot plant testing of the ECO2 technology will be started in 2008. If it is successful, a 100MW system is planned for a commercial demonstration unit. This unit would start operations in 2011, and full-scale systems could be expected to begin in 2015. Capitals costs for a 500 MW plant would be in the range of \$150 to 250 million, provided a pollution control unit (ECO) is already installed. This could make it economically preferable over IGCC. The US Department of Energy has estimated that an ECO2 system will cost \$14/ton of CO_2 removed and 5.5 cents/kWh. This is much less than the estimates for a new PC power plant with a super-critical steam cycle that has a 90% CO_2 capture rate, conventional pollution control systems, and MEA as the sorbent. Such a system is estimated to cost \$47/ton of CO_2 removed and 7.6 cents/kWh.

Sorbent Economics

Many of the other sorbents being tested in place of amines are not as cost-effective. The ratio of makeup flow of sorbent to the amount of sorbent being regenerated needs to be very low in order to keep low costs. An equation to calculate the cost of sorbent/kg of CO_2 removed can be seen below:

Cost of Sorbent =

$$\left(\frac{makeup.flow.of.sorbent}{amount.of.sorbent.in.regeneration.loop}\right)\left(\frac{\cos t.of.sorbent.necessary.to.react.with.1.mol.CO2}{molar.mass.of.CO2}\right)$$

For MEA, this comes out to \$0.0019/kg CO_2. An equation that allows for process energy changes is found by multiplying the cost of sorbent by the ratio of \$/metric ton of CO_2 avoided to \$/metric ton of CO_2 captured. This ratio is approximately 1.4 in MEA systems.

Another factor that needs to be considered is the average number of sorbent-desorption cycles that can be completed by a sorbent molecule. An equation for this number can be seen below:

$$N_{1/2} = \frac{\ln(2)}{\ln\left(\frac{sorbent.makeup.flow}{sorbent.regeneration.flow}+1\right)}$$

For MEA, this average number is approximately 4,500 cycles. This number can be plotted against sorbent cost, which can then be used to compare new sorbents to the popular MEA.

Sequestration

Technologies are being developed to manage the CO_2 that is collected at power plants, a process known as sequestration. There are two main types of sequestration, terrestrial and geologic. In terrestrial sequestration, biological materials such as crops, trees, and grasses absorb CO_2 from the air and eventually transfer it to the soil. In geologic sequestration, carbon dioxide is injected into permanent storage, often in depleted oil or natural gas fields, unmineable coal seams, or saline aquifers.

The storage reservoirs that hold CO_2 are usually more than 2,500 feet deep and made up of sandstone or other porous rocks. Layers of nonporous rock act as a seal to prevent leakage of carbon dioxide. Pressures in these reservoirs are normally above 1,100 psi, which helps the CO_2 be more easily contained for long periods of time, due to the supercritical nature of the fluid. Depleted oil and gas fields are very attractive for this use because their geology is well understood, they have succeeded at containing oil and gas for long periods of time, and the quantity of material that has been retrieved from these areas is known.

The carbon dioxide stream from the power plant must be extremely pure in order to minimize the storage volume of carbon dioxide and allow for compression to a supercritical state. This compression can occur because CO_2 in a supercritical state has a density near that of a liquid. The pressurized CO_2 from the power plant flows into the pores of the rocks in the reservoir. Scientists believe that over time the CO_2 may react with minerals to form a stable solid, dissolve into salt water, or pool below the rocks capping the reservoir.

Effects of Sequestration

There are many concerns regarding sequestration. Safety is a big issue. The fluid is acidic and health effects are observed for CO_2 concentrations of 15,000 ppm or greater. Loss of consciousness or death may occur at 50,000 to 100,000 ppm. Sequestration sites need to be kept far away from the drinking water supply, geological faults, and places where seismic activity may be possible. There are also questions about the ownership and liability for storage reservoirs.

Several leaks from sequestration reservoirs have occurred in the past. In 1982, the Sheep Mountain CO_2 dome in Southern Colorado experienced failure in one of its production wells. Seven years after initial production, a well blew out and was uncontrollable for seventeen days. The flow rate was estimated between 7000 to 11,000 tons of CO_2 per day. No one killed in the accident, despite the massive amount of CO_2 leakage. The environment surrounding the area helped mitigate some of the effects the CO_2 may have had (the sloped terrain and local weather conditions enabled the CO_2 to mix rapidly with the atmosphere). The failure was immediately recognized as dry ice accumulation on the casing, which "blew off the well in chunks." The case appears to provide an upper limit of CO_2 leakage from a single well. The well was finally able to be controlled and closed, with no documented subsequent leakage. From this case, it can be concluded that proper placement of wells, monitoring, and operations can prevent substantial harm from CO_2 emission rates of this magnitude.

Studies have been done that show the effect that CO_2 sequestration can have on groundwater. In 2004, a Department of Energy pilot field experiment injected more than 1800 of CO_2 into the Frio saline formation in Texas. This experiment was designed to validate simulations of CO_2 transport and fate in one of the largest saline formations in the U.S. A monitoring well located about 100 feet from the injection well collected direct fluid samples using a U-tube apparatus. This tool, among others, detected the arrival of a CO_2 plume in the monitoring well 7 days after injection. A substantial amount of dissolved metal was recovered in the U-tube. The workers initially thought that the well casing was reacting to carbonic acid in the reservoir. However, laboratory studies and geochemical analyses confirmed that a substantial fraction of the metals were the product of mineral dissolution, specifically the oxide and hydroxide coatings of mineral grains that represent less than two percent of the surrounding rock. The rapidity of mobilization and the high concentrations suggested strongly that carbonic acid formed from dissolved CO_2 brines might quickly and dramatically alter groundwater chemistry.

The effects of CO_2 sequestration vary based on the kind of aquifer, in particular carbonate systems or silicilastic systems. This classification is based on the composition of the reservoir rock. The composition of the rock greatly affects the response to any carbon acid that forms. Silicate materials react slowly with CO_2, which means that there is little change in porosity and permeability over the duration of the injection; however, the brines with the dissolved CO_2 will remain acidic. In contrast, carbonate rocks react quickly with CO_2 and could change permeability and porosity quickly. However, the rapid kinetics will result in rapid increase of brine pH and buffering of the brine-CO_2 system, reducing reactivity over time. From these “competing effects,” it is not clear which fundamental rock composition is more prone to leakage or to mobilization of metals, and little work has focused on direct comparison of these two primary aquifer compositions.

Sequestration Projects

The U.S. Department of Energy has advanced to a second stage of its plan to develop carbon sequestration technologies. One-hundred million dollars was given to seven projects created in 2002 to support the US sequestration network. These projects were used to determine the most suitable technologies, regulations, and infrastructure requirements for CO_2 sequestration. Teams used computer modeling and geographic, as well as economic, analysis to identify sites with the potential to store over 600 billion metric tons of CO_2, equivalent to 200 years of US energy source emissions. Stage two of this project involves the same group of seven organizations doing a four year (2005-2009) study concentrated on field testing and validation of sequestration technologies. They will also identify the most promising regional repositories for CO_2, look into permitting requirements, and identify best management practices. The seven projects are listed below.

