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A phased approach to building a hypothetical pipeline network for CO_2 transport during CCUS

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Abstract

Carbon capture, utilization, and storage continue to receive attention as a way to reduce carbon dioxide (CO_2) emissions and would likely employ a pipeline network to transport the CO_2 to the storage locations. The Plains CO_2 Reduction (PCOR) Partnership estimated how a theoretical CO_2 pipeline network might be built out in the PCOR Partnership region, over what time frame it might be built, and how much it might cost. It was found that a hypothetical pipeline network of trunk lines roughly 10,780 km in total length could provide an overall CO_2 reduction for the region of about 555.6 Mtonnes CO_2/yr by 2050.

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1. Introduction

Carbon capture, utilization, and storage (CCUS) continue to receive considerable attention as an approach to reduce carbon dioxide (CO_2) emissions. Enormous capital investment will be required to capture, compress, and transport the CO_2 to storage targets if the concept is deployed on a large scale. Absent national policy or regulatory drivers, this huge capital cost means that the utilization of CO_2 for enhanced resource recovery (enhanced oil recovery [EOR] or enhanced coalbed methane [ECBM] recovery) is likely to provide the impetus for the early deployment of CCUS. National carbon management policies (i.e., carbon regulation by the U.S. Congress and/or emission standards enacted by the U.S. Environmental Protection Agency) likely would expand this deployment. Unfortunately, many of the large CO_2 sources are not located near appropriate geological storage areas, either saline formations or enhanced resource opportunities, and it is likely that a pipeline network would be needed to transport the CO_2 from the sources to the storage sinks.

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Nomenclature

CCUS	carbon capture, utilization and storage
CO_2	carbon dioxide
ECBM	enhanced coalbed methane
EOR	enhanced oil recovery
IEA	International Energy Agency
IECM	Integrated Environmental Control Model
km	kilometers
Mtonnes	million tonnes
PCOR	Plains CO_2 Reduction [Partnership]
ppmv	parts per million by volume
yr	year

2. Methodology

2.1. Development of a phased approach to pipeline network design

Various approaches could be taken to planning a CO_2 pipeline network that supports widespread CCUS [1]. One approach is a nationwide network that would transport CO_2 from the large industrial sources located in geographically diverse areas to large-scale geological storage sites. A second model consists of a gradual build-out of regional networks in which large CO_2 point sources are connected to existing pipeline infrastructure that serves EOR operations with local storage. A third version considers that shorter pipelines would directly link many large CO_2 power plant sources with nearby storage locations. Because there are only a few thousand utility and industrial CO_2 emission sources and even fewer large geologic storage targets, it is more likely that the third approach will be the one that is implemented. In this scenario, a few very large CO_2 sources would feed dedicated pipelines that carry the gas to a few large EOR injection sites [1]. The CO_2 from smaller industrial sources is unlikely to be captured and transported in a pipeline network because the compression of small amounts of CO_2 for pipeline transport would make such a system cost-prohibitive [1].

The cost of a CO_2 pipeline network is the subject of considerable interest, especially with regard to which entities might fund all or parts of a network. A blend of private- and public-sector involvement may be required to develop CCUS as a viable industry. The choice of which specific approach would be more appropriate would depend on the specific circumstance. For example, if the economics are positive, private funding may be sufficient to construct and operate a pipeline from a particular source or cluster of sources to an enhanced resource opportunity. Other pipelines may need government funding to defray a part of the costs, while still other pipelines that may be mandated by the government to meet an emission reduction target will never be economically viable and may require government funding for the life of the project.

It is highly unlikely that a pipeline network would be built quickly, as the drivers for rapid implementation of CCUS are not in place. Instead, it is more likely that a network would be built in stages or phases, with the first phase consisting of pipeline segments that connect sources with EOR opportunities, followed by the addition of other sources and sinks as dictated either by the marketplace (in the case of EOR) or national or regional carbon management policy.

An effort was undertaken by the Plains CO_2 Reduction (PCOR) Partnership to estimate how a theoretical CO_2 pipeline network might be built out in the PCOR Partnership region, over what time frame it might be built, and how much it might cost.

The first step in determining the timing of the pipeline phases requires a presumption of how aggressively CCUS will be pursued in a region based on various approaches. The International Energy Agency’s (IEA’s) BLUE Map scenario has put forth the concept of a 50% emission reduction (compared to levels from the year 2000) by 2050 [2]. This reduction falls between the two approaches outlined by Dooley et al. [3] when they examined the effects on the U.S. electricity generation assets of stabilizing atmospheric concentrations of CO_2 at 450 ppmv and at 550 ppmv.

