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System integration linking CO2 Sources, Sinks, and Infrastructure for the Ordos Basin, China.

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Abstract

In this work, we present a collaborative effort between US and Chinese ACTC scientists to create the first comprehensive study of what a large and integrated commercial scale CCUS system could look like in China. We focus on the Ordos Basin, which is slightly larger than New Mexico, the fifth largest state in the US. The basin has a large number of chemical and power industries found within its perimeter, which generate 100s MT of CO2 per year, and has the potential capacity to store CO2 in a wide range of target formations including CO2 utilization. Oil fields and unminable coal seams in the area have been identified targets for enhanced oil recovery (EOR) and enhanced coal bed methane recovery (ECBM) using available waste CO2 streams. , As the Ordos Basin shares many key characteristics with the Illinois Basin in the US, we have leveraged experience and understanding of the sequestration potential of the Illinois Basin to enhance and accelerate the assessment of the Ordos Basin.

Using the *SimCCS* decision model on this candidate network, we developed optimized combinations of CCS infrastructure in response to (1) a CO2 capture target amount and (2) a CO2 tax on emissions. Example results show an emissions penalty below \$24/tCO2 does not stimulate any CO2 capture; that is, all industries emit their entire CO2 emissions because it is cheaper than capturing. From \$24/tCO2 until \$52/tCO2, approximately 50 MtCO2/yr is capture system wide from the cheapest sources (e.g., coal to liquid plants). Beyond \$52/tCO2, it becomes economical to capture CO2 from coal-fired power plants. Results from this study show that candidate pipeline routes in the Ordos Basin could avoid high cost areas such as population centers and topographically complex terrain, particularly in the southern portion of the Ordos Basin toward the city of Xi’an.

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1. Introduction

Recent dramatic increases in China's use of coal for both energy and chemical production have led to corresponding increases in carbon dioxide (CO2) emissions, launching China into the position as world leader in this arena. In fact, the United States and China are the two most prolific producers of waste CO_2 and account for greater than 40% of total world emissions [1].

In an effort to combat the impacts of CO_2 on climate change, the leaders of the United States (US) and China reached an historic agreement in 2009 (Figure 1) to create virtual research collaborations under the framework of the Clean Energy Research Centers (CERC) [2]. Three such centers were created to tackle energy efficiency, transportation emission, and clean coal (Figure 2). These centers have parallel teams on both the US and Chinese sides tasked with collaboration and integration of research. The clean coal center, Advanced Coal Technology Consortium (ACTC) [3], is working on a range of tasks including Carbon Capture, Utilization, and Storage (CCUS). As the ACTC has evolved over the past 3 years, the storage theme has grown to include not only subsurface geological issues but now comprises the components needed to create basin scale system analyses that link CO_2 sources to subsurface sinks around existing surface features through pipeline networks.

Figure 1. (a) Presidents Obama and Hu agree to create the CERC project in 2009 (b) CERC logo.

2. Methods

2.1. Infrastructure model

In order to develop infrastructure to capture, transport, and store CO_2, potential pipeline routes need to be identified in the Ordos Basin. Some country wide data for China is published in the open literature [4]. However, prior to this study, the detailed information necessary to create a weighted-cost surface was not readily available. As a result, we have developed the first ever weighted-cost surface China that can uses shortest path algorithms to identify low-cost corridors for pipelines [5]. The weighted-cost surface is based on multiple data inputs including topographic slope, population density, roads, railroads, rivers, land cover, and aspect ratio (Figure 2). These data were gathered from publicly available sources for the entire country of China. Building the cost surface for the entire country means that the cost surface model can be, for the first time, straightforwardly deployed to any region in China.

