The Economics of Carbon Capture and Sequestration

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Presentation Outline

- The impetus for decarbonization and purpose of this report
- Carbon Capture and Storage (CCS) policy and technology
- Factors affecting the economic viability of CCS
- Recommendations

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Report Purpose and Impetus for Decarbonization

Purpose

- To explain the economic and regulatory treatment of carbon capture and storage (CCS) as applied to the generation of electricity

Impetus

- UN Secretary-General António Guterres characterized the August 2021 Intergovernmental Panel on Climate Change's report as a "code red for humanity"
- The Paris Climate Agreement represents unprecedented international consensus on the need to decarbonize
- CCS provides a valuable tool for decarbonization

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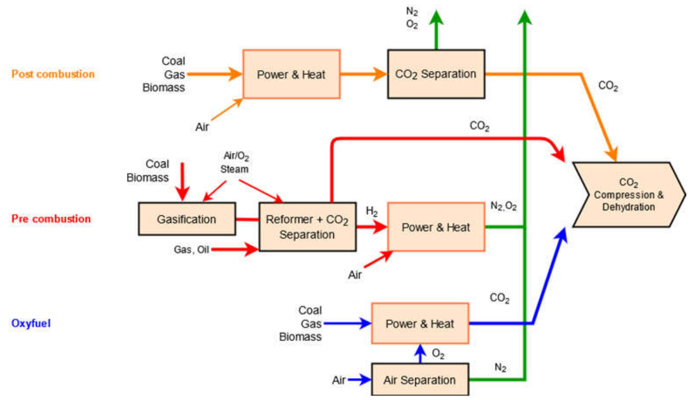
Carbon Capture Technologies

(for electric power generation)

Option 1: Remove CO2 from flue gas using absorbents

Option 2: Remove carbon from fuel before combustion

Option 3: Produce flue gas >90% CO2



NRRI construct based on data from B. Metz, O. Davidson, H. Coninck et. al., "Carbon dioxide capture and storage," Intergovernmental Panel on Climate Change. (2005): 108.

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The Governance of Carbon Reductions

- International: Agreements, treaties
- Federal: Goals and standards; market oversight; subsidies & incentives; federal power systems
- Regional: Reduction goals; regional markets; cooperation
- State: Reduction goals; resource adequacy & planning; IOU ownership; rate treatment; subsidies & incentives
- Local: Local restrictions; municipal/cooperative utility ownership; corporate/community commitments

