ASSESSMENT OF OIL AND GAS FIELDS IN INDIANA FOR CO_2 SEQUESTRATION

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MIDCARB

Midcontinent Interactive Digital Carbon Atlas and Relational dataBase

"A consortium of five state geological surveys investigating geological carbon sequestration through distributed computing over the network"

ISGS Illinois State Geological Survey

KGS

Sponsored by: United States Department of Energy
National Energy Technology Laboratory

ABSTRACT

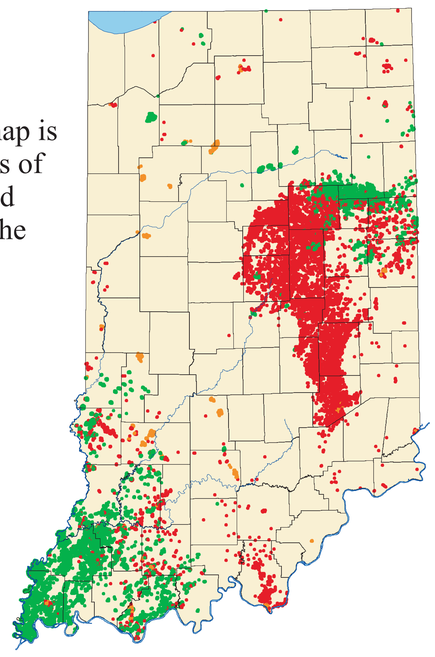
Atmospheric concentrations of CO_2, Earth's most voluminous greenhouse gas, are presently about 32 percent higher than at the onset of the industrial revolution, some 150 years ago. Sequestering CO_2 in subsurface reservoirs is one method that has been proposed to reduce the volume of CO_2 entering the atmosphere. The Mid-continent Interactive Digital Atlas and Relational dataBase (MIDCARB) Project, funded by the U.S. Department of Energy, is a consortium of five states (Illinois, Indiana, Kansas, Kentucky, and Ohio), that was created to construct a digital atlas containing the geological and cultural information necessary to evaluate the potential for capturing and storing CO_2 in geological formations. This atlas includes data on oil and gas fields, CO_2 sources, saline aquifers, geologic controls, and industrial and public infrastructure.

Oil and gas exploration in Indiana began in the late 1800s, and more than 600 oil and gas fields have been produced since that time. Most are at or near the end of their economic lives, having gone through primary, secondary, and even tertiary recovery. These fields are optimal candidates for the long-term storage of CO_2. A potential added benefit of storing CO_2 in nearly "dead" oil and gas fields is the recovery of additional petroleum.

An inventory of petroleum reservoirs in Indiana, including their size, production histories, and reservoir characteristics will help to determine the volume of CO_2 that could be stored and also will help to assess potential challenges that may be encountered.

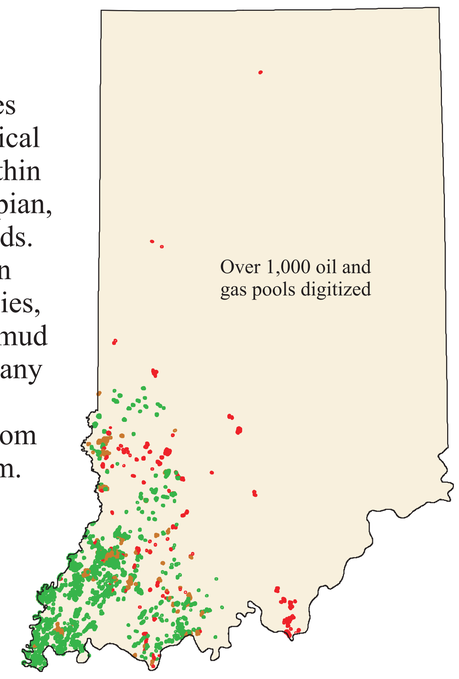
INDIANA PRODUCTION MAP

The Indiana production map is based on historical records of oil and gas exploration and production that began in the late 1800s.



CURRENT O&G MAPPING FOR CO_2 SEQUESTRATION

Current mapping includes data from twelve geological formations occurring within the Devonian, Mississippian, and Pennsylvanian periods. Oil pools occur mainly in clastic and carbonate facies, while gas pools include mud facies from the New Albany Shale, coal seams, and abandoned coal mines from the Pennsylvanian system.