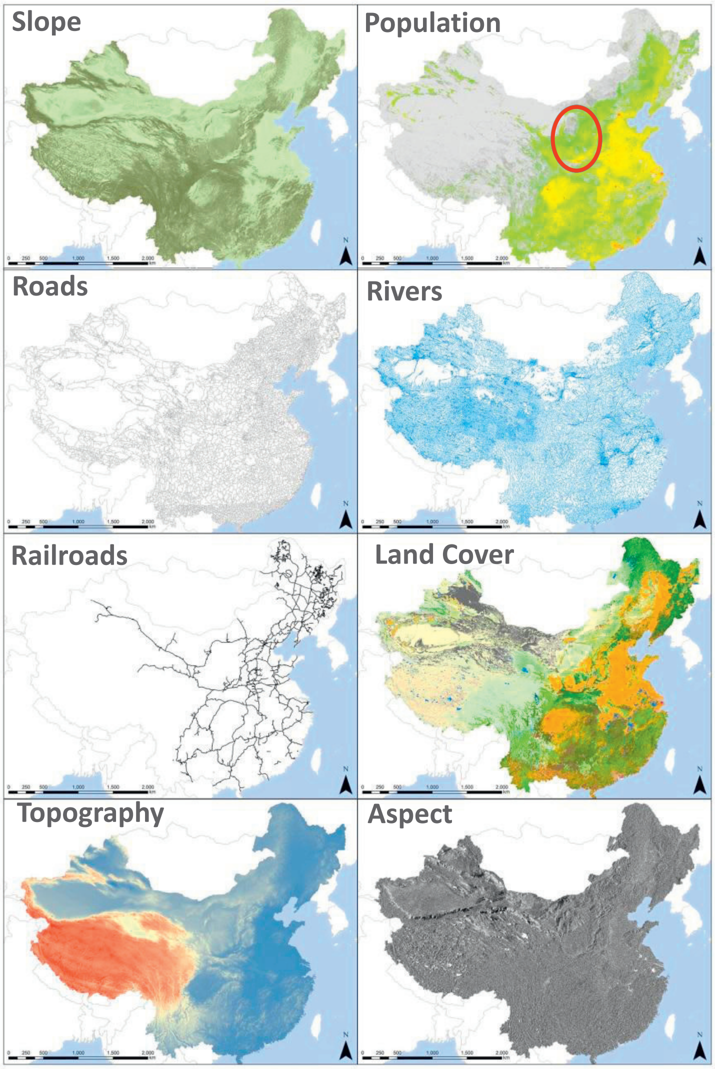
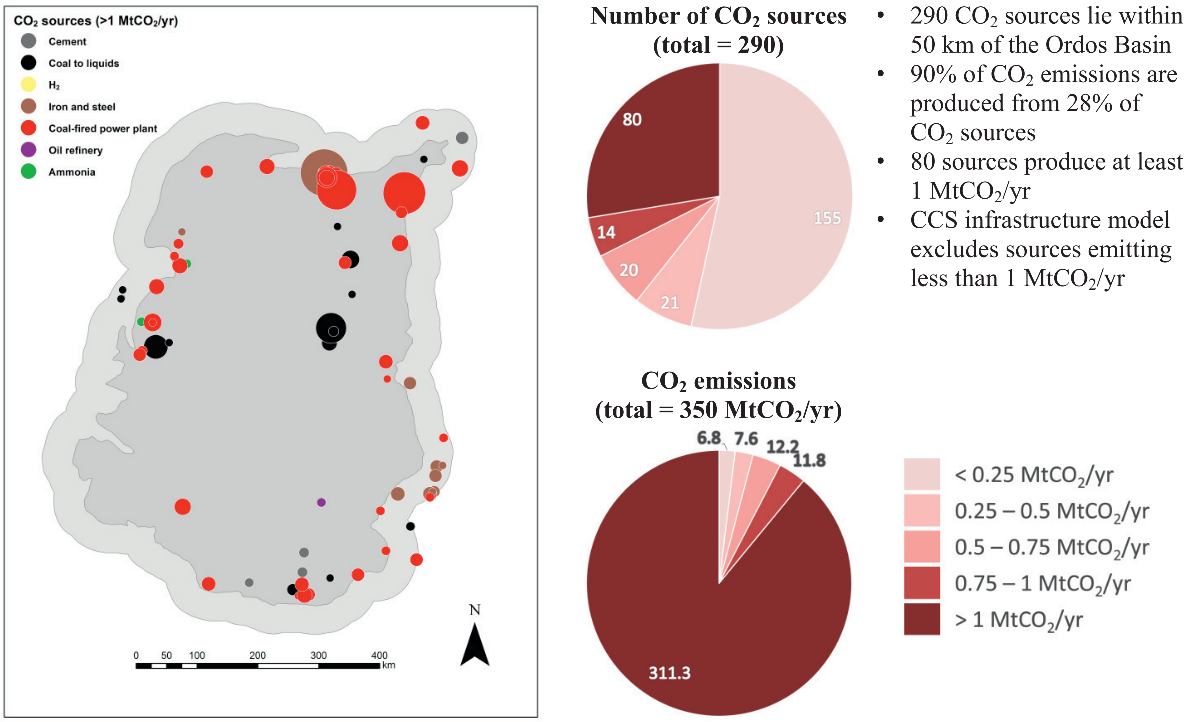