1.) Big Sky Regional CSP will demonstrate geologic storage in mafic/basalt rock formations.
2.) Midwest Geological Sequestration Consortium will determine the ability, safety, and capacity of geological reservoirs to store CO_2 in deep coal seams, mature oil fields, and saline reservoirs.
3.) Midwest Regional CSP will test injections into deep geologic reservoirs to demonstrate safety and effectiveness.
4.) Southeast Regional CSP will examine three field sequestration validation tests on enhanced oil recovery, stacked reservoirs, coal seams, and saline reservoirs.
5.) Southwest Regional CSP will conduct five field tests on carbon sink targets and deep saline sequestration.
6.) Plains CO_2 Reduction Partnership will complete four field trials of storage, monitoring, and mitigation in oil/gas reservoirs and unmineable coal seams.

7.) West Coast Regional CSP will conduct two storage tests in gas and saline reservoirs.

Recently, the United States Department of Energy committed $197 million over the next ten years to fund three new carbon sequestration projects. An additional $250 million in governmental funding is also expected to be granted. That money will fund four more projects, including one in Illinois.

Regulations

Many states are taking CO_2 mitigation issues into their own hands, while the presidential administration is still uncertain and opposes mandatory changes. New York and California, two of the most active states, have actually made future greenhouse gas cuts legally binding. So far, twenty-nine states have at least made plans to reduce CO_2 emissions due to burning fossil fuels. Starting in 2009, New York plans to auction credits that allow plants to emit limited amount of CO_2 each year. In 2015 the program would cut emissions by 10% by reducing the amount of such credits available. This program would affect coal power plants the most, as they account for double the CO_2 emissions of other natural gases. In addition, the governor of New York announced a plan this year that would cut electrical consumption by 2015 through increased efficiency standards. Three states, California, New Jersey and Hawaii, went even further and put targeted statewide CO_2 reduction into laws that future administrations will have to meet. New Jersey's law mandates a cut to 1990 levels by 2020 and a cut by 2050 of 80% of the current 2007 levels. California and Hawaii's laws require cuts to 1990 levels by 2020. California's law requires that a plan to reach this goal be in place by 2011. However, a fragmented state-by-state approach can't take the place of a strong federal policy, which is unlikely until a new president takes office in 2009.

There are many areas of sequestration being researched, each with its own set of items which could be regulated. For surface leakage, the impact of accidental CO_2 leaks, topics include: human health, ecosystem health, and climate change mitigation effectiveness. The category of groundwater quality encompasses the safety and aesthetics of drinking water as well as irrigation water quality. Underground Injection Control (UIC) regulations, set by the U.S. EPA with an objective of protecting public sources of drinking water, will likely form the framework for these laws. Regional groundwater and hydrocarbon resource protection and managing the risk of induced seismic activity are regional impacts that will likely be managed. The current regulatory framework does not address the displacement of subsurface fluids on a regional scale. Permanence, or how long the CO_2 can be stored away, is another issue. Laws will likely created covering the minimum time required for sequestration, maximum allowable leakage rates, and monitoring requirements for completed geological sequestration projects. Development of monitoring and verification (M & V) protocols will need to be developed, as well as geological sequestration siting guidelines.

B. Outputs from Research

Two final reports will be generated from the research completed by this IPRO: one for the IPRO office and one for Sargent & Lundy. These reports will provide the basic framework for the second semester of this project, in which one of these systems will be designed.

C. Deliverables

The written reports are the only deliverables for this IPRO. No products are being created.

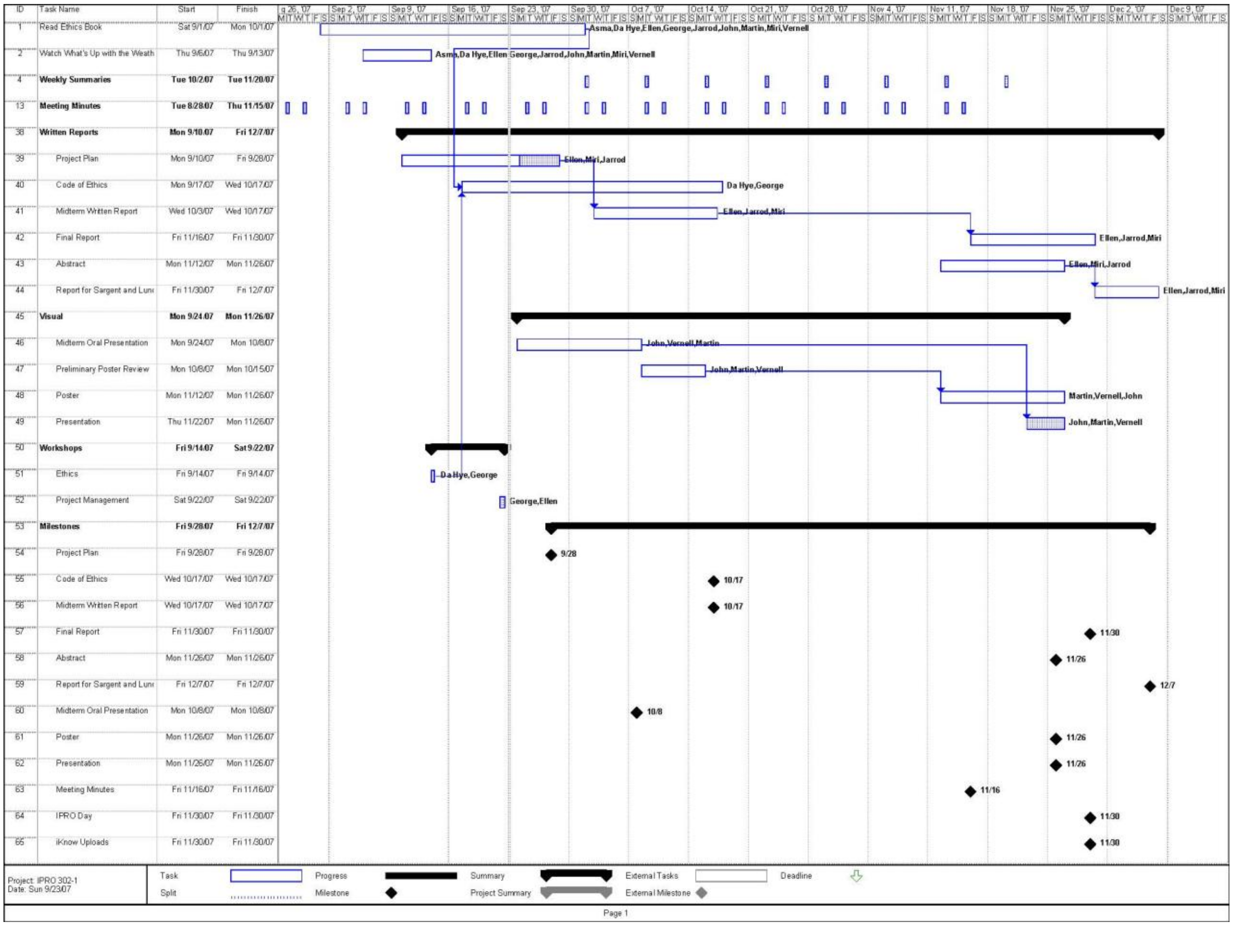
D. Sponsor Problem

The current results do satisfy the requirements of Sargent & Lundy, but more research work is needed in order to thoroughly cover the topics on which information was requested.