GENERALIZED PALEOZOIC STRATIGRAPHY

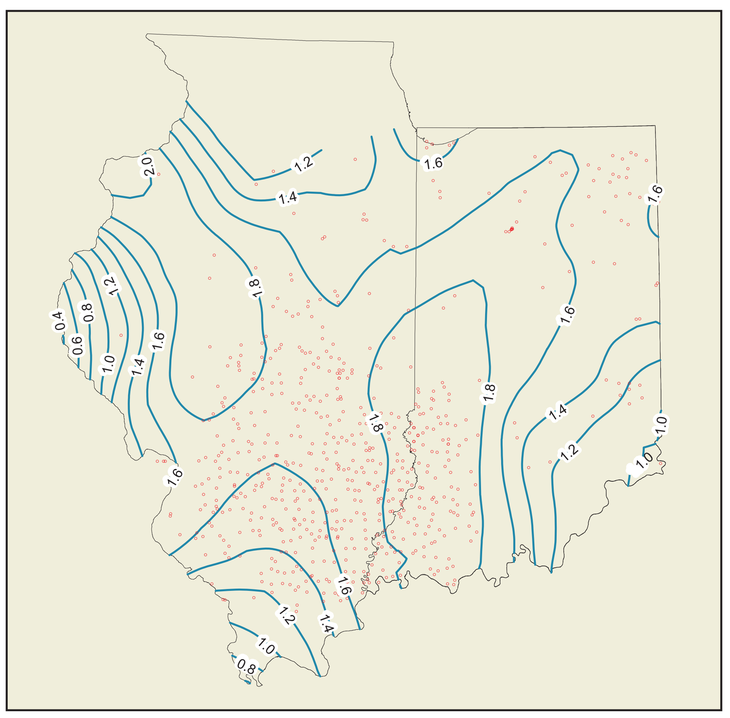
Time Unit: Period	Time Unit: Epoch	Rock Unit: Significant Member	Rock Unit: Formation	Rock Unit: Group	Sample or Strip Log Pick	IGS Productive Petroleum Horizon	Popular Industry Terminolgy
Pennsylvanian	Missourian	Merom Ss.	Mattoon	McLeansboro		Pennsylvanian (sandstones) or Penn. Coal (CBM or Coal Mine Gas)	
		Livingston Ls. / Carthage Ls. / Vigo Ls. / West Franklin Ls.	Bond / Patoka / Shelburn				
	Desmoinesian	Danville Coal / Hymera Coal / Alum Cave Ls. / Springfield Coal / Survant Coal / Colchester Coal	Dugger / Petersburg / Linton	Carbondale			
	Atokan	Seelyville Coal / Perth Ls. / Minshall Coal / Lower Block Coal / Lead Creek Ls.	Staunton / Brazil / Mansfield	Raccoon Creek			
	Morrowan	SW Ind. only: Grove Ch. Sh. / Kinkaid Ls.		Buffalo Wallow	Base Penn.		
Mississippian	Chesterian	Negli Creek Ls. / Siberia Ls. / Leopold Ls. / Vienna Ls.	Degonia Ss. / Clore Ls. / Palestine Ss. / Menard Ls. / Waltersburg Ss. / Vienna Ls. / Tar Springs	Tobinsport / Branchville		Degonia Fm. / Clore Fm. / Palestine Fm. / Waltersburg / Tar Springs	Degonia ss. / Palestine ss. / Waltersburg ss. / Tar Springs ss.
			Glen Dean Ls. / Hardinsburg / Haney Ls. / Big Clifty / Beech Creek Ls.	Stephensport	Glen Dean	Hardinsburg Fm. / Jackson	Barlow ls. / Hardinsburg ss. / Jackson ss.
			Cypress / Elwren / Reelsville Ls. / Sample / Beaver Bend Ls. / Bethel	West Baden	Barlow / Cypress / L. Paint Creek	Cypress / Paint Creek / Bethel	Cypress ss. / L. Paint Creek ls. / Bethel ss.
	Valmeyeran	Downeys Bluff Ls. / Levias / Spar Mountain / Fredonia	Renault / Aux Vases / Ste. Genevieve Ls. / St. Louis Ls.	Paoli Ls.	Renault	Renault / Aux Vases / Ste. Genevieve / St. Louis Ls.	Renault ls. / Aux Vases ss./ls. / Rosiclare ss. / O'hara ls. / McClosky ls.
		Salem Ls. / Harrodsburg Ls. / Muldraugh / Floyds Knob Ls.	Ramp Creek / Edwardsville / Spickert Knob / New Providence Sh.	Sanders / Borden	Salem / Harrodsburg	Salem / Harrodsburg / Muldraugh / Borden	Warsaw ls. / Carper ss.
	Kinderhookian	Rockford Ls. / New Albany Sh.	Coldwater Sh. / Sunbury Sh. / Ellsworth Sh. / Antrim Sh.		Rockford / New Albany (north Ind. only: Sunbury / Ellsworth / Antrim)	New Albany / Antrim	
Devonian	Erian	North Vernon Ls. / Jeffersonville Ls. / Geneva Dol.	Traverse / Detroit River	Muscatatuck	Devonian Ls.	Muscatatuck	
	Ulsterian	SW. Indiana Only: Clear Creek Chert / Grassy Knob Chert	Backbone Ls.	New Harmony		New Harmony	
Silurian	Cayugan	Kenneth Ls. / Kokomo Ls. / Mississinewa Sh. / Liston Cr. Ls. / Salina Gr.	Wabash	Bailey Ls. / Mocc. Springs	Silurian	Silurian	
	Niagran	Limberlost Dol. / Laurel / Osgood	Pleasant Mills / Louisville Ls. / Waldron Sh. / St. Clair Ls. / Salamonie Dol.	Bainbridge			
	Alex.		Cataract / Brassfield Ls. / Sexton Creek Ls.				
Ordovician	Cincinnatian	Saluda	Brainard Sh. / Whitewater / Ft. Atkinson Ls. / Dillsboro / Scales Sh. / Kope	Maquoketa	Maquoketa (formerly Cincinnatian)		
	Champlainian		Trenton Ls. / Lexington Ls. / Plattin / Pecatonica / Joachim Dol. / Dutchtown / St. Peter Ss.	Ancell	Trenton or Lexington / Black River / Ancell (formerly Chazyan)	Trenton Ls. or Lexington Ls. / Black River Gr.	
	Canadian	SW Indiana Only: Everton Dol. / Shakopee Dol. / Oneota Dol.		Prairie du Chien / Knox Supergroup	Knox	Knox Supergroup	
Cambrian	St. Croixan	Potosi Dol. / Franconia / Ironton Ss. / Davis / Galesville Ss. / Eau Claire		Munising / Potsdam Supergroup	Davis sth. Ind. / northern Ind. only: Franconia / Ironton Ss. / Galesville Ss. / Eau Claire		
		Mount Simon Ss.			Mt. Simon		
Pre-camb.					Precambrian		

Oil is produced from Pennsylvanian sandstones.

