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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Foreword

This report was commissioned by the Conference of Great Lakes St. Lawrence Governors and Premiers (GSGP) and is part of the Great Lakes Impact Investment Platform Research Series. GSGP and its partners launched the Platform and its Research Series to help position our region as a global destination for investments that boost climate resilience, reduce emissions and create other benefits.

This report explores the region's potential to attract investments through the voluntary carbon markets to store carbon in nature-based solutions like trees, underground through geologic storage and other emerging techniques. Historically, our region has been a hub for innovation and forward-looking policy. As a result, our region is positioned in a central role to assist companies, governments and others work to meet their carbon reduction goals through carbon offset markets. Voluntary carbon markets are expected to grow dramatically in the years ahead, and combined with our region's distinctive natural resources, this represents a tremendous environmental and economic opportunity.

Together, we must seize this opportunity to create lasting benefits for the environment, the economy, and the people of the region. We thank the Global CO_2 Initiative and the University of Michigan students for their exceptional work and important contributions toward our shared goals.

David Naftzger

Executive Director, Conference of Great Lakes St. Lawrence Governors and Premiers

The Global CO_2 Initiative welcomed the challenge to identify and quantify options for the Great Lakes region to bolster the voluntary carbon markets. An interdisciplinary team assessed nature-based solutions such as planting trees to store carbon dioxide, and explored engineered solutions such as concrete and biochar with exciting conclusions for the amount of CO_2 that can be stored and new revenues that are possible. In order to solve the climate problem, we need every option available to us. Making our region a go-to for carbon offset solutions will not only have positive environmental outcomes, but a positive impact on jobs.

Volker Sick

Director, Global CO_2 Initiative at the University of Michigan

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Glossary & Key Concepts

Definitions

Most definitions are sourced from the Carbon Dioxide Removal (CDR) Primer and the EPA.

Additionality	Evaluates the degree to which an intervention (e.g., a CDR project) causes a climate benefit above and beyond what would have happened in a no-intervention baseline scenario. By definition, this counterfactual baseline scenario cannot be directly observed (because it did not happen), so can only be estimated or inferred based on contextual information. Additionality can be assessed at the level of individual projects or protocols that define categories of projects. In policy regimes such as cap-and-trade programs, where emissions are permitted in exchange for reduction or storage elsewhere, failures of additionality result in increased emissions.
Carbon Negative	When an organization removes more carbon emissions than it emits. It requires both the setting of a science-based target to reduce emissions to get to net zero and offsetting or removing even more of its unavoidable emissions.
Carbon Neutral	Any CO_2 released into the atmosphere from a company's activities is balanced by an equivalent amount being removed.
Carbon Positive	The opposite of carbon negative, used to denote that an organization emits more than it removes. This term is also commonly how organizations describe actions that benefit the environment. Due to the multiple meanings of this term, we avoid its use in this report in order to prevent confusion.
Carbon Offsets	Programs or policy regimes in which companies or individuals pay for activities that result in emissions reductions or Carbon Dioxide Removal (CDR). In voluntary offset programs, individuals or companies pay project developers (or similar) directly to implement some activity that results in emissions reductions or CDR. In compliance offset programs, such as cap-and-trade programs, companies that are responsible for large amounts of emissions are allowed to continue to emit above a certain cap in exchange for projects taking place elsewhere that reduce emissions or remove carbon. In a compliance regime, an offset has no effect on total emissions in the best-case scenario and will result in more emissions than would have occurred otherwise if the project is ineffective in any way (e.g., due to failures of additionality or permanence).

Class II and Class VI Wells in Geologic Formations

A Class II well is drilled for enhanced oil recovery, or using liquid CO_2 to flush up natural oil stores in porous geologic formations. A Class VI well is drilled into saline or similar formations, and is only used to store liquified CO_2 underground permanently. Geologic formations can be described in terms of type of formation (sedimentary formations, volcanic rock formations, and ultramafic formations). In this report, storage is defined for sedimentary basins according to the resource / type of reservoir (deep saline aquifers, unmineable coal, and depleted oil and gas reservoirs).

Climate Tipping Points

Abrupt and irreversible climate events, such as ice sheet loss and ecosystem collapse.

Durability

The duration for which CO_2 can be stored in a stable and safe manner. Storage duration can differ significantly, depending on the type of reservoir. For example, concentrated CO_2 stored in geologic formations deep underground is effectively permanent (thousands of years), whereas forest carbon stocks can release carbon back into the atmosphere due to wildfire or tree harvesting.

Asymmetry of Information

Information relating to a transaction in which one party has relevant information that is not known by or available to the other part.

Gigaton

One billion tons.

Greenwashing

The act or practice of making a product, policy, activity, etc. appear to be more environmentally friendly or less environmentally damaging than it really is.

Hard-to-avoid (or hard-to-abate) emissions:

Emissions that are either physically extremely difficult to eliminate within a certain timeframe (e.g., because of dependence on a particular infrastructure with a long lead time for carbon-free substitution, or because avoidance would require a technology that relies on a scarce resource) or which would be unacceptable to avoid from a social justice perspective (e.g., if mitigation would deprive people of the means to satisfy their basic needs, like food security).

Abbreviations

45Q

45Q Tax Credit

BECCS

Bioenergy Carbon Capture and Storage

CCU

Carbon Capture and Utilization

CCS

Carbon Capture and Storage

CDR

Carbon Dioxide Removal

DAC

Direct Air Capture

EOR

Enhanced Oil Recovery

GHG

Greenhouse Gas

LCA

Life Cycle Assessment

SAF

Sustainable Aviation Fuel

VCM

Voluntary Carbon Market

Concepts

Carbon Removal	Carbon removal, also known as carbon dioxide removal (CDR) or carbon drawdown, is the process of capturing carbon dioxide (CO_2) from the atmosphere and locking it away for decades or centuries in plants, soils, oceans, rocks, saline aquifers, depleted oil wells, or long- lived products like cement.
Inflation Reduction Act	A historic down payment on deficit reduction to fight inflation, invest in domestic energy production and manufacturing, and reduce carbon emissions by roughly 40 percent by 2030.
Paris Agreement	A 2016 agreement formed by Parties to the United Nations Framework Convention on Climate Change (UNFCCC) to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low-carbon future.
Québec's Cap and Trade Emissions System:	A climate policy that environmentally and economically limits emissions and puts a price on them. The cap on greenhouse gas emissions that drive global warming is a firm limit on pollution. The cap gets stricter over time. The trade part is a market for companies to buy and sell allowances that let them emit only a certain amount, as supply and demand set the price. Trading gives companies a strong incentive to save money by cutting emissions in the most cost-effective ways.
45Q Tax Credit:	A U.S. tax credit for carbon capture and sequestration that provides an incentive for capturing carbon and storing it underground in geologic or Class VI saline formations, underground through oil recovery, or in long-term secure storage through CO_2 utilization products.

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.

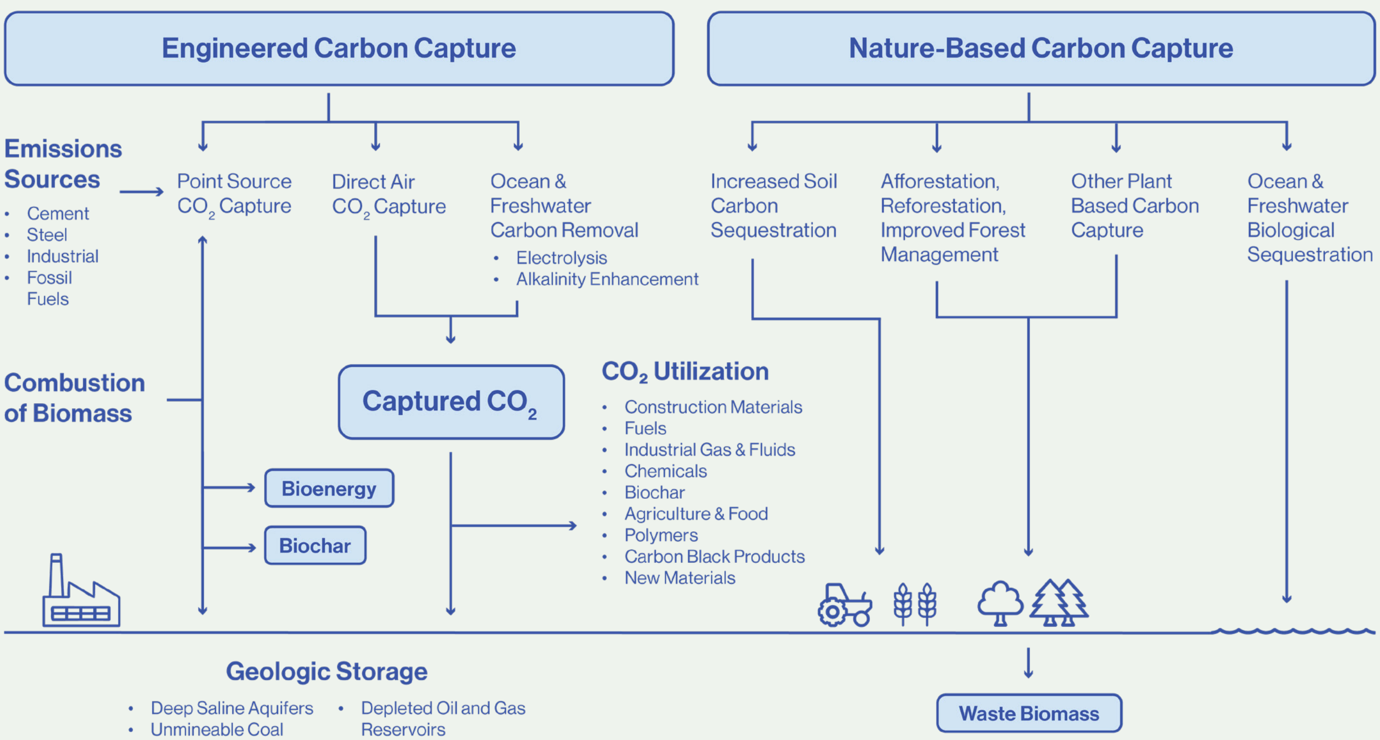

Figure 1 Overview of nature-based and engineered carbon capture and storage options for the Great Lakes region.

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

		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**	
Track 1 or 2	**Pure carbon materials** Carbon black	**14 - 66**	**0.04 - 0.20**	
Track 1 or 2	**Polymers** Polyurethane	**130 - 190**	**0.002 - 0.013**	
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.

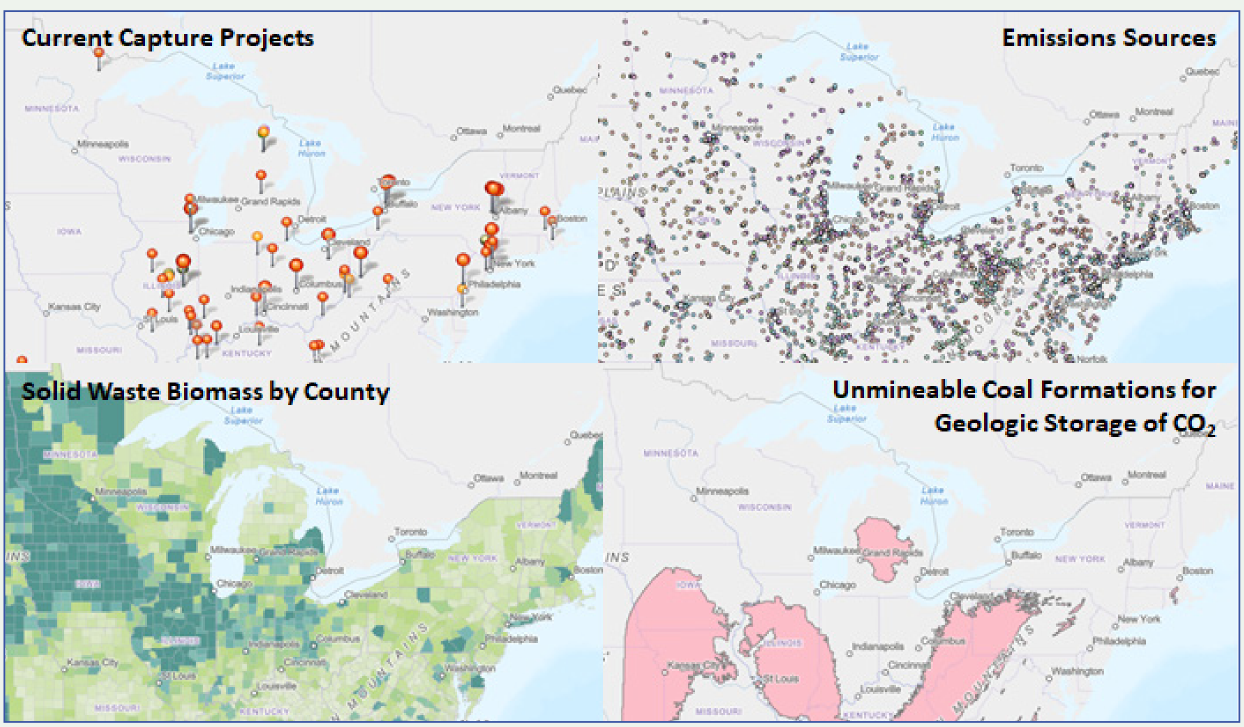

Figure 5 Examples of maps available in the open-source GIS platform created for this project. There are many other data layers available in the online version that help to visualize the intersections of assets and information that can lead to carbon offset projects.

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

Project Scope & Background

Overview

The objectives of this report are to:

1) Characterize the relevant basis for carbon offset markets and the overall framework in which they operate.
2) Define high-quality carbon offsets.
3) Analyze historical voluntary carbon market offset transactions in the Great Lakes St. Lawrence region.
4) Identify and review current and future regional options for storing and selling carbon in the voluntary carbon markets.
5) Make recommendations on actionable steps and further studies that the Conference of Great Lakes St. Lawrence Governors and Premiers can take to establish the region a global leader in the supply of high-quality carbon offsets into the voluntary carbon markets.

"Positioning the Great Lakes Region as a Leader in the Voluntary Carbon Offset Market" used carbon offset market frameworks, supply side and demand side analysis, and a review of carbon capture and storage (CCS), carbon capture and utilization (CCU) methods as well as nature-based solutions to recommend voluntary carbon offset implementation supply solutions for the Great Lakes community. Our quantitative research and stakeholder interviews identified multiple economically, socially and environmentally conscious carbon dioxide removal (CDR) opportunities in the Great Lakes region. Findings suggest that both nature-based and engineered carbon removal solutions can work together simultaneously to mitigate the harmful impacts of carbon emissions and to help develop a high-quality, at-scale portfolio of carbon offset supply for the region and globally.

Brief Climate History

Global warming has become an increasingly relevant concern as record temperatures continue to rise, natural disasters become more frequent, and weather patterns have become more irregular. Human-produced carbon dioxide and other greenhouse gases (GHGs) have been accumulating in our Earth's atmosphere since the early 1800's. The industrial revolution began an era that is heavily responsible for contributing to global warming, or what our modern society now knows as the enhanced greenhouse effect. Following the national Industrial Revolution, the Great Lakes region became a hub for agriculture and manufacturing. This era was also when early signs of climate change became increasingly detectable, such as severe droughts and more dramatic weather patterns. Some believe the onset of climate change in the United States was the Dust Bowl of 1930. In the 1950's, more research was done on carbon dioxide emissions in our atmosphere with an emphasis on their impact on human life on Earth. By the 1970's, scientists publicly theorized that ambient pollution would not cause global warming, but rather global cooling due to the pollutants shielding sunlight from the Earth. While there was a brief international cooling period from 1940-1970, due to a post-World War boom of aerosol pollutants, the warming resumed soon after. 1988 was a historic climate tipping point, this can be attributed to the hottest temperatures ever recorded, widespread droughts, and wildfires in the United States.

As more people became aware and concerned about the effects of climate change, increased pressure was placed on governments and companies to make plans to reduce emissions and take climate action. Following the climate events of 1988, the United Nations formed the Intergovernmental Panel on Climate Change (IPCC) to conduct scientific research on climate change and its social and economic consequences. In 1997, both the United States and Canada signed the Kyoto Protocol that called for "reducing the emission of six greenhouse gases in 41 countries and the European Union to 5.2% below 1990 levels during the target period of 2008 to 2012". Most recently, the Paris Climate Agreement was signed by 197 countries including the United States and Canada in 2015, which aims to keep global temperature increase under 2 degrees Celsius by 2050, preventing catastrophic environmental consequences. In 2018, the IPCC changed the recommended maximum warming temperature limit to 1.5 degrees Celsius[1].

Increasingly more organizations have created carbon neutrality plans to meet these goals for 2030, 2040, and 2050, including carbon offsets that are based upon emissions reductions, avoidance, or carbon removal as a part of their climate strategies. By definition a carbon offset[61] is "an action that is intended to compensate for the emission of carbon dioxide in the atmosphere as a result of industrial or other human activity". The first instance of carbon offset trading was within the Clean Development Mechanism as a part of the Kyoto Protocol, which allowed countries with sustainability commitments to implement carbon reduction projects in developing countries.

While the gestures, policies, and inventions created to slow and eventually mitigate the root causes of climate change are being developed and advocated for each day, **there is still much more we need to do in order to meet our mid-century and end of century climate goals and to depoliticize the effects of climate change, as they will inevitably impact our entire global community.**

> "We should recycle CO2 as we recycle any other commodity"
>
> Senior National Laboratory Scientist

Overview of Voluntary Carbon Markets

Carbon offset projects that are to be sold in the voluntary carbon markets need to utilize an approved methodology by a carbon registry. There are a number of carbon registries, but the four most often used are Verra (VCS), the American Carbon Registry (ACR), Climate Action Reserve (CAR), and Gold Standard for the Global Goals. These registries develop *methodologies* which are peer reviewed. *Monitoring, reporting and verification* **(MRV) of registered and approved carbon offset projects are best done independently**, and dozens of agencies are available globally for this purpose. *Verification* ensures that the emissions claims in a project are actually delivered over time. The division between the method body and the verification body helps create the best quality offsets. There are other carbon registries as well, some of whom use this approach, and some who don't (they both register and verify under one roof). Many, but not all voluntary carbon offset projects are registered with the carbon registries. Private business-to-business deals for large volumes of credits don't necessarily get registered, for example. Also, not all of the engineered solutions described in this report have an approved methodology yet in the carbon registries. **High quality voluntary carbon offset credits are registered, independently measured, verified and reported, and are retired after purchase to avoid the possibility of double counting (two organizations claiming the same credit).**

Additional processes related to carbon offsets include carbon accounting and lifecycle assessment. *Carbon accounting* is the process by which organizations quantify their greenhouse gas emissions, so that they may understand their climate impact and set goals to limit emissions. In some organizations, this is also known as a carbon or greenhouse gas inventory. *Lifecycle assessment* is a process using specific methods and data for assessing environmental impacts associated with all the stages of the life cycle of a commercial product, from resource extraction to end of life. For carbon utilized products such as carbonated aggregates, a lifecycle assessment calculates the total emissions and other environmental impacts of the product from when it is made to when it is disposed of or reused.

Compliance carbon markets arise from and are regulated by mandatory national and regional emissions reduction plans. Examples of compliance markets are Québec, California, the Regional Greenhouse Gas Initiative, and the EU's Emissions Trading System.