Although the reductions needed to stabilize the atmospheric CO_2 concentration at 450 ppmv appear to be so stringent as to be nearly unattainable, the timing seems to appropriately delineate the breaks between phases of theoretical pipeline development and was therefore adopted for this study. As a result, Phase I was defined as lasting from about 2015 to 2035, with Phase II running from 2035 to 2050, and Phase III beginning in 2050.

2.2 PCOR Partnership methodology for routing hypothetical pipeline networks

The PCOR Partnership phased pipeline planning methodology was developed to compare routes for hypothetical pipeline networks by relatively quickly estimating the amount of CO_2 that can be stored as well as the length and cost of the trunk pipelines required to store that CO_2. The approach is not intended as a method for developing a detailed pipeline network design.

Clusters of CO_2 sources are identified by noting which sources are proximally located to each other on the map. The CO_2 emission rate for each of the sources is taken from one of the many online emission databases, keeping in mind the appropriate capture level for the source type. Expected emission trends are then determined and applied to the known emission values to estimate future CO_2 emission rates.

The CO_2 storage capacity of each sink or sink cluster must be researched. Some data sets containing this information are available online.

Hypothetical pipeline routes can be determined using a pipeline routing software, or they can be roughly determined by measuring the distances between the centroid of the cluster of CO_2 sources and the centroid of the sink cluster. Pipeline costs can be approximated using preliminary engineering estimates or the Carnegie Mellon University IECM (Integrated Environmental Control Model), a free product that is readily available online.

2.3 Results–case study application of the methodology to a hypothetical pipeline network in the PCOR Partnership region

It is important to remember that the phased pipeline network discussed here is hypothetical. The PCOR Partnership methodology was developed solely for the purpose of estimating a theoretical pipeline network route and approximate timing for its phased implementation. The methodology was tested by using it to estimate a hypothetical phased pipeline for the PCOR Partnership region.

While the easiest sources from which to capture CO_2 are ethanol plants and gas-processing facilities, the earliest storage (i.e., Phase I) likely will be in areas in which the CO_2 can be profitably used, such as during enhanced resource development activities (i.e., EOR or ECBM production). Many gas-processing facilities are situated on or near oil fields, making them ideally located for this type of activity, assuming that the product from several facilities can be gathered to form a large enough stream to supply an EOR project. Ethanol plants, on the other hand, are more widely distributed and may not be located proximally to storage sinks. The majority of the ethanol plants probably will not come into play until late in Phase II or during Phase III network development because the value of the CO_2 volumes, even when consolidated, will not exceed the cost to dehydrate, compress, and build a lengthy pipeline to transport the CO_2 to a storage target. Besides larger gas-processing plants and well-situated large ethanol plants, other Phase I sources that would be included in a hypothetical Phase I network would be any power plants having corporate reasons for being an early adopter (e.g., government grants, etc.). It is expected that Phase I pipelines will be a combination of judiciously sited pipelines linking several sources (i.e., a source cluster) to a sink (or a cluster of sinks in a localized area) and one-to-one pipelines transporting CO_2 between one specific CO_2 source to a specific storage target. Whenever possible, existing pipelines should be incorporated into the hypothetical pipeline network.

Phase II of a network would incorporate more power plants, some of the larger industrial facilities (particularly cement kilns), and the rest of the ethanol and gas-processing facilities, if it makes economic sense to do so. Target geological sinks would include the rest of the EOR opportunities as well as nearby saline formations. Some of the pipelines in this phase will be the branch lines as well as trunk lines.

Phase III of a network will come into play if sufficiently stringent climate policy and regulations have been put into place so as to force more widespread adoption of CCUS. This phase will include the remainder of the larger coal-fired power plants that must capture CO_2 as well as larger industrial facilities. Target geological sinks added to the network at this point would consist primarily of saline formations. During this phase, the trunk lines could be connected to other trunk lines in the network, and feeder lines could be added from large facilities to hook them up with the branch lines. It is also possible that it might not make economic sense to connect all of the pipeline segments together to form a single network during Phase III. In this case, there might be multiple pipeline segments connecting specific source and sink clusters as well as smaller pipeline networks serving specific areas.

