PNNL-SA-164051

Pacific Northwest NATIONAL LABORATORY

Getting to Global Net Zero

CO_2 Removal, Use and Sequestration in the Pacific Northwest

Community Science & Technology Seminar
13 July 2021

Casie Davidson
Senior Research Scientist | Energy & Environment
Portfolio Manager | Carbon Management & Fossil Energy
Pacific Northwest National Laboratory

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DOE's 17 **national laboratories** tackle critical scientific challenges

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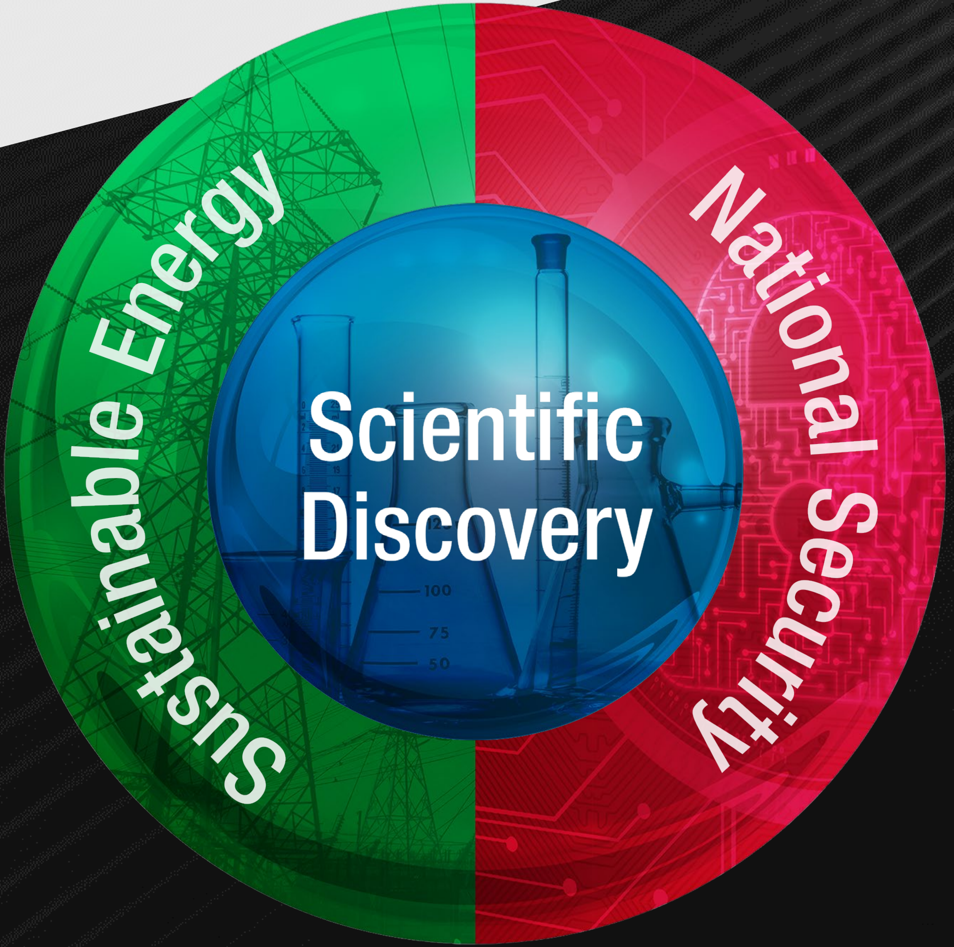
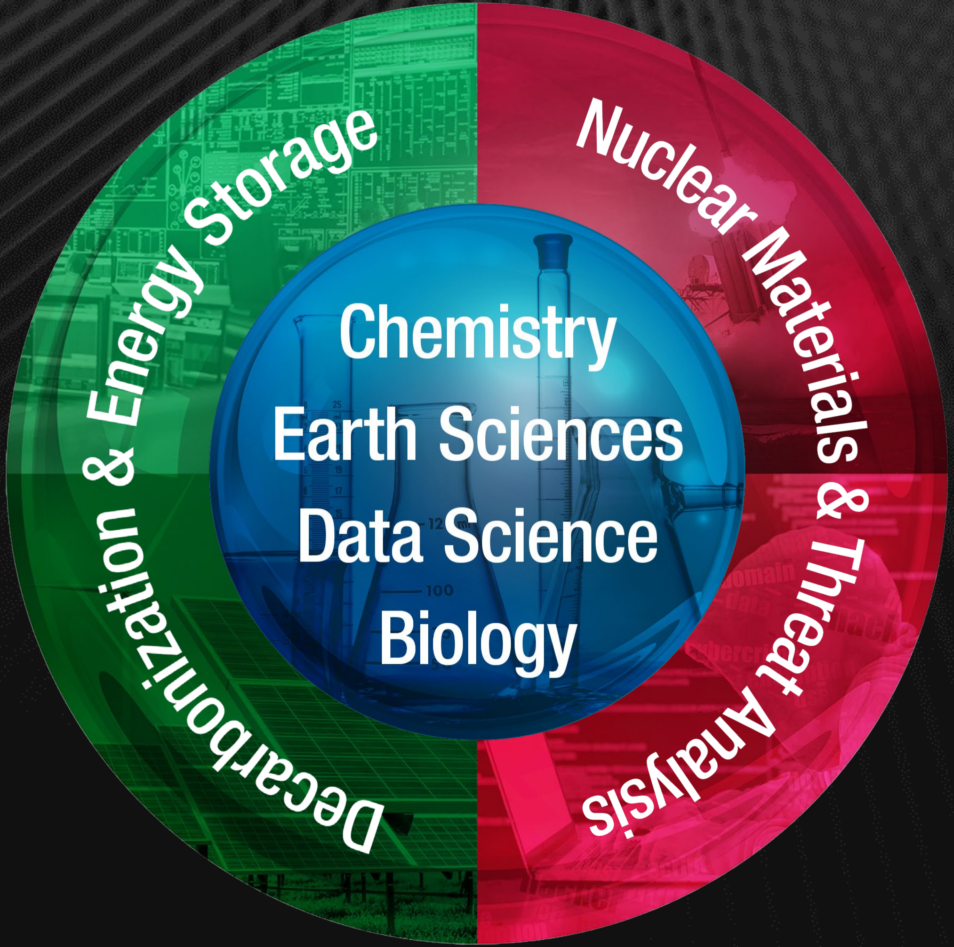
PNNL is **advancing scientific frontiers** and **providing solutions** to critical national needs; our distinguishing **strengths** enable mission **impact**