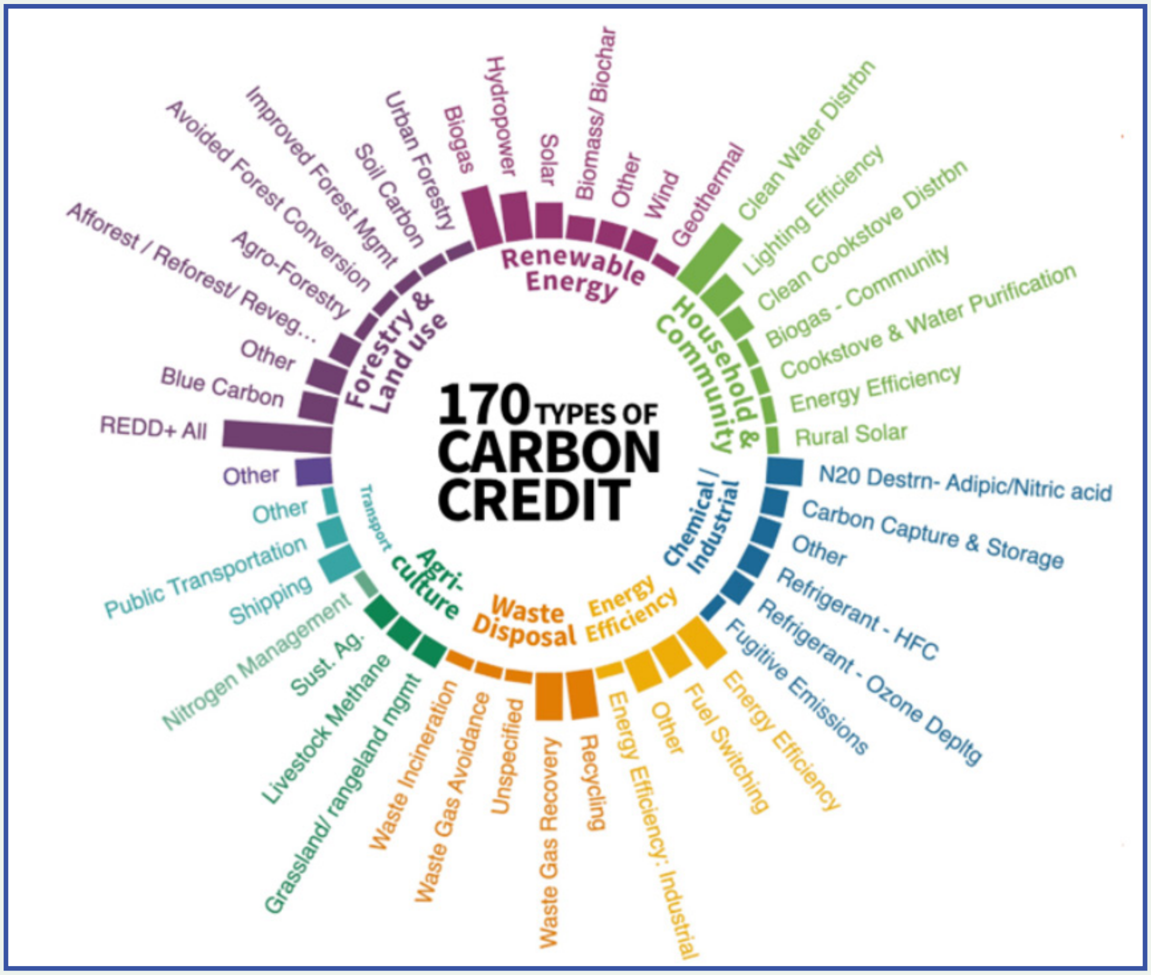

Figure 6 Types of Carbon Credits reported to Ecosystem Marketplace from 2020-2021. Source: Ecosystem Marketplace.

It is important to note that many of these credits listed are emissions reductions and avoidance, which, as we defined earlier, do not constitute high-quality offset projects.

Currently there are many kinds of offset credit being traded and reported in the Voluntary Carbon Market. For buying and selling carbon credits approved to 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 outlet to observe market conditions. They distribute annual surveys to project developers, retailers, investors and others to collect information so that 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 with a focus on high-quality carbon removal and storage.

The trend to offset carbon emissions via nature-based and engineered solutions is attractive in theory. But there are a host of legitimacy concerns that have offset markets confusing and somewhat ineffective for taking bold steps towards climate progress. Concerns include the difficulty of calculating and measuring the actual CO_2 emissions removed in a project, double counting of carbon credits, using credits to avoid changing business practices for emissions, and many others. **Carbon offsets are ideally a method that *removes new carbon* from the atmosphere as a result of a financial investment, instead of just reducing or avoiding emissions (se Section 1.1).** But without consistent high-quality carbon offset criteria being broadly used for offsets sold in the voluntary carbon markets, they will not drive durable carbon storage as effectively as could be, and will continue to be a source of confusion for purchasers and corporate investors.

With the breadth of variability today in offset quality, the carbon registries that develop methodologies for carbon offset projects and some regulations are working to improve quality. In addition to the carbon registries, other drivers of carbon offset quality include Canada's Canadian Net-Zero Emissions Accountability Act, the United States' latest version of the 45Q Tax Credit, the proposed U.S. Securities and Exchange Commission SEC ruling requiring disclosure of ESG goals and metrics, and the individual state and provincial sustainability commitments.

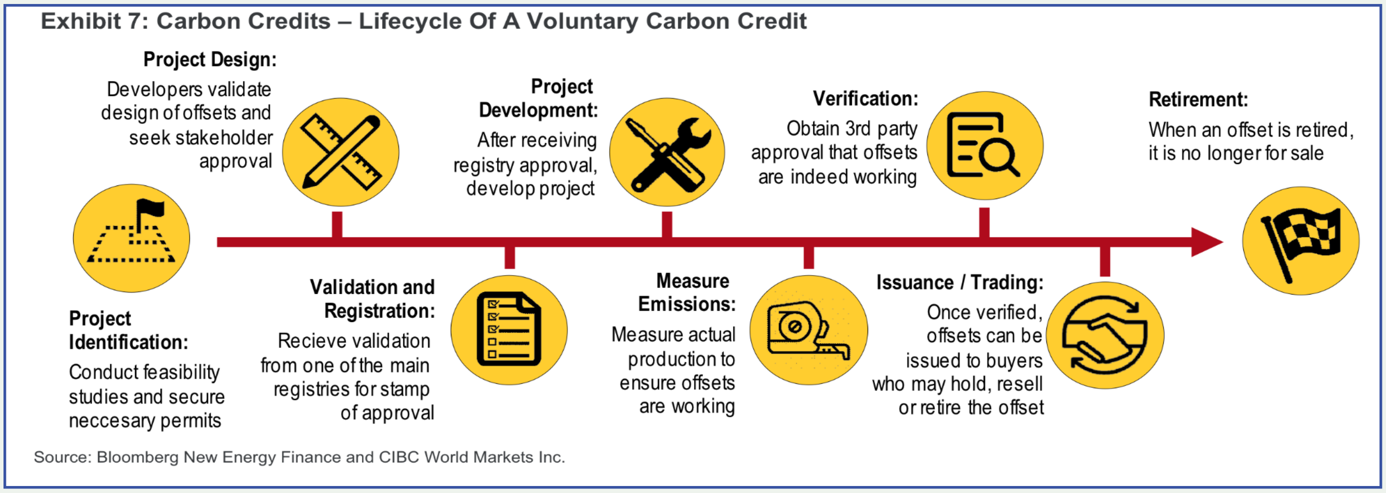

Figure 7 The life cycle of a carbon credit in the voluntary markets. Source: Bloomberg New Energy Finance and CIBC World Markets Inc.

National and State Level Policies & Tax Incentives for Carbon Emissions Reductions

In the United States the 45Q Tax Credit passed in August 2022 in the Inflation Reduction Act is more incentivizing and environmentally just than its previous version. It offers a baseline pricing of $12 per ton for carbon utilization and $17 per ton for carbon sequestration. But if the 45Q-qualified facility meets specific wage, hour, and apprenticeship requirements, the credit can be multiplied by five. Once multiplied by five, the **carbon utilization tax credit is $60 per ton and the carbon sequestration tax credit is $85 per ton.** Similar regulations apply to DAC facilities, the carbon utilization tax credit is $26 per ton and the sequestration tax credit is $130 per ton. If the 45Q-qualified facility meets specific wage, hour, and apprenticeship requirement, then the **DAC utilization tax credit increases to $130 per ton and sequestration is $180 per ton.**

In Canada, the Canadian Net-Zero Emissions Accountability Act is the national government's commitment to achieving net-zero greenhouse gas emissions by 2050. The Act includes a legally binding process to set five-year national emissions reduction targets as well as develop credible, science-based, reduction plans to achieve each target. It establishes the 2030 greenhouse gas emissions target as Canada's Nationally Determined Contribution (NDC) under the Paris Agreement emissions reductions of 40-45 percent below 2005 levels by 2030. The Act also establishes a requirement to set national emissions reduction targets for 2035, 2040, and 2045, ten years in advance.

Québec operates a regulated carbon market with a cap-and-trade system that 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 mechanism 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 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 and are earmarked for the financing of the different initiatives contained in the 2013-2020 Climate Change Action Plan.

Great Lakes Region State and Province Climate Commitments

Québec and Ontario both abide by the Canadian Net-Zero Emission Accountability Act as well as their own provincial climate plans. Illinois, Michigan, Minnesota, Pennsylvania, New York, and Wisconsin have state-wide targets for emissions reductions and carbon neutrality. Indiana and Ohio, do not have state level carbon neutrality commitments, but do have collegiate and civic discussion and action in these states. Please see details in Appendix 3.

Illinois: Issued an executive order that emphasizes each Illinois citizen's right to clean air, water, and a safe environment. Illinois was the first Great Lakes state to commit to a 100 percent carbon-free energy standard by 2045.

Michigan: Goals are to reduce GHG emissions 28% below 2005 levels by 2025, 52% by 2030, and achieve economy-wide carbon neutrality by 2050.

Minnesota: Targets reducing GHG emissions 30% from 2005 levels by 2030 and 80% by 2050, balancing any GHG emissions with carbon storage, especially in landscapes with a detailed supporting plan released in summer 2022. s

New York: Is developing a Draft Scoping Plan to be released by January 1, 2023. The plan will outline actions to help the state meet its goals of reducing GHG emissions 40% from 1990 levels by 2030, and 85% by 2050.

Ontario: Ontario abides by the Canadian Net-Zero Emissions Accountability Act aiming for net-zero emissions by 2050 and the Made in Ontario Climate Plan.

Pennsylvania: Released the fourth update of its Pennsylvania Climate Action Plan in September 2021. The plan outlines 18 strategies to reduce GHG emissions 26% by 2025 from 2005 levels, and 80% by 2050.

Québec: Abides by the Canadian Net-Zero Emissions Accountability Act and its own climate legislation, "The 2030 Plan for a Green Economy"[62] that seeks a 37.5% emissions reduction compared with 1990 levels, and to reach carbon neutrality by 2050.

Wisconsin: Released its Governor's Task Force on Climate Change Report in December 2020. The plan includes policy recommendations to help the state meet its goal of reducing GHG emissions 26–28% below 2005 levels by 2025 and achieving 100% carbon-free electricity by 2050.

Methodological Approach for Report

Both quantitative and qualitative methods were used to evaluate the objectives of this report. Figure 8 is a summary of objectives and methodologies used to formulate the thinking and results of our research.

Quantitative Analysis Goals	**Method**
Categorize and describe demand side VCM market drivers	Corporate carbon neutrality commitments and emissions reductions plans, websites and reports
Identify appropriate high-quality, additional carbon storage options for the region that would also drive new revenues	Published papers and resources such as the CDR primer, Department of Energy Reports, Carbon Registries, etc
For supply side carbon offset options, create first order estimates of carbon storage potential and associated revenues	Government sources, published papers and reports, interviews
Describe historical carbon offset transactions in the Great Lakes region	Berkeley/Carbon Direct Voluntary Carbon Market Database
Describe criteria for high-quality carbon offsets	Microsoft criteria, published papers, carbon registries (Verra, Gold Standard for the Global Goals, American Carbon Registry, Climate Action Reserve)
Qualitative Analysis Goals	**Method**
Find non-published pathways to connect with current on-the-ground activities on the supply side and demand side	Interview a broad range of stakeholders including researchers, government staff, and corporate stakeholders. Interviews were requested from companies with headquarters or significant assets in the Great Lakes region in the U.S. and Canada.

Figure 8 An overview of the research methods used to produce this analysis and report.

Results

The Great Lakes region is in a unique position to employ nature-based and engineered carbon sequestration solutions into the voluntary carbon markets to reach carbon reduction goals. Over time, this has the potential to generate hundreds of billions of dollars in revenue into the regional economy. Collaboration amongst the Great Lakes states and provinces is warranted to leverage each jurisdiction's strengths.

In this section, trajectories for emissions reductions and how carbon offsets fit will be described along with criteria for high-quality carbon offsets. This is followed by an overview of historical carbon offset transactions in the Great Lakes region. Both the demand side and supply side for carbon offsets will be examined next along with market size, and lastly recommendations to support the region in becoming more active as a supplier of carbon offsets and areas for follow-on study will be presented.

1 - Basis for Carbon Offset Markets and Criteria of High-Quality Projects

1.1 - The Role of Carbon Offsets in the Emissions Transition

Illustrated in Figure 9 below is an overview of strategies that an organization can employ to reach net-zero goals. By definition, achieving net-zero emissions requires that any emissions that are not reduced must be removed. Emissions reduction, avoidance and removal are different tasks[28]:

- **Reduced emissions** are existing emissions that no longer occur. Functionally this task involves emitting fewer emissions in the first place. Examples include energy efficiency measures, energy conservation, turning off equipment, displacing existing emissions sources, and carbon capture and storage from smokestacks.
- **Avoided emissions** are those that might have occurred but do not. Examples include walking instead of driving or installing wind turbines instead of a natural gas power generation plant.
- **Removed emissions** are legacy emissions previously emitted and subsequently retrieved. Examples include natural processes such as mineral weathering, managed ecosystems such as reforestation, or engineered systems such as bioenergy with carbon capture and sequestration.

To achieve net-zero emissions, all emissions trajectories must decrease. **For any residual emissions that are not reduced or mitigated, net zero emissions require that an equal mass of CO_2 be removed to balance them.** In many scenarios and descriptions, residual emissions are considered "hard-to-abate", meaning either the cost is extremely high (e.g., for aviation) or the technology does not exist (e.g., application of fertilizer). This is the core arithmetic of a net-zero emissions plan., and emissions removal involves sequestering emissions from the atmosphere that cannot be avoided through the use of nature-based solutions, direct air capture, or a hybrid of nature-based and engineered solution.

> "The vast number of credits that exist are avoidance. In the past couple of years, there has been a great shift towards removal"
>
> Senior Manager of Carbon Consulting Firm

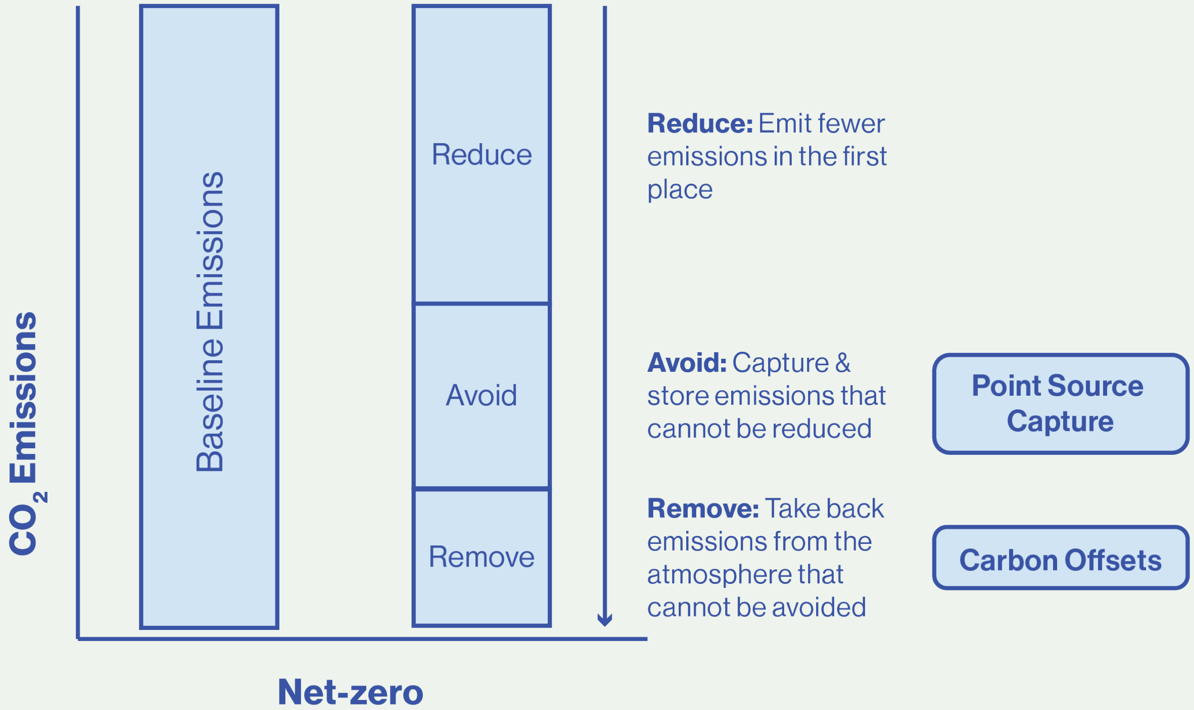

Figure 9 Methods for achieving net-zero emissions targets. Concept resulted from a conversation with Pete Psarras at the University of Pennsylvania.

We suggest the following guidelines in the time of emissions transition between now and 2050 in the Great Lakes region:

1. **Offsets must be paired with aggressive emissions reductions.** Emitting organizations and governments should curate a plan to reduce their emissions to limit global warming to no more than 1.5 degrees Celsius increase in global average temperatures by 2050, in accordance with Paris Climate Agreement goals.
2. **Emissions that cannot be reduced should be avoided through use of point source capture.** Point source capture of emissions can be implemented to avoid further emissions. Point source capture technology can be attached directly to an exhaust stream to prevent additional greenhouse gases from entering the atmosphere.
3. **Emissions that cannot be avoided should be removed from the atmosphere.** Direct air capture allows for sequestration of CO_2 directly from the atmosphere. There may also be potential for CO_2 removal from oceans and other bodies of water.
4. **Plan and implement renewable and very low carbon energy** and energy storage (such as nuclear, hydro, or bio-energy with carbon capture and sequestration) that will be required to support the shifts in Points 1-3. Low carbon energy infrastructure enables reduced emissions by transitioning sources of energy from fossil-based sources to sustainable sources, as well as providing low-carbon energy needed to support carbon capture, storage and carbon utilization activities.
5. **The carbon offset market should be a tool for decarbonization and long term change.** The carbon offset market should enable carbon neutrality and be an interim step towards decarbonization for all sectors. By 2050, the goal is that only hard-to-abate sectors such as concrete and some industrial processes will need offsets, and that easier-to-abate sectors will be fully decarbonized.

6. **Care should be taken to determine how resources and revenue from offset projects are utilized.** There is a limited supply of high-quality offset projects, especially in contrast to the surplus of emissions sources. Due to the scarcity of these resources, there should be considerations made on what sectors are allowed to use them, especially as an alternative to reducing or avoiding emissions. If a sector is more easily decarbonized, they should prioritize emissions reductions and avoidance, and some percentage of offsets should be reserved for hard-to-abate sectors. **Ideally, hard-to-abate sectors would be prioritized for offsets, and easier-to-abate sectors would undertake aggressive emissions reduction and avoidance targets.**

1.2 - Criteria for High-Quality Carbon Offset Projects

To position the Great Lakes region as a leader in carbon offset transactions, it is recommended that the following criteria for quality be reflected in carbon offset projects to ensure maximum climate benefits.

This summary came from interviews that were conducted, evaluation of published methodologies, criteria from companies, and the standards set by the largest carbon registries - Verra, Gold Standard, American Carbon Registry, and Climate Action Reserve.

1. **Projects should be centered around carbon removal** as much as possible with a goal of being carbon negative through a life cycle assessment.
2. **Additionality - the project should be additive and incremental**, and should not have occurred otherwise. Carbon offset projects should cause a climate benefit by reducing atmospheric CO_2 concentrations and exceed what otherwise would have happened in a no-intervention scenario (CDR Primer)[63].
3. No double counting - a singular carbon credit should not be claimed and reused for multiple emissions. Credit issuances and retirements should be accounted for in a registry or database to prevent double counting and reuse of credits.
4. Carbon offset projects should go through **monitoring, reporting and verification processes from independent, third-party audits** and demonstrate the long-term carbon removal potential of the project over the specified timeframe.
5. **The project should prioritize high durability**, meaning that it prioritizes long-term carbon storage with a low risk of reversibility and re-emission of carbon back into the atmosphere. Low, medium, and high durability solutions can be categorized as follows (Microsoft):
    - **Low-durability solutions** sequester and store carbon for 100 years or less. Low-durability solutions explored in this report include forestry and soil-based projects.
    - **Medium-durability solutions** sequester and store carbon between 100 - 1,000 years. Medium-durability solutions explored in this report include biochar.
    - **High-durability solutions** sequester and store carbon for over 1,000 years. High-durability solutions explored in this report include BECCS, geologic storage, and mineralization in aggregates ad concrete.
6. The project should ensure environmental justice by involving community input and transparency in all stages of the decision making process. Stakeholders and communities should consider potential harms and discuss equitable distribution of project costs and resulting benefits to ensure that the project not only prevents environmental injustice, but also has a positive impact on surrounding communities such as improved air quality and economic dividends from project lands (from Carbon180)[64].

2 - Overview of Current Market Demand Drivers

Through the IPCC and other climate accords, global action is being taken to protect the environment and mitigate climate change. Internationally, both governments and corporations have pledged net-zero and emission reductions commitments. Carbon offsets can serve as a temporary solution for hard-to-avoid emissions, such as aviation fuels and industrial transportation, and long-term balance hard-to-abate sectors such as concrete and steel. This is why it is imperative that carbon offset actions be paired with carbon removal and sequestration actions to achieve the climate commitments and goals that have been outlined for local, national, and global communities.