The development methodology was applied to the PCOR Partnership region to estimate a hypothetical pipeline network that could be implemented in phases over the next 40 to 50 years. The PCOR Partnership region consists of the states of North Dakota, South Dakota, Nebraska, Minnesota, Iowa, Missouri, and Wisconsin; the Powder River basin portions of Montana and Wyoming; the provinces of Manitoba, Saskatchewan, Alberta, and the extreme northeast corner of British Columbia. The volume of CO_2 that would be available from each cluster of sources in the region was determined for three time periods (the present until 2035, from 2035 to 2050, and after 2050) and the most likely storage targets for each source cluster were identified. Theoretical pipeline routes connecting the sources and sinks were determined. Finally, when viewed as a regional whole, the hypothetical routes were optimized for each network phase.

It was found that a hypothetical pipeline network of trunk lines roughly 10,750 km in total length could transport sufficient quantities of CO_2 such that the IEA BLUE Map scenario could be met for the PCOR Partnership region by 2050. (The IEA BLUE Map scenario reduction would equal roughly 403.4 Mtonnes CO_2/yr for the PCOR Partnership region.) Meeting this target is dependent upon two critical assumptions. The first, put forward by the Energy Research Group at Dalhousie University [4], is that the CO_2 output from Canada's electricity generation fleet will increase dramatically until at least 2050. The second assumption is that the Canadian government's goal of CO_2 emission capture (which equates to a 98% CO_2 emission capture rate in 2050 using values included by the Energy Research Group [4]) actually would be attained. These assumptions result in the storage of 335 Mtonnes/yr of CO_2 in the Canadian portion of the PCOR Partnership. When coupled with the expected U.S. CO_2 storage of 220.8 Mtonnes/yr, the overall reduction for the PCOR Partnership region is about 555.6 Mtonnes/yr by 2050. Table 1 summarizes the estimates of length, cost, and amount of CO_2 transported during the three hypothetical pipeline network development phases. The theoretical pipeline routes are shown in Figures 1–3.

Table 1. Summary of the hypothetical phased pipeline network for the PCOR Partnership region

	U.S.			Canada				
Phase	I	II	III	I	II	III	Total of Phases I and II	Total, including Phase III
km of new hypothetical pipeline	1078	4184	0	2520	2969	1384	10,751	12,135
CO_2 transported by new hypothetical pipeline, Mtonnes/yr	52.6	168.2	0	145.6	184.5	82.4	551	633.3
Capital cost of new hypothetical pipeline $M (2009 US$)	676.5	2965.6	0	1251	1887	1136	6780.1	7916.1
O&M[1] cost of new hypothetical pipeline, $M (2009 US$)	3.4	13.6	0	8.1	9	4	34.0	38.0
Levelized annual cost of new hypothetical pipeline, $M (2009 US$)	79.6	348.0	0	145.6	222	132	795.2	927.2

1 Operating and maintenance.

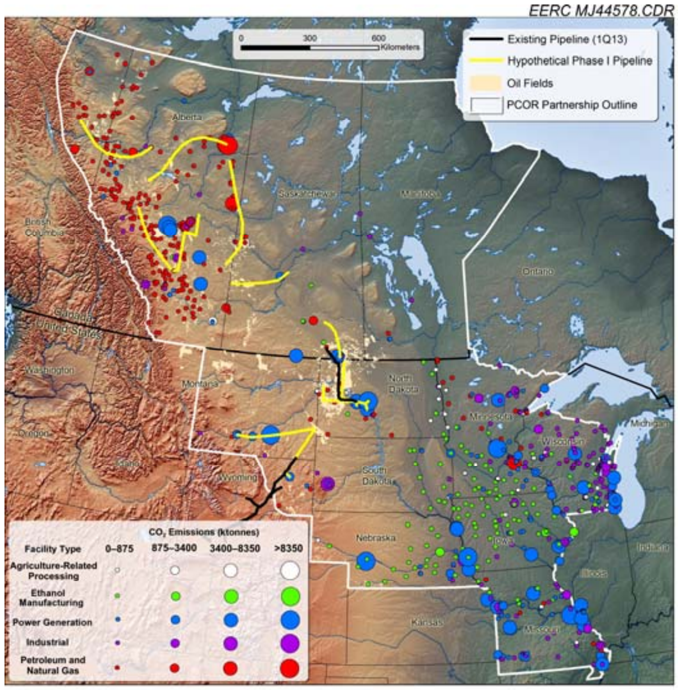

Fig.1. The hypothetical Phase I pipeline network as determined for the PCOR Partnership region