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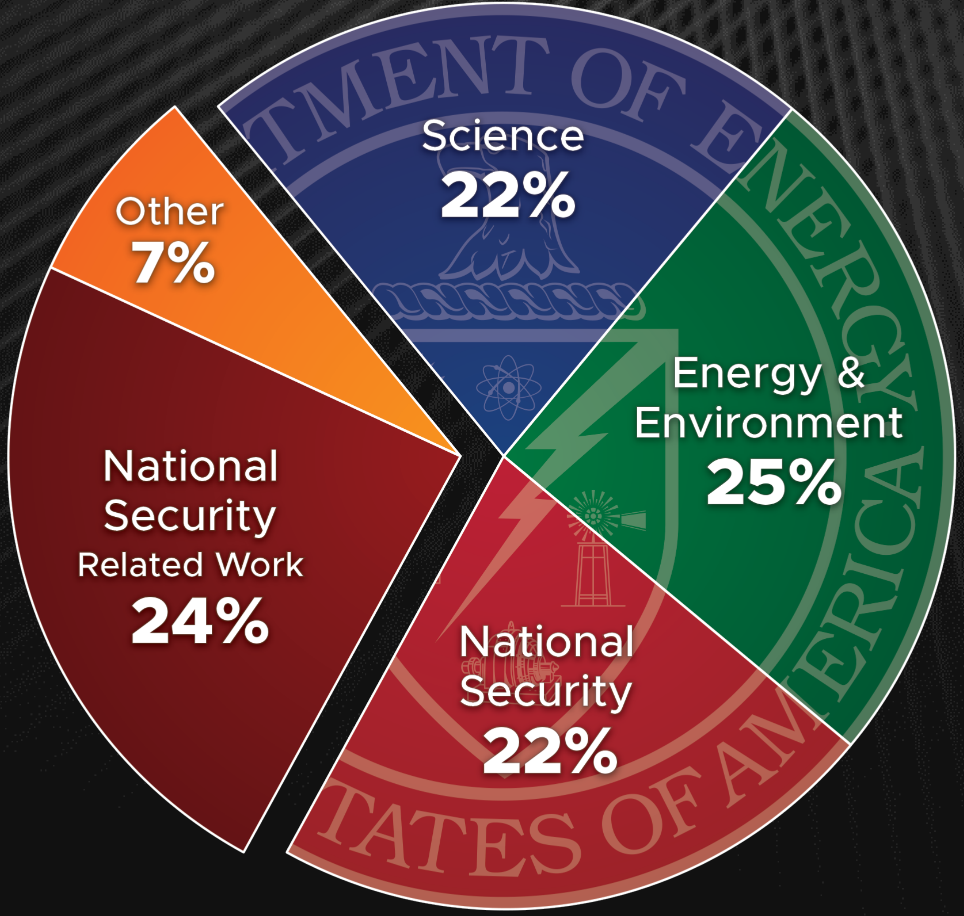
PNNL is DOE's most diverse national laboratory

