The Role of CO_2 Enhanced Oil Recovery In Ohio's Economy and Energy Future

Working Paper
Prepared for
The Pew Center on Global Climate Change

Preface

The Pew Center on Global Climate Change, with the support of the Joyce Foundation, commissioned Kleinhenz & Associates of Cleveland, Ohio to analyze, study and report on the industries directly affected by the construction of a CO_2 pipeline in Ohio and the development of a CO_2 EOR market. This report was prepared jointly by Jack Kleinhenz, Ph.D. and Russ Smith, Ph.D. of Kleinhenz & Associates with assistance from Steve Melzer, Melzer Consulting, and Jim Robey, Ph.D. and the research department at TeamNEO. We would like to thank Kurt Waltzer of the Clean Air Task Force for his overall project guidance, comments and support.

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I. Purpose of the study

The Pew Center on Global Climate Change seeks to explore the potential development and use of coal gasification and carbon capture and storage (CCS) technology in Ohio. Primary benefits of developing and deploying CCS in Ohio include power generated using readily available coal while achieving substantial reductions in greenhouse gas emissions from this generation. Additional benefits include many chemical by-products, especially captured CO_2 which can be used commercially for Enhanced Oil Recovery (EOR). Prior research completed by Kleinhenz & Associates for the Pew Center analyzed the economic activity factors related to coal gasification and how the location of a number of key support industries in Ohio could provide the state with a competitive advantage in this area.[i] This prior research did not address injection of CO_2 into deep saline formations (sequestration), or storage of CO_2 in association with EOR. The study also did not offer an estimate of the required pipeline network or the industries and employment affiliated with development of an Ohio CO_2 market. Ohio firms have been major suppliers of the heavy equipment utilized in the oil and gas industry throughout North America. A CO_2 EOR and sequestration industry would utilize similar types of heavy equipment in large volumes.

Further development of coal-gasification plants in Ohio depends upon a full understanding of the development of a CO_2 market. The CO_2 byproduct can be captured during the gasification process and transported via pipeline and injected in an oil or gas well to enhance recovery. With minor modifications to the process, volumes of CO_2 stored through EOR can be documented. Carbon dioxide might also be sequestered (long-term) in a suitable underground reservoir containing no hydrocarbons (deep saline formation). Texas serves as a good example of a state in which the commercialization of CO_2 for enhanced oil recovery as well as state regulations are well defined, while the CO_2 industry in Ohio is neither defined nor commercialized. However, the Ohio House and Senate recently adopted an energy bill that would establish a regulatory framework for CO_2,[ii] and provide credits to utilities that installed equipment for capturing carbon dioxide.

The purpose of this study is to identify Ohio-based industries and employment that might play a role in Ohio's CO_2 market as a result of:

a) The development and construction of a CO_2 pipeline and
b) The injection of CO_2 for EOR purposes.

Method

Estimating the potential impact on Ohio-based industries requires a framework that includes the creation of a conceptual Ohio CO_2 pipeline network. This network links proposed major sources of CO_2 – such as coal gasification plants and biofuel plants – to some potential CO_2 sinks with strong potential as EOR sites. Melzer Consulting

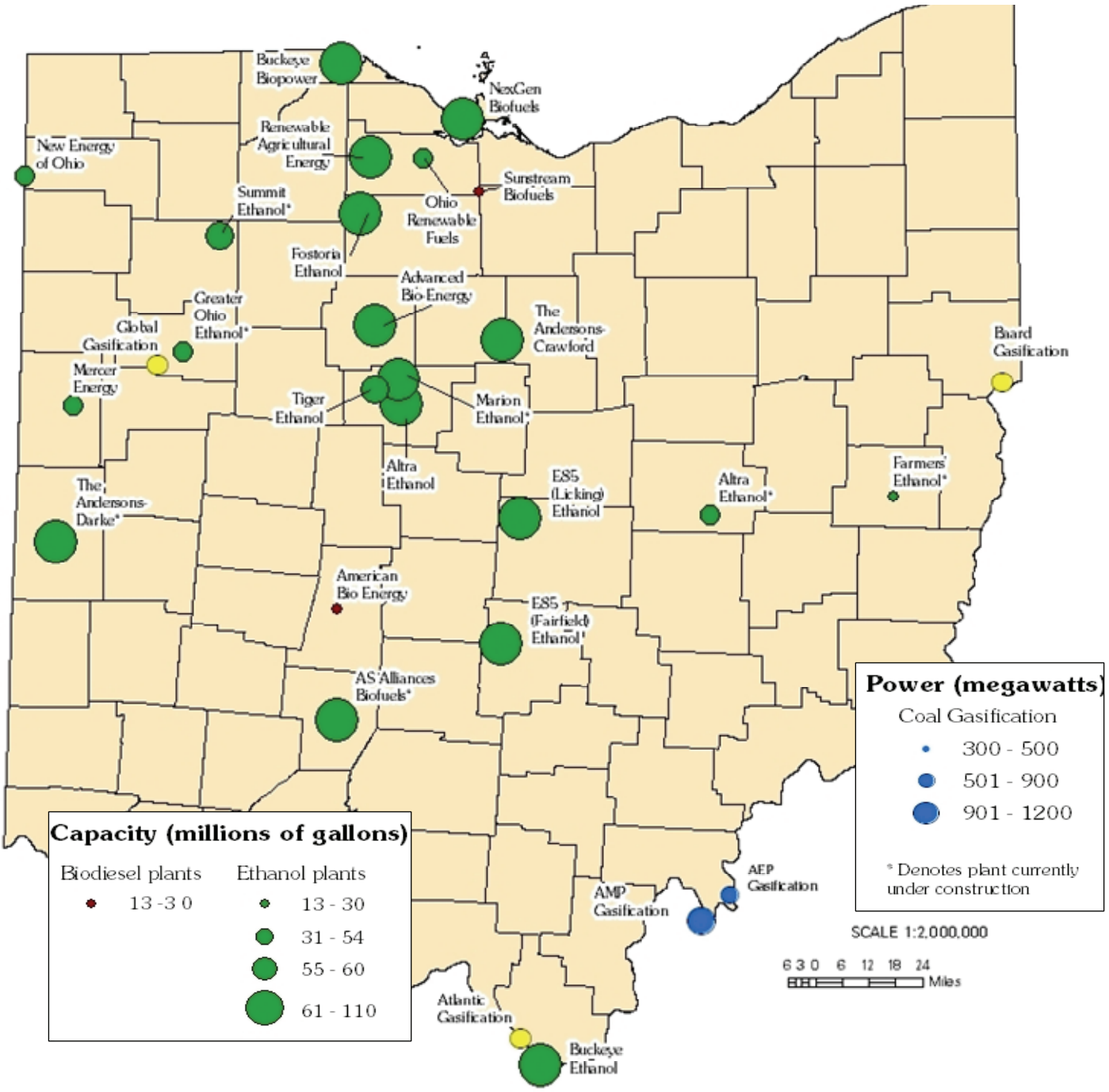
developed the conceptual pipeline network for this study. Using preliminary results of a study previously begun at the Ohio Geological Survey and employing a beta version MIT Pipeline software product, Kleinhenz and Associates generated cost estimates and maps. To estimate the extent to which such a network might affect Ohio's economy, lists of pipeline construction and CO_2 EOR industries were developed. We first identified the set of relevant industries and activities that comprise the relatively mature Enhanced Oil Recovery (EOR) Texas market. We then identified Ohio industries that would perform the same pipeline construction and CO_2 EOR functions using The North American Industrial Classification codes (NAICS) for the Texas market.

