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Creating markets for captured carbon: Retrofit of Abbott Power Plant and Future Utilization of Captured CO_2

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Abstract

The successful implementation of CCUS requires the confluence of technology, regulatory, and financial factors. One of the factors that impact this confluence is the ability to utilize and monetize captured CO_2. The generally accepted utilization approach has been CO_2-based Enhanced Oil Recovery (EOR), yet this is not always feasible and/or a preferable approach. There is a need to be able to explore a multitude of utilization approaches in order to identify a portfolio of potential utilization mechanisms. This portfolio must be adapted based on the economy of the region. In response to this need, the University of Illinois has formed a Carbon Dioxide Utilization and Reduction (COOULR) Center. The open nature of the university, coupled with a university policy to reduce CO_2 emissions, provides a model for the issues communities will face when attempting to reduce emissions while still maintaining reliable and affordable power. This Center is one of the key steps in the formation of a market for captured CO_2. The goal of the Center is to not only evaluate technologies, but also demonstrate at a large pilot scale how communities may be able to adjust to the need to reduce GHG emissions.

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Keywords: carbon capture; utilization market; coal-fired power plant retrofit; emissions goals;

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1. Introduction

The 2016 Paris Agreement firmly established CO_2 as the primary driver of global warming and has stimulated investor pressure and voluntary responses from many multinational firms thereby creating significant opportunities for technological advances. There are a variety of market and regulatory pressures coming together within the USA that could influence the installation of capture systems at power generation facilities. Some states, such as California, have already established mechanisms that put a price on carbon (e.g. Cap and Trade). The U.S. Environmental Protection Agency's Clean Power Plan is currently being challenged at the U.S. Supreme Court. Even though the final outcome is not known at this time, the proposed plan has impacted decisions being made in the power generation market place.

The U.S. Department of Energy (DOE) has been investing in second generation capture systems. Many of these systems have been under development for close to a decade. These systems have now reached the stage where they are ready for large scale pilots (10 MWe or greater). These large scale pilots are key in order to assure that the next generation capture technologies are commercialized and eventually available for deployment. Large scale pilots are important because they provide a means to better understand engineering issues that can impact the installation and operation of capture systems. These issues would not be uncovered during smaller scale testing. It is important to rapidly transition to large scale pilots since they precede the knowledge and cost reductions that occur during deployment [1, 2].

It is also important to consider the economic and social impacts of CCUS, especially when considering the retrofit of existing power plants. Utilization can serve as a stimulus for CCUS since CO_2 is treated as a revenue source, not a waste that must be disposed. CO_2 Enhanced Oil Recovery (EOR) has often been discussed as a means for utilization. While CO_2 EOR is important, it should not be relied upon as the only means for utilization. It would be more advisable to have a portfolio of utilization options available. This portfolio approach might decrease the business risk associated with utilization, since multiple markets and multiple revenue streams are possible. Portfolios also provide a means to mitigate risks associated with the possibility of "flooding" markets with CO_2 and thereby depressing market prices. Figure 1 provides a list of some of the utilization options that have been discussed in the literature or have been evaluated in the field.

CCUS deployment can also be stimulated if it provides positive social impacts. The establishment of a regional market for captured CO_2 offers the chance to create new jobs and new businesses. This goal requires engaging and building the entire CO_2 supply chain – CO_2 sources and CO_2 sinks. There may be opportunities for new businesses to manage the off-take of the CO_2 from the plant and its transfer to other partners within the supply chain as well as opportunities to employ operators of the capture plant.

What is needed is a large scale pilot that demonstrates not only economical capture, but also provides a test bed for utilization technologies. It should be able to examine all of the risk factors that concern the multitude of stakeholders in the business and societal ecosystem. This approach provides a template for other communities that would be impacted by retrofitting power plants for CCUS.