E. Incorporation of Current Results

The current findings will be combined with the research that will be completed in the next few weeks to make the final reports.

3.0. Revised Task / Event Schedule



ID	Task Name	Start	Finish
1	Read Ethics Book	Sat 9/1/07	Mon 10/1/07
2	Watch What's Up with the Weath	Thu 9/6/07	Thu 9/13/07
4	**Weekly Summaries**	**Tue 10/2/07**	**Tue 11/20/07**
13	**Meeting Minutes**	**Tue 8/28/07**	**Thu 11/15/07**
38	**Written Reports**	**Mon 9/10/07**	**Fri 12/7/07**
39	Project Plan	Mon 9/10/07	Fri 9/28/07
40	Code of Ethics	Mon 9/17/07	Wed 10/17/07
41	Midterm Written Report	Wed 10/3/07	Wed 10/17/07
42	Final Report	Fri 11/16/07	Fri 11/30/07
43	Abstract	Mon 11/12/07	Mon 11/26/07
44	Report for Sargent and Lun	Fri 11/30/07	Fri 12/7/07
45	**Visual**	**Mon 9/24/07**	**Mon 11/26/07**
46	Midterm Oral Presentation	Mon 9/24/07	Mon 10/8/07
47	Preliminary Poster Review	Mon 10/8/07	Mon 10/15/07
48	Poster	Mon 11/12/07	Mon 11/26/07
49	Presentation	Thu 11/22/07	Mon 11/26/07
50	**Workshops**	**Fri 9/14/07**	**Sat 9/22/07**
51	Ethics	Fri 9/14/07	Fri 9/14/07
52	Project Management	Sat 9/22/07	Sat 9/22/07
53	**Milestones**	**Fri 9/28/07**	**Fri 12/7/07**
54	Project Plan	Fri 9/28/07	Fri 9/28/07
55	Code of Ethics	Wed 10/17/07	Wed 10/17/07
56	Midterm Written Report	Wed 10/17/07	Wed 10/17/07
57	Final Report	Fri 11/30/07	Fri 11/30/07
58	Abstract	Mon 11/26/07	Mon 11/26/07
59	Report for Sargent and Lun	Fri 12/7/07	Fri 12/7/07
60	Midterm Oral Presentation	Mon 10/8/07	Mon 10/8/07
61	Poster	Mon 11/26/07	Mon 11/26/07
62	Presentation	Mon 11/26/07	Mon 11/26/07
63	Meeting Minutes	Fri 11/16/07	Fri 11/16/07
64	IPRO Day	Fri 11/30/07	Fri 11/30/07
65	iKnow Uploads	Fri 11/30/07	Fri 11/30/07

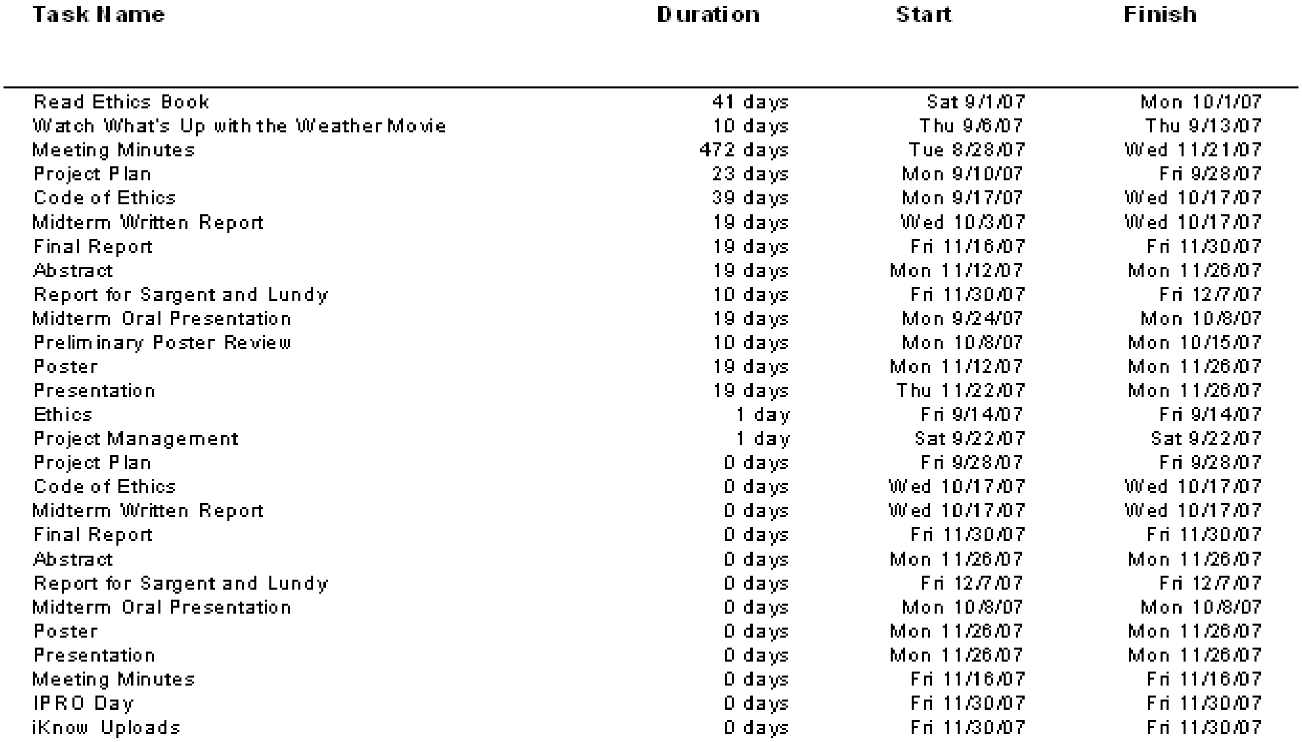
Project: IPRO 302-1
Date: Sun 9/23/07

A. Changes in Project Tasks

There have been no changes in the tasks needed to complete this project.

B. Changes in Summary Tasks

There have been no changes in summary tasks, and all due dates have stayed the same.