5,000 Staff

$1.1B Spending

1,280 Peer-reviewed publications

340 Invention disclosures



FY 2020 Staff

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Enriching our community through **engagement, philanthropy, and volunteerism** is central to our mission

PNNL helps carry DOE's commitment to train, support, and inspire scientists, mathematicians, and engineers. Collectively, the national laboratories train and educate more than 250,000 K–12 students; 22,000 K–12 educators; and over 11,000 undergraduate, graduate, and postdoctoral researchers annually.

This photo was taken before the COVID-19 pandemic

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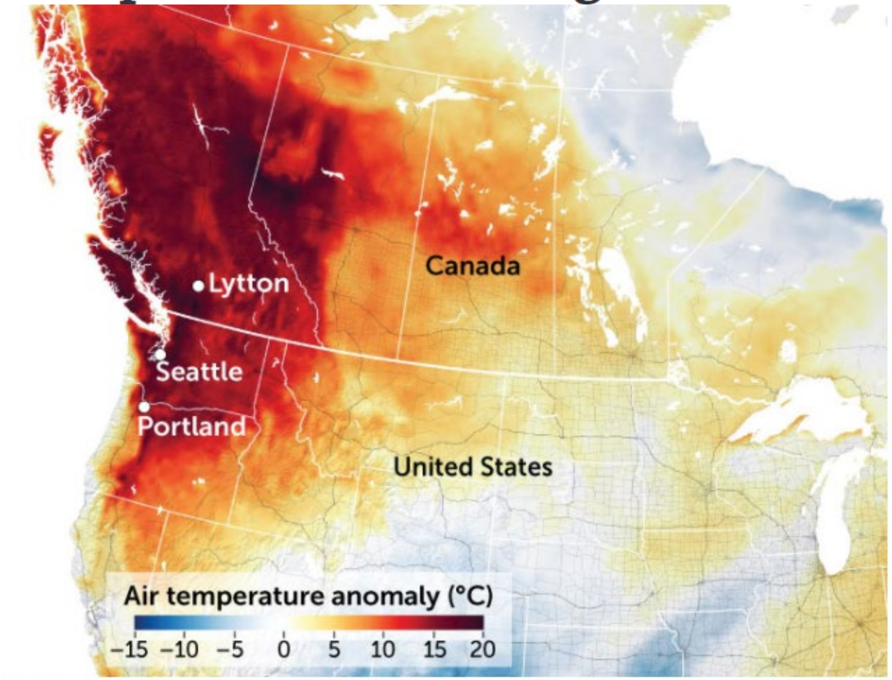
Impacts of changing climate have arrived

ScienceNews
INDEPENDENT JOURNALISM SINCE 1921

Human-driven climate change sent Pacific Northwest temperatures soaring



NASA

June 29, 2021 temperature compared with the 2014–2020 average for that day

"An event like this—currently estimated to occur only once every 1000 years—would occur roughly every 5 to 10 years in [a] future world with 2 °C of global warming."