Manufacturing data as reported in the U.S. Economic Census and collected in 2002 was matched against the selected industry. This data set contains detailed information on the structure of individual industries, industry groups, and subsectors and is classified on a 6-digit system. A second set of data from Moody's Economy.com was also employed that includes more current estimates (2007) for these NAICS codes but are only available at less detailed, 4-digit level. LexisNexis data gathered and mapped by Team NEO resulted in maps of Ohio showing the density of firms across counties.

II. Development of a Conceptual CO_2 Pipeline Network

Figure 1 shows proposed coal gasification and biofuel projects[iii] in Ohio that would likely generate sufficient quantities of CO_2 to finance pipeline construction and EOR activities. No financial analysis was carried out regarding pipeline or EOR feasibility. The CO_2 source projects shown are proposed and the resulting pipeline network is conceptual .[iv]

Figure 1**. Proposed Coal Gasification and Biofuel Project Locations**



Typically, CO_2 will be stored (retained in the reservoir) as a result of enhanced oil recovery in depleted oil fields.[v] Since CO_2 EOR has not been practiced in Ohio to date, pilot tests are required to assess the outcomes and impacts of CO_2 flooding of specific fields of interest. Ohio does have several such candidate EOR fields, shown below in and briefly described in Figure 2.

CO_2 storage capacity figures for the four oil producing formations are dependent on a number of unknowns, only some of which are technical. Fostering the right policy incentives to achieve the dual objectives of enhancing oil production while storing CO_2 is as important as the commercial pilot tests. Assuming the pieces are in place for the development of a CO_2 EOR industry, it is useful to assess the ultimate storage capacity of each of the candidate regions to jumpstart construction of the transportation infrastructure. This can help lay a foundation for later sequestration along the pipeline route or interconnections to markets for CO_2 in other areas.

Table 2 provides a first order estimate of CO_2 storage capacity for the four candidate fields shown in Figure 2. Total Ohio capacities beyond these four fields are about double those shown here. Total sequestration capacities for deep saline formations are also cited in the source provided below.

