Overview of CO_2 Sequestration Opportunities in New York State

New York State Energy Research and Development Authority

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PREFACE

This document was prepared by the New York State Energy Research and Development Authority as a technical appendix in the New York Power Authority's 2006 solicitation for the Advanced Clean Coal Power Plant Initiative (ACCPPI). Substantial contributions to the report were made by the New York State Museum (Section D), with some input from WorleyParsons (Sections C1 and C2).

The geological data presented in this document as it pertains to New York State is *preliminary* data and should be used accordingly and with caution. NYSERDA and the New York State Museum are currently refining and updating these data and assumptions.

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NOTICE

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A. Background

Many scientists theorize that anthropogenic climate change is caused or exacerbated by several pollutants known as greenhouse gases (GHG). If the theory is correct, these gases trap energy from the sun, warming the earth's atmosphere and causing changes in climate patterns worldwide. Carbon dioxide is the GHG of most concern because it is emitted in enormous amounts worldwide and is thought at this time to be the greatest contributor to the greenhouse effect. According to the U.S. Environmental Protection Agency, in 2004 CO_2 accounted for 84.6 % of all GHG emissions in the U.S.; of that amount, approximately 40% of the CO_2 emitted was attributed to fossil-fuel-fired power plants[1].

In the United States, no federal regulations regarding greenhouse gasses have been enacted thus far, but individual states are taking their own actions. In the Northeast, nine states, including New York, are members of the Regional Greenhouse Gas Initiative (RGGI), whose goal is to reduce CO_2 emissions from power plants by implementing a mandatory emissions cap-and-trade program. The RGGI timeline begins in 2009, and carbon capture and sequestration may be one method used by power plants to reduce their emissions to compliance levels.[2]

Several options have been identified to help reduce greenhouse gas emissions, and it is likely that a combination of these will need to be implemented to significantly reduce greenhouse gas emissions. The list of options includes increasing energy efficiency and energy conservation; switching to non-carbon-based fuels such as renewable energy sources, nuclear power, or hydrogen power; and carbon capture and sequestration.

B. Sequestration Options

In general, carbon sequestration reduces net CO_2 emissions by storing CO_2 instead of releasing it into the atmosphere. More specifically, sequestration activities generally fall into one of two main categories: terrestrial and geological.

The U.S. Department of Energy defines terrestrial sequestration as "the enhancement of CO_2 uptake by plants that grow on land and in fresh water," and carbon storage in soils"[3] as well as "the prevention of CO_2 net emissions from the terrestrial ecosystems into the atmosphere."[4] Successful terrestrial sequestration, then, can be achieved by manipulating natural processes to maximize CO_2 uptake and by protecting areas that naturally have high uptake of CO_2, like forests.

This could involve, for example, changing management of agricultural lands to low- or no-till farming methods, which decreases the decomposition of organic material, keeping carbon in the soil; planting winter cover crops that would continue to use CO_2 from the atmosphere, rather than leaving cropland empty during times of the year when economic crops are not normally grown; conversion of marginal cropland to forests or grasslands; reclamation of abandoned mine lands through reforestation, choosing tree species that are fast growing and long lived and would therefore use a large amount of CO_2 over their lifespan; and planting grazing lands with grass species that will maximize CO_2 uptake.

Another terrestrial sequestration option being developed is the concept of the algae farm. In this process, CO_2 is separated and captured from the exhaust stream. The CO_2 is then passed through colonies of algae, which use the CO_2 in photosynthesis, effectively storing the carbon. The algae can later be converted to biofuels. This concept is currently in the very early stages of development.

For geological sequestration, CO_2 is separated and captured at the source—for power plants, this can occur either pre- or post-combustion—and then transported to a location where it is injected into a suitable geological formation deep underground.

C. State of the Technology

Carbon capture, transport, and geological sequestration are all developing technologies, with some forms closer to commercial implementation than others.

1. Carbon Dioxide Separation & Capture [a, 20]

The goal of CO_2 capture is to concentrate the CO_2 stream from a CO_2-emitting source for future transport and injection at a storage site. It is necessary to achieve a highly concentrated, highly pure CO_2 stream for practical and economic reasons. Large volumes of dilute CO_2 would require large compression and transport equipment and would result in very high energy costs to compress the gas to storage conditions. As a result, it is necessary to concentrate the carbon dioxide stream prior to compression and transport. Capture processes are currently used commercially in industrial chemical production and natural gas separation processes. These processes demonstrate concept feasibility and lend credibility to future plans to capture large quantities of CO_2 from power plants. However, it should be noted that CO_2 capture is not currently deployed at any large power plants.

There are several major methods of capturing CO_2 from a power plant, each of which can be characterized as either pre-combustion or post-combustion capture technology. Using these methods, carbon dioxide is removed from the plant process either before or after the fuel has been combusted to reduce or eliminate the carbon dioxide emissions entering the atmosphere.

Pre-Combustion
Pre-combustion capture technologies include gasification technologies and are practiced widely in ammonia production plants. Gasification technologies enable the production of a synthesis gas, or syngas, composed mainly of hydrogen and carbon monoxide. This syngas is converted to a mixture of hydrogen and CO_2 by reacting the carbon monoxide in the syngas with steam and passing the mixture through a “shift” reactor. The result is a mixture of hydrogen and CO_2, which can be passed through a CO_2 removal system. The CO_2 is removed from the mixture by passing the gas through a solvent in an absorber column. The solvent is regenerated and reused in the process. While the process is multi-stepped and more complex than post-combustion methods, the higher concentration of CO_2 (roughly 50%[5])and the higher operation pressures of these processes result in a more efficient removal of CO_2. Pre-combustion technologies would be employed at integrated gasification combined cycle (IGCC) facilities. Studies have concluded that the addition of CO_2 capture at IGCC plants would result in a cost-of-electricity (COE) increase of 20-70%[6].

Post-Combustion Methods (Flue-Gas Separation)
Post-combustion capture technologies involve the removal of CO_2 from combustion exhaust flue gases, at atmospheric pressures. Carbon dioxide is absorbed from the flue gas by using a liquid solvent. Post-combustion capture uses either air combustion or oxy-fuel combustion. The removal of the carbon dioxide is similar in each method; the difference lies in the composition of the exhaust gas that is treated.

A pulverized coal power plant would typically require post-combustion technology to remove CO_2. Post-combustion capture technologies remove CO_2 from the flue gas with the use of a solvent. For systems considered in advanced pulverized coal power systems, monethanolamine (MEA) is a typical solvent that would be used to remove CO_2. This solvent process was developed over 60 years ago to remove CO_2 and H_2S from natural gas streams. In this process, flue gas is passed through an MEA solution in an absorber column. The MEA solution absorbs the CO_2 from the flue gas, and the solution is then sent to a stripper column. The solution is boiled in the stripper column, and the CO_2 is released from the MEA solution, resulting in a highly concentrated CO_2 stream leaving the stripper, while the MEA solution is recycled back to the absorber.

