# *Potential Carbon Sequestration Volumes in Indiana for Petroleum Fields, Aquifers, Coals, and Shales*

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## Abstract

The Midcontinent Interactive Digital Carbon Atlas and Relational DataBase (MIDCARB) was created by a consortium of five state geological surveys (Illinois, Indiana, Kansas, Kentucky, and Ohio) to investigate potential sources and options for geological carbon sequestration using distributed computing capabilities. As part of MIDCARB, an evaluation of Indiana's potential for carbon sequestration was determined.

Using geographic information system (GIS) tools to integrate the geological information available for oil and gas, shales, unminable coals, and deep-saline aquifers, the calculations obtained represent the maximum volumes available for carbon capture assuming that all pore spaces are contacted during injection. Such an ideal scenario is unlikely as variations in reservoir characteristics (i.e., porosity, permeability, and lithology) are ubiquitous and cannot be modeled accurately. Notwithstanding these uncertainties, the idealized assessment for carbon sequestration potential in geological formations in Indiana is: 1) **oil and gas reservoirs ~276 million, 2) unminable coal seams ~1.6 billion, 3) Saline aquifer ~74.5 billion, and ~7.8 billion metric tons in the 4) New Albany shale**.

Carbon sequestration volumes were calculated using ESRI ArcMap® software. Temperature, pressure, thickness, and porosity data were interpolated into raster grids as a proxy for estimating the overall distribution of each parameter. A Visual Basic® macro that adds the resulting values from the calculated raster data sets, while also taking into account the physical properties of $CO_2$, was created. For each reservoir type, three scenarios are presented in order to account for errors introduced through raster interpolations and inherent uncertainties from the absence of other parameters (i.e., permeability and water saturation values).

## 1) Oil and Gas Fields

Two different scenarios were considered: pools that are distributed at depths shallower than 2500ft (subcritical) and pools deeper than 2500ft (supercritical). Deeper pools, because of their ability to sequester $CO_2$ under supercritical condition, will volumetrically hold more $CO_2$. The $CO_2$ sequestration potential of abandoned and nearly depleted oil and gas fields in the state was determined using ESRI ArcGIS® tools and custom scripts for Visual Basic®. A total of 1,499 pools were digitized in ArcGIS® based on information available from the Petroleum Data Management System (PDMS) database of the Indiana Geological Survey. There are 620 oil fields in Indiana. The pools deeper than 2500ft are interspersed in 372 oil fields.

