Positioning the Great Lakes Region as a Leader in the Voluntary Carbon Offset Market

A summary of carbon offset markets from 2003 - 2022 and an outlook for carbon capture, utilization, and storage to 2050

Prepared by request for the Great Lakes St. Lawrence Governors & Premiers

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Executive Summary

Great Lakes St. Lawrence Region

Overview

The request from the Conference of Great Lakes St. Lawrence Governors and Premiers (GSGP) in creating this report was to better understand how the Great Lakes St. Lawrence region could become a "go-to" destination for voluntary carbon offsets with economic, environmental, climate, and social benefits. A multidisciplinary team at the University of Michigan tackled a high-level framing of this question in summer 2022. This report is not intended to be comprehensive - it is a starting point, and will provide high level estimates for potential regional supply of projects into the voluntary carbon markets, as well as supporting policy recommendations and next steps.

For the purposes of this report the 'Great Lakes region' means the Great Lakes St. Lawrence region including the entirety of the eight U.S.States bordering the Great Lakes - Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania and Wisconsin - and the Canadian Provinces of Ontario and Québec. The prominent features that make this region unique are the Great Lakes and St. Lawrence, abundant forests, agricultural regions, and the highly productive industrial economy. Additionally, there are vastly abundant sedimentary geologic formations (saline formations and unmineable coal) that span the majority of the region with the ability to store billions of metric tonnes of CO_2.

The conclusion of this report is that the region has many possibilities to supply both nature-based and engineered carbon projects into the voluntary carbon offset markets (VCMs). 52 gigatonnes (gtons) of at-scale, environmentally sound, high quality (additional, durable, and unclaimed) carbon dioxide storage is available in the Great Lakes region by 2050 with a revenue potential of at least $783B USD.

These figures do not include solid waste biomass that can be used to make biochar (burned organic matter). There are 0.08 gigatons of raw feedstock available in the region annually to make biochar, which can be used as a soil amendment and possibly other materials (or fuels or electricity, but these are not carbon offsets). The totals also omit geologic storage potential in depleted oil and gas reservoirs, estimated to be 1.8-5.3 gigatons total.

Compared to the region's annual emissions of approximately 1.5 gtons (see Appendix 4), this offers a comfortable margin for balancing regional emissions as well as selling some of the carbon storage potential into the global carbon offset markets to generate new regional revenues and significant environmental co-benefits. To further place this in context, in order to keep global warming below the 1.5 degrees Celsius limit[1] recommended by the Intergovernmental Panel on Climate Change, **it is estimated that**[2] 10 gtons of carbon removal will be needed globally every year between now and 2050, and 20 gtons annually from 2050 to 2100. Carbon dioxide removal (CDR or "negative emissions") is a process of removing legacy emissions from the atmosphere for long-term storage. In all 1.5 degree C scenarios, CDR will be needed in addition to carbon capture and storage (CCS, or capturing emissions from a smokestack or point source before they reach the atmosphere and then either placing them underground in a geologic formation or using them as a feedstock in durable engineered products).

According to the Berkeley Carbon Trading Project and Carbon Direct Database, carbon credit issuances and retirements in the Great Lakes region have been increasing since 2006, following global trends. Issuances reached a maximum of 10,525,764 tons or 0.11 gtons in 2019, which is 7.6% of global issuances, and retirements reached a maximum of 12,959,262 tons or 0.13 gtons in 2020. Chemical Processes are the most common type of carbon credit, followed by Agriculture and Forestry. Less than 3% of global carbon offset projects were indicated as being of high quality in the database, with even less in the Great Lakes region. The issue is that credits are emissions reductions instead of carbon dioxide removal - which provided an additional motivation to focus on durable carbon dioxide removal for this report.

There are two potential sources of revenue in this region for *producers* creating a carbon offset: selling credits into the carbon markets, claiming the U.S. 45Q federal tax credit for projects located in the states, or possibly both.

Carbon Offset Registries and Markets

There are two types of carbon markets. Voluntary markets, addressed by this report, enable companies and others to purchase carbon offsets to meet their greenhouse gas emissions reductions goals. Compliance markets involve mandatory participation from larger emitters in a carbon credits system as required by regulatory bodies. Corporations or individuals most commonly use carbon credits to offset emissions from their operations (see Appendix 3 for examples of corporate climate commitments in the region). When a purchaser buys and retires an offset, they hope to undo the climate impact of a ton of carbon dioxide emitted or planned for emission. **The purpose of these offsets are to avoid, reduce, or remove Greenhouse Gas (GHG) emissions**[3]. Unfortunately, projects in today's voluntary carbon market mostly do not provide high integrity in meeting these goals4, although this is beginning to change. In the voluntary carbon markets, offsets have been accused5 of not delivering on the promised6 climate benefit or being of poor quality due to difficulties in assumptions about baseline and additional carbon in a project, measurement and verification of carbon outcomes, and other issues. The carbon economy is new field, and many missteps that have occurred to date are a result of lack of common guidelines for measuring and reporting on carbon emissions or incomplete knowledge from new actors. **But there is strong pressure on improving offset quality by public scrutiny**[7]. **Companies such as Microsoft**[8] **or Shopify**[9]**, employees, and investors**[10] **via the proposed SEC draft ruling**[11]. The ruling would require companies to disclose information about their climate risks including greenhouse gas emissions and potential impacts on company strategy, operations and financials in the future. Investors are looking for apples-to-apples comparisons of the status of corporate Environmental, Social and Governance (ESG) claims[12] presented with the same level of transparency, detail and supporting documentation that are shared for company financials. This is intended to facilitate better informed decisions about corporate climate risk.

