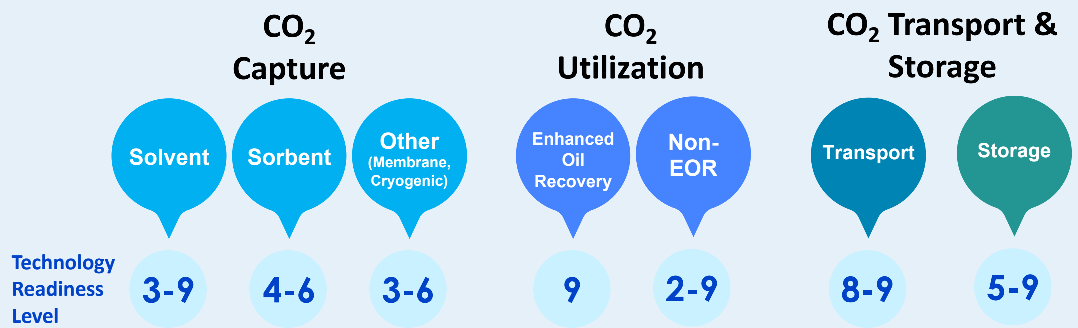
Status of CO_2 Capture & Storage (CCS) in Power Generation

CCS Value Chain Today

Technology readiness varies for CCS value chain components



Lessons learned from across industries can inform additional power sector deployment

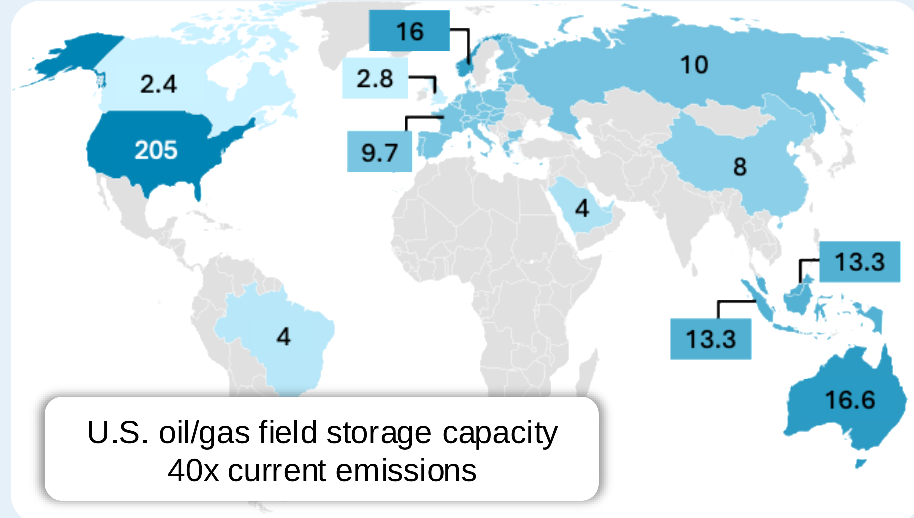
U.S. CO_2 Pipelines

- 5,000+ miles in U.S.
- Regulated by PHMSA

U.S. CO_2 Storage (Class VI Wells)

- Total Approved: 15 (including 8 in ND and 3 in WY)
- Total Pending/In Review: 152 (including 3 in ND and 4 in WY)

Enabling CCS for a net-zero future requires accelerated permitting and buildout of supporting infrastructure

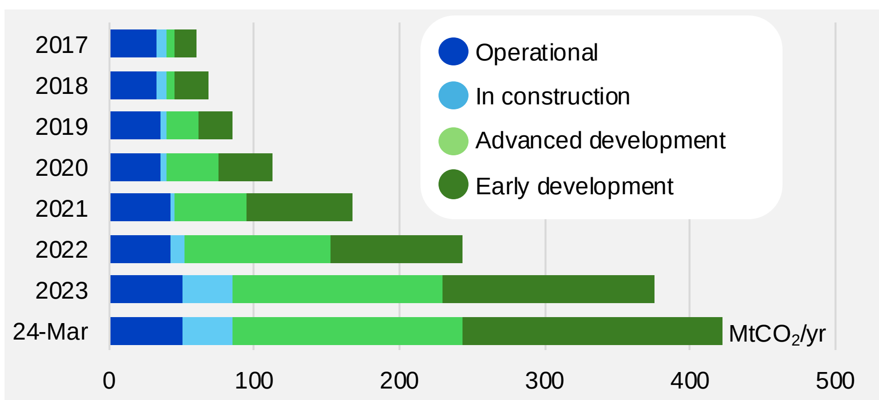


Potential CO_2 Storage Capacity in Oil / Gas Fields (Gton CO_2)