[a] This section was in large part contributed by WorleyParsons. Specific statistics are from other sources, where noted.

The efficiency of this process is highly dependent on the concentration of the CO_2 in the flue gas. Higher concentrations of CO_2 result in greater removal efficiencies. Because conventional pulverized coal power plants use atmospheric air for combustion, there is an abundant amount of nitrogen in the flue gas, resulting in a dilute CO_2 stream (typically only 3-15% of the flue gas[6]). The combination of the dilute CO_2 stream and the large volumetric flow of gas to be treated (due to atmospheric pressure) results in the need for a large and high-energy-consumption facility to remove CO_2 from this type of plant. Capture costs have been investigated in numerous engineering studies, and the addition of CO_2 capture to an advanced pulverized coal plant is estimated to result in a cost-of-electricity (COE) increase of about 34-87%.[(e.g. 6, 7)]

Because conventional coal power plants use atmospheric air for combustion, CO_2 removal technologies must be designed to treat diluted flue gas streams. An alternative to these technologies is an oxy-fuel combustion technology, which is currently in the early stages of development. This technology requires an air separation plant to provide high-purity oxygen for coal combustion. The result is a flue gas stream with a higher CO_2 concentration (>80%[8]), with the remainder of the gas composed of water vapor. The water vapor is removed by cooling the mixture, and the resultant highly pure CO_2 stream is compressed. Further purification of the gas stream may be required to remove components such as nitrogen and air pollutants from combustion.

2. Carbon Dioxide Transport [b, 20]

Transport of CO_2 is necessary when storage locations are not in the immediate vicinity of the capture site. For ease of transport, CO_2 is generally compressed to approximately 95 atm (9.6 MPa).[9]

Pipeline Transport of CO_2
Carbon dioxide has been transported long distances by pipelines since 1970.[9] In the United States, over 2,500 km of pipeline transports more than 50 metric tons of CO_2 per year from sources to sites mainly in Texas, where CO_2 is used for enhanced oil recovery.[9] A pipeline also transports CO_2 320 km from the Great Plains Synfuels Plant in Beulah, ND, to Weyburn, Saskatchewan, where the CO_2 is also used for enhanced oil recovery.[10] These pipelines are operated at high pressures, sometimes employing booster compressor stations at intermediate locations.

Pipeline Design
Moisture-laden CO_2 is highly corrosive and would require pipeline designs with stainless or corrosion-resistant alloys. Dry (moisture-free) CO_2 is required to prevent corrosion of carbon steel piping, which is tolerant of other contaminants such as oxygen, hydrogen sulfide, and sulfur and nitrous oxides.

Monitoring and Pipeline Safety Considerations
CO_2 could leak to the atmosphere during transport. As a result, pipeline transport of CO_2 through populated areas requires a design approach similar to that of natural gas, namely detailed route selection, over-pressure protection, leak detection, and other design factors.

3. Carbon Dioxide Sequestration

CO_2 storage as a response to climate change has been developing since Marchetti proposed ocean sequestration in 1977.[11] Although CO_2 injection for the purpose of enhanced oil recovery (EOR) has been occurring since the 1970s, the concept of long-term geological sequestration of the gas is relatively new, proposed in the early '90s.[12] Research into both areas has been occurring globally in recent years.

Several international organizations have been recently focused on the sequestration issue. The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environmental Programme in 1988 to "assess on a comprehensive, objective, open and

[b] This section was in large part contributed by WorleyParsons. Specific statistics are from other sources, where noted.

transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation." The IPCC is not a research organization but mainly bases its assessments on peer-reviewed scientific literature. Over the years, the Panel has produced numerous assessments, technical papers, and special reports related to the state of the science of climate change. The most recent publication released by the IPCC was the September 2005 *Special Report on Carbon Dioxide Capture and Storage*, dedicated solely to geological sequestration and its effects on climate change. The Carbon Sequestration Leadership Forum (CLSF) was established in 2003 to foster research and development of carbon sequestration and to identify research gaps. The CLSF currently comprises twenty-two countries, including the United States.

Several large-scale geological sequestration projects are currently in operation, and more are scheduled to come on line in the future. Statoil operates the Sleipner project in the North Sea, which separates and captures CO_2 from the offshore natural gas production platform and reinjects the CO_2 into a saline aquifer beneath the sea floor. Beginning operation in 1996, Sleipner was the world's first commercial-scale sequestration project.[12] According to Statoil, the Sleipner project has so far sequestered approximately 1 million tonnes of CO_2 per year since the project's start. Statoil's Snohvit natural gas production complex in the Barents Sea will begin operation in 2007, which will include reinjection of CO_2, as at Sleipner. The company has also recently signed an agreement with Shell to co-develop the world's largest offshore EOR project using CO_2, in Norway.[13]

The U.S. has also been involved in sequestration research. Under the international collaboration of the Weyburn Project, CO_2 produced at a gasification plant in North Dakota is being piped into Saskatchewan and sequestered into oil fields for EOR.[10] The Frio Brine Pilot Project, run by the Gulf Coast Carbon Center, injected 1600 tons of CO_2 into a saline aquifer off the coast of Texas and is continuing to research the feasibility of sequestration in the Gulf.[14] The FutureGen clean coal power plant project will include geological sequestration as part of its plan to achieve zero CO_2 emissions.[15] The U.S. DOE sponsors a carbon sequestration research and development program that aims to lower the cost incurred with CO_2 capture and to understand the factors that influence underground storage performance.[16] EOR tests using CO_2 have been performed in the Appalachian Basin, in formations similar to those found in New York State.[17]

Separately, DOE's National Energy Technology Laboratory created the Regional Carbon Sequestration Partnerships program in 2003 to assess the opportunities for sequestration throughout the U.S., in preparation for a future that may require sequestration. Forty states were grouped into seven regional partnerships, each tasked with assessing sequestration options within their region, including both terrestrial and geological opportunities. In their geological studies, the regions are including saline aquifers, depleted oil and gas reservoirs (along with EOR and enhanced gas recovery, or EGR), unminable coal beds with methane recovery, shale formations with EGR, and even basalt formations. The partnerships have also been studying the regulatory framework and other issues that would accompany large-scale implementation of sequestration. By the conclusion of the partnership program, NETL envisions that twenty-five test wells will be drilled throughout the seven regions to further characterize the most promising geological sequestration opportunities.[18]

New York State's own involvement in carbon sequestration is in the very early stages of development. A joint project in the mid-1990s by Hydrocarbon Generation, Inc., NYSERDA, and DOE investigated EOR in Cattaraugus County, NY, using CO_2 from flue gas, although the focus was not on long-term storage of the CO_2. The New York State Museum, which houses the New York Geological Survey, is in the initial stages of characterizing the geology of New York in relation to carbon sequestration options.