Table 2: CO_2 Sequestration Capacity

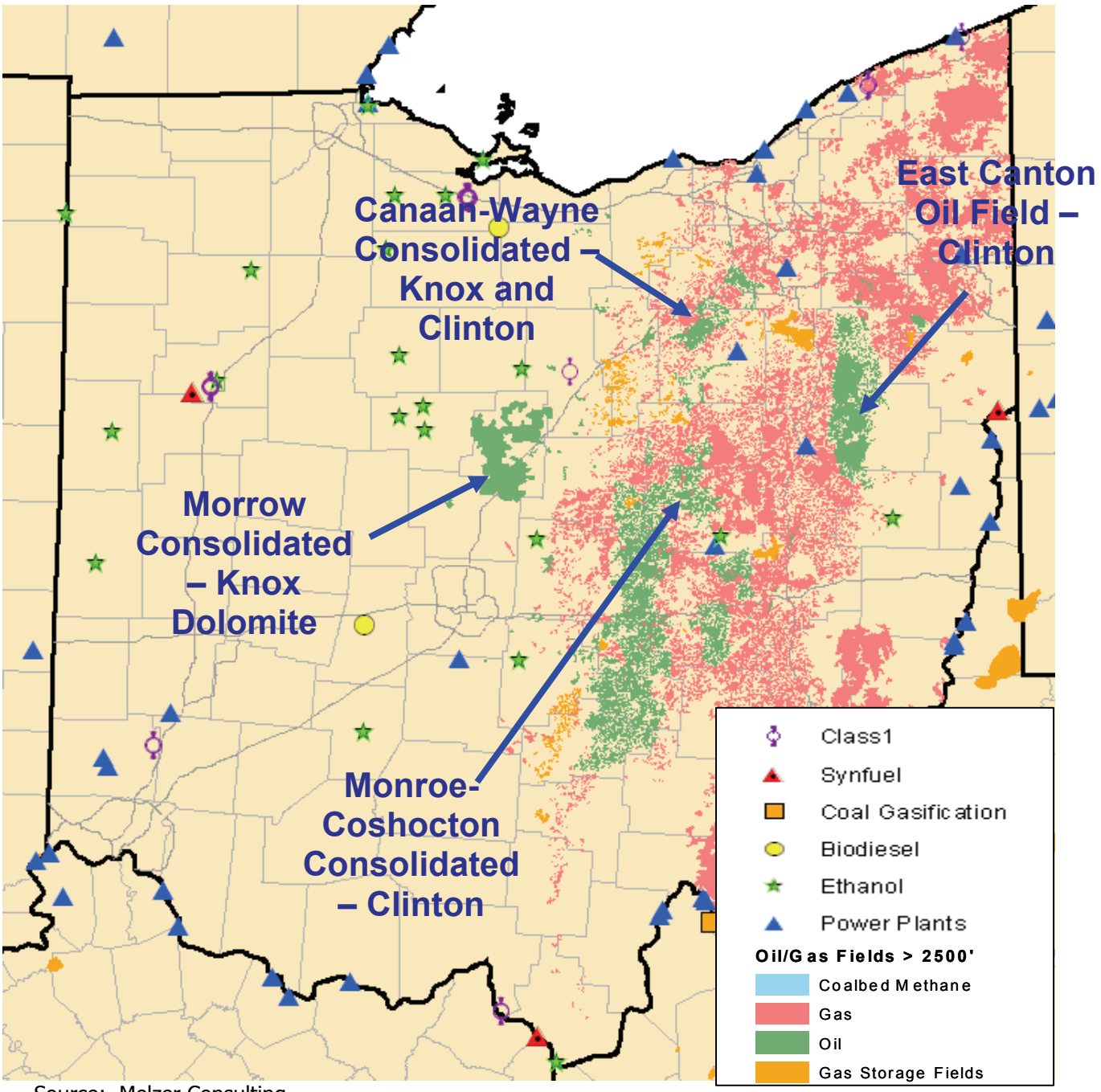
FIELD NAME	SEQ_VOL tonnes	SEQ_VOL tcf (surface)	SEQ_VOL mmcfpd*
EAST CANTON CONSOLIDATED	340,624,314	6.56	898
MONROE-COSHOCTON CONSOLIDATED	28,059,082	0.54	74
CANAAN-WAYNE CONSOLIDATED	7,254,199	0.14	19
MORROW CONSOLIDATED	26,640,789	0.51	70
TOTAL	402,578,384	8	1,062

* for a 20-year injection duration

Source: "Characterization of Geologic Sequestration Opportunities in the MRCSP Region." Phase I Task Report Period of Performance (October 2003-September 2005). DOE Cooperative Agreement No. DE-PS26-05NT42255

The 400 MT shown in Table 2 compares to a total of 46.3 GT for deep saline formation storage. Although being smaller in volumes, the oil reservoirs can serve as catalysts for initial projects, starting the CO_2 pipeline network required and providing significant oil revenues to the state and industry.

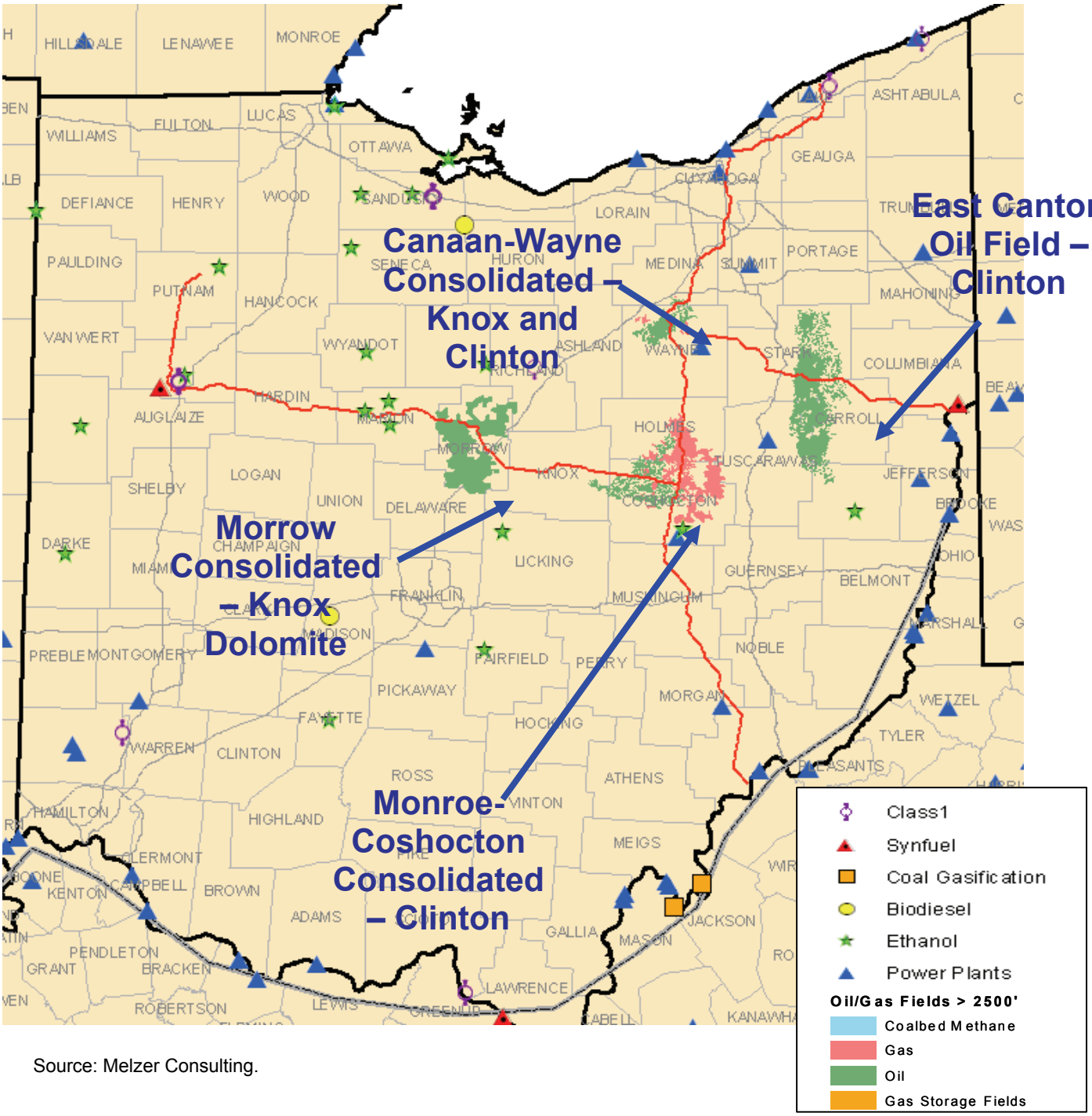
Figure 2. Existing and Planned CO_2 Sources and Ohio Oil/Gas Fields



