March 2023

Carbon Capture Commercial Considerations

Development Issues in today's Carbon Capture Utilization Storage ("CCUS") marketplace

Presented by

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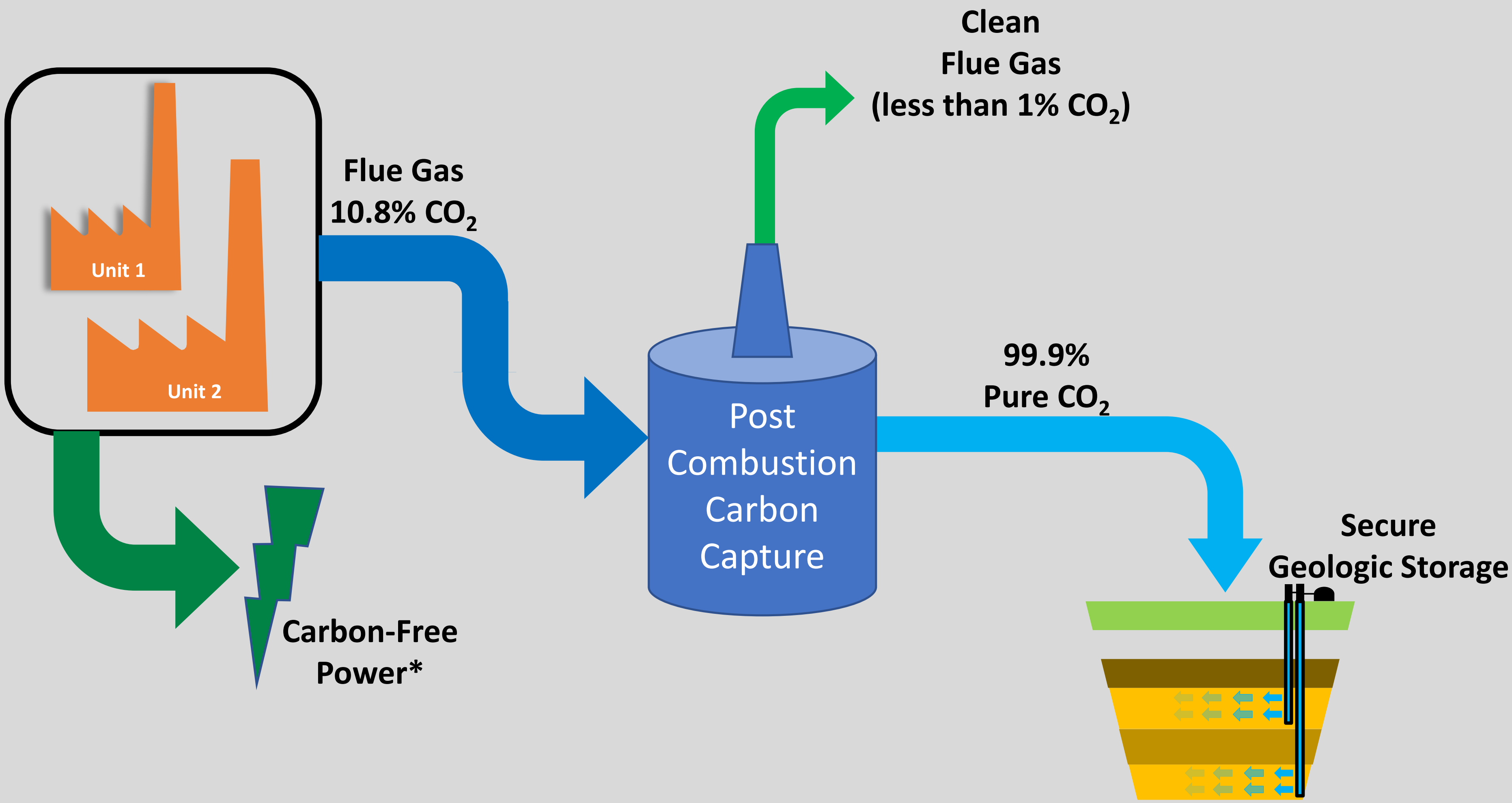
David Greeson

David Greeson is a consultant to the carbon capture and power generation industries. Until his retirement in 2018, David was the Vice President of Development for NRG Energy where he led NRG's Gulf Coast business development group and the company's carbon capture program.

He was the developer of the $1 billion Petra Nova project near Houston, TX from inception through commissioning and is now consulting with companies planning development of CO_2 capture projects.

David began his career in the power industry 43 years ago at Houston Lighting & Power. Over the years, he has developed five major power projects here in the US which represent over $3 billion of investment.

Overview of Carbon Capture

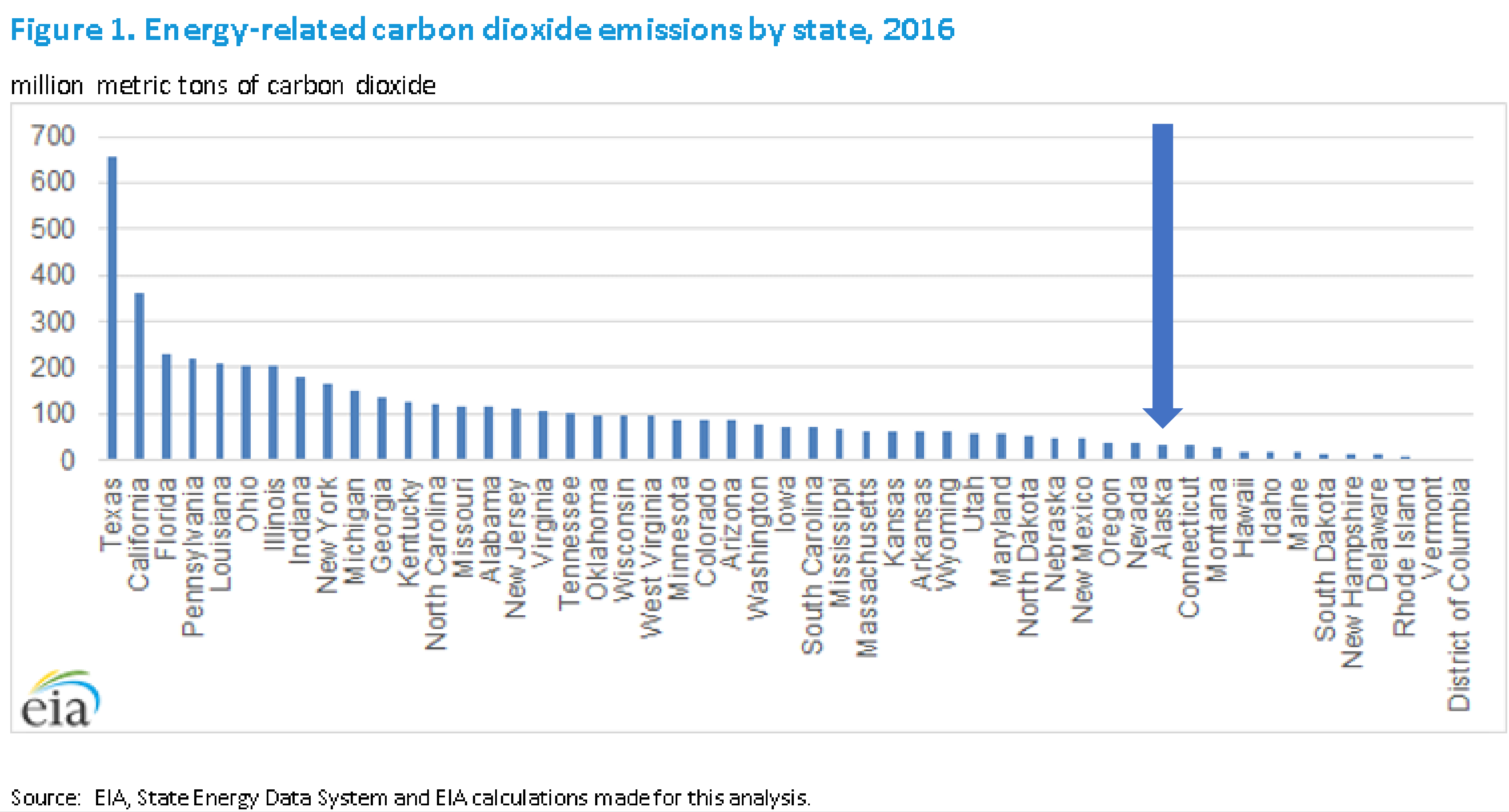


** Remainder of station MWs are at normal coal-fired carbon intensity*

State Policy Should Focus on <u>Deployment</u> – Not More Research

- DOE is shouldering the burden on research
- Congress has enacted incentives for first movers
- <u>States should focus on filling the gaps to deployment</u>
  - Policies and local incentives that make sense

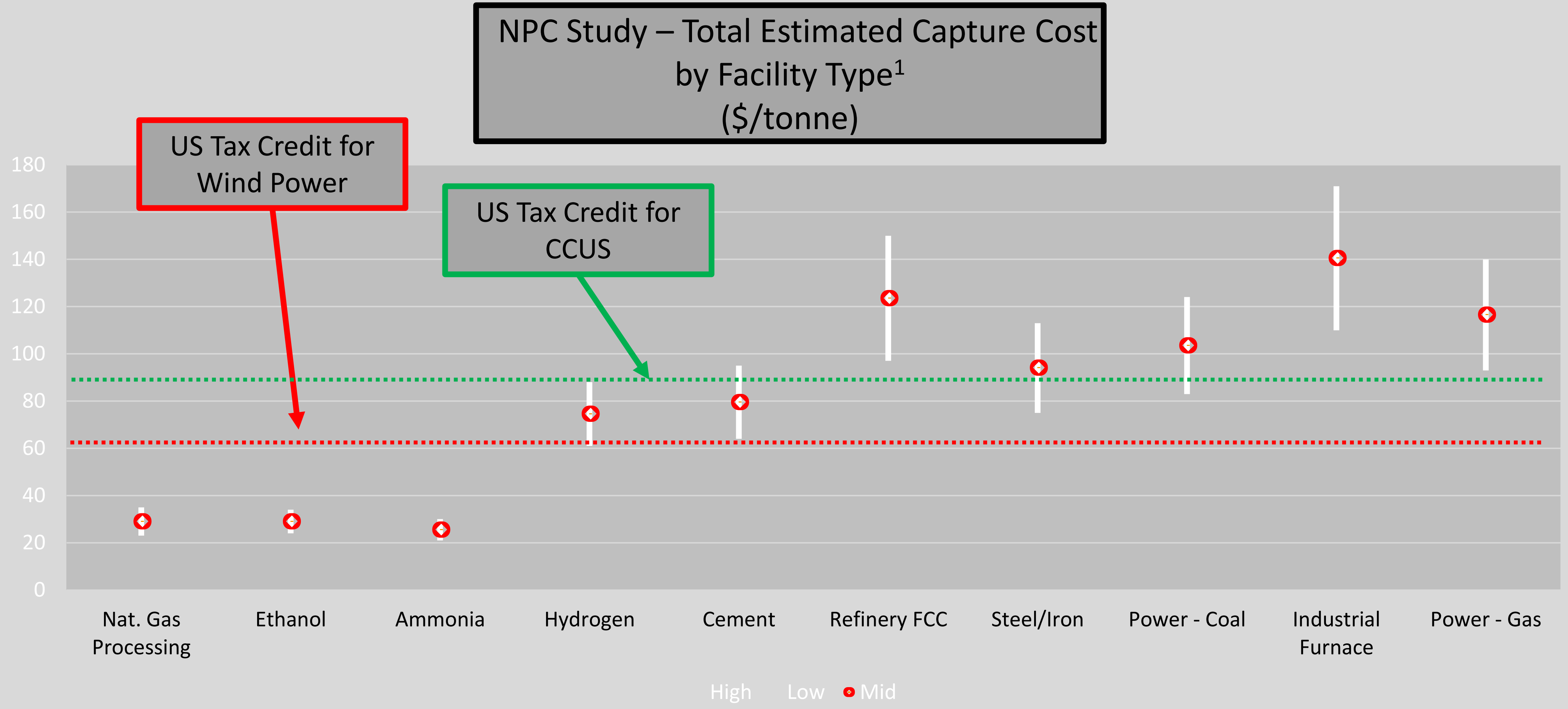
Alaska in perspective



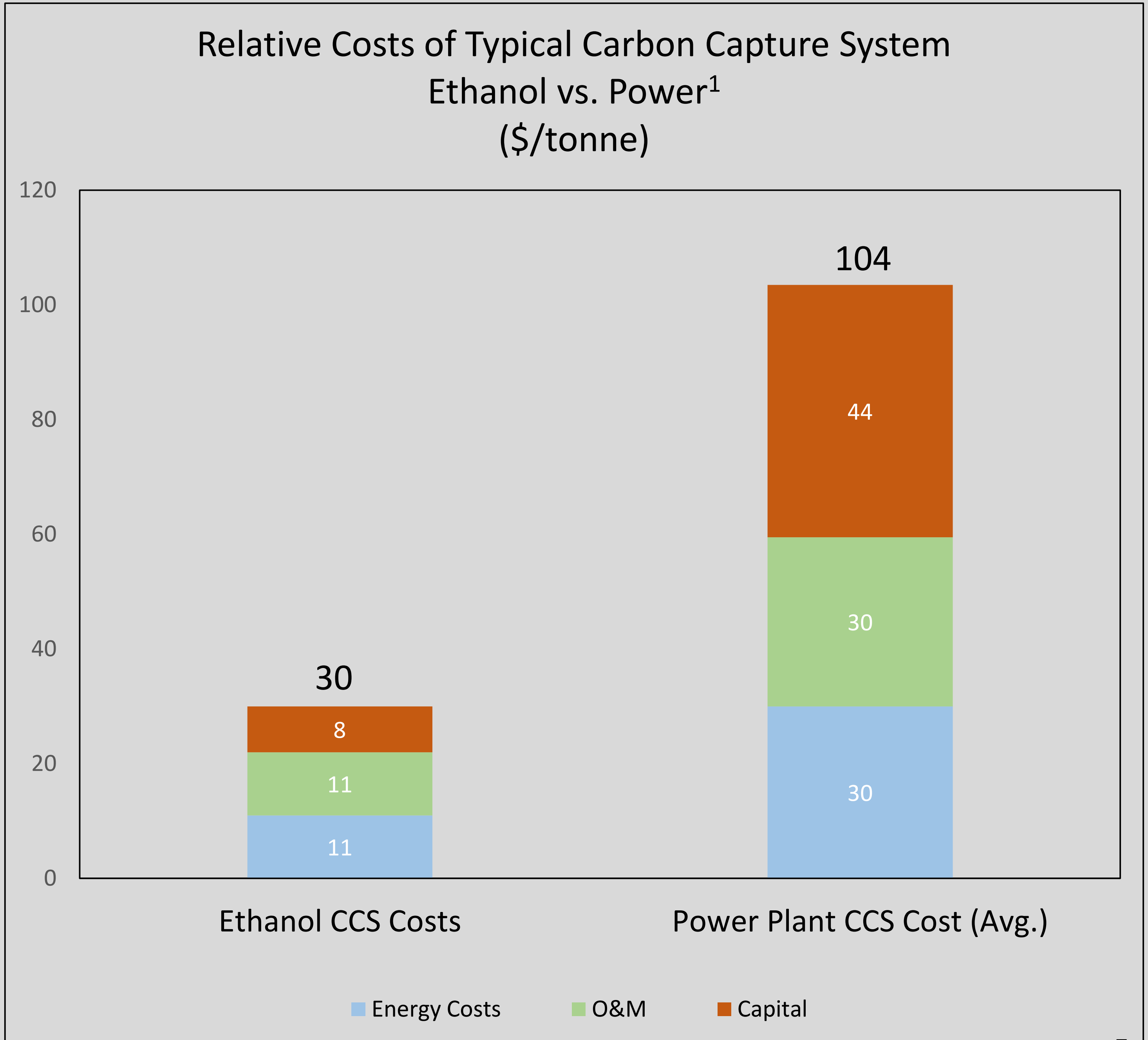
Cost of capture varies greatly

Source:

1. Costs from National Petroleum Council report "Meeting the Dual Challenge" 2019



Large difference in economics



Source:

1. Costs from National Petroleum Council report "Meeting the Dual Challenge" 2019

NPC Study Estimated Cost of CCS

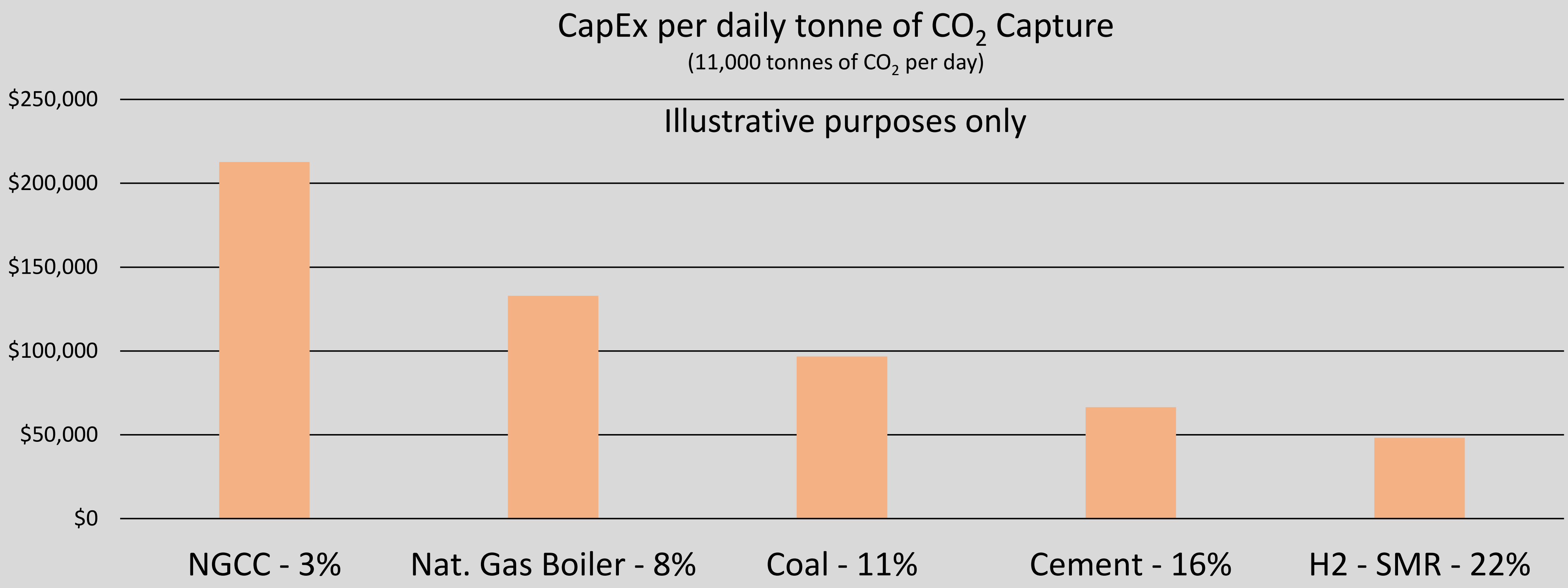
CCS Component	Range ($/tonne)	Value Assumed ($/tonne)
Transport	2 - 38	27
Storage	7 - 11	8
Capture		
Power & Steam	9 - 31	16
O&M	6 - 126	15
Capital	6 - 155	44
Total		110

Source:

1. Costs from National Petroleum Council report “Meeting the Dual Challenge” 2019

CapEx as a Function of CO_2 Concentration

Cost per tonne of of flue gas processed per day is ~ $9,000 in all cases



CCS is Expensive – There is Reason for Hope

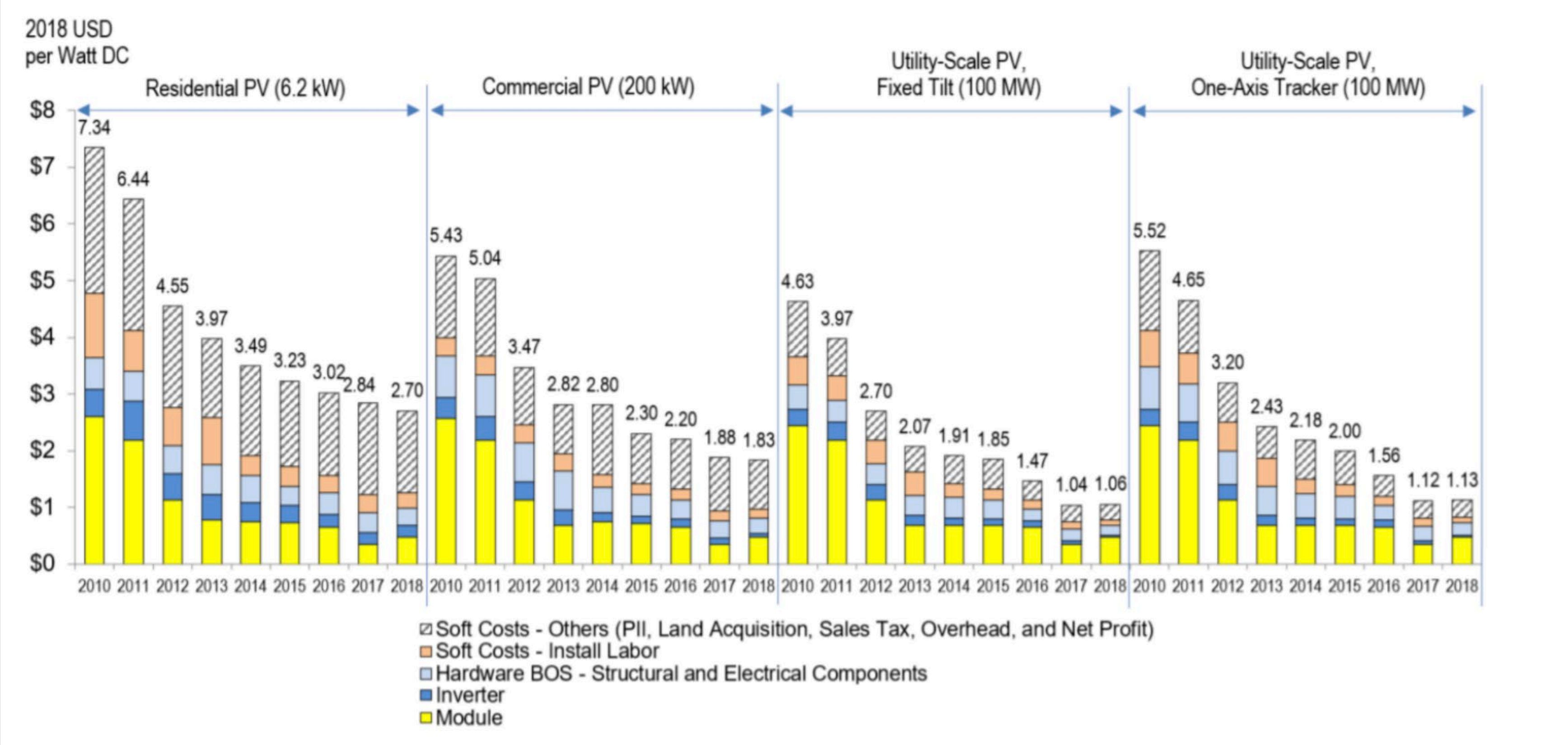


Figure ES-1. NREL PV system cost benchmark summary (inflation adjusted), 2010–2018

- Solar technology was not even close to economic just 10 years ago
- Today, costs are close to the value of ***intermittent*** power

Source: *Solar Energy Cost Trends Over Time* by Ryan Austin

https://earthtechling.com/solar-energy-costs-trends/

Policies Developers Look For

- **Primacy** on Class VI permitting
- Public lands opportunity for storage solves a lot of problems for CCUS developers
  - One creditworthy landowner
  - Storage cost certainty
  - Consistent with other public interest missions of the state
- Long-term liability for stored CO_2

Thank you!

Carbon Capture, Use, and Storage (CCUS)

Alaska CCUS Workgroup and a Roadmap to Commercial Deployment

- Frank Paskvan, University of Alaska Fairbanks—Institute of Northern Engineering (UAF-INE), International Reservoir Technologies, Inc.
- Haley Paine, Alaska DNR-DOG
- Christine Resler, Esther Tempel, ASRC Energy Services (AES), LLC
- Brent Sheets, UAF-INE
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Alaska CCUS Workgroup Focus

Institute of Northern Engineering
University of Alaska Fairbanks

The CCUS workgroup mission is to accelerate commercial carbon capture projects in Alaska.

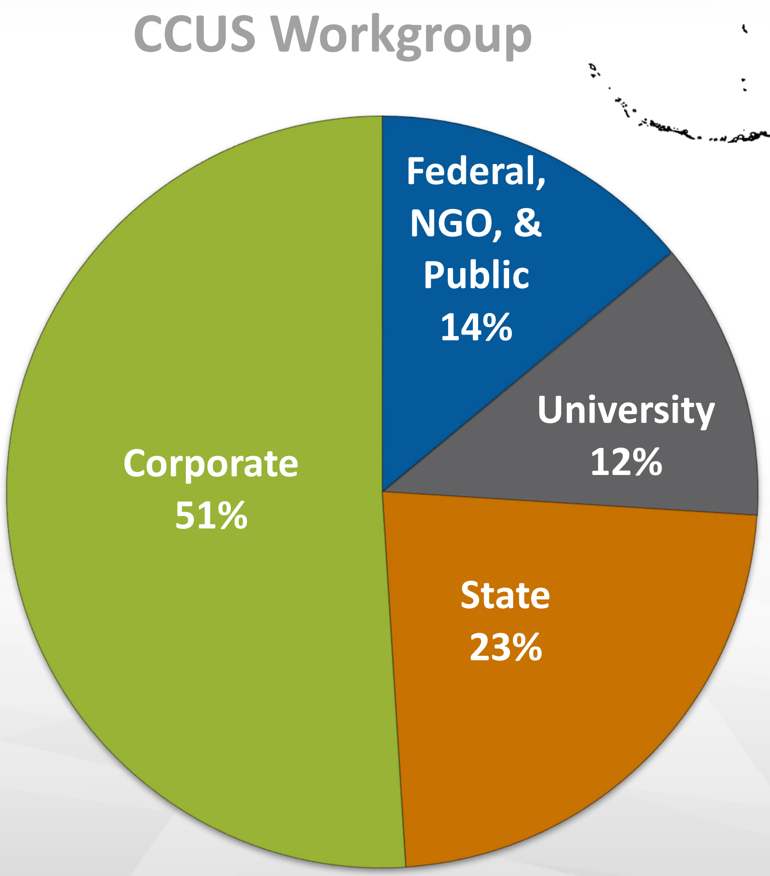
Why?

- To attract new investments and
- To create options to decarbonize activities vital to the State's economy including power generation, refineries, and oil and gas production.

Develop a State legal and regulatory framework → **Track and respond to funding opportunities** → **Perform public education and outreach** → **Develop a Roadmap to accelerate commercial CCUS**

Alaska CCUS Workgroup

- Kicked off July 2022, continuation of group working Alaska's DOE RFI response
- 110 attending meetings
- 30—50 members meet up to 4 times a month
- Diverse representation on the Workgroup
- University of Alaska Fairbanks has lead role
- Leadership represents Academia, Industry, and State Government
- DOE funds support the UAF-led Workgroup via PCOR, a Regional Carbon Sequestration Partnership



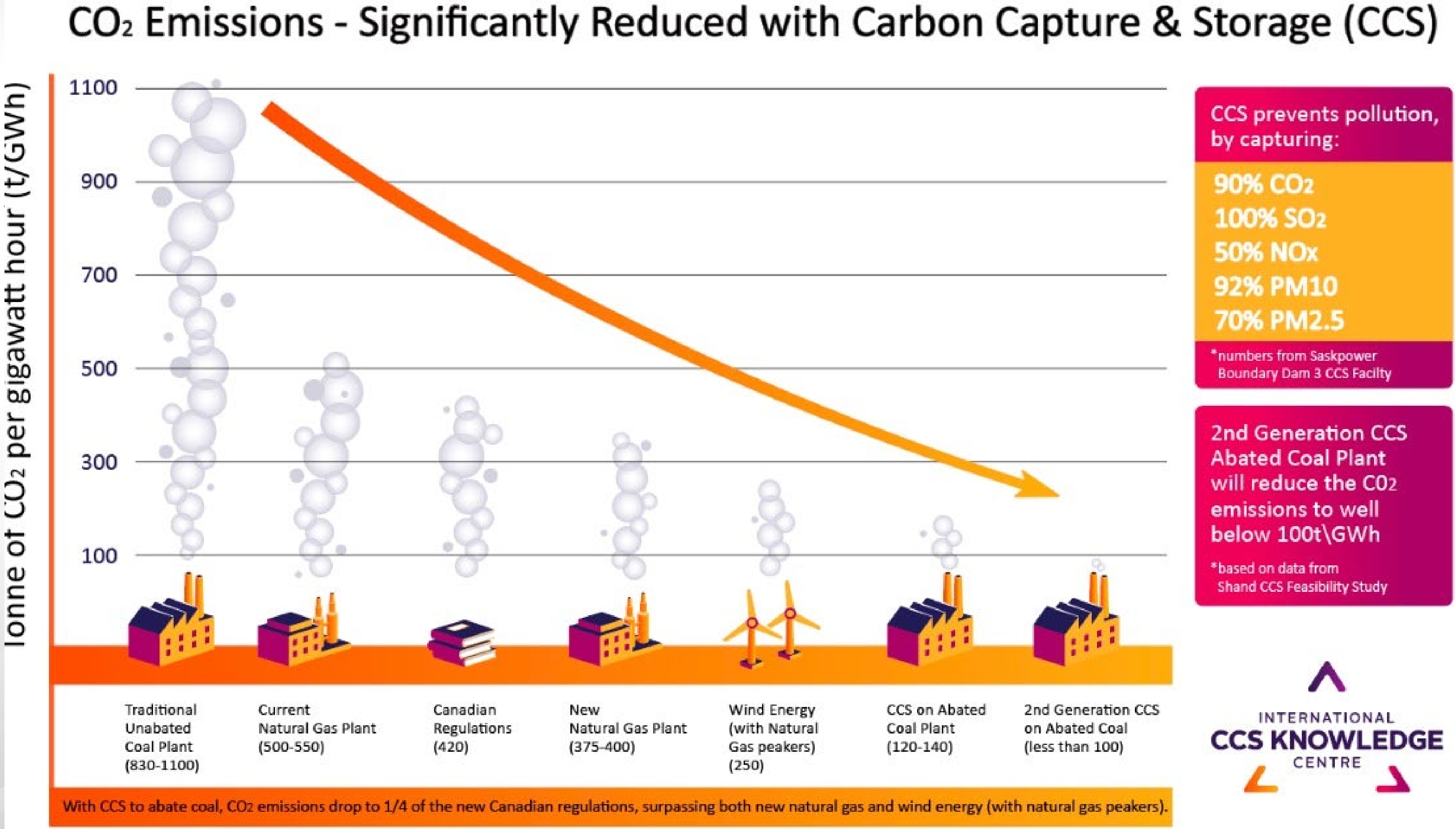
CCUS Impact on Emissions

World faces dual challenge of increasing energy demand and risks of climate change