Nomenclature

CCUS	carbon capture, utilization, and storage
CO_2	carbon dioxide
COOULR	Carbon Dioxide Utilization and Reduction Center
DOE	Department of Energy
R&D	research and development

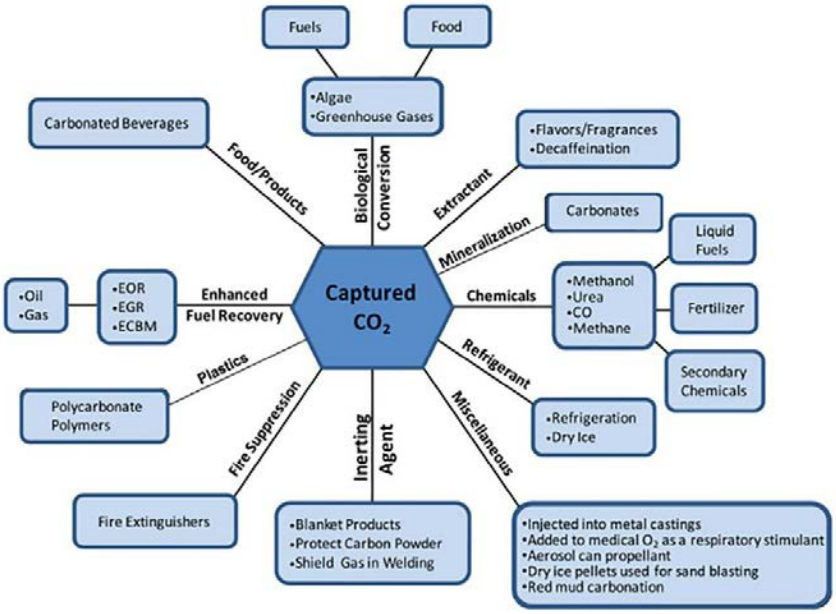

Figure 1. Variety of CO_2 utilization options that have been discussed in the literature [3].

2. Illinois: A Major Hub for CCUS Related Research and Development

One of the key components of the Illinois economy is its manufacturing base. As a result, reliable power that is also low cost is vital to maintain and grow the state's economy. Illinois has one of the lowest costs of electricity in the USA [4]. This low cost is driven by the fact that the two major sources for electricity generation are nuclear and coal (see Figure 2). Based on data collected by the Energy Information Administration (EIA), Over 40% of the electricity generation within the state of Illinois is derived from coal [5]. This translates into approximately 6,500 GWh coal-based production of electricity. Figure 3 demonstrates the extent of coal reserves within Illinois. Reserves underlie 37,000 sq. miles or 68% of Illinois. More than 211 billion tons of identified resources are currently estimated to lie beneath the state. The demonstrated reserve base is 112 billion tons, as defined in terms of minimum thickness and some geologic assurance of coal's presence. This demonstrated coal reserve base is the second largest in the United States and, for bituminous coal, is the largest in the nation.

Coal-fired generation is under pressure from a variety of factors. For example, the U.S. Environmental Protection Agency (EPA) Clean Power Plant has established targets for CO_2 reductions for each state. As demonstrated in Figure 4, these requirements result in an approximate 42% reduction in CO_2 emissions within the state of Illinois by 2030. An economical means to perform CCUS is vital for a coal state such as Illinois.

Illinois is not only a coal state, but also an agricultural-based state. Electric cooperatives have long been a critical link in supplying the electricity needs of Illinois' agricultural base. Many of these cooperatives rely on coal-based power generation. The looming regulations of the Clean Power Plan are perceived as a risk by this industry.

Illinois realizes the connection between economic growth and reliable, low-cost power generation. At the same time, the state actively pursues methods to reduce carbon emissions. The University of Illinois at Urbana Champaign (UI) and its partner universities are strongly entrenched in research and development efforts that will enable Illinois to maintain cost effective power generation while simultaneously reducing carbon emissions. This challenging effort is being accomplished through a unique confluence of Illinois' agriculture, geology, and mineral assets with strong research and development (R&D) capabilities and environmental policies. The confluence of these factors enables the formation of the Carbon Dioxide Utilization and Reduction (COOULR) Center.