Carbon offset projects sold in the voluntary carbon markets must use an approved methodology by a carbon registry. **There are a number of carbon registries, but the four most often used by companies buying carbon** offsets are Verra (VCS)[13] **, the** American Carbon Registry (ACR)[14]**,** Climate Action Reserve (CAR)[15]**,** and Gold Standard[16]**.** These registries develop methodologies which are peer reviewed and independently verified by dozens of globally agencies. For agriculture credits, U.S. based Nori[17] focuses on high-quality carbon offsets (they do not sell emissions reductions or avoidance credits, see Section 1.1 for more information) and in Canada, ALUS[18] is also working on high-quality credit guidelines for Canadian markets.

For buying and selling carbon credits approved by a carbon registry methodology, there is no centralized location to transact carbon credits for the voluntary markets.

The Ecosystem Marketplace[18] is a well-established place to observe market conditions. It distributes annual surveys to project developers, retailers, investors and others to collect information so that the pricing of carbon offsets is as transparent as possible. The Ecosystem Marketplace tracks pricing for 170 types of carbon credits in the following categories: renewable energy (biogas, solar, geothermal, others), household and community (clean cookstoves, energy efficiency, rural solar, others), chemical and industrial (refrigerants, carbon capture and storage, fugitive emissions, others), energy efficiency, waste and disposal (recycling, waste incineration, others), agriculture, transportation, and forestry and land use (afforestation, reforestation, soil carbon, others). This report will only focus on a small number of these potential project types that can be sold into the carbon markets.

The team looked at a range of potential carbon offsets that would be suitable for the region to supply- methodologies that capture carbon dioxide from a smokestack or directly from the air and store it on a temporary or permanent basis. Nature-based solutions include forests and waste biomass including biochar and fuels. Engineered solutions include placing compressed liquified CO_2 into underground geologic reservoirs for permanent storage and exposing alkaline minerals in precast concrete or general purpose construction stones to CO_2, where it is permanently bound to the material. The team was able to access more limited quantitative and qualitative sources of information for Canadian markets, and the report does not cover them in as much detail as the U.S. markets. For meeting long-term climate goals and keeping warming to 1.5 degrees Celsius or less, these solutions offer different ways of mitigating climate impact. Capturing CO_2 from a smokestack (avoiding emissions of CO_2 into the atmosphere, can be carbon neutral at best) and capturing CO_2 directly from the air (can result in carbon removal and can be carbon negative, or "carbon dioxide removal") are both needed and can provide valuable carbon offsets. Beyond 2050, durable carbon dioxide removal and storage such as reforestation and CO_2 storage in minerals are expected to be the priority as the usage of fossil fuels is forecast to steadily decrease.

> "Where do the states and provinces in the region have shared or separate goals around carbon?"
>
> Retired National Laboratories Associate Director

Types of Carbon Offset Projects Suitable for the Great Lakes Region

The Great Lakes St Lawrence Governors and Premiers requested information that would help position the region for *high-quality* carbon offsets.

This report targeted projects with new carbon storage as a project outcome - where an exchange of money in the voluntary carbon markets creates additional carbon storage that *would not have happened* without the investment. This filter ruled out projects such as new solar installations which are currently sold as carbon offsets, but because the cost of renewables is now the same as natural gas powerplants[19], the resulting carbon savings are not additional – from an economic perspective, additional money is no longer required to install a solar project instead of a natural gas plant because the cost is comparable. Utilities are prioritizing building renewables and new investment is not necessary to create the removal of carbon. This filter also rules out paying for forest carbon offsets for trees that are not planned to be harvested. Using high-quality and "additional" carbon offsets as the primary identifiers of potential projects for the Great Lakes region, Figure 1 shows proposed categories of carbon capture and sequestration and utilization.

Information Sources and Calculations

Key sources of quantitative information that guided this report included the Global CO_2 [20] Initiative Market Studies[21], CDR Primer[22], National Academies Negative Emissions Technologies and Reliable Sequestration Report[23], Microsoft's Carbon Negative by 2030 Report[24] and 2022 Update[25], Nature Conservancy Reforestation Hub[26] data, Carbon Registries13, Ecosystem Marketplace[27], Julio Friedmann[28] and Carbon Direct,[29] Midwest Regional Carbon Initiative[30], The Berkeley Carbon Project Voluntary Registry Offsets Database[31], key academic papers, multiple sources from the United States Department of Energy including reports[32] and maps[33], and many others which are listed in the references section.