Figure 2. Data inputs for the cost-weighted pipeline routing surface. The Ordos Basin is circled in red on the population figure.

2.2. Emissions source data

We built a CO_2 emissions database of 290 individual sources that emit approximately 350 MT of CO_2 per year; these sources are located within a 50 km margin of the Ordos Basin (Figure 3a). The sources consist of a wide range of industries including coal-fired power generation, cement manufacture, coal-to-liquids production, ammonia manufacture, and iron and steel production.
. In the absence of individual facility information, we used publicly-available capture costs estimates coupled with the annual CO_2 streams. For this study, only sources greater or equal to 1 MT/yr were included in the analysis (Figure 3b).



- 290 CO_2 sources lie within 50 km of the Ordos Basin
- 90% of CO_2 emissions are produced from 28% of CO_2 sources
- 80 sources produce at least 1 $MtCO_2$/yr
- CCS infrastructure model excludes sources emitting less than 1 $MtCO_2$/yr

Figure 3 LEFT: Locations, sizes, and industrial source for CO2 emmisions around the Ordos Basin. RIGHT: Source statistics displayed by source size.

2.3. Geologic storage sites capacity and injectivity

For this study, the Majiagou formation was selected as the target saline aquifer storage formation in the Ordos [6]. The Majiagou is a thick carbonate that ranges in depth from surface outcrops to many kilometres deep. Isopach maps were used to delineate depth and thickness of this formation (Figure 4), and formation permeabilities and porosities were estimated using a combination of observed values and estimates from the literature. Nine target regions were pre-selected based on analysis completed by the Chinese Academy of Sciences based on most likely CO_2 storage scenarios (Table 1).

Table 1. Properties used for the 9 geologic sinks in the Majiagou formation

Geologic Sink Name	X (or LON)	Y (or LAT)	Depth (m)	Thickness (m)	Area (km^2)
1	110.6089	40.01542	1088	189	10
2	107.4401	38.89795	3965	431	332
3	107.3506	38.21991	3987	527	346
4	107.1083	37.58041	4365	525	347
5	110.6832	37.04562	1877	572	242
6	110.5423	36.28265	1896	444	202

7	109.9047	35.4809	1854	316	206
8	108.5704	35.05224	3183	470	373
9	107.6924	35.0034	4180	444	372

In the absence of detailed information, permeability (9.4e-15 m^2) and porosity (0.1) are assumed constant for the Majiagou. Injectivity was calculated using *CO_2-PENS [7,8]*, a reservoir simulation framework developed at Los Alamos National Laboratory (LANL). Minimum injection depth was set to1 km, and a total of 30 Gt of CO_2 storage capacity was identified based on restricting the 9 target regions to 20% land use availability for injection infrastructure.