Reservoirs that occur at depths **shallower than 2500 ft**

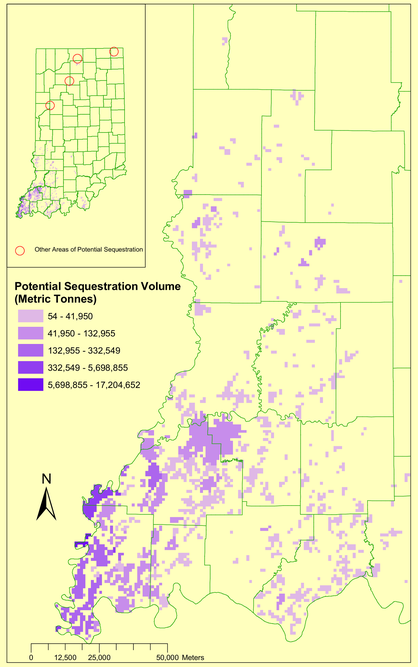
| Formation | Avg. Depth [ft] | Avg. Porosity [%] | Avg. Pressure [psi] | Avg. Temp. [°F] | Avg. Thickness [Ft] | Area [Acres] | No. of Wells | $CO_2$ Sequestration Potential [tonnes] |
|---|---|---|---|---|---|---|---|---|
| Pennsylvanian | 1,162.05 | 18.1 | 503.17 | 68.81 | 13.23 | 38,325.60 | 3,779 | 9,111,357.38 |
| Degonia | 1,793.77 | 16.5 | 776.70 | 74.37 | 8.92 | 2,077.60 | 95 | 631,391.36 |
| Clore | 1,881.90 | 16.5 | 814.86 | 75.09 | 13.10 | 1,380.70 | 65 | 523,932.29 |
| Palestine | 1,691.16 | 16.0 | 732.27 | 73.96 | 9.11 | 6,534.30 | 370 | 1,914,932.27 |
| Waltersburg | 1,840.83 | 17.4 | 797.08 | 75.73 | 15.74 | 15,618.72 | 1,339 | 54,251,192.70 |
| Tar Springs | 1,442.06 | 17.0 | 624.41 | 71.84 | 15.40 | 15,536.98 | 1,404 | 17,843,604.43 |
| Hardinsburg | 1,410.89 | 16.4 | 610.91 | 72.95 | 9.19 | 11,949.42 | 689 | 3,091,641.82 |
| Jackson | 1,085.53 | 17.5 | 470.03 | 70.46 | 10.56 | 20,692.97 | 1,614 | 4,108,903.39 |
| Cypress | 1,676.62 | 16.0 | 725.98 | 75.67 | 9.64 | 38,069.33 | 2,201 | 29,770,578.78 |
| Paint Creek | 1,104.29 | 13.1 | 478.16 | 71.17 | 8.57 | 1,817.82 | 85 | 193,210.90 |
| Bethel | 1,609.41 | 16.9 | 696.67 | 76.40 | 20.84 | 17,138.22 | 868 | 9,398,434.80 |
| Renault | 1,747.30 | 15.5 | 756.58 | 78.27 | 6.58 | 6,981.62 | 339 | 2,442,028.31 |
| Aux Vases | 1,541.84 | 14.9 | 667.62 | 76.03 | 14.65 | 16,107.45 | 765 | 4,453,166.43 |
| Ste. Genevieve | 1,641.12 | 12.7 | 710.60 | 76.63 | 7.11 | 28,786.01 | 2,168 | 8,127,223.29 |
| St. Louis | 1,735.31 | 12.3 | 751.39 | 78.61 | 13.69 | 2,927.04 | 116 | 1,325,049.89 |
| Salem | 1,613.69 | 13.1 | 698.73 | 77.55 | 10.42 | 9,081.67 | 412 | 2,505,994.93 |
| Harrodsburg | 1,954.33 | 10.0 | 846.23 | 83.41 | 8.29 | 3,479.80 | 165 | 1,450,745.51 |
| Borden | 1,310.67 | 8.5 | 567.52 | 73.75 | 16.33 | 362.63 | 14 | 49,674.68 |
| Devonian | 1,503.25 | 11.6 | 650.91 | 77.16 | 14.10 | 15,032.84 | 760 | 4,174,454.65 |
| Geneva | 1,446.57 | 13.1 | 626.37 | 76.75 | 10.00 | 1,739.42 | 82 | 198,167.60 |
| Silurian | 676.40 | 12.4 | 292.88 | 63.24 | 101.20 | 689.19 | 24 | 573,972.23 |
| Lexington | 217.33 | 8.0 | 94.11 | 57.17 | 49.00 | 222.18 | 6 | 14,950.61 |
| Knox | 1,442.50 | 12.0 | 624.60 | 74.42 | 39.33 | 940.91 | 46 | 606,036.41 |

The net sequestration potential estimated for oil and gas reservoirs that occur at depths shallower than 2,500 ft is 1.56 x $10^8$ tonnes. This scenario assumes 100% displacement and it does not take

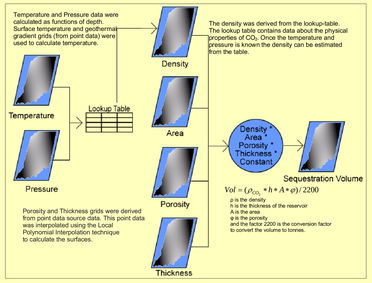
Reservoirs that occur at depths **deeper than 2500 ft**

| Formation | Avg. Depth [ft] | Avg. Porosity [%] | Avg. Pressure [psi] | Avg. Temp. [°F] | Avg. Thickness [Ft] | Area [Acres] | No. of Wells | CO2 Sequestration Potential [tonnes] |
|---|---|---|---|---|---|---|---|---|
| Tar Springs | 2,516.33 | 17.7 | 1089.57 | 82.39 | 12.33 | 1,953.69 | 456 | 3,663,528.43 |
| Cypress | 2,554.92 | 14.2 | 1106.28 | 81.90 | 8.85 | 2,782.82 | 136 | 3,638,037.72 |
| Bethel | 2,678.75 | 16.3 | 1159.90 | 83.99 | 9.25 | 2,495.93 | 117 | 4,094,035.78 |
| Renault | 2,748.63 | 14.3 | 1190.16 | 85.08 | 7.59 | 4,511.46 | 230 | 4,998,068.79 |
| Aux Vases | 2,723.02 | 14.0 | 1179.07 | 83.18 | 12.88 | 12,959.58 | 685 | 80,158,962.37 |
| Ste. Genevieve | 2,729.02 | 11.9 | 1181.67 | 84.64 | 9.06 | 9,106.16 | 943 | 10,139,022.23 |
| St. Louis | 2,956.00 | 12.8 | 1279.95 | 87.99 | 18.92 | 3,962.49 | 147 | 9,325,344.31 |
| Salem | 2,866.25 | 10.5 | 1241.09 | 90.43 | 10.00 | 2,428.11 | 102 | 1,849,789.75 |
| Harrodsburg | 3,309.75 | 10.0 | 1433.12 | 92.33 | 11.75 | 918.96 | 31 | 1,033,846.16 |