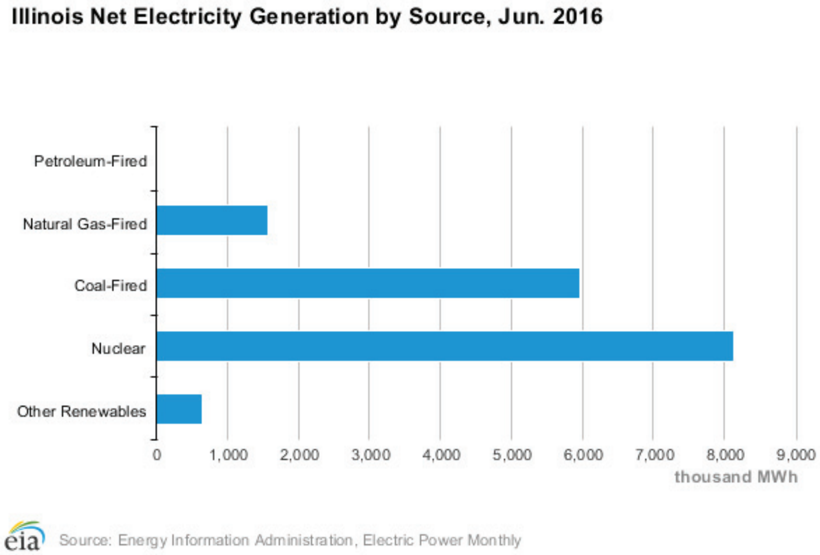

Figure 2. Electricity generation in Illinois [5].

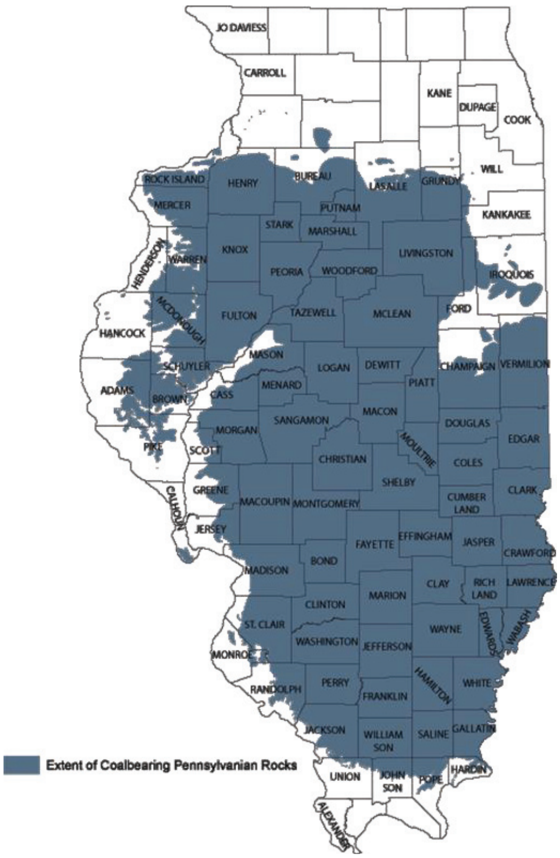

Figure 3. Coal reserves within Illinois [6].