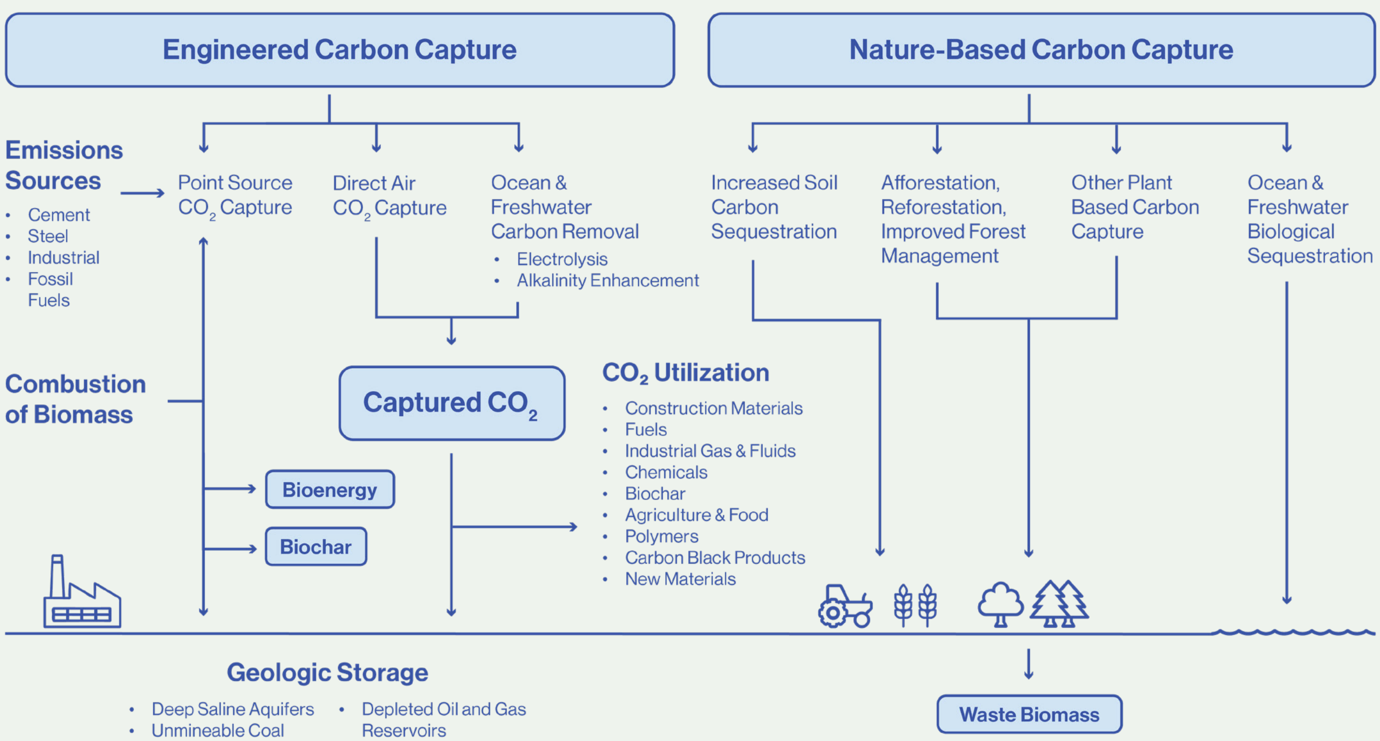

Figure 1 Overview of nature-based and engineered carbon capture and storage options for the Great Lakes region.

Because the field of carbon markets is changing so rapidly, in addition to reviewing numerous data sources and published work, 34 interviews on the carbon offset demand side and supply side were conducted.

Included were company representatives, scientists, engineers, foresters, developers, non-profits, and others in order to understand what carbon offset projects might be possible for this region on the carbon offset supply side and what buyers are seeking on the demand side.

Market studies done in 2016[34] and 2022[35] by the Global CO_2 Initiative at the University of Michigan for carbon capture and utilization *products* were also used as sources. These studies focus exclusively on carbon utilization, or using captured carbon to make useful products with economic value. **Fuels – specifically jet fuel made from captured CO_2– are the largest global financial opportunity for carbon-utilized products-to replace fossil sources. Aggregates are the largest market opportunities for carbon-utilized products in terms of gigaton storage potential and climate mitigation.** The aggregates, some carbon black materials, and some polymers represent durable carbon storage and a high-quality carbon offset. Due to the tremendous circular economy value that fuels made from captured CO_2 represent, they can also be implemented to reduce fossil fuel use.

Annual potential in 2050 — **Utilization of 2 to 27 gigatonnes of CO_2; Market opportunity of $1,100 to $4,400 billions**

Track	Product	Annual market opportunity ($ billions)	Annual CO_2 consumption (gigatonnes)	
Track 1	**Construction materials** Precast concrete, aggregates	**800 - 1,000**	**1.0 - 9.5**	**CO_2 is a new ingredient**
Track 2	**Fuels** Jet fuel, methane	**21 - 2,060**	**0.28 - 10.80**	**CO_2 replaces fossil carbon**
Track 2	**Chemicals** Formic acid, methanol	**100 - 180**	**0.26 - 0.58**	**CO_2 replaces fossil carbon**
Track 1 or 2	**Pure carbon materials** Carbon black	**14 - 66**	**0.04 - 0.20**	**CO_2 replaces fossil carbon**
Track 1 or 2	**Polymers** Polyurethane	**130 - 190**	**0.002 - 0.013**	**CO_2 replaces fossil carbon**
Track 2	**Food** Animal feed	**18 - 920**	**0.005 - 0.400**	**CO_2 is a new ingredient**

Figure 2 Global market potential for annual revenue and gtons of CO_2 consumption for a variety of carbon-utilized products that use CO_2 captured from the air or an industrial smokestack as an ingredient in manufacturing. The Great Lakes region could participate in the production of all of these products. Some products de-fossilize our economy such as fuels and chemicals which are made from fossil sources and could be replaced with carbon-utilized products to enable the circular carbon economy (Track 2) although these products are considered emissions avoidance and not carbon removal so the carbon offset quality is not as high as Track 1 products. Track 1 products support durable carbon removal and storage such as construction materials and some carbon black products and polymers. Biochar products are not shown and contain some similarities to pure carbon materials with contain a significant fraction of durable carbon storage. Biochar characteristics (feedstock dependent; corn stover provides a different char than forest residues) is an area of active research to understand longevity and potential applications in agriculture and building materials. Source: Global CO_2 Initiative at the University of Michigan market study[36], 2022.

Synthesizing the quantitative and qualitative inputs the team reviewed for this paper, the key markets for carbon offsets for the Great Lakes St. Lawrence Governors and Premiers region are shown in Figure 3.