Source: Melzer Consulting

This figure (and Figure 3 below) shows Ohio oil and gas fields with depths greater than 2,500 feet. The East Canton area is primarily a Canton sandstone oil reservoir target. The Morrow Consolidated site consists of a vuggy dolomite (subcrop erosional ridges) at a depth of about 3,500 feet. The Canaan Wayne area is a target rich environment consisting of deeper Knox vuggy dolomite reservoirs as well as Clinton Sandstone and some Lockport Dolomite reservoirs. The Monroe-Coshocton site is just one of many Clinton fields in the heart of the Clinton Sandstone reservoir trend. Deeper Rose Run production -- and even deeper Beekmantown (Knox) production -- is now being developed a little to the southeast of this area, but those deeper reservoirs tend to be gas vs. oil dominant.

Figure 3. A Scenario of Potential CO_2 Pipeline Development in Ohio[vi]



Source: Melzer Consulting.

The conceptual pipeline network runs through the following 20 counties: Lake, Geauga, Cuyahoga, Summit, Medina, Wayne, Holmes, Coshocton, Muskingum, Morgan, Washington, Stark, Carroll, Columbiana, Knox, Morrow, Marion, Hardin, Allen, and Putnam. Using the pipeline modeling program from MIT, estimated construction costs amount to $280 million for this 450-mile network, 12-inch diameter CO_2 pipeline

system.[vii] Operating and maintenance costs are estimated to be $2.3 million per year. As a comparison, the mature CO_2 region of the Permian Basin area of west Texas and SE New Mexico lies within an area of 240,000 square miles and has 2,300 miles of CO_2 pipelines. By comparison, the State of Ohio has an area of about one-sixth the size of the Permian Basin. The 450-mile CO_2 pipeline network represented herein is also about one-sixth of the aggregate length of the pipeline network in the Permian Basin.

III. Industries Affected by CO_2 Pipeline Development and CO_2 EOR

Potential Industry Supply Chain for a CO_2 Pipeline in Ohio

A list of potential contractors to build or supply materials for the construction, operation, and maintenance of a conceptual CO_2 pipeline in Ohio was developed. Tables 1 and 2 provide a listing of sectors for a CO_2 pipeline. A 4-digit NAICS code level of employment, wage, and GDP information is provided by using 2007 Economy.com data. A more in depth, 6-digit level, is provided using Census Bureau latest available data (2002). Census Bureau variables include the Number of Establishments, Value of Shipments, Size of Payroll, and Employment.

At the aggregated 4-digit level, industries that could be suppliers for construction and operation of a CO_2 pipeline represent five percent of Ohio employment and seven percent of wages and gross Ohio product (Table 1). In total, industries with an estimated 303,382 jobs with wage earnings of over $16 billion a year would benefit from pipeline construction expenditures. The largest industry sector represented is Architectural, Engineering, and Related Services, with over 42,000 employees and $2.6 billion in annual wages.

Table 1. CO_2 Pipeline Supply Chain Industries: Employment, Wages, and GDP*

NAICS	INDUSTRY	Employment	Wage	GDP
				(Yr 2000 Dollars)
237	Heavy & Civil Engineering Construction	24,076	$1,348,702,684	$1,672,631,625
3252	Resin, Synthetic Rubber, Artificial Fibers & Filaments Mfg	6,192	$384,960,898	$990,184,645
3262	Rubber Product Mfg	19,218	$847,096,790	$1,716,700,314
3311	Iron & Steel Mills & Ferroalloy Mfg	12,598	$1,069,550,451	$1,865,218,913
3312	Steel Product Mfg from Purchased Steel	8,754	$563,349,449	$991,286,557
3315	Foundries	17,103	$837,745,774	$1,620,338,367
3329	Other Fabricated Metal Product Mfg	25,943	$1,362,894,072	$2,420,461,232
3331	Agriculture, Construction, & Mining Machinery Mfg	6,501	$386,005,355	$576,811,598
3335	Metalworking Machinery Mfg	24,409	$1,205,000,737	$1,901,952,288
3336	Engine, Turbine, & Power Transmission Equip Mfg	5,110	$337,746,679	$487,121,931
3339	Other General Purpose Machinery Mfg	26,601	$1,455,753,296	$2,205,314,928
3345	Navigation, Measuring, Electromed, & Control Instru. Mfg	9,789	$522,163,994	$2,017,936,754
4235	Metal & Mineral (except Petroleum) Wholesalers	10,720	$640,908,970	$1,085,882,784
4238	Machinery, Equip, & Supplies Wholesalers	34,566	$1,787,777,496	$3,189,334,573
486	Pipeline Transportation	1,059	$83,795,221	$201,776,978
4889	Other Support Activities for Transportation	2,112	$61,769,452	$75,951,353
5324	Commercial & Industrial Machinery & Equip Rental & Leasing	3,649	$190,008,912	$694,803,987
5413	Architectural, Engineering, & Related Services	42,392	$2,612,395,162	$4,249,497,322
5419	Other Professional, Scientific, & Technical Services	22,592	$784,832,560	$1,155,983,579
Sum of Sectors		303,382	$16,482,457,949	$29,119,189,729
Sum of Sectors as a Percent of State Totals		5%	7%	7%
State Total		5,578,347	$222,324,018,210	$403,084,242,630