As mentioned in Section 1.1, the IPCC has set a global target of warming less than 1.5 degrees Celsius by 2050. Nationally, both the United States and Canada have an economy-wide goal of net-zero by 2050.

2.1 - Corporate Carbon Neutrality Commitments

Many companies worldwide have pledged net-zero commitments. **By the conclusion of the COP26 Summit in November 2021, over 5,200 businesses globally pledged to meet net-zero carbon targets by 2050**[65]. Most companies begin net zero implementation by procuring renewable energy and reducing value chain emissions. Along with these efforts, some purchase carbon credits to offset the further residual emissions. For example, Steelcase[66], a furniture company primarily based in Grand Rapids, MI, has reduced greenhouse gas emissions from their operations, invested in carbon offset projects, achieved carbon neutrality in 2020 for purchased electricity, and is now focusing on further reducing their emissions, improving energy efficiency, and working with their suppliers.

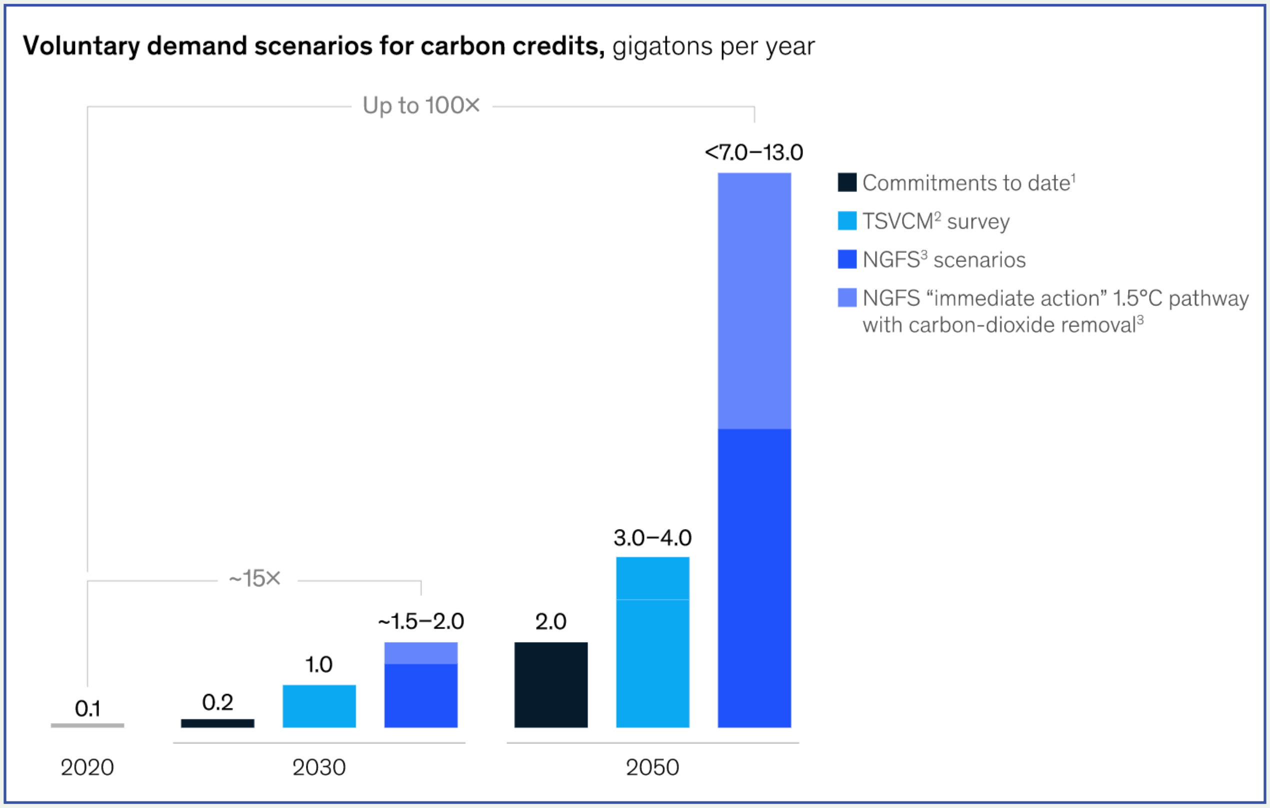

Figure 10 Anticipated demand for voluntary carbon credits based upon commitments from 700 large companies. Source: Task Force on Scaling Voluntary Carbon Markets, Network for Greening the Financial System, McKinsey.

As more and more companies transition from visionary carbon neutrality goals to concrete plans to decarbonize, demand for carbon offsets is expected to increase.

Based on carbon credit demand statements, the Task Force on Scaling Voluntary Carbon Markets (TSVCM), and the emissions reductions required to meet the 1.5 degree Celsius global warming target, in Figure 10 McKinsey[67] estimates that annual global demand for carbon credits could reach up to 1.5 to 2.0 gtons of carbon dioxide ($GtCO_2$) and up to 7-13 $GtCO_2$ by 2050 (Figure 8). This is a 15x increase by 2030 and 100x increase by 2050. Depending on various price scenarios and underlying factors, the market size in 2030 could range from a low of $5 billion to $30 billion to a high of $50 billion or more. Note that these figures fall far short of what is predicted to be needed to keep global warming under the 1.5 degree 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. A number of people interviewed for this report felt that demand for high-quality carbon credits will always exceed supply.

In mid-August of 2022, Europe's carbon price hit an all-time high[68] of just over €99 for a ton of carbon dioxide emissions since the EU's cap-and-trade market was launched in 2005. The Asia Pacific carbon markets have relatively low trading activity, and prices are too low[69] to force big emitters to change their behavior. China's carbon market trades at less than $10 per ton, and also has very little trading volume. India, the third-highest-emitting country after China and the U.S., has only a voluntary market.

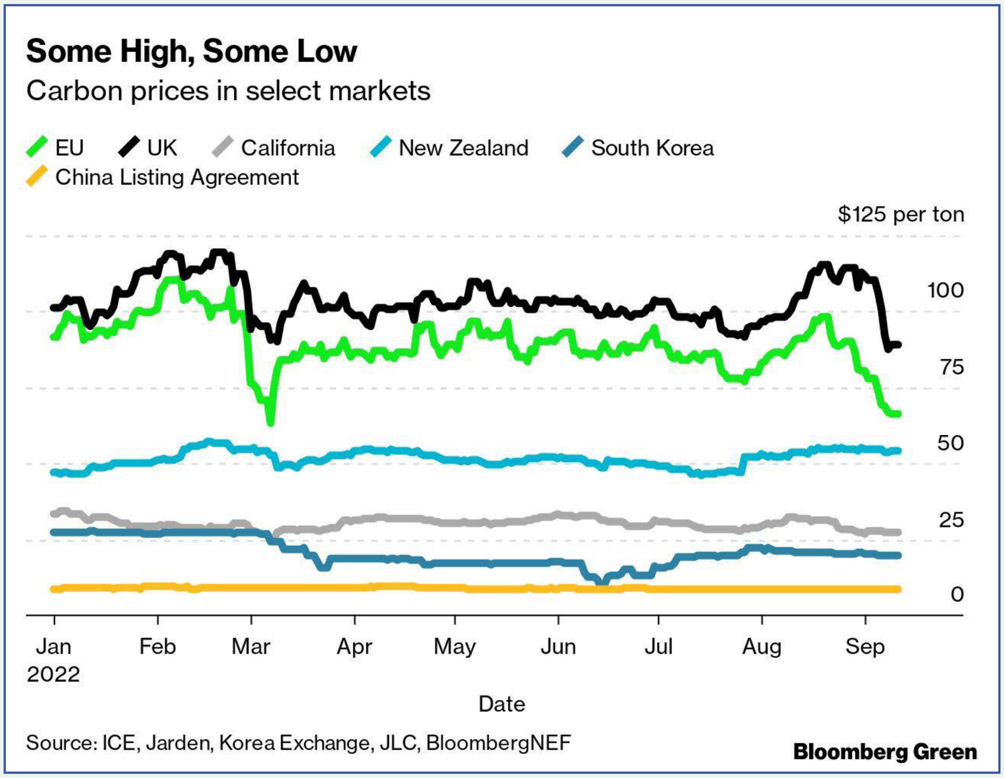

Figure 11 Carbon offset price trends globally for 2022. Source: Bloomberg Green newsletter 9/15/22.

“Our order of importance in picking an offset:

1. Quality and standard
2. Carbon removal project if we can afford it, an avoidance project if not
3. Offset represents the region where we manufacture
4. Sustainable development goals are represented
5. The offset provides a good story that we can share with our customers”

Director of Sustainability for Fortune 500 Household Goods Manufacturer

Corporate stakeholders that were interviewed for this report who are actively purchasing offsets or planning on purchasing offsets as a part of their decarbonization plan indicated price to be a major deciding factor, followed by location, certification, and social and environmental co-benefits. Due to a lower price and higher availability of projects, many offset projects purchased by corporate stakeholders are located in countries or areas where the company does not possess many assets. **Stakeholders expressed interest in purchasing offsets locally, but cited lack of projects and lack of co-benefits as barriers to purchasing locally.** Additionally, some corporate stakeholders were unaware of the potential for engineered based carbon offset solutions and expressed interest in purchasing these offsets if they use approved methodologies and independent MRV processes.

Stakeholders in interviews frequently expressed concern over the controversial nature of carbon offsets. In response to forest-based credits being touted as a tool to achieve net zero, they expressed concern[70] (echoed in the media) that carbon offsets are not a solution and that CO_2 sequestered by forests is not permanently fixed. Many companies are also cautious about using carbon offsets and wisely use them as the last resort for emissions they cannot otherwise balance. For instance, Ben and Jerry's,[71] a Unilever group company, focuses on directly reducing carbon emissions from farms by feeding their livestock with innovative feed additives that reduce the generation of methane as cows digest their food, and mentioned that they won't buy carbon offsets until they reduce as much of their baseline emissions as they can. Some of the companies interviewed for this report are still considering carbon offset purchasing strategies. **Given that offsets are a relatively new strategy for decarbonization and the lack of regulations in the voluntary carbon market, many companies are hesitant to purchase offsets without vigorous certification and proof of additive carbon storage in fear of experiencing similar reputational risks and backlash incurred by other companies investing in low-quality forest offsets.** Currently, there are guidelines for corporate credit purchasing, such as the *Tropical Forest Credit Integrity Guide* by the eight authoring organizations, VCMI's *Provisional Claims Code of Practice*, and the University of Oxford's *The Oxford Principles for Net Zero Aligned Carbon Offsetting*. Some companies, such as Microsoft,[72] have also published their criteria to invest in carbon projects. The first step for companies is to determine their own stance, and establish criteria that will achieve their emissions goals and prevent unintentional greenwashing. Additionally, companies interviewed said that they would be inclined to purchase local offsets if they could guarantee high quality and similar social and/or environmental co-benefits as non-local offsets.

2.2 - Regional Voluntary Carbon Offset Market Transaction Summary:

The Berkeley Carbon Trading Project's Voluntary Registry Offset Database[31] includes registered projects from the four largest registries (Verra[13] the American Carbon Registry,[14] Climate Action Reserve[15] , Gold Standard[16]). These projects can also be used in regulated carbon markets. The database shows carbon offset issuances and retirements increasing over time, meaning that more projects are being supplied by developers, verified and brought into the market.

By using the Berkeley Carbon Trading Project's Voluntary Registry Offset Database, we determined **the current size of the Voluntary Carbon Market in the 8 states and 2 provinces. There are 393 projects in the Great Lakes region out of 6081 in total. 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 in 2019, which is 7.6% of global issuances, and retirements reached a maximum of 12,959,262 tons in 2020.** Chemical Processes are the most common type of carbon credit, followed by Agriculture and Forestry.

> "The sustainability officer needs to justify why more expensive and less tons are better than cheap tons of lower quality"
>
> Program Manager, Carbon Consulting Firm

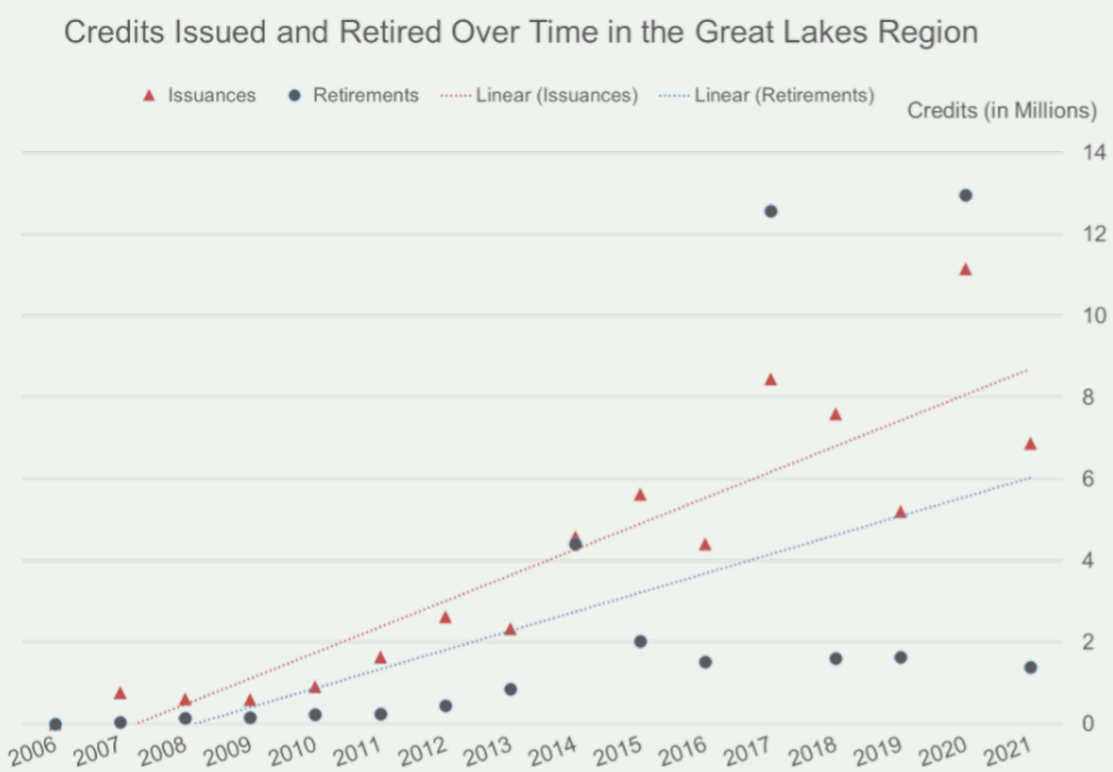

Figure 12 Carbon offset issuances and retirements over time in the Great Lakes region from 2006 to 2021. Data source: Berkeley Carbon Trading Project Voluntary Registry Database.

Below is a breakdown of the types of existing projects under each category registered in the database. It is important to note that many of these projects involve emissions reductions, which do not meet criteria for high-quality offsets.

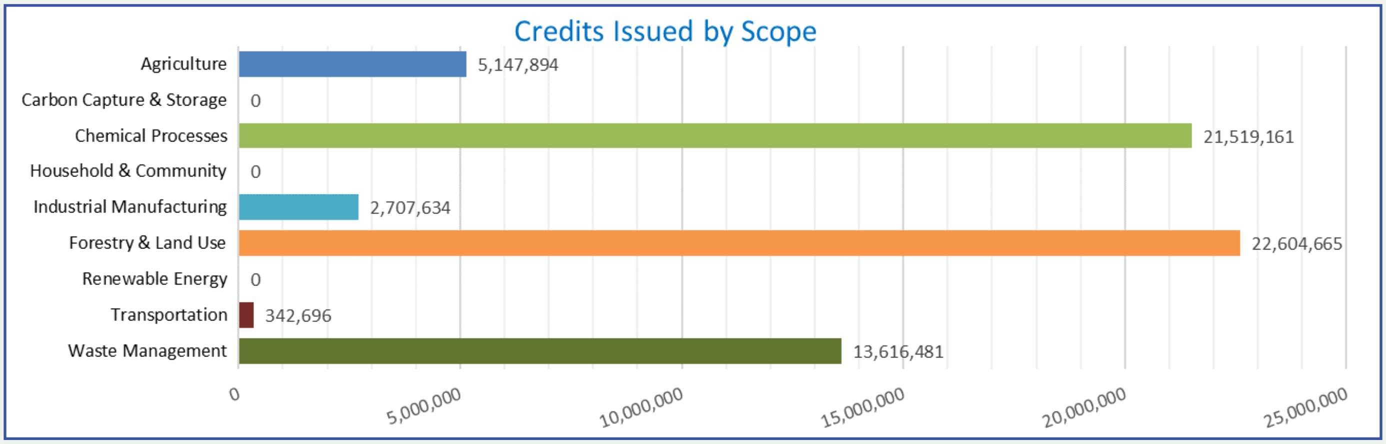

Figure 13 Existing carbon offset categories used in the Berkeley Carbon Direct database.

Below in Figure 14 the types of credits are further broken down into project types.

Category	Existing Projects
Agriculture	- Nitrogen Management - Manure Methane Digester - Mine Methane Capture
Chemical Processes	- HFC Refrigerant Reclamation - HFC Replacement in Foam Production - Ozone Depleting Substances Recovery and Destruction - N2O Destruction in Nitric Acid Production
Transportation	- Truck Stop Electrification - Fleet Efficiency
Waste Management	- Landfill Methane
Forestry and Land Use	- Improved Forest Management
Renewable Energy	- Biomass

Figure 14 Berkeley Carbon Direct database examples of existing projects.

On a state and province level, as Figure 15 shows, Ohio has the most issuances and retirements, followed by New York and Michigan. There was no available data for Québec in the database.

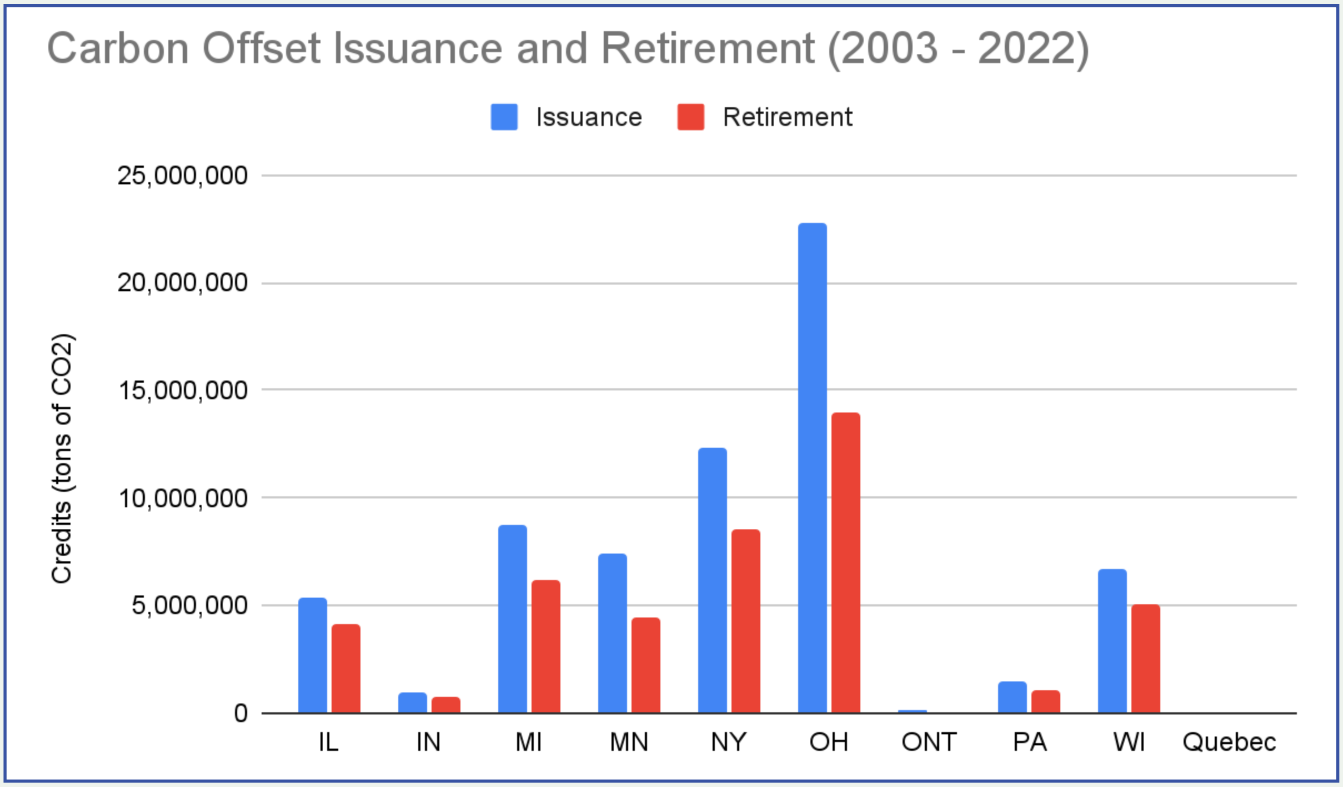

Figure 15 Berkeley Carbon Direct database tracking for carbon offset issuances and retirements.

