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The Case for Large-Scale Carbon Capture and Utilization in Louisiana

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The Case for Large-Scale Carbon Capture and Utilization in Louisiana

by

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I. Introduction

Louisiana undoubtedly faces the greatest threats and challenges of climate change more than any other state in the United States. The state's Gulf Coast and deltaic nature make its communities and biodiversity particularly vulnerable to extreme storms, sea-level rise, and subsidence. In the past two years, Louisiana has seen two of its most intense storms in recorded history. Hurricanes Laura and Ida both spun into the coast at 150 miles per hour in 2020 and 2021, respectively.[2] According to the International Panel on Climate Change (IPCC)'s Sixth Assessment Report (AR-6), if the average global temperature increase exceeds 1.5^{o}C, sea level rise will irreversibly accelerate and further submerge low-lying coastal communities.[3] The 2015 Paris Agreement set a global goal limit warming to 1.5^{o}C to avoid the worst impacts of climate change.[3] However, global greenhouse gas emissions rose in 2016 and continue to rise.[4] Even without considering climate change, though, the state has lost over 1,800 square miles of land since the 1930s.[5] After the Great Flood of 1927, the federal government leveed the entire lower Mississippi River, preventing any connection between its rich sediment load and the surrounding, sinking delta.[5] As a result, rising seas and stronger storms will quickly overpower and devour the endangered coast if greenhouse gases emissions continue at current or higher rates.

Louisiana faces a Climate Catch-22. Not only does the state face the worst effects of climate change, but Louisiana is also economically intertwined with the sectors that are largely responsible for climate change: energy and industry.[4] Petroleum and coal product manufacturing, Louisiana's largest industry, brings the state almost 21 billion GDP annually.[6] The state must protect its economy as well as confront its own emissions if it wants to remain afloat. In February 2022, the governor's office released a Climate Action Plan with the goal of reaching net zero emissions by 2050.[7] According to the 2021 Louisiana Greenhouse Gas (GHG) Inventory, industrial facilities are responsible for 66% of the state's carbon dioxide emissions based on data from 2018.[8] Industry dominates Louisiana's emissions, whereas in the United States overall, industrial facilities are only responsible for 17% of the nation's carbon dioxide emissions.[8]

Electrification of industrial processes is one decarbonization pathway. Some high heat processes, however, cannot be electrified, requiring fossil fuels.[7] Furthermore, energy and product demands are rising, and renewable energy alone cannot meet these demands, despite the global expansion of wind, solar, and hydropower electricity generation.[9] The industrial and power sector must meet current and growing demands by burning fossil fuels while also decarbonizing to combat climate change. Thus, carbon capture, utilization, and sequestration (CCUS) strategies must be employed in Louisiana. According to the state's energy policy tool, if the state achieved 100% carbon capture and sequestration (CCS) in the industrial and power sectors, Louisiana would be about 50 million metric tons away from net zero emissions in 2050, as opposed to over 250 million metric tons in the business-as-usual scenario (see Figure 1.0).[1] Of all the energy policies in the simulator such as electric vehicle rollout, building sustainability,

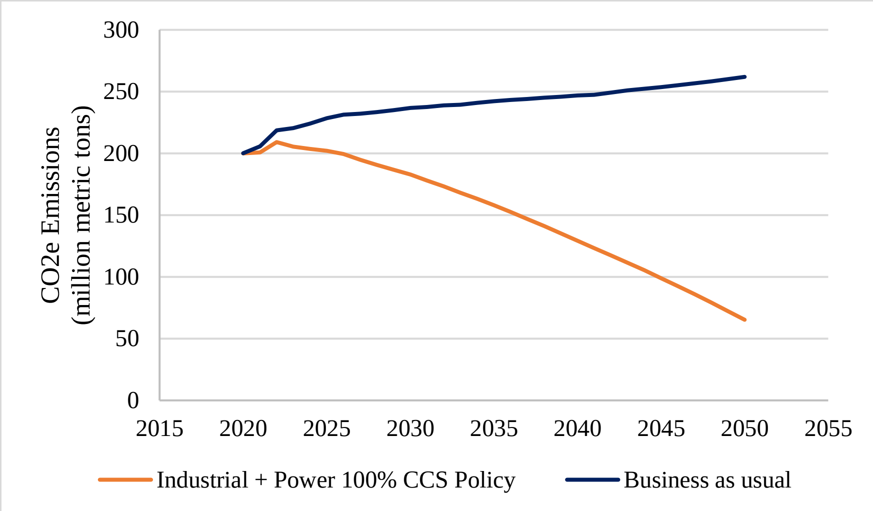

Figure 1.0 The Effect of 100% CCS Policy on Louisiana's Emissions[1]

and land use management, the CCS policy most drastically lowers emissions by 2050. Immediately achieving 100% sequestration immediately is optimistic. If CCS policy is combined with industrial electrification policy, though, achieving 100% sequestration becomes more feasible.[1] Envisioning these possibilities is informative; because CCS policy lowers Louisiana's emissions the most, the state should dedicate

Carbon capture technology is commercially available, and researchers continue to improve those strategies. Once captured, carbon dioxide can be transported to either a sequestration site or a utilization facility. Sequestration is particularly attractive in Louisiana; suitable geological formations scatter the coast.[10] According to some scientific and industrial community members, though, carbon sequestration serves as a bridge solution to the ultimate pathway to confront emissions: carbon capture and utilization (CCU).[11] When carbon emissions are transformed into a marketable product, companies can generate sustainable economic opportunities. Furthermore, CCU strategies will give Louisiana's petrochemical facilities a competitive advantage over its international counterparts.