*GDP = gross domestic product, GDP is the net value added that labor contributes to the final product of Ohio firms
Source: Economy.com, 2007

At the six digit level, the industries shown are more specific to oil and gas pipelines and production than industries shown at the 4-digit level. Industries detailed in Table 2 reflect this precision, showing the number of establishments to be 11,478, employment to be 118,500 and shipments to be valued at $31 billion in 2002. These numbers are derived from the most recent 2002 census data. These employment levels amount to 2.1 percent of total Ohio employment.

Table 2. CO_2 Pipeline Supply Chain Industries: Number of Establishments, Value of Shipments

NAICS	Description	# of Ohio Establishments*	Value of Shipments ($1000)**	Annual Payroll ($1000)**	Employees**
237120	Oil & Gas Pipeline & Related Structures Construction	1	254,828	83,727	1,698
237990	Other Heavy & Civil Engineering Construction	442	445,162	112,564	3,081
325212	Synthetic Rubber Mfg	25	D	D	(500-999)
326299	All Other Rubber Product Mfg	208	1,032,798	188,396	5,501
331111	Iron & Steel Mills	243	6,368,766	970,552	18,848
331210	Iron & Steel Pipe & Tube Mfg from Purchased Steel	39	1,006,549	158,352	3,940
331511	Iron Foundries	71	1,138,065	510,370	8,655
332911	Industrial Valve Mfg	45	419,236	114,957	2,808
333120	Construction Machinery Mfg	129	468,308	78,362	2,097
333132	Oil & Gas Field Machinery & Equip Mfg	19	16,370	3,095	79
333512	Machine Tool (Metal Cutting Types) Mfg	187	498,454	118,636	2,516
333611	Turbine & Turbine Generator Set Units Mfg	15	335,960	66,113	1,325
333911	Pump & Pumping Equip Mfg	74	644,754	135,592	3,568
333996	Fluid Power Pump & Motor Mfg	11	283,512	73,038	1,587
334513	Instruments Mfg for Measuring & Controlling Indust. Process Variables	132	508,818	144,440	2,913
334514	Totalizing Fluid Meter & Counting Device Mfg	15	217,192	28,189	735
423510	Metal Service Centers & Other Metal Merchant Wholesalers	708	8,118,693	449,285	10,029
423830	Industrial Machinery & Equip Merchant Wholesalers	2,184	5,733,472	793,115	17,801
486110	Pipeline Transportation of Crude Oil	51	D	D	(20-99)
486210	Pipeline Transportation of Natural Gas	105	516,347	63,237	979
488999	All Other Support Activities for Transportation	708	69,219	18,383	842
532412	Construction, Mining, & Forestry Machinery & Equip Rental & Leasing	182	348,546	60,671	1,579
541330	Engineering Services	2,778	3,070,930	1,369,904	25,715
541990	All Other Professional, Scientific, & Technical Services	3,106	139,793	104,895	2,280
	Sum	11,478	31,635,772	5,645,873	118,576

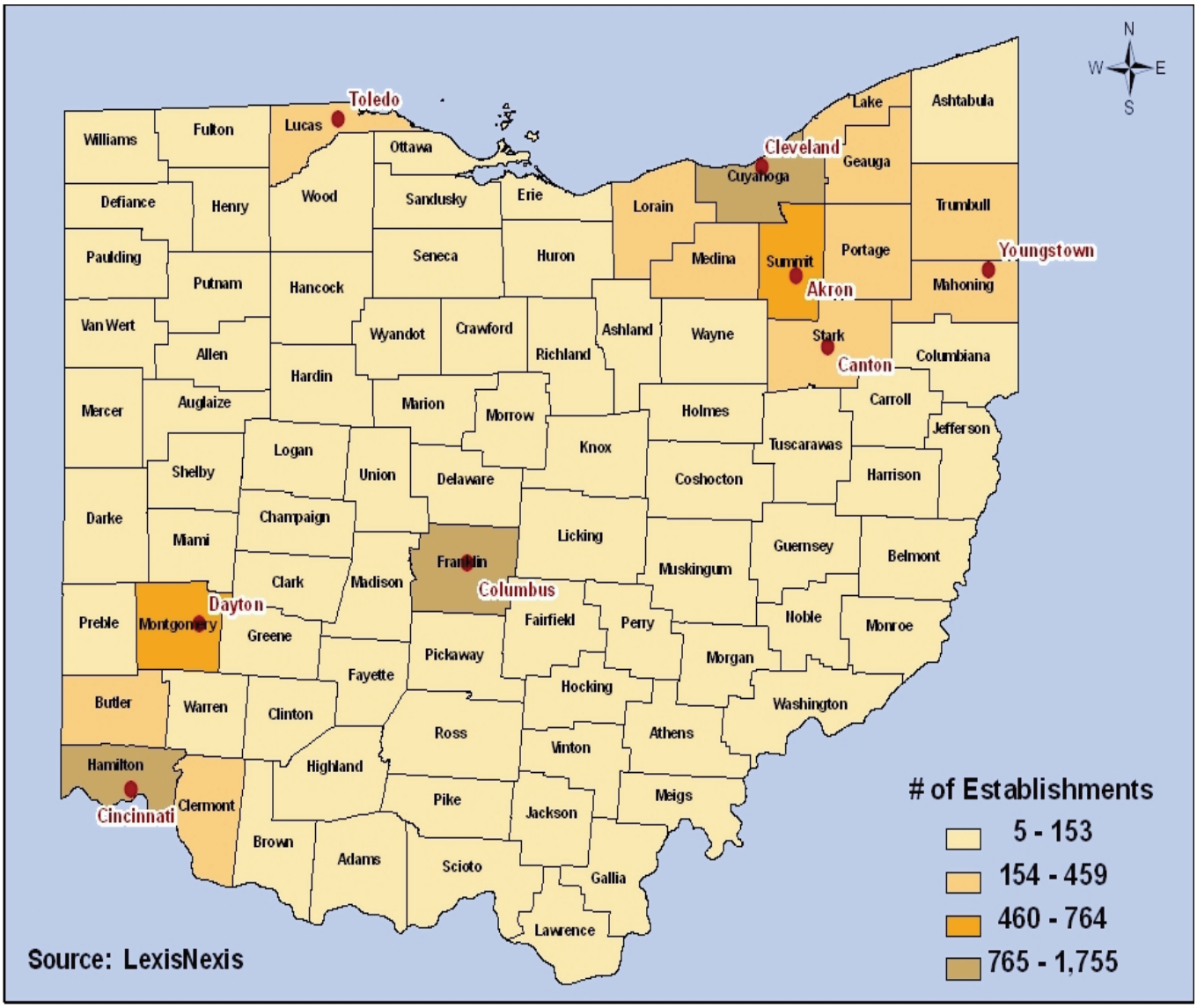
D = Withheld to avoid disclosing data of individual companies; data are included in higher level totals