Taking a closer look at these three states, chemical processes is the most common category of project in Ohio, Waste Management in New York, and Forestry & Land Use in Michigan. A detailed breakdown of types of credits issued per state and province is given in Appendix 2. The EPA has[73] an excellent breakdown of carbon projects nationally as well. In 2020, they note that most of the CO_2 captured from industrial processes (57 percent) and nearly all of the CO_2 produced from natural sources (93 percent) was used for enhanced oil and gas recovery. Food and beverage manufacturing is the second most common end use, followed by other end uses such as pulp and paper manufacturing, fire-fighting equipment, and metal fabrication.

3 - Carbon Sources and Sinks in the Great Lakes Region

The Great Lakes region is home to plentiful natural resources and opportunity for nature-based, engineered, and hybrid carbon removal. Each element touched upon in this section can also be found in interactive map format linked here.[45]

3.1 - Carbon Sources, Transportation Infrastructure, and Current CCUS Activity

The Great Lakes Region is home to 1771 stationary CO_2 emission sites, according to 2013 U.S. data from the NETL and DOE's NATCARB Viewer. Collectively, these sources are responsible for over 750 million metric tons of CO_2 emissions annually. Québec and Ontario emitted 226 million metric tons of CO_2 equivalent in 2020[74], which puts the region at just under a billion metric tons of CO_2 stationary emissions annually. If transportation emissions[75] are included, the total is approximately 1.5 gtons (see Appendix 4). **The region also has extensive pipeline infrastructure for crude oil, petroleum products, hydrocarbon gas liquids, and natural gas. CO_2 pipeline infrastructure needs to be scaled, but the current infrastructure is relevant because the same easements can be used for the construction of CO_2 pipelines.** Research is currently being done to convert existing pipelines into CO_2 pipelines via corrosion resistant coatings. Because of this, CO_2 transportation infrastructure could be more easily integrated into current infrastructure.

There are also some examples of point source carbon capture, DAC, and site characterization for geologic storage occurring in the region. To date, there are 4 research organizations in the region working on various

DAC projects and 46 carbon capture and geologic storage projects in the region, including small scale projects to validate injection feasibility, small scale capture projects, and large scale capture projects of over a million metric tons of CO_2. One post-combustion capture demonstration project[76] has been completed in the region in Wisconsin, which removed 40 tons of carbon per day from early 2008 - October 2009. There are 4 other combustion capture demonstration projects currently active or in the planning process (WCCUS - NATCARB Viewer). Further details of each project can be found on the interactive map dashboard[44]. There is already some work being done in this region, but these projects could be accelerated and scaled with the assistance of further government incentives and support.

3.2 - Available Solutions in the Great Lakes Region

Carbon removal projects that can be sold into the carbon offset markets can be nature-based, engineered, or a hybrid of both methods. Nature-based removal solutions discussed in this report include forestry and soil sequestration. Engineered carbon removal solutions include direct air capture to geologic storage or carbon utilization, and mineralization. Hybrid removal solutions include turning waste biomass into electricity, heat, biochar and/or sustainable liquid fuels. Figure 16 is an overview of the nature-based, engineered, and hybrid solutions available in the Great Lakes region.

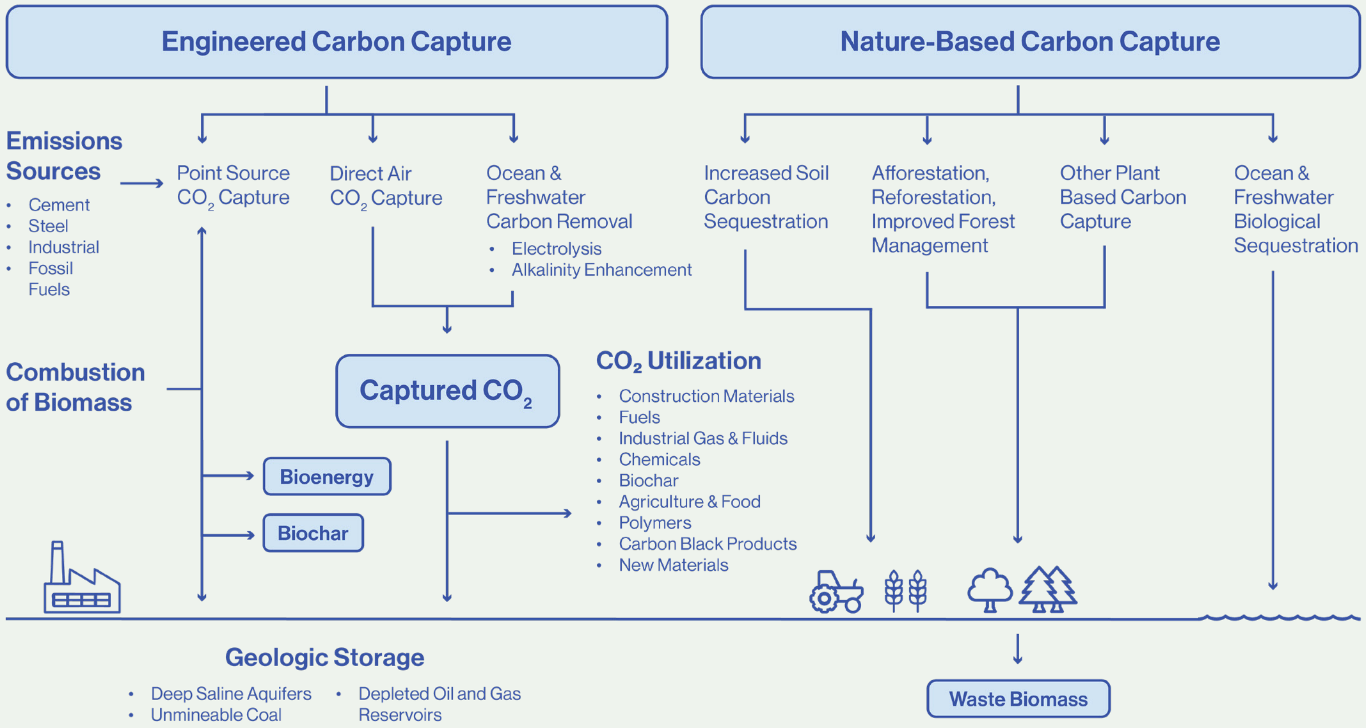

Figure 16 Recommended prime solutions for carbon offset projects in the Great Lakes region. Each type of solution shown above was evaluated based upon different metrics listed below such as cost, land use, water consumption, risk of reversal, and implement readiness. Source: Adapted by authors from the CDR Primer.

Below is a table that characterizes the carbon removal pathways in the region for key characteristics

including cost, energy requirement, land use, water use, risk of the carbon not being stored for the promised timeframe or carbon reversal, verifiability or how easy it is to quantify how much carbon was stored initially and over the timeframe of the carbon credit, and how ready the solution is for implementation.

Great Lakes Region CO_2 Capture Utilization and Storage Methods

		Cost	Energy Use	Land Use	Water Use	Durability & Risk of Reversal	Verifiability	Implement Readiness
Nature Based Solutions	Reforestation & IFM	Generally Acceptable / Available	Generally Acceptable / Available	Potentially Unacceptable/Unavailable	Exercise Caution	Exercise Caution	Generally Acceptable / Available	Generally Acceptable / Available
	Wetland Restoration	Generally Acceptable / Available	Generally Acceptable / Available	Generally Acceptable / Available	Generally Acceptable / Available	Exercise Caution	Exercise Caution	Generally Acceptable / Available
	Soil Carbon Restoration	Generally Acceptable / Available	Generally Acceptable / Available	Generally Acceptable / Available	Generally Acceptable / Available	Exercise Caution	Potentially Unacceptable/Unavailable	Exercise Caution
Engineered Solutions	Geologic Storage	Potentially Unacceptable/Unavailable	Exercise Caution	Generally Acceptable / Available	Generally Acceptable / Available	Generally Acceptable / Available	Generally Acceptable / Available	Exercise Caution
	Aggregates	Exercise Caution	Exercise Caution	Generally Acceptable / Available	Potentially Unacceptable/Unavailable	Generally Acceptable / Available	Exercise Caution	Exercise Caution
	Terrestrial Enhanced Weathering	Exercise Caution	Exercise Caution	Generally Acceptable / Available	Exercise Caution	Generally Acceptable / Available	Generally Acceptable / Available	Exercise Caution
	Lake Alkalinity Modification	Exercise Caution	Exercise Caution	Generally Acceptable / Available	Generally Acceptable / Available	Generally Acceptable / Available	Exercise Caution	Potentially Unacceptable/Unavailable
Hybrid solutions	BECCS	Exercise Caution	Generally Acceptable / Available	Potentially Unacceptable/Unavailable	Exercise Caution	Generally Acceptable / Available	Exercise Caution	Generally Acceptable / Available
	Biochar	Exercise Caution	Generally Acceptable / Available	Potentially Unacceptable/Unavailable	Exercise Caution	Exercise Caution	Potentially Unacceptable/Unavailable	Generally Acceptable / Available

Legend	**Generally Acceptable / Available**	**Exercise Caution**	**Potentially Unacceptable/Unavailable**

Figure 17 Summary table of Great Lakes Region carbon removal pathways, highlighting strengths, weaknesses, and technical potential.

A chart summarizing strengths and weaknesses of nature-based solutions and engineered solutions is below.

<table>
<tr><th>Strengths</th><th>Weaknesses</th></tr>
<tr><th colspan="2">Nature Based Solutions</th></tr>
<tr><td>Relatively easy to implement

Inexpensive

Widely adapted geographically, there are nature-based solutions available in many areas

Usually multiple, highly valuable co-benefits are associated with nature-based solutions including preservation of biodiversity, water filtration, recreation or hunting, wood and wood products production, and enhanced soil quality

Easy to market and sell when projects are high quality and additional. Companies buying carbon offsets are looking for stories they can feel good about sharing with customers</td><td>Difficult to measure amount of CO_2 actually stored

Difficult to guarantee storage permanency in forests which are subject to pests, diseases, and wildfires

Lack of ongoing monitoring, verification, and reporting

Decadal scale carbon storage, eventually trees die or are cut down, risking CO_2 releasing back into the atmosphere

Time needed to accrue carbon storage in one tree is measured in decades. Some carbon registries are moving towards “ton year” accounting, instead of 1 tree storing carbon for 40 years, an offset contract could be for 40 trees storing carbon for one year. This addresses the risk of land ownership changing hands over the carbon accrual timeframe. However, ton year accounting brings new risks for forest offsets to be non-additional, non- permanent, or both and has the potential to weaken the quality and credibility of forest offsets

Not storing “additional” carbon - as one example, selling offsets for forests that were not going to be cut down anyway. The carbon registries are working to strengthen guidelines in some cases

Land use for carbon storage is potentially substantial, and can compete with other land uses

Landowners tend to be in their 60’s and a major transfer of land is expected in the next 15-20 years; 40 year+ contracts for forest carbon sequestration may not be welcomed in plans to transfer family assets to heirs

Incremental carbon storage potential, nature-based nature - based solutions don’t have enough capacity by themselves to store CO_2 relative to societal need</td></tr>
<tr><th colspan="2">Engineered Solutions</th></tr>
<tr><td>Tens of gigatons of CO_2 storage is available in underground regions

Permanent, geologic storage of carbon possible

Enables the possibility of manufacturer being able to switch out fossil-based carbon feedstocks for captured feedstocks, enabling a circular carbon economy

When a product is sold using captured CO_2, there is earned revenue and job creation

Usually easy to measure, and verify, it is known exactly how much carbon was removed and the durability of tat storage</td><td>Cost - to retrofit one natural gas plant with carbon capture is hundreds of millions of dollars, and one DAC Plant at scale is similarly capital intensive. It’s not that society cannot afford it (CA spends 3% of GDP on their trash), it is that we are accustomed to fossil fuel usage and not having to pay for downstream externalities. “Green” products usually need to account for those up front, in contrast

Creates additional demand for low-carbon energy in the form of renewables, biomass, nuclear, or hydro such that offsets can be low carbon, carbon neutral, or carbon negative. This land use is potentially substantial, and can competes with other land uses

Story may be less appealing to companies who are potentially buying these offsets- especially if the solution is CCS. At least in today’s market, they prefer offsets with geographically related or core-business related components. (what happens in 2030-2050 is anyone’s guess)

In some cases, solutions need green hydrogen which is not yet readily available</td></tr>
</table>

Figure 18 Strengths and weaknesses of nature-based and engineered solutions.

3.2.1 - Nature-Based Solutions

Nature-based solutions available in the Great Lakes region include wetland restoration, improved soil sequestration, reforestation, afforestation, and Improved Forest Management (IFM). Due to the scope of this report, we were not able to investigate the potential for coastal blue carbon and wetland restoration or improved soil sequestration in the region.

Forest carbon storage has temporal variability. A newly planted tree will store a small amount of carbon dioxide at the beginning, then it starts to substantively accumulate carbon at 20-30 years. Eventually forest ecosystem respiration and decomposition will come into balance with photosynthesis and forests become carbon neutral, but this is likely 100-300 years from starting depending upon the forest. The timing of this process is highly variable with species, climate and other factors. Most forests in the Great Lakes and U.S. are not at this point. The biggest challenges with forests are determining additionality and not taking credit for natural regrowth as well as hazards such as invasive species and wildfires. Over the very long term, scientific work suggests that land-based solutions could reach a state of carbon release rather than carbon storage.

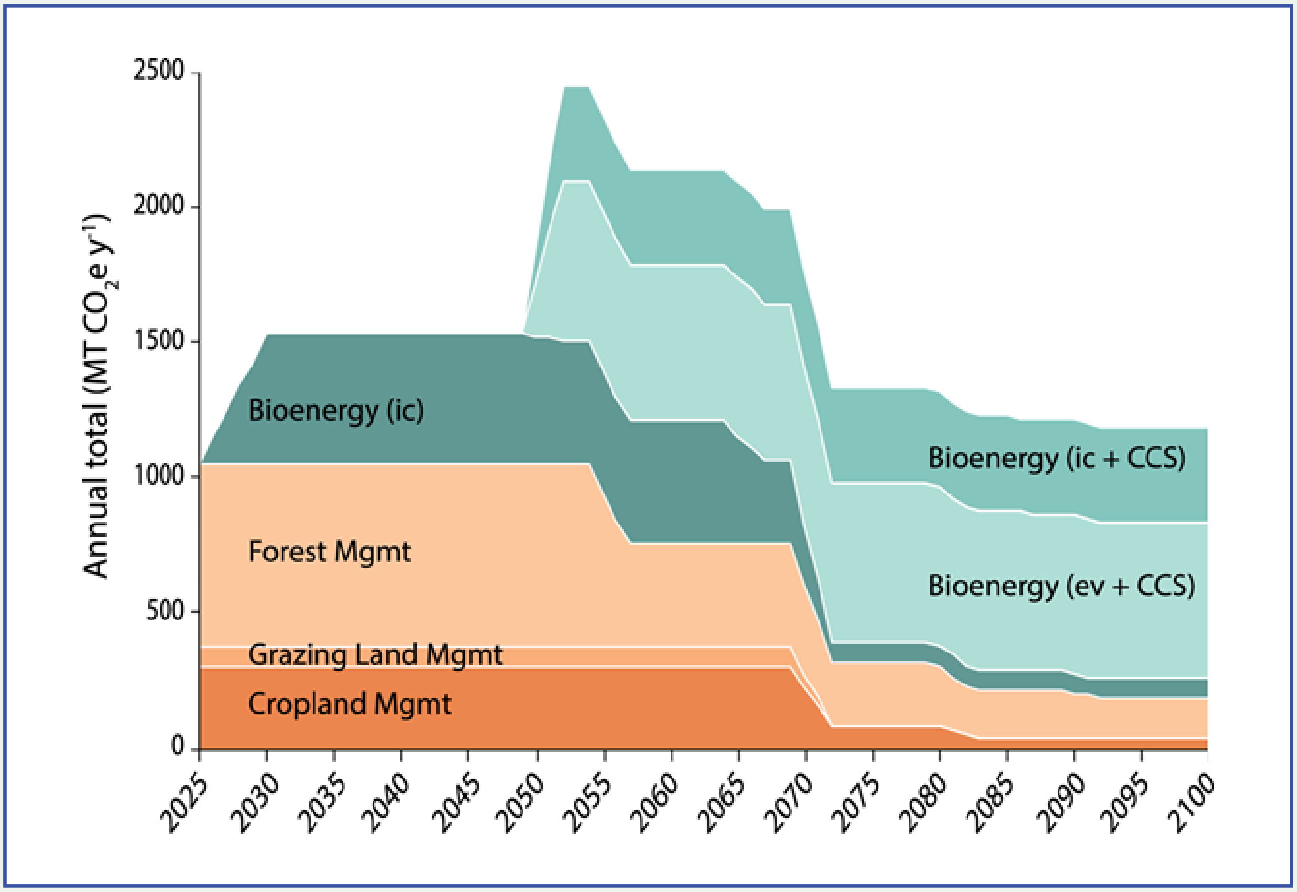

Figure 19 Annual United States mitigation potentials through 2100 for different emissions categories considering the strengths and durations of various sinks and the presumed availability of geologic carbon capture and storage beginning ca. 2050. The "ic" represents a scenario where bioenergy makes liquid fuels for vehicles that are internal combustion engine, and "ev" is a scenario where electric vehicles are powered with bioenergy electricity. The steep declines in nature-based sinks (soil organic carbon and tree biomass) reflect the assumption in the calculations of an abrupt termination of their effectiveness, when in reality they would approach carbon saturation in a more gradual and asymptotic manner. Source: G Philip Richardson, "Land-Based Climate Solutions for the United States", Global Change Biology, May 2022

Despite these limitations, planting forests is something that can and should be done now to help with climate impact as long-term sustainability models for emissions are understood.

According to data from The Nature Conservancy's Reforestation Hub, the total sequestration potential through reforestation and afforestation in the Great Lakes region is approximately 78 million metric tons of CO_2 per year, with roughly 77 million metric tons per year occurring on privately owned land, and one million per year occurring on state owned lands.

A further breakdown of sequestration potential is available in Appendix 1. The stark contrast of carbon storage availability between private and state-owned land was also highlighted in our stakeholder interviews. Many interviewees said that a challenge of scaling forestry-based solutions is the fact that most public forestland is already well managed with an opportunity for incremental carbon storage at best. The best opportunity is on lands that are privately owned and managed, but getting these lands into durable carbon storage and the carbon offset markets is full of challenges. Parcels are often small, and aggregation of multiple landowners is needed to create saleable offsets of meaningful transaction size. There are programs such as the Family Forest Carbon Program[77] (30 acres or larger in specific counties of PA, WI, MN, and NY) that are performing this function now and others starting up. A staff member in the Ministry of Québec said the INRS University is currently drafting a draft protocol for afforestation or reforestation on private lands in Quebec. **Interviewees also cited increased education and outreach as an effective strategy to incentivize better land management practices - many private landowners are not managing their forests for things they can see, such as invasive species, much less for carbon dioxide removal.** Timber Investment Management Organizations (TIMOS) include larger landowners and there is awareness of carbon market opportunities in those organizations. One large and well-respected global NGO that we interviewed recommended that nature-based carbon credits be retired when they are sold to avoid double counting of credits and bad actors.

Revenue from delayed harvest, reforestation, and IFM needs to be competitive with revenue from alternative land usage, such as timber harvests or agriculture. Interviewees also stated additionality being a concern on state-owned lands, since many states already have robust reforestation plans and excellent management practices on their lands. Some other challenges faced with nature-based solutions, specifically forests, include lack of durability and high risk of reversal of carbon back into the atmosphere and high land use. **Many nature-based solutions only store carbon for 100 years or less. In the case of forests, this can be drastically reduced by the increasing threat of wildfires and invasive species with global warming.** Some invasive species in this region are capable of destroying an entire forest within a few years, while others drastically sicken trees and reduce their ability to sequester carbon. When issuing nature-based offsets, stringent accounting of baseline and additional carbon storage is critical, as well as periodic verification over the project timeline to validate sequestration.