Carbon (CO_2) Capture and Storage (CCS) also removes other pollutants

Adding CO_2 Use (CCUS) like agriculture, electricity can be net zero emissions and support local food and energy security

Cost for clean energy security more than doubles without CCUS [IPCC]

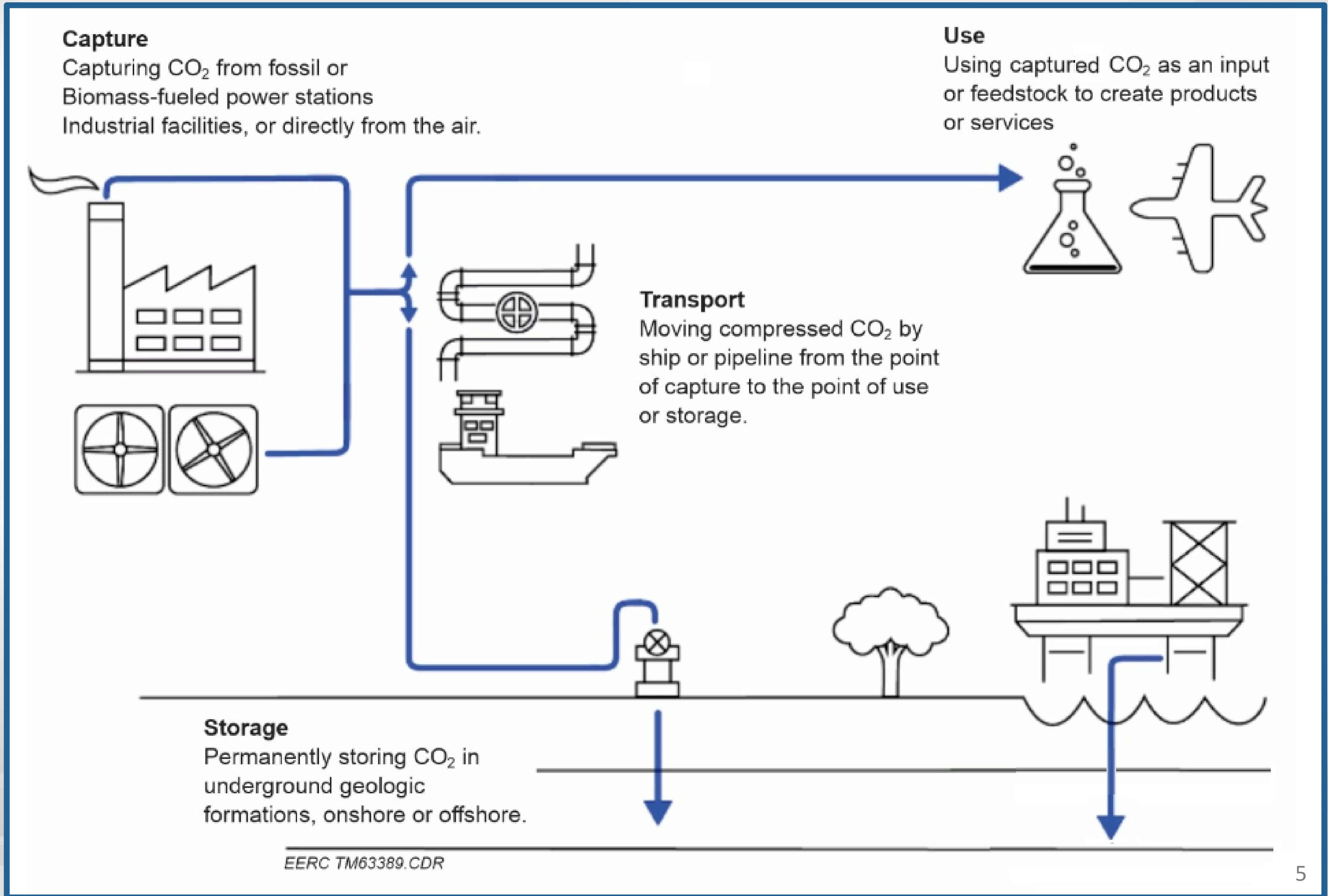


The CCUS Process

- **Stationary point source Capture**
- **Direct Air Capture (DAC)**

CCUS Steps:

1. Capture CO_2
2. Transport
3. Store (or Use)



Foundational Elements

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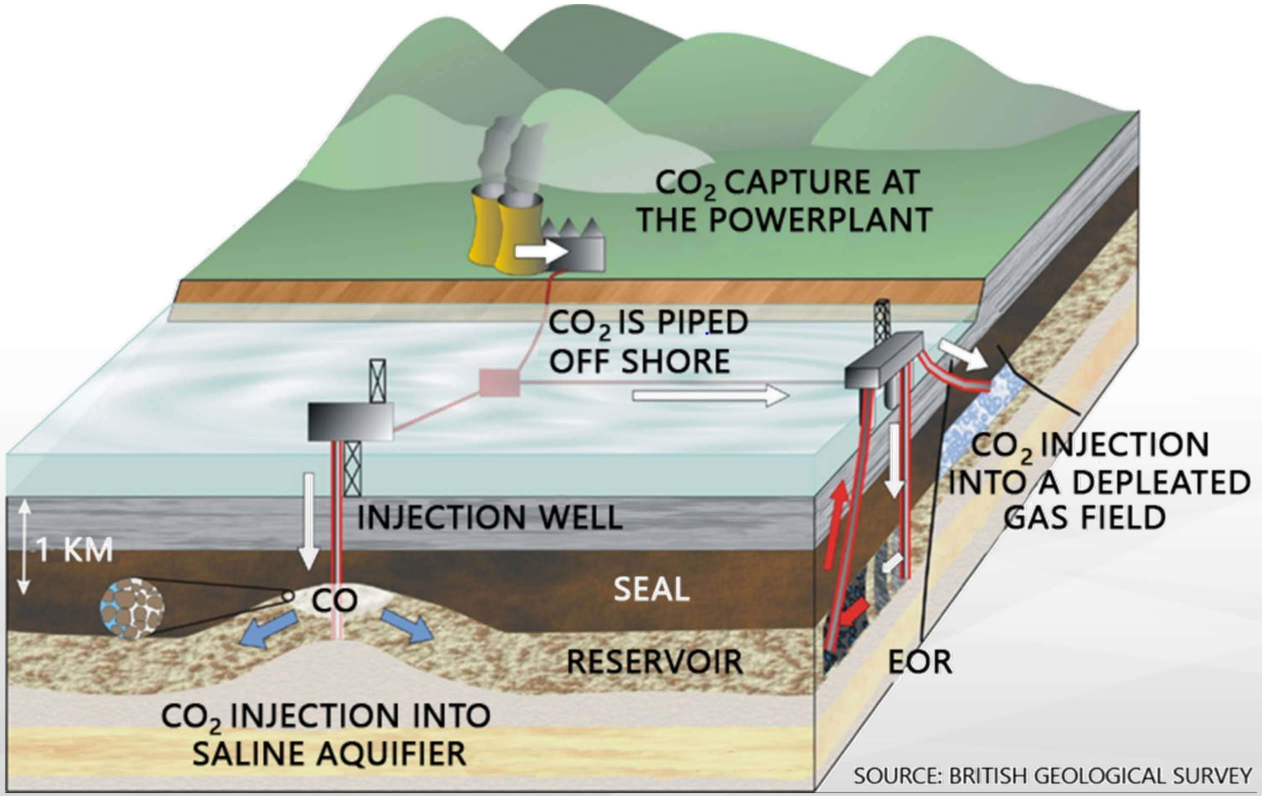

Geologic Storage Potential

Stakeholder Engagement & Community Outreach

Regulatory Framework

US Department of Energy Perspective

Assistant Secretary of Energy Brad Crabtree on 21Feb2023 at the Alaska CCUS Workshop at APU:

- **US has a leading role in CCUS globally**
  - BIL (Bipartisan Infrastructure Law)
    - Addresses all elements of CCUS
    - $12 billion for carbon management
  - IRA (Inflation Reduction Act)
    - $300 billion in clean energy including 45Q credits
    - Co-investment government & industry
    - Early project funding 80% Feds & 20% Industry; Later Stages 50/50 plus loan guarantees
- **Cook Inlet – World Class Storage**
- **Alaska grid unique in USA, Potential for Decarbonization**
- **Impressed Alaskans are agents of opportunity**

Funding Opportunity Examples

$820 Million for 10 projects

Funding Opportunity Announcement (FOA) late Feb 2023

Industry, University Developers, State eligible

Carbon Capture Large-Scale Pilot Programs

- Designed to establish a carbon capture technology program for the development of transformational technologies that will significantly improve the efficiency, effectiveness, costs, emissions reductions, and environmental performance of coal and natural gas use, including in manufacturing and industrial facilities.
- FOA is seeking projects that
  - Represent the scale of technology development beyond laboratory development and bench scale testing, but not yet advanced to the point of being tested under real operational conditions at commercial scale;
  - Represent the scale of technology necessary to gain the operational data needed to understand the technical and performance risks of the technology before the application of that technology at commercial scale or in commercial-scale demonstration; and
  - Are large enough to validate scaling factors and to demonstrate the interaction between major components so that control philosophies for a new process can be developed and enable the technology to advance from pilot to commercial-scale demonstration/application

$1.7 Billion for 6 projects

FOA late Feb 2023

Industry, University Developers, State eligible

Carbon Capture Demonstration Projects Programs

- Description: To establish and carry out a carbon dioxide transportation infrastructure finance and innovation program.
- Eligibility: Of the demonstration projects carried out (i) 2 shall be designed to capture carbon dioxide from a natural gas electric generation facility; (ii) 2 shall be designed to capture carbon dioxide from a coal electric generation facility; and (iii) 2 shall be designed to capture carbon dioxide from an industrial facility not purposed for electric generation.
- The program will focus on integrated carbon capture, transport, and storage technologies and infrastructure that can be readily replicated and deployed at fossil energy power plants and major industrial sources of CO_2, such as cement, pulp and paper, iron and steel, and certain types of chemical production facilities.

Sovereign Legislation Survey

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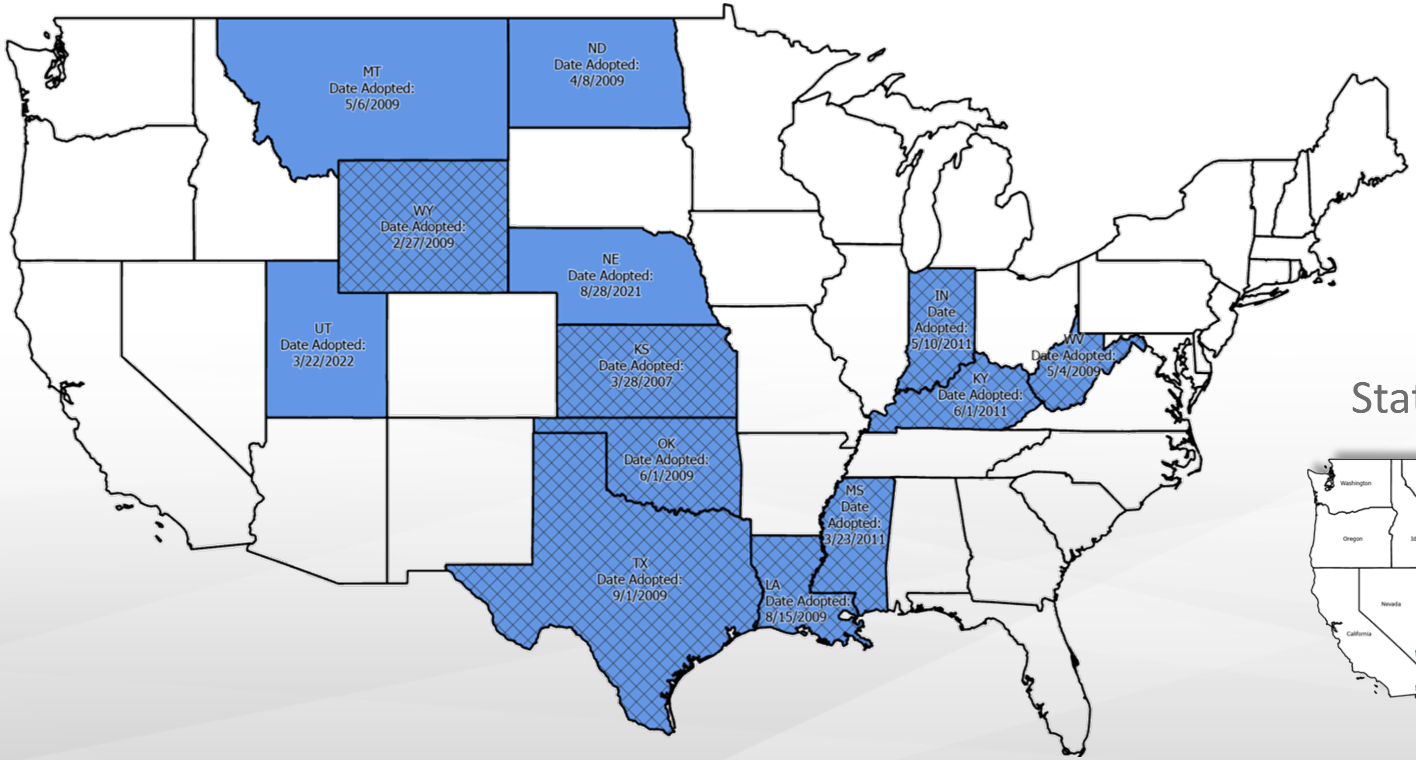
States with Comprehensive Legislation