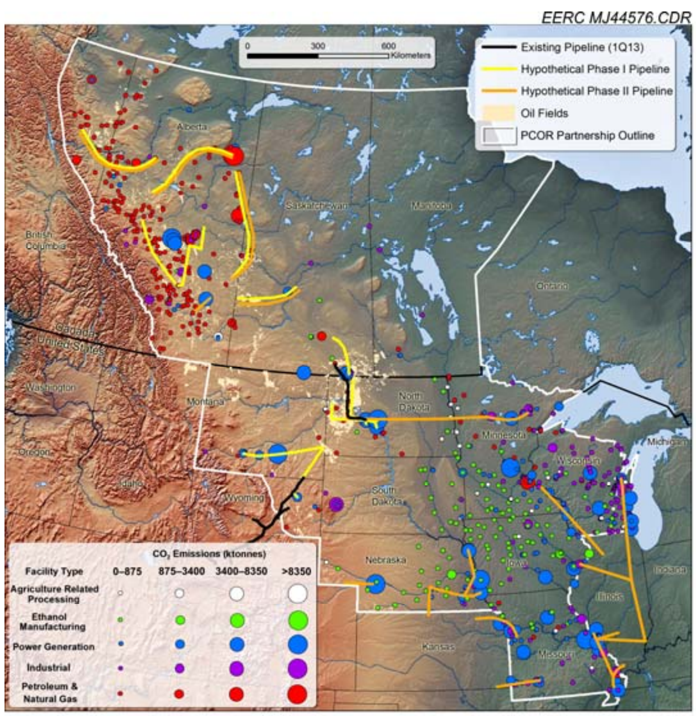

Fig. 2. The hypothetical Phase II pipeline network as determined for the PCOR Partnership region

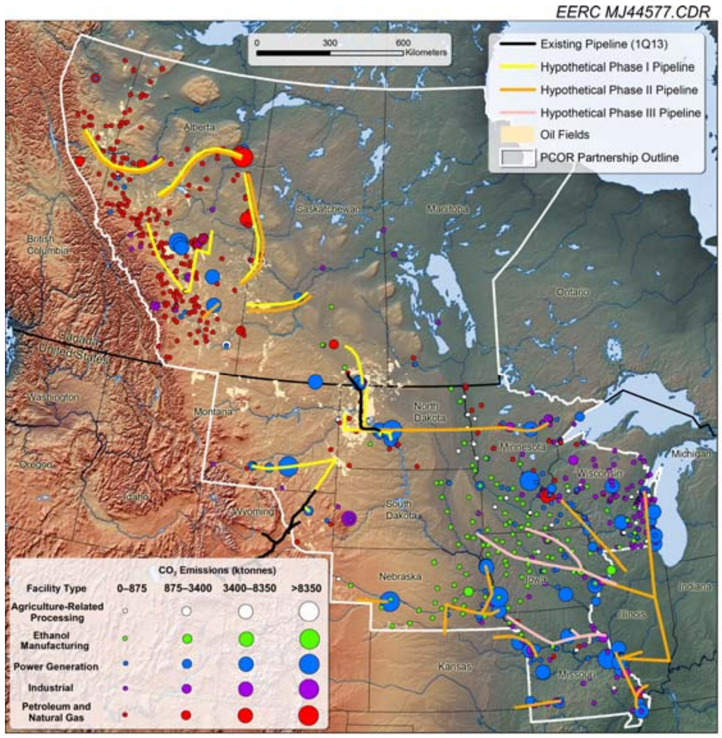

Fig. 3. The hypothetical Phase III pipeline network as determined for the PCOR Partnership region

3. Conclusion

The PCOR Partnership's methodology for estimating preliminary phased pipeline routes appears to work reasonably well. The hypothetical phased network that was produced during a case study test of the methodology seems to agree with results obtained by others. Dooley and others [5] estimated that about 45,000 km of pipeline would be needed in the United States to meet the scenario in which the atmospheric CO_2 is stabilized at 450 ppmv by 2050. The hypothetical pipeline estimates obtained using the PCOR Partnership methodology indicate that the length required for the U.S. portion of the region totals 5260 km. At first glance, this seems a bit low, but when the relatively short distance between clusters of large CO_2 sources and appropriate geologic sinks (especially EOR opportunities) are considered, it is obvious that the average pipeline segment would be shorter in the PCOR Partnership region than in many other areas of the United States.

According to the IEA, long-term strategies are needed to cluster CO_2 sources and develop CO_2 pipeline networks such that source-to-sink transmission of CO_2 is optimized. The hypothetical phased pipeline routing methodology developed by the PCOR Partnership could help to address this challenge.

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