SY Philip, et al. "Rapid attribution analysis of the extraordinary heatsave on the Pacific Coast of the US and Canada June 2021. https://www.worldweatherattribution.org/wp-content/uploads/NW-US-extreme-heat-2021-scientific-report-WWA.pdf

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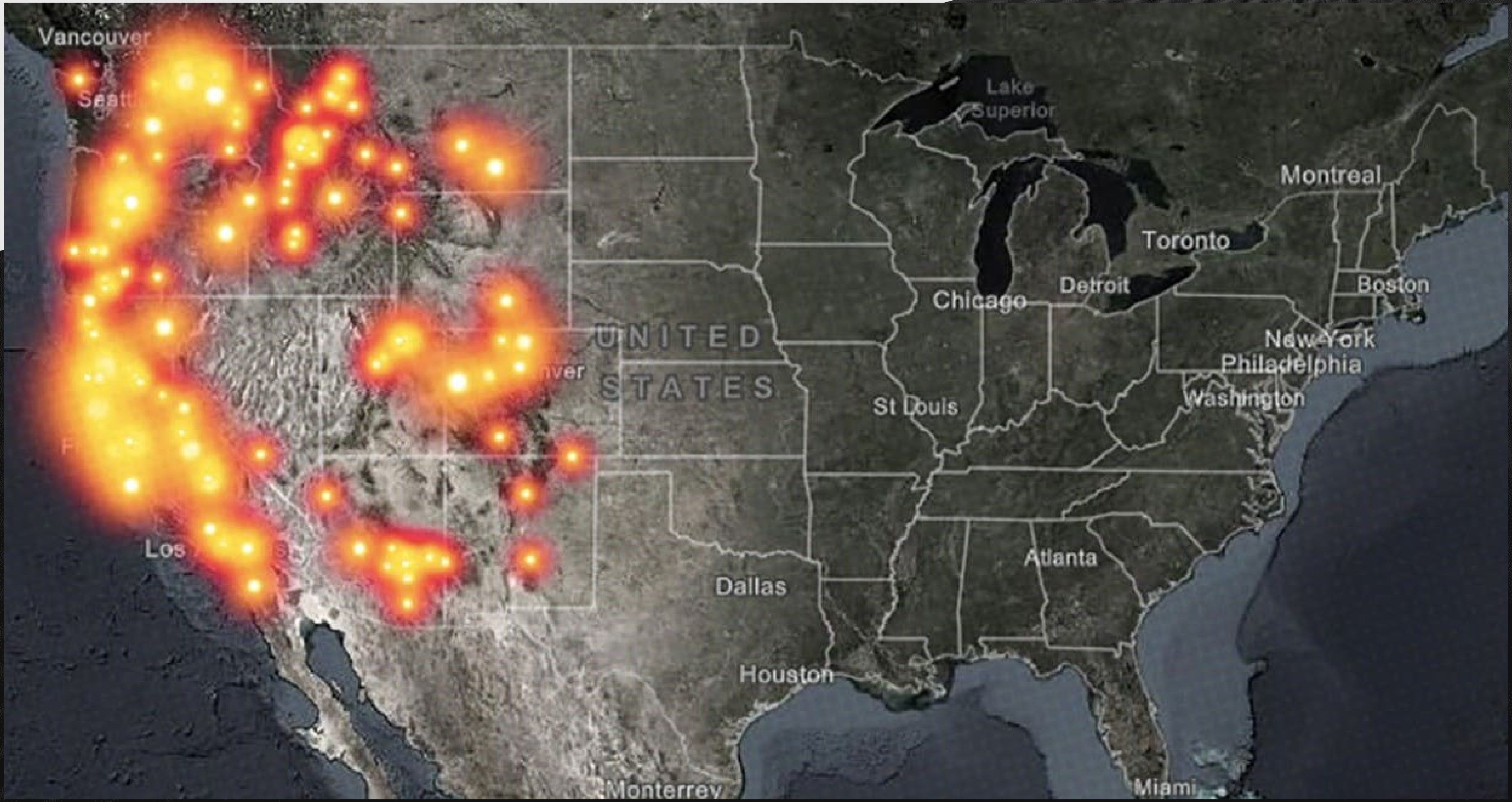
Reducing emissions is key to reducing climate impacts on health and resources