In cooperation with NYSERDA, the NYS Museum is also in negotiations with Battelle, the lead agency for the Midwest Regional Carbon Sequestration Partnership (one of the NETL's seven), or MRCSP, to join the Partnership as a research agency. Phase I of the program consists of identifying possible suitable sites for geological sequestration throughout New York State, in addition to integrating New York's intellectual data and network of businesses and agencies into the Partnership. Phase II activities will involve field validation tests of

promising sequestration opportunities, with a possibility of eventually having a demonstration well drilled in New York State.[19]

On the terrestrial front, a NYSERDA project is focusing on the algae farm concept in western New York. The current study is testing the commercial viability of using algae to consume CO_2 and heat from power plant exhaust and converting the algae into biomass.

D. Preliminary Report on Geological Carbon Sequestration in New York [c]

The following information was provided by the New York State Museum. This should be considered preliminary guidance information. Inclusion of a site's location within a "green" area of sequestration potential does not guarantee that sequestration is possible at that site. Much more research and site-specific analysis needs to be done before any conclusive answer can be given to the question of carbon sequestration potential in New York State.

1. Summary

This report summarizes a preliminary look at geological carbon sequestration potential in New York. This is the first phase of a planned four-year project on geological carbon sequestration that will be conducted by personnel at the New York State Museum. In summary:

- Geological sequestration means storing CO_2 underground in subsurface geological formations in such a manner that it will not escape for thousands of years.
- CO_2 occurs in four phases: liquid, gas, solid and supercritical fluid. Most geological sequestration should be done in the supercritical phase which requires higher pressures and temperatures only found at depths of at least 2500 feet.
- In New York, the best options for geological sequestration currently available are deep saline aquifers and depleted oil and gas reservoirs. These all occur in sedimentary rocks of central and western New York. The number of potential formations for sequestration increases from north to south because the layers all get deeper to the south. There is little potential north of the Mohawk River and east of the Hudson River. The Southern Tier offers the most potential sequestration opportunities.
- There is also good potential for carbon sequestration offshore either in saline formations or in ocean sediments, but this would require significant infrastructure investment.
- There is some potential to store CO_2 in caverns dissolved into deeply buried salt layers, but there is a major problem disposing of the dissolved salt that may make this uneconomic.
- Other more theoretical options include shale storage and mineral carbonation. These require more study before they can be considered real options. Some of these ideas could open up a wider area of potential sequestration opportunities if they can be demonstrated to work on the scale necessary.
- CO_2 has been used successfully in other states for enhanced oil recovery (EOR). EOR is not likely to be a major sink for CO_2 in New York because most of the oil reservoirs in the State are less than 2500 feet deep and have many old unplugged and decrepit wells where the CO_2 might escape to the surface or into potable groundwater.
- There is some potential in the State for enhanced gas recovery (EGR) using CO_2. This could be part of the solution and provide some economic benefit. It is not currently known how much CO_2 could be disposed of in this manner and if producers would be willing to try this unproven concept.

The planned NYSERDA- and DOE-funded study by the New York State Museum will help to better understand sequestration options available within the state.

[c] This section was in large part contributed by the New York State Museum.

2. Carbon Dioxide Properties

Carbon dioxide can exist in four phases: a solid, liquid, gas, or supercritical phase which acts as both a gas and a liquid (Figure 1). In the supercritical fluid phase, the CO_2 will fill space like a gas, but have the density of a liquid which makes it the ideal phase for sequestration. Several hundred times more CO_2 can be stored in the same pore volume in the supercritical phase than can in the gas phase (which is how it occurs at surface pressures and temperatures). In order to get CO_2 to the supercritical phase, it must be at a temperature of at least 31.1°C (87.8°F) and a pressure of at least 7.38 MPa (72.8 atm). Given the normal geothermal gradient in New York, these pressures and temperatures will occur at depths greater than approximately 2500 feet (800 m). Any formation that is buried to a depth of less than 2500 feet will be designated as unsuitable for supercritical CO_2 sequestration. CO_2 could be sequestered as a gas in these areas, but the volume of pore space required will go up by several hundred times. In a state where porosity in the subsurface is not very common, this effectively eliminates from serious consideration the areas where the storage aquifers are less than 2500 feet from the surface.

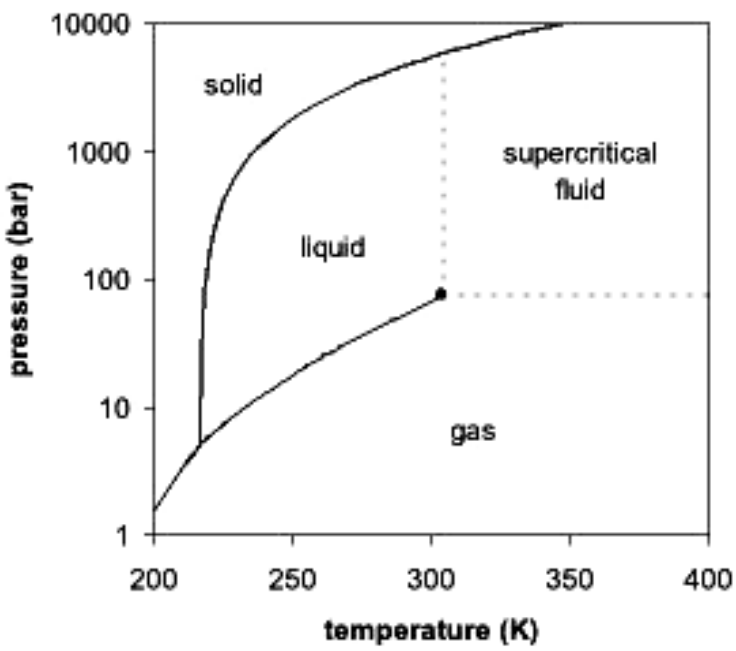

Figure 1. Physical properties of CO_2.

3. Possible Geological Sequestration Options in New York

The five types of geological sequestration currently under consideration by the NYSM are depleted oil and gas reservoirs where the CO_2 could be stored or used for enhanced oil and gas recovery (EOR and EGR), deep saline aquifers, salt caverns, shale, and mineral carbonation. The last two of these, shale and mineral carbonation, are in the earliest stages of research and may or may not work for large-scale sequestration. If shale can be used as a sequestration reservoir, a much wider area in the state opens up for potential sequestration. Mineral carbonation opportunities would be smaller in volume, but they all occur near New York City, which adds some appeal. We will be following research into shale and mineral carbonation sequestration very closely to see if these may be applied in New York State.