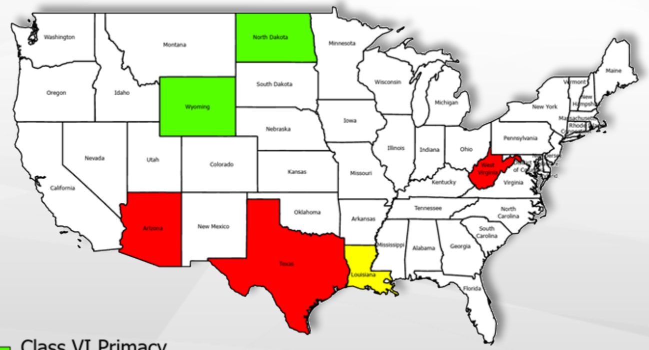


Legislation Recently Updated

States with Comprehensive Legislation

Other Sovereigns:
Norway
UK
Australia
Canada

States with Class VI Primacy



Class VI Primacy Approved

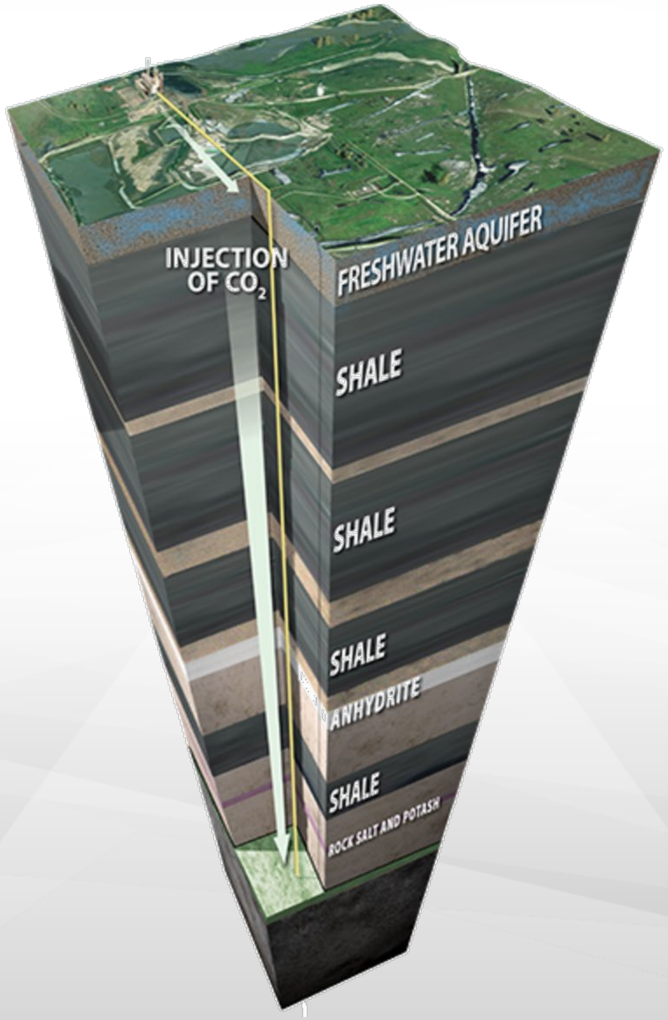
Class VI Pending Application

Class VI Pre-Application

Regulatory Framework

Slide with permission from AK DNR

- Provides for the use of public lands for CCUS
- Accounts for the amalgamation of property interests and protection of correlative rights
- Outlines relationship between other commercial minerals and reservoirs to be used for storage
- Allows for CO_2 transportation pipelines
- Defines ownership of carbon dioxide and ascription of liability
- Addresses authority for USDW Class VI well primacy
- Accounts for state tax structure on projects



Alaska CCUS Public Engagement

Institute of Northern Engineering
University of Alaska Fairbanks

Develop a State legal and regulatory framework → **Track and respond to funding opportunities** → **Perform public education and outreach** → **Develop a Roadmap to accelerate commercial CCUS**

Community Outreach

- Inclusion and education
- Engagement at each phase of project development
- Process of achieving social license

UAF – ACEP

- Stakeholder mapping
- Public polling
- Workshop development & implementation
- Continued stakeholder engagement

alaskaresource™ EDUCATION

- Elementary through Highschool classroom outreach
- Curriculum development

National

- Following CCUS projects and engagement worldwide
- Documenting best practices
- Plan to utilize API's recommended practice 1185 on effective engagement with environmental justice

Slide with permission from ASRC

Benefits of CCUS in Alaska

North Slope natural gas can fuel CCUS, reducing emissions (DAC and natural gas)

CCUS reduces project carbon intensity, entices funding, eases permitting, meets company ESG goals

Hydrogen production with CO_2 capture

CCUS makes CO_2 for agriculture use, enhancing local food security

Low cost, low emission power from coal with CCS benefits Railbelt and whole State via Power Cost Equalization

Alaska has high carbon sequestration potential, including mineralization and utilization

Easy access for CO_2 import at Southcentral ports

Aging Oil and Gas Fields with world class storage

Alaska CCUS Opportunity Roadmap

North Slope

Advantaged by low-cost natural gas

- Natural gas-fired capture
- Direct Air Capture (DAC)
- Subsurface data integration & site-specific data gathering needed
- 40 year track record of successful CO_2 sequestration & use, ~15 TCF
- Major Gas Sales 2015 LNG plan sequestered CO_2 back in reservoir

Interior

Existing coal plant infrastructure

- Coal-fired capture
- Basic regional subsurface data gathering needed

Southcentral

Proximity to Port, potential for import

- Capture not attractive at natural gas plants or refineries due to gas supply shortage & high price
- Coal or Hydrogen power with CCS can address natural gas shortage, food security, lower emissions
- Imported CO_2 storage (US West Coast or Asia-Pacific)
- Subsurface data integration & site-specific data gathering needed

Alaska CCUS Workgroup Focus

The CCUS workgroup mission is to accelerate commercial carbon capture projects in Alaska.

Why?

- To attract new investments and
- To create options to decarbonize activities vital to the State's economy including power generation, refineries, and oil and gas production.

Develop a State legal and regulatory framework → Track and respond to funding opportunities → Perform public education and outreach → Develop a Roadmap to accelerate commercial CCUS

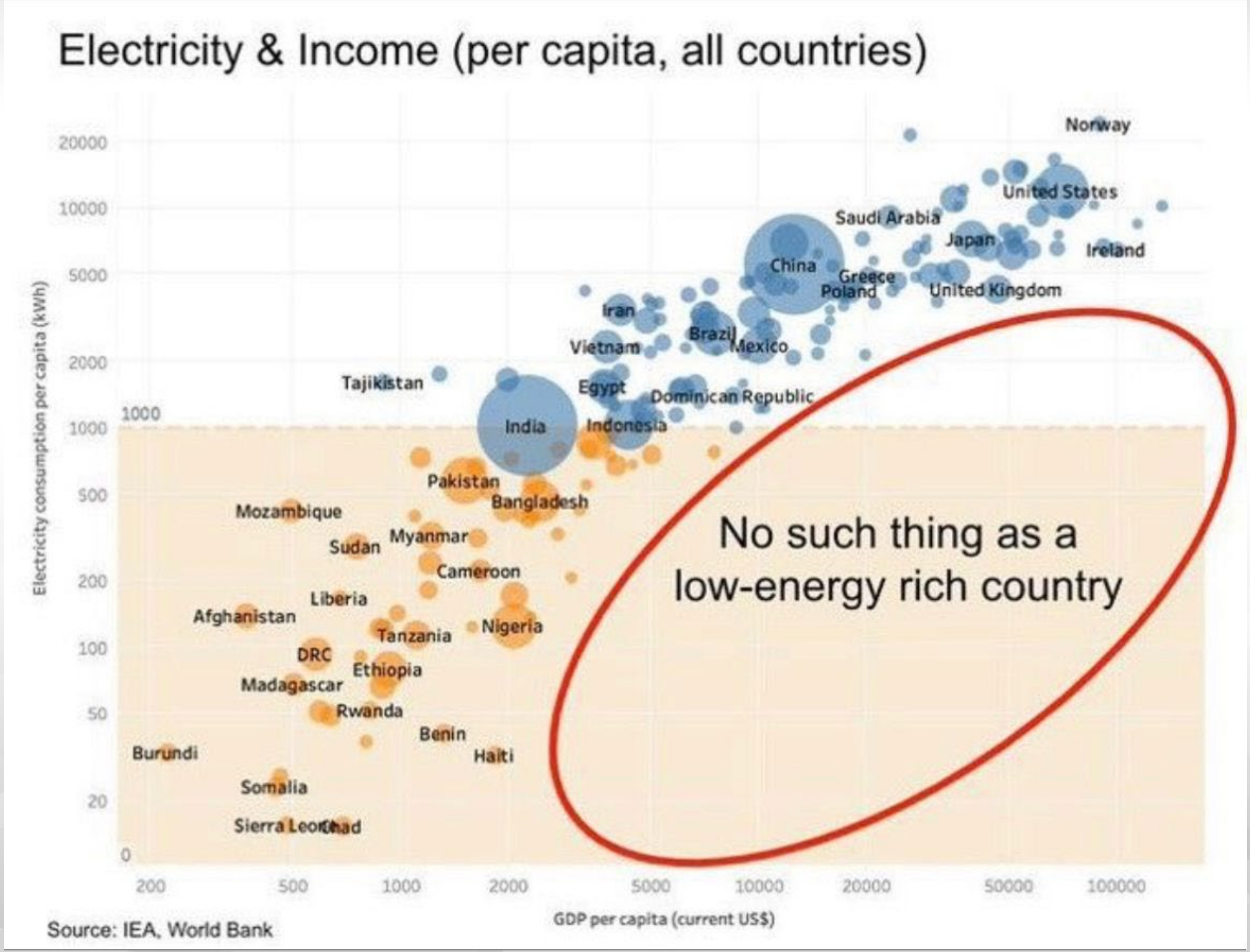
Thank you

- Questions?

- Follow-up: Frank.Paskvan@gmail.com
- SPE 213051 is accepted in pre-print to be published on OnePetro for the SPE Western Regional Meeting, 22—25 May 2023, Anchorage, Alaska

Electricity Powers Progress

- **Affordable, Reliable Power Essential to Human Well Being**
- **Electricity costs in Alaska are high**



The Nature Conservancy

“

Even after we have maximized the carbon sequestration possible from natural climate solutions, we will still need to clean up excess carbon remaining in the atmosphere.

“

Carbon capture, utilization and storage is a valuable set of tools in the climate solutions toolbox, but it is one of many tools.

Carbon Capture: One of Many Tools with Benefits

Modeling by the International Energy Agency (IEA) and Intergovernmental Panel on Climate Change demonstrates the critical role that carbon capture technology must play in meeting global climate goals. In its analysis of scenarios for limiting warming to 2° Celsius, the IEA found that carbon capture contributes 20 percent of necessary emissions reductions annually by 2050, with nearly half those reductions from industrial processes that have no other cost-effective way to decarbonize. In other words, while it is certainly possible to reach net zero emissions by 2050 without carbon capture technology, with CCUS technology we can get there much more cost-effectively. CCUS will help the most carbon- and heat-intensive industries operate with little to no greenhouse gas emissions, which in turn will support jobs for workers within these energy intensive industries. In some instances, CCUS might end up being the only viable decarbonization alternative.

Such tough challenges require technological innovation, and this is where carbon capture, utilization and storage (CCUS) comes into play. As one recent paper indicates, the strategies and economics that eliminate the last 10 percent of emissions from the utility industry are radically different from the initial 90 percent – and the main types of CCUS are among the key technologies that can get us that last 10 percent.

Jason Albritton, Director of Climate & Energy Policy for The Nature Conservancy
https://www.nature.org/en-us/what-we-do/our-insights/perspectives/carbon-capture-utilization-storage-albritton/

CO_2 Streams → Cost and Feasibility

- **Capture cost increases as CO_2 concentration & gas pressure decrease**
  - Streams with other contaminants, like from cement, make capture more challenging

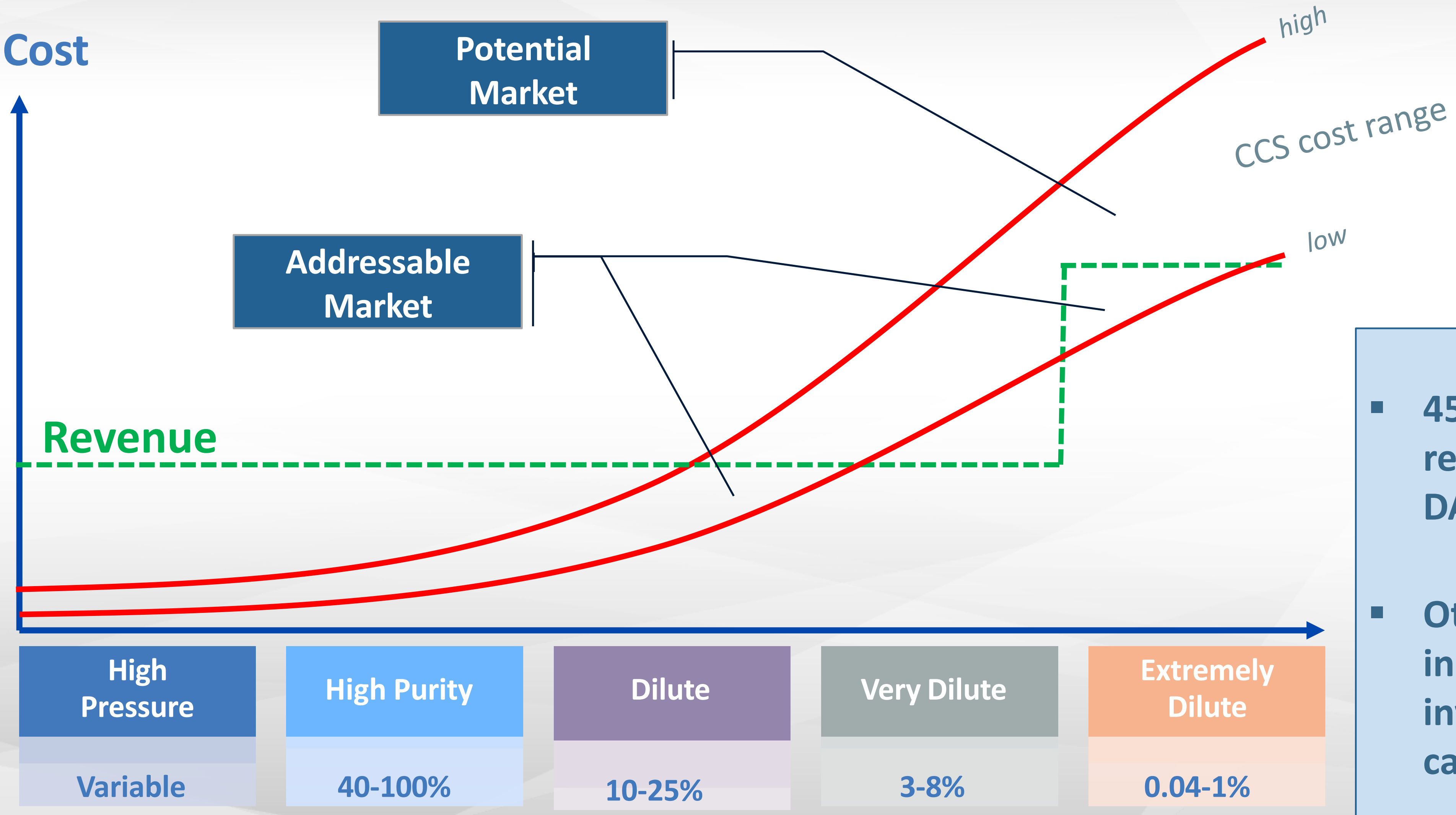
	High Pressure	High Purity	Dilute	Very Dilute	Extremely Dilute
CO_2 Concentration	Variable	40-100%	10-25%	3-8%	0.04-1%
Sources:	*Gas processing* *LNG* *Synthesis gas*	*Ethanol* *Ammonia* *Ethylene Oxide* *Hydrogen*	*Coal* *Cement* *Crackers* *Steel & Iron*	*Natural Gas-Fired* *Furnaces*	*Air* *Confined Spaces (spaceships)*