Because of its existing industrial presence, Louisiana has an opportunity to become a leader in carbon capture and utilization strategies. First, commercialization potential for CCU strategies in Louisiana will be examined. Then, an industrial cluster will be selected to contextualize the commercialization potential for a specific CCU facility. The costs and financial feasibility of CCU strategies will be examined by performing a techno-economic analysis on the CCU facility required to convert the selected industrial cluster's emissions. Last, relevant federal and state actions will be analyzed to determine if sufficient government backing exists to support CCU buildout. This report will analyze the commercialization potential, the costs and financial feasibility, and the government backing of carbon capture and utilization strategies in Louisiana and ultimately prove that the state is primed to become a CCU leader in the near future.

II. Commercialization Potential

Industrial clusters and human capital provide a unique opportunity for Louisiana to lead the nation in commercializing carbon capture and utilization strategies, and some companies are already investing in CCUS strategies here. Massive power generation facilities and industrial complexes are no stranger to the state of Louisiana: 353 petrochemical and/or power facilities reported greenhouse gas emissions to the EPA in 2020.[12] The top 10 power generation sources emitted a total of 30,192,234 metric tons of CO_2, and the top 10 industrial sources emitted 57,376,309 metric tons of CO_2.[8] Louisiana needs to find ways to utilize power sector emissions as well as industrial emissions on a cluster level. Most of Louisiana's top twenty emitting facilities lie in southwestern Louisiana or along the petrochemical corridor, which stretches along the Mississippi River between Baton Rouge and New Orleans.[8] See Figure 2.0, which maps Louisiana's top 20 carbon dioxide emissions sources. Because most of these big emitters lie in clusters, these plants can share risks and resources as they adopt decarbonization technologies.[7] Facilities can share the cost of transporting emissions and attracting conversion facilities. Furthermore, a highly concentrated industry presence has led to a highly skilled workforce in the southwestern and southeastern regions of the state. Experts in industrial processes and transporting materials via pipeline live in those areas.[7] Louisiana State University's College of Engineering has a strong relationship with its industry partners and leverages this relationship to enhance its curriculum and facilities. In the past, energy production has dominated discussions in LSU's classrooms. LSU's current administration prioritizes the energy *transition*: President Tate's office will request 11.25 million USD to fund a new Carbon Management Innovation Center, a pilot-scale CCU electrolysis facility, carbon management workforce curriculum, and carbon management studies/pilot projects.[13] With these investments, LSU will contribute even more graduates with industrial carbon management knowledge to the state's human capital.

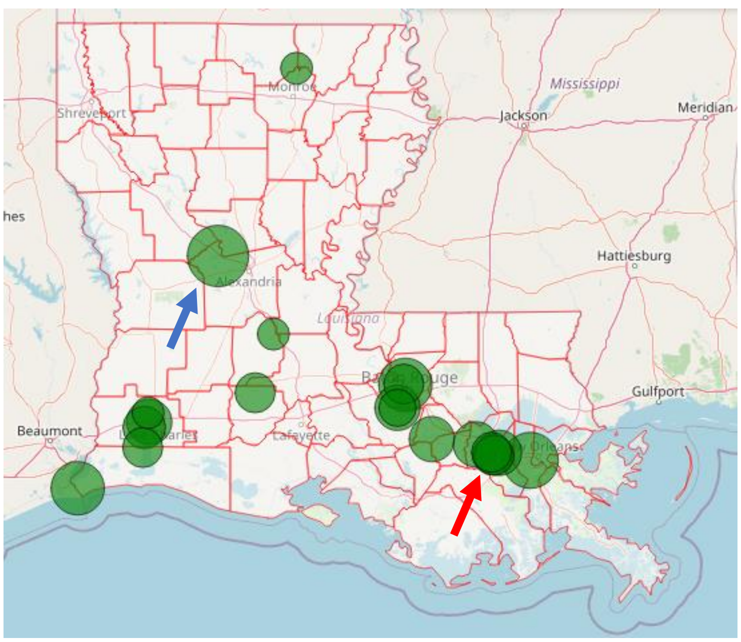

Figure 2.0 Louisiana's Top 20 Emitters (EPA FLIGHT Tool)

Companies have already begun planning massive decarbonization strategies. In October 2021, Governor Edwards announced that Air Products, a chemical company, is planning a 4.5 billion USD blue hydrogen complex with carbon capture and sequestration.[14] The carbon capture technology planned will capture 95% of the facility's emissions.[14] Air Products claims the project will create 170 new jobs with a total annual payroll of 15.9 million USD.[14] These types of investments have a compounding effect: Air Products will bring their own carbon capture experts and in turn will attract similar expertise in CCUS overall to the state. In April 2022, Cleco Corporate Holdings LLC announced a 900 million USD CSS project for Brame Energy Center, which is the largest emitter in the state (identified by a blue arrow in Figure 1.0).[15] Project "Diamond Vault" will create 30 to 40 new permanent jobs.[15] Taking that large emitter off the map is a large step towards the state's goal of net zero emissions by 2050. Removing the layer of green dots identified by the red arrow on Figure 2.0 is an even larger step towards net zero. Capitalizing on the commercial value of those emissions is more sustainable than simply storing those emissions. This industrial cluster will be the focus of the CCU facility case study.