* Source: Lexis Nexis, Team NEO

** Source: US Census, Industry Series, 2002 (most recent available).

There are 11,478 establishments in Ohio that could be part of the CO_2 pipeline supply chain. The largest concentration of potential CO_2 pipeline construction firms operate in Cuyahoga, Franklin, and Hamilton counties (Figure 4). Sixteen out of Ohio's 88 counties contain more than 150 potentially affected firms within their respective boundaries. All counties have at least 5 establishments that fit the supply chain criteria. An establishment is defined as an economic unit that produces goods or services, usually at a single physical location, and engaged in one or predominantly one activity. A firm is a legal business, either corporate or otherwise, and may consist of one establishment, a few establishments, or even a very large number of establishments.

Figure 4. Map of Ohio CO_2 Pipeline Construction and Operation Supply Chain Firms



Potential Industry Supply Chain for CO_2 EOR in Ohio.

Firms that would participate in CO_2 EOR would include those that undertake mapping, seismic shots, drilling feeder/input wells and directional drilling. Two tables are provided. A 4-digit NAICS level of information is provided by using 2007 Moody's Economy.com data while a more in-depth, 6-digit level, is provided using US Census Economic Census data (2002).

There are an estimated 23 industry sectors at 4-digit NAICS levels that are involved in supplying parts or services to the EOR activity in Ohio. Employment totals 321,000 with annual wages of $17.6 billion (Table 3). This supply chain amounts to six percent of employment, eight percent of wages, and eight percent of GDP in Ohio.

Table 3. EOR CO_2 Supply Chain Industries: Employment, Wages, and GDP*

NAICS	INDUSTRY	Employment	Wage	GDP (Yr 2000 Dollars)
2111	Oil & Gas Extraction	2,438	$243,920,550	$524,319,656
2131	Support Activities for Mining	2,784	$145,695,085	$50,230,686
237	Heavy & Civil Engineering Construction	24,076	$1,348,702,684	$1,672,631,625
3241	Petroleum & Coal Products Mfg	4,559	$288,447,968	$732,621,016
3252	Resin, Synthetic Rubber, Artificial Fibers & Filaments Mfg	6,192	$384,960,898	$990,184,645
3262	Rubber Product Mfg	19,218	$847,096,790	$1,716,700,314
3311	Iron & Steel Mills & Ferroalloy Mfg	12,598	$1,069,550,451	$1,865,218,913
3312	Steel Product Mfg from Purchased Steel	8,754	$563,349,449	$991,286,557
3315	Foundries	17,103	$837,745,774	$1,620,338,367
3324	Boiler, Tank, & Shipping Container Mfg	8,075	$452,988,287	$830,838,168
3329	Other Fabricated Metal Product Mfg	25,943	$1,362,894,072	$2,420,461,232
3331	Agriculture, Construction, & Mining Machinery Mfg	6,501	$386,005,355	$576,811,598
3335	Metalworking Machinery Mfg	24,409	$1,205,000,737	$1,901,952,288
3336	Engine, Turbine, & Power Transmission Equip Mfg	5,110	$337,746,679	$487,121,931
3339	Other General Purpose Machinery Mfg	26,601	$1,455,753,296	$2,205,314,928
3345	Navigation, Measuring, Electromed, & Control Instru. Mfg	9,789	$522,163,994	$2,017,936,754
4235	Metal & Mineral (except Petroleum) Wholesalers	10,720	$640,908,970	$1,085,882,784
4238	Machinery, Equip, & Supplies Wholesalers	34,566	$1,787,777,496	$3,189,334,573
486	Pipeline Transportation	1,059	$83,795,221	$201,776,978
4889	Other Support Activities for Transportation	2,112	$61,769,452	$75,951,353
5324	Commercial & Industrial Machinery & Equip Rental & Leasing	3,649	$190,008,912	$694,803,987
5413	Architectural, Engineering, & Related Services	42,392	$2,612,395,162	$4,249,497,322
5419	Other Professional, Scientific, & Technical Services	22,592	$784,832,560	$1,155,983,579
Sum of Sectors		321,239	$17,613,509,839	$31,257,199,255
Sum of Sectors as a Percent of State Totals		6%	8%	8%
State Total		5,578,347	$222,324,018,210	$403,084,242,630

Source: Economy.com, 2007

At the six-digit level there are 30 industries that make up the Ohio EOR supply chain (Table 4). According to the 2002 Census data, there are 13,010 establishments in Ohio for these 30 industries. This supply chain pays wages of $6 billion per year and employs 136,000 workers. Workers amount to 2.5 percent of all Ohio workers.