Increasing Cost and Decreasing feasibility →

Categorization adapted from Howard Herzog, MIT Energy Initiative

Source: CCUS Economics and Costing presentation, Alaska CCUS Workgroup, by Nick Fulford & Fernando Rolla, GCA, on December 13, 2022

Economic Viability of CCS Projects



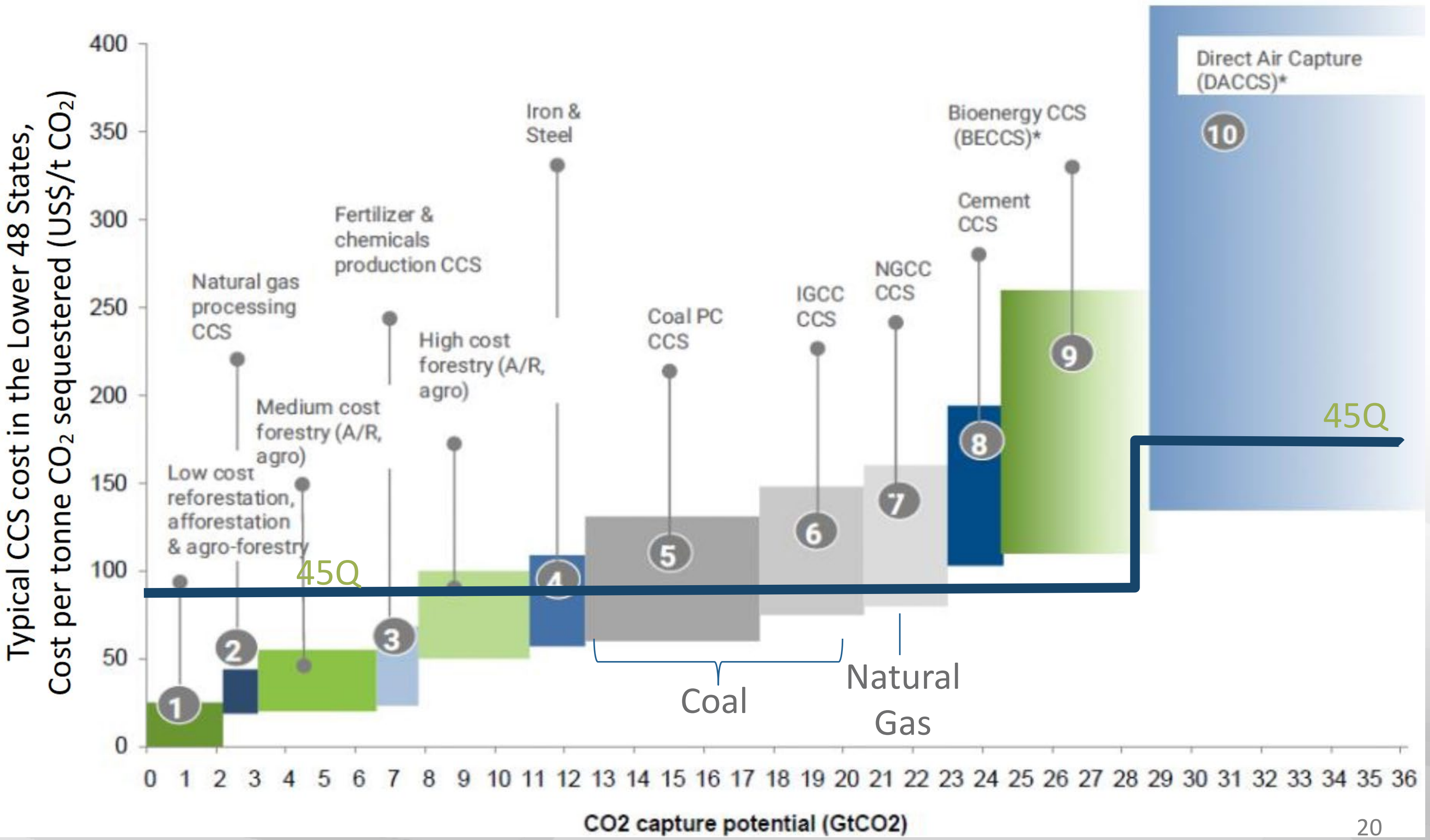
- 45Q is primary CCS revenue source: $85 tonne, DAC $180 tonne
- Other value drivers can include beneficial use, investment tax credits, carbon credits, ESG

Source: CCUS Economics and Costing presentation, Alaska CCUS Workgroup, by Nick Fulford & Fernando Rolla, GCA, on December 13, 2022

Economic Viability of CCUS Projects

- **Capture cost increases as CO_2 concentration and gas pressure decrease**
- **45Q covers much of capture costs**
  - Other value drivers: Beneficial Use, investment tax credits, carbon credits, ESG
- Coal can be attractive
- DAC may be attractive
- Natural Gas borderline

Typical CCS cost per tonne CO_2 (Lower 48 States Pricing)

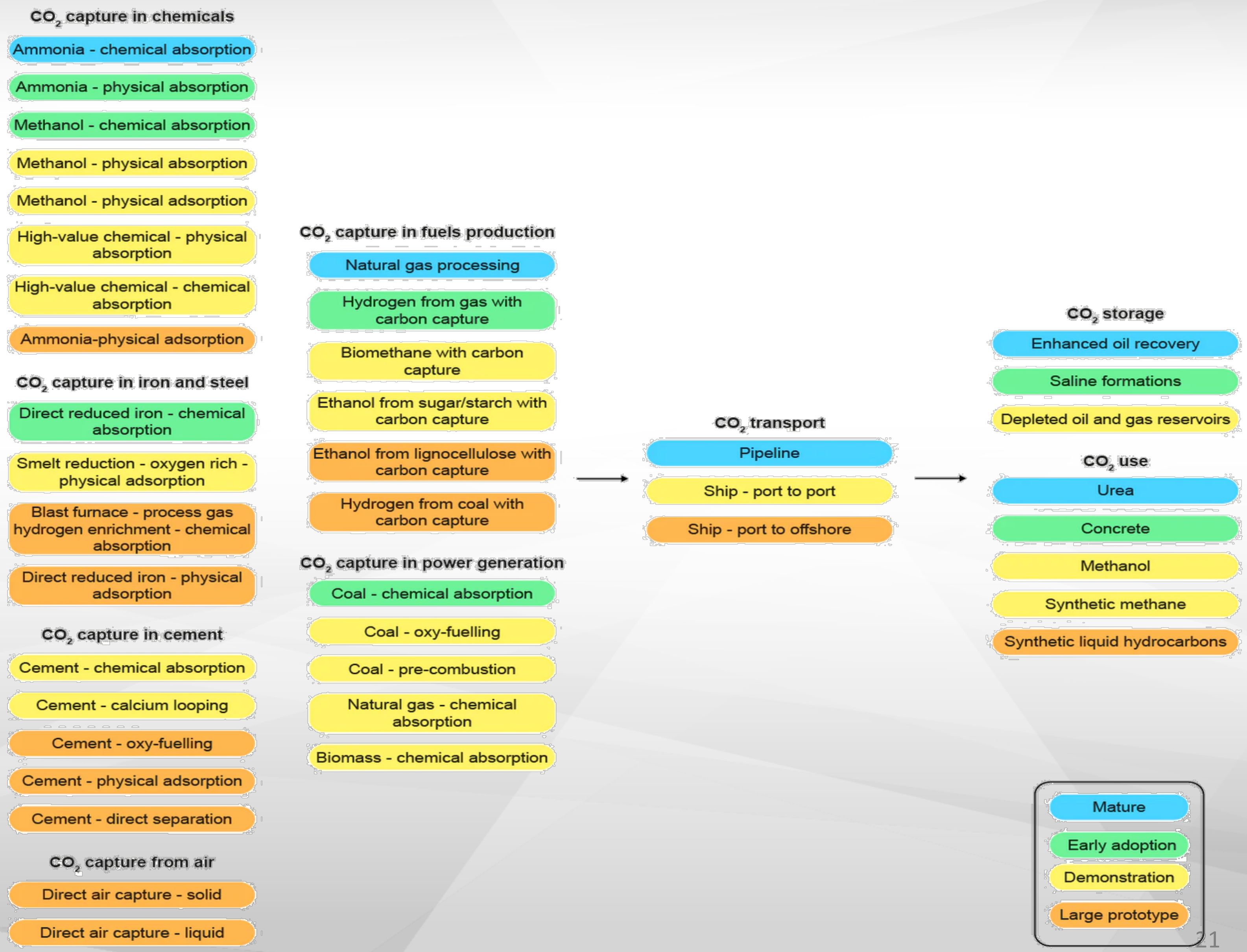


Source: Global CCS Institute, Goldman Sachs Global Investment Research

State of Technology in CCUS

Institute of Northern Engineering
University of Alaska Fairbanks

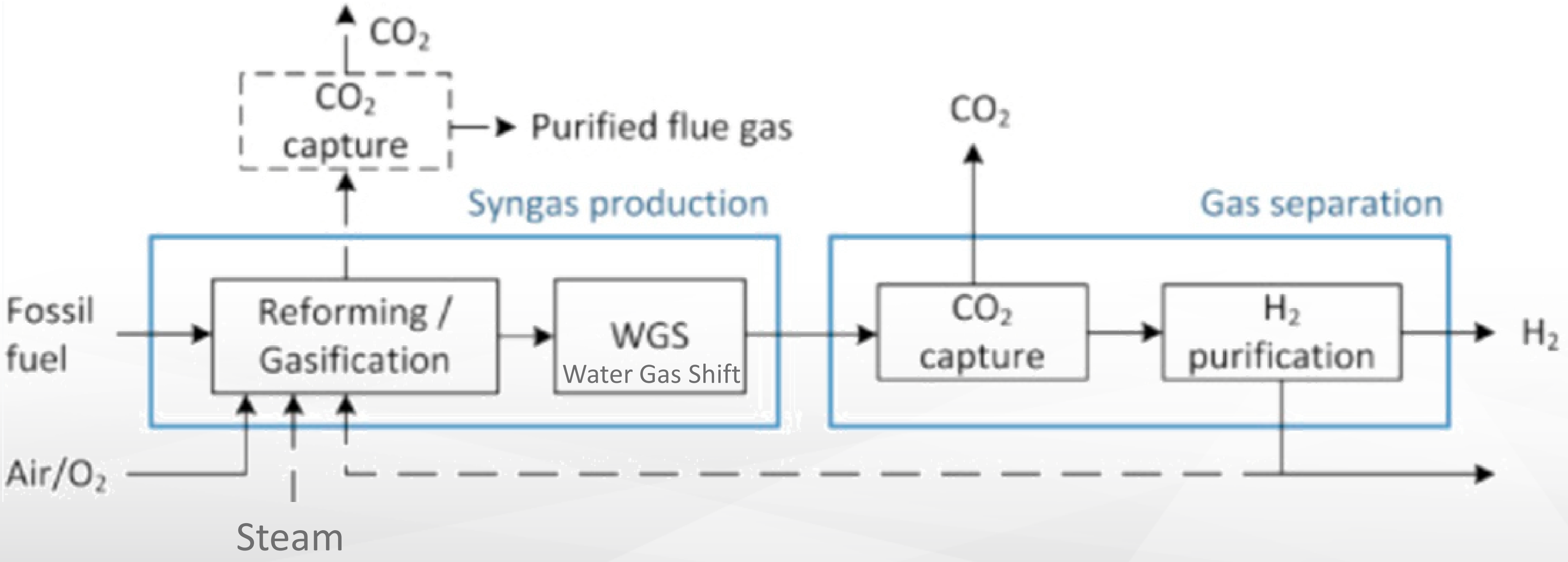
- Two-thirds of cumulative CCUS emissions reductions through 2070 will employ technology now in prototype or demonstration stages
- 45Q activating Research, Development, and Projects, evolving to lower cost and higher efficiency
- Given deployment time lag, innovation encouraged to enable new, commercially viable technologies



CCUS technology innovation – CCUS in Clean Energy Transitions – Analysis - IEA

CCUS supports Hydrogen Production

- Hydrogen production with CO_2 capture could be a key transition technology moving toward a sustainable hydrogen-using society.