To analyze the commercialization of a CCU facility, the industrial/power cluster was selected using the EPA Facility Level Information on Greenhouse Gases Tool (FLIGHT). To minimize transportation and conversion costs, the smallest area with the highest greenhouse gas emissions was selected using only the top 20 highest emitting facilities in Louisiana. Only high-emitting facilities have the financial means to implement carbon capture technologies; therefore, only these facilities could contribute to a CCU plant. According to the FLIGHT tool, four facilities in St. Charles Parish emitted the most carbon dioxide within the smallest geographical area in 2020.[12] In previous years, Calcasieu Parish saw the highest CO_2 emissions in a concentrated area, but since Entergy's St. Charles Power Station became fully operational in 2020, St. Charles Parish now experiences the highest CO_2 emissions in a concentrated area. The St. Charles cluster consists of one natural gas power plant, two chemical manufacturing facilities, and one petrochemical complex (featuring both petroleum refining and chemical manufacturing). Combined, these four facilities emitted 9,820,707 metric tons of CO_2 in 2020.[12]

Multiple players would be involved in capturing emissions from each plant and transporting those emissions to a utilization facility, where one player would be responsible for converting the carbon dioxide emissions into a commercial product. Carbon dioxide can be converted into cement, transportation fuels, petrochemicals and polymers, animal feed/supplements, cosmetics, and pharmaceuticals.[16] Three major pathways facilitate carbon dioxide conversion: chemical utilization, biological utilization, and mineral carbonation.[16] We will examine carbon dioxide conversion via electrolysis: electricity charges an electrochemical cell, where electrodes facilitate reactions to develop useful chemical products. A formic acid electrolyzer can convert carbon dioxide to formic acid using only water. Commercially available lab-scale formic acid electrolyzers contain cutting-edge catalysts and operate at low-temperatures. A scaled-up formic acid electrolyzer facility will be studied to confront the St. Charles Parish cluster's emissions. Note that formic acid electrolyzers remain in the research and development phase of commercialization. Envisioning this scale-up, though, is the first step to its potential implementation. Figure 3.0 lays out the overall process to convert emissions and sell the resulting formic acid product.

Formic acid is attractive for its expanding market and its clean energy uses. Agriculture and animal feed, leather and textiles, and chemicals and pharmaceuticals dominate the formic acid market. Currently, the global market for formic acid is 363.4 million USD; however, the pre-pandemic 2018 market was 430 million USD.[17] Market analysts expect the formic acid market to grow by 208.72 million USD by 2024.[17] Regarding formic acid's clean energy uses, industry sees formic acid as an attractive hydrogen source and transportation mechanism. Hydrogen is critical for industrial operations but requires specific temperatures and pressures to transport, whereas formic acid may be transported at ambient conditions.[18] Furthermore, the automotive industry sees formic acid as a potential input for fuel cell electric vehicles.[19] Formic acid fuel cells could generate clean electricity for non-automotive uses as well.[19] Ultimately, the St. Charles conversion facility will reduce carbon dioxide to formic acid, a product with profit and clean energy potential.

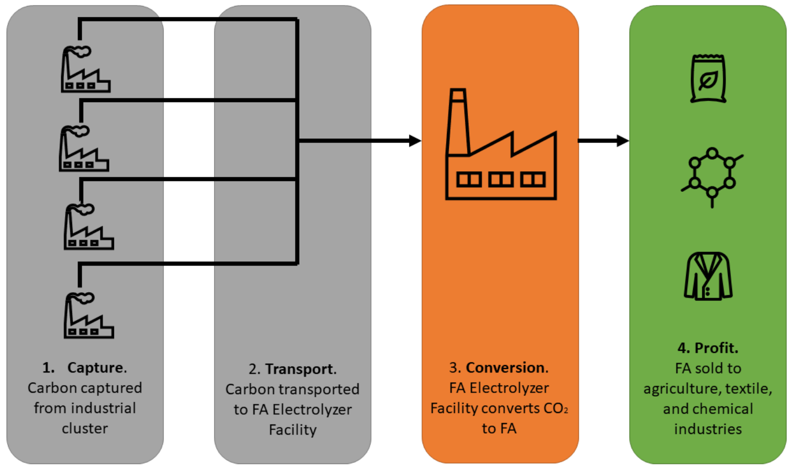

Figure 3.0 Large-Scale Formic Acid Electrolysis Flow Diagram

Louisiana is ready to lead the nation in CCU strategies. The proximity of large emitters to one another lowers the risks for individual companies' investments; the industrial and carbon management human capital exists in the state and will continue to flourish; and companies have already made CCS investments in Louisiana, so CCU is the natural next step. Our case study contextualizes the commercialization potential for CCU. Because the St. Charles Parish facilities are big emitters and lie near one another, a conversion facility is easier to commercialize: costs of carbon capture, transportation, and conversion are cheaper. The next section will analyze those cost estimations.