Live wildfire map, September 2020. Source: ESRI

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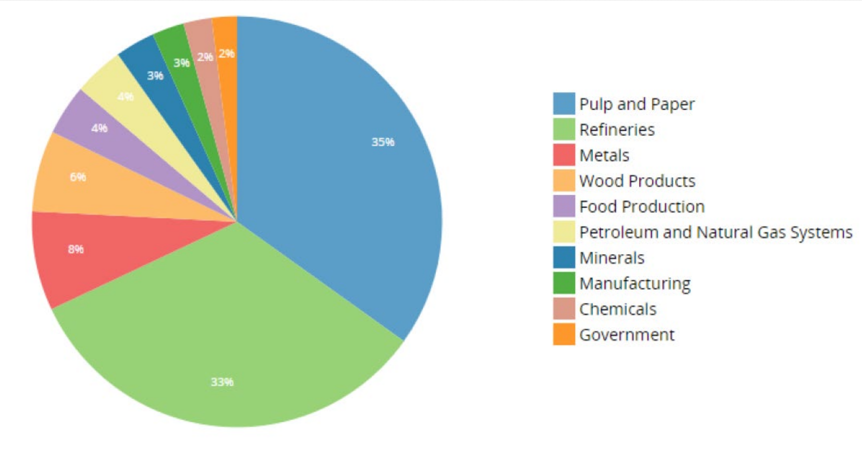
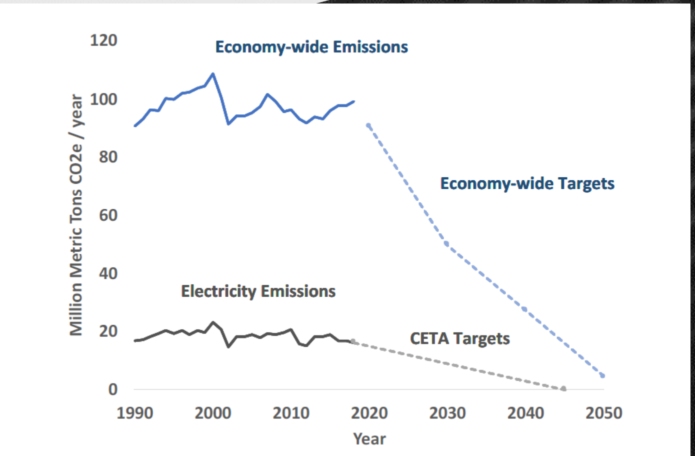
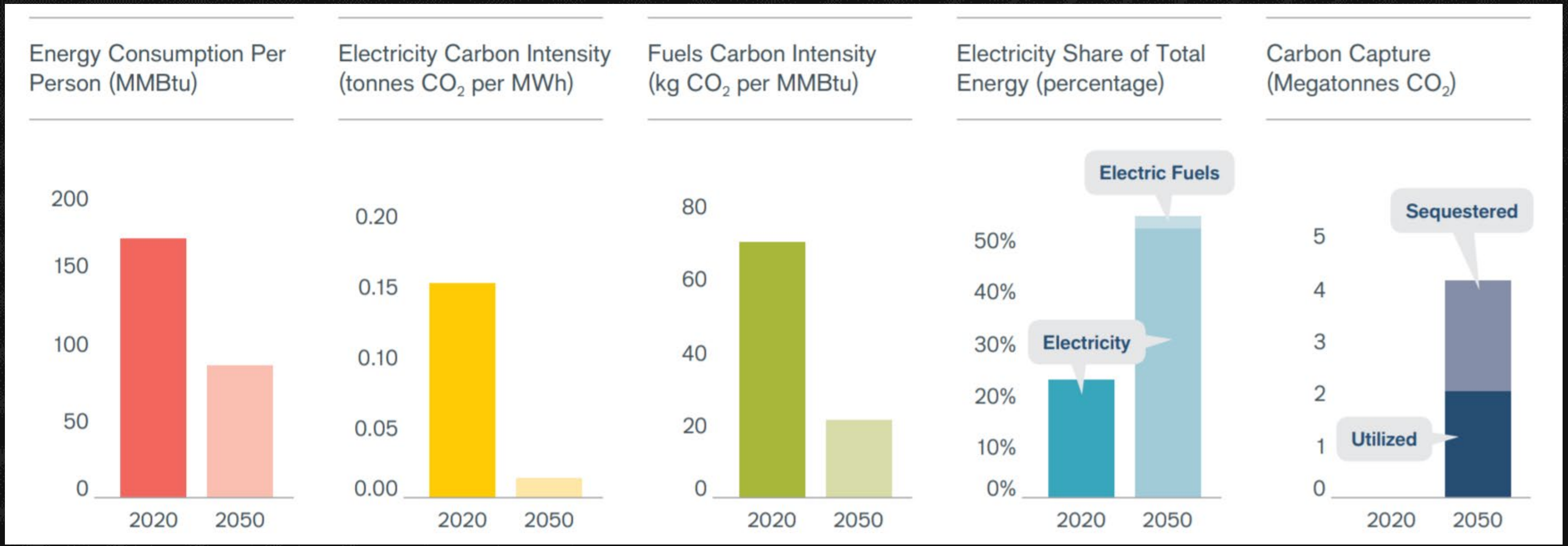
For now, integrating renewables means building more gas-fired power