Total Great Lakes Region Carbon Offset Market Potential 2022-2050

Revenue: $205 - 783 billion

Carbon Utilization: 14.4 - 52 gigatonnes CO_2

	Cumulative Revenue (billions $USD)	**Cumulative CO_2 Removal (gigatonnes)**
Reforestation - Public Lands	$0.85	0.034
Reforestation - Private Lands	$5.5 - $55	0.2 - 2.2
Aggregates for Construction & Concrete	$2.6 - $12.6	0.16 - 0.79
Precast Concrete	$0.003 - $0.150	0.0001 - 0.0052
Geologic Storage	$196 - $714	14.0 - 51.0

Figure 3 This chart frames minimum and maximum market size in gigatons of CO_2 storage and millions of U.S. dollars for various high-quality nature-based and engineered solution carbon offset types. Reforestation calculations assume that the maximum annual tree planting potential as identified by The Nature Conservancy is reached and maintained each year on public forestlands. For private forestlands, the minimum carbon storage is assumed to be 10% of the potential, and the maximum is 100%. Crushed stone assumes that 10% of the incumbent aggregates market switches to carbonated aggregates for usage in construction projects, and the high and low estimates reflect 0.440 ton of CO_2 absorbed per ton of aggregate and 0.087 ton CO_2 absorbed per ton of aggregate respectively. Aggregates and precast concrete also assume construction market-related growth rates. The calculations for geologic storage assume that compressed liquefied carbon dioxide is stored in 10% of reservoirs (unmineable coal, saline formations) identified by the U.S. Department of Energy's NATCARB database. The low estimate is 10% of the NATCARB low estimate, and the high estimate is 10% of the NATCARB high estimate. Note that NATCARB describes storage estimates instead of capacities, which are likely lower. Storage available in depleted oil and gas wells was not included in this estimate, but the total potential is estimated to be in the range of 1.8 – 5.3 gigatons of CO_2. There is also possible storage potential not yet known and not represented in the NATCARB database. For Canada, Ontario does not allow carbon storage, and estimates for Québec of 0.70 to 8.6 gigatons in sedimentary basins are available. It is unclear if these estimates are conclusive, so they are not included in the above figures. The region would produce 2.4 gigatons of waste biomass over this timeframe and this report did not address the best usage of that material – if could be used to produce energy, durable carbon storage in soils, possibly building materials or other uses.

The potential CO_2 supply can also be used to calculate the order of magnitude of geologic storage possible for the region. Very rough estimates could assume that the region keeps emitting the same amount of 1.5 Gt of CO_2 annually until 2050 and all of the emissions are captured, which would result in 42 Gt of CO_2 captured. Considering some direct air capture (DAC) plants, an upper limit of 51 gtons of CO_2 stored in geologic formations in Figure 3 is a reasonable estimate in order of magnitude. The report did not attempt to quantify how many Class VI wells would be required to achieve this or how long they would take to build (a Class VI well is drilled into rock formations for storage of compressed, liquified CO_2 underground. No oil or natural gas is harvested from a Class VI well). Installation of a Class VI well requires site assessment, test wells, and permitting, and these processes require time and investment. Direct air capture plants are currently capturing at the scale of thousands of tons of CO_2 per year and will need time to get to the scale of capturing millions of tons of CO_2 annually. Other assumptions would change the overall projections - for example, the assumption that aggregates capture only 10% of the incumbent market could be assumed to be 50% instead. This would not alter the general conclusion of the report which was to frame first-order estimates of revenue potential.

Class II enhanced oil recovery wells are not included in the report. Although CO_2 is durably stored in Class II wells, since the CO_2 is used to extract oil and gas to the surface which is subsequently used (with related CO_2 emissions) these wells are not good candidates for high quality carbon offsets. Storage in depleted oil and gas reservoirs is also not included in calculations and may be a good option. The potential storage at 1.8-5.3 gtons in total is smaller than in saline and unmineable coal, but the wells theoretically are tested and could safely store CO_2. There was not time to fully explore this option for this report.

With aggressive action, additional storage and sales could be possible in the long term. As one example, if 100% of the low limit of geologic storage as described by the U.S. Department of Energy's NATCARB database was used, an additional 91 gtons of storage valued at $1.43T is possible. If 100% of all aggregates used in construction regionally contained waste CO_2, 0.3 gtons of material priced at $5B per year could be sold.

Costs and capital investment needed to deliver these revenues are not described. The field of CCUS is in its infancy, and costs will change dramatically as technologies gradually scale - for example, solar panels are 98% cheaper than they were 30 years ago.[37]

Figure 3 shows that there are multiple high-quality carbon offset supply streams available in the region. Despite the wide range of market values, the team's recommendation is that **all** of these solutions are appropriate for the region and should be pursued concurrently. Every feasible solution to mitigate climate change should be implemented. Each of the solutions above has very different co-benefits to society and can be implemented on different timescales and geographies.

Geologic storage is the largest category for high-quality carbon offset supply. It was difficult to create meaningful assumptions for how much CO_2 would be placed into the available reservoirs. If the region only uses 1/1000th of the calculated capacity, it would still be an economically and climatologically meaningful avenue for carbon offsets. Underground carbon storage in Class VI wells is considered to safely store carbon dioxide on geologic time scales. Use of these types of wells could create near-term employment opportunities for workers currently employed in the oil and gas industry and others with positions involving transporting and storing liquid CO_2. **One of the greatest co-benefits of geologic storage is the ability to utilize the CO_2 capture and transportation infrastructure for CO_2 utilization.** Manufacturers can utilize waste CO_2 as a new ingredient in products such as precast concrete, construction

> "Mineralization and geologic sequestration are the two best options for durable and long-term carbon storage"
>
> Faculty member from Canadian University

stone and aggregate,[38] liquid fuels that can replace fossil fuels, chemicals such as ammonia, fertilizers such as urea, plastics, and other products. CO_2 utilization brings revenue from added economic value and new jobs as a co-benefit.