Data from Global CCS Institute

CCS Deployment Today

Commercial & Developing Facilities (all industries)



Global CO_2 Capture Capacity ~50 $MtCO_2/yr$

Global CO_2 Pipeline Capacity ~420 MtCO2/yr

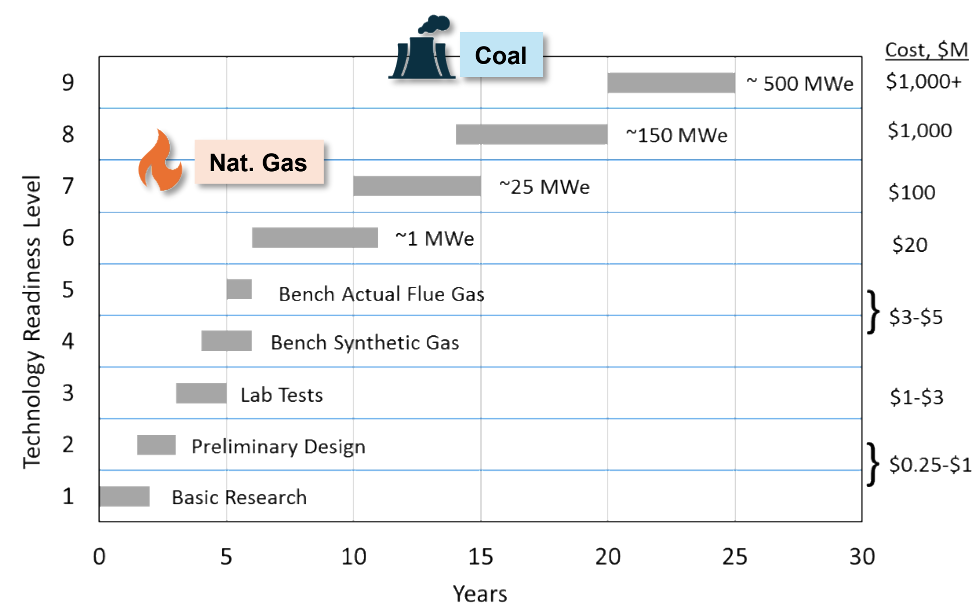
Data from Global CCS Institute

Commercial CCS Facilities for Power Generation

Canada SaskPower Boundary Dam (coal)	2014	1 $MtCO_2/yr$
U.S. Petra Nova Carbon Capture (coal)	2017	1.4
China National Energy Guohua Jinjie (coal)	2021	0.15
China National Energy Taizhou (coal)	2023	0.5
China (2 coal power plants)	2025+	1.7
Denmark (2 bioenergy plants)	2026	0.43
Iceland Silverstone (CHP)	2025	0.03

Pathway to Achieve At-Scale Deployment

Additional CCS Demonstrations Needed



Keys to successful power generation demonstrations

- Choose large-scale capture on power plants
- Identify lower risk, large-scale CO_2 storage options
- Improve understanding of CO_2 storage management
- Understand public engagement, acceptance, liability, etc.