Table 4. EOR Supply Chain Industries: Number of Establishments, Value of Shipments in Ohio

NAICS	Description	# of Ohio Establishments*	Value of Shipments ($1000)**	Annual Payroll ($1000)**	Employees**
211111	Crude Petroleum & Natural Gas Extraction	214	1,000,000	D	4,000
213111	Drilling Oil & Gas Wells	129	52,267	17,430	479
213112	Support Activities for Oil & Gas Operations	197	54,106	23,007	708
237110	Water & Sewer Line & Related Structures Construction	754	1,130,875	263,358	7,673
237990	Other Heavy & Civil Engineering Construction	442	445,162	112,564	3,081
324110	Petroleum Refineries	63	6,800,322	121,582	1,707
325211	Plastics Material & Resin Mfg	142	D	D	(2500-4999
325212	Synthetic Rubber Mfg	25	D	D	(500-999)
326299	All Other Rubber Product Mfg	208	1,032,798	188,396	5,501
331111	Iron & Steel Mills	243	6,368,766	970,552	18,848
331210	Iron & Steel Pipe & Tube Mfg from Purchased Steel	39	1,006,549	158,352	3,940
331511	Iron Foundries	71	1,138,065	510,370	8,655
332420	Metal Tank (Heavy Gauge) Mfg	4	364,574	122,091	3,132
332911	Industrial Valve Mfg	45	419,236	114,957	2,808
333120	Construction Machinery Mfg	129	468,308	78,362	2,097
333132	Oil & Gas Field Machinery & Equip Mfg	19	16,370	3,095	79
333512	Machine Tool (Metal Cutting Types) Mfg	187	498,454	118,636	2,516
333611	Turbine & Turbine Generator Set Units Mfg	15	335,960	66,113	1,325
333911	Pump & Pumping Equip Mfg	74	644,754	135,592	3,568
333912	Air & Gas Compressor Mfg	30	318,519	70,301	1,455
333996	Fluid Power Pump & Motor Mfg	11	283,512	73,038	1,587
334513	Instruments Mfg for Measuring & Controlling Indust. Process Variables	132	508,818	144,440	2,913
334514	Totalizing Fluid Meter & Counting Device Mfg	15	217,192	28,189	735
423510	Metal Service Centers & Other Metal Merchant Wholesalers	708	8,118,693	449,285	10,029
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541330	Engineering Services	2,778	3,070,930	1,369,904	25,715
541990	All Other Professional, Scientific, & Technical Services	3,106	139,793	104,895	2,280
	Sum	13,010	41,101,607	6,179,915	136,032

D = Withheld to avoid disclosing data of individual companies; data are included in higher level totals

* Source: Lexis Nexis, Team NEO

** Source: US Census, Industry Series, 2002 (most recent available).

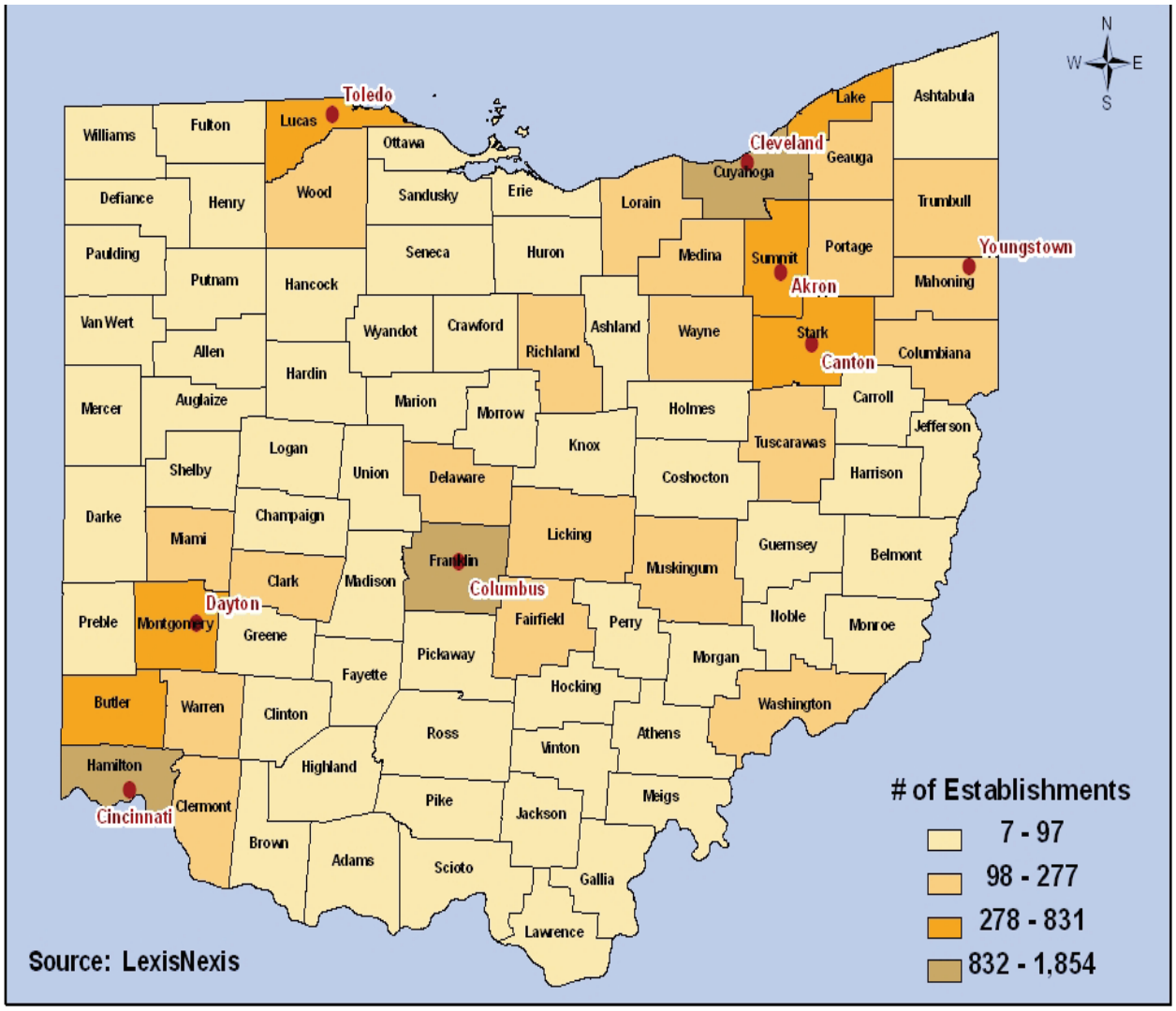
There is a large degree of overlap between the industries identified in the pipeline construction supply chain and the industries identified in the CO_2 EOR supply chain. Eight industry sectors were determined to be unique to Ohio's EOR supply chain and were not identified as part of Ohio's CO_2 pipeline supply chain (Table 5). Their component industries show EOR's economic link to oil and natural gas drilling and extracting industries as well as to equipment required for EOR activities.