Gas is mainly produced from Pennsylvaian coal seams, as coal bed methane (CBM) or from coal mines, also termed coal mine void (CMV)

Oil wells
Gas wells
Oil and Gas wells

RESERVOIR TEMPERATURE AND PRESSURE DETERMINATION

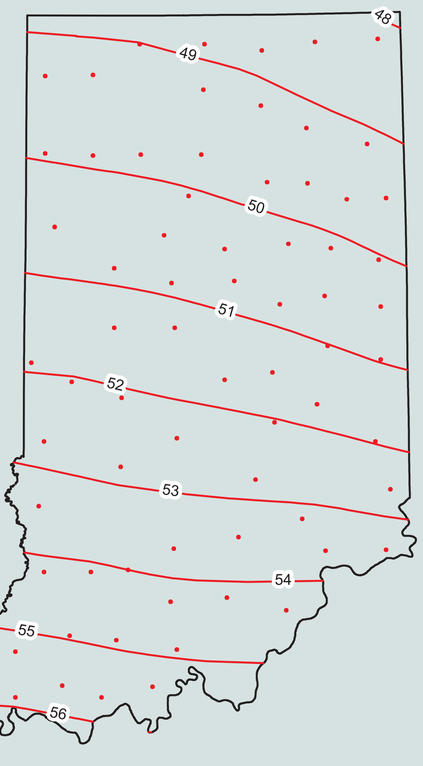


Surface temperature data was obtained from the normal 1971-2000 monthly mean temperatures by climate division in Indiana. Annual averages per county were selected and plotted closely as possible to the collected location per county.

Source data:
http://shadow.agry.purdue.edu/sc.norm-geog.html

A contour grid was created and the interpolated values were used to determine the reservoir temperature using the following expression:

T = (GG*Average depth)+calculated Surface T

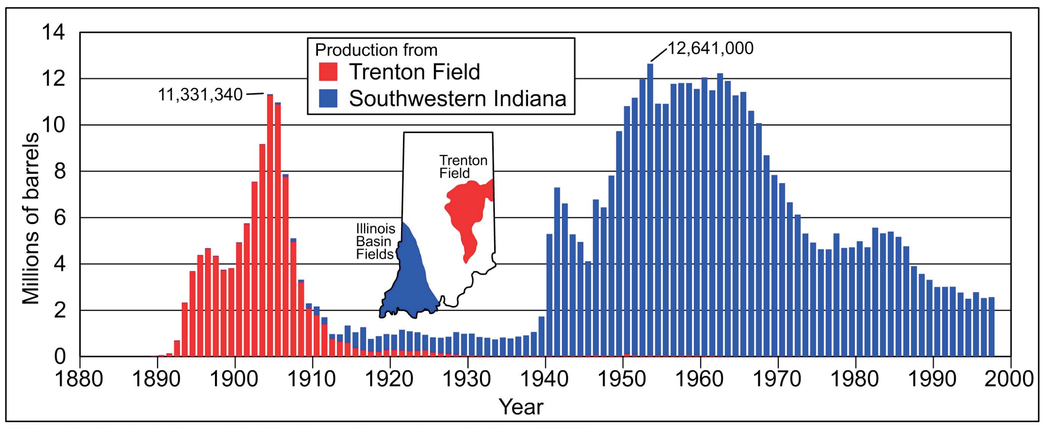


Based on historical temperature data from Illinois and Indiana, and from temperature logs available at the Indiana Geological Survey, a geothermal gradient map was created to calculate the average temperature of the reservoirs.
The data points used to calculate the geothermal gradient were interpolated to produce a grid of 2,250 square meter spacings for the entire area.

Pressure values are calculated using the formula

P = 0.433 * Average depth to the pool

assuming that all reservoirs occur under normal (hydrostatic pressure conditions) and that no over or under-pressure reservoirs exist.



Oil production in Indiana. Modified from Carpenter and others (1995).

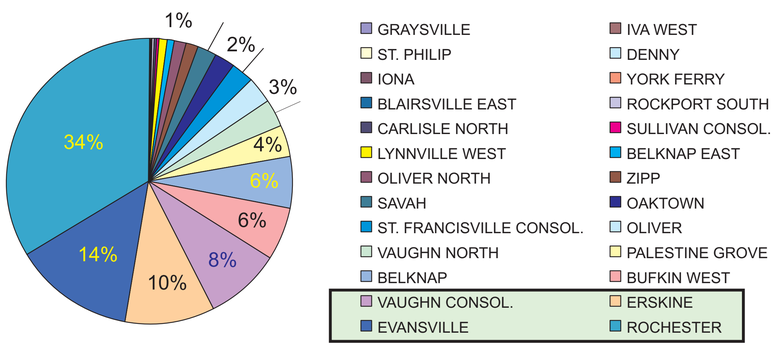
PETROLEUM PRODUCTION IN INDIANA

Nearly 550 MMBO have been produced in Indiana since the discovery of the first oil field in the mid 1800's. 388,324,000 BO have been produced from 259 petroleum fields in SW Indiana, from the 11 Formations shown in the pie-diagrams. This is equivalent to approximately 70% of the total oil production for the state.

Production data from petroleum reservoirs can be used as a proxy for estimating the CO_2 storage capacity. Pie-diagrams indicate the proportion of oil produced by a single field. The CO_2 storage capacity is calculated using the replacement of produced oil calculator from MIDCARB web site.

PENNSYLVANIAN PERIOD

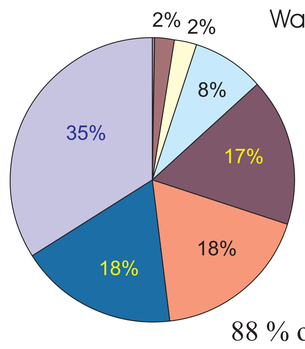
Pennsylvanian (20,805 MBO)



78 % or 3.17 MMCF approx.

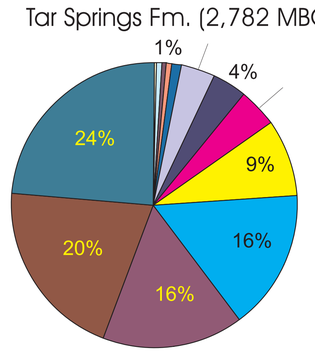
MISSISSIPPIAN - UPPER CHESTERIAN (Buffalo Wallow Group)

Waltersburg Fm. (4,311 MBO)



88 % or 1.93 MMCF approx.