U.S. CCS Test Centers

NATIONAL CARBON CAPTURE CENTER — ITC WYOMING INTEGRATED TEST CENTER

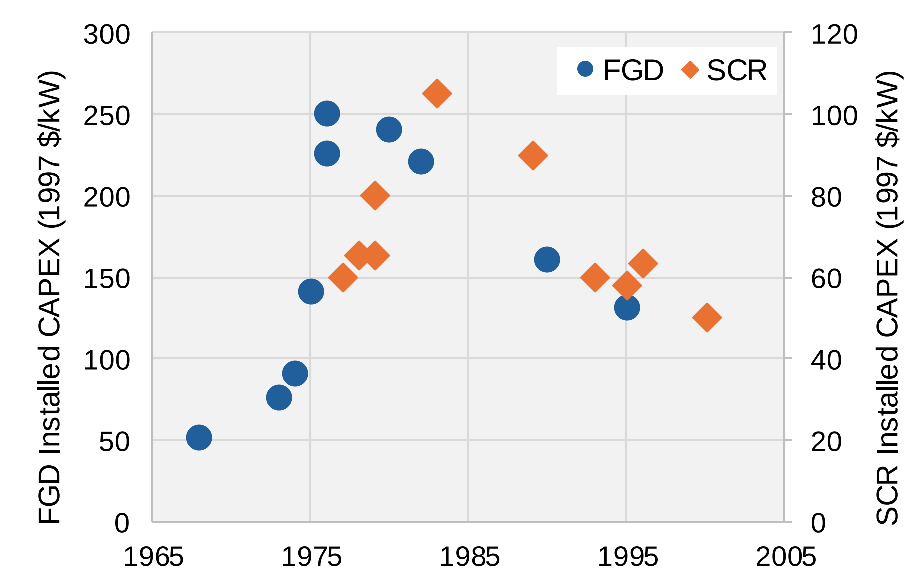
- Test centers support small- and large-scale pilots
- Nearly $1B invested at U.S. test facilities

Achieving nth-of-a-kind cost potential requires "learn by doing" approach

Critical aspects of "learn by doing"

- Deploy full CCS value chain at scale
- Share learnings and incorporate into subsequent projects
- Develop engineering, manufacturing, supply chains, etc.
- Build confidence for stakeholders

Past deployments of power generation technologies resulted in costs increasing before decreasing



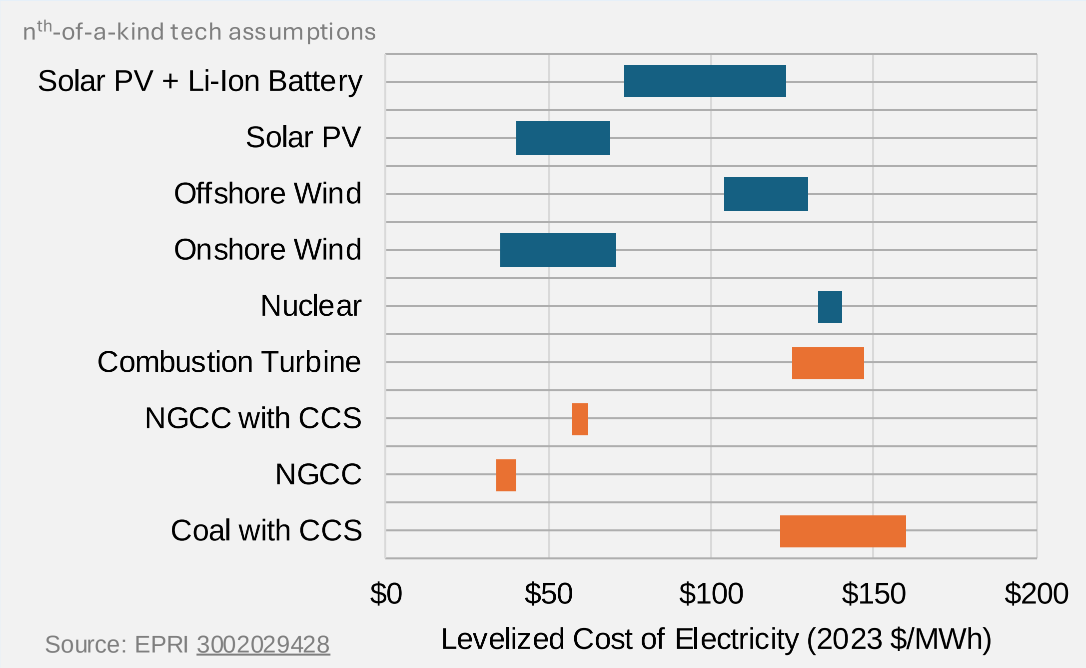
Modified from E. Rubin, CMU

EPRI

Status of CO_2 Capture & Storage (CCS) in Power Generation

CCS Costs and Incentives

Comparative LCOE for New Deployment Projects
CCS costs assume 90% capture and $10/t$CO_2$ transport & storage cost