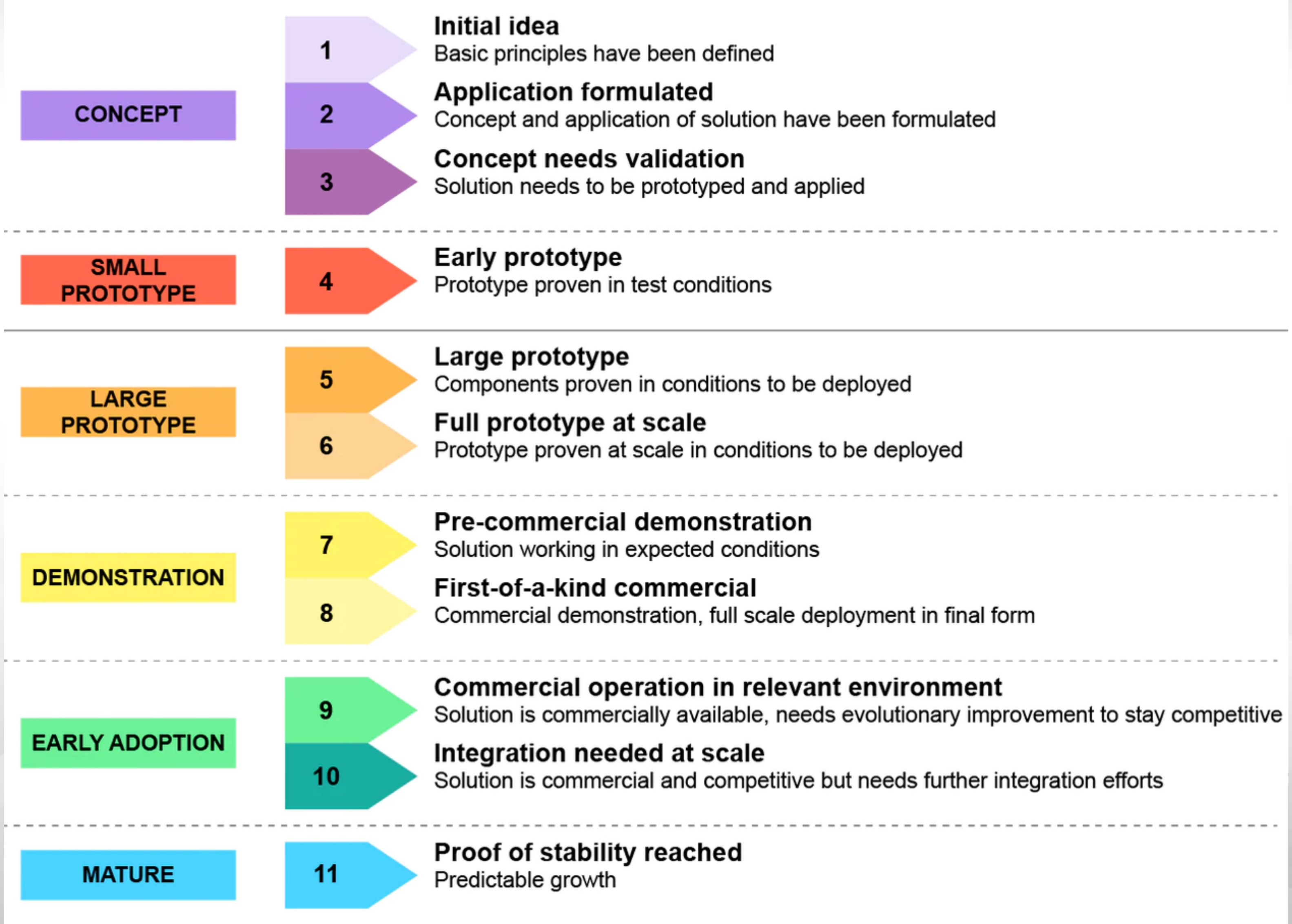


https://www.sciencedirect.com/science/article/abs/pii/S0360319915312659

CCUS Technology Maturity

- **Two-thirds of the cumulative emissions reductions from CCUS through to 2070 come from technologies that are currently at the prototype or demonstration stage**

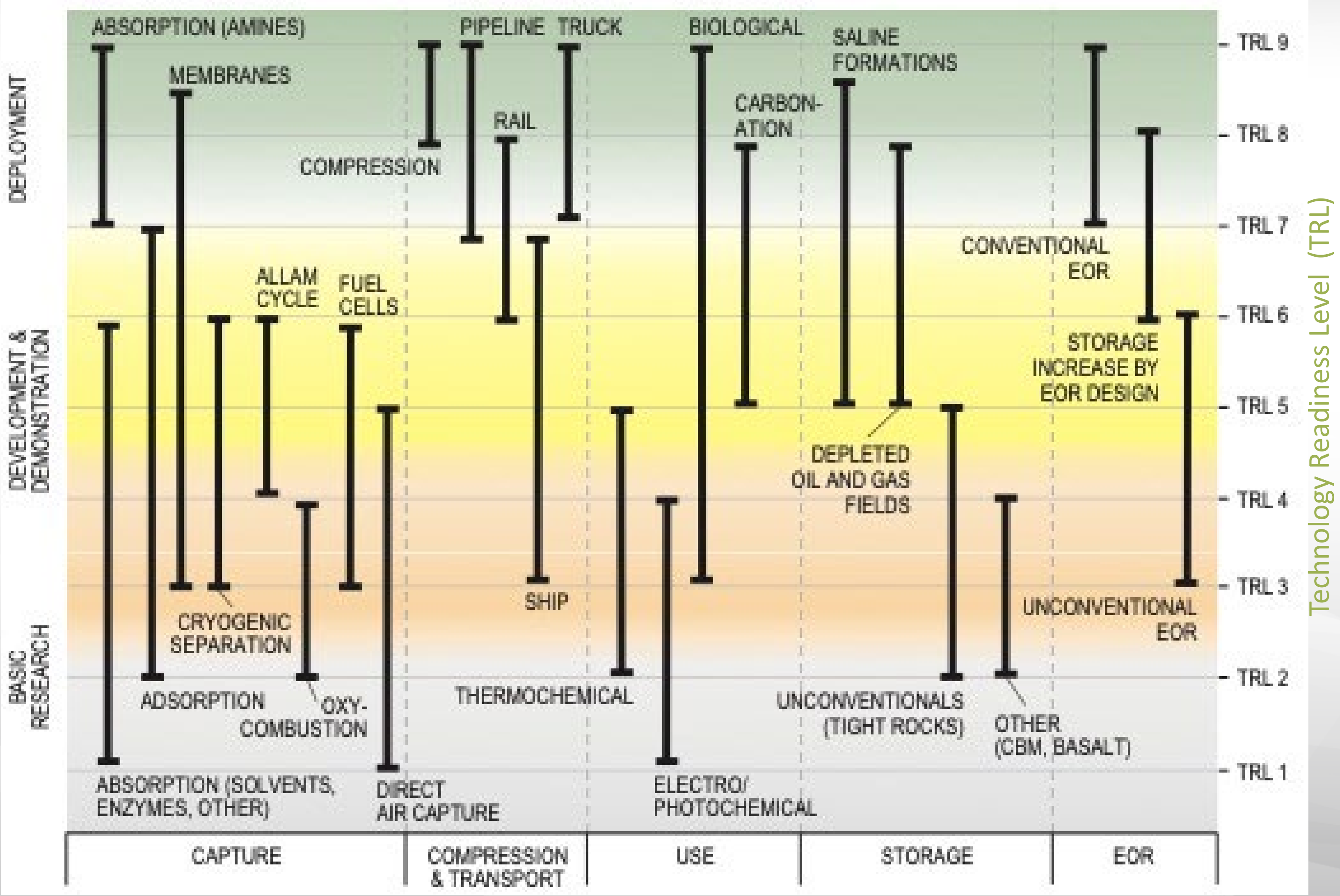
- **Given time lag, innovation needs to be stepped-up now to ensure key applications are commercially available**



CCUS technology innovation – CCUS in Clean Energy Transitions – Analysis - IEA

CCUS Technology

- Technology evolves to lower cost, higher efficiency
- Two-thirds of emissions reductions by 2070 will employ technology now in prototype or demonstration stages [IEA 2020]
- A project choosing mature technology employs:
  - Amine capture
  - Pipeline transport
  - Saline formation storage
  - Biological or EOR use, optional



Source: NPC Roadmap, 2019, p. 32

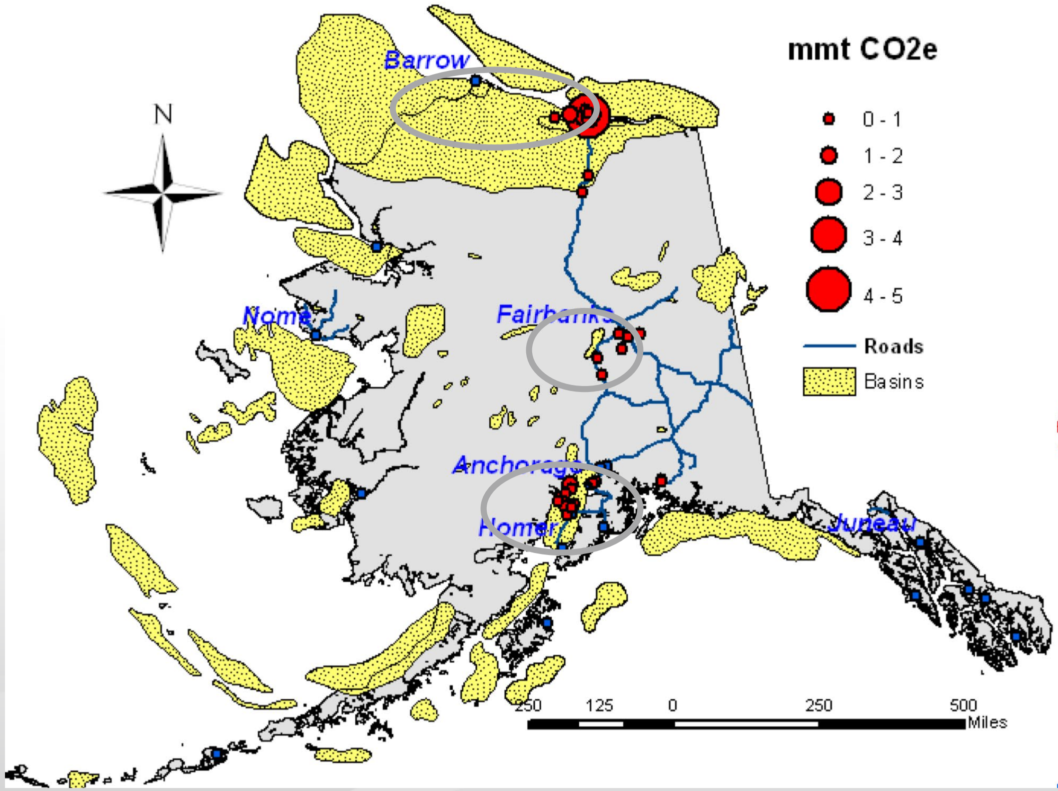
Alaska CO_2 & Storage Potential

- **Three potential Carbon Capture and Storage Regions**
  - Based on 2010 Screening. Project-specific work needed to assess CCS applicability.

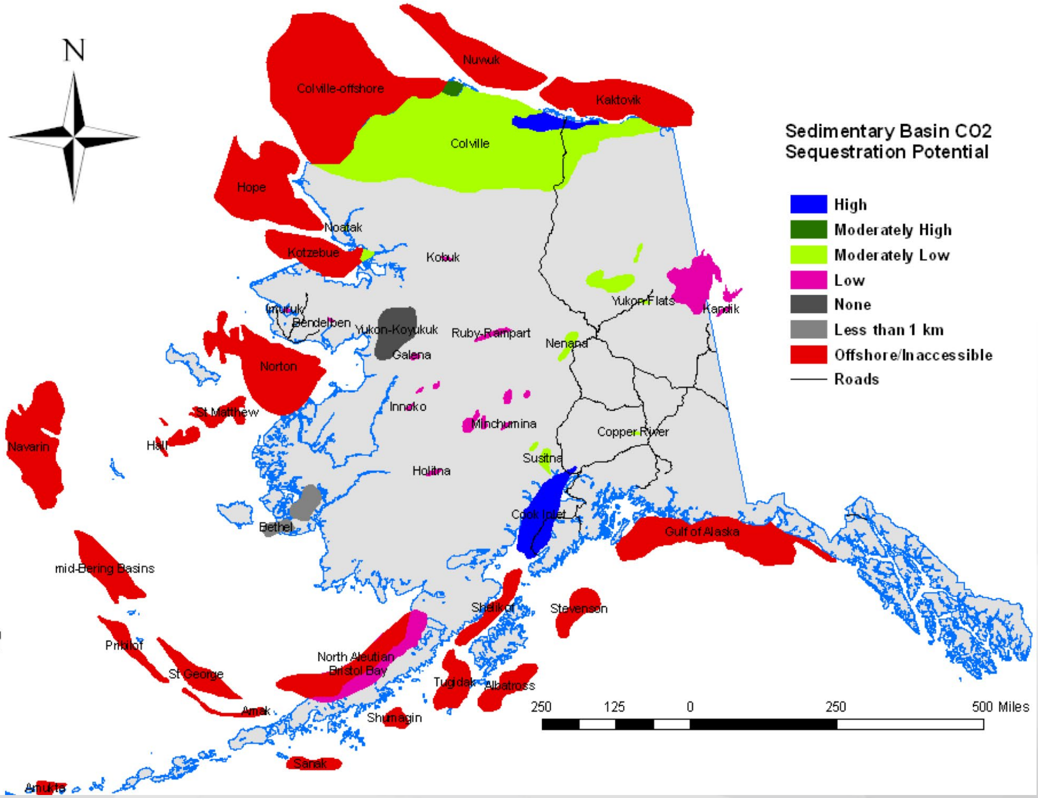
North Slope
Natural gas fired

Interior
Coal fired

Southcentral
Natural gas fired



CO_2 Stationary Sources (red) & Deep Sedimentary Basins (yellow).