Task Name	Duration	Start	Finish
Read Ethics Book	41 days	Sat 9/1/07	Mon 10/1/07
Watch What's Up with the Weather Movie	10 days	Thu 9/6/07	Thu 9/13/07
Meeting Minutes	472 days	Tue 8/28/07	Wed 11/21/07
Project Plan	23 days	Mon 9/10/07	Fri 9/28/07
Code of Ethics	39 days	Mon 9/17/07	Wed 10/17/07
Midterm Written Report	19 days	Wed 10/3/07	Wed 10/17/07
Final Report	19 days	Fri 11/16/07	Fri 11/30/07
Abstract	19 days	Mon 11/12/07	Mon 11/26/07
Report for Sargent and Lundy	10 days	Fri 11/30/07	Fri 12/7/07
Midterm Oral Presentation	19 days	Mon 9/24/07	Mon 10/8/07
Preliminary Poster Review	10 days	Mon 10/8/07	Mon 10/15/07
Poster	19 days	Mon 11/12/07	Mon 11/26/07
Presentation	19 days	Thu 11/22/07	Mon 11/26/07
Ethics	1 day	Fri 9/14/07	Fri 9/14/07
Project Management	1 day	Sat 9/22/07	Sat 9/22/07
Project Plan	0 days	Fri 9/28/07	Fri 9/28/07
Code of Ethics	0 days	Wed 10/17/07	Wed 10/17/07
Midterm Written Report	0 days	Wed 10/17/07	Wed 10/17/07
Final Report	0 days	Fri 11/30/07	Fri 11/30/07
Abstract	0 days	Mon 11/26/07	Mon 11/26/07
Report for Sargent and Lundy	0 days	Fri 12/7/07	Fri 12/7/07
Midterm Oral Presentation	0 days	Mon 10/8/07	Mon 10/8/07
Poster	0 days	Mon 11/26/07	Mon 11/26/07
Presentation	0 days	Mon 11/26/07	Mon 11/26/07
Meeting Minutes	0 days	Fri 11/16/07	Fri 11/16/07
IPRO Day	0 days	Fri 11/30/07	Fri 11/30/07
iKnow Uploads	0 days	Fri 11/30/07	Fri 11/30/07

C. Revised Hours Estimate and Team Member Assignments

IPRO 302 still needs to complete the abstract, poster, final presentation and two reports. Three team members will be primarily working on each of these projects, although other team members may help. The estimated number of hours for these projects has not changed. It is expected that each of these deliverables will take two weeks to prepare, except for the final report for Sargent and Lundy. This final report is planned to only take one week, because the report for the IPRO office will have already been created.

4.0. Changes in Task Assignments and Designation of Roles and Team Organization

A. Changes to Team Organization

The team organization has remained the same, although the team leader has changed.

To accomplish the necessary research, the team broke up into three groups, each focused on a type of source: newspapers, patents, and technical journals. Within the source groups, each person is focusing on a particular topic, but is not limiting their research to just that topic. A second set of sub teams consists of the presentation team, the written report team, and the ethics team.

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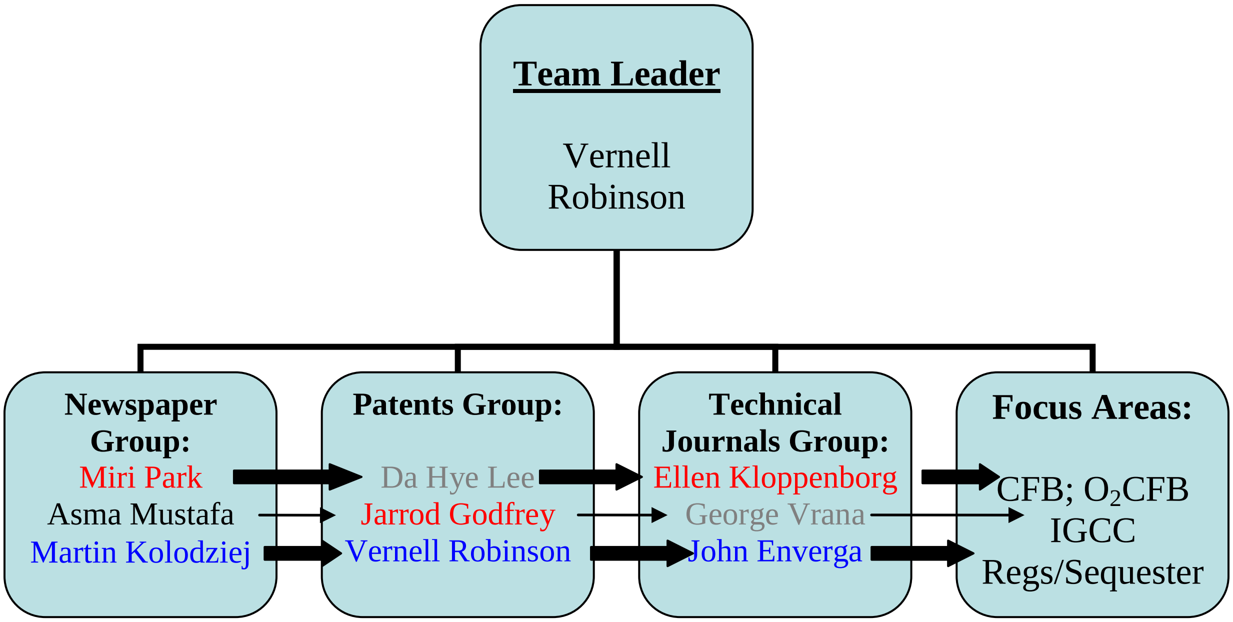


Presentation team (Blue): John Enverga, Martin Kolodziej, Vernell Robinson
Written report team (Red): Jarrod Godfrey, Ellen Kloppenborg, Miri Park
Ethics team (Grey): Da Hye Lee, George Vrana

B. Sub Team Assignments and Responsibilities

Each of the research sub-teams will use their particular source to find information, and within them each person will investigate their specific topic. Miri Park, Da Hye Lee, and Ellen Kloppenborg are concentrating on the conventional pulverized coal-fired boiler and oxy-combustion pulverized coal-fired boiler approaches. Asma Mustafa, George Vrana, and Jarrod Godfrey are focusing on the integrated gasification/combined cycle process. Martin Kolodziej, Vernell Robinson, and John Enverga are studying the current and future regulations and sequestration techniques.

The presentation team will prepare the midterm and final presentations and the poster. The written report team will write the project plan, midterm report, final report, and abstract. The ethics team will attend the ethics workshop. They will then present this information to the whole group and lead them in developing the code of ethics.

C. Changes in Team Member Roles

Vernell Robinson is now the team leader instead of Asma Mustafa. He has also taken over the roles of Agenda Maker, Time Keeper, and Weekly Timesheet Collector/Summarizer.

Miri Park has taken on the role of Minute Taker instead of Da Hye Lee.

All of the other roles are the same as in the project plan and as summarized in part b, above. Jarrod Godfrey is still the Master Schedule Maker, and Ellen Kloppenborg is managing iGROUPS.

D. **Cause of Changes in Team Organization**

The team leader position was changed, due to unexpected familial circumstances.

5.0. Barriers and Obstacles

A. **Obstacles Encountered**

The magnitude of information available on the different technologies has been difficult to sort through and organize. Team members have to learn to determine which information is current and relevant to the ultimate goal and objectives of the project. Every member of the team comes from different disciplines; it has been demanding working as a combined effort because of different approaches to solving problems within the project. This project has introduced several key concepts that deal with mechanical and chemical engineering that are foreign to several team members because of their different backgrounds; understanding and comprehending these key concepts have been a barrier for members.

B. **Resolution of Obstacles**

In order to break down the information and make it easier to understand we have broken down the team into smaller sub teams comprised of three people. Sub teams are now meeting weekly to discuss findings, help each other discover which data is important, and aid one another in the information gathering process. By having each team-member span several sub-teams, communication and situational awareness are further enhanced among all team members.