III. Costs and Financial Feasibility

Any CCU process must consider the costs of carbon capture, transportation, and conversion. In general, the larger the emissions and the higher the CO_2 concentration in the stream, the cheaper the capture system will be. For gas processing, ethanol, and ammonia facilities, the CO_2 stream is purer; those facilities only pay for CO_2 compression. See Appendix Table 4.0 for relevant industry purity percentages and their respective capture and compression costs. The Air Products Ammonia complex planned for Ascension Parish, for instance, will pay approximately

17 USD per ton captured and compressed.[20] Almost all other emitters require separating CO_2 from other gases emitted in output streams as well as compression. A gas power plant, such as the power plant in our St. Charles Parish Cluster, for example, would pay approximately 57 USD per ton of CO_2 captured and compressed.[20] Amine-based carbon capture systems, the most commercially available technology, remove SO_x, NO_x, particulate matter, and most metals from emission streams. An amine solution absorbs about 90% of the CO_2 gas, and then a stripper/stripping vent or regenerator heats the solution to separate CO_2 from the aqueous solution.[21] Once separated, CO_2 must be compressed via reciprocating compressors or centrifugal compressors.[20] After compression, CO_2 may be transported through pipeline. Carbon dioxide may be transported via train, truck, or simply in cylinders. In the context of transporting carbon dioxide within an industrial cluster, though, pipeline is most practical. Using National Energy Technology Laboratory (NETL) models and case studies, Dismukes et al. estimated new CO_2 pipeline costs for a variety of pipe diameters and lengths. For a 30-inch outside diameter spanning 30 miles, the pipeline would cost just over 41.5 million USD.[22] For a 26-inch outside diameter spanning about 14 miles, the pipeline would cost 17.5 million USD.[22] This pipeline more closely matches the pipelines required for our case study.

For the St. Charles Parish cluster, the C2FA facility would need to accept 9,820,707 metric tons of CO_2 per year.[12] Table 1.0 provides the facility's base case parameters for the facility. See Table 5.0 in appendix for optimistic and pessimistic facility parameters.

Table 1.0 Conversion facility base case parameters

CO_2 Inlet Flow Rate (kg/day)	Total Current (A)	Electrolyzer Active Area (m^2)	Power Required (MW)	Formic Acid Produced (kg/day)
26,906,000	956,029,531	478,015	22,546	16,747,699

Electrolyzer scale-up was modeled after technoeconomic analysis (TEA) in relevant CO_2 electrolysis literature.[23] To convert such a large amount of CO_2, an active area of almost half a kilometer squared, or about 118 acres. See Equation 2.0 in the Appendix for that scale-up calculation. The active area of an electrolyzer unit includes the anode, cathode, membranes, and ion exchange material. The active area may be stacked into a multitude of electrolyzer units, so the conversion facility would not occupy 118 acres. Inside each electrolyzer unit, critical reactions take place to transform carbon dioxide into formic acid (see Figure 4.0). Electricity powers the water electrolysis reaction, which occurs on the anode. The cation membrane transfers the hydrogen

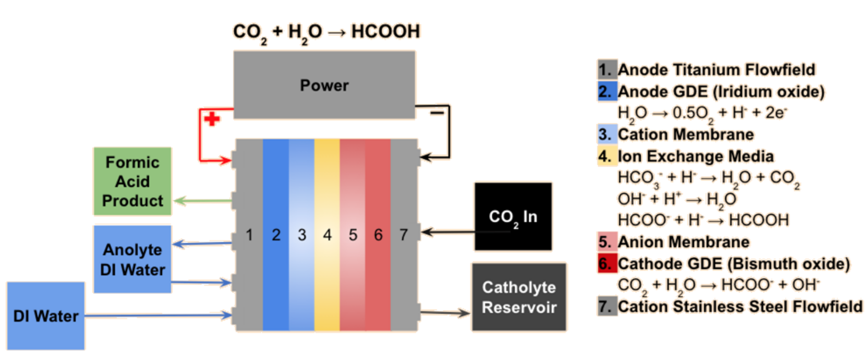

Figure 4.0 Electrolyzer unit reactions and details

ion (H^+) to the central ion exchange media. The cathode reduces CO_2 to formate ion ($HCOO^-$), which the anion membrane transfers to the ion exchange media. There, H^+ joins $HCOO^-$ to form HCOOH (formic acid). These sensitive membranes and electrodes become less effective over time. The base case for membrane electrode assembly (MEA) replacement is once per year. The pessimistic and optimistic cases are available in Table 2.0. Researchers continue to conduct studies to lengthen the MEA lifespan. Optimistically, MEA replacement occurs once every year and a half, lowering the cost per kilogram of formic acid produced by 2.4%. If no research continues, MEA replacement might occur twice each year, increasing the cost per kilogram of formic acid by 8.1%. See Figure 5.0, a sensitivity analysis chart depicting the effect of each optimistic and pessimistic criterion on the base case cost.