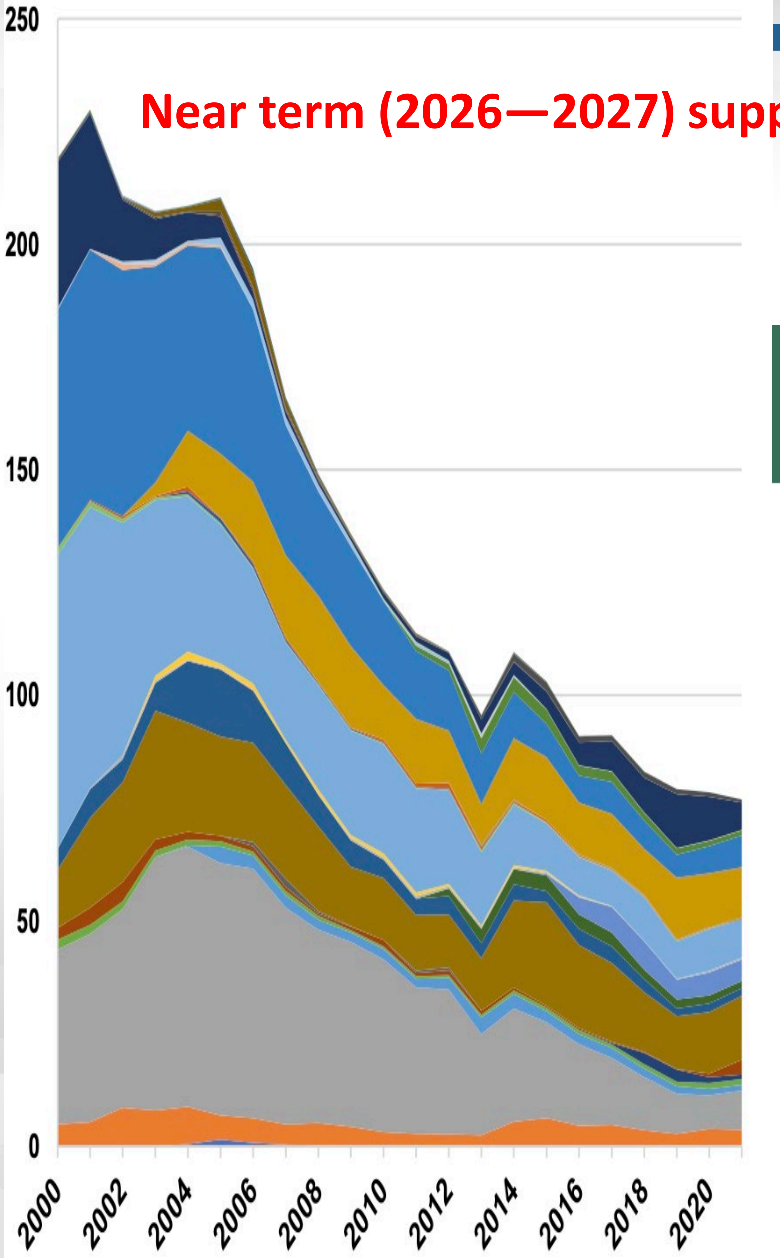


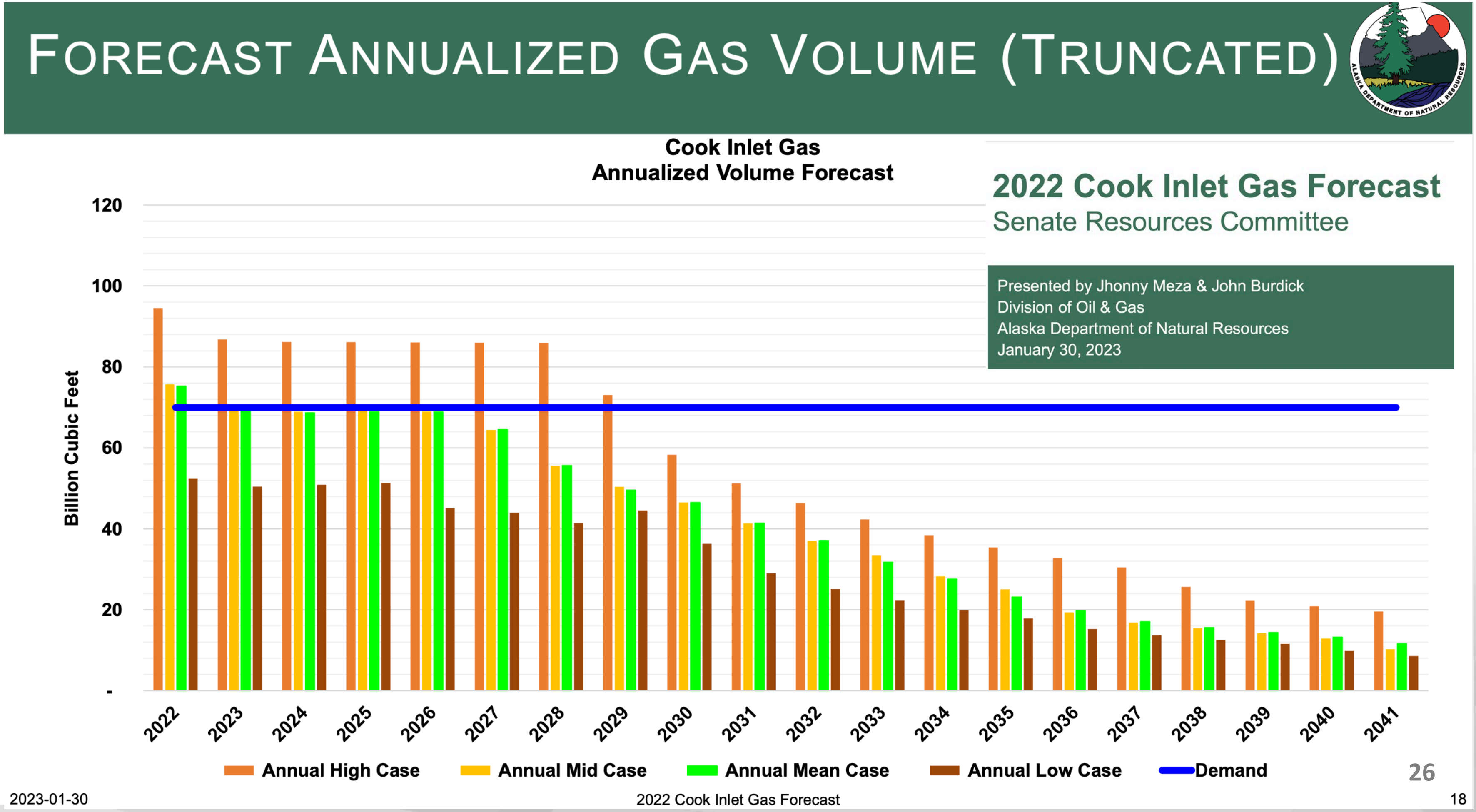
Sedimentary Basin Sequestration Potential [Shellenbaum and Clough, DNR, 2010]

Cook Inlet Gas Supply Analysis

Institute of Northern Engineering
University of Alaska Fairbanks

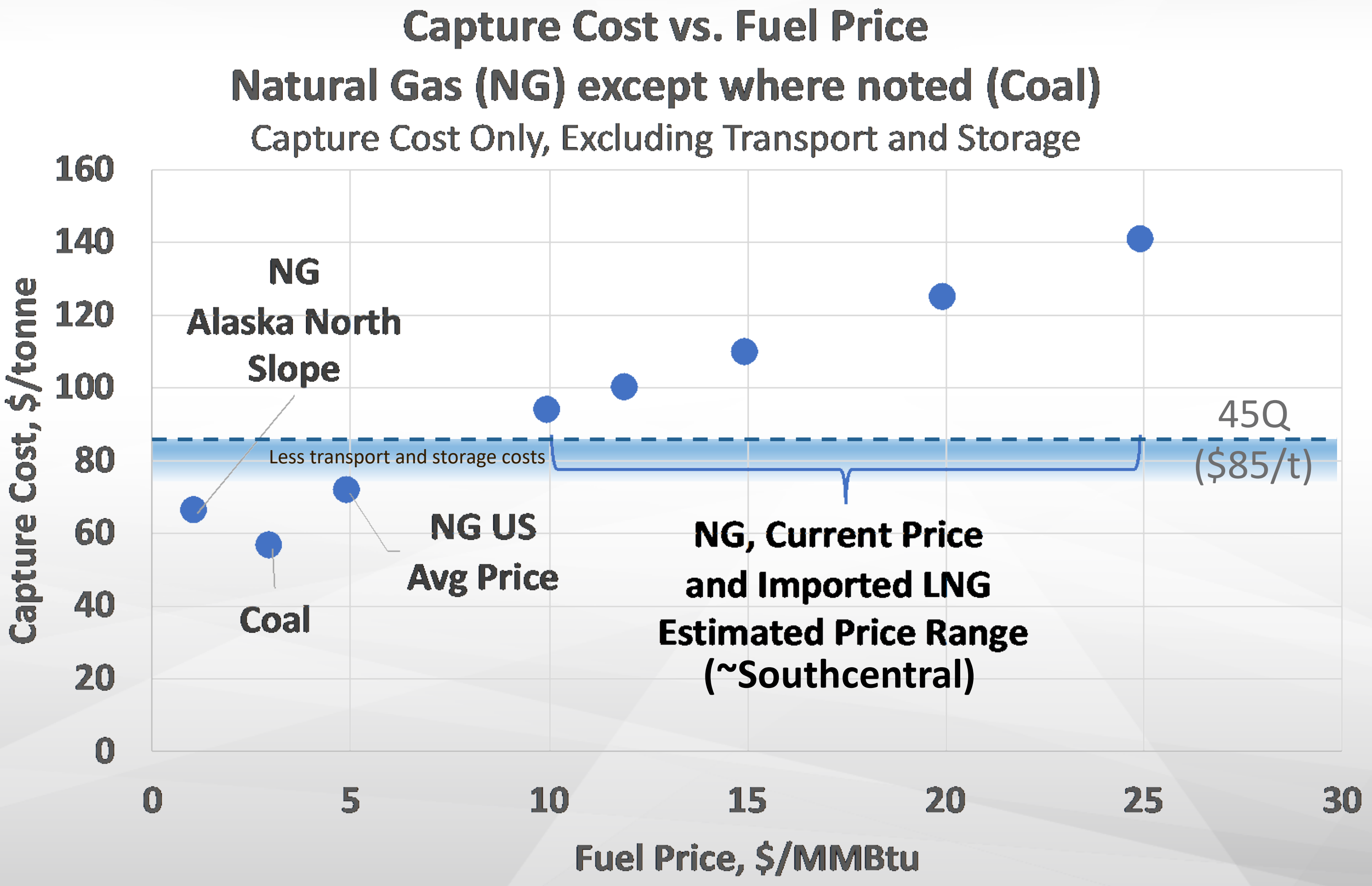
Near term (2026—2027) supply shortfall for Southcentral's main fuel:





Alaska CCUS Opportunities: Capture Costs

- **Alaska Capture Screening**
  - Using typical Lower 48 costs
  - Fuel price a key cost driver[1]
- **With Lower 48 costs and 45Q**
  - Natural gas capture prospective on North Slope
  - Natural gas capture not attractive for Southcentral
  - Coal capture looks prospective Statewide
- **Further work needed for prospective projects**



[1]Cost methodology benchmarked against NETL, U.S. Department of Energy National Energy Technology Laboratory, 2015, "Cost and performance baseline for fossil energy plants volume 1a: Bituminous coal (PC) and natural gas to electricity" revision 3. July 6, 2015, DOE/NETL-2015/1723.

Alaska's Interest in CCUS

- **Alaskan entities (DNR, AEA, AGDC, AOGCC, AES, CPAI, Hilcorp, ENI, UAF, and Usibelli) supported by the Governor responded in January 2022 to DOE Request for Information (RFI) "Deployment and Demonstration Opportunities for Carbon Reduction and Removal Technologies"**

- **These entities along with others responding to Funding Opportunities (FOAs), notably:**
  - DNR responded to Area of Interest 2 (State Geological Data Gathering, Analysis, Sharing, and Engagement) of DE-FOA-2799, "Regional Initiative to Accelerate CCUS Deployment: Technical Assistance for Large-Scale Storage Facilities and Regional Carbon Management Hubs"

- **Look forward to future opportunities including Pilots, Projects, and Geologic data gathering**

Alaska CCUS opportunities have:

- A robust and competitive carbon intensive industrial base.
- High potential for carbon sequestration, including through mineral carbonization or utilization.
- Fossil-energy producing region with high levels of coal, oil, or natural gas resources.
- Considerable carbon sequestration scalability.
- Opportunities for skilled training and long-term employment in an economically disadvantaged region.
- A geographically diverse location from the contiguous United States.
- Climatic conditions that provide unique commercialization advantages.

Observations for Potential CCUS Projects

For the North Slope:

- The North Slope contains high sequestration formation potential and extensive subsurface well and geophysical data from commercial oil and gas development. This data, primarily gathered to appraise hydrocarbons, can to some extent be repurposed to delineate geologic CO_2 storage potential.
- The North Slope emits half of the State's stationary CO_2 emissions from natural-gas fired equipment, making it the largest opportunity for industrial scale capture and storage.
- The North Slope contains abundant, developed natural gas resources. Low-cost fuel improves natural gas carbon capture costs as discussed and may make CCS projects economically attractive.
- Carbon capture would make CO_2 available for EOR use which could enhance project value.

For the Interior:

- The Interior has six coal-fired plants which may be attractive for deploying capture technology, but the Interior has moderately low saline sequestration potential based on initial screening.
- The Interior has un-minable coal seam CO_2 sequestration potential, which has a lower technology readiness level than other storage targets.
- The Interior, within the Northern Foothills Fold and Thrust Belt, has greater potential for surface rupturing faults than the North Slope or Southcentral [Salisbury 2022].
- The Interior lacks detailed subsurface data. Further work, especially fundamental geological and geophysical data gathering, is needed to assess and verify secure geologic storage capacity.

For Southcentral:

- Southcentral contains high sequestration formation potential and extensive subsurface well and geophysical data primarily gathered to appraise hydrocarbons for oil and gas development.
- Carbon capture would make CO_2 available for EOR or enhanced gas recovery use which could enhance project value.
- Southcentral has high natural gas prices compared to the national average, resulting in carbon capture costs that exceed the potential financial benefits of the 45Q tax credit.
- Southcentral has an imminent gas supply shortfall. The Cook Inlet proved gas supply is forecast to fully meet demand until 2026—2027 [AK DNR 2022, p. 17], after which a shortfall is expected.
- Southcentral has abundant coal available as a low-cost fuel, which when coupled with CCUS can provide clean, reliable, affordable energy at one-half or lower emissions than natural gas.

Screening Findings and Recommendations

Screening Findings:

1. For Southcentral and the Interior, natural gas plant carbon capture appears unattractive economically in this screening due to regionally high natural gas prices, current 45Q tax credits, and using project costs typical of the lower 48 states. Capture costs alone, excluding transport and storage, exceed the current 45Q tax credit amount.
2. Carbon capture on the North Slope and Cook Inlet could enhance oil recovery and oil production revenue by making CO_2 available for EOR use, which may increase CCS project value. CO_2, a well-known EOR injection fluid, can also enhance gas field recovery.
3. Coal-fired plants with CCS produce electricity at one-half or lower carbon intensity of a natural gas-fired plant without CCS. Coal-fired CCS tends to be attractive economically using 45Q tax credits and lower 48 capture costs, and may achieve carbon neutrality with beneficial use such as food growing operations.
4. In-state carbon capture could enhance food security by making CO_2 and heat available for local greenhouse use.
5. Transportation and storage costs are assumed to be no more than $20/tonne for this study. This is based in part on the difference between current 45Q tax credits and estimated capture costs and is a placeholder until further, site-specific costs are analyzed.

Screening Recommendations:

1. A legal and regulatory framework for CCUS should be established for the State. The Legislature should consider passage of the recently introduced Carbon Storage bill into law.
2. The State should seek Class VI injection well Primacy from the US Environmental Protection Agency (EPA), clarify departmental roles and responsibilities to facilitate timely project evaluations, appropriate necessary funding and staff, and set and publish internal targets for the time required for project reviews and approvals. Recently introduced legislation allows the Alaska Oil and Gas Conservation Commission (AOGCC) to seek Primacy ("may" not "shall"), and AOGCC has notified the EPA in a letter of intent that it will seek offered funding to assess the work required to establish State Primacy for Alaska.
3. Subsurface data should be organized and made publicly available so project teams can evaluate local and regional storage options. The Alaska DNR applied for DOE-FOA-2799 AOI-2 funding to progress this work.
4. An appraisal project should be kicked-off to deepen understanding of Alaska's geologic storage potential. A CarbonSAFE Phase II Study, or perhaps three considering Alaska's key basins, would focus on one or more specific reservoirs within the defined storage complex, drill at least one characterization well and acquire and integrate geologic data from seismic surveys, core logs, and well tests. Six Phase II Studies have been completed in the US, funded by DOE plus other entities.
5. Pipeline analysis should be performed to evaluate economic advantages for carbon capture CO_2 pipeline networks from sources to a CO_2 hub storage site.
6. Coal-fired power generation CCS projects appear prospective economically, when screened using current 45Q tax credits and lower 48 state's typical capture costs, and should be evaluated for existing and new plants. US tax code Section 48 provides an additional 30% investment tax credit for coal-fired power generation CCS projects which was not considered in this screening.
7. For the North Slope, with the State's largest stationary emissions sources, CCS represents an opportunity to reduce CO_2 emissions by 90% from its natural gas-fired equipment. North Slope natural gas CCS, advantaged by low-cost fuel, assuming capture costs typical for lower 48 states, appears economically attractive in this preliminary screening and should be evaluated further.
8. DAC may also be attractive on the North Slope given abundant, low-cost natural gas fuel and colder temperatures that increase operating efficiency. Further evaluation and DAC pilot projects should be considered.