Oil and Gas Reservoirs

CO_2 can be injected into depleted oil and gas reservoirs in the western part of New York State for either permanent sequestration or enhanced oil and gas recovery (see Figure 2). If reservoirs trapped economic quantities of oil and gas, then it is very likely that they will be safe carbon dioxide sequestration reservoirs. Many of the depleted gas reservoirs in the state are deeper than 2500 feet, so it is likely that the CO_2 could be

stored as a supercritical fluid. However, depleted reservoirs currently used for natural gas storage would probably not be good candidates for CO_2 sequestration for economic reasons—why turn a money-making storage field into a non-money-making CO_2 sequestration field? The best depleted reservoir option is probably the Medina Formation, which has produced a substantial amount of gas and has significant capacity but is generally unsuitable for natural gas storage. Figure 2 displays all existing reservoirs, however, and considers them potential sequestration targets.

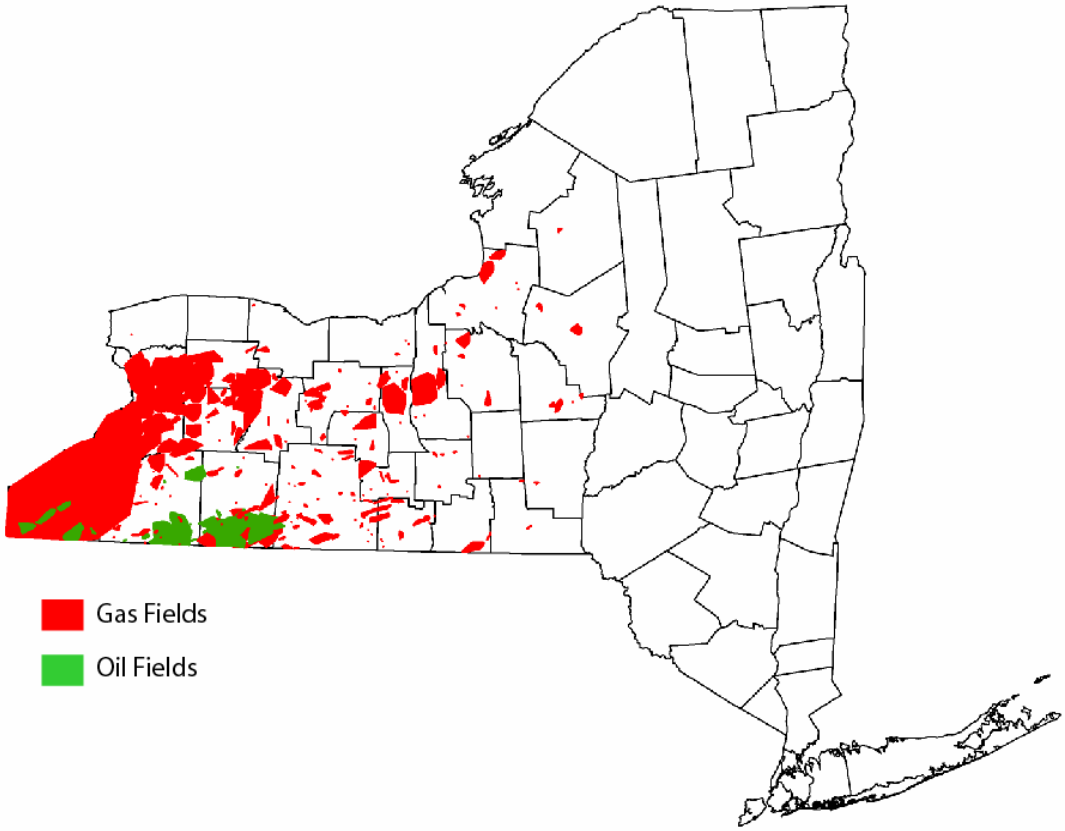

Figure 2. Oil and Gas Fields of New York. These fields are in many different stratigraphic layers, not all of which are below 2500 feet.

Enhanced Oil Recovery (EOR)

Oil is commonly first produced by natural flow (primary recovery), followed by a water flood (secondary recovery), in which water is injected around producing wells to help maintain pressure and sweep more oil out of the reservoir. In some cases, water floods have been successfully followed by CO_2 floods. In successful floods of this type, CO_2 is injected into the reservoir, where it mixes with the remaining oil and decreases its viscosity, allowing the oil to flow more easily out of producing wells. Successful CO_2 floods have helped to produce up to 20% more oil from oil reservoirs in the western US and Canada. Approximately 70 oil fields worldwide currently inject CO_2 for EOR (U.S. DOE, 2004). Most successful floods are miscible CO_2 floods, in which the CO_2 is at or near the supercritical phase, so reservoirs need to be at a depth of at least 2500 feet. With exception of the Bass Islands Trend in Chautauqua County, most of New York's oil reservoirs are buried to a depth of less than 2500 feet. There are also many old wells in the oil fields that have not been plugged or that have very poor, old cement caps that might allow CO_2 to escape to the surface or into the potable groundwater. This makes EOR much less attractive in New York. Some CO_2 may be disposed of into these fields, but there will be additional costs.

Enhanced Gas Recovery (EGR)

In gas fields, as gas is removed from the reservoir, the pressure of the reservoir decreases, making it difficult to recover all of the gas in place. CO_2 is denser than the methane gas (CH_4) that is produced in most natural gas reservoirs. As CO_2 is injected, it sinks to the bottom of the reservoir and slowly increases the pressure, pushing the remaining CH_4 up to producing wells near the top of the reservoir. Once the reservoir is completely drained of methane and filled with CO_2, the CO_2 could be stored there permanently. Some supercritical CO_2 could also be used as a "cushion gas" in natural gas storage reservoirs, where it is important to leave some gas in the reservoir at all times. There is great potential for EGR in New York. The forthcoming study by the NYS Museum will help determine the volume that may be sequestered in this manner.

Saline Formations

Saline formations represent the greatest opportunity for large-scale geological sequestration. The water in these formations is very salty—more than six times saltier than seawater—so it cannot be used for drinking water. It would be imprudent and against regulations to store CO_2 in formations that contain fresh water, but most of New York's formations that are below the critical depth of 2500 feet contain very saline fluids. There are several formations that may have potential to store supercritical CO_2. In this type of reservoir, pressurized CO_2 is injected down a specially constructed well into the reservoir, where it displaces and mixes with the saline water, fills the pore spaces between the mineral grains of the rocks, and is trapped within the rock matrix. As with depleted hydrocarbon reservoirs, there must be a seal or caprock that will not allow the CO_2 to escape. Salinity makes the water undesirable as drinking water, but it also makes it less receptive to CO_2. The saltier the water is, the less CO_2 it can dissolve. However, even the saltiest water will mix with significant quantities of supercritical CO_2.