Table 2.0 Criterion for electrolyzer facility parameters

	Electricity Price (USD/kWh)	Single-pass Conversion (%)	Current Density (mA/cm^2)	MEA Replacement (occurrences/yr)	CO_2 Price (USD/metric ton-CO_2)
Optimistic Case	0.01	90	300	0.67	20
Base Case	0.03	70	200	1	40
Pessimistic Case	0.05	50	100	2	60

Optimizing current density is also a priority; the amount of current flowing through a certain area directly affects MEA area required. Most commercially available formic acid electrolyzers operate at a current density of 200 mA/cm^2. If current density is optimized to 300 mA/cm^2, then the cost per kilogram of formic acids decreases by 3.5%. If electrolyzer units operate at 100 mA/cm^2, then the base case cost rises by 11.5%. CO_2 price impacts the base case cost the least. A CO_2 price of 20 USD/metric ton versus 60 USD/metric ton alters the base case cost by 2.5% and 3%, respectively. The pessimistic case might result from the high cost of carbon capture and transportation, but because carbon cost has a small impact on base case cost, high carbon capture and transportation costs are not a barrier to implementing a CCU facility.

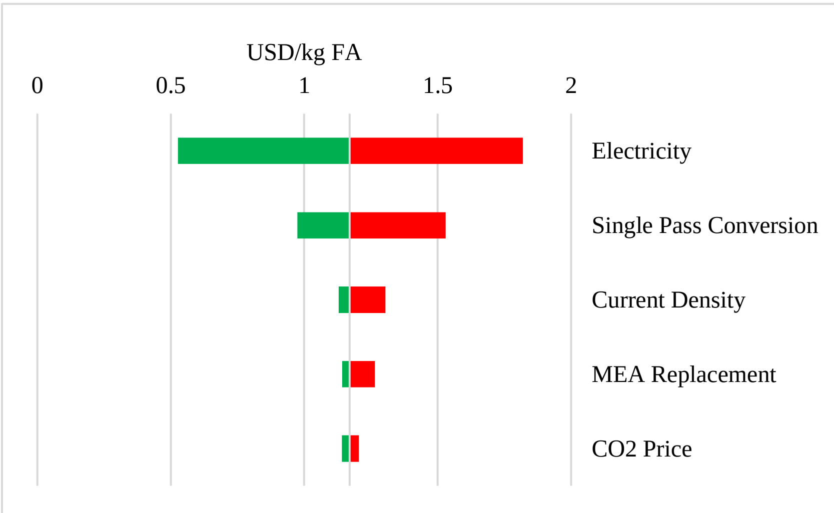

Figure 5.0 Sensitivity Analysis of Electrolyzer Facility Criterion

Electricity affects the base case cost more than any other criterion, as Figure 5.0

depicts. If electricity costs 0.01 USD/kWh versus 0.05 USD/kWh, the cost per kilogram of formic acid shrinks by 55% versus expanding by 55.5%. The optimistic case would occur if, for instance, the CCU facility struck a deal with Entergy's natural gas power plant. However, as Table 1.0 denotes, the facility requires 22,546 megawatts. The current grid cannot supply such a massive power input while meeting other electricity demands. Industry experts have considered building a small nuclear plant to generate electricity for a CCU facility, although not this specific C2FA facility.[24] The urgent need for CCU overpowers the controversies associated with nuclear power generation; this energy source should be considered. The single pass conversion rate is essentially the percent difference between CO_2 entering and exiting the facility, which directly impacts the required amps. Optimizing the facility to operate at a 90% single pass conversion rate lowers the base case cost by 16.7%, whereas if the facility operates at a 50% single pass conversion rate, the base case cost rises by 30.8%.

The base case single pass conversion rate of 70% means 30% of the CO_2 exits the facility unconverted. Also exiting the facility are waste gases from the reactions within each electrolyzer unit (see Figure 3.0). Because of these outputs, the electrolyzer facility must attach a pressure swing adsorption (PSA) system and distillation unit. The PSA would accept oxygen, hydrogen, unconverted CO_2, and carbon monoxide (some CO forms on the cathode from a byproduct reaction). The PSA separates each gas using a series adsorption beds and pressure drops. The PSA recycles CO_2 back into the input stream, and the remaining gases will be sold for profit. The distillation column will filter liquid outputs to achieve the desired formic acid concentration.