Interviews with the heads of forestry in multiple states and senior personnel in land conservation organizations all described **public forestlands as being well managed with only incremental opportunity for carbon storage** and related carbon offset sales Foresters said that getting paid with voluntary carbon credits for something they were going to do anyway is not truly additional carbon storage, which should be the focus. Others we spoke to also reported wariness from bad experiences with earlier sales of carbon credits - for often unwittingly offering or buying low quality carbon offset projects that they were later criticized for. No one wants to be caught in negative press about their participation in a carbon offset project. As a result, **the ability to move the needle with carbon storage by changing management practices lies primarily on privately held lands, but in order to make this happen a lot of education and aggregation of private landowners is needed.** In the United States, Michigan, Minnesota and Pennsylvania have the greatest opportunity for "pay for practice" programs of this nature, where landowners are paid to delay lumber harvesting or other management practices. Details about the types of forests where this makes the most sense and the terms for landowners are still under development. **Our interviewees also described the upper Great Lakes as a potential hotspot for a long-term resilient and connected landscape.** Resilience for biodiversity, wetlands, wildlife, human recreation, water

quality and other nature-based solutions co-benefits is maximized when there are large, connected tracts of land at scale. Societal benefits overall will be maximized if private landowners can be incentivized to plant and protect forests.
Older forests store more carbon, and it is helpful to be thoughtful about harvesting them. For state-owned lands, foresters do not have control over what happens to the lumber - it is purchased by a company who harvests and sells the timber to wood pallets, paper, and lumber for products.

Other concerns heard from interviewees for this report were that some states have forest management plans that are renewed with the public every 5-10 years, and one forestry staff member wondered about the potential gap if they sign a 40-year carbon offset contract and the public changes their minds in 20 years on how they want to use their forests.

DNR managers are juggling many priorities with forests - recreation, economics from forest products, hunting, fishing, water quality, air quality, and now, carbon. How to balance all of these priorities from the perspective of carbon credits is tricky. For private landowners, it's a lot simpler in most cases - you are cutting your forest down, or you are getting paid not to cut your forest down. In the case of reforestation, private landowners at least in one state only get 50% cost share on plantings. 100% cost share plus the ability for the landowner to make money would be more effective at driving results. 40-year carbon offset commitments can be problematic for private landowners, and one agency suggested that shifting to ton years (instead of 1 tree for 40 years, purchase 40 trees for one year) might be a better way to sell credits. However, there is concern that the ton year accounting approach will not lead to truly additional carbon offsets and instead could result in non-additional, short-term storage. A related issue with private landowners is their age, they are often in their 60's or older. As a result, significant tracts of land are expected to be transferred or sold into smaller parcels en masse in the next 15-20 years, and smaller landowners especially do not want to lock their grandchildren into a 40-year contract. If a 6" high tree seedling is planted and it takes 20-30 years for the tree to start accumulating carbon, the first thinning happens at that time and is the first opportunity for revenue. But to support biodiversity, both young forests and old forests are needed - some wildlife need young forests. Overall forest resilience and ecosystem health mandates trees of a variety of ages.

> "It is hard to know if forests will be around 500 years from now.... but the Great Lakes states and the northeastern US are the best places in the US longer term for forests. Other areas of the country are at risk for losing forests from drought, wildfires and other issues"
>
> University Forestry Faculty Member

Lastly, some forestry managers noted concerns with aging state-owned seedling facilities that cannot support a high reforestation goal - there is awareness of this issue and some work is being done.

Some scientists interviewed were concerned about the albedo effect of planting trees. The albedo effect is the way of measuring the proportion of sunlight and energy that is reflected back into the atmosphere by the Earth. How much is reflected back changes depending on what's on the ground. Snow has high albedo, meaning it reflects back a lot of sunlight, and tree cover has lower albedo, and that can vary depending on the kinds of trees and leaf color. If many darker trees are planted, they will absorb more energy, cutting into the cooling benefit the trees are intended to have. There has been concern in some areas that new forests created local warming. Natural Resources Canada focuses on replanting harvested trees to minimize this impact.

Québec has implemented ton-year accounting.[78] A central idea in ton-year accounting is that the climate impacts of CO_2 can be characterized by the quantity of CO_2 involved and the time it resides in the atmosphere. Within this framework, a larger quantity of CO_2 stored for a shorter period of time and a smaller quantity of CO_2 stored for a longer period of time can claim equivalent climate outcomes. There are issues with this framework, as CO_2 persists in the atmosphere for a long time, and this method omits how much warming happens at what point in time as well as other issues. However as noted above, decadal scale forestry contracts can be problematic for both public and private landowners. It is unclear how to resolve these issues.

It is essential that carbon credits are not double counted - the best way to ensure this is to retire credits once they are sold. On publicly owned lands, who gets to claim the carbon credits, the harvesting company or the state? How does the jurisdiction want to ensure that they are not double counted, and are high-quality credits in this regard?

Even though there are concerns and issues with nature-based solutions, they are urgently needed. Engineered solutions also have issues. There is no perfect solution, to succeed we need to employ every decrbonization and carbon storage tool available.

3.2.2 - Engineered Solutions and Carbon Utilization

Engineered solutions offer the benefits of measurement precision and verification of how much carbon was removed, and what happened to it. There isn't yet community agreement in the CCU world on how long removed carbon should stay sequestered to be considered durable storage -100 years or 1,000 years? The Global CO_2 Initiative in their latest market study suggests at least 100 years for the carbon to be considered durably stored. And multiple people interviewed for this report affirmed the need for carbon storage on a geologically relevant timescale of at least 100 years. Then there are related questions about pricing. Should there be price differences for a credit that stores for 50 years or 500 years? Market forces are already starting to recognize the differences in carbon offset quality and high-quality projects are commanding higher prices.

Annual potential in 2050		Utilization of 2 to 27 gigatonnes of CO_2 Market opportunity of $1,100 to $4,400 billions		
		Annual market opportunity ($ 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 20 Market study showing the annual dollar value and carbon sequestration potential for a variety of carbon utilization products. Source: Global CO_2 Initiative at the University of Michigan market studies, 2016 and 2022.

Engineered solutions include products made from captured carbon, or carbon utilization. These tend to be commodity products, such as fuel, concrete, aggregates, chemicals, or polymers. There are a few consumer products, including vodka, hand sanitizer and mattresses. One of the people interviewed for this report said that Canada is looking at fertilizers and perhaps methanol as possible carbon utilization products. In the case of fuels, chemicals and fertilizers made using captured CO_2 as a feedstock, these products reduce the usage of fossil resources and support a circular carbon economy. Green hydrogen, or hydrogen produced sustainably can also be needed to make these products. In the case of plastics, cements, or aggregates, the CO_2 is durably stored and can be considered a climate mitigation tool. High quality engineered solutions available in the Great Lakes region include durable CO_2 storage in aggregates and precast concrete, direct air capture to geologic storage, and these other forms of carbon dioxide utilization.

For storing CO_2 in above ground minerals in the Great Lakes region, extrapolating from annual crushed stone production data given from the National Stone and Gravel Association[80] and assuming a constant compound annual growth rate (CAGR) from 2022 - 2050, we produced a low annual estimate of 8 million metric tons of CO_2 sequestered each year in 2050, and a high estimate of 41 million metric tons of CO_2 sequestered each year. A similar process was used for projecting the annual sequestration potential for precast concrete in 2050. We extrapolated data from 2015 production amounts from the National Ready Mix Association and used a constant CAGR from 2015 to 2050 to achieve a low estimate of 7 thousand metric tons of CO_2 sequestered in 2050, and a high estimate of 370 thousand metric tons of CO_2 sequestered in 2050. An important consideration of these estimates is that suitable raw materials for carbonation are required - not every mineral or waste material can be carbonated, thus it is important to assess that the feedstock for these processes consist of materials with potential for carbon sequestration. Surface based storage in natural minerals or industrial wastes such as mine tailings or steel slag is possible, but the supply chain needs coordination and investment leverage to make it happen. **Decentralized storage of CO_2 in minerals is a more flexible method for permanent, durable carbon storage but does not offer the same scale as underground geologic storage.** Surface storage with localized capture does not necessarily require CO_2 transport or storage, local capture using raw flue gas is possible and small modular capture systems with the footprint of two shipping containers are becoming available.

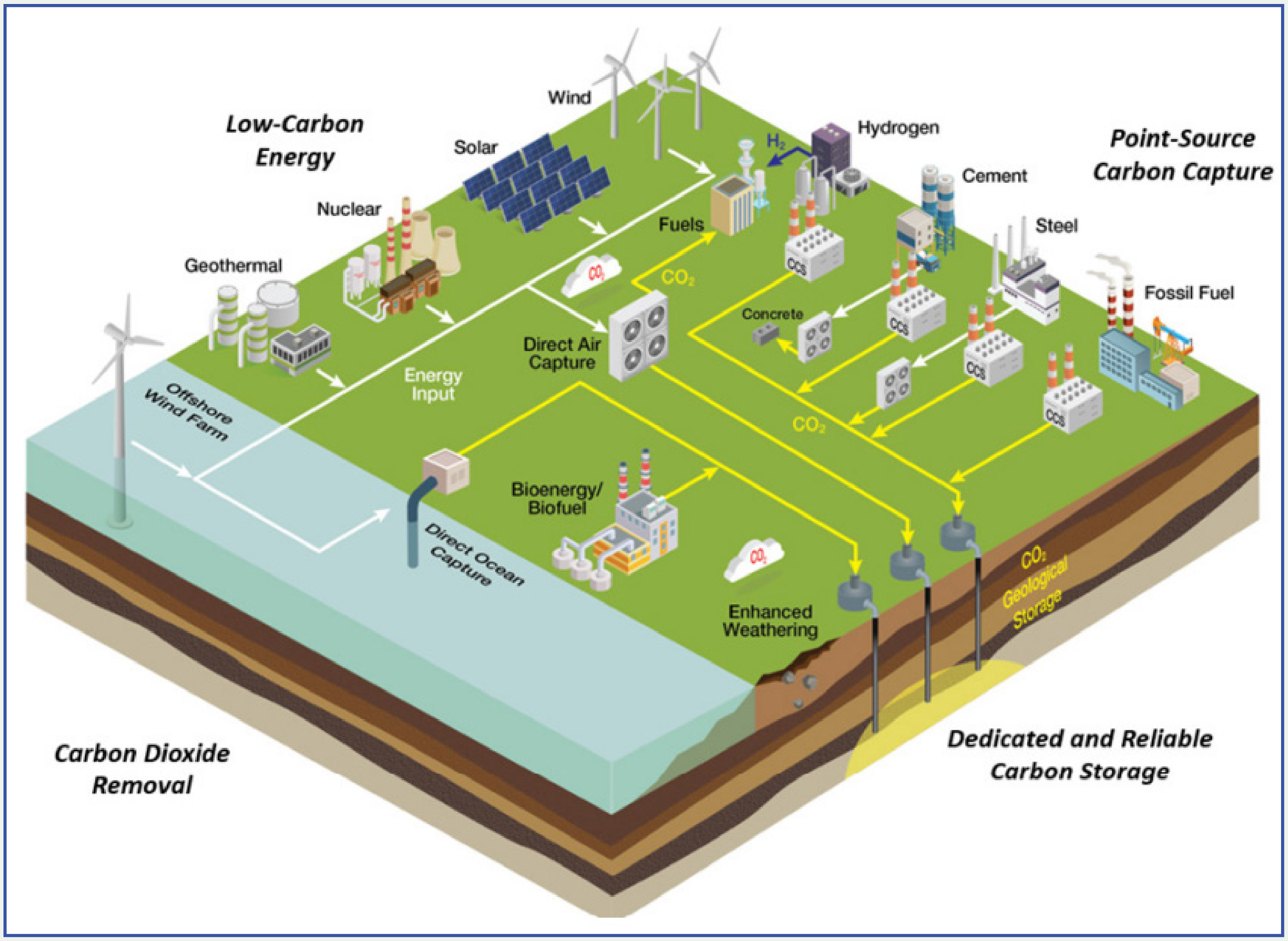

Figure 21 Overview of how engineered solutions for our region relate to the carbon removal ecosystem. Low carbon energy is essential to support emissions reductions for organizations as well as to power the creation of carbon offsets. Carbonated aggregates, biochar and other carbon utilization approaches described in this Great Lakes report are not shown on the diagram. Source: U.S. Department of Energy Strategic vision report.

In this report durable **geologic storage describes U.S. Class VI well storage and the equivalent type of storage in Canada's sedimentary rock** (not Class II enhanced oil recovery storage). A Class VI well is drilled into porous underground formations for injection and permanent storage of captured carbon dioxide. The term carbon capture and sequestration or CCS is often used to describe this process. The public can be skeptical of CCS, and some have found that introducing it into communities that are already familiar with oil and gas activity is helpful. Experts told the team that permanence and verification of geologic storage is the easier part to accomplish, and compressing the gaseous CO_2 into a liquid and transporting it to get it underground is the more challenging aspect. Not technically, but logistically, and from an investment perspective. The transport and storage infrastructure needs to be easily accessible for sources and for sinks - geologic storage, and/or companies who want to use the CO_2 for manufacturing. Terminology for storing in geologic formations can be thought of in terms of type of formation (sedimentary formations, volcanic rock formations, and ultramafic formations) or according to the resource/type of reservoir (deep saline aquifers, unmineable coal, depleted oil and gas reservoirs). Based upon data from the Department of Energy and National Energy Technology Laboratory, potential for underground geologic storage of CO_2 was given as a low and high estimate for saline basins and unmineable coal formations. The low estimate for total storage in the basins is approximately 144 gigatons of CO_2, with a high estimate of approximately 510 billion metric tons of CO_2. Data was only available in the 8 states, with no saline basin data for Wisconsin. Where storage is sought in rocks under the earth's surface, suitable rocks are permeable such as dolomite, limestones, and sandstone. CCS is not possible in Wisconsin, but Illinois and Indiana have feasible storage at a lower cost, Michigan and Ohio at a medium cost, and Pennsylvania at a higher cost. In Canada, Québec is all igneous rocks underground that cannot store CO_2, but Ontario is changing their current policy from not allowing underground storage

> "Geologic storage should be prioritized for really hard to abate (emissions) sectors like iron, steel, and cement; don't let oil and gas use all of the storage potential. In the long run we won't even have refineries so it doesn't make sense"
>
> Chief Scientist, National Laboratory Carbon Program

to allowing it. Storage potential in depleted oil and gas reservoirs estimated at 1.8-5.3 gigatons for the region is not included in report totals - the team was unable to get to the task of understanding the potential for this type of storage to be a high quality carbon offset.

Challenges to engineered solutions in this region are lack of implementation readiness, lack of infrastructure, and cost of technology. Technologies for capturing carbon oxides, both through point source and DAC, are relatively nascent and expensive. According to one of our stakeholder interviews, the cost of DAC to geologic storage is currently $450/ton, but can go up to $1100/ton depending upon technology and location. These costs can decrease through more research and development and scaling infrastructure and technology, similar to what happened for the solar industry over time. It is essential for point source capture and DAC to be powered by low carbon energy. Ideally, emissions sites and DAC plants would be located close to injection sites to minimize transportation of CO_2 and the necessity for additional infrastructure. At present, there are not many CO_2 pipelines, but there is currently research being done to convert existing pipelines into CO_2 pipelines by using corrosion resistant coatings. Additionally, new CO_2 pipelines can be built alongside existing pipeline infrastructure, preventing the need for new easements.

Implementing the infrastructure for DAC, point source capture, and/or geologic storage enables the utilization of CO_2 as a feedstock in manufactured goods such as concrete, aggregates, fuels, chemicals, fertilizers, plastics, and other products. If captured CO_2 is available, it is easier for organizations to tap into an existing supply rather than creating their own. Over time, carbon utilization has the potential to become a major carbon sink and source of revenue. Instead of storing carbon underground with CCS, captured CO_2 can be utilized as a new ingredient in different products and applications, including as a replacement in any process that currently uses CO_2 derived from the combustion of fossil fuels.

Long term, to ensure high quality of offsets, it is important for the source of carbon to be directly removed from the atmosphere via DAC, as opposed to avoided emissions through point source capture. While both are necessary to reach net-zero emissions, the highest quality offset credits come from DAC-based projects. At present DAC is more expensive than point source capture technology, due to the lower concentration of CO_2 in the atmosphere (0.04%) as opposed to the higher concentrations from an emissions source (10-20%) in a smokestack. Given that the cost of prematurely shutting down power generation plants - especially natural gas, which are much cleaner than coal - is not something society is likely to want to bear, point source capture to CCS and CCU as a bridging strategy to when power plants reach retirement age and can be replaced with sustainable sources is helpful.

Oxy has a 500,000 ton DAC to geologic storage facility planned[79] for Texas that will be completed in a few years. Today, DAC plants capture 4,000 tons per year - this does not justify drilling a class VI well. But there are billions of tons of geologic storage in the Illinois basin area. Archer Daniels Midland captures CO_2 from an ethanol plant at 99.9% purity at 1M tons per year, and most of it is sold into the food industry. Two Illinois test wells are demonstrating the viability of underground injection for the methanol industry - and 45Q (even before the recent Inflation Reduction Act increases) makes this economically viable for potential producers. Knowing that geologic storage is essential for meeting climate goals as highlighted by the IPCC and other reports, co-location of point sources with Class VI wells reduces the need for pipelines and transportation and should be encouraged as much as possible. Geologic storage needs less monitoring than nature-based solutions, and is usually much more permanent. However, it does not bring the significant co-benefits of nature-based solutions.

3.2.3 - Hybrid Solutions

Hybrid solutions available in the Great Lakes region include lake alkalinity modification, the utilization of waste biomass for BECCS and biochar.

Lake alkalinity modification involves removing CO_2 from water, causing atmospheric CO_2 to diffuse into the water, which in turn lowers the amount of CO_2 in the atmosphere. This can occur through a biological process involving aquatic plants, an electrocatalytic process, or a chemical process involving the temporary removal of water from a Great Lake. Due to the limited scope of this report, we recommend further research into the potential for ecologically-friendly carbon removal from freshwater. Because the concentration of CO_2 is higher in water than in the atmosphere, this method has the potential to be more cost effective than DAC.

Waste biomass can be converted into bioenergy which can then be captured and stored in a process known as BECCS. Bioenergy derived from the combustion of waste biomass is a renewable replacement for fossil fuel derived energy, and allows for many useful applications derived from the solid, liquid, and gaseous combustion byproducts. Gaseous emissions from the combustion process can be condensed into liquid fuels, industrial chemicals, or syngas. This also offers potential for a sustainable aviation fuel (SAF) to be created from the liquid combustion waste because of the solid byproduct biochar, a nutrient rich charcoal made from biomass, with the potential for carbon sequestration and soil enhancement for agricultural or forestry purposes. The durability of biochar varies from 100 to over 1,000 years, depending upon chemical composition and storage conditions. Poor soil management at the storage location can accelerate weathering and decrease the lifetime of biochar. According to data from the National Renewable Energy Laboratory[81], solid waste biomass available in the Great Lakes region is approximately 84 million metric tons annually in the 8 states. No data was found for Québec and Ontario. To implement and scale this technology as an option for carbon removal, it is necessary to locate biomass processing facilities as close as possible to waste biomass sources and end-use applications of bioenergy and biochar, to minimize emissions from transportation that could possibly make the process carbon positive. In our region, the forests and waste biomass are already present, as is the potential for geologic storage. What is needed are plans for implementation and investment.

Many of the offsets sold in today's markets are biochar. Biochar can also be used to replace coal, or used in agriculture as a soil enhancement. One researcher interviewed said that for land application, there is a pandora's box of questions about the durability of the carbon storage. Biochar has a labile fraction and a stable fraction of carbon that is stable for 100's of years, but there is a lot of noise in the data and results are inconclusive. One municipal manager interviewed in charge of making biochar noted that feedstock assessment is important as it is not practical to ship across large distances, and more feedstocks are needed for their operation. He also described differences between high temperature biochars and low temperature biochars, where low temp chars stimulate soil microbial activity and hold water and nutrients.

3.3 - Carbon Capture Utilization and Storage Potential in the Great Lakes Region

Using the assumptions described above for high-quality carbon offsets and suitable types of carbon offsets for the Great Lakes regions, Figures 22 and 23 represent the potential market value and storage potential for carbon offsets in the region. Further assumptions can be found in Appendix 1.

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 22 This table frames the carbon dioxide storage potential in tons and price per ton used to calculate market size in Figure 3. Note that 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 and there are 2.4 gigatons available in the U.S. Estimates for total geologic storage are based upon carbon storage potential estimates for unmineable coal and saline basins from the Department of Energy NATCARB database. Estimates for Canada's geologic storage (a range of 0.70-8.58 gtons for Quebec) are not included as the information found seemed 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 not included, which the Department of Energy Carbon Storage Atlas estimates as 1.8-5.3 gtons for the region.