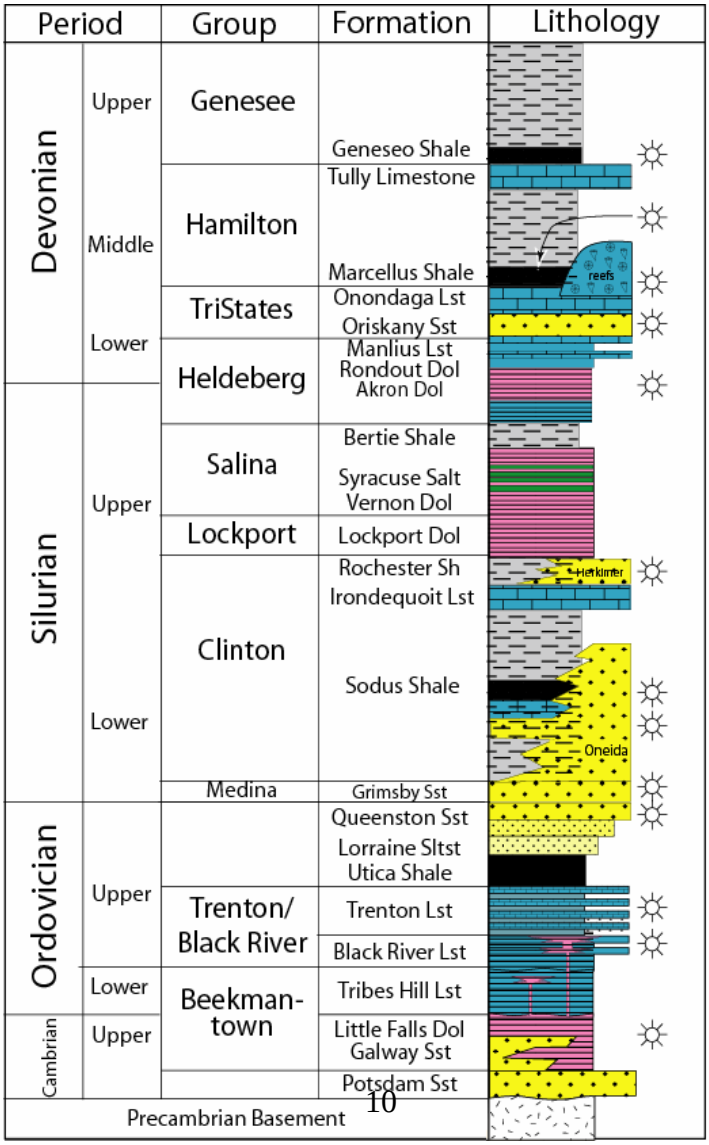

Figure 3. Stratigraphic column with producing gas formations in Central New York. Formations that have produced gas (those with the "sun" symbol next to them) are possible sequestration targets

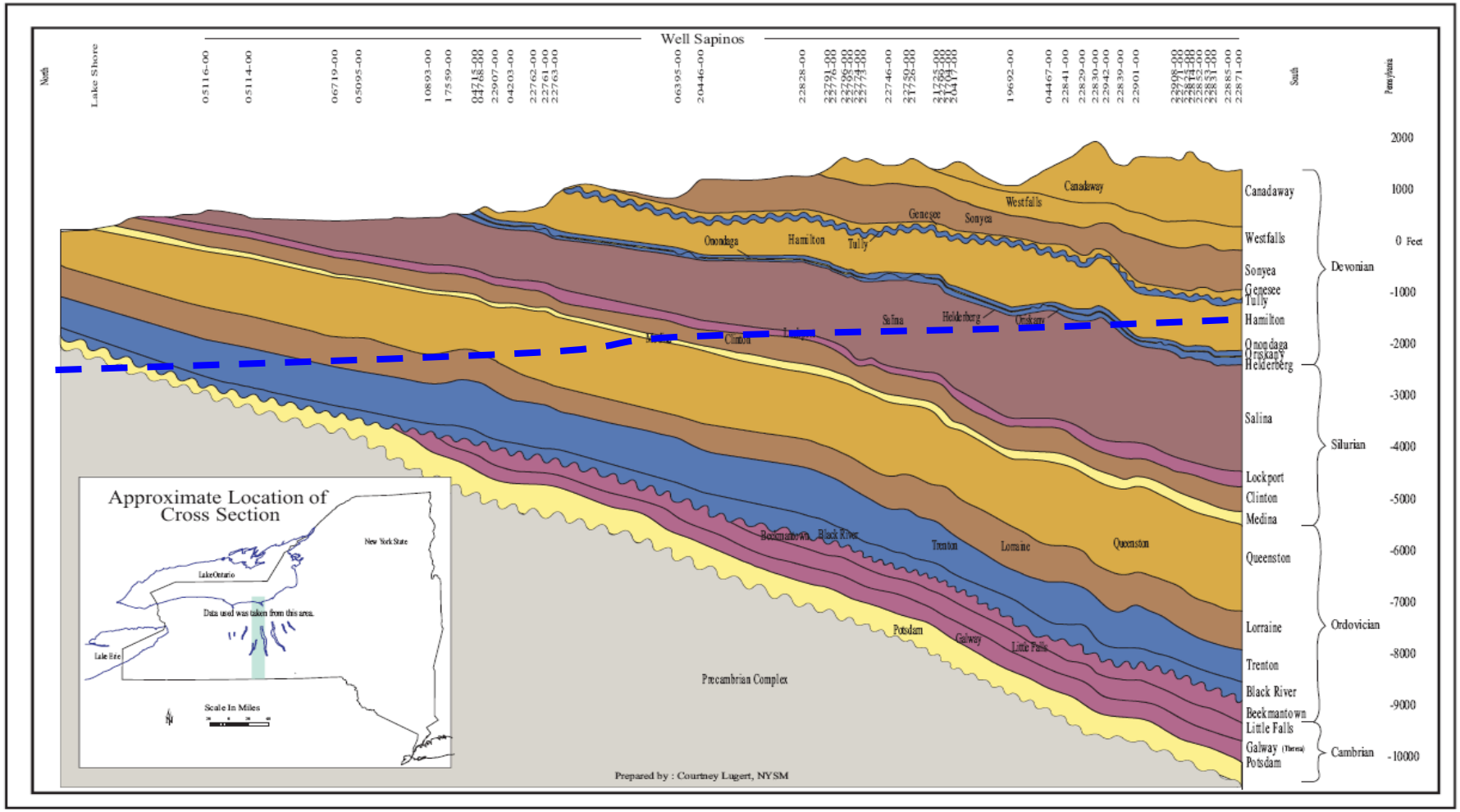

Figure 4. North–South Cross Section showing regional dip to south. Blue dashed line is approximately 2500 feet below the surface; all formations have potential for supercritical CO_2 storage where they fall below this line.

In New York, saline formations occur in sedimentary rocks that include limestone, dolomite, and sandstone. Aquifers generally have a relatively high porosity, which means that there are very small holes in the rock that can store oil, gas, water, or CO_2. The permeability of the rock is essentially the connectedness of the pores and determines how a material will flow within the formation. Without porosity and permeability, it is very difficult to store anything in the rocks. Rocks with low permeability (such as shale and evaporites like salt) are generally called seals, and they keep the oil, gas, water, or CO_2 trapped in the porous and permeable rocks below them. The sedimentary rocks of New York are shown in Figure 3. The Precambrian, shown at the bottom of the figure, consists of igneous and metamorphic rocks that are not thought to have any potential to store CO_2.