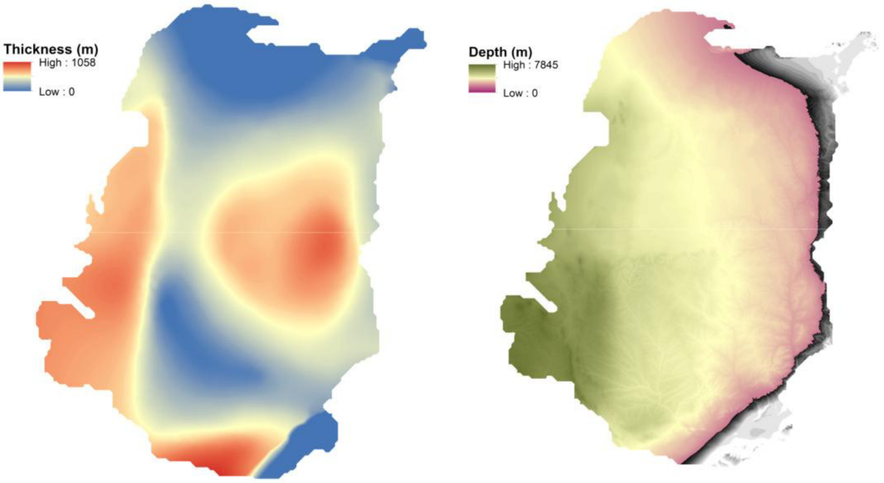


Figure 4. (a) Thickness and (b) Depth to the top of the Majiagou formation in the Ordos Basin

2.4. Pipeline routing and optimization algorithm

SimCCS [5,9] is an economic-engineering optimization model for designing CCS infrastructure. The model deploys CCs infrastructure (CO_2 sources, pipelines, and reservoirs) within a cap-and-trade environment (minimize costs to meet a carbon cap, or maximize capture CO2 within a constrained budget) or in response to price on emitting CO_2. To do this, *SimCCS* simultaneously considers: (i) which CO_2 sources, (ii) how much, and (iii) when to capture CO_2; (iv) what capacity, (v), where, and (vi) when to build a dedicated CO_2 pipeline network; (vii) which geologic reservoirs, (viii) how much, and (ix) when to inject and store CO_2; and (x) how to optimally distribute CO_2 between the CO_2 sources and sinks [9-11].

3. Results

3.1. Candidate pipeline network

Figure 5 shows the candidate pipeline network for the Ordos Basin. The 80 sources emitting greater than 1 MT/yr in the basin have been aggregated into 38 groups. The groups were chosen to have no more than a 20 km radius. The candidate pipeline network avoids high cost areas such as population centers and topographically complex terrain, particularly in the southern portion of the Ordos Basin toward the city of Xi’an. The network links together all the sources of CO2 and the subsurface CO2 storage reservoirs in a set of possible connections. The actual connections of the network will vary depending on both the amount of CO2 flowing and cost constraints that preferentially lead to capture at lower cost emitters.

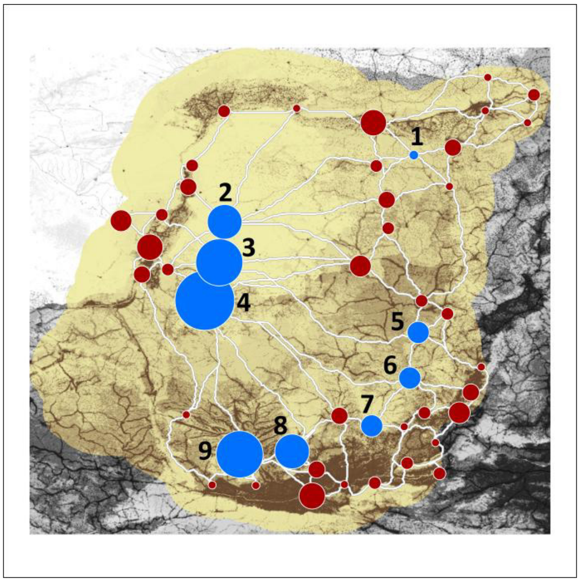


Figure 5. Candidate pipeline network linking the sources of CO2 (red) to the geologic storage reservoirs (blue) in the Ordos Basin.

3.2. Optimization of the network

Using the *SimCCS* decision model and on this candidate network, we developed optimized combinations of CCS infrastructure in response to a CO_2 tax on emissions. Infrastructure cost is a combination of capture, transport, and storage costs. Results show an emissions penalty below \$24/tCO_2 does not stimulate any CO_2 capture; that is, all industries emit their entire CO_2 emissions because it is cheaper than capturing (Figure 6). From \$24/tCO_2 until \$52/tCO_2, approximately 50 MtCO_2/yr is capture system wide from the cheapest sources (e.g., coal to liquid plants). Beyond \$52/tCO_2, it becomes economical to capture CO_2 from coal-fired power plants. Capture amounts ramp up when CO_2 price exceeds cost to capture from coal-fired power plants.