Renewable Power Assessment for Railbelt

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University of Alaska Fairbanks

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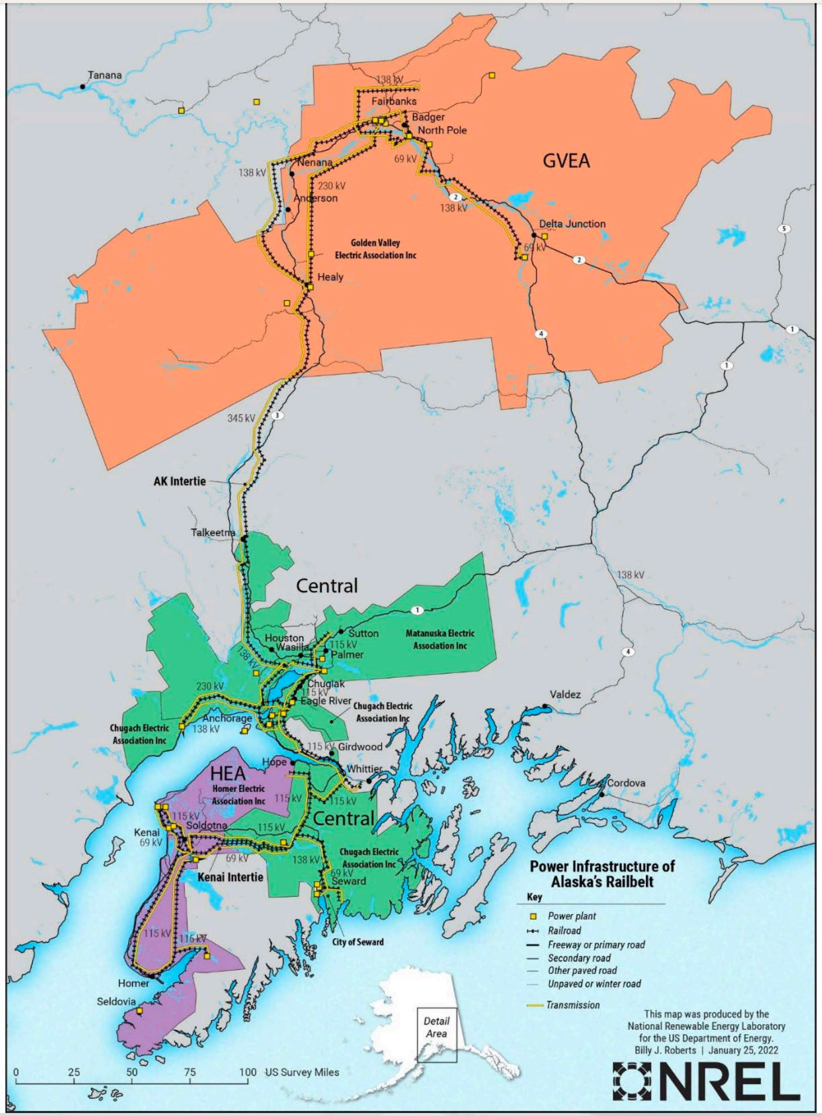

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Table 2. Generation Resource Types for the Utilities in Alaska's Railbelt (2020 Data)[6]

Generator Type	Capacity[a] (MW)	Generation (GWh)	Generation Fraction
Gas/oil combustion turbine (CT)	754	632	14%
Gas/oil internal combustion (IC)	193	732	16%
Gas/oil combined cycle (CC)	561	1,676	36%
Coal	75	348	8%
Unspecified fossil purchases[b]	n/a	310	7%
Fossil Subtotal	**1,585**	**3,698**	**80%**
Hydropower	190	815	18%
Wind	44	97	2%
Landfill gas	7	39	1%
Solar	1	1	<1%
Renewable Subtotal	**241**	**951**	**20%**
Total[c]	1,826	4,649	100%

[a] This does not include the 147 MW of combined heat and power plants in the Railbelt system reported on EIA 861. These units generated about 444 GWh in 2020. Much of this electricity was used on site. However, some of this was sold to utilities and accounts for some of the unspecified energy.

[b] This value was estimated based on estimated total generation (see note c) minus the total generation accounted for in Form EIA-923.

[c] This value was estimated based on the total generation required for retail sales plus losses reported in in Form EIA-861.

Denholm, Paul, Marty Schwarz, Elise DeGeorge, Sherry Stout, and Nathan Wiltse. 2022. *Renewable Portfolio Standard Assessment for Alaska's Railbelt*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5700-81698. https://www.nrel.gov/docs/fy22osti/81698.pdf.

Railbelt Power System Cost Savings via Power Cost Equalization has Statewide benefits

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University of Alaska Fairbanks

- **Coal is lowest cost fuel**
  - Per MMBtu:
    $4/MMBtu Coal
    $10—15 Nat Gas
    $20—35 Diesel
  - Abundant supply
  - With CCS, Coal emits
    - ½ to ¼ of natural gas
    - ½ of wind with natural gas peakers
- **Natural gas price forecast (from AEA) may not reflect price risk for high cost imported LNG**

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Fuel Prices

Fuel prices trajectories were derived from projections by the Alaska Energy Authority (Figure 5).

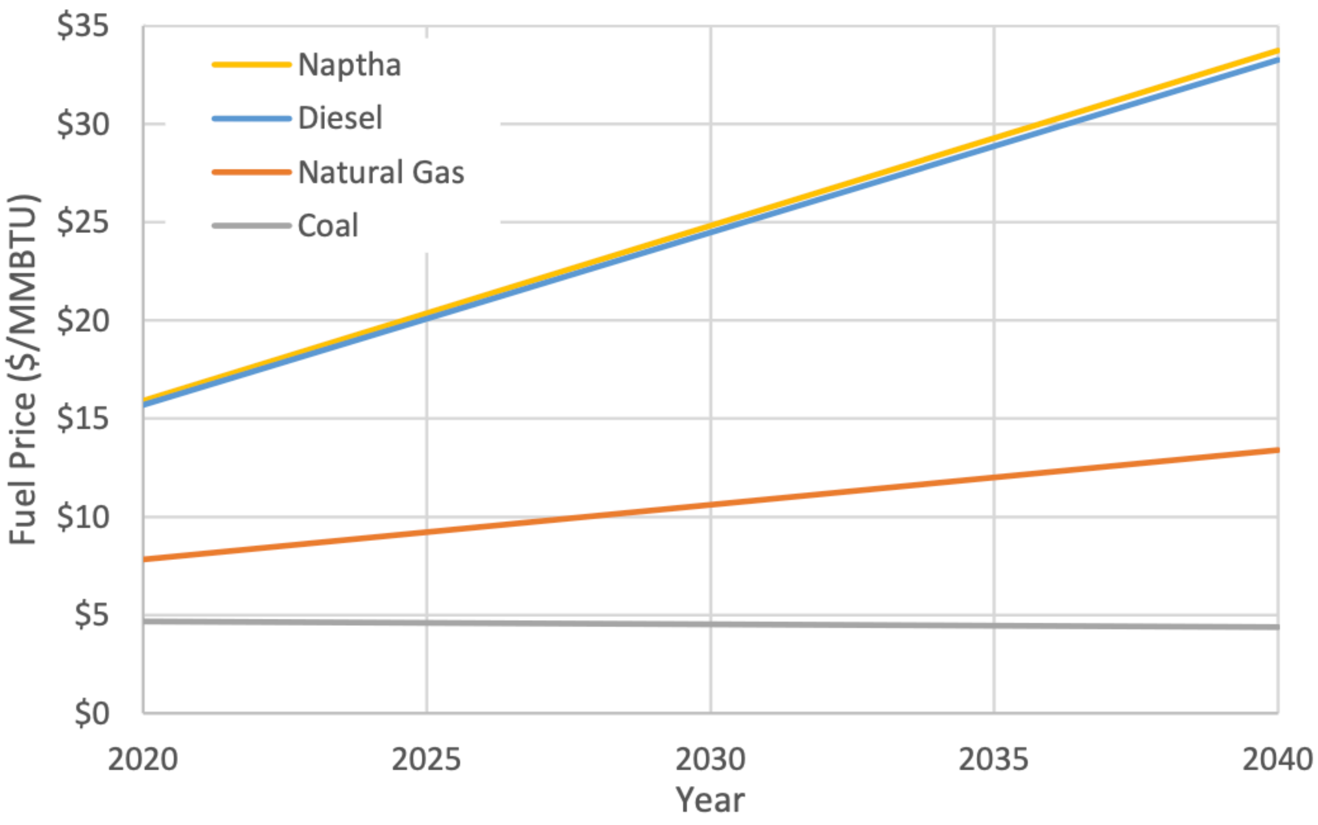

Figure 5. Assumed fuel price trajectories (2020$)

Railbelt Power System

- 80% renewable energy power study for Railbelt showed little reduction in fossil thermal power generation, coal and natural gas
- Scenarios were not tested for extended or extreme conditions
- Additional Scenario(s) including CCUS needed

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with annual average outage conditions. The extended outage cases establish reliable operation, but we do not attempt to achieve an 80% renewable energy under extended or extreme outage conditions (see Section 4). Table 4 provides the final portfolio for the six modeled scenarios.

Table 4. Final Portfolio: Capacity (MW)

Technology (Existing *and* New)	Base Case	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Wind	45	202	826	847	847	777
Solar	1	30	258	456	150	132
Hydropower (storage)	186	866	324	248	248	186
Hydropower (run-of-river)	25	0	25	25	25	25
Geothermal	0.4	0.4	0.4	0.4	25.4	50.4
Biomass	0	50	50	50	50	50
Landfill gas	7	7	7	7	7	7
Tidal	0	0	0	0	50	75
Battery Storage	163	163	163	163	163	163
Fossil thermal	2,048	1,968	1,824	1,911	1,897	1,890
Total	**2,474**	**3,286**	**3,477**	**3,707**	**3,462**	**3,355**

Railbelt Power System

- **80% renewables scenarios exist**
- **All Scenarios require fossil thermal-energy backup, minimum 75% of base case, for reliable power generation**
  - Maintaining back up power has costs
  - Fuel savings may pay for renewables
- **Scenario costs not performed in this study, NREL working to extend this to including costing of scenarios.**

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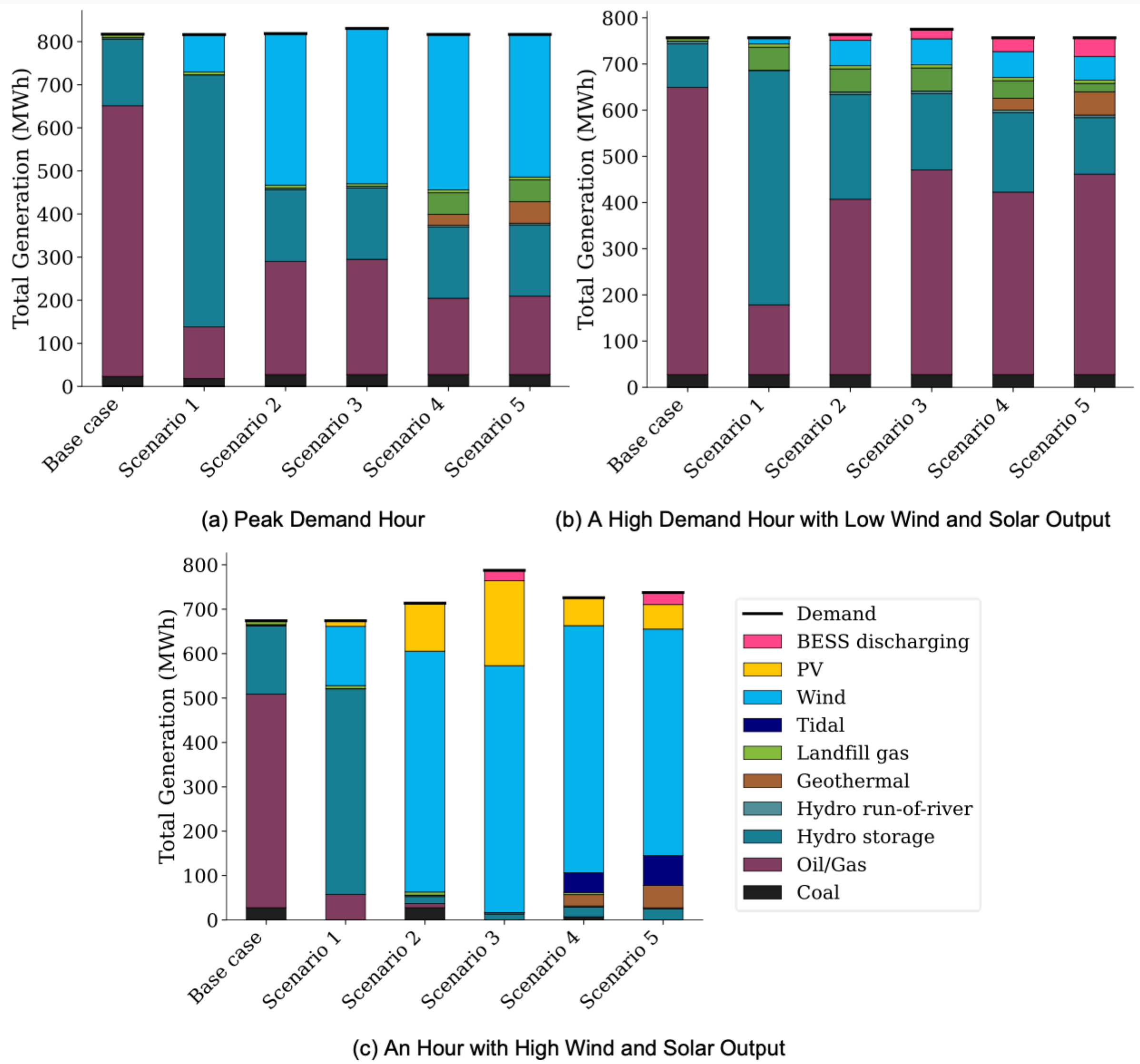

Figure 6. Stacked bar charts of sources of generation during three hours for the six scenarios