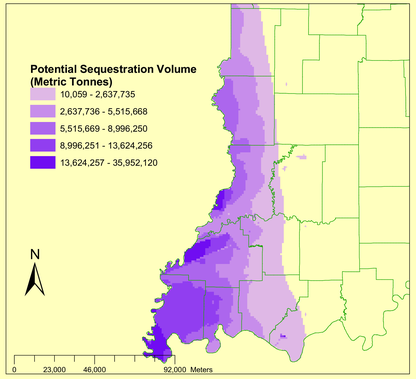
The net sequestration potential estimated for oil and gas reservoirs that occur at depths deeper than 2,500 ft is 1.18 x $10^8$ tonnes. Again, this scenario assumes 100% displacement and it doesn't take into account water saturations.




Map of Indiana showing the distribution of potential $CO_2$ sequestration volumes in Oil and Gas Fields

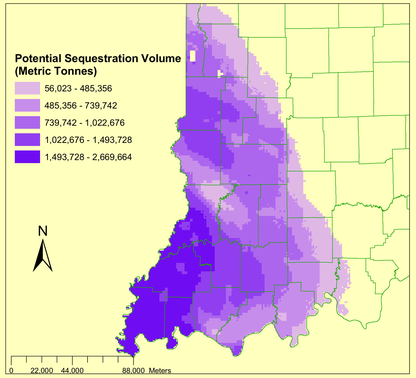



## 2) Coal Seams




Map of Indiana showing the distribution of potential $CO_2$ sequestration volumes in Coal Seams

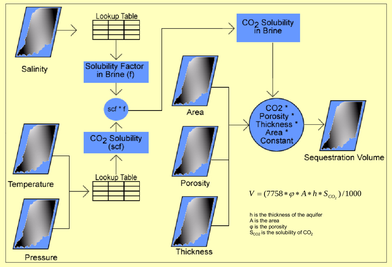
## 3) Aquifers



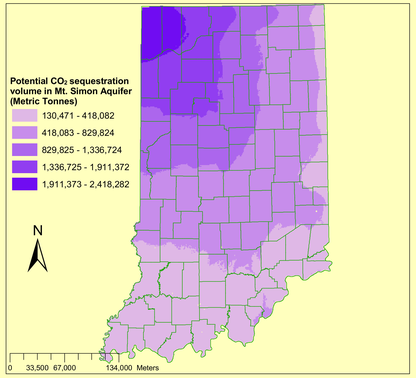

Map of Indiana showing the distribution of potential $CO_2$ sequestration volumes in the Silurian-Devonian (Hunton) Aquifer

Deep saline aquifers represent the largest sequestration potential option in the state. These units are generally widespread and relatively continuous with porosities that allow saline waters to flow through them at very slow rates over long periods of time.

The depth of these units is critical for maintaining the $CO_2$ injected under supercritical (liquid-like) conditions. In Indiana, calculations were done for two major sequences: The Silurian-Devonian (Hunton) carbonate aquifer system and the Cambrian Mt. Simon Sandstone. The former has an idealized sequestration potential of 20.4 Billion tonnes and 74.5 Billion tonnes for the latter, which is also considered the most attractive option because of depth and mineral composition.




The $CO_2$ solunility is determined as a function of temperature pressure and salinity. First a lookup table with the solubility of $CO_2$ in relation to temperature and pressure is used to determine the solubility and then the salinity (total dissolved solids) is used to determine the factor of solubility. The temperature and pressure are calculated in a similar manner to the oil and gas pool calculations. The salinity is a surface derived from point data. The porosity and thickness are also derivbed from point source data. ArcMap was used with geostatistical analyst to create the continuous data from the point source data.




Map of Indiana showing the distribution of potential $CO_2$ sequestration volumes in the Mt.Simon Aquifer

## Coal Seams and Shales

The $CO_2$-sequestration potential calculations in coals represent a series of simple mathematical operations on defined geographic information system (GIS) raster grids. The calculations are summarized in the flow diagram.

