An Open-Source, ML-Informed, Geospatial-Driven Tool for Identifying & Evaluating CO₂ Transport Routes

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Meeting CTS Challenges with Smart and Spatial Solutions

Challenge

- The evolving energy transport landscape requires a **dynamic response**
- Many **complex and interconnected factors** can greatly affect the success of developing new transport and impact project costs
- Need for evaluating existing transport corridors for reuse
 American

Solution



- Interactive smart, geospatial tool and database to assist route planning
- Accelerate carbon management development through a multivariate, Alinformed algorithm







Leveraging Data-Science, Geospatial Technologies & Competencies



Objectives Carbon Storage Global Oil & Gas Open 1.Build-off existing resources to Infrastructure Database provide a national Database comprehensive spatial 4665 database 2.Integrate data and critical Smart CO2 Transport-Routing Toc qualitative governance to advance transport planning Built to inform <u>reliable</u> 3. Enable stakeholders to domestic carbon identify potential routes & management IDENTIFY ROUTE EVAL evaluate existing rights-ofplanning and way development



Technical Workflow



Built to Inform CTS Planning & Development





Carbon Transport Spatial Database

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- Geospatial database
 - Version 1, 2023
 - Version 2, 2024
- 60+ weighted layers
- Metadata

- Original sources
- Weight definitions
- re 4. A.) Map displaying CCS potential by state and CCS legislation availability. B.) Map illustrat ate participation in none, or one or more DOE Regional Carbon Sequestration Partnerships (RCSP)





Currently in **Review** – should be available soon!

 Publication available 	Categories	Layer Examples						
Carbon Herald	CCS by State	Restrictions & regulations						
Safely Routing Carbon-Capture Pipelines The Dominion Past and provide and prov	Boundaries	Protected areas, urban areas, buildir						
NETL Creates Expansion Technic Route Plannin A resource and a r	Infrastructure	Pipelines, wells, roads						
A curated data resource to support safe carbon dioxide transport-route planning carbon dioxide transport-route planning carbon dioxide transport-route planning	Natural Hazards	Floodplains, earthquake, wildfire, landsli						
Pair Mender ** Jennefer Rouer.** Stalk Roue.* Diagram SCO2VEC Show more ∨ + Add to Mendelay < 51 Gre	Hydrology	Lakes, rivers, aquifers, groundwater						



https://edx.netl.doe.gov/dataset/ccs-pipeline-route-planning-database-v1

Report of Spatial Insights from Database



Boundaries

Area Coverage by Land Type (e.g., wetland, pasture, water) Historic Sites Count and List National Monument Area Coverage National Park Area Coverage and List Protected Area Coverage and Local Designations

Counties

States

Tribally-Controlled Land Area Coverage and List

Urban Area Coverage and List

Wilderness Area Coverage



CCS by State CO2 Emission in Million

Metric Tons by State

Sources by State State Sum of Median Storage Estimates by State State CO2 Group Involvement

> Easy to adjust variables!

Hydrology

Area Coverage by Aquifer Count of CO2 Emission Groundwater Monitoring Count Regulations Category by National Hydrology Area Coverage National Hydrology Waterbody Coverage National Hydrology Well Count National Hydrology **Flowline Length**

Active Sink Count

Active Source Count

Building Count

Infrastructure

High Consequence Area Count Hydrocarbon Pipeline Length Manufacturing Facility Count Natural Gas Pipeline Length

Oil Gas Well Count

Port Count

Power Plant Count

Primary Road Length

Processing Plant Count

Natural

Hazards

Railroad Length

Refinery Count

Secondary Road Length

Storage Count

Station Count

Landslide Susceptibility Area Coverage (Very High)

FEMA NRI Risk Score

FEMA NRI Coastal Flood **Risk Score**

FEMA NRI Resilience Score

Coverage of Areas >30% Grade Slope

FEMA NRI Earthquake Risk Score FEMA NRI Expected Annual Loss Score FEMA NRI Landslide Risk Score **FEMA NRI Riverine Flood Risk Score** FEMA NRI Social Vulnerability Score FEMA NRI Wildfire Risk Score FEMA NRI Earthquake **Risk Score** Area Coverage Soil Frost Action Potential (Low, Moderate, High) Area Coverage of Soil Steel Corrosion Potential (Low, Moderate, High)

Smart CO₂ Transport-Route Planning Tool

- Alpha version (Leveckis et al. 2024)
- Open-source & stand-alone
- Utilizes Monte Carlo Tree Search
 - Model-based Reinforcement Learning
 - Heuristic algorithm -'near optimal' solutions