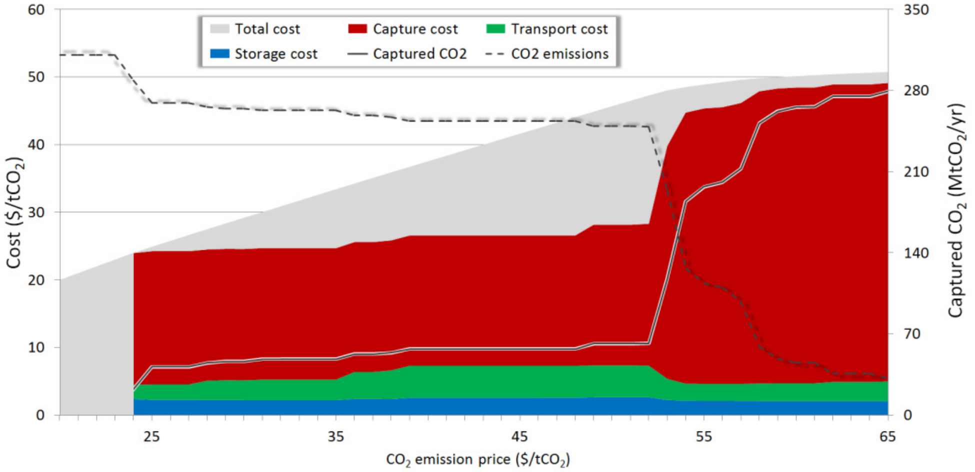


Figure 6. Evolution of costs and captured CO_2 as a function of emissions tax.

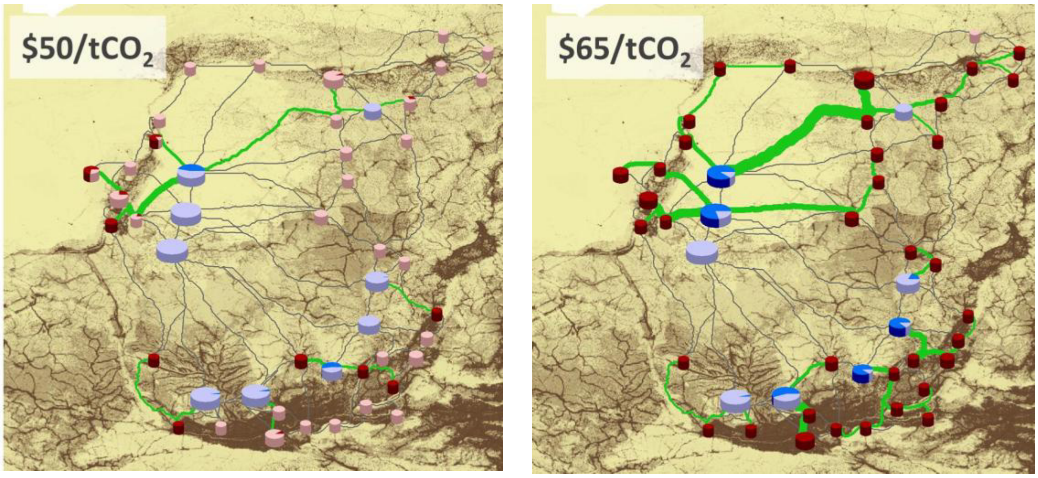


Figure 7. Pipeline network for two CO2 emissions tax rates (a) 50$/ton and (b) 65$/ton.

4. Future Plans

The next phase in the system level analysis of the Ordos basin will be to improve the fidelity of the subsurface capacity and injectivity calculations through use of more detailed geologic data. Another area of improvement will be to couple utilization such as enhanced water recovery (EWR) and enhanced oil recovery (EOR) into the model. The inclusion of utilization targets will provide cost off-sets and lead to lower CO2 taxes necessary to stimulate carbon capture from coal fired power plants.

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