Nine major coal seams were selected for $CO_2$ sequestration calculations in Indiana. The table listed below indicates these units in stratigraphic order. Notwithstanding uncertainties in the assessment of net coal resources for various seams in the state, all the seams listed correspond to more than 90% of the identified resources (~35 billion tons).

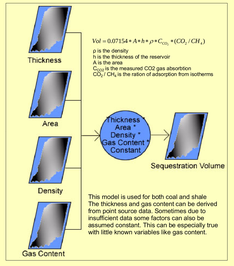
| Coal Bed | Original Resources (Billion short tons) | Density (g/cc) | Maximum $CH_4$ Adsorption at 400 psi (scf/ton) | $CO_2$:$CH_4$ Ratio | $CO_2$-sequestration potential area (Acres) | Average thickness (Inches) | $CO_2$-sequestration potential (Million Metric tons) |
|---|---|---|---|---|---|---|---|
| Danville | 5.53 | 1.38 | 202 | 3.5 | 507,055 | 30.97 | 64.25 |
| Hymera | -- | 1.38 | 154* | 2.0 | 617757 | 34.64 | 87.49 |
| Springfield | 4.13 | 1.38 | 142 | 4.6 | 942,203 | 51.28 | 259.62 |
| Houchin Creek | -- | 1.38 | 154* | 2.0 | 1,211,050 | 26.75 | 133.98 |
| Survant | -- | 1.38 | 154* | 2.0 | 1,338,060 | 33.57 | 183.65 |
| Colchester | -- | 1.38 | 154* | 2.0 | 1,487,310 | 16.92 | 103.03 |
| Seelyville | 12.85 | 1.38 | 128 | 4.6 | 1,560,210 | 42.49 | 321.68 |
| Upper Block | -- | 1.38 | 160 | 3.5 | 2,044,280 | 40.17 | 335.79 |
| Lower Block | -- | 1.38 | 150 | 2.0 | 1,427,270 | 29.02 | 170.22 |
| | | | | | | | |
| **Total for Indiana** | | | | | | | **1,659.71** |

* indicates average $CH_4$ adsorption

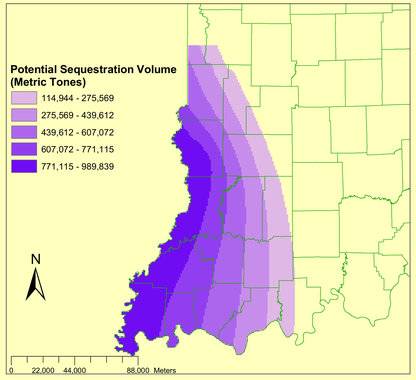
Calculations were done using a modified version of the standard GRI methodology for gas content estimation in coals. The general equation includes the ratio of preferential $CO_2$ sorption over $CH_4$ determined from adsorption isotherm studies. The density of Indiana coals was assumed to be constant and equal to 1.38 g/cc, and the maximum adsorbed gas content for each seam was used in the calculations.

By analogy with coals, the $CO_2$ sequestration calculation followed in shales used the standard methodology for gas content estimation. The density of the shales was assumed to be constant throughout the area where it occurs, and a cutoff value of 50 ft was used as minimum thickness suitable for $CO_2$ sequestration. The maximum gas content for the New Albany shale was also assumed to be constant throughout the area and equal to 50 scf/ton.

The idealized $CO_2$ potential sequestration of the New Albany Shale in Indiana is approximately 7.82 Billion metric tonnes.




## 4) Shale




Map of Indiana showing the distribution of potential $CO_2$ sequestration volumes in Shales

## Summary

The calculated $CO_2$ sequestration potential in geological reservoirs in Indiana is presented as three case scenarios: Ideal (100%) where all pores are contacted and filled; optimistic (70% of the total pore volume); and moderate (30% of the total pore volume). These percentage values are designed to consider variations in displacement and sweep efficiencies.

| Reservoir Type | Potential sequestration volumes (Million Metric Tonnes) | | |
|---|---|---|---|
| | Ideal (100%) | Optimistic (70%) | Moderate (30%) |
| Saline Aquifers* | 95,000 | 66,500 | 28,500 |
| Shale (New Albany) | 7,800 | 5,500 | 2,300 |
| Coal Seams | 1,600 | 1,100 | 500 |
| Oil and Gas | 276 | 193 | 83 |

* Includes the total for Mt. Simon and Hunton saline aquifers combined

http://www.midcarb.org
http://igs.indiana.edu