C. Remaining Obstacles

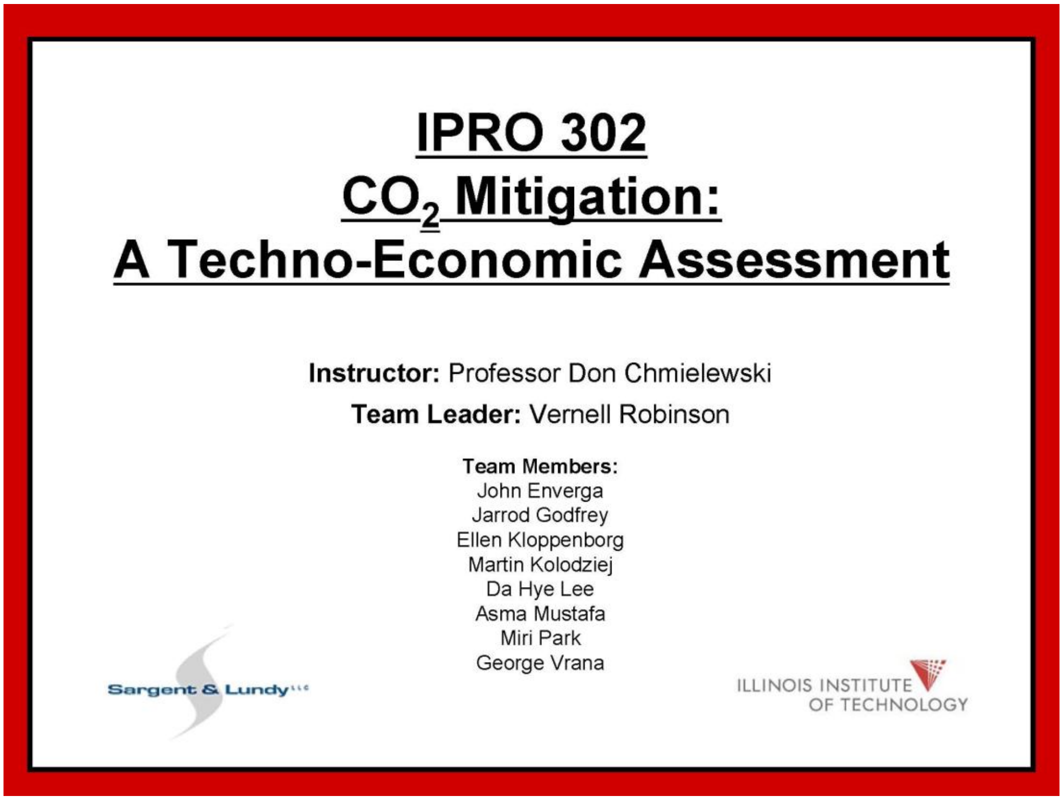
The team is still challenged by the obstacles that were encountered at the beginning of the project. It is an ongoing process of disseminating all of the information and relaying it to team members in terms that everyone can understand.

D. **Dealing with Obstacles**

The students in the various sub teams will continue to meet and help each other address this issue. Unforeseen future obstacles will thus be identified early so that appropriate steps can be taken to resolve them in a timely manner.

6.0. Code of Ethics (Attached as a Separate Document)

7.0. Midterm Presentation Slides



IPRO 302
CO_2 Mitigation:
A Techno-Economic Assessment

Instructor: Professor Don Chmielewski

Team Leader: Vernell Robinson

Team Members:
John Enverga
Jarrod Godfrey
Ellen Kloppenborg
Martin Kolodziej
Da Hye Lee
Asma Mustafa
Miri Park
George Vrana

Sargent & Lundy LLC

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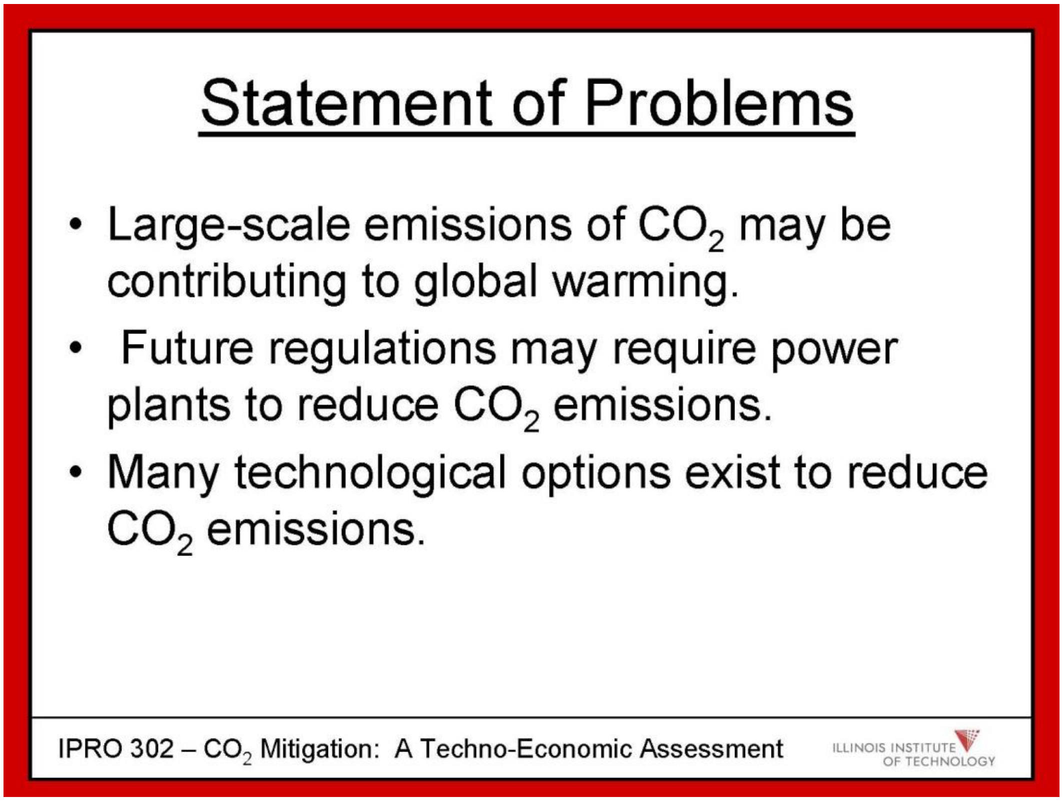

Statement of Problems

- Large-scale emissions of CO_2 may be contributing to global warming.
- Future regulations may require power plants to reduce CO_2 emissions.
- Many technological options exist to reduce CO_2 emissions.

Sponsor

Sargent & Lundy LLC

Sargent & Lundy is sponsoring IPRO 302. They have:

- Over 100 years experience in providing comprehensive consulting, engineering, design, and analysis for electric power generation and power delivery projects worldwide.
- A large, highly experienced staff solely dedicated to the energy business.
- The ability and expertise to take on the smallest tasks as well as the largest projects.