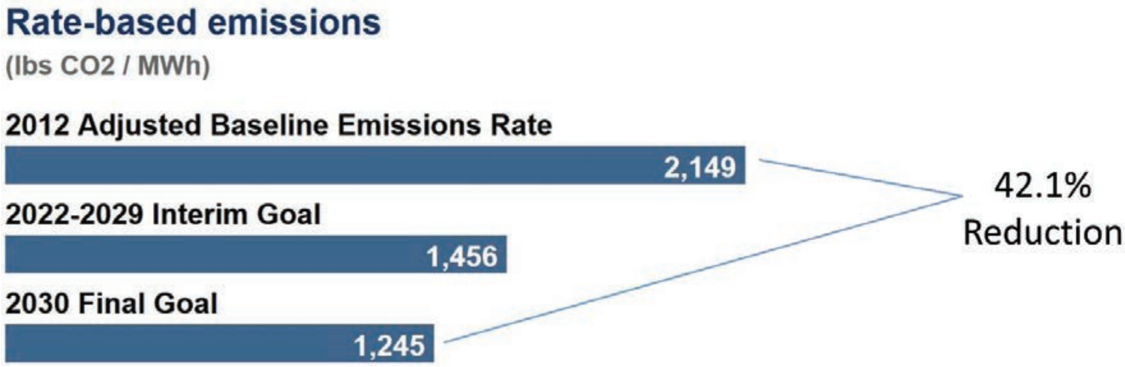

Figure 4. Reductions required by Illinois under the U.S. EPA's Clean Power Plan [7].

3. University of Illinois: Model Ecosystem for Evaluating CCUS

3.1. Power Plant and Capture Technology

The University of Illinois is a microcosm for many communities in the region, nation, and globe. The University has set in place its own regulatory guidelines (i.e. the Illinois Climate Action Plan (iCAP) [8]) to limit the carbon emissions from the University. The Abbott Power Plant (see Figure 5), which supplies heat and power to the campus, is the largest point source on campus. The plant has explored other means and has determined that carbon capture should be part of the solution to achieve iCAP goals. As a result, the installation of a capture unit at the Abbott Power Plant will provide a blueprint to demonstrate the feasibility of retrofitting regional power plants. In later phases, the captured CO_2 can be used to evaluate the range of utilization approaches that were previously listed in Figure 1.

The Abbott Plant has a number of features that make it attractive for large scale pilots. The total nameplate capacity of the plant is 84 MWe, 35 MWe being coal.

Abbott's maximum steam production capacity is about 800,000 lb/hr (363,200 kg/hr). Of the total seven boilers, three are coal based, all of which are of the chain-grate stoker design. The remaining four are fired by natural gas. The downstream system of the coal-fired boilers is COMPLETELY SEPARATE from that of the natural gas-fired boilers. This facilitates running the coal-fired boilers completely separate from the natural gas-fired boilers, Two coal boilers are each capable of producing up to 68,100 kg/hr of steam and another one has a capacity of producing 90,800 kg/hr of steam. An Illinois high sulfur coal is burned, with the coal delivered to the plant via semi-trucks. Electrostatic precipitators and a wet Flue Gas Desulfurization (FGD) scrubber are used in conjunction with the coal boilers to remove particulate and SO_2 from the flue gas. The three coal boilers combined are permitted to produce up to 158,900 kg/hr of steam as limited by the capacity of the FGD scrubber. Standard operating procedure is to run no more than two coal fired boilers simultaneously. At least one boiler is held in reserve. This translates into an equivalent of a 15 MWe output from the boilers. Most importantly, the plant has a tradition of evaluating new emission technologies and showcasing them to other power plants and education groups.

Another attractive feature of the plant is its dual fuel capabilities. The natural gas side of the plant could also be retrofit in order to enable side by side comparisons between capture and utilization from coal-fired systems vs capture and utilization from the natural gas side of the plant. This attribute is very important since some power plants are considering fuel switching from coal to natural gas.

Figure 5. Street view of the Abbott Power Plant.

3.2. Capture Technology and Installation

The carbon capture technology selected to retrofit the Abbott Power Plant is the Linde/BASF novel amine based advanced CO_2 capture absorption system, which has already shown the potential to be cost-effective, energy efficient, and compact at the 0.5-1.5 MWe pilot scales. Through its 1.5 MWe pilot testing program at the National Carbon Capture Center (NCCC), the technology demonstrated the promise of driving down the cost of CO_2 capture from commercial scale coal-fired power plants significantly toward the DOE-NETL target of $40/tonne.