Profits are generated from both formic acid output and the PSA's waste gases. Formic acid is typically sold for 0.50 USD/kg. To reach a 12% profit margin, this C2FA facility will need to sell formic acid for 0.99 USD/kg, almost twice the market price. The facility would need to market its formic acid as sustainably made to attract buyers. Manufacturers across the board have implemented sustainability strategies, and purchasing formic acid from a CCU facility rather than a fossil fuels-based facility will help those manufacturing companies achieve their sustainability goals. However, the amount of formic acid produced from this facility would dominate the market. To address this issue, we can take two paths forward. First, the facility could leverage the clean energy uses of formic acid. We could market formic acid as hydrogen storage, as previously mentioned. If marketed effectively, the formic acid market would expand. The facility could also attract buyers with fuel cell interests, expanding the market even further. Second, the facility could diversify its products. We could split the facility into three production zones, for instance: ethylene, ethanol, and formic acid. The ethylene and ethanol products require similar electrolyzer units but different MEAs. Ethylene is primarily used in plastics, textiles, antifreeze, PVC piping, and medical devices.[25] Ethanol is largely used in personal care products, household products, food additives, and fuels.[26] Like formic acid electrolyzer units, ethylene and ethanol electrolyzer units have waste gases that could be sold for profit. Thus, the facility could diversify its buyers.

Ultimately, the facility would generate a profit of over 2 million USD per day. See Table 3.0 for base case facility costs and benefits. Of course, certain conditions must exist to make the benefits outweigh the costs. First, Formic acid must be sold above the current market price, as previously discussed. The facility would need to find buyers for its waste gases as well and sell those waste gases at average market prices. The facility must also take advantage of the 45Q tax credit available for CCU technologies. For every metric ton of CO_2 utilized, the facility would receive 35 USD.[27] Table 6.0 in the Appendix breaks down these benefits as well as capital expenses (CapEx) and operating expenses (OpEx).

Table 3.0 Electrolyzer facility base case costs and benefits

Costs	Benefits	**Profit Margin (USD/day)**
Total CapEx + OpEx (USD/day)	FA sales + waste gas sales + 45Q tax credit (USD/day)	
19,643,000	22,000,000	**2,357,000**

Last, the relationship between the cost to convert one kilogram of CO_2 and the emissions a C2FA facility would need to treat was analyzed (see Figure 6.0). Due to the polynomial relationship between conversion costs and facility intake, the cost to convert one kilogram of CO_2 lowers until about 15,000,000 metric tons per year. Beginning around 6 USD/kg CO_2, the conversion cost lowers to a minimum of 4.62 USD/kg CO_2. Thus, our case study facility, which accepts 9,820,700 metric tons of CO_2 per year, converts CO_2 for close to the minimum cost. This polynomial relationship is the case for electrolyzer CCU facilities overall: there will be an optimum amount of intake emissions.

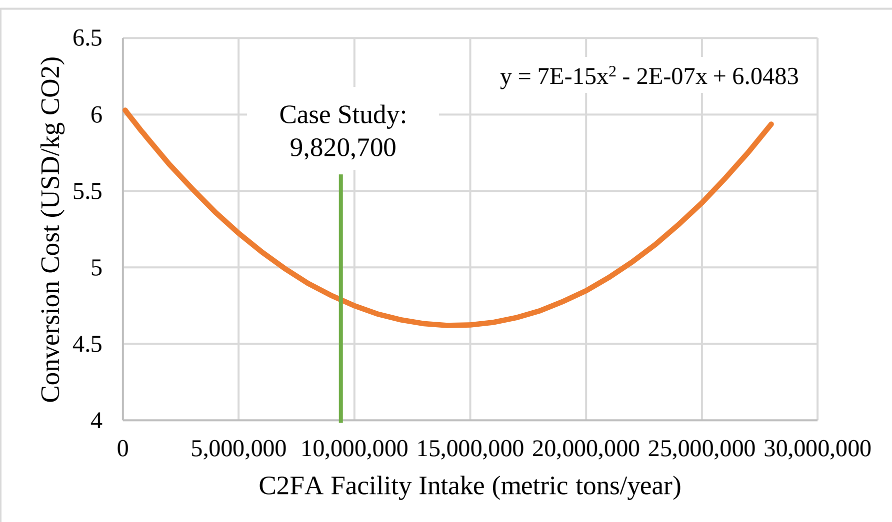

Figure 6.0 Optimizing CO_2 conversion cost

A C2FA facility is financially feasible in Louisiana, given electrolyzer research continues. Specifically, researchers need to improve the lifespan of the MEA. While electricity is a concern, a small nuclear plant could supply discounted electricity, lowering overall costs. For the case study facility to generate a 12% profit margin, the facility would need to sell formic acid at almost double the current market price. With sufficient government support, the facility could sell formic acid at the going market price. In the next section, we will examine whether government backing exists to make our CCU product competitive, or any other CCU product competitive.