To date, over 32,000 wells are known have been drilled into the subsurface of New York, with over 79,000 formation tops existing from 15,000 of those wells. From these data, structural contour and isopach maps can be made for potential sequestration targets and seals. This data can also provide initial information on porosity of formations and the potential for CO_2 sequestration.

In New York State, the formations all get deeper to the south. Formations that outcrop on the surface near Lake Ontario are up to 10,000 feet deep near the Pennsylvania border (Figure 4). Because of that general *dip* to the south, there is a line that denotes where most of the formations cross from being less than 2500 feet deep, where CO_2 could not be stored in a supercritical state, to where those same formations are more than 2500 feet deep and therefore become possible supercritical-CO_2 sequestration reservoirs (Figures 4, 5, and 6).

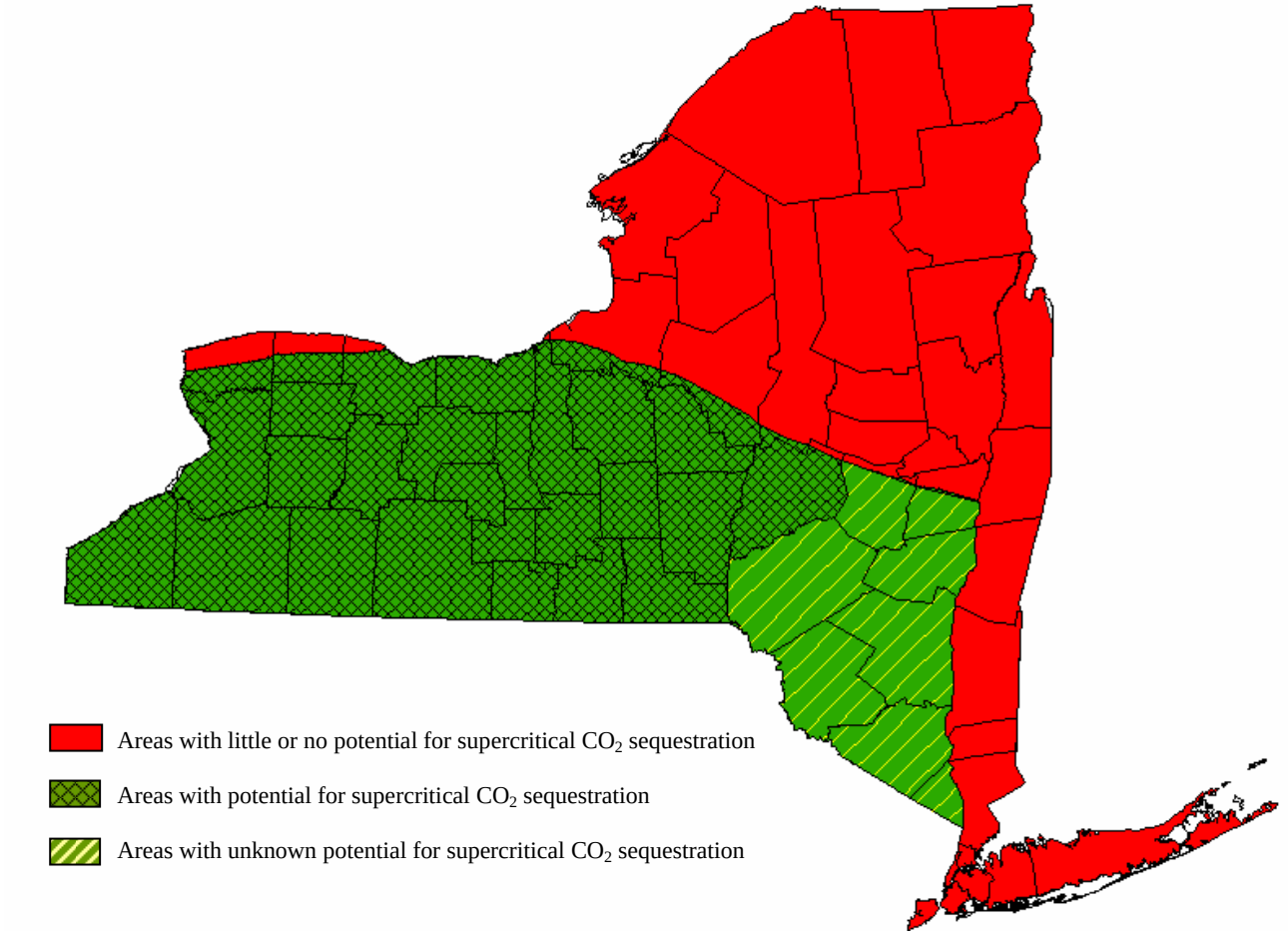

Figure 5. Potential areas for saline aquifer and depleted reservoir storage of supercritical CO_2.

Figure 5 is a simplified map of the potential for CO_2 storage in New York State. It shows areas with known potential for supercritical storage in green, unknown potential in green with yellow stripes, and no potential in

red. Although the Catskill Park (in blue) may have *geological* potential for sequestration, the area has been blocked out as not available for sequestration, due to permitting and other issues. Areas with potential contain sedimentary rocks that are buried to at least 2500 feet and for which subsurface data exists. There are several counties near the Catskills where the sedimentary rocks are deep enough, but the potential is unknown because there is very little or no data on the subsurface in these areas. These include Sullivan, Orange, Ulster, and Greene Counties. More data will be needed before these counties can be evaluated for CO_2 sequestration potential. Areas of no potential have no sedimentary rocks that are more than 2500 feet deep.

Several maps have been prepared that show where each of several potential formations crosses that line. (The maps have been summarized in Figure 6. The individual maps can be obtained from the New York State Museum Reservoir Characterization Group.) For each map, the area where that formation is less than 2500 feet deep is colored red, and the area where it is more than 2500 feet deep is colored green. The green areas cover locations where there is potential for supercritical CO_2 storage. The 2500-foot line moves progressively farther south for younger and younger formations (Figure 6). For each map, all formations that age and older have potential. For example, on the Cambrian Potsdam Formation map, only the Potsdam has potential because everything below that is impermeable Precambrian basement. But on the Late Ordovician Queenston map, the Queenston and all older sedimentary formations (such as the Trenton, Black River, Tribes Hill, Galway, Little Falls, and Potsdam) all have potential. Therefore, power plants built in the southern parts of western New York have more possible targets for CO_2 sequestration than those in the northern half because there is a much thicker sedimentary rock section.