Of these examples, **crushed stone and precast concrete are great candidates for CO_2 utilization in the region for durable, long-term carbon storage and the creation of high-quality carbon offsets for the voluntary markets**. Carbonated crushed stone can be deployed locally to create new jobs and economic revenue when used to make concrete, asphalt, or for general construction purposes. The technology to capture and process concrete and stone exists but is only beginning to scale up for deployment. Carbonated concrete is ahead of aggregates and crushed stone in technological readiness with companies such as Carboncure[39] and Carbonbuilt[40] that already have their carbonated building materials utilized in construction.

Aggregates can use the Carbon8[41] process which is a decentralized, two shipping container system that can be placed near any emissions source to be filled with rocks, minerals and flue gas or DAC so the minerals can absorb and durably store the carbon dioxide. There are also new companies entering this market. **Unlike fuel or chemical production processes which are well suited to a centralized hub approach with large-scale production in tons per year, the physical weight and bulkiness of aggregates favors a decentralized, local approach.** Industrial waste minerals[42] (steel slag, fly ash, mine tailings, etc.) are also candidates for carbonization and usage in construction, with the potential for solving an environmental waste issue and supporting climate change mitigation. For some waste materials, carbon uptake and the risk of leaching toxic components is still undergoing research assessment.

For nature-based carbon offsets shown in Figure 3, reforestation, especially when done on private lands, provides opportunities to store large amounts of new carbon dioxide. This process needs to be done correctly and monitored regularly to ensure that wildfires, invasive species, tree illness, or other maladies do not impact carbon sequestration, and that forest projects sold as carbon offsets do not interfere with food production or other land uses. Many of the states and provinces in the region possess public forests as well, but the opportunities for incremental carbon storage on those lands is small because forests on state-owned lands are already very well managed. **Forest projects are in widespread development today for use in carbon offset markets.** Nature-based solutions have broad societal and environmental co-benefits including water filtration, improved air quality, creation of wildlife habitats, biodiversity preservation, and spaces for hunting and recreation.

Organizations buying forestry offsets have a good ecological story to tell their investors, customers, and employees. While engineered solutions don't have as many direct co-benefits to ecosystems, they provide a good narrative in that they are drivers of economic activity, job creation, and longer-term climate sustainability.

Technology	Total Storage Potential	Average price per ton (2022 $USD)	Total Revenue Potential (billion $USD)
Total Geologic Storage (low estimate)	14 $GtCO_2$	$14	$196
Total Geologic Storage (high estimate)	51 $GtCO_2$	$14	$714
Technology	**Storage Potential** *from 2022 - 2050*	**Average price per ton (2022 USD)**	**Total Revenue Potential (billion $USD)**
Reforestation - Private Lands (low estimate)	0.2 $GtCO_2$	$25	$5.5
Reforestation - Private Lands (high estimate)	2.2 $GtCO_2$	$25	$55
Reforestation - Public Lands	34 million tCO_2	$25	$0.85
Crushed Stone (low estimate)	160 million tCO_2	Not available, estimate of $16/ton used in Fig. 2	$2.6
Crushed Stone (high estimate)	790 million tCO_2	Not available, estimate of $16/ton used in Fig. 2	$12.6
Precast Concrete (low estimate)	0.10 million tCO_2	Not available, estimate of $29/ton used in Fig. 2	$0.0029
Precast Concrete (high estimate)	5.2 million tCO_2	Not available, estimate of $29/ton used in Fig. 2	$0.15

Figure 4 This table frames the carbon dioxide storage potential in tons and price per ton used to calculate market size in Figure 3. Solid waste biomass can be used to make synthetic liquid fuels as replacement for fossil sources or biochar as a coal replacement, for bioenergy with carbon capture and sequestration which creates low-carbon electricity, or as a soil amendment. There are 2.4 gigatons available in the U.S. Estimates for total geologic storage based upon carbon storage potential estimates for unmineable coal and saline basins from the U.S. Department of Energy NATCARB database. Estimates for Canada's geologic storage (a range of 0.70-8.58 gigatons for Québec) are not included as the information found was inconclusive. Also, there is potential for additional carbon storage in the entire region in basalt, peridotite and other geologic formations which are unidentified. Storage in depleted oil and gas wells is also not included.

Key pricing data used in the calculations supporting Figure 3 are shown in Figure 4, and details with assumptions are located in Appendix 1 and Section 4 of this report. Data sources for storage potential include The Nature Conservancy (reforestation), U.S. Energy Information Administration and U.S. Department of Energy NATCARB (geologic storage in saline formations, unmineable coal and sedimentary rocks), National Renewable Energy Laboratory (solid waste biomass), the National Stone and Gravel Association (crushed stone), and National Ready Mix Association (precast concrete). Data sources for prices include the Ecosystem Marketplace[27], interviews with foresters

> "Carbon offsets are there to get the last 10-20% of a carbon neutrality plan....DAC (Direct Air Capture) at the end is very attractive, even at $200 a ton, then we can get to net-zero."
>
> Senior Engineer, Large Industrial Manufacturer

> “The Great Lakes St. Lawrence Governors and Premiers can differentiate the region on the climate trajectory as a revenue source rather than a social cost.”
>
> Great Lakes Environmental and Economic Consultant

and carbon offset project developers, and corporate purchasers of carbon offsets.

Solid waste biomass refers to waste from trees or plants that can be burned to directly create heat and/or electricity, or thermochemical conversion into liquid biofuels and/or solid biochar for later use. **With abundant forest and farming activity in the region, a total of 0.08 gtons of solid waste biomass is available annually for conversion**. This figure does not include Ontario and Québec because data could not be located. Potential production options[43] include biomass to energy with geologic carbon storage (BECCS) and potential byproducts of biochar and liquid fuel. BECCS using waste biomass is only carbon free if the entire supply chain is carbon free when viewed from a lifecycle perspective, and that is difficult to achieve when accounting for the materials required to build a plant such as to produce cement and steel.