IV. Government Backing

A CCU facility like our C2FA plant is feasible on a regulatory level as well. The Louisiana Climate Action Plan, the IIJA, and other state and federal efforts are paving governmental pathways for CCU technologies and strategies. In August 2020, Louisiana Governor John Bel Edwards launched the Climate Initiatives Task Force via executive order: the first step in his plan for Louisiana to become net zero by 2050.[7] Experts in science, law, equity, and economics, with perspectives from government, private sector, academia, environmental advocacy, and community advocacy work towards the same goals in the Climate Task Force.[7] These experts developed a Climate Action Plan that outlines how Louisiana can reach net zero by 2050 while jumping on economic opportunities, improving quality of life, highlighting equity, and aligning the state with the 2015 Paris Agreement.[7] In February 2022, the Governor released a draft of the Climate Action Plan, which outlines 28 strategies and 84 actions the state can take to confront climate change. Strategy 5 sets the most authoritative goal to decarbonize industry by aiming to "…Accelerate industrial electrification, switching to low-or-no-carbon fuels and low-or-no-carbon feedstocks."[7] Strategy 5 emphasizes the importance of capturing, storing, and/or using high-intensity carbon emissions that remain after all electrification routes have been employed. Specifically, the following actions prioritize carbon capture, sequestration, and utilization (CCUS):

- Action 5.3: Support the safe and responsible deployment of carbon capture, utilization, and storage for high-intensity and hard-to-abate emissions
- Action 5.4: Invest in research for utilizations of captured carbon and life cycle analyses to understand their overall impact
- Action 5.5: Develop Industrial Cluster Decarbonization Plans to plan for and direct facility-level investment[7]

The Climate Action Plan marks Actions 5.3 – 5.5 as "funding needed."[7] When Congress passed the IIJA, funding these key Action items became more attainable. Additionally, the Biden administration's domestic climate goal to reach net zero by 2050 calls for cooperation among federal agencies and coordination with state agencies to accelerate CCUS implementation.[16] With the IIJA and federal administrative support, Actions 5.3 – 5.5 become more than ambitious executive targets, though the Climate Task Force was diligent in setting targets. The Climate Action Plan lists near-term actions the state can take to achieve each Action's goal. For Action 5.3, which supports the safe deployment of CCUS, the state's near term action is to "Invest in research for siting and impact assessments of CCUS buildout."[7] The Louisiana Department of Natural Resources (DNR), U.S. Department of Energy (DOE), Industry, and Communities are listed as implementation partners for this near-term action. The IIJA requires that DOE develop standards and certifications necessary to facilitate CCU commercialization.[28] Once established, state agencies can ensure CCU companies meet those standards. Federal and state agencies can work together to accelerate environmental impact statements and other permitting processes. The Biden administration encourages agencies to develop a streamlining process for CCUS strategies.[16]

For Action 5.4, which supports CCU research efforts, the state's near-term action is to "Solicit funding to understand utilization techniques."[7] Universities are key for these research efforts. The Chair of LSU's Chemical Engineering Department, Dr. John Flake, runs a research group that studies the electrochemical reduction of carbon dioxide. Dr. Flake's lab receives funding from the National Science Foundation (NSF) as well as Intel®.[29] The LSU Chemical and Petroleum Engineering departments are asking the state for a 75 million USD pilot-scale electrolysis CCU facility. As previously mentioned, the current LSU administration is incorporating part of this cost into requests from the state.[13] LSU and its research groups are well-practiced in soliciting funds regularly from private, public, and non-profit sources. The IIJA can help fund CCU research as well; the act establishes a carbon utilization grant program, where states, localities, and public utilities can win funding to procure and use products made from emissions.[28] This grant program will be established by August 2022, so the state should prepare applications for CCU project research *now*. The state can then disseminate funds to state school research groups. With cooperation throughout labs at LSU and with other state schools, Louisiana's brightest minds can tackle the complexities of CCU technologies, such as lengthening the lifespan of electrolyzer MEAs.

For Action 5.5, which supports Industrial Cluster Decarbonization Plans, the state's near-term action item is to "Strategically plan decarbonization of industrial clusters."[7] Industries should lead cluster decarbonization efforts with guidance from the Department of Environmental Quality (DEQ), DNR, and DOE. Communities and utilities should also be key players in developing Industrial Cluster Decarbonization Plans. Congress bolstered the carbon dioxide transportation infrastructure finance and innovation (CIFIA) program in the IIJA. Private entities can pursue new federal credits and low-interest loans for large-scale CO_2 transportation investments.[28] Industrial clusters need to consider CIFIA savings as they develop decarbonization plans. Facilities already exchange so many materials between one another; CO_2 would just be another output from one facility entering a second facility. The case study C2FA facility would be crucial for a St. Charles Parish Cluster Decarbonization Plan. CCU facilities, in general, are crucial for cluster decarbonization plans. With the Governor's Office poised to provide CCUS opportunities, IIJA funding, and federal administrative support, the state is ready to accelerate CCU buildout, Louisiana's universities are ready to research CCU technologies, and industry is ready is to develop Decarbonization Plans.

V. Conclusion

Louisiana is equipped to adopt CCU strategies in the near future. Because industry lies in clusters, industrial human capital thrives in the state, and companies are already investing in CCUS, the commercialization potential of CCU strategies is greater here than in other states. By examining a case study conversion facility, we saw that a C2FA facility was financially feasible, and further research coupled with government support would raise the profit margin. Recent federal and state government actions administratively and financially support CCU technologies. Because of Louisiana's Climate Action Plan, the state is primed to take advantage of those federal funds. In sum, Louisiana is ground zero for the nation's energy and petrochemical production, two sectors that majorly contribute climate change. As Louisiana state representative Malinda White stated, "X marks the spot."[30] Representative White was arguing that because of the industrial and energy presence in the state, cutting edge solutions to confront emissions will be discovered here. Naturally, Louisiana should lead the energy transition, and the state is equipped to begin that transition *now*.