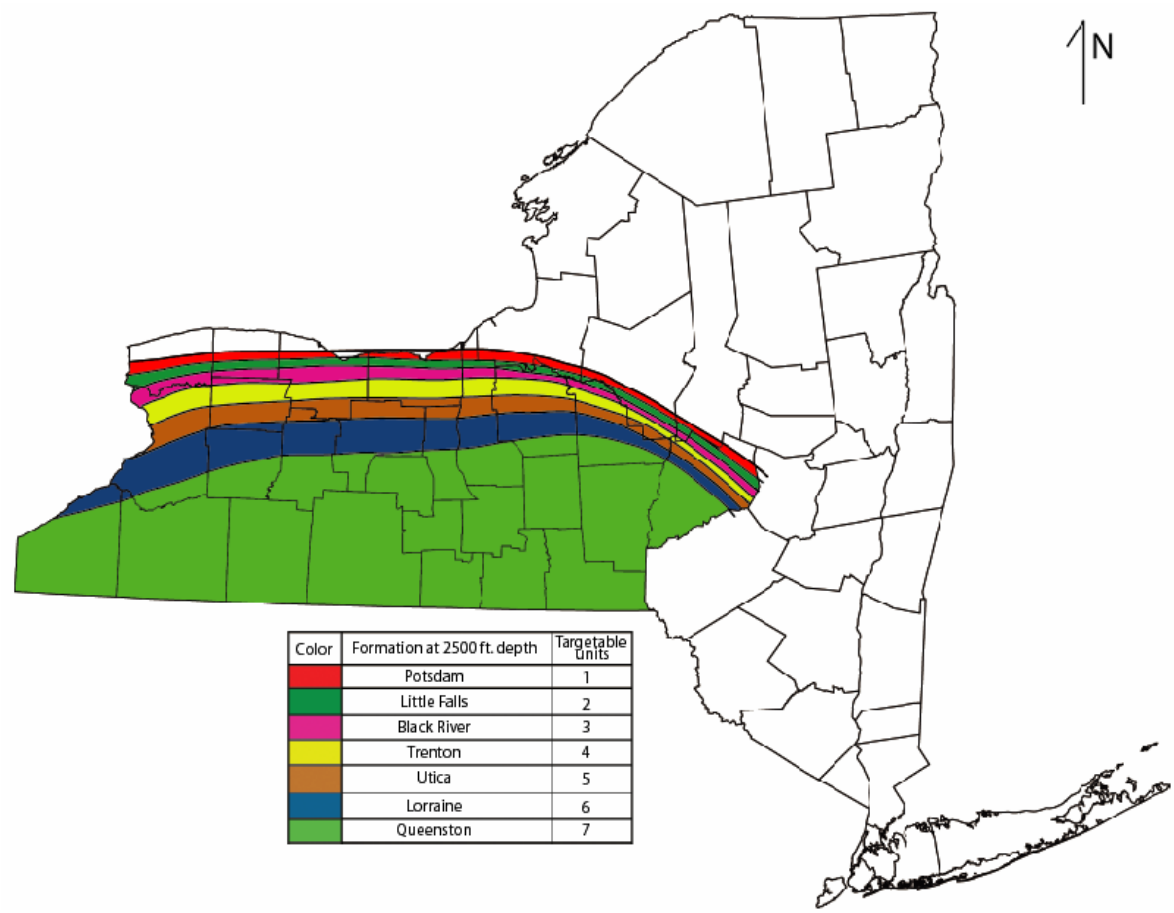

Figure 6. Potential for multiple sequestration targets increases to south.

There is no guarantee that *any* of the formations will have the necessary porosity and permeability for sequestration at any site, even in the green areas. Many formations have porosity and permeability in one part of the state but not in others. The NYS Museum's future work with the Midwest Regional Carbon Sequestration

Partnership (MRCSP) will help to refine understanding of the distribution of porosity and permeability in various potential CO_2 sequestration reservoirs across the state. Research will be completed and the full report available by the end of 2009.

Salt Caverns

There is some potential to store CO_2 in abandoned salt mines and solution-mined caverns. Salt mines are generally open to the surface and would therefore need a man-made seal that would keep the CO_2 in place. There is also some risk that the salt mines might collapse, releasing all stored CO_2 to the atmosphere. The mines are all less than 2500 feet deep, so the CO_2 would have to be stored as a gas, not a supercritical fluid; the gas phase requires several hundred times more volume to store than does the same amount of supercritical CO_2.