Tar Springs Fm. (2,782 MBO)

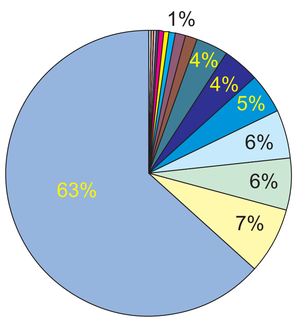


85 % or 0.28 MMCF approx.

MISSISSIPPIAN - LOWER CHESTERIAN

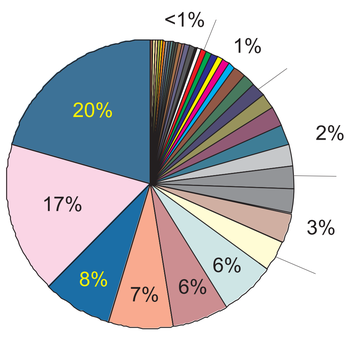
Stephensport Group

Big Clifty (Jackson) Fm. (17,197 MBO)



87 % or 22.13 MMCF approx.

Cypress Fm. (145,740 MBO)



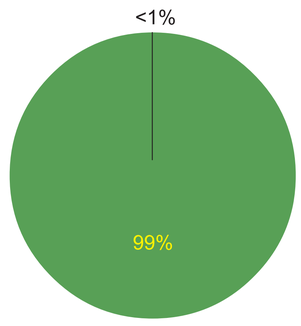
64 % or 97.27 MMCF approx.

West Baden Group

HARMON
JASPER WEST
JASPER CENTRAL
JASPER NORTH
OAK GROVE
CENTERVILLE
TROY EAST CONSOL.
ALGIERS
TRI-COUNTY
PELZER
LIBERAL
SCOTT
CABORN WEST
ELLIOTT
ROCKPORT CONSOL.
FRANCISCO NORTH CONSOL.
SPURGEON CONSOL.
VIENNA
COE SOUTH
WHEATONVILLE CONSOL.
CABORN CONSOL.
UNION-BOWMAN CONSOL.

HOLLAND SOUTH
CATO
LYNNVILLE
TENNYSON
SKELTON
GENTRYVILLE SOUTH
SMITH MILLS NORTH
HUNTINGBURG SOUTH
DEGONIA SPRINGS NORTH
PATOKA SOUTH
MAUCK
FULDA WEST
ST. THOMAS CONSOL.
PRINCETON WEST
BRISTOW
FRANCISCO SOUTH CONSOL.
NEWTONVILLE CONSOL.
MONROE CITY CONSOL.
PATOKA EAST CONSOL.
OWENSVILLE CONSOL.
MT. CARMEL CONSOL.

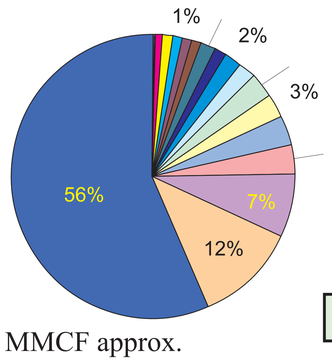
Bethel Fm. (224.5 MBO)



99 % or 0.03 MMCF approx.

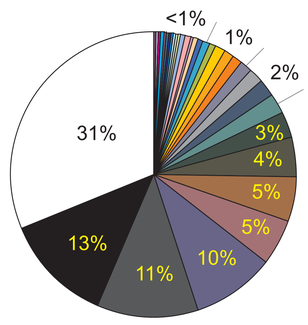
MISSISSIPPIAN - VALMEYERAN (Blue River Group)

Aux Vases Fm. (148,952 MBO)



75 % or 235.97 MMCF approx.

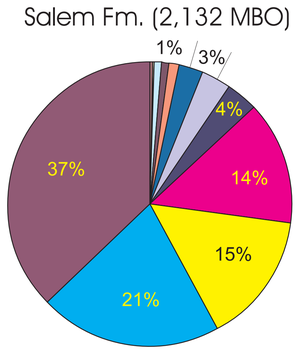
Ste. Genevieve Fm. (13,193 MBO)



70 % or 14.41 MMCF approx.

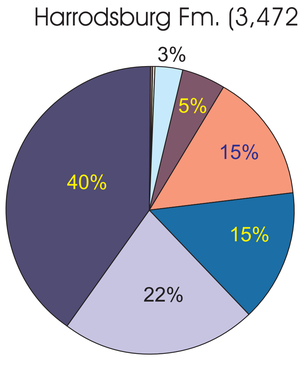
MISSISSIPPIAN - VALMEYERAN (Sanders Group)

Salem Fm. (2,132 MBO)



87 % or 0.55 MMCF approx.

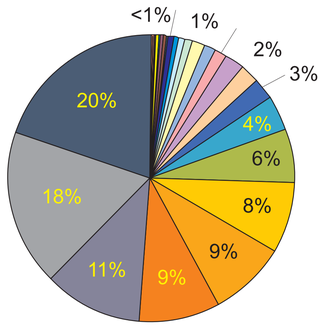
Harrodsburg Fm. (3,472 MBO)



92 % or 2.01 MMCF approx.

UPPER-MIDDLE DEVONIAN (Muscatatuck Group)

Devonian Fm. (29,516 MBO)



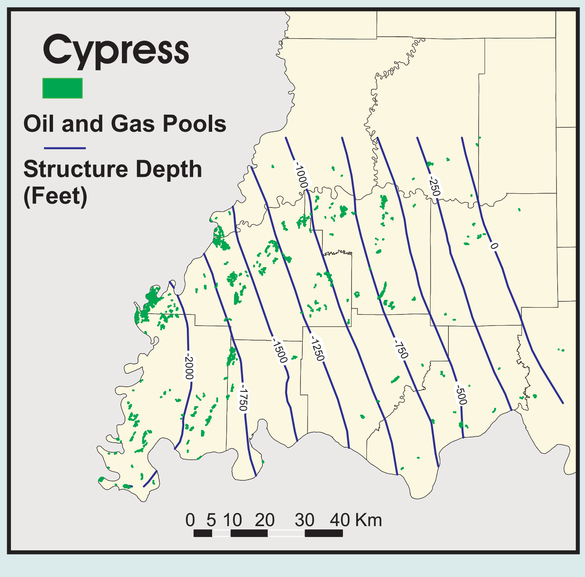
75 % or 14.83 MMCF approx.