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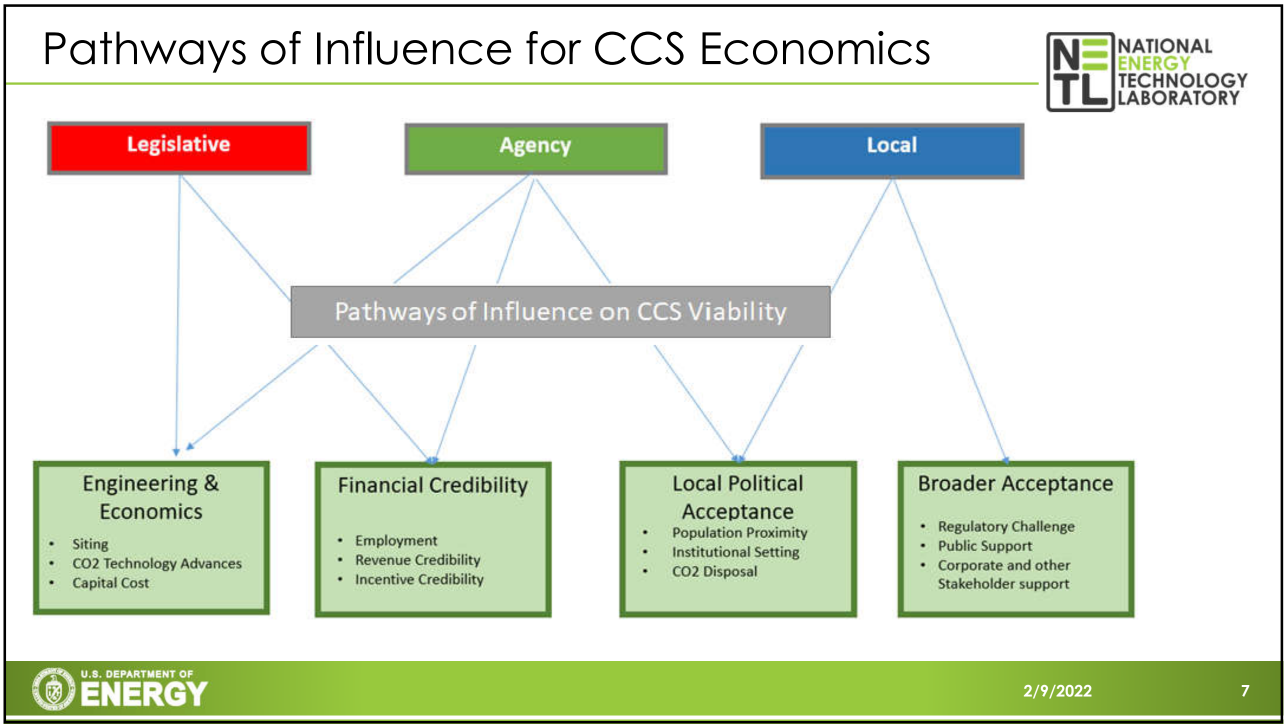
Pathways of Influence for CCS Economics
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Legislative
Agency
Local
Pathways of Influence on CCS Viability
Engineering & Economics
• Siting
• CO2 Technology Advances
• Capital Cost
Financial Credibility
• Employment
• Revenue Credibility
• Incentive Credibility
Local Political Acceptance
• Population Proximity
• Institutional Setting
• CO2 Disposal
Broader Acceptance
• Regulatory Challenge
• Public Support
• Corporate and other Stakeholder support
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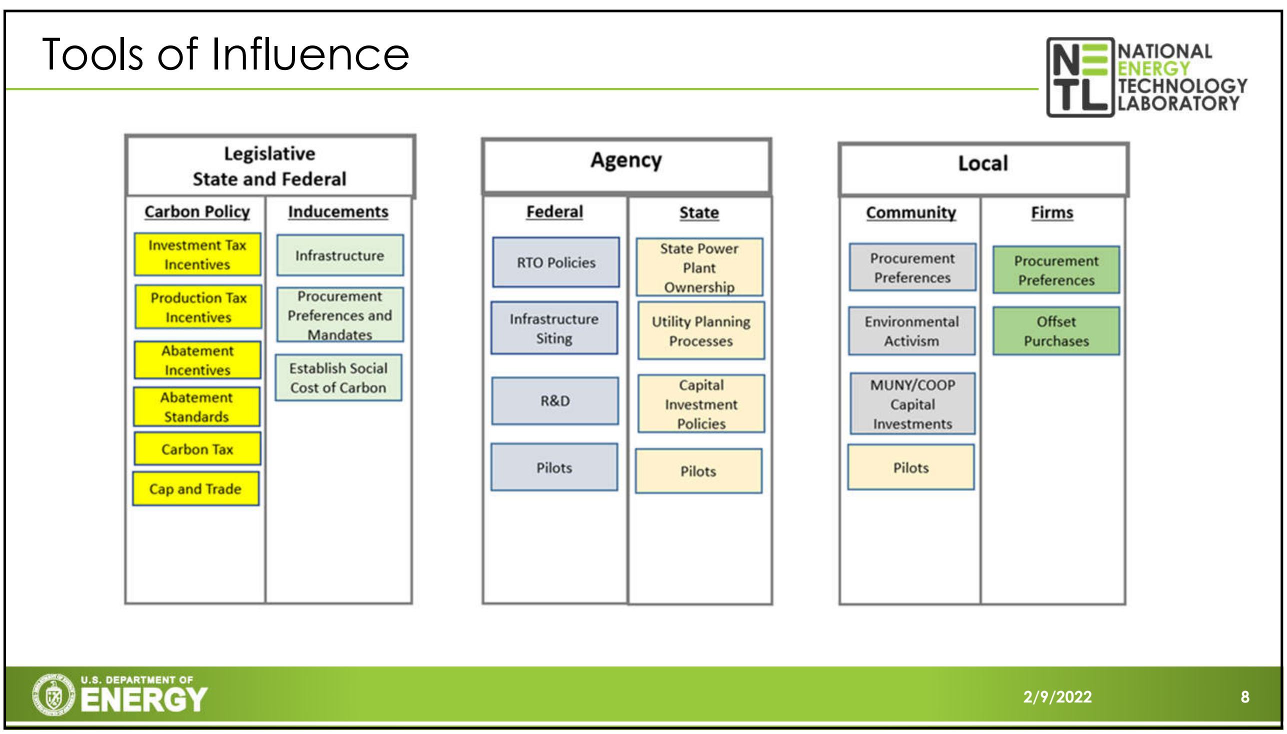
Tools of Influence
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Legislative State and Federal
Carbon Policy
Investment Tax Incentives
Production Tax Incentives
Abatement Incentives
Abatement Standards
Carbon Tax
Cap and Trade
Inducements
Infrastructure
Procurement Preferences and Mandates
Establish Social Cost of Carbon
Agency
Federal
RTO Policies
Infrastructure Siting
R&D
Pilots
State
State Power Plant Ownership
Utility Planning Processes
Capital Investment Policies
Pilots
Local
Community
Procurement Preferences
Environmental Activism
MUNY/COOP Capital Investments
Pilots
Firms
Procurement Preferences
Offset Purchases
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Factors Affecting the Economic Viability of CCS