CETI 2021 Industry Sector Framing Document



CETI 2021 Electricity Sector Framing Document



CETI Deep Decarbonization Pathways, 2019

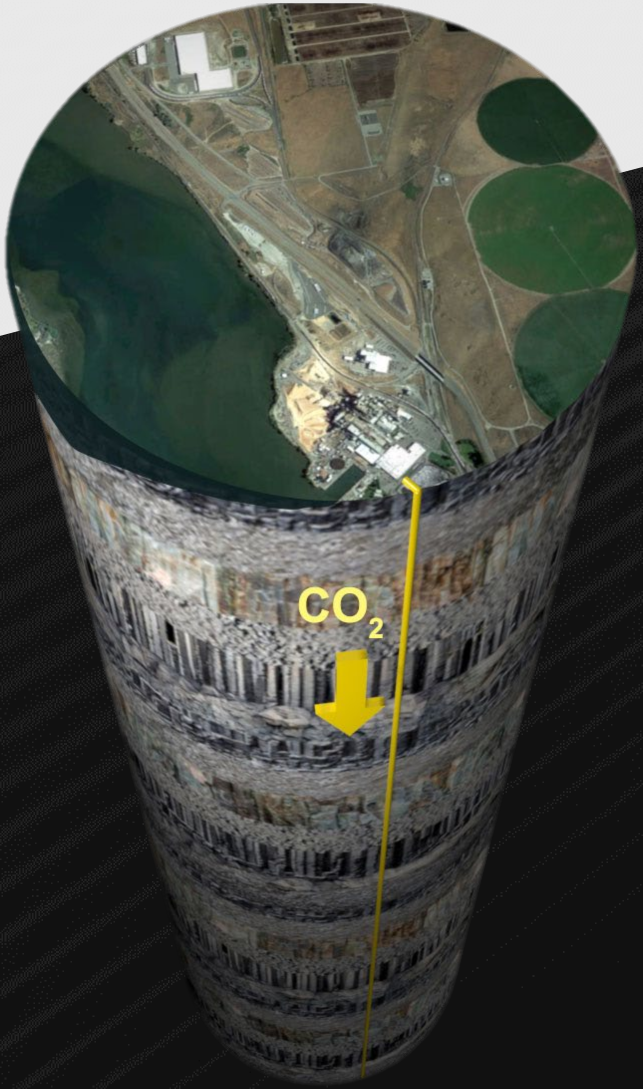
NATURAL GAS WILL REMAIN ESSENTIAL TO SUPPORT RENEWABLE POWER

As renewables replace fossil baseload capacity, demand for new gas-fired balancing assets is expected to increase.

This likely holds true for additional renewable build-out to meet increased demand associated with transport and industry electrification.