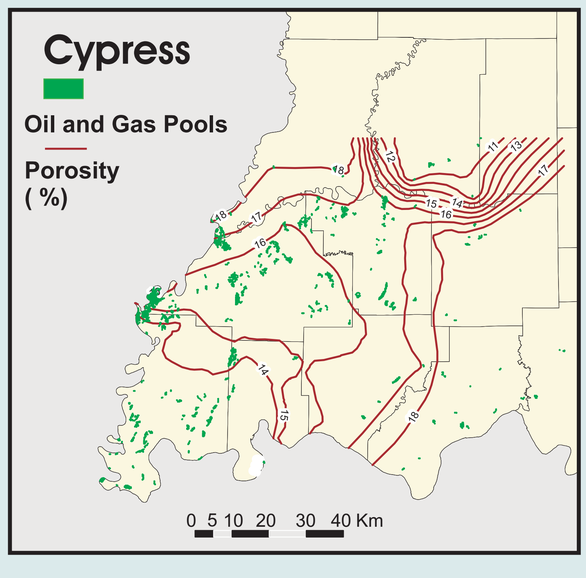
Preliminary calculations from production data of individual reservoirs (green boxes) indicate approximately 392.6 MMCF available for CO_2 sequestration. This calculations were made based on the replacement of produced oil with carbon dioxide.

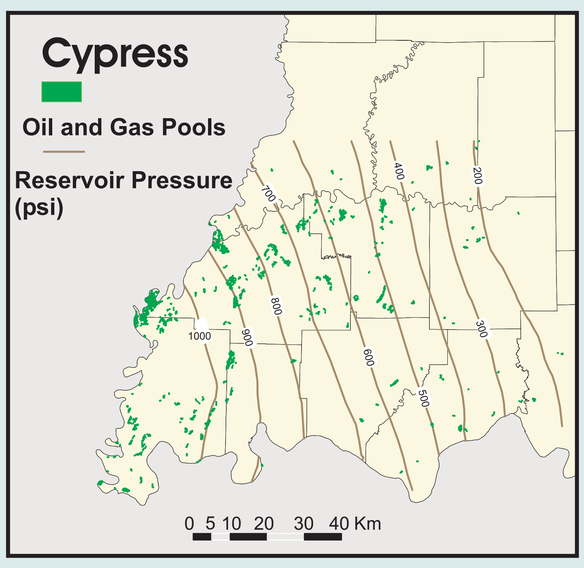
DISTRIBUTION OF RESERVOIR CHARACTERISTICS IN SELECTED UNITS

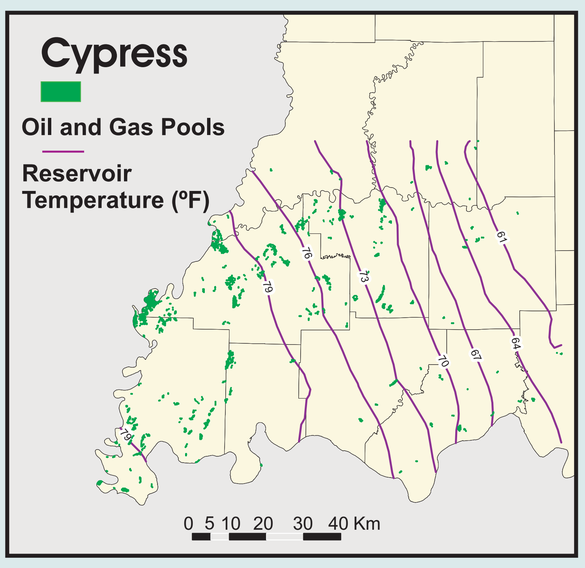
Reservoir properties, such as porosity, structural depth, pressure, and temperature were used to produce a volumetric assessment for the CO_2 sequestration potential of petroleum producing units. This poster show examples of three distinct petroleum-bearing units in south western Indiana used in this assessment. Variability in reservoir characteristics is mainly a function of lithology and environment of deposition.

MISSISSIPPIAN (CHESTERIAN)