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Costs
- Capital, finance, O&M
- Transportation (pipeline)
- Sequestration

Revenues
- Electric market revenues (energy & capacity)
- Subsidies
- Greenhouse gas-related revenues (offsets & beneficial use)
- Regulated revenues

The Role of Planning
- Overall decarbonization plan
- Need determination

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Potential to Drive Down CCS Costs

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Standardization of capture technologies may reduce costs
- One factor that drove nuclear costs was the idiosyncratic nature of plant design
- In contrast, the success of gas combined cycle was based upon standardized design
- Is it possible to have standardized design of CCS?

Transportation infrastructure is needed
- Majority of the CO2 pipeline network is west of the Mississippi
- Most sources requiring CO2 capture are east of the Mississippi

De-risking developing CCS storage reservoirs
- Selection of CCS sites can take years and millions of dollars that can be lost if the site is determined to be inadequate.
- Inexpensive and rapid assessment of CCS reservoir viability can be performed before drilling by analyzing volatiles (e.g, CO2, gas, oil) in rock samples from pre-existing wells even if decades old.
- Assessment of past fluid leakage and migration informs about the probability of leakage in proposed CCS reservoirs before final site selection and drilling.
- Volatiles analysis of materials from new wells can be performed rapidly to help guide the go/no-go decision on continuing investment.

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CCS Ownership Models Define Cost Recovery & Profitability

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Utility

- Investor-owned (IOU)
- Municipal (Public Power)
- Member-owned rural cooperative (COOP)

Competitive

- Self-generation
- Merchant plant

State/federal

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Utility Business Model is Based on Revenue Requirement

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$$\begin{Bmatrix} Revenue \\ Requirement \end{Bmatrix} = \begin{Bmatrix} Cost\ of \\ Capital \end{Bmatrix} \times \begin{Bmatrix} Inservice \\ Capital\ Costs \end{Bmatrix} - \begin{Bmatrix} Accumulated \\ Depreciation \end{Bmatrix} + O\&M + Taxes$$

Where the rate base = In-service capital costs - depreciation

There are two fundamental differences between Investor-Owned Utilities and both Public Power and COOPs:

- **Finance**
  - IOU cost of capital is based on debt and equity
  - Public Power and COOPs finance with 100% debt
- **Taxes**
  - Public Power and COOPs do not pay taxes or receive tax benefits

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Development by Competitive Firms

- **Private investment** financed with **debt** and **equity**
- **Profitability** equals **net revenues** after payment of carrying costs, O&M, and taxes (both liabilities and benefits)
- **Revenues** are based upon electric sales, sale of offsets, and value brought to production facilities (e.g., heat for industrial processes)

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The Nature of Electric Revenues

The marginal cost of electricity reflects both the cost of production and the cost of energy not served:

$$\begin{Bmatrix} \text{Marginal Cost of} \\ \text{Electricity} \end{Bmatrix} = \begin{Bmatrix} \text{Marginal Energy} \\ \text{Costs} \end{Bmatrix} + \begin{Bmatrix} \text{Marginal Expected} \\ \text{Curtailment Costs} \end{Bmatrix}$$

Therefore, in a competitive market, where prices equal marginal cost:

$$\begin{Bmatrix} \text{Wholesale Electricity} \\ \text{Price} \end{Bmatrix} = \begin{Bmatrix} \text{Energy} \\ \text{Price} \end{Bmatrix} + \begin{Bmatrix} \text{Capacity} \\ \text{Price} \end{Bmatrix}$$

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The Nature of Electric Revenues (Continued)

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Energy price determined by economic dispatch

Capacity price reflects the requirement to maintain generating reserves to operate reliably.