Figure 6 outlines the capture technology and its interface to the power plant. The flue gas feed for the capture system will be taken post-FGD and reheater, and downstream of the Continuous Emissions Monitoring System (CEMS) used by Abbott Power Plant for regulatory compliance. This approach reduces regulatory / permitting risks that could negatively impact the schedule for installation of the capture unit. The anticipated flue gas feed for the capture system would be the exit stream of the FGD, after the flue gas reheater. The conditions of the flue gas are presented in Table 1.

A simplified schematic of Linde's pilot plant, along with tie-in points with Abbott Power Plant is shown in Figure 7. The site layout for the capture facility is shown in Figure 8. The space provides sufficient room for the construction of the capture system and an auxiliary cooling tower needed to supplement the needs of the capture system.

This large scale pilot for CO_2 also provides a source to explore ways to utilize the captured CO_2. The University and its partners are forming a global center for excellence to actively explore relationships with domestic and international organizations that are developing utilization technologies. An international advisory board has been formed to provide guidance to the Center. The goal of the Center is to explore the range of utilization approaches that have been previously outlined in Figure 1.

It is significant that this source is located at a university since it enables future knowledge sharing in order to encourage and facilitate the retrofit process. It will also include elements related to workforce and professional development to ensure that sufficient human capital is available to implement the retrofit and utilization technologies.

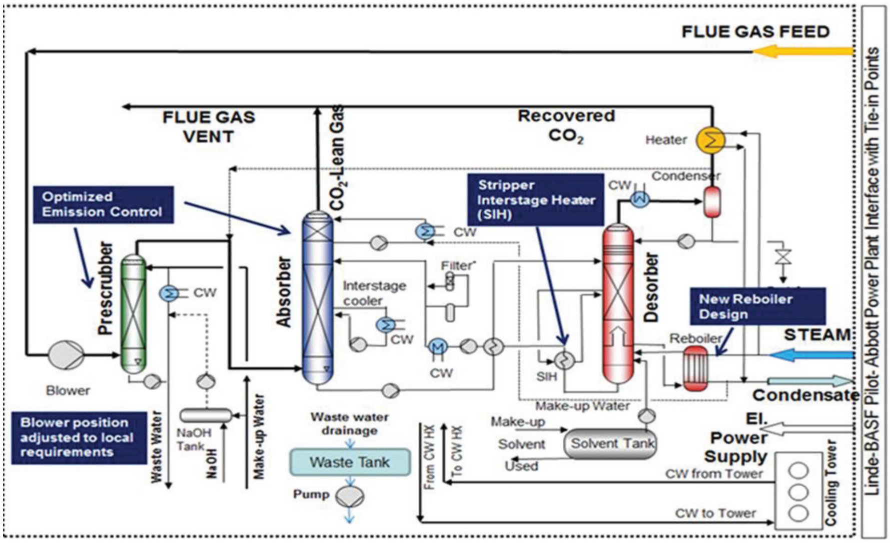

Figure 6. Linde/BASF capture technology used at Abbott Power Plant.

Table 1. Flue gas for the capture system.

Flue Gas Conditions	Exit Stream Values of FGD
Flow Rate	171,009 lb/hr (77,638 kg/hr) (slightly varies with test cases below)
Pressure	0.2 psig (1.4 KPa, gauge)
Temperature	200°F (93.3°C)
Composition	5.7%mol CO_2, 14.4%mol H_2O, 68%mol N_2, 10.30%mol O_2, 0.8%mol Ar, 68 ppmv SO_2 (max 200 ppmv), 211 ppmv NO_x, 4.1 mg/Nm^3 particulate matter