As shown above, the greatest potential for carbon storage in the Great Lakes region is geologic storage. While further work needs to be done estimating the potential for storage in sedimentary basins, the total storage capacity estimated in saline basins and unmineable coal formations far exceeds maximum storage potential in nature-based and hybrid solutions from 2022-2050. Additionally, if the infrastructure for geologic storage is scaled, i.e. CO_2 transportation, point source capture, and direct air capture, carbon utilization can be enabled and provide further storage capacity and revenue.

Additionally, for nature-based carbon offset supplies, the potential for reforestation on private lands far exceeds the potential on public lands. From our stakeholder interviews with state forestry departments, state-owned public lands are well-managed, with existing plans for reforestation. While there still is significant potential for reforestation on these lands, there is the concern of additionality if these trees were to be sold for carbon credits. Alternatively, maximizing education and outreach on privately owned land for reforestation and improved forest management could lead to billions of tons of storage potential as quantified above.

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 23 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.

> “California and Texas are doing the most with carbon removal, there is so much oil and gas knowledge that allows them to do a lot of CO2 (geologic) sequestration, they have DAC plants and wind energy to power it all”
>
> Senior Scientist, Research Center Focused on Carbon

3.4 - Supporting Regional Infrastructure to Enable Engineered and Hybrid Solutions

3.4.1 - Regional Carbon Hubs for Centralized Carbon Capture

The Great Plains Institute identifies three regional carbon and hydrogen hubs in the Great Lakes region in their report “An Atlas of Carbon and Hydrogen Hubs for United States Decarbonization.”82 These hubs have high concentrations of key economic, geographic, and geologic factors that are ideal for the development of carbon and hydrogen hubs. The three hubs they identified in the Great Lakes region are Illinois, Michigan and Ohio, and Western Pennsylvania. Collectively, these three hubs possess adequate transportation infrastructure, geologic potential, and the ability to collectively sequester roughly 63 million metric tons of CO_2 near-to-medium term, over the next 10-15 years.

These three hubs are not the only potential locations for centralized hubs, but they are assessed for CO_2 sequestration and storage in the near term. Further development of hubs in this region will depend on access to low-carbon energy, proximity to injection sites or CO_2 processing facilities, and transportation infrastructure.

3.4.2 - Decentralized Approaches for Carbon Capture

While certain carbon capture approaches favor a more centralized approach, sequestration strategies such as carbonated building materials and biochar from waste biomass favor a decentralized approach.

Carbonated Building Materials

Aggregates and precast concrete derived from alkaline minerals and industrial waste streams have the potential to bind to CO_2 molecules, mineralize it, and store the carbon on geologic time scales. The CO_2 can be captured from point source or direct air capture sources. Traditionally, many types of building materials are sourced and deployed in a decentralized, local approach, so it also makes sense to deploy the carbonated versions of these materials locally as well. This is done to minimize transportation costs of heavy aggregates and concrete. Companies like Mitsubishi[79] are developing compact carbon capture units for decentralized applications that could be used to efficiently mineralize CO_2 when exposed to alkaline minerals. Carbon8’s[41] CO_2tainer is a modular point source capture method that allows for the on-site generation of carbonated aggregates which can be used in cement blocks, road filler, and roofing substrate that can be deployed locally to emissions sites.

Biochar from Waste Biomass

The production and distribution of biochar from waste biomass is best served in a decentralized setting to ensure a carbon negative lifecycle. Identifying waste biomass sources and locating decentralized processing facilities close to the source of biomass as well as the location of the intended application will help to minimize emissions from transportation.

3.4.3 - Regional Example of a Carbon and Hydrogen Hub - Marquis Complex

In Hennepin, Illinois, the Marquis Companies[83] are constructing the world's first carbon-neutral industrial complex with on-site carbon injection into geologic formations. The Marquis Industrial Park in Hennepin, Illinois is a 3300-acre industrial site with multiple natural gas lines, access to the electrical transmission grid, year-round river barge loading, interstate highway, and Class 1 railroad. In addition to the blue hydrogen and blue ammonia project, the plan includes a state-of-the-art soybean crushing facility to produce bio-based feedstocks for the production of renewable diesel and sustainable aviation fuels.

From the project website, their goal is for the "Marquis Industrial Complex to be the world's first carbon-neutral industrial complex with on-site carbon injection." They hope to "bring together like-minded low carbon industries and grow the low carbon economy together."

The park includes 1700 feet of sandstone well which has the potential to store 3 million tons of CO_2 total on over 5,000 acres of pore space. They expect to source one million tons of CO_2 for the first few years from ethanol fermenters, with additional tonnage from boilers. They are expecting to receive a Class VI well injection permit from the EPA soon. The park is located in close proximity to a major interstate highway with lots of industrial emitters and the ability to create a CO_2 pipeline with existing easements in close proximity to existing refineries and industry with millions of tons of CO_2 emissions.

Future visions of the hub involve the development of Lanzajet ethanol Sustainable Aviation Fuel (SAF) within 2-3 years, Direct Air Capture, and the goal of 4-5 injection wells storing 4-5% of Illinois's total emissions. They have started constructing two blue hydrogen and blue ammonia facilities with a throughput of 600 tons per day, and plan to manufacture carbon-neutral bio-based chemicals and plastics. They plan to create jobs across all income levels, with a minimum wage of at least $20/hour.

"The sheer size of the challenge means that we need a large amount of people and companies working on climate change mitigation, it will be a massive business and it makes sense to step in now"

Senior Scientist, Research Center focused on Carbon

4 - Market Size

4.1 - Demand and Pricing in the Voluntary Carbon Market

In the United States and globally there are two types of carbon markets - voluntary carbon markets and regulated or compliance markets. In the U.S., markets are primarily voluntary although California and Washington have regulated markets, and other states are looking at possibly adopting also. The EPA is not involved in regulating carbon emissions in the United States (but are newly considering it). However, in Canada there is national governance over carbon including carbon offsets. The collection of qualifying characteristics for carbon offsets is called the Canadian Greenhouse Gas Offset Credit System[84] regulations. Canada is a global leader in the regulated carbon market space along with Europe's Emissions Trading System. In addition to Canada having a national carbon offset and credit regulation, Québec has a cap[85] and trade system that was devised and passed with significant support in 2011. Quebec's government signed an order in 2009 for the region to achieve a sizable GHG reduction target by 2020. Ontario[86] had a cap-and-trade system that was canceled in 2018. While the target GHG emissions level was not achieved in Québec, Québec and Ontario are significantly ahead of the U.S. in meeting emissions reductions targets as their national government has advocated for impactful environmental legislation and regulation[87].

Globally, prices in voluntary and regulated carbon markets have been rapidly increasing as organizations seek to lower their carbon footprint. In mid-August, Europe's cap-and trade market price reached 99 euros ($99) for a ton of carbon dioxide, an all-time high. Under the program, In the EU companies can trade allowances for the tons of CO_2 they emit.

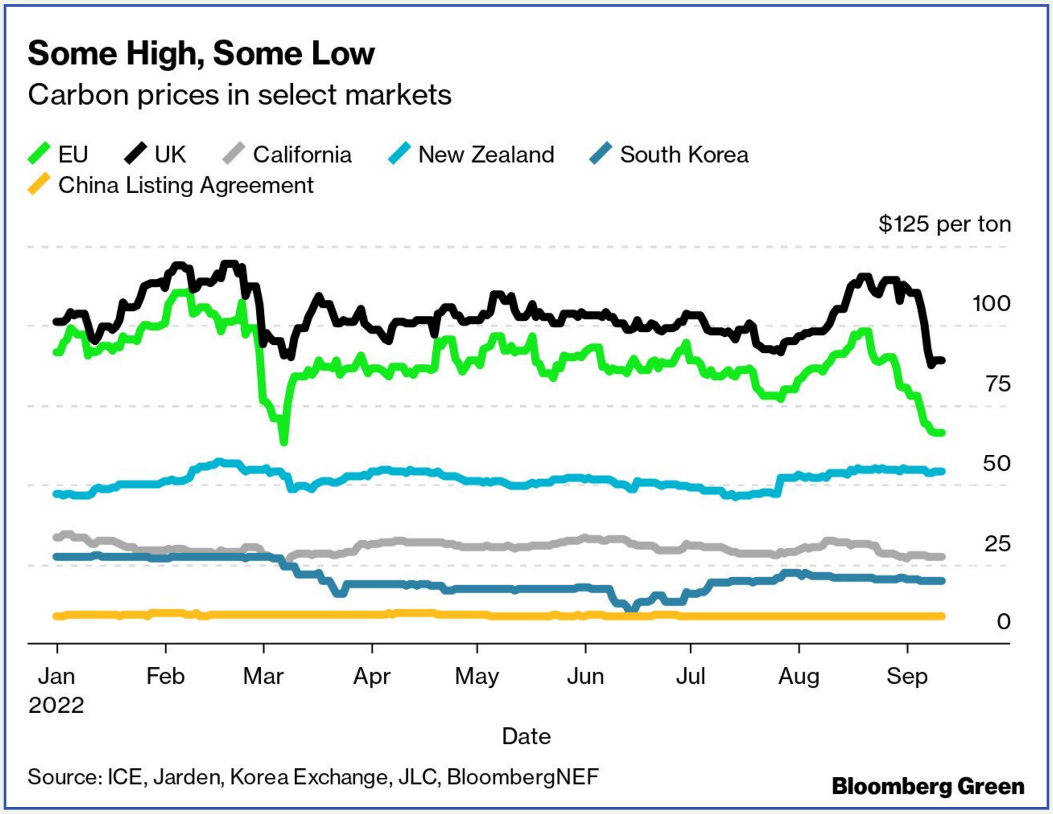

Figure 24 Summary of 2022 average carbon prices. Source: Bloomberg Green Newsletter, September 2022.

Globally, in the Asia Pacific region, country carbon markets have relatively low trading activity, and prices are too low[69] to force big emitters to change their behavior. Only New Zealand's prices come within striking distance of Europe's. China's carbon market has not only very low prices (less than $10 per ton), but also very little trading volume. India, the third-highest-emitting country after China and the U.S., has only a voluntary market to date.

In 2018, the prices of offsets in the voluntary[88] market ranged from $0.1/tCO$_2$e to over $70/tCO$_2$e. Prices typically ranged from $3-6/tCO$_2$e. Suppliers of carbon offsets that we interviewed in the forestry sector noted prices of $5-$25 ton and more in summer 2022, and direct air capture credits are being sold at 100's of dollars per ton. According to our interviews with corporate stakeholders with large assets in the Great Lakes region, prices are a significant deciding factor for offset projects, however, companies are willing to pay higher prices for carbon offsets that align with their ESG goals, have environmental and social co-benefits, and that are located within geographic regions in which they operate. They are looking for affordable credits with a good storyline that they can feel good about sharing with their customers.

One Michigan-based company buying offsets said they would like to buy in-state, but they can't afford local prices. Local prices can be from $2 per ton to $60 per ton, they seek to maintain an average of $10 per ton, and purchases range from $4 to $60 per metric ton, with the higher value representing high-quality projects. They also are interested in engineered solutions, but want to clearly see the accounting for how carbon is being removed from the atmosphere.

	Price $/ton 2019 Ecosystem Marketplace	Prices from Interviews
Afforestation/Reforestation	$6.60	$5-$40
Biochar/Biomass	$3	$10
Soil Carbon Storage	$2.70	$10
Coastal Blue Wetlands	$7	$10
CCS (Class II wells)	$14	n/a

Figure 25 Pricing for carbon offsets.

In the U.S. the above projections do not include the added benefits to producers from the 45Q tax credit and the Inflation Reduction Act (IRA) of 2022[89]. Prior to the signing of the IRA into law,[90] there was a $50 per ton baseline for all carbon sequestration in Class VI wells and $35 baseline per ton for all Class II enhanced oil recovery wells or durable carbon dioxide utilization in products. These baseline tax credits were the same regardless of whether the CO_2 was removed via CCUS or DAC. Prior to the IRA, 45Q did not have social justice requirements on their credits. After the IRA was signed into law on August 16th, 2022, the U.S. 45Q Tax Credit per metric ton 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 not yet clear how the producer tax credit will impact carbon offset market pricing. Producers in unregulated markets can both claim the tax credit and sell carbon offsets into the voluntary markets. The tax credit is expected to increase supply of carbon[89] offsets.**

Several people interviewed emphasized that from a capital investment perspective, long term the value of CCU products is that they bring open-market revenue from sales, in contrast to CCS which requires a tax credit to be economically successful.

4.2 - Potential Revenue

The revenue potential from 2022 - 2050 as shown in Figure 23 for the Great Lakes region was calculated as $205-$783B, corresponding to $14.4-52 gtons of carbon dioxide storage. Reforestation was calculated with a price of $25/ton, solid waste biomass at $3/ton, and geologic storage at $14/ton. Very little data was found for Ontario and Québec to support these calculations, so the actual potential is higher.

4.3 - Regional Barriers to a Higher Quality Offset Market

We discovered several common barriers to establishing a higher quality offset market in the Great Lakes region across our qualitative interviews. In order to accelerate scaling the storage and revenue potential in this region, these barriers must be addressed. The first is a lack of supporting infrastructure for engineered solutions, including CO_2 pipelines, easy access to Class VI well permits, low carbon energy sources, and green hydrogen for carbon utilization. Second, many stakeholders lack awareness about what carbon removal is and how addressing it can create new revenue streams. Third, there is a lack of planning and coordination amongst emissions sources and entities that can use the CO_2 to place underground or make products. Finally, there is a lack of profitability for new, truly additional supply-side carbon solutions that are just entering the market without the advantage of volume.

“In the upper Great Lakes states, the opportunity is big...price trends are going north and fast”

Land Conservation Director of Global Nature Focused NGO

5 - Recommendations

5.1 - Policies - Types of Incentives that Can Be Scaled

Types of Incentive Policies:

The EPA recommends the following five policies to effectively mitigate environmental externalities in the market and to incentivize consumers and corporations to partake in reducing their environmental footprint.

1. Creation of Markets – creation of a tradable government issued privilege (how much one can pollute or consume) for the discharge of pollutants or use of scarce environmental resources.
2. Monetary Incentives – methods to change market incentives, including subsidies, reduction of subsidies that produce adverse effects, fees, and taxes.
3. Deposit/Refund Systems – Schemes to discourage disposal and encourage central collection of specific products.
4. Information Disclosure – actions to improve existing market operations by providing additional information to consumers.
5. Procurement Policies – the federal government uses its own buying power to stimulate the development of markets

The policy recommendations included in the next section are based on the first EPA incentive policy recommendation, the creation of markets.The Great Lakes region can differentiate itself by ensuring their project supply into the voluntary carbon market creates truly additional revenue and meets high-quality carbon offset criteria. VCMs hold promise as a way to grow the local economy and create a new form of economic resilience for the region.

5.2 - Policy and Other 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 System47 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 II[54] and Class VI[55] wells have some amount of public ownership[56] 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 fund[57] 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 Fund[58] 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.

5.4 - Further Research

Listed below are opportunities for further research that would relate to this report.

1. Investigate Freshwater Carbon Dioxide Removal Feasibility

Water bodies around the planet have absorbed approximately 40% of humanity's carbon dioxide emissions[93]. We propose the investigation of sustainable ex-situ freshwater alkalinity modification in the Great Lakes. Assessment would include impacts on freshwater aquatic ecosystems. As water absorbs CO_2, it becomes more acidic with a lower pH which has negative impacts on aquatic life. The CO_2 concentration in water is higher than it is in air, which may allow for CO_2 removal from water to be more cost effective than DAC. If CO_2 is removed from water, the surrounding air will release more CO_2 into the water, so removing carbon from water also removes carbon from the atmosphere. Some research has already been done on this process in oceans, but this study would look at how this could function in the Great Lakes. Objectives of this study could be to 1) explore technical feasibility for safe, sustainable practices without harmful ecosystem impacts, 2) assess economic viability, 3) estimate overall job creation and revenue potential, 4)identify ecological impacts and regulatory considerations 5) and also consider if there are any coastal blue carbon approaches such as invasive species removal or mineralization that could perform a similar function.

2. Further Research the Implementation Pathways, Supply Chain, and Investment Options for Carbonated Aggregates and Carbonated Precast Concrete Production

Viable, at-scale markets were identified by the Global CO_2 Initiative in 2016 and confirmed in 2022 for carbon utilization products that use CO_2 as a new ingredient and durably store it. Aggregates and precast concrete production are mostly carried out by small, local producers as the materials are heavy and should not be moved long distances. For aggregates, assessments of potential waste streams (mine tailings, steel slag, fly ash, others) with potential for carbon storage that could be carbonated and placed into concrete and asphalt and suitable supply chains would be a logical next step for investigation. For precast concrete, determining the source of CO_2 for concrete curing and potential supply chain would be the next step. Planning for renewable or low carbon energy and any other infrastructure needed to power these processes to maximize the climate benefits would also be helpful.

3. Investigate Direct Air Capture Plant Implementation

In a post-2050 timeframe, it is hoped that point source capture will no longer be taking place except for in hard to abate sectors. The expectation is that fossil-based power plants will largely be closed. Along the way between now and 2050, direct air capture will need to scale up to capture legacy CO_2 emissions. A roadmap-type study could be conducted to look at how to make it easy for the region to do this, perhaps looking to Texas and other areas with DAC plants as examples. Optimal locations could be identified considering geologic storage, industry, pipelines, and locations of renewable energy.

4. Study the Best Usage of Waste Biomass in the Region

The region is rich with woody and crop residue wastes. A study could be carried out to look at the best pathways for use, how to tailor production processes to locally available biomass available in each state and province, and steps to attract investment and implementation. The production options include electricity production with carbon capture, production of waste heat or fuels, biochar, and combination strategies.

5. Optimize a Regional Forest Carbon Storage Strategy

The first research objective would be to investigate the feasibility of state-owned forestry agencies to specify that timber harvested from public lands must be used for semi-durable purposes such as dimensional lumber or furniture, which will store carbon at least on a decadal scale, instead of paper or pallets which will return the CO_2 to the atmosphere relatively quickly. How could states and provinces incentivize private landowners to not sell off their land, and instead to help landowners get paid for keeping their lands and getting paid for carbon storage from the voluntary carbon offset markets? One possible route to explore is if easements are a viable option, and how to implement them. Another issue mentioned in a qualitative interview was nursery support for tree seedlings and whether it is adequate in the region to meet anticipated demand. The state and province level DNR's might have this well underway, that is unclear. Lastly, possibly look at using ton-year accounting for the region to make nature-based solutions especially for forests of higher quality, while also seeing if there are solutions that address the shortcomings of ton-year accounting.

6. Assess Additional Geologic Storage Potential in the Region

Conduct a study to examine whether there is additional geologic CO_2 storage potential in the region in basaltic, peridotite, or other formations and depleted oil and gas wells.

7. Assess Feasibility of Operator Cost Recovery for Carbon Capture

An area for a follow-up study would be if the cost of carbon capture, both point source and Direct Air Capture (DAC), should be included in the electric rate base for states and provinces. Utilities are a logical first choice for installing carbon capture equipment on power plants, however, a carbon capture retrofit costs hundreds of millions of dollars for a natural gas plant. How utilities recover that cost beyond a grant program didn't seem to be clear. Also consider working with regional grid operators who coordinate the movement of wholesale electricity (Midcontinent independent Operator (MISO), the Pennsylvania New Jersey Maryland Interconnection (PJM) and New York ISO (NYISO)) to determine how plants with carbon capture equipment can be prioritized for dispatch, right now the way the system works is that the lowest cost electricity is prioritized, and plants with carbon capture are at risk for not being dispatched as often. Perhaps these issues have already been addressed, one person interviewed raised them. If it is an issue, it might be very important for regional coordination, just not sure who should do it. Long term, it might be helpful to determine a mechanism that can support carbon capture costs in the rate base for direct air capture plants and CCU product manufacturing.

5.5 - Conclusion

The Great Lakes St. Lawrence region possesses a wealth of potential for carbon storage in both nature-based and engineered applications. As a global leader in technological innovation, the region possesses the infrastructure necessary to make carbon removal feasible and profitable. Our region paved the way for industrialization, and we have the opportunity to once again lead the world in managing carbon and turning waste emissions into profitable applications that also benefit the environment. Now is the opportune moment to take action towards emissions reductions to ensure a healthy climate and wealth for future generations. Globally, thousands of organizations have pledged net-zero commitments, with many struggling to take action to meet those commitments. The current voluntary market lacks organization and a clear distinction between low- and high-quality offsets, with very few carbon removal options existing on the market today. Taking steps now to form a regional collaborative for emissions management and a voluntary offset market will not only position the region as a global leader, but also as a global destination for organizations wanting to guarantee high-quality offsets that remove carbon from the atmosphere. Prompt action is required to maximize both economic prosperity and environmental protection. Implementing a regional strategy for carbon removal, storage, and utilization will allow the Great Lakes region to protect our natural resources for generations to come, lead the world in reaching net-zero, and reverse the human-induced effects of climate change. Choosing to not utilize the technologies and methods we have outlined above to mitigate the impacts of climate change would be a missed opportunity. We urge prompt action for the sake of the entire region and its citizens.