- Peak Load Pricing Theory demonstrates that in a competitive system with an optimal capacity mix and a reserve margin requirement – there will be a revenue shortfall equal to the cost of a Peaker (a measure of pure capacity)
- The optimal capacity mix is the combination of generating units that minimize the cost of providing power, recognizing the tradeoff between generator capital and operating costs
- At the desired reserve margin…

$$\left\{\begin{matrix} Marginal\ Expected \\ Curtailment\ Cost \end{matrix}\right\} = \{Cost\ of\ a\ Peaker\}$$

- This observation, first formulated in 1949, explains what is now called the "missing money problem."

Generators Earn Infra-marginal Rents when their Cost of Production is Less Than the Market Price

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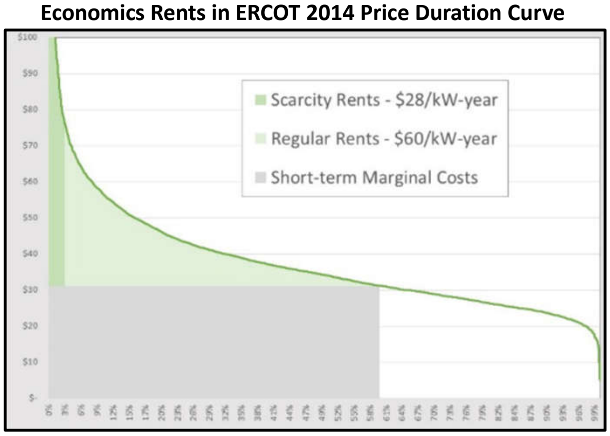
Economics Rents in ERCOT 2014 Price Duration Curve



Gimon, E., "On Market Designs for a Future with a High Penetration of Variable Renewable Generation," *Energy Innovation*, September 2017.

Capacity Markets are Administrative Constructs

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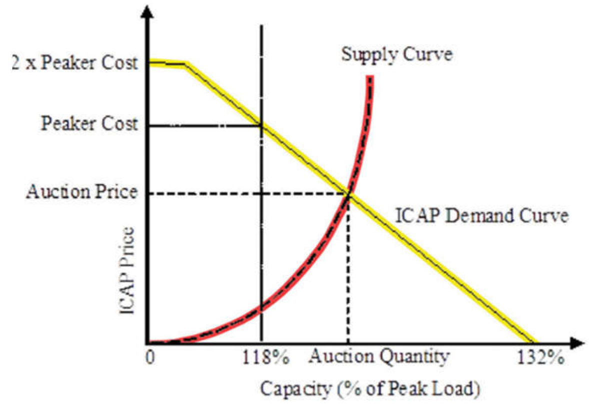
- Based on peak load pricing literature
- At a reserve margin target of 18%, capacity price = Peaker cost
- Key values are administratively set, without empirical basis

1. the maximum allowable price (two times the cost of a Peaker)
2. the point at which the incremental value of capacity (i.e., its price) is zero are not supported by empirical analysis, for example, a study of customer behavior.

New York Demand Curve (2003)



NRRI construct based on Electricity Consumers Resource Council v. F.E.R.C., 407 F.3d 1232, 1234 (D.C. Cir. 2005). (“ECRC v. FERC”).

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Renewable Energy Poses an Existential Threat to Current Market Design

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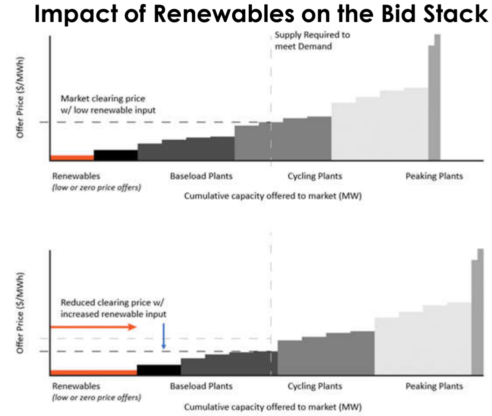
- Renewables produce at zero marginal costs,
- With Production Tax Credit, wind can profitably bid negative prices
- There is no longer a sense of an optimal capacity mix
- Theoretical underpinnings of market are being undermined
- Need new concepts of dispatch and capital cost recovery (such as long-term contracts
- Capacity is an elusive product to define