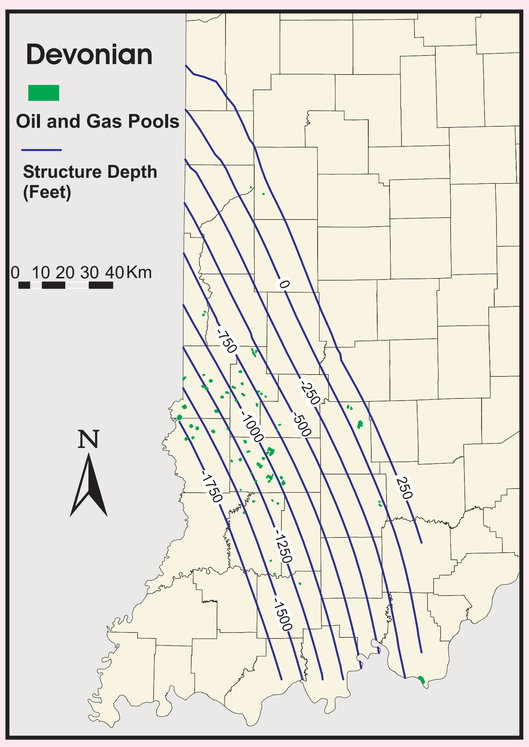


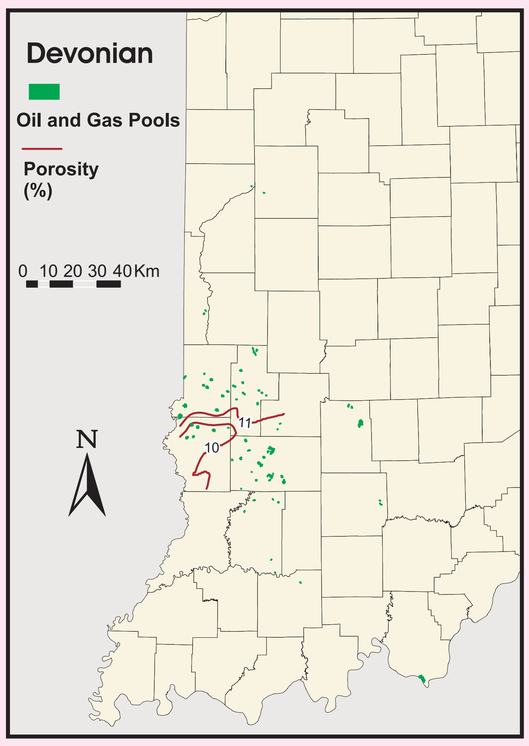
The Cypress Formation is a clastic sequence characterized by sandstones, siltstones and shales.

In southwestern Indiana, Cypress reservoirs occur at depths between 0 and 2500 ft below sea level.

Reservoir pressure and temperature maps were created based on surface data, and well log info.

DEVONIAN (ERIAN)



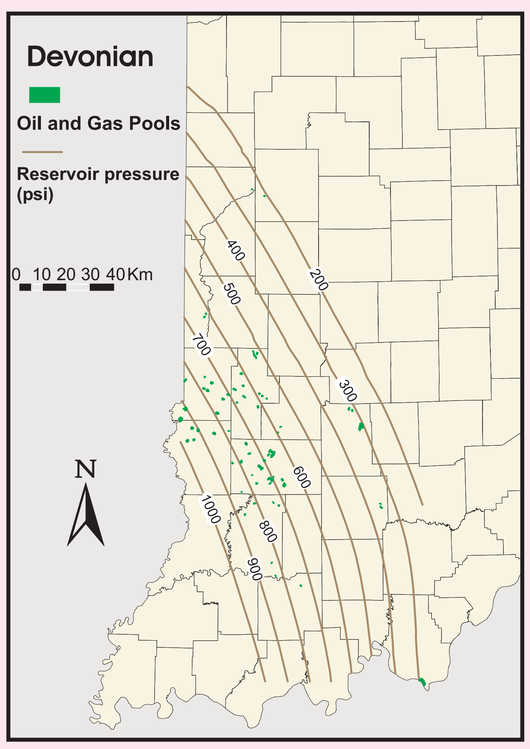


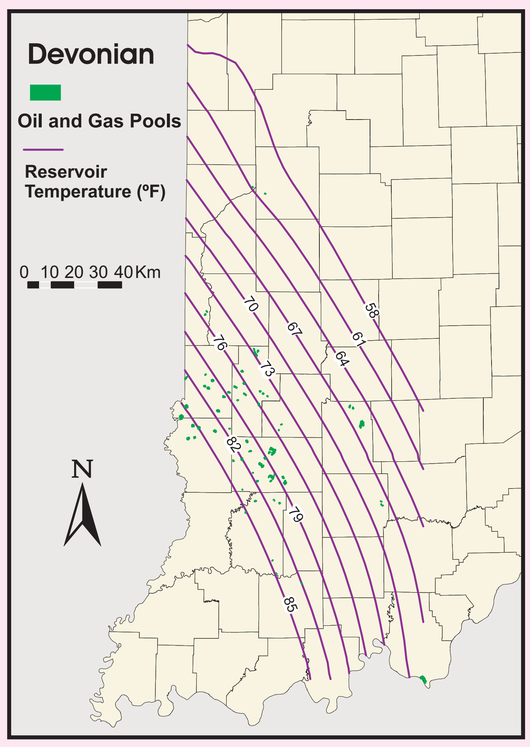
Oil and gas reservoirs of the Devonian period are made up of carbonate rocks, mainly oolitic and fossiliferous grainstones, packstones, and dolomitic sandstones that exhibit a wide range in porosity.

These Devonian pools lie in the Muscatatuck Group, formed by North Vernon, Jeffersonville and Geneva Formations. Geneva Fm. has the greatest porosity zones (dolomitic), but the unit thickness is rather irregular, as paleotopography was inherited from Silurian pinnacle reefs.

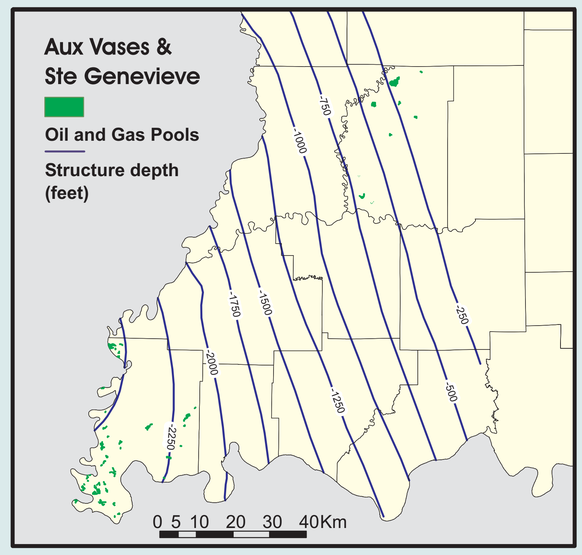
The Jeffersonville and North Vernon limestones locally show some good porosity development. However, porosity readings from actual core analyses was not available for these reservoirs. Porosity varies so much within smaller areas, that a true estimation for porosity was not possible.