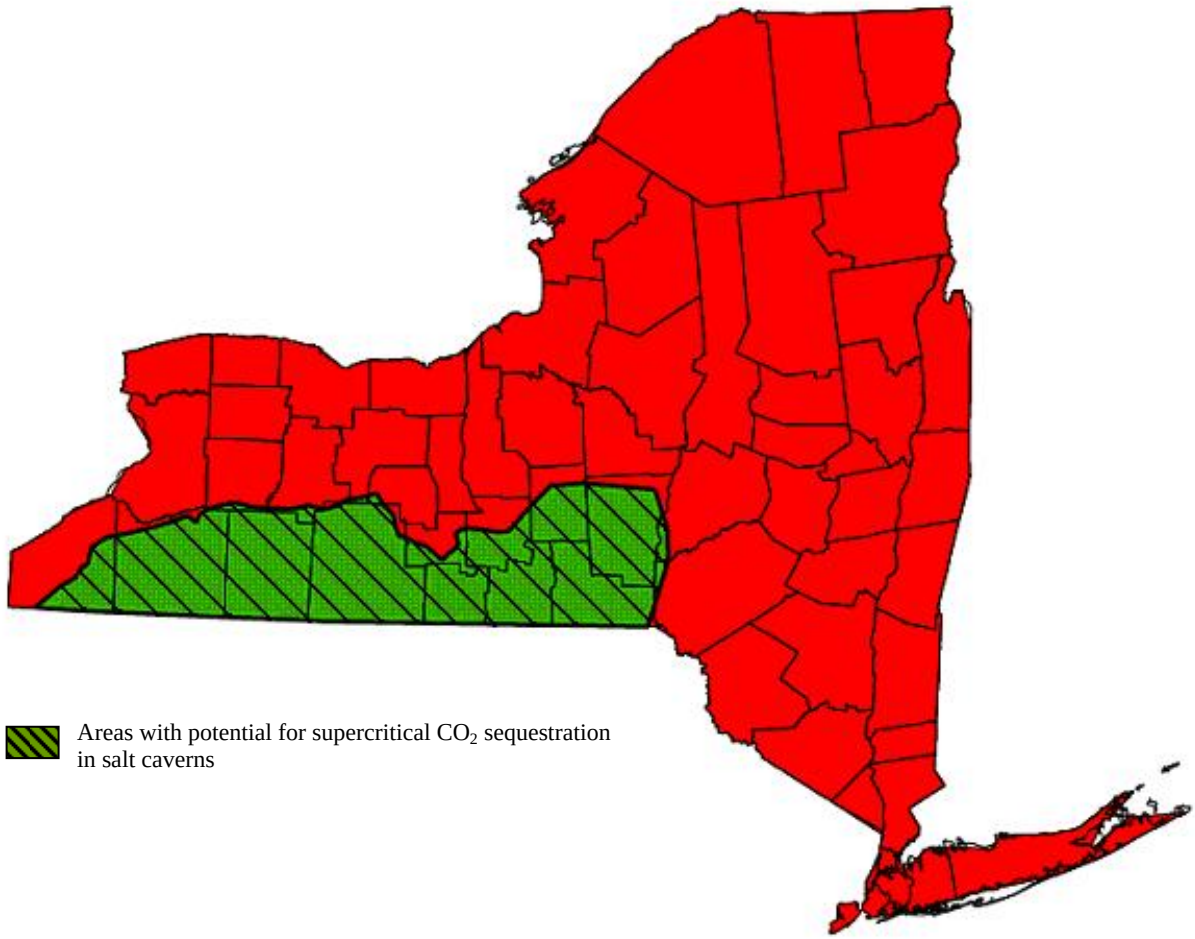

Figure 7. Area where salt is thick enough and deep enough to make successful supercritical CO_2 salt storage caverns. Red area has no potential; green has potential for supercritical CO_2 storage.

Salt caverns can be formed by solution mining where the salt is at greater depth. These salt caverns would be ideal for CO_2 sequestration if they were at a depth greater than 2500 feet. However, these caverns would also be ideal for natural gas storage and much more profitable. The problem with these caverns is that it is very difficult to dispose of the brine that is the product of the solution mining. It cannot be dumped on the surface in any large volume because it will kill all freshwater fish and other organisms. It might be injected into deep saline aquifers, but one might as well directly inject CO_2 into the aquifers. Because of the brine disposal problem, this is a very unlikely option for CO_2 sequestration; however, a map has been prepared to show suitable salt formations in the state.

Carbonaceous Shales

One of the more theoretical ideas for CO_2 sequestration is shale. Shales are usually seals for underlying reservoir rocks and are also source rocks for oil and gas reservoirs. Injection of CO_2 into carbonaceous shales might enhance any existing gas production with the added valued of long-term CO_2 storage at relatively shallow depths (Nutall, 2005). This could also be done at relatively shallow depths with CO_2 in the gas phase. This is currently highly theoretical and requires much additional study. If all shales can be used, this opens up the area where CO_2 sequestration to include much of the state (see Figure 8). Again, this approach might not provide the amount of storage needed, but it could be part of the solution. The possible areas for sequestration in shale appear in yellow in Figure 8, to highlight that this is an unproven technology.

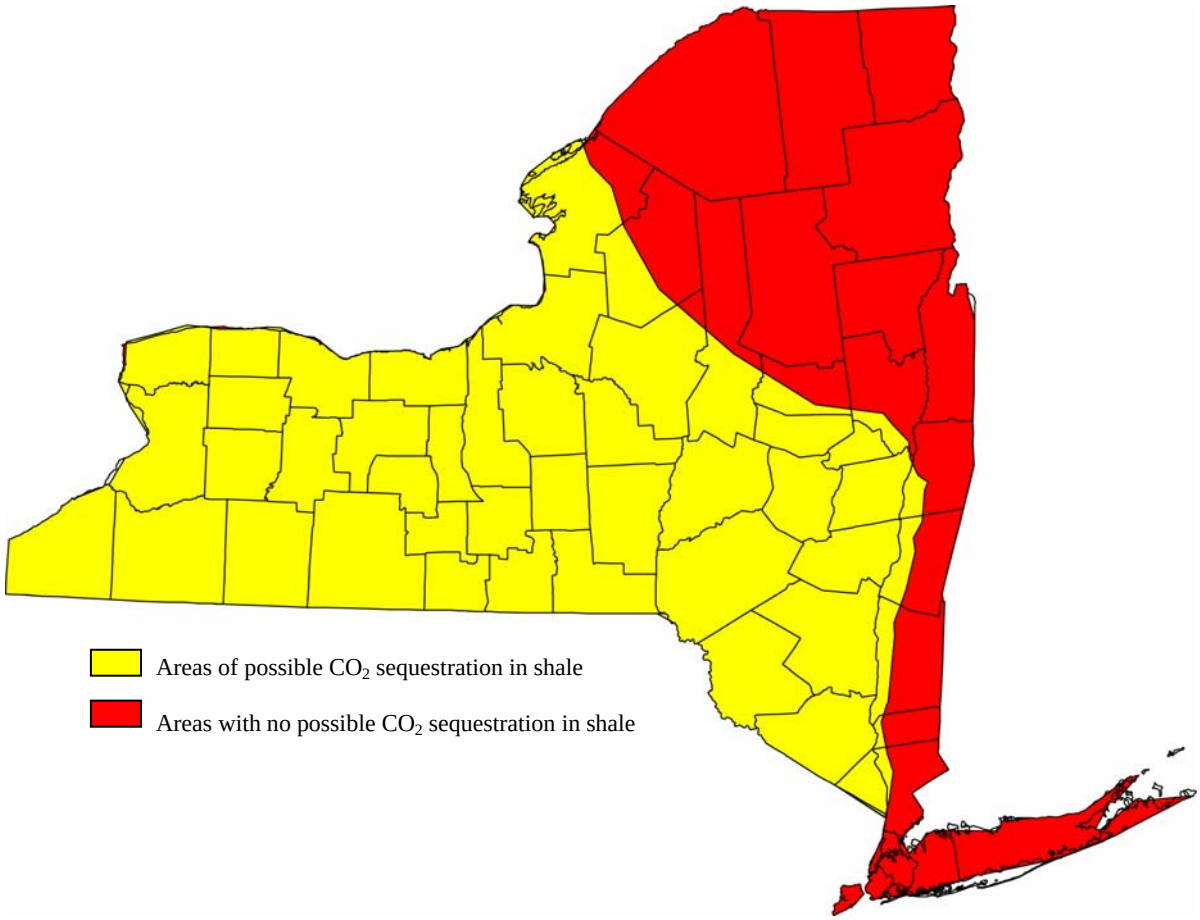

Figure 8. Area of possible shale sequestration if shale storage is deemed to be feasible.

E. Conclusion

In order to combat climate change, it is likely that a combination of strategies will need to be implemented to significantly reduce greenhouse gas emissions. This includes increasing energy efficiency, decreasing energy consumption, switching to non-carbon-based fuels such as renewable energy sources, and carrying out carbon capture and sequestration (CCS) operations wherever feasible.

Although no federal regulations regarding greenhouse gasses have been enacted thus far, individual states are taking their own actions. Collaboratives like the Regional Greenhouse Gas Initiative (RGGI) will soon regulate CO_2 emissions, and CCS may be needed to reach compliance levels. However, in order to be able to implement CCS strategies as swiftly as possible when the time comes, it is essential that research be carried out now, particularly in the case of geological sequestration.

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