Source: EPRI 3002029428

CO_2 Pipeline and Storage Costs Vary by Region

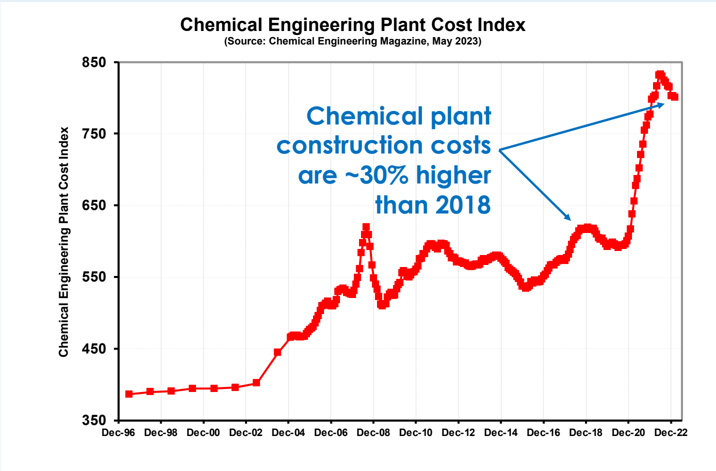
- U.S. storage costs range $7-11/t$CO_2$
- U.S. pipeline costs range $80K-$150K/in-mi

Source: National Petroleum Council

U.S. IRA CO_2 Tax Credits Aim to Incentivize Near-Term Deployment

- Up to $85/ton-$CO_2$ captured for entire value chain; adjusted for inflation after 2026
- 12-year eligibility, must begin construction by 2032
- Projects cannot stack 45Q and other credits; minimum capture requirements apply

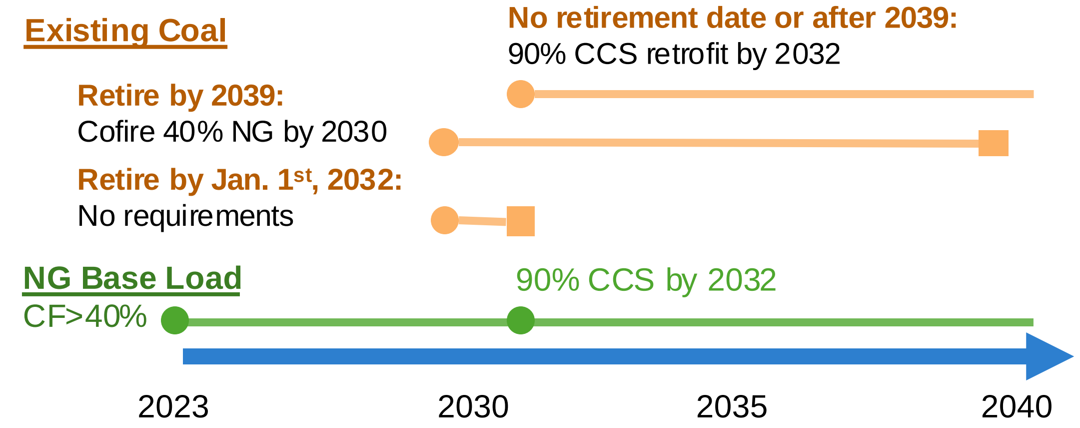
Trends in Chemical Engineering Plant Costs



The path to cost-competitive CCS depends on developments across the entire value chain and energy economy