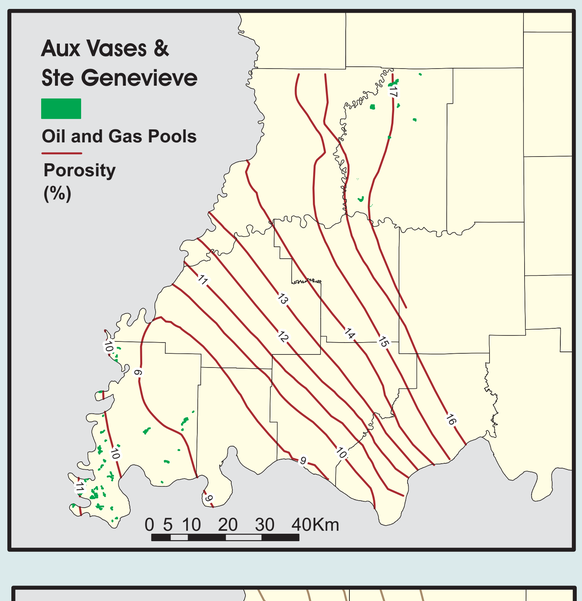
Average depths for these reservoirs is between 250 and 1750 ft below sea level. Reservoir pressure ranges between 200 and 1000 psi. Estimated maximum reservoir temperatures reach 85ºF, and increase normally towards the depocenter of the Illinois basin.

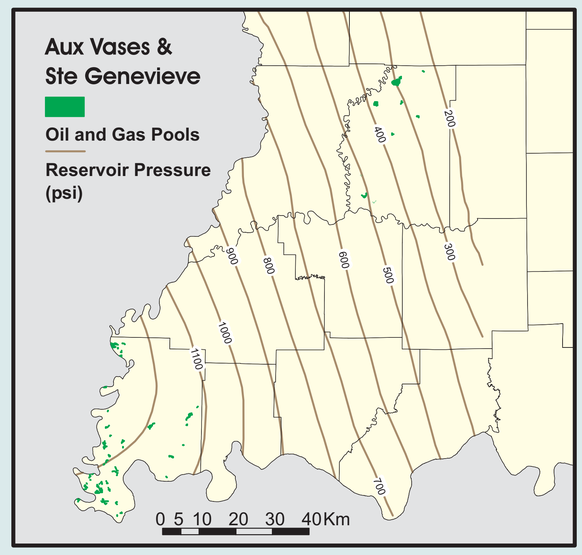


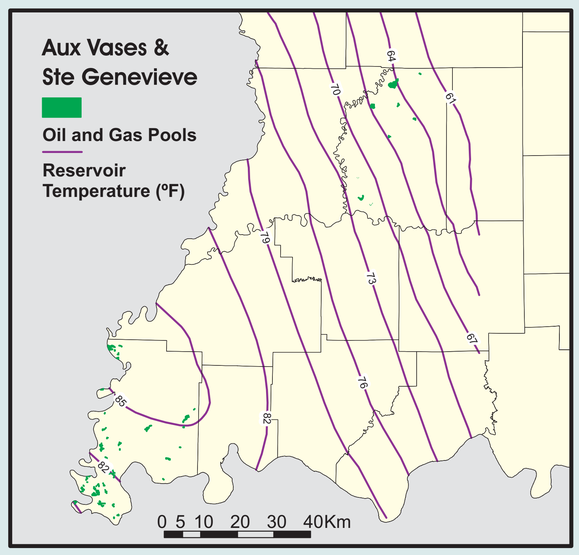


MISSISSIPPIAN (VALMEYERAN)



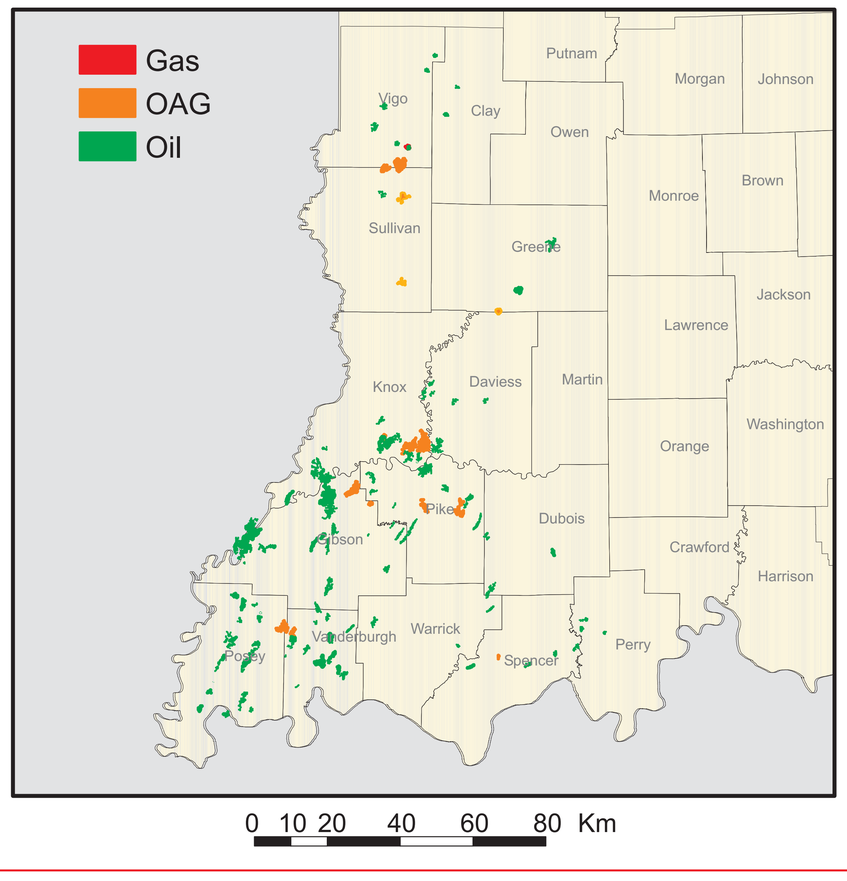






The Aux Vases Formation in south western Indiana includes dolomite, green calcareous shale, and green clacareous dolomite, all of which grade into fine- to medium-grained quartz and limestone sand in a green argillaceous matrix. This formation may represent part of the Ste. Genevieve limestone in some localities. The Ste. Genevieve limestone Formation in Indiana is a carbonate-rock sequence that is 45 to 220 ft thick and that thickens towards the south and south west. It is largely composed of oolitic, skeletal, micritic, and detrital limestone. Due to inconsistency of correlation during drilling operations through time, both Aux Vases and Ste. Genevieve were merged for practical purposes.