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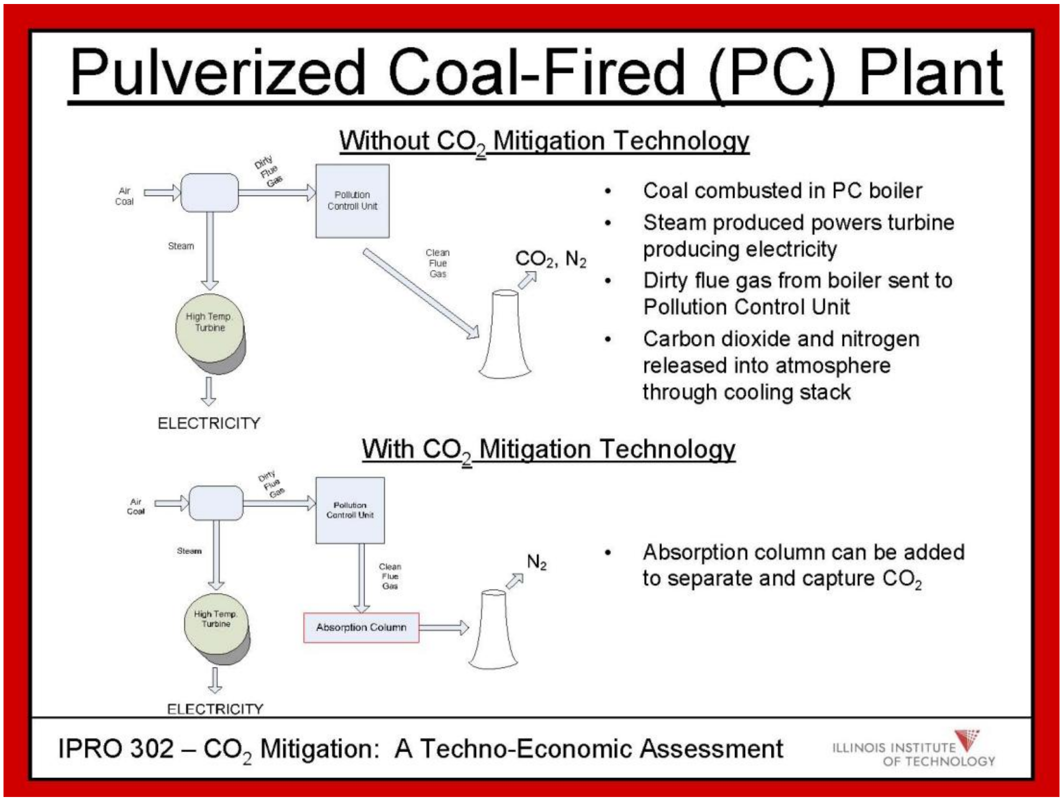

Pulverized Coal-Fired (PC) Plant

Without CO_2 Mitigation Technology

- Coal combusted in PC boiler
- Steam produced powers turbine producing electricity
- Dirty flue gas from boiler sent to Pollution Control Unit
- Carbon dioxide and nitrogen released into atmosphere through cooling stack

With CO_2 Mitigation Technology

- Absorption column can be added to separate and capture CO_2

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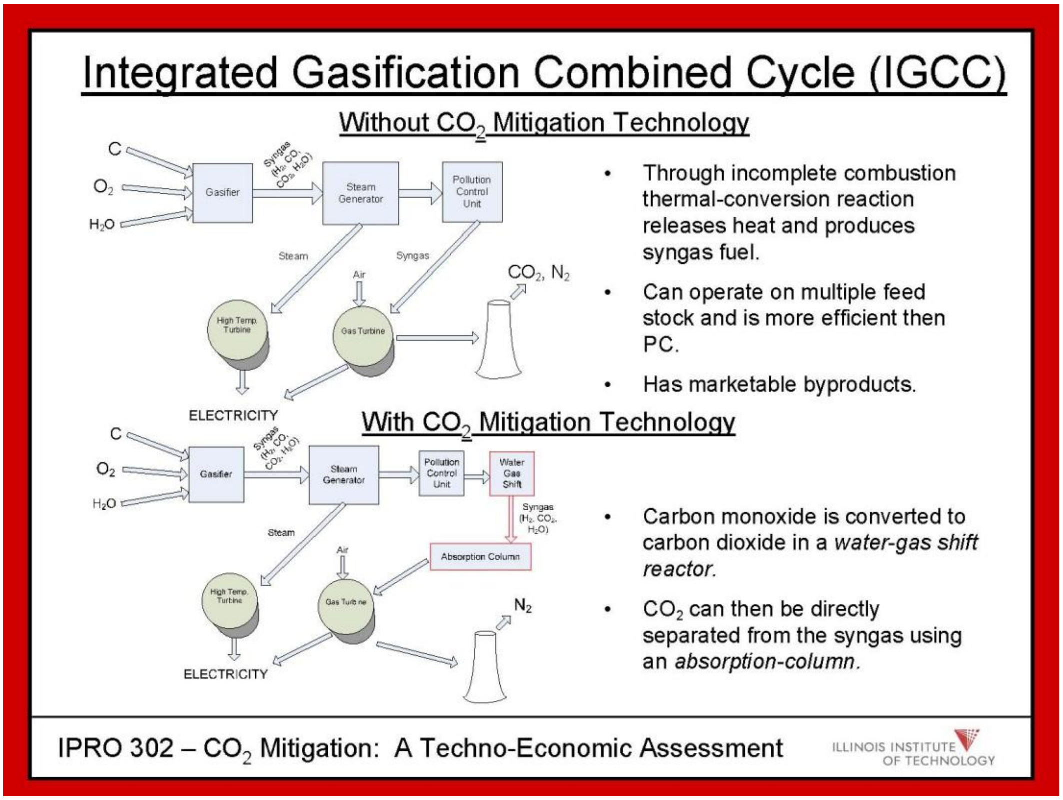

Integrated Gasification Combined Cycle (IGCC)

Without CO_2 Mitigation Technology

- Through incomplete combustion thermal-conversion reaction releases heat and produces syngas fuel.
- Can operate on multiple feed stock and is more efficient then PC.
- Has marketable byproducts.