Impact of Renewables on the Bid Stack



NRRI *construct based on* Appunn, Kerstine., “Illustrating electricity price fluctuations due to the merit order effect,” *Clean Energy Wire (2015). (CC BY 4.0)*

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The Growing Importance of Essential Reliability Services (ERS)

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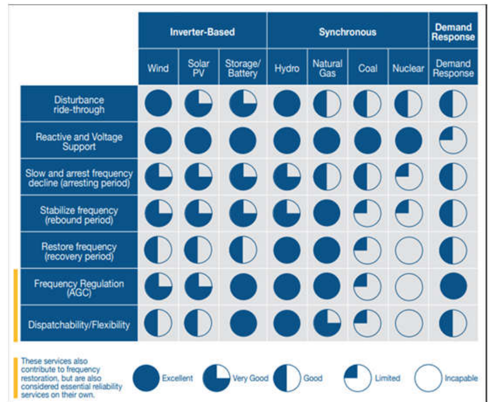
- Ancillary services are critical elements of system operation that were bundled by vertically integrated utilities
- As intermittent renewables and distributed generation take on a larger role, the nature of and need for required ancillary services will change
- Some reliability services are captured in existing ancillary service markets, while others are more difficult to measure
- The need for dispatching and ramping of generation is increasing (duck curve)
- The role for baseload generation (e.g., CCS) requires further examination, given the growing need to maintain adequate levels of ERS

Synchronous and Inverter-based Ability to Provide Reliability Services



Milligan, M. Butz, T. Lancaster, R. "Grid Reliability in North Dakota." Great Plains Energy Corridor, (2021): 38.

Tax Credits Encourage CCS

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- The initial 45Q program, established in 2008, provided a credit of \$20/Mt for CO2 stored in geological formations and \$10/Mt for CO2 used for enhanced oil recovery(EOR) or enhanced gas recovery (EGR)
- The initial program required individual facilities to capture at least 500,000 Mt/year, with the credits ending after 75 MMT of CO2 were captured and stored
- The Bipartisan Budget Act of 2018 expanded eligibility to include qualified carbon oxides (COx), reduced the annual CO2 capture minimum, provided greater flexibility for entities to claim credits, and modified the CO2 credit amounts

Current 45Q Credits

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	MINIMUM SIZE OF ELIGIBLE CARBON CAPTURE PLANT BY SIZE	RELEVANT LEVEL OF TAX CREDIT GIVEN IN OPERABLE YEAR (USD/tCO_2) 2018	2019	2020	2021	2022	2023	2024	2025	2026	LATER
DEDICATED GEOLOGICAL STORAGE	500 $KtCO_2$/YR3	$28	31	34	36	39	42	45	47	50	
STORAGE VIA ENHANCED OIL RECOVERY	500 $KtCO_2$/YR	$17	19	22	24	26	28	31	33	35	
OTHER UTILIZATION PROCESSES*	25 $KtCO_2$/YR	$17	19	22	24	26	28	31	33	35	

*each CO_2 source cannot be greater than 500$KtCO_2$ /yr. Any credit will only apply to the portion of the converted CO2 that can be shown to reduce overall emissions.

NRRI construct based on Lee Beck, "The US Section 45Q Tax Credit for Carbon Oxide Sequestration: An Update," *The Global CCS Institute*, (2020): 2.

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Not All Potential Developers Eligible for 45Q

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- To fully take advantage of 45Q, entities must be able to use tax credit
- Public Power and COOPs are not eligible
- Other developers might not have tax appetite (can't take advantage of 45Q or Production Tax Credit)
  - Developers are increasingly using tax equity partnerships, for example, NextEra uses these partnerships for over 80% of its annual production tax credits
- Tax advantages can be realized through transaction with Tax Equity Partners, complicating nature of transaction and adding costs
- Direct pay mechanisms would streamline financing

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The Impact of Carbon Pricing

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- One way to mitigate the GHG externality is to put a price on carbon
- Two approaches:

Carbon Tax	Tradeable Allowances (Cap & Trade)
Sets price	Sets quantity
Price certainty	More certainty in meeting targets