PETROLEUM RESERVOIRS WITH IP > 700 BOPD

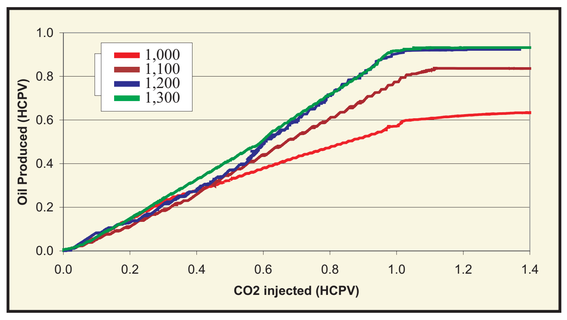


Available reservoirs with initial open flow greater than 700 BOPD may provide an indication of good reservoir characteristics, suitable for CO_2 sequestration.

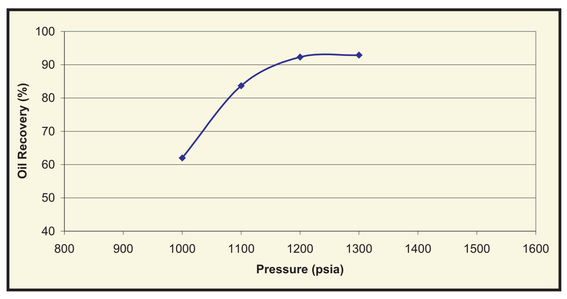
This map shows that most petroleum pools meeting this criteria lie within the south western portion of the state.

MINIMUM MISCIBILITY PRESSURE TESTS

Minimum miscibility pressure tests (MMP) for oil samples from the Cypress Formation in Indiana (Gibson Co.) were conducted at the TORP laboratory at University of Kansas.



Oil recovery results in slim-tube experiment with CO_2 displacing Indiana oil sample at 101ºF.



Ultimate oil recovery as a function of pressure for Indiana oil sample at 101ºF.

The MMP is about 1200 psia, based on the trend line and the definition of reaching 90% recovery at 1.2 hydrocarbon pore-volume (HCPV) of CO_2 injection.

An adequate inventory of reservoir volumetrics is necessary for the determination of CO_2 sequestration potential. However, detailed calculations on individual petroleum reservoirs are required for more comprehensive and accurate estimations.

CONCLUSIONS

AVERAGE RESERVOIR CHARACTERISTICS AND CO2 SEQUESTRATION POTENTIAL

Formation Name	Average Depth (ft)	Net Pool Area (Acres)	Avg. Porosity (%) (if available)	Avg. Reservoir Temperature (ºF)	Avg. Reservoir Pressure (psi)	Avg. Reservoir Thickness (ft)	CO_2 Phase	Produced Oil (MBO)	CO_2 Sequestration Volume Metric Tonnes	MMCF	Reservoir Conditions
Aux Vases	2,347	8,340	14	79	1,016	10	Liquid	148,952	10,112,023	288	Critical
Bethel	629	810	- - - (1)	64	272	11	Vapor	224.5	47,809	< 1	sub-Critical
Cypress	1,744	40,880	16	76	755	10	Vapor	145,740	12,380,950	62	Sub-Critical
Devonian	1,527	14,940	11	77	661	15	Vapor	29,516	3,669,721	10	Sub-Critical
Harrodsburg	2,292	4,400	9	86	992	9	Dense Vapor	3,472	1,007,700	2	Super-Critical
Jackson	1,085	20,719	17	70	470	11	Vapor	17,197	3,766,666	4	Sub-Critical
Pennsylvanian	1,049	35,403	18	67	448	16	Vapor	20,805	7,469,636	3	Sub-Critical
Salem	1,795	11,510	11	79	777	10	Vapor	2,132	2,396,575	1	Sub-Critical
Ste. Genevieve	2,024	37,892	8	80	876	6	Vapor	13,193	4,487,165	7	Sub-Critical
Tar Springs	1,433	16,513	17	72	620	15	Vapor	2,782	5,277,583	1	Sub-Critical
Waltersburg	1,803	10,619	17	76	781	16	Vapor	4,311	5,467,3341	2	Sub-Critical

(1) Porosity assumed to be 10%

Data on CO2 Properties from
Practical Aspects of CO2 Flooding, SPE Mongraph Vol 22, Appendix F

Average values were used to calculate the CO2 sequestration volumes shown in this table. However, individual reservoir calculations must be done for proper estimation of available volumes.

1. A preliminary assessment for the CO_2 sequestration potential in Oil and Gas reservoirs in Indiana was made based on data from historical drilling records available at the Indiana Geological Survey.
2. Reservoir data along with estimated temperatures and pressure were used to calculate the volumes that could be sequestered in petroleum reservoirs, using the calculator tools provided in the MIDCARB web site http://midcarb.org/calculators.shtml
3. Geological and reservoir conditions indicate that CO_2 sequestration in Indiana may be accomplished economically in the south western portion of the state, where pressures and temperatures are adequate for storing significant volumes of carbon dioxide in largely depleted oil and gas reservoirs.
4. The total area calculated for all petroleum producing pools mapped accounts for 50,542 acres, equivalent to 24.5% of the reservoir area currently mapped (205,764 acres).
5. Porosity values ranges between 7.5 and 19%. However, an accurate value for porosity is lacking in most areas due to significant lateral and vertical stratigraphic variability.
6. Preliminary calculations from oil producing fields indicate a CO_2 sequestration capacity of 28.5MM Tons, equivalent to approximately 494 MMCF.
7. Laboratory experiments indicate that minimum miscibility pressures (MMP) for Indiana oils are about 1,200 psia.