With CO_2 Mitigation Technology

- Carbon monoxide is converted to carbon dioxide in a *water-gas shift reactor.*
- CO_2 can then be directly separated from the syngas using an *absorption-column.*

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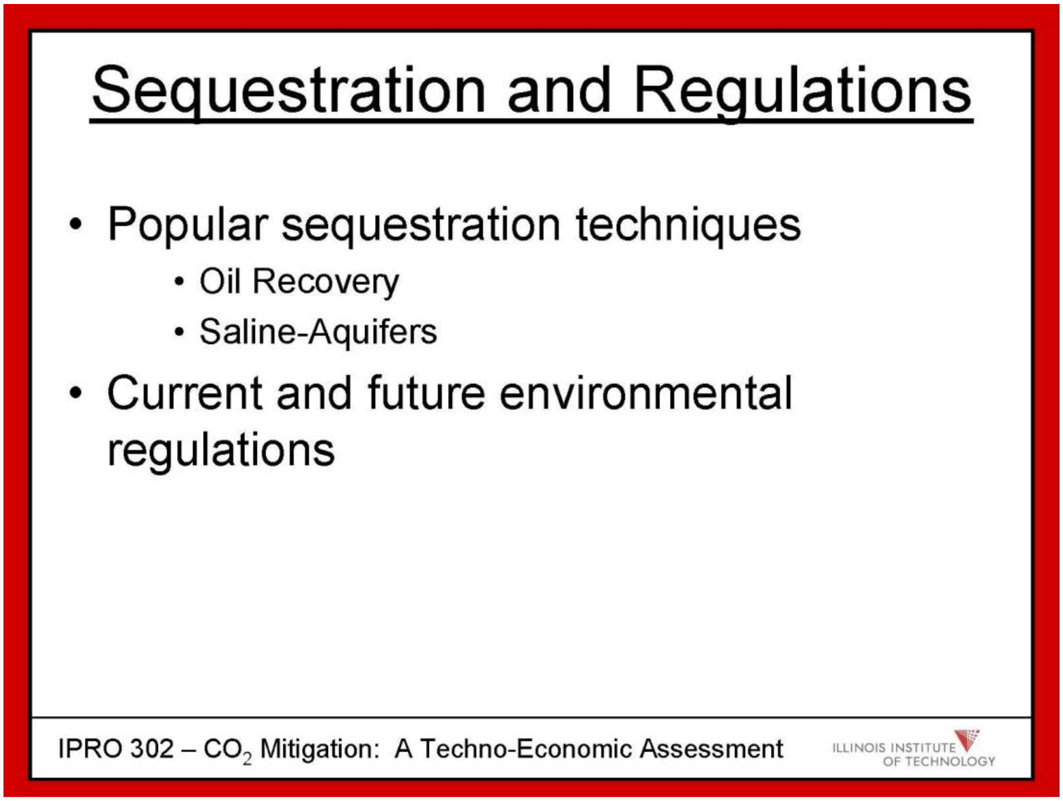

Sequestration and Regulations

- Popular sequestration techniques
  - Oil Recovery
  - Saline-Aquifers
- Current and future environmental regulations

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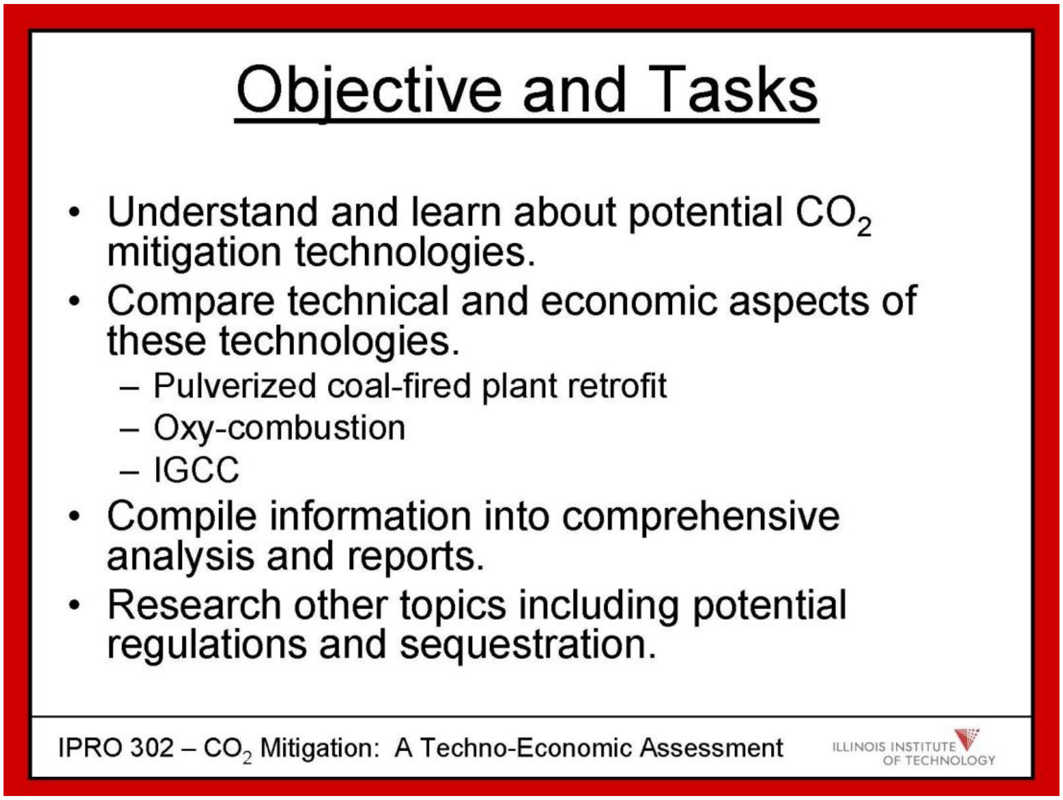

Objective and Tasks

- Understand and learn about potential CO_2 mitigation technologies.
- Compare technical and economic aspects of these technologies.
  - Pulverized coal-fired plant retrofit
  - Oxy-combustion
  - IGCC
- Compile information into comprehensive analysis and reports.
- Research other topics including potential regulations and sequestration.

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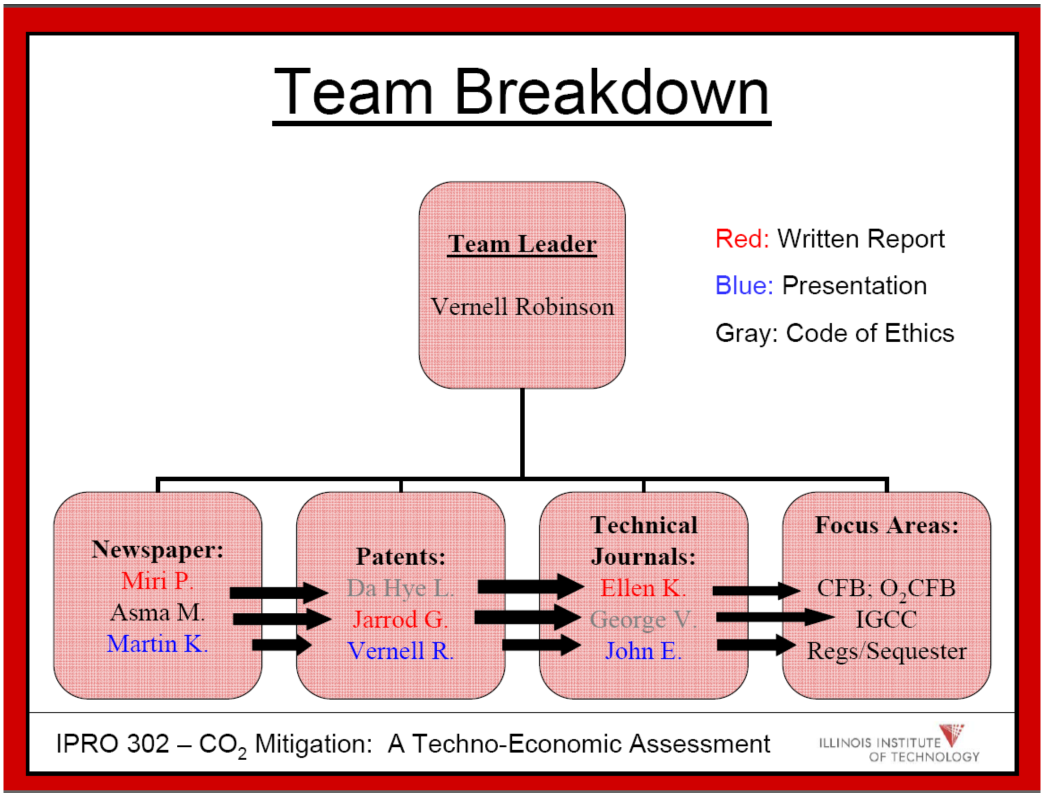

Team Breakdown

Team Leader

Vernell Robinson

Red: Written Report

Blue: Presentation

Gray: Code of Ethics

Newspaper:
Miri P.
Asma M.
Martin K.