CO_2 CAPTURE AND GEOLOGIC STORAGE

Demystifying the technology



CAPTURE

[power generation, hydrogen, fertilizer, chemicals, cement, iron and steel, atmospheric air]

TRANSPORT

[pipelines]

STORAGE

[sandstones*, limestones*, basalts]

*enhanced oil recovery potential

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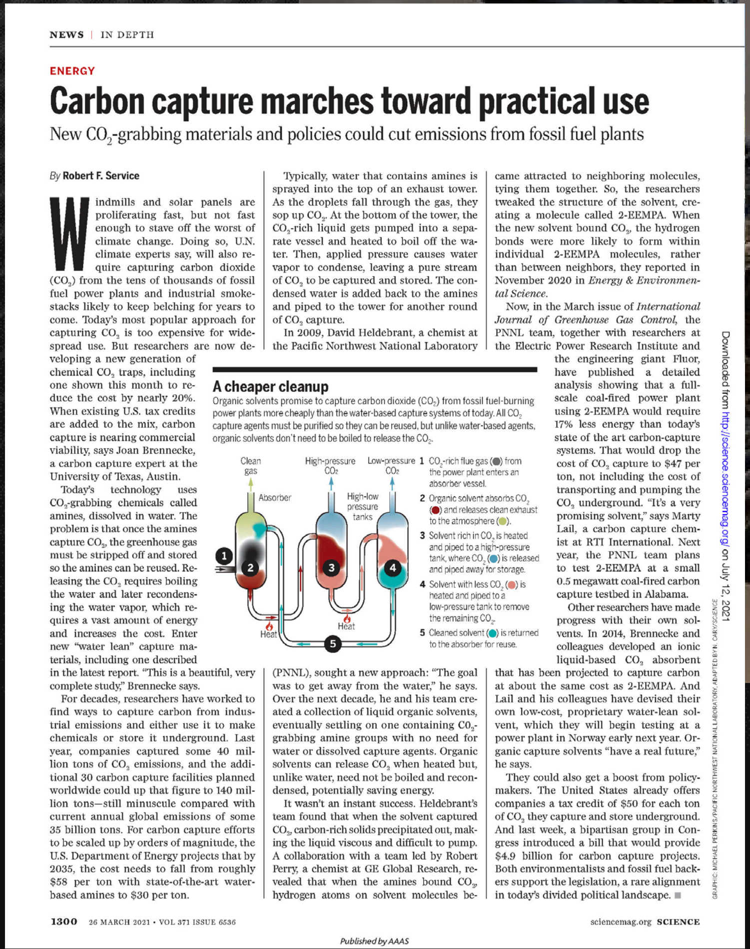
CO_2 capture from industrial point sources is essential for net zero

"Today's most popular approach for capturing CO_2 is too expensive for widespread use. But researchers are now developing a new generation of chemical CO_2 traps, including one shown this month to reduce the cost by nearly 20%."



ENERGY

Carbon capture marches toward practical use

New CO_2-grabbing materials and policies could cut emissions from fossil fuel plants

By Robert F. Service

Windmills and solar panels are proliferating fast, but not fast enough to stave off the worst of climate change. Doing so, U.N. climate experts say, will also require capturing carbon dioxide (CO_2) from the tens of thousands of fossil fuel power plants and industrial smokestacks likely to keep belching for years to come. Today's most popular approach for capturing CO_2 is too expensive for widespread use. But researchers are now developing a new generation of chemical CO_2 traps, including one shown this month to reduce the cost by nearly 20%. When existing U.S. tax credits are added to the mix, carbon capture is nearing commercial viability, says Joan Brennecke, a carbon capture expert at the University of Texas, Austin.

Today's technology uses CO_2-grabbing chemicals called amines, dissolved in water. The problem is that once the amines capture CO_2, the greenhouse gas must be stripped off and stored so the amines can be reused. Releasing the CO_2 requires boiling the water and later recondensing the water vapor, which requires a vast amount of energy and increases the cost. Enter new "water lean" capture materials, including one described in the latest report. "This is a beautiful, very complete study," Brennecke says.