As an example of what is possible, using a range of conversion ratios from 5 to 50% depending on production methods, regional biomass could be converted to 0.12 to 1.2 gigatons of biochar. Priced at $10 per ton of waste biomass in the carbon offset markets, this is valued at $1.2B to $12B. Most of these processes are not carbon negative, although they do sequester some of the carbon dioxide and can be carbon negative depending upon the supply chain such as BECCS.

Tailoring the biochar production process to utilize locally available waste feedstocks is helpful. Ongoing research is being conducted to increase the longevity of carbon storage and soil improvements and to understand the impacts of biochar (a black, charcoal-like substance) on soil health and the ability of the earth’s surface to reflect sunlight into the atmosphere instead of absorbing it and creating more local warming. The International Biochar Initiative described other potential uses of biochar as a feedstock in building materials such drywall and insulation. This is a new area of research just getting underway. Similar to forest carbon projects, there is potential for biomass projects to compete with food production or other land uses.

The team was unable to study every carbon offset solution in detail. For example, **coastal blue carbon was not researched for the Great Lakes**, which refers to carbon storage in living coastal and aquatic organisms and coastal ecosystems. There could be significant storage potential in the region with invasive coastal plants being a potential source of waste biomass, although we recommend further study to fully assess this potential. **Biomass solutions (including biochar) made from forest, crop and plant residues were only partially explored (BECCS, biomass to energy)**. **Sources of zero-carbon or low-carbon energy such as wind, solar, nuclear and hydro as well as sustainably**

produced hydrogen are *essential* to the transition to net-zero and require careful planning. Not only are they needed for shifting away from burning fossil resources as the primary energy source over time as homes and businesses shift to clean electricity instead, but also as the source of energy for DAC, carbon sequestration, and carbon utilization solutions where required. For example, it would not make sense to use energy from a coal plant to capture CO_2 and produce hydrogen to make jet fuel. Additional clean energy capacity will be needed in the long term.

In addition to this report, detailed maps using data from many of the sources described above were created in GIS to visualize state and local level emissions sources, sinks, forests, biomass, pipelines and other features. The maps are user interactive. Please visit here[44] and here[45] to see the dashboard with the maps embedded.

Market Drivers and Pricing

There are two potential sources of revenue in this region for *producers* creating a voluntary carbon offset: selling credits into the carbon markets, claiming the U.S. 45Q federal tax credit, or possibly both. Pricing for the offsets is difficult to determine because the field is still rapidly developing. We relied heavily on project developers and corporate buyers whom we interviewed for current pricing. Forestry projects sell from $5 to $40 per ton of CO_2, with a typical price of $25 per ton of CO_2, with prices rapidly increasing over the last year. Other nature-based solutions such as coastal blue carbon or biochar are around $10 per ton of CO_2. CCS was $14 a ton of CO_2 in 2019 as reported by the Ecosystem Marketplace. DAC projects sell for $250 to $600[46] per ton of CO_2. Québec's current carbon pricing[37] in its regulated market was $35 CAD/ton of CO_2 ($27 USD/ton of CO_2) in August 2022.

Updated in August 2022 in the Inflation Reduction Act, the U.S. 45Q Tax Credit policy now includes more incentives and equity considerations than the previous version. The per-metric ton 45Q tax credit is substantially increased, now up to $85 for captured and geologically sequestered CO_2, and $60 for CO_2 that is reused in durable carbon-utilized products - provided that prevailing wages are paid during the construction phase and the first 12 years of operation and the facility meets wage and apprenticeship requirements. For direct air capture, the Act provides a maximum tax credit of $180 per metric ton captured and geologically sequestered, and up to $130 per metric ton for carbon oxide captured and included in durable carbon-utilized products, subject to the same wage and apprenticeship requirements. It is unclear how this tax credit for producers will impact the voluntary carbon offset markets, other than there is a much larger incentive to be engaged in carbon capture activities.