Help documentation



eneral Ro oute Area: 43	ute Information 572,465 5 km
Counties h	v State
State	Counties
lowa	Black Hawk, Boore, Cedar, Cerro Gordo, Chresteler, Dinklasser, Clarke, Cally, Clarkov, Conerlord, Dan Weines, Edivision, Dulyou, Emmer, Fayeller, Fayel, Fansikh, Freenot, Genere, Hamilton, Harcolo, Hardin, Humboldi, Ha, Kotaka, Kossah, Lucas, Lynn, Morrow, Mongymerry, Mauszter, Olirein, Oscola, Page, Palo Mao, Piynova, Petit Puttasattarese, Scott, Shetty, Soca, Stery, Wayne, Webster, Wirveshiek, Woodbury, Work, Wagit
Spatially I NOTE: Res	ntersecting Features by Category uits based on where route intersects tract or 10 km grid cell that also intersects spatial
Jana.	
n. Doundarie	5
1. Develop	ed Lands Coverage
Total	Area = 94,450,690.902.71 km
Maxin	num Area = 252,934,937.71 km
Mean	Area = 182,354,631.09 km sum Area = 29,843,390.47 km
2. Pistonc 53 ou	ote Count t of 556 10km cells contain values (9.04%)
Total	Count = 97
Maxim	num Count = 12
Minin	um Count = 1
3 Matoric	Site by Source
53 ou	t of 560 10km cells intersect (8.04%)
List	Camp Creek Cemetery and Chapel; Arbor Lodge; Nebraska City Historic District; South 13th
Shee	LHistoric District, South Nebraska City Historic Datrict, Tabor Antislavery Historic District, Fort
Scho	of Sacred Heart Catholic Church Complex; Leone, Florentine, and Carpathia Apartment
Build	ings; Otson's Market; Country Club Historic District; Vinton Street Commercial Historic District;
Nicho	ias Street Historic District; Old Market Historic District; South Omaha Main Street Historic
Broad	to onana hat are commerce matrice based, doe coast metoric besite, too book of west
Distri	It; Park/Gien Avenues Historic District; Haymarket Commercial Historic District; Fort Omaha
Histor	ic District; Fort Atkinson; Carstens Farmstead; Hartan Courthouse Square Commercial District;
Sant	sonnace Lanner Lanner Lanner, Lanner, Hosewen and Elizabeth, Farmstead Historic District; nan Parry Historic District Southal Holese County Park Historic District Park Motel Lincoln
Highs	wy-West Greene County Rural Segment; Lincoln Highway-Raccoon River Rural Segment;
Jeffer	son Square Commercial Historic District; Lincoln Highway-Buttrick's Creek to Grand Junction
Histor	ent, Lincoln Highway-Grand Junction begineitt, Old Town Historic District, Bandshell Park ic District: Elkader Downtown Historic District Boone Viaduct: Dolliver Memorial State Park.
Pionie	; Hiking & Maintenance Area (Area B); Eldora Downtown Historic District; Hardin County Home
	Page 28

Outputs spatial data and report





https://edx.netl.doe.gov/dataset/smart-co2-transport-route-planning-tool

Output Reports

PDF Includes:

- Table of contents
- Line length or polygon area evaluated
- States and Counties crossed
- For each of the **60+ spatial layers**:
 - Number, percent, and area of cells and Census Tracts intersected
 - **Statistics** for scored values (e.g., National Risk Index maximum, mean, minimum)
 - Lists of historical sites, protected areas, and urban areas that also intersect cells



Provides insights by **spatial intersections** against **geodatabase layers** joined to

(A) 10km multivariate grid or

(B) Census Tracts (where applicable)

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Updates & Enhancements

Beta Version Release Anticipated Spring 2025

Updated user interface & database

- View key layers in map
- Revised database



Implemented capabilities

- Intermodal functionality
- Multiprocessing support
- Customize agent behavior (*distance vs cost*)

Linear

20

40

60

80







Increasing Useability & Usefulness

Next Steps

- Version 2 (Anticipated Spring 2025)
 - + rail mode
 - + updated geospatial database
 - + view data in UI
 - + enhanced smart logic
- Enable dynamic weighting
- Add more **mapped variables**
- Expand intermodal functionality
- Support dynamic weighting
- Decrease run times

Valued Delivered Interactive, stand-alone, geospatial tool designed to accelerate CO₂ transport route planning that accounts for legislation, best practices, and is complementary to related capabilities.





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DOE CO₂ Transport Toolbox



	X Curren		/ In	pro	gres	S	 Not in current scope 													
			Tool is			Analytics apply					Variables include						I			
	Build for	Supports	Open-Source	Stand-alone	Spatial	Temporal	AI/ML	Multi-scale	Multi-modal	Multi-stops	Phase-based	Land Use	Energy infrastructure	Public infrastructure	Economic	Community	Risk Likelihood	Baseline Da Published	Outputs Include	
CO₂ Transport Cost Model	Industry, regulators, researchers (government, academic, non-profit)	Estimating the cost of new CO ₂ pipelines	x	x	x	x	I	x	_	_	1	_	x	x	x	_	/	Ι	Pipeline diameter, number of pumps, cash flows, NPV, break-even CO ₂ price	
SimCCS Pipeline Network Model		Transport network modeling and cost analysis	x	-	x	x	-	x	x	x	x	x	x	x	x	x	-	-	Optimal network; costs for capture, transport, and storage	
Smart CO ₂ Transport- Route Planning Tool		Inform planning, development, and repurposing; risk assessments	x	x	X	-	x	X	x	_	-	x	x	x	x	x	x	x	Optimal network as spatial layer; report of route evaluation against variables	



NETLThankRESOURCESyou!

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