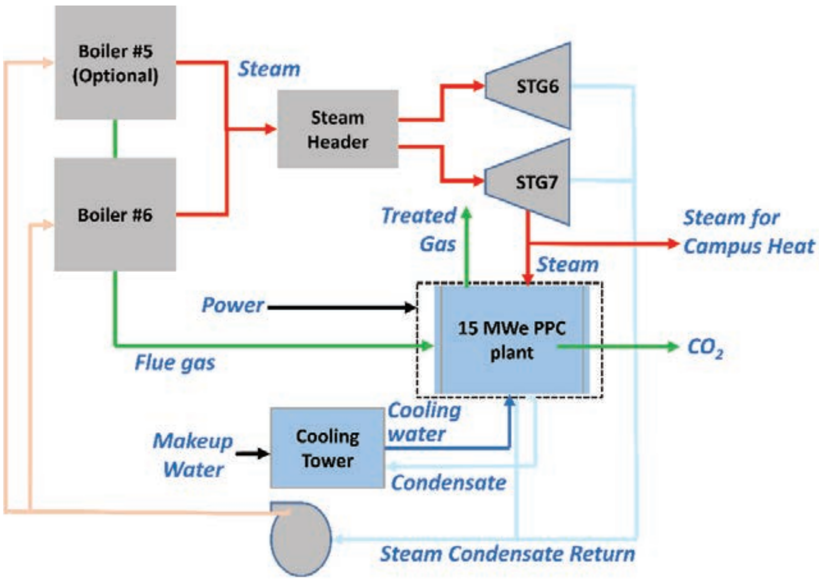

Figure 7. Integration of capture system with power plant.

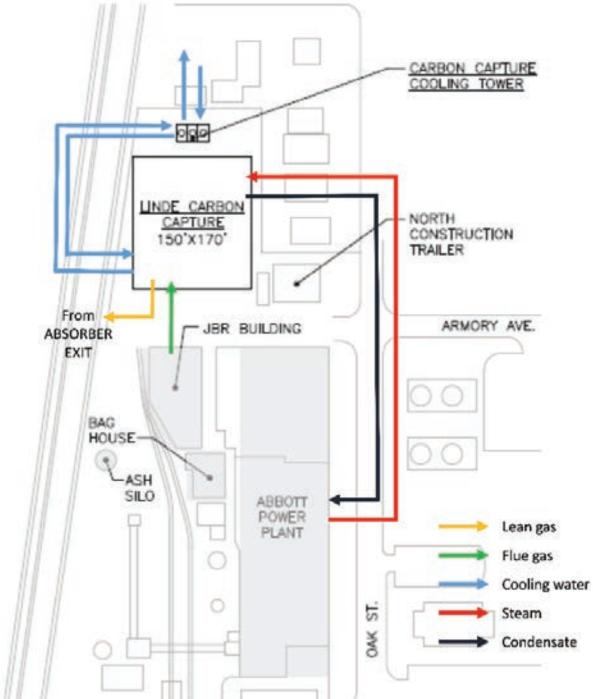

Figure 8. Site layout of capture facility at Abbott Power Plant.

4. Illinois as a Global Test Bed

The establishment of Abbott Power Plant as a site for large scale R&D related to carbon capture builds on existing University R&D. It also leverages existing projects, capabilities, and natural resources that are available within the State of Illinois (see Figure 9). This concentration of R&D, capabilities, and natural resources creates the opportunity to establish the State of Illinois as a global center of excellence in the management of carbon emissions from power generation facilities. It is especially significant that some of these resources would be within approximately 50 miles of the Abbott Power Plant – a very unique concentration of large scale carbon management projects.

A critical existing large scale project for the sequestration of CO_2 is the Illinois Basin – Decatur Project (IBDP). The IBDP project is being managed by the Illinois State Geological Survey (ISGS) as part of the Midwest Geological Sequestration Consortium (MGSC) [9]. This project is one of the most successful projects being conducted as part of the DOE's Regional Carbon Sequestration Partnerships (RCSP) Initiative [10]. IBDP is the first 1 million tonne CO_2 capture and storage project from a biofuel facility (Archer Daniel Midland's (ADM)) in the U.S. Post-injection monitoring will continue through 2017.