Patents:
Da Hye L.
Jarrod G.
Vernell R.

Technical Journals:
Ellen K.
George V.
John E.

Focus Areas:
CFB; O_2CFB
IGCC
Regs/Sequester

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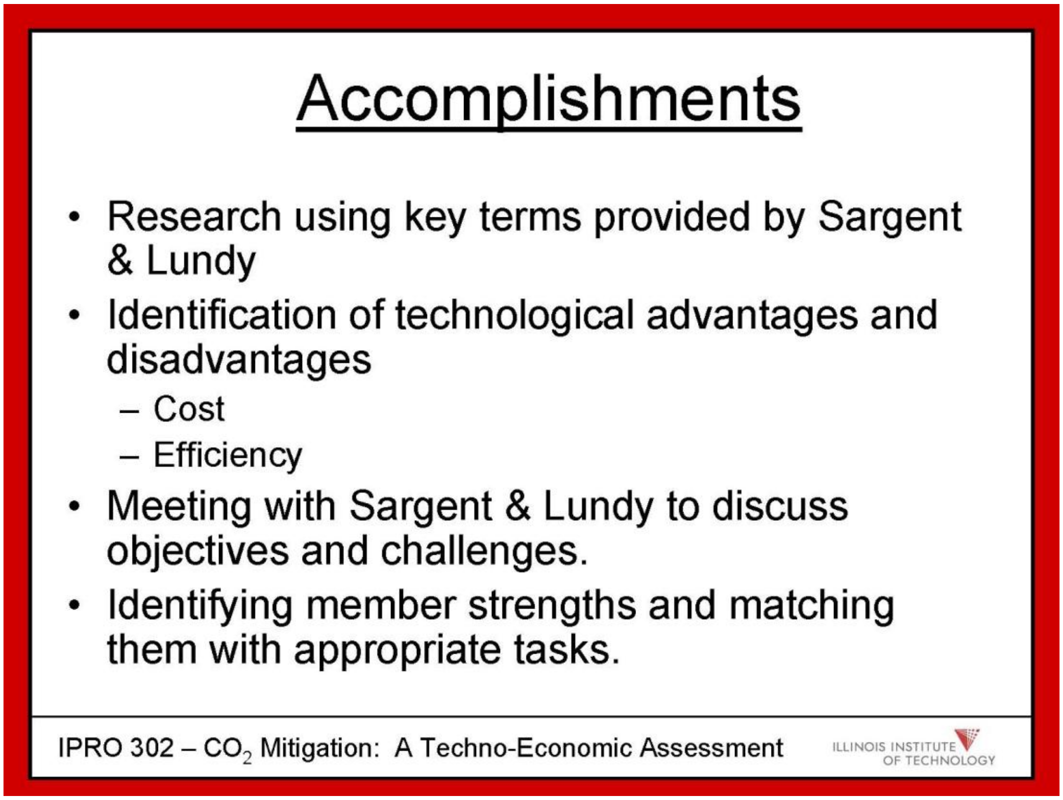
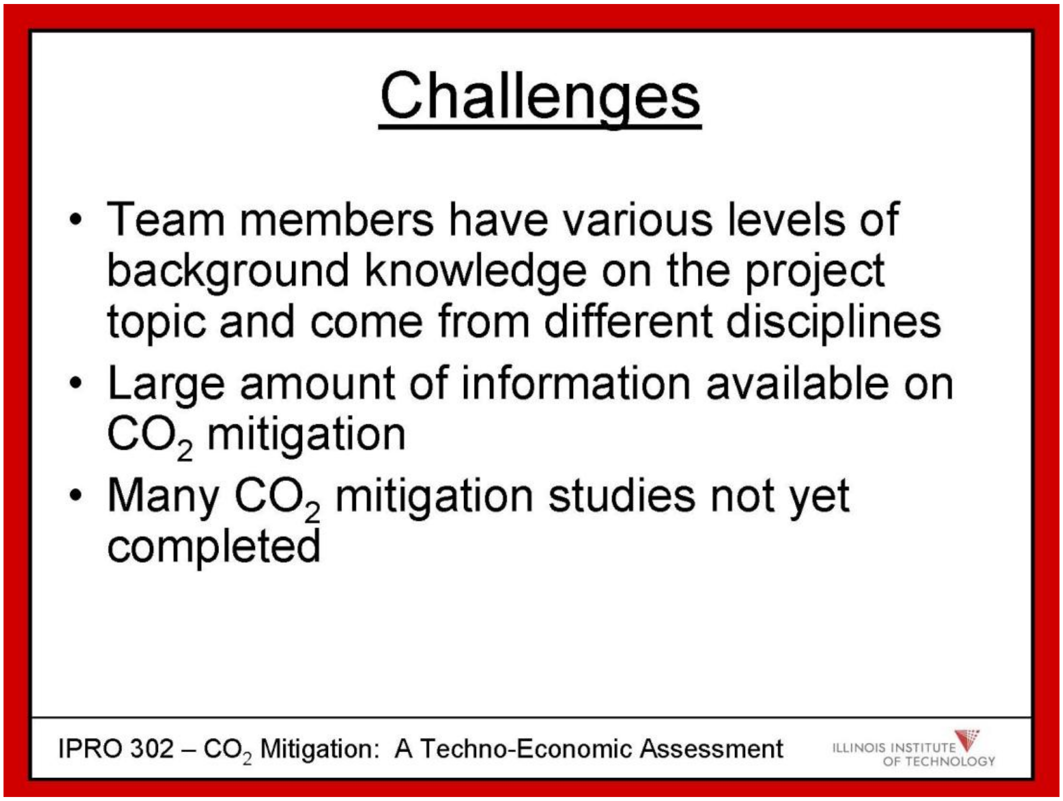


Accomplishments

- Research using key terms provided by Sargent & Lundy
- Identification of technological advantages and disadvantages
  - Cost
  - Efficiency
- Meeting with Sargent & Lundy to discuss objectives and challenges.
- Identifying member strengths and matching them with appropriate tasks.



Challenges

- Team members have various levels of background knowledge on the project topic and come from different disciplines
- Large amount of information available on CO_2 mitigation
- Many CO_2 mitigation studies not yet completed

Thank You

Questions?

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