Table 5. Sectors Unique to Ohio's EOR Supply Chain

NAICS	Description	Employees
211111	Crude Petroleum & Natural Gas Extraction	4,000
213111	Drilling Oil & Gas Wells	479
213112	Support Activities for Oil & Gas Operations	708
237110	Water & Sewer Line & Related Structures Const.	7,673
324110	Petroleum Refineries	1,707
325211	Plastics Material & Resin Mfg	(2500-4999)
332420	Metal Tank (Heavy Gauge) Mfg	3,132
333912	Air & Gas Compressor Mfg	1,455
Sum		19,154

Figure 5 shows the location of Ohio establishments matching the NAICS codes for EOR operations (Table 4 above). Total Ohio EOR establishments amount to 13,010. As was the case with the CO_2 pipeline supply chain, the three counties with the highest concentration of establishments are Cuyahoga, Franklin, and Hamilton. The addition of eight industries unique to EOR's supply chain (Table 5 above) results in more counties having higher concentrations of establishments than in the case of pipeline construction. This implies diversity and a broader economic base of impact for EOR activity.

Figure 5. Map of Ohio CO_2 EOR Supply Chain Establishments.



IV. Conclusions and Implications

A conceptual Ohio CO_2 pipeline was developed and mapped reflecting planned CO_2 sources and depleted oil fields that could be viable for EOR. Industries were identified based upon potential pipeline construction and operation activities as well as upon potential EOR activities within the state. These supply chain industries were measured in terms of employment, wages, GDP, shipments, and number of establishments. The number of establishments was mapped by county to offer initial indicators of where economic activity might occur within the state.

A 450-mile-long CO_2 pipeline network had a construction cost estimate of $280 million. Operating and Maintenance costs were estimated to be $2.3 million per year. This conceptual pipeline system ran through 20 counties, linking four major oil field sinks with fifteen ethanol, synfuel and power plants as sources of CO_2.

CO_2 pipeline and EOR activity in the state of Ohio would positively impact 13,000 establishments and 136,000 employees (Table 6). This represents 2.5 percent of all Ohio workers. Cuyahoga, Franklin, and Hamilton counties would realize the most impact given the concentration of supply chain establishments within their borders.

Table 6. Measures of Pipeline and EOR Supply Chain Magnitude

Measure	Value	
Number of Establishments	13,010	
Value of Shipments	$41	billion
Annual Payroll	$6	billion
Employees	136,032	

Source: Table 4.

Implications of the results found in this study are two-fold. CO_2 pipeline and EOR activity in the state of Ohio would have a widespread economic impact. All counties had at least five firms that met the supply chain criteria and many had an even greater concentration.

Secondly, while the CO_2 pipeline network displayed in this report is conceptual in nature, it is based upon formations suitable for EOR and likely sources of CO_2. The network could be phased in and constructed in conjunction with CO_2 sources. There are three advantages to constructing a CO_2 pipeline network in Ohio. First, EOR activity is feasible under current federal regulations and there are likely opportunities for positive cash flow to pay for pipeline construction. Secondly, a built-out Ohio CO_2 pipeline network can serve to link Ohio CO_2 production to deep saline formation sinks in Ohio as well as EOR and sequestration sinks elsewhere in the nation. Finally, as Ohio's CO_2 EOR rules are developed and the value of sequestered CO_2 becomes known, Ohio producers of CO_2 can begin to integrate various pipeline networks.

[i] See http://www.pewclimate.org/Ohio-Coal-Gasification, "Creating Power, Technology, and Products: The Role of Coal Gasification in Ohio's Economy and Energy Future," Kleinhenz and Associates, 2007.

[ii] Amended Senate Bill 221.

[iii] As is the case with coal gasification projects, large biofuels projects are excellent sources of concentrated CO_2.

[iv] Ohio Geological Survey

[v] In some states, the CO_2 Enhanced Oil Recovery business is well-established and mature. This is particularly true in the Permian Basin region of west Texas.

[vi] Developed in Discussions with the Ohio Geological Survey. All Pipeline Representations Are Conceptual.

[vii] The construction and O&M costs were derived by the MIT Pipeline model and are subject to change given current inflationary material and labor costs. The MIT pipeline modeling software was developed by the MIT Carbon Capture and Sequestration Technologies Program. This software is publicly available online at http://e40-hjh-server1.mit.edu/energylab/wikka.php?wakka=MIT (accessed 8/15/08); the version used to develop the pipeline models in this paper was version two.