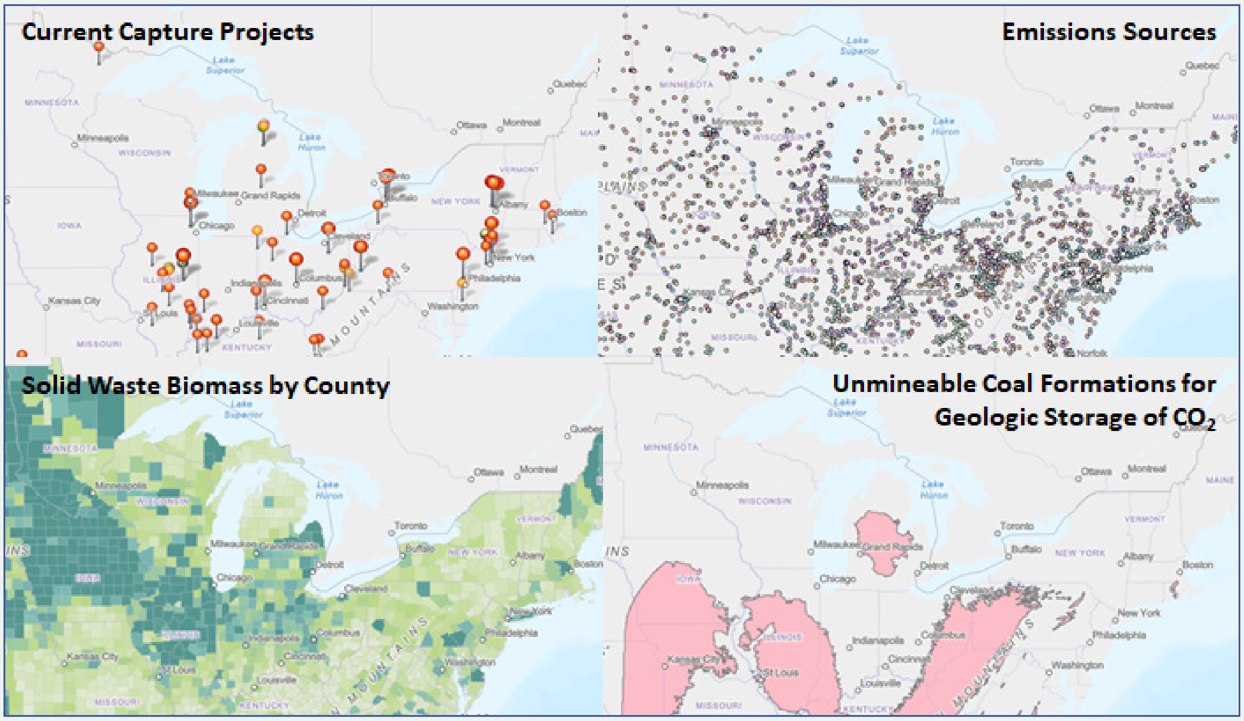

Figure 5 Examples of maps available in the open-source GIS platform created for this project. There are many other data layers available in the online version that help to visualize the intersections of assets and information that can lead to carbon offset projects.

Recommendations

Listed below are our proposed policy and other recommendations. Each recommendation was designed to maximize carbon reduction and prioritize environmental, economic, and social benefits in the Great Lakes region. As this report was going to publication, the United States Federal Government Accounting Office also released recommendations to support CCUS[91] which are valuable for anyone thinking about encouraging supply and demand for carbon projects in their area.

1. The region's U.S. states with significant geologic potential to store CO_2 in Class II or Class VI wells should submit a primacy application to the U.S. EPA as soon as possible.

It is our understanding that some states in the region do not have primacy. The process of getting a primacy application[59] approved by the EPA is slow, which means it is essential that states and regions with potential apply as soon as possible. After the passage of the Inflation Reduction Act, which includes much higher payouts for 45Q, primacy applications and approval timelines are expected to increase. Of the states in the Great Lakes region, Michigan, Indiana, Illinois, Ohio, and Pennsylvania all have assessed feasible saline CO_2 storage potential according to the Great Plains Institute's Carbon and Hydrogen Hubs Atlas. All of the Great Lakes states, with the exception of Minnesota, have at least some potential for saline storage, though Wisconsin has only minimal capacity. For the provinces, Ontario does not allow geologic storage, and Québec has some geologic storage well capability[60] in sedimentary formations. This process will be challenging for those states with less or no experience with Class VI wells, but considering the minimum timeframe of hundreds of years for Class VI well operations, there is the potential for greater control and responsiveness to permit applications.

2. The state and provincial agencies should coordinate with "hard-to-abate industries" such as iron, steel, cement, and ideally all industry actors with substantial size for emissions abatement planning.

Hard to abate sectors – heavy industry and transport companies are more difficult to decarbonize for a variety of reasons. These are industries with perpetual emissions expected to still be present in 2050. Driving emissions to net zero for all concrete, steel, pulp, heavy equipment and other industrial manufacturers by mid-century is not expected to be feasible. These industries – especially concrete - will need long-term plans for emissions mitigation. Convenings of these companies could focus on what information, external resources, incentives, policies, and other resources are needed to invest in carbon capture and utilization technologies in the region. This could also include how to position industrial emissions sources for both geologic storage and carbon utilization, and to also help companies understand carbon sequestration and how to maximize 45Q and carbon offset market revenues. Governments could get insight into forthcoming needs for low-carbon energy or other supporting CCU infrastructure. The use of renewable and/or low-carbon energy sources to power carbon capture activities is an essential component of abatement planning, as there are limits to how many renewables can be installed from a land use perspective. Manufacturing communities within the states and provinces should encourage point source capture and direct air capture to reduce their carbon footprint, and also encourage the co-location of carbon capture, carbon sequestration, and carbon utilization wherever possible to attract investment and production of carbon credits into the markets.

3. The Great Lakes region should hold 45Q Tax Credit, carbon emission reduction, and carbon offset seminars twice annually (once before United States federal taxes are due and once following), so that regional companies and individuals are informed of the issues and opportunities for carbon storage and reduction and to facilitate conversation and collaboration.

These seminars could have two target groups: companies and industrial manufacturers, and private landowners with the potential to store carbon. These seminars would provide a great opportunity to encourage companies to shift to low-carbon energy sources and to examine ways to reduce or eliminate fossil carbon as feedstocks in their business models.

4. The Great Lakes St. Lawrence region should create a program similar to the Québec Cap and Trade System[47] or Regional Greenhouse Gas Initiative (RGGI)[48] to establish a regulated carbon market designed to maximize environmental benefit.