For decades, researchers have worked to find ways to capture carbon from industrial emissions and either use it to make chemicals or store it underground. Last year, companies captured some 40 million tons of CO_2 emissions, and the additional 30 carbon capture facilities planned worldwide could up that figure to 140 million tons—still minuscule compared with current annual global emissions of some 35 billion tons. For carbon capture efforts to be scaled up by orders of magnitude, the U.S. Department of Energy projects that by 2035, the cost needs to fall from roughly $58 per ton with state-of-the-art water-based amines to $30 per ton.

Typically, water that contains amines is sprayed into the top of an exhaust tower. As the droplets fall through the gas, they sop up CO_2. At the bottom of the tower, the CO_2-rich liquid gets pumped into a separate vessel and heated to boil off the water. Then, applied pressure causes water vapor to condense, leaving a pure stream of CO_2 to be captured and stored. The condensed water is added back to the amines and piped to the tower for another round of CO_2 capture.

In 2009, David Heldebrant, a chemist at the Pacific Northwest National Laboratory (PNNL), sought a new approach: "The goal was to get away from the water," he says. Over the next decade, he and his team created a collection of liquid organic solvents, eventually settling on one containing CO_2-grabbing amine groups with no need for water or dissolved capture agents. Organic solvents can release CO_2 when heated but, unlike water, need not be boiled and recondensed, potentially saving energy.

It wasn't an instant success. Heldebrant's team found that when the solvent captured CO_2, carbon-rich solids precipitated out, making the liquid viscous and difficult to pump. A collaboration with a team led by Robert Perry, a chemist at GE Global Research, revealed that when the amines bound CO_2, hydrogen atoms on solvent molecules became attracted to neighboring molecules, tying them together. So, the researchers tweaked the structure of the solvent, creating a molecule called 2-EEMPA. When the new solvent bound CO_2, the hydrogen bonds were more likely to form within individual 2-EEMPA molecules, rather than between neighbors, they reported in November 2020 in *Energy & Environmental Science*.

Now, in the March issue of *International Journal of Greenhouse Gas Control*, the PNNL team, together with researchers at the Electric Power Research Institute and the engineering giant Fluor, have published a detailed analysis showing that a full-scale coal-fired power plant using 2-EEMPA would require 17% less energy than today's state of the art carbon-capture systems. That would drop the cost of CO_2 capture to $47 per ton, not including the cost of transporting and pumping the CO_2 underground. "It's a very promising solvent," says Marty Lail, a carbon capture chemist at RTI International. Next year, the PNNL team plans to test 2-EEMPA at a small 0.5 megawatt coal-fired carbon capture testbed in Alabama.

Other researchers have made progress with their own solvents. In 2014, Brennecke and colleagues developed an ionic liquid-based CO_2 absorbent that has been projected to capture carbon at about the same cost as 2-EEMPA. And Lail and his colleagues have devised their own low-cost, proprietary water-lean solvent, which they will begin testing at a power plant in Norway early next year. Organic capture solvents "have a real future," he says.

They could also get a boost from policymakers. The United States already offers companies a tax credit of $50 for each ton of CO_2 they capture and store underground. And last week, a bipartisan group in Congress introduced a bill that would provide $4.9 billion for carbon capture projects. Both environmentalists and fossil fuel backers support the legislation, a rare alignment in today's divided political landscape. ■

A cheaper cleanup

Organic solvents promise to capture carbon dioxide (CO_2) from fossil fuel-burning power plants more cheaply than the water-based capture systems of today. All CO_2 capture agents must be purified so they can be reused, but unlike water-based agents, organic solvents don't need to be boiled to release the CO_2.

1 CO_2-rich flue gas (●) from the power plant enters an absorber vessel.
2 Organic solvent absorbs CO_2 (●) and releases clean exhaust to the atmosphere (●).
3 Solvent rich in CO_2 is heated and piped to a high-pressure tank, where CO_2 (●) is released and piped away for storage.
4 Solvent with less CO_2 (●) is heated and piped to a low-pressure tank to remove the remaining CO_2.
5 Cleaned solvent (●) is returned to the absorber for reuse.

GRAPHIC: MICHAEL PERKINS/PACIFIC NORTHWEST NATIONAL LABORATORY, ADAPTED BY N. CARY/SCIENCE

PNNL's Yuan Jiang, et al, International Journal of Greenhouse Gas Control, March 2021

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