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Appendix 1 - Carbon Capture Storage Potential Assumptions

Precision of Estimates: all estimates are first order, and thus given with up to two significant figures. Data sources, assumptions, probabilities, and rationale for estimates are given in this document.

Rationale for CDR Solutions Investigated: the CDR Primer[94] was the background information for this project. Chapter 2 details CDR solutions, and these were investigated in relation to their availability in the Great Lakes Region via data sources. Solutions investigated in depth are those with quantifiable data for additional storage, current research and development, and characterization project activities.

Carbon Sources:

- Data from NATCARB Viewer > Atlas Layers > Stationary CO_2 Sources95
- Accessed 8/16/2022
- Method: downloaded CSV file for layer, filtered by states and provinces, summed total amount of projects and total tonnage of annual emissions
- Assumed tonnage of CO_2 is in metric tons, and
- Scope of data: only U.S. States, no Canadian Provinces

Pipeline Infrastructure:

- Data from U.S. Energy Information Administration > U.S. Energy Mapping System > Selected Layers96
- Layers extracted:
    - Crude Oil Pipeline
    - Petroleum Product Pipeline
    - HGL Pipeline
    - Natural Gas Pipeline
- Accessed 8/16/2022
- Rationale: illustrate existing pipeline infrastructure to show possible CO_2 transportation routes from emission sites to injection locations
    - According to Battelle, work is currently being done to convert existing pipelines into CO_2 pipelines and existing infrastructure is relevant because existing easements can be used to construct new CO_2 pipelines

Current CCUS Activities:

- Direct Air Capture (DAC): https://carbon180.org/dac-mapp[97]
    - Access date: 8/01/2022
    - Scope: worldwide, data for U.S. states and Canada
- Point Source Carbon Capture
    - https://netl.doe.gov/carbon-management/carbon-capture/ccmap98
        - Scope: U.S. States, no data for Canadian provinces
    - NATCARB Viewer > WCCUS > World Carbon Capture and Storage Database layer95
        - Scope: GLR U.S. States and Canada, no available data for Québec and Ontario
- Site Characterization + Field Projects:

- NATCARB Viewer > Field Projects > All Layers95
    - Scope: United States and Canada, no available data for Ontario and Quebec

Potential Locations for Carbon Removal Hubs:

- The Great Plains Institute publication on Carbon and Hydrogen Hubs[82] was used to locate GIS map data and learn more about potential locations for hubs in the Great Lakes region.

Reforestation:

- The Nature Conservancy's Reforestation Hub26
    - Scope: U.S. States, no available data for Canada
    - Gives data on a county level, with both annual acreage and tonnage of CO_2 sequestration potential. Data is broken down by land type and ownership (federal, state, private, and other)
    - Method: filtered by state and summed up county level data to get statewide annual reforestation potential in acres and metric tonnage of CO_2 for state owned land and privately owned land

Solid Waste Biomass:

- https://www.nrel.gov/gis/biomass.html81
    - Scope: U.S. States, no available data for Canada
    - Method: filtered "Total Solid U.S Biomass Resources" by state, summed up county level data for each state
    - Since there are varied applications of solid waste biomass, a distinction of end use application is not given (note that this data is NOT given in metric tons of CO_2 like the other data)
    - Further investigation into what percentage of biomass could be converted into bioenergy/biochar, conversion of biomass to bioenergy, conversion of bioenergy to CO_2, and amount of CO_2 sequestered per ton of biochar is needed

Geologic Storage:

- Saline Basins
    - NATCARB Viewer > Atlas Layers > RCSP Saline Basin 10km Grid95
        - Scope: U.S. states, no data available for Wisconsin. Low, medium, and high volume of CO_2 storage estimates given in metric tons of CO_2
        - Limitations: no data available in Ontario, Quebec, and Wisconsin. The absence of data from Wisconsin in the NATCARB database differs from data researched from the Gulf Coast Carbon Center, linked here[99]
        - Another source is DOE's National Carbon Atlas[100] report, although these calculations relied on NATCARB
        - Method: downloaded CSV file, filtered by formation, and added up CO_2 storage estimates for both the low and high estimates per basin formation. It should be noted that some basins cover areas in states that are not a part of 8 states we are concerned with, so based upon the available data, it may be an overestimate of potential. The data shown represents the total storage potential of the basins that cover the 8 Great Lakes states. Because of this, storage potential is currently available by specific basin, but not on a state by state level
        - Improvements to method: upload shapefiles of the 8 states, and capture the overlap between

the underlying saline 10km grid layer, download into a CSV file, sum the low and high potentials. This would also allow for a state by state breakdown of the storage potential. Finding a data source for the basins in Wisconsin would also be ideal.

- Unmineable Coal
  - NATCARB Viewer > Atlas Layers > RCSP Coal Basins 10km Grid[95]
    - Scope: U.S. states. Low, medium, and high volume of CO_2 storage estimates given in metric tons of CO_2
    - Limitations: no data available in Ontario and Quebec.
    - Method: downloaded CSV file, filtered by formation, and added up CO_2 storage estimates for both the low and high estimates per basin formation. It should be noted that some basins cover areas in states that are not a part of 8 states we are concerned with, so based upon the available data, it may be an overestimate of potential. The data shown represents the total storage potential of the basins that cover the 8 Great Lakes states. Because of this, storage potential is currently available by specific basin, but not on a state by state level
    - Improvements to method: upload shapefiles of the 8 states, and capture the overlap between the underlying coal 10km grid layer, download into a CSV file, sum the low and high potentials. This would also allow for a state by state breakdown of the storage potential.
- Sedimentary Basins
  - NATCARB Viewer > Atlas Layers > North American Sedimentary Basins[95]
    - Limitations: there is no volume estimate of amount of CO_2 that can be stored underground, but provides the area in which sedimentary basins are present. Sedimentary basins comprise depleted oil and gas reservoirs, unmineable coal reservoirs, and saline reservoirs. Calculations for unmineable coal and saline reservoirs are detailed above.
    - Scope: U.S. States, Canada
- Other basins:
  - It has been mentioned that basalt and periodotite among other formations have CO_2 storage potential. This could be grounds for added research, or a follow up email to a geologist.

Crushed Stone (Aggregates):

- Data source: https://www.nssga.org/aggregate-resources/data-state[80]
- Storage Calculation Assumptions/method:
  - Project incumbent product production each year to 2050 using a CAGR of 3.3% and the formula:
    - Assume CAGR is constant
    - Future Value = Present Value(1 + CAGR)^(final year - start year)
  - Assumed that crushed stone with CO_2 storage included would capture 10% of the incumbent market each year until 2050
  - Assumed a low and high CO_2 uptake value per ton
    - Low estimate: (0.087 ton CO_2 uptaken / metric ton crushed stone)
    - High estimate: (0.440 ton CO_2 uptaken / metric ton crushed stone)
    - Source: Carbonation of minerals or waste materials can consume between 0.087 and 0.440 tons of CO2 per ton of aggregate depending on the starting raw material, conversion process, and resulting product material (Woodall et al., 2019). As a starting point, for 2020, the global amount of suitable waste materials was estimated to about 6.6 gtons per year (Carey, 2018; Hepburn et al., 2019) while the global annual production of alkaline minerals (wollastonite,

olivine, serpentinite) was at 16.2 million metric tons (U.S. Geological Survey, 2022). That then determines the range of potential CO2 use when multiplied by an assumed market penetration for carbonated aggregates.

- Calculate total tonnage sequestered each year, and sum from 2022 - 2050 to get total sequestration potential.

- Pricing Assumptions/method:
    - 20% premium on the incumbent price due to emitters willing to pay a premium for removal processes (produce provides an added benefit beyond just a building material and should thus be valued more)
        - Team assumption
    - Incumbent price for crushed stone in 2020 = $10/metric ton
        - From interviewee
    - Assume 1.5% increase each year
        - From interviewee
    - Project price each year (based off of incumbent price and 20% premium) from 2022 - 2050, and multiply by projected production of crushed stone with the corresponding year

Precast Concrete

- Data source: based on 2015 state-by-state production data given in cubic yards from the National Ready Mix Association
    - State-by-state production data was not able to be sourced from the National Precast Concrete Association.
- Storage Calculation Assumptions/method:
    - Assume precast concrete is 10% of Ready Mix production
        - Assumption from interviewee upon trade association data
    - Assume density of precast concrete is 150 lbs/cubic foot[101]
    - Convert to metric tons
    - Project incumbent product production each year to 2050 using a CAGR of 6.3% and the formula:
        - Assume CAGR is constant
        - Future Value = Present Value(1 + CAGR)^(final year - start year)
    - Assumed that precast concrete with CO_2 storage potential would capture 10% of the incumbent market each year until 2050
    - Assumed a low and high CO_2 uptake value per ton
        - Low estimate: (0.001 ton CO_2 uptaken / metric ton precast concrete)
        - High estimate: (0.05 ton CO_2 uptaken / metric ton precast concrete)
        - Source: Frontiers Paper[102]

          ...."in precast concrete, CO2 utilization estimates range from 0.001 to 0.085 tons per ton of concrete (Zhang and Shao, 2016; Henrion et al., 2021b) but we use a more conservative upper bound of 0.05 tons for the projections. It is noted that while there are indications that CO2 curing might not affect the natural ability of concrete to further take up CO2 over its lifetime, this is an ongoing debate for research (Zhang and Shao, 2016)."
    - Calculate total tonnage sequestered each year, and sum from 2022 - 2050 to get total sequestration potential.

- Pricing Assumptions/method:
    - 20% premium on the incumbent price due to emitters willing to pay a premium for removal processes (product provides an added benefit beyond just a building material and should thus be valued more)
        - From interviewee
    - Incumbent price for precast concrete in 2020 = $19/metric ton
        - From interviewee
    - Assume 1.1% increase each year
        - From interviewee
    - Project price each year (based off of incumbent price and 20% premium) from 2022 - 2050, and multiply by projected production of crushed stone with the corresponding year

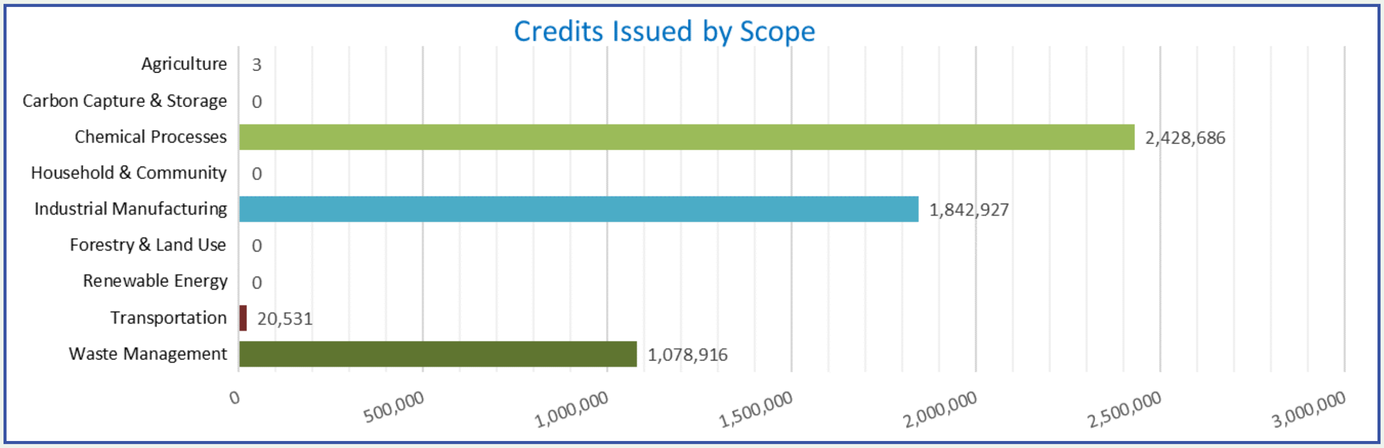
2022-2050 Potential Storage and Market Size Assumptions:

- Assumed that 100% of annual estimates from reforestation, solid waste biomass given from the databases were met each year and stayed constant from 2022 - 2050. Additional considerations would be projections for increase/decrease in availability of reforestable land and supply of solid waste biomass.
    - NOTE: biomass is given in metric tons of biomass per year, NOT metric tons of CO_2 per year.
    - Geologic storage: assumed 100% of capacity of basins were met from 2022 - 2050. The estimates only include data from the NATCARB viewer for Saline and Unmineable coal formations and do not include sedimentary formations or other possible storage formations. State shapefile data should be uploaded to capture the capacity within state boundaries.
- Prices for each application (with the exception of crushed stone and precast concrete) were sourced from the data in the cost/pricing table in the report.
    - Prices for crushed stone and precast concrete were sourced from Fred Mason, and calculation method is detailed above

Appendix 2 - Historical Carbon Credits by State and Province

All charts come directly from the Berkeley Carbon Trading Project database. No data was available for Québec in the database.

Illinois



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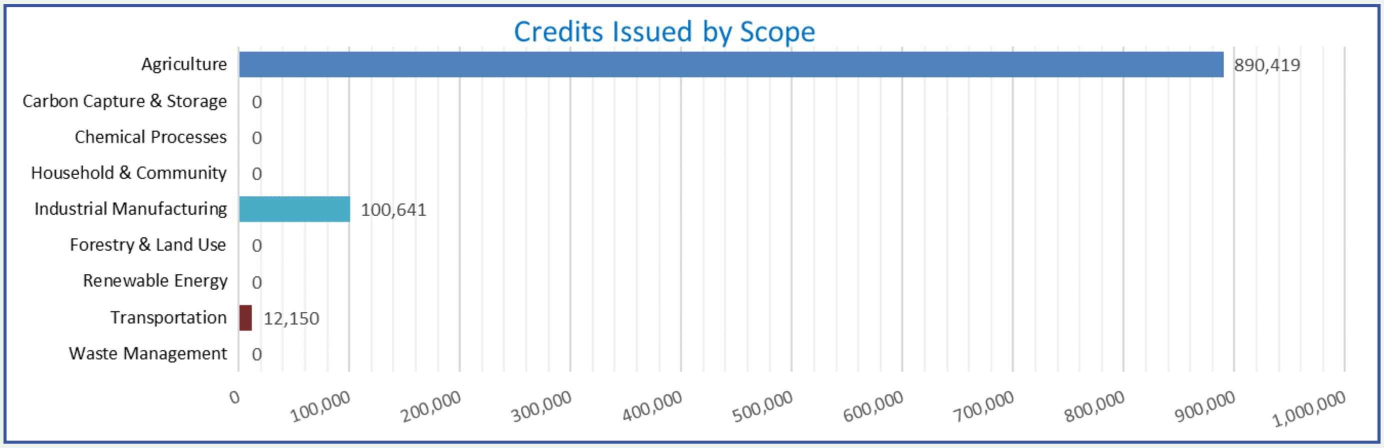

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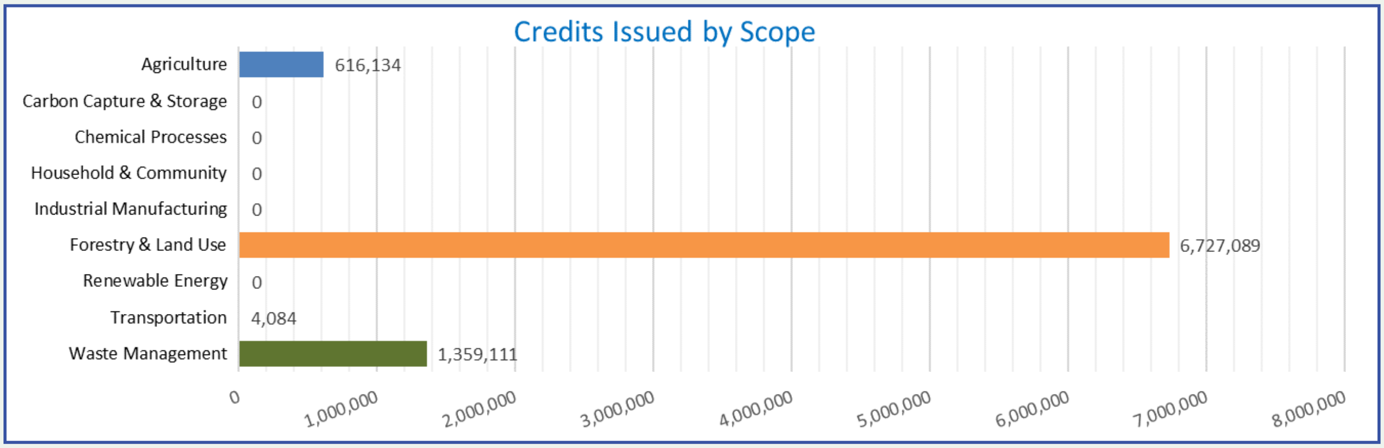

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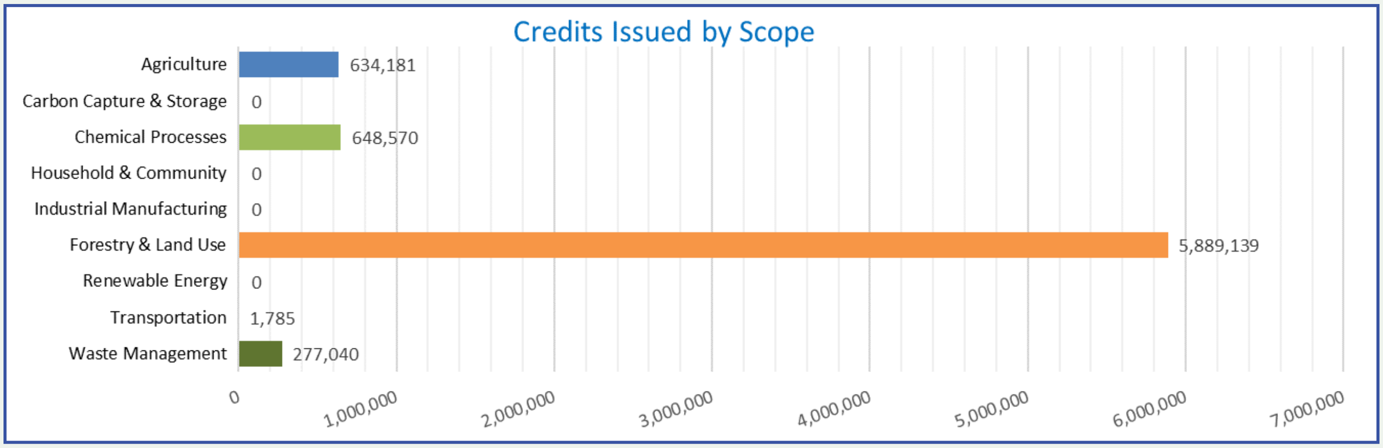

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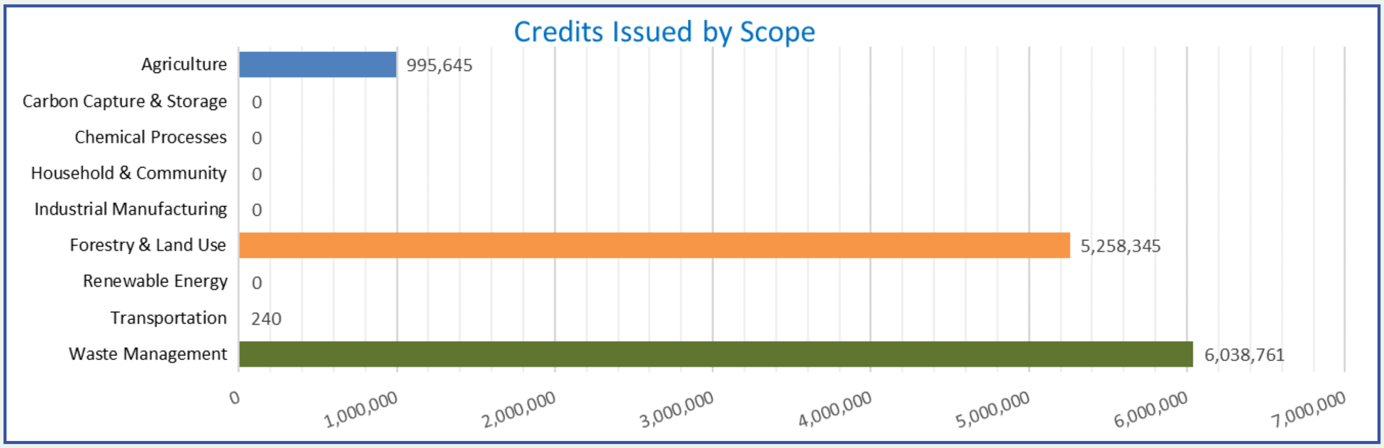