CO_2 Regulations & CCS Permitting

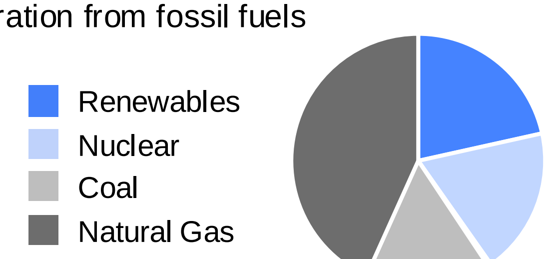
U.S. EPA 111 Regulations



April 2024: EPA finalizes 111 rules

Early 2026: State plans due to EPA

60% of 2023 U.S. power generation from fossil fuels

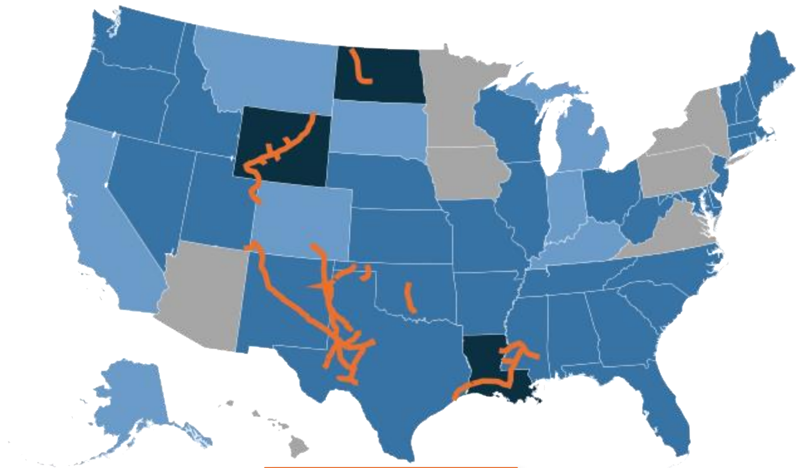


Data from US EIA

Evolving regulations are driving decisions this decade

U.S. CO_2 Storage Permitting for Class VI Wells

- Primacy granted to ND, WY, & LA
- EPA targeting 2-year permitting timeframe
- Formation type / geology impacts storage characteristics
- 15 storage facilities capture 0.4% of total annual CO_2 emissions



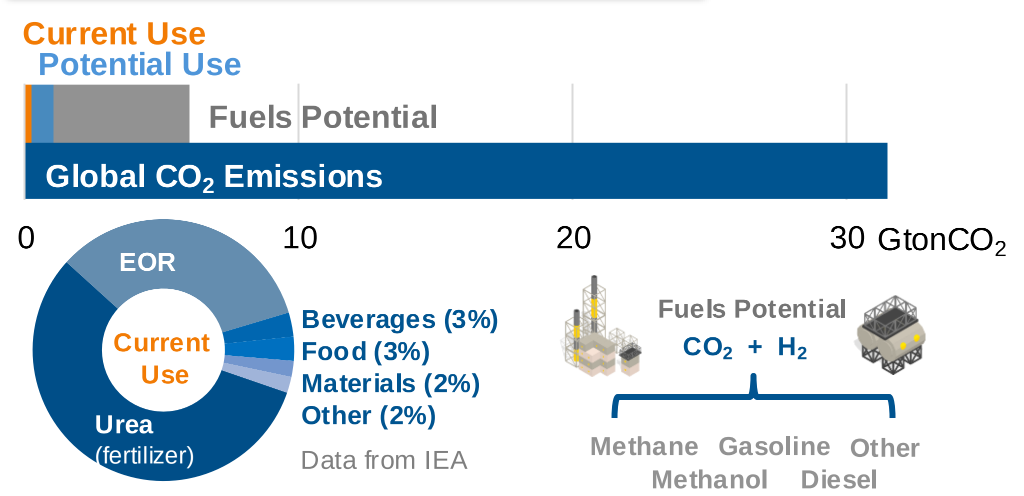
U.S. EPA Permitting

- EPA manages all well classes
- State has primacy for Class II wells only
- State has primacy for multiple well classes
- State has primacy for **all** well classes (Classes I, II, III, IV, V, and VI)

Modified from U.S. EPA

Permitting timelines and certainty are critical to future deployment

CO_2 Uses



Data from IEA

Uses for CO_2 limited compared to total emissions

Known Challenges for CCS deployment in power generation

- Economics
- Regulatory timelines
- Permitting certainty and timing
- New infrastructure needs
- Lack of at-scale experience
- Technology & supply chain maturity
- Public perception

EPRI