VI. Appendix

The following equations were adapted from Shin et al.'s TEA on CO_2 electrolysis processes. For more details on equations used, see Shin et al.

Equation 1.0

$$Current\ [A] = \frac{Target\ kg\ FA}{day} * \frac{1\ day}{86400\ sec} * 1000\frac{g}{kg} * \frac{mol}{46.03\ g\ FA} * \frac{2e^-}{1\ mol} * 96485\frac{C}{s}$$

Equation 2.0

$$Active\ Area\ [m^2] = Total\ Current\ [A] * \frac{cm^2}{0.3\ A} * \frac{1\ m^2}{10^4\ cm^2}$$

Table 4.0 Carbon dioxide purity percentages and capture and compressions costs by industry. Adapted from Abramson and Brown.[20]

Concentration of Capture CO2	**Main Equipment Needed**	**Industry**	**Average Estimated Cost ($/ton)**	**Range of Cost Estimates ($/ton)**
Pure CO_2	Compression + dehydration	Gas Processing	$14	$11-16
		Ethanol	$17	$12-30
		Ammonia	$17	$15-21
16-50%	Amine CO2 separation equipment + compression	Chemicals	$30	$19-40
		Hydrogen	$44	$36-57
		Refineries	$56	$43-68
		Petrochemicals	$59	$57-64
~13-15%		Coal Power Plant	$56	$46-60
~4%		Gas Power Plant	$57	$53-63

Table 5.0 Optimistic, base, and pessimistic C2FA facility parameters

		Optimistic Case	Base Case	Pessimistic Case
Electrolyzer Parameters	CO_2 Inlet Flow Rate (kg/hour)	1,121,085.27	1,121,085.27	1,121,085.27
	CO_2 Flow Rate (kg/hr)	1,008,976.75	784,759.69	560,542.64
	Total Current (A)	1,229,180,825.67	956,029,531.08	682,878,236.49
	Electrolyzer Active Area (m^2)	409,726.94	478,014.77	682,878.24
	Power Required (MW)	23,502.13	22,546.10	21,590.07
	Formic Acid Produced (kg/day)	24,066,021.63	16,747,699.27	10,555,272.65

Cathode Outlet Streams	CO_2 Outlet Flow Rate (m^3/hr)	226,481.87	226,481.87	226,481.87
	H_2 Outlet Flowrate (m^3/hr)	25,507.55	59,517.62	70,854.31
	CO Outlet (m^3/hr)	28,171.29	65,733.01	78,253.58
	Total Cathode Outlet Streams (m^3/hr)	251,989.43	285,999.50	297,336.19
Anode Outlet Streams	O_2 Outlet Flow Rate (m^3/hr)	256,753.42	199,697.10	142,640.79
	CO_2 Outlet Flow Rate (m^3/hr)	7,077.56	7,077.56	7,077.56
	FA Outlet Flow Rate (m^3/hr)	821.25	571.52	360.20
	Total Anode Outlet Streams (m^3/hr)	264,652.23	207,346.18	150,078.55

Table 6.0 Optimistic, base, and pessimistic C2FA facility cost breakdown

		Outright Cost (USD/day)		
Operating Costs	Electricity	5,640,511.89	16,233,194.42	25,908,088.59
	Maintenance (350 day/year)	112,674.91	131,454.06	187,791.52
	PSA Cathode	45,358.10	51,479.91	53,520.51
	PSA Anode	47,637.40	37,322.31	27,014.14
	CO_2 Purchase	538,120.93	1,076,241.86	1,614,362.79
	Water	26,747.06	20,803.27	14,859.48
	Cell Compartment Replacement	92,609.51	108,044.43	154,349.19
	MEA Replacement	662,298.34	1,545,362.80	3,311,491.72
	TOTAL OPEX	7,165,958.15	19,203,903.07	31,271,477.94
Capital Costs	Electrolyzer Cost	216,088.87	252,103.68	360,148.11
	Balance of Plant	138,155.18	161,181.04	230,258.63

	PSA	26,597.17	25,684.33	23,769.34
	TOTAL CAPEX	380,841.22	438,969.04	614,176.08

Table 7.0 Overall optimistic, base, and pessimistic C2FA facility costs and benefits

		Optimistic Case	Base Case	Pessimistic Case
Costs	Total CAPEX + OPEX (USD/day)	7,546,799.37	19,642,872.11	31,885,654.02
Benefits	FA Sold (USD/day)	23,826,050.43	16,580,701.76	10,450,022.12
	45Q Credit of $35/tonne used (USD/day)	941,711.63	941,711.63	941,711.63
	Waste gas profits (USD/day)	4,854,177.96	4,477,603.37	3,699,810.72
	Total Benefits (USD/day)	29,621,940.01	22,000,016.76	15,091,544.46
Profit Margin	(USD/day)	22,075,140.65	2,357,144.65	-16,794,109.56

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