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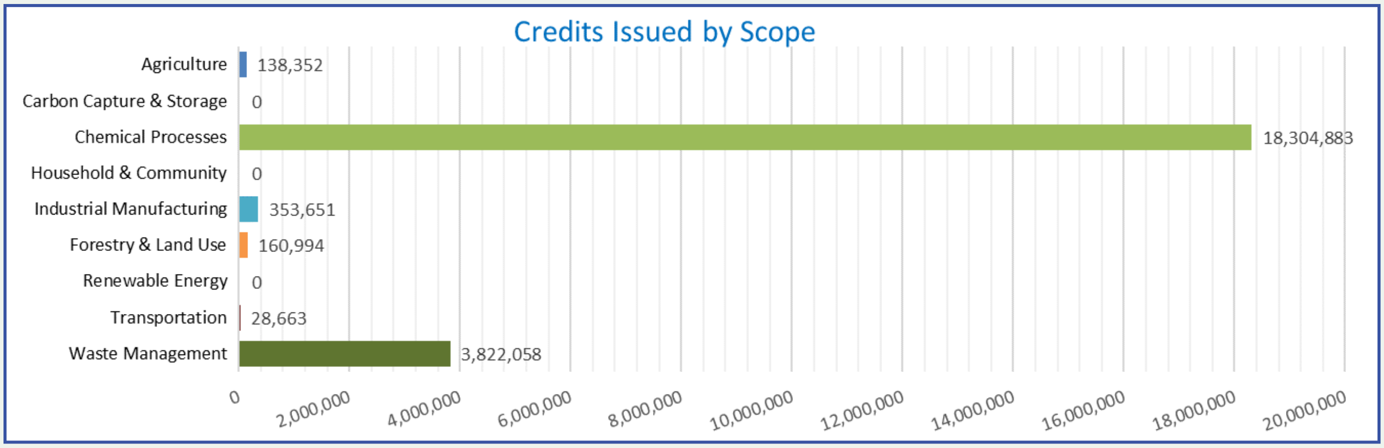
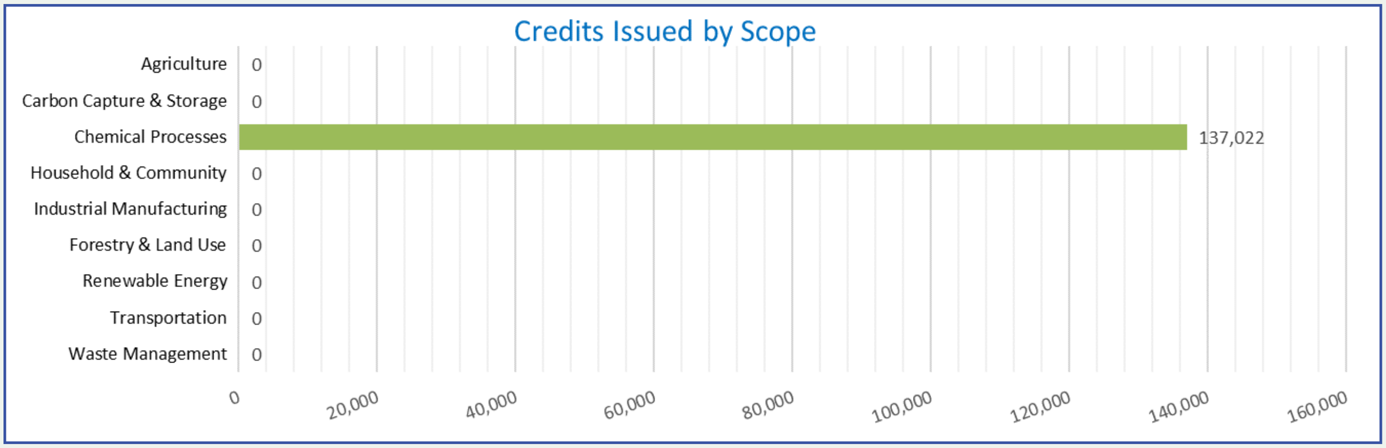
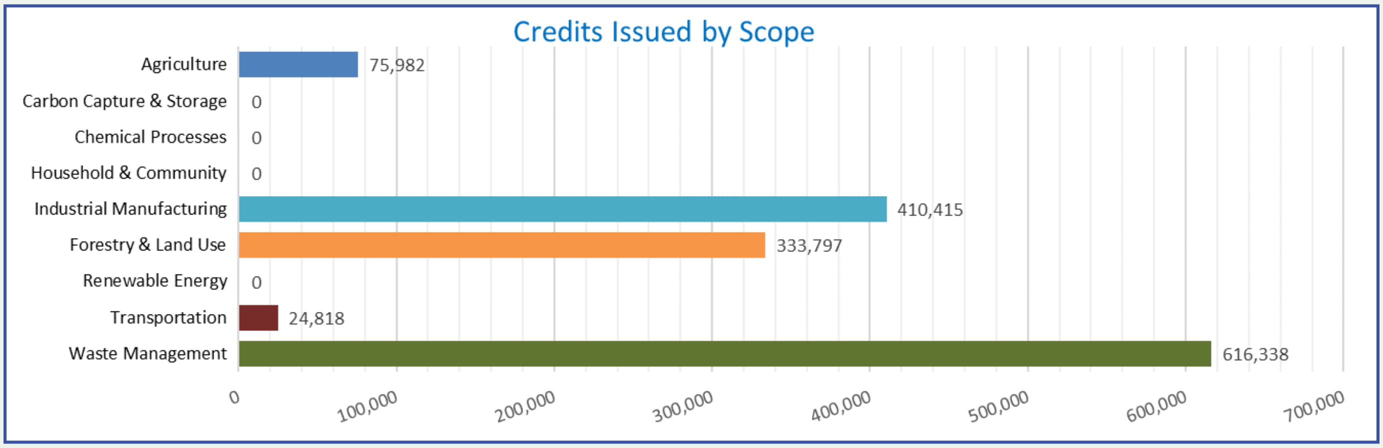


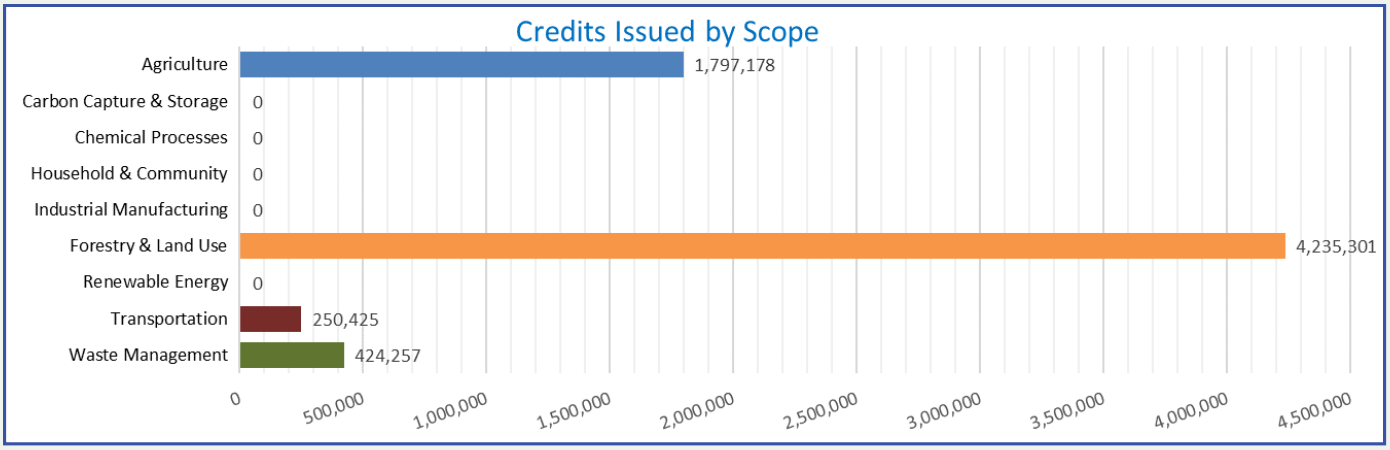
Ontario



Pennsylvania



Quebec



Appendix 3 - Great Lakes Region State, Province and Corporate Climate Commitments

State or Province:	Climate Plan Details:	Date of Commitment or Enactment:	Source Information:
Illinois	There is an executive order that was passed that emphasizes each Illinois citizen's right to clean air, water, and a safe environment. Additionally, this policy does address that climate change is a threat to their population and that regardless of Presidents' decisions in the Paris Climate Agreement that they will uphold the objectives and values of the Agreement. Illinois was the first Midwestern state to commit to a 100 percent carbon-free energy standard by 2045. .	January of 2019	https://www.illinois.gov/government/executive-orders/executive-order.executive-order-number-6.2019.html https://www.nrdc.org/media/2021/210913103
Indiana	There is a report by the Nature Conservancy that outlines Indiana's potential climate solutions and options they have to meet their climate goals. However, nothing has been signed into law in the state of Indiana that holds them seriously accountable to uphold these environmental goals.	Unavailable	https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_Indiana_Climate_Change_Roadmap.pdf104
Michigan	There is a policy plan that has been paired with an executive target for the state of Michigan. The plan recommends reducing GHG emissions 28% below 2005 levels by 2025, 52% by 2030, and achieving economy-wide carbon neutrality by 2050. Key aspects of the plan include ensuring that at least 40% of state funding for climate-related and water infrastructure benefits disadvantaged communities, generating 60% of the state's electricity from renewables by 2030, and protecting 30% of Michigan's water and land by 2030. Michigan released a previous climate action plan in 2009.	April of 2022	Whitmer Unveils MI Healthy Climate Plan State Climate Policy Maps105
Minnesota	Minnesota released Minnesota's Climate Action Framework in the summer of 2022. The plan will includes strategies and policies to help the state meet its target to reduce GHG emissions 30% from 2005 levels by 2030 and 80% by 2050. Key aspects of the plan cover transportation,avoiding grassland conversion to other land uses, achieving 55% renewable electricity by 2040, and developing programs to reskill Minnesotans for clean economy jobs. Minnesota released its last climate action plan[106] in 2015. This plan included the same GHG emissions targets as the most recent draft plan. Key aspects of the 2015 plan include expanding mass transit, increasing the renewable electricity standard, and retiring coal plants.	Updated Publication Released Summer 2022	https://climate.state.mn.us/sites/climate-action/files/Climate%20Action%20Framework.pdf107

New York	New York is developing its Draft Scoping Plan to be released by January 1, 2023. The plan will outline actions to help the state meet its goals of reducing GHG emissions 40% from 1990 levels by 2030, and 85% by 2050. Key aspects of the draft plan include requiring 6,000 MW of distributed solar generation by 2025, having nearly 100% of light-duty vehicle sales be zero-emission vehicles by 2030, adopting zero-emission building codes, and developing prioritization models for forests in need of management. New York released its previous climate action plan in 2010. The plan recommends strategies to meet the state's goal of reducing GHG emissions 80% below 1990 levels by 2050. Key aspects included setting higher performance standards in new buildings, investing in public transit, and adopting a more aggressive renewable portfolio standard.	Intended Publication in 2023	https://legislation.nysenate.gov/pdf/bills/2019/S6599
Ohio	Ohio University and Ohio State University have created climate plans for the State, however, the State of Ohio has not adopted an actual plan for climate action or carbon emission reductions.	Unavailable	https://www.ohio.edu/sites/default/files/sites/sustainability/files/2021%20OHIO%20Sustainability%20and%20Climate%20Action%20Plan.pdf https://si.osu.edu/sites/default/files/CAP_Final_04082020.pdf
Ontario	The province abides by the Canadian Net-Zero Emissions Accountability Act. Additionally, Ontario has its own provincial goals in the "Ontario Climate Action Series". The series includes: • **A policy report** analyzing climate change in Ontario, organizational leadership, and policy recommendations for governments to take action. • **Sustainability seminars** focused on different opportunities for climate innovation in Ontario – including cleantech, hydrogen, small modular reactors, zero-emission vehicles, and natural resources. • **A blog series** highlighting private sector sustainability efforts in different sectors of our economy. • **An advocacy and communications** campaign to build awareness around Ontario's climate advantage.	June of 2021	https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html108

Pennsylvania	Pennsylvania released the fourth update of its Pennsylvania Climate Action Plan[109] in September 2021. The plan outlines 18 strategies to reduce GHG emissions 26% by 2025 from 2005 levels, and 80% by 2050. Key aspects include supporting energy efficiency through building codes, developing incentives for EVs to capture 70% of the light-duty vehicle market by 2050, increasing production of renewable natural gas, and achieving a 100% carbon-free electricity grid by 2050. Pennsylvania released a previous climate action plan in 2019.	September of 2021	https://www.oa.pa.gov/Policies/eo/Documents/2019-01.pdf
Quebec	The province abides by the Canadian Net-Zero Emissions Accountability Act and its own climate legislation, "The 2030 Plan for a Green Economy". It engages Québec in an ambitious project to lay the groundwork for a green economy by 2030 that is both resilient to climate change and more prosperous. The Plan will help achieve the 2030 greenhouse gas emissions reduction target Québec has set for itself, namely a 37.5% reduction compared with 1990 levels, and to reach carbon neutrality by 2050. It will also strengthen Québec's capacity to adapt to the consequences of climate change.	June of 2021	https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html108
Wisconsin	Wisconsin released its Governor's Task Force on Climate Change Report in December 2020. The plan includes policy recommendations to help the state meet its goal of reducing GHG emissions 26–28% below 2005 levels by 2025 and achieving 100% carbon-free electricity by 2050. Key aspects of the plan include creating an Office of Environmental Justice, expanding Focus on Energy program funding, supporting EV infrastructure, and avoiding all new fossil fuel infrastructure. Wisconsin released a previous climate action plan[110] in 2008.	December of 2020	https://osce.wi.gov/Documents/SOW-CleanEnergyPlan2022.pdf https://climatechange.wi.gov/Documents/Final%20Report/GovernorsTaskForceonClimateChangeReport-LowRes.pdf

Some highlights of corporate commitments in the region are shown in the table below.

Industry	Name	Place	Description	Target year
Food	Domino Pizza	MI	Domino's is committed to achieving net zero emissions across its value chain by 2050. Reduce our scope 1 & 2 emissions 67% by 2035. Reduce our scope 3 emissions 40% by 2035.	2050
Energy	DTE Energy	MI	DTE Electric's CleanVision Plan aims to achieve net-zero carbon and greenhouse gas emissions by 2050 while providing clean, reliable, and affordable energy to customers.	2050
Retail	Steelcase	MI	Achieve Absolute Reductions by 2030 Reduce absolute emissions from own operations by 50%. Reduce emissions from waste generated in operations by 14%, equating to a 20% total tonnage reduction in waste globally. Reduce emissions from business travel by 14%. Invest in carbon offset projects like reforestation to maintain carbon neutrality for direct operations.	2030
Retail	Meijer	MI	Meijer announced today an ambitious goal to reduce absolute carbon emissions by 50 percent by 2025.	2025
Food	Kellogg	MI	Kellogg Company commits to a 15% reduction in emissions (tonne of CO_2e per tonne of food produced) by 2020 from a 2015 base-year (scopes 1 & 2). Kellogg commits to reduce absolute value chain emissions by 20% from 2015-2030 (scope 3). Kellogg also has a long-term target of a 65% absolute reduction in emissions by 2050 from a 2015 base-year (scopes 1 & 2) and to reduce absolute value chain emissions by 50% from 2015-2050 (scope 3).	2050
Transportation	Air Canada	QBC	Air Canada has committed through carbon offsets through Less Emissions company, and has given the option for consumers to purchase carbon offsets as part of net zero goals	2050
Transportation	Canadian National Railway	QBC	Net zero goals by 2050, as well as reducing scope 1 and 2 emissions by 43%, and scope 3 by 40% by 2030	2050
Consumer Goods	SC Johnson	WI	Net zero goals at headquarters to reach by 2025 through Geothermal Exchange, Solar Energy, Photovoltaic Wind Lights, Recycled Asphalt Pavement Achieved a 68% reduction in greenhouse gas emissions, with goal being 90% by 2025	2025?
Energy	Johnson Controls	WI	Net zero by 2040, with science based targets being set for 2030 (specifically reducing customer's emissions by 16% and operational by 55%)	2040

Telecom	Verizon	NY	Operational net zero by 2035, reducing scope 2 emissions (majority of their emissions at 90%). Has issued 3 green bonds in last 3 years Aims to use 50% renewable energy by 2025	2035
Consumer Goods	PepsiCo	NY	Wants to achieve net zero by 2040, with multiple different goals in sustainable packaging by 2030	2040
Manufacturing	Arconic	PA	Hints at Net Zero commitments but no solidified statement that it is net zero by 2050. Strategy of reducing truck weight to offset carbon emissions in that sector	2050
Energy	Air Products & Chemicals	PA	Goals to reach net zero by 2050, with a facility being opened (in Canada) operated 100% by Hydrogen Using Wolf Carbon solutions (carbon capture technology) to offset 95% of carbon emissions, with remaining 5% through 100% hydrogen model	2050
Energy	Cummins	IN	No clear 2050 goal set, although a program named PLANET 2050. Many goals are labeled with 2030, reducing GHG by 50%, scope 3 by 30%, and investing in carbon neutral air technologies to reach hypothetical 2050 goals	2050
Manufacturing	Berry Global	IN	Aims to be 100% reusable.recyclable products being produced by 2025, while reducing scope 1 and 2 by 25% and 8% for scope 3	2025
CPG	P&G	OH	In September 2021, P&G announced an ambition to achieve net zero greenhouse gas (GHG) emissions across supply chain and operations by 2040, from raw material to retailer. Set science-based interim targets for 2030 to keep on track and make meaningful progress this decade.	2040
Manufacturing	Goodyear	OH	The Goodyear Tire & Rubber Company has a goal to reach net-zero value chain greenhouse gas (GHG) emissions by 2050, aligned with the Science Based Targets initiative (SBTi) and its new Net-Zero Standard. Also has near-term science-based targets by 2030.	2050
Food	McDonalds Corporation	IL	McDonald's Corporation is committed to achieve net zero emissions across its global operations by 2050. As part of this initiative, the Company is joining the United Nations Race to Zero campaign and signing on to the Science Based Targets initiative's (SBTi) Business Ambition for 1.5°C campaign. In pursuit of a 1.5°C future, McDonald's will increase the emissions reduction levels in its existing 2030 science-based target across all scopes of emissions in line with developing SBTi best practices and will set a long-term reduction target to reach net zero emissions.	2050
Manufacturing	Boeing	IL	Boeing achieved net-zero at manufacturing and worksites in 2020 by expanding conservation and renewable energy use while tapping responsible offsets for the remaining greenhouse gas emissions.	2020

Transportation	United Airlines	IL	Planning to become 100% green by reducing greenhouse gas (GHG) emissions by 2050 without relying on traditional offsets.	2050
Retail	Target Corporation	MN	Through Target Forward strategy, commit to being a net zero enterprise by 2040 to reduce climate impacts across our operations and supply chain.	2040
Agriculture	Cargill	MN	Reduce GHG emissions in operations by 10% by 2025. Reduce GHG emissions in supply chain by 30% per ton of product sold by 2030. Committed SBTi 2 degrees.	2025
Retail	Best Buy	MN	Best Buy's participation builds on existing efforts to reduce carbon footprint. Have reduced emissions 61% since 2009 and have pledged to be carbon neutral by 2040.	2040
Manufacturing/ Engineering	Bird Construction	ONT	Net Zero by 2050, includes the use of Mass Timber which offsets CO_2e emissions with 2.2b value	2050
Manufacturing	Kontrol Technologies	ONT	No net zero commitments, but company is based on assisting other companies with sustainable solutions that include carbon offsets	

Appendix 4 - Regional Annual Emissions Calculation

	2020	2019[75]
Quebec	76.2	
Ontario	149.6	
Michigan		159.2
Illinois		203.4
Ohio		196.7
Indiana		176.1
Minnesota		92.1
Pennsylvania		218.7
New York		169
Wisconsin		94.8
Total	*225.8*	*1310*
Total for Region	**1535.8**	*Mostly million metric tons CO_2 with fraction of CO^2e*
	Million metric tons or megatons CO_2e for Quebec	million metric tons 1 x 10E6 Megatons
	and metric tons CO_2 for Ont	gtons 1 x 10E9
	Million metric tons for US	
	Totals Calculation	
	1,535,800,000	Total million metric tons
	1.54	gtons, approximately

GLOBAL CO_2 INITIATIVE
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