- Both approaches "internalize" the environmental cost of carbon emissions
- Electric generators that emit carbon will incorporate the cost of carbon into their offers to sell electricity, raising the market price
- As the electric system decarbonizes, the impact of carbon pricing will diminish – at some point ceasing to provide additional revenues to CCS

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Greenhouse Gas-Related Revenue – Beneficial Use

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Broad Classification	Examples
Agriculture and Forestry Based[1]	• Algae production (for food, fuel, plastics, chemical feedstocks) • Enhancing growth in commercial greenhouses
Alternative Energy Carriers[2]	• Synthetic fuel production
Construction Products, Industrial and Commercial Products	• Materials that embody stored carbon, such as cement, wallboard, metals (e.g., steel), and mineralized materials as fillers or fire retardants (e.g., in paper, paints, textiles, polymers, electronics) • Use in beverages, for sterilization, or in food preservation • As a fumigant for grain silos • As a solvent for food processing, dry cleaning, and supercritical fluid extraction • Used in processes for recovering rare earth elements or other valuable metals, from bottom ash, mining wastes, desalination plants, and in wastewater processing
Power Production[1]	• Used in Brayton cycle turbines • As a cushion for natural gas storage

See paper for citations

More product development will enhance the currently-limited beneficial use market and therefore, the economic viability of CCS

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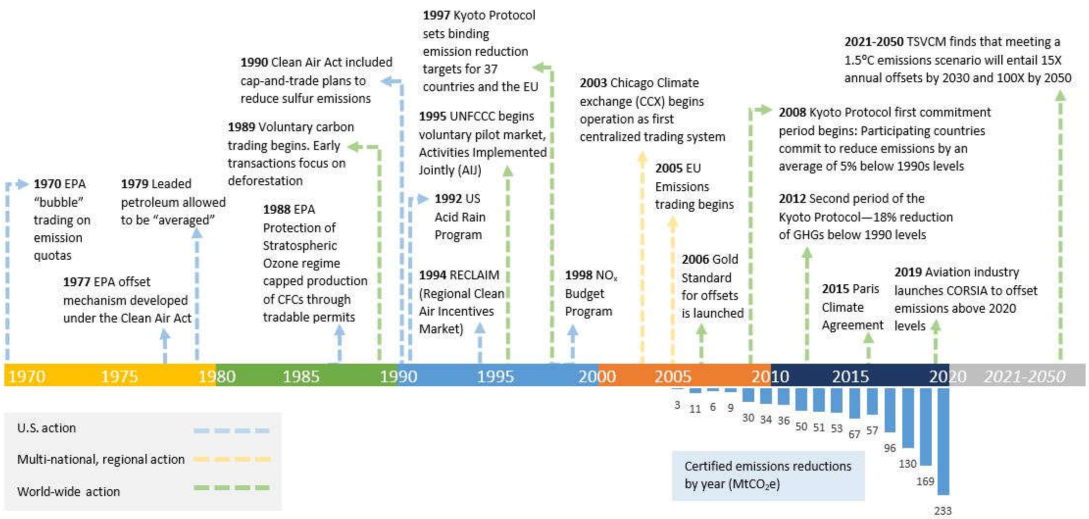
Offsets Provide a Pathway to Decarbonization



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Utility Regulation and CCS – Rate Treatment

- State public utility commissions (PUCs) will determine whether utilities can participate in CCS development and how to recover the costs
- CCS investments affect customer rates through the Revenue Requirement

$$\left\{\begin{matrix}\text{Revenue}\\\text{Requirement}\end{matrix}\right\} = \left\{\begin{matrix}\text{Return to}\\\text{Capital}\end{matrix}\right\} + \{\text{Expenses}\} + \{\text{Taxes}\}$$

where:

$$\left\{\begin{matrix}\text{Return to}\\\text{Capital}\end{matrix}\right\} = \left\{\begin{matrix}\text{Return on}\\\text{Capital}\end{matrix}\right\} + \left\{\begin{matrix}\text{Return of}\\\text{Capital}\end{matrix}\right\}$$

- Regulatory mechanisms that can impact revenue requirement
  - CWIP and AFUDC – accounting mechanisms allow interest pass-through during construction to reduce the rate base
  - Securitization eliminates the equity component and reduces the allowed return on capital

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Adding CCS to the Rate Base

The prudence standard determines whether costs are recoverable based on whether the decision was reasonable, given the information that was known and knowable at the time it was made; utilities must demonstrate that:

- The decision to pursue CCS was reasonable
- Facility development did not incur unnecessary costs

Determining prudence will likely require demonstrating that CCS had advantages:

- Cost effectiveness
- Offsets not a reasonable option to meet decarbonization goals

Prudence determination to pursue CCS can be based on the need to:

- Provide an element of the least cost capacity addition necessary for achieving decarbonization goals
- Deliver significant carbon reductions quickly
- Provide electric reliability services

The Role of Planning

- Electric system planning provides a method for establishing the role of CCS
- Currently, electric planning is fragmented with different segments of the industry subject to different planning regimes

Jurisdiction	Focus
Federal	Transmission
Utility/State	Resource adequacy
Utility/distribution company	Distribution system planning

- Only California's planning process focuses on decarbonization

A Decarbonization Plan Can Establish the Need for CCS

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- "Need" was used to support the licensing of nuclear power plants from a resource adequacy perspective
- Need for CCS could be based upon its critical role in decarbonization
- A planning process that addresses decarbonization can support PUC's recognition of the need for and cost recovery of CCS
- A National Energy Policy Plan undertaken under Title VIII of the Department of Energy Reorganization Act focused on decarbonization could provide a vehicle for determining the need for CCS

Pathways of Influence for CCS Economics

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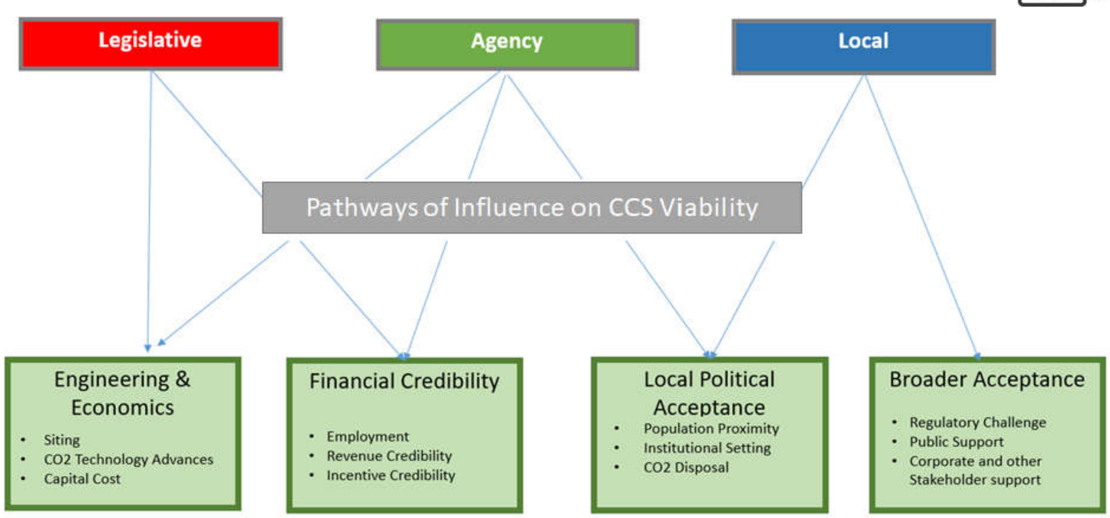

Recommendations

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1. Develop a national decarbonization plan that articulates the role of and need for CCS.
2. Encourage state regulatory actions that reduce the in-service cost and regulatory risk associated with the development of CCS plants, including pre-declarations of prudence, providing cash returns on Construction Work in Progress (CWIP), and securitization to limit costs.
3. Encourage states and the federal government to adopt direct pay provisions to support CCS.
4. Provide funding and technical assistance to enhance the analytical capabilities of state PUCs, utilities and stakeholders to better plan decarbonization pathways.
5. Include CCS as an eligible technology in state renewable portfolio standards.
6. Examine the impact of wholesale market design on the recovery of capital costs for CCS.
7. Examine the value of CCS in ensuring sufficient capacity for providing essential reliability services.
8. Develop mechanisms to measure and verify the value of carbon offsets.
9. Create trackers on state regulatory and legislative actions affecting decarbonization, including the treatment of carbon offsets, policies affecting CCS, renewable portfolio standards, and methods for integrated resource planning.
10. Analyze carbon pricing proposals and their impact on CCS

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The Economics of CCS

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