Initiated in 2003, the Québec cap-and-trade system applies to industrial, electricity generation and fossil fuel distribution emitters of 25,000 metric tons per year or more of equivalent CO_2. An electronic trading system is operated by the Western Climate Initiative,[49] also supporting California, Washington, and Nova Scotia for carbon credit transactions. The system is open to others who are not required to participate in carbon markets but wish to do so. The Western Climate Initiative is the largest North American market and one of the largest in the world. All Québec proceeds go to the Québec Green Fund for the financing of the different initiatives contained in the 2013-2020 Climate Change Action Plan. RGGI's program requires large fossil fuel power plants to buy annual pollution permits, and the number of permits is reduced each year, so that the region's power plants contribute progressively fewer emissions. Auction proceeds are used to generate local and regional economic and climate benefits. For the Great Lakes region, the proposed regional agreement could be based on a scientifically determined carbon allowance implemented with carbon permits for the top polluters in the region. Permit trading proceeds could be used to support low carbon electricity generation, job training, infrastructure needed for the transition to net-zero and voluntary carbon markets, and incentives to drive corporate investment in DAC, geologic storage, and carbon utilization. The implementation of an emissions trading system can drive new types of jobs and create additional economic revenue for the region. Québec and RGGI are suggested sources for more information to illustrate the impacts to emissions reductions, jobs, and environmental benefits - or European colleagues familiar with their Emissions Trading System.[50] Ontario's cap-and trade system was canceled in 2018,[51] but can provide important lessons. Lastly, the IEA issued a CCUS Handbook[52] and database of global laws and policies[53] in the summer of 2022 that further outline important considerations. A key question to consider is **whether it makes sense for all 10 regional jurisdictions to work together for a Québec or RGGI type agreement, or to separate into smaller partnerships based on each state or province's strengths and weaknesses so that the collective has balance.**

For the region to go above and beyond in reducing carbon emissions and becoming a national and global leader in the CCU/CCUS space, a Low Carbon Fuel (LCF) Standard, comparable to California's LCF Standard, could be considered for vehicles in the region. LCF standards, like carbon allowances, are a form of a Cap-and-Trade program to reduce emissions which has the advantage of market creation. A LCF standard for transportation emissions and a regional carbon allowance for stationary emissions would complement one another. A LCF standard has the potential to incentivize car manufacturers in this region such as Ford, GM, Stellantis, and others to increase production on hybrid and electric vehicles. Climate benefits are achieved if vehicle charging is from non-fossil sources, and low carbon electricity planning and development would also be important to support additional grid loads.

5. The Great Lakes St. Lawrence region should develop and support a sovereign wealth fund for the citizens residing in the 8 states and 2 provinces as a means to protect the environment while accruing economic benefits for future generations.

Class II54 and Class VI55 wells have some amount of public ownership56 due to the impacts they can have on shared land and resources in the region. Under this scenario, the owners and operators of the wells could provide 1-2% of revenue to the wealth fund. Anyone using publicly generated waste biomass or operating direct air capture plants could also be asked to contribute. The region would decide the best usage of collected funds on an annual basis. Norway's sovereign wealth fund57 which was started in 1990 and held assets of $1.4T or approximately $250,000 per resident as of December 2021, is the inspiration for this suggestion. The Michigan Natural Resources Trust Fund58 is another example, collecting $15-$20M in revenues annually from the development of state-owned mineral resources, primarily oil and gas. Funds are used to offer grants to local governments or other entities to purchase land or land rights for recreation, recreation facilities, or protection. The trust fund could also help backstop liability concerns for states with carbon storage in class VI wells. This could help encourage companies to invest in carbon storage and utilization.

Suggestions for Further Study

Topics of potential further study were identified by the team and are described in detail later in the report. Suggestions include:

- Investigate how to safely and sustainably reduce CO_2 levels of the waters of Great Lakes to support freshwater health, indirectly reduce atmospheric greenhouse gas emissions, and generate a new type of carbon credit (underway as of fall 2022 at the University of Michigan).
- Research the implementation pathways, supply chain and investment options for carbonated aggregates and precast concrete production.
- Investigate direct air capture plant implementation, to study the best use and production pathways for the 0.08 gtons of waste biomass generated in the region each year.
- Create a regional forest carbon strategy that provides for ecosystem services and economic goals.
- Assess the potential for additional geologic storage in the region.
- Assess the feasibility of operator cost recovery for installing carbon capture systems with regional grid operators and others.

> "A key enabler is advocacy at the state, regional and local levels, and cross-borders to lower the hurdles to get carbon neutral technologies in place."
>
> Senior Engineer, Large Industrial Products Manufacturer

Closing

There is no ideal single voluntary carbon offset solution, either nature-based or engineered, for this region. Instead, there are a range of choices, each with their own strengths, weaknesses, opportunities for revenue and jobs, and co-benefits to the local community. Regionally implemented solutions, including both nature-based and engineered solutions, should align with the strengths of the specific geography and socio-economic community involved for both the short and long term. Nature-based solutions are available now and bring numerous environmental and social co-benefits to communities. Engineered solutions are mid-term to longer-term and bring the possibility to permanently store carbon at very large scales while supporting a sustainable economy and job creation.

The regional revenue potential by 2050 is $205 - $783 billion, corresponding to 14.4-52.2 gigatons of high-quality carbon sequestration.

This compares to 0.13 gigatons of carbon credits that have been retired in the region as of 2020. Significant regional planning to coordinate CO_2 emissions sources, CO_2 sinks in geologic storage, land-based carbon storage or carbon utilization in products is needed. Planning for a solid underpinning of clean electricity generation, land use, and CO_2 transport and storage infrastructure is also needed, with associated investment strategies.

The emissions transition will take time. The region can take incremental steps over the next decade and beyond to position itself as a place to find high-quality carbon offsets for companies to meet their 2030, 2040, and 2050 carbon neutrality commitments.

If implementation planning starts now, the Great Lakes St. Lawrence region can take advantage of these opportunities and become a leading source of carbon offsets globally.

"The Great Lakes has a lot of diversity – a lot of shipping, industry, universities, lumber, cars, and high population density that will grow over time. And it is an area of the world that is uniquely free of climate disasters, wildfires, floods, and mudslides and so it will be a promising economic zone. There is no clear leader in the Great Lakes region, and it makes sense to plan due to the natural resources and industry."

Chief Scientist, Global Non-Profit Organization

GLOBAL CO_2 INITIATIVE
UNIVERSITY OF MICHIGAN

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GOVERNORS
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