The City of Mattoon was one of the sites selected for sequestration of CO_2 in the FutureGen 1.0 project. As a result of this selection, a significant amount of geological characterization has already been performed in the area. The area could provide a possible site for CO_2 based Enhanced Oil Recovery (EOR) within the State of Illinois.

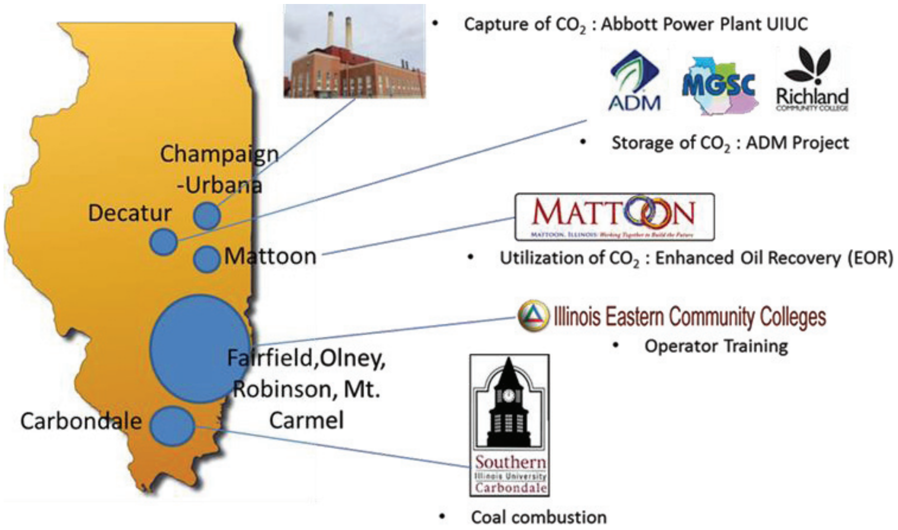

Figure 9. Aspects of COOULR Center design.

The Advanced Coal and Energy Research Center (ACERC) at Southern Illinois University was established in 1974 [11]. It has since expanded its focus in 2014 to include the broad array of energy innovation occurring across campus. ACERC is the hub for access to resources and information regarding advanced coal and energy research, development and commercialization for SIU and the regional community. Research includes: carbon dioxide utilization, chemical looping combustion, gasification, microalgal fermentation and advanced materials for fuel cells.

Illinois Eastern Community Colleges is a community college district headquartered in Olney, IL, with college campuses located in Olney, Fairfield, Robinson, and Mount Carmel [12]. Illinois Eastern Community Colleges District #529 (IECC) is located in a 3,000-square-mile (7,800 km^2) area of southeastern Illinois near the Illinois-Indiana border. The College District also includes a highly successful Workforce Education program which provides short-term training for some 10,000 employees each year at plant sites throughout the State of Illinois and in other states and countries as well. This workforce training program includes programs related to the coal industry.

This team is not only skilled at evaluating new technologies at a large pilot scale, but will also be able to access regional benefits afforded by capture and utilization. Illinois Eastern provides a training ground for new operators for capture and utilization facilities. The agricultural programs at UI and the surrounding agricultural facilities offers an attractive option for the captured CO_2 utilization. Large manufacturers who utilize CO_2 in their processes are within a radius of less than 150 miles.

The Center is evaluating utilization technologies that include algae production for the use of biofuel and other product generation, crop growth, generation of fine chemicals, plastic production, and applications in cement production. The Center welcomes technology providers that could perform large pilots to utilize the planned capacity of approximately 300 tons/day of CO_2 from the coal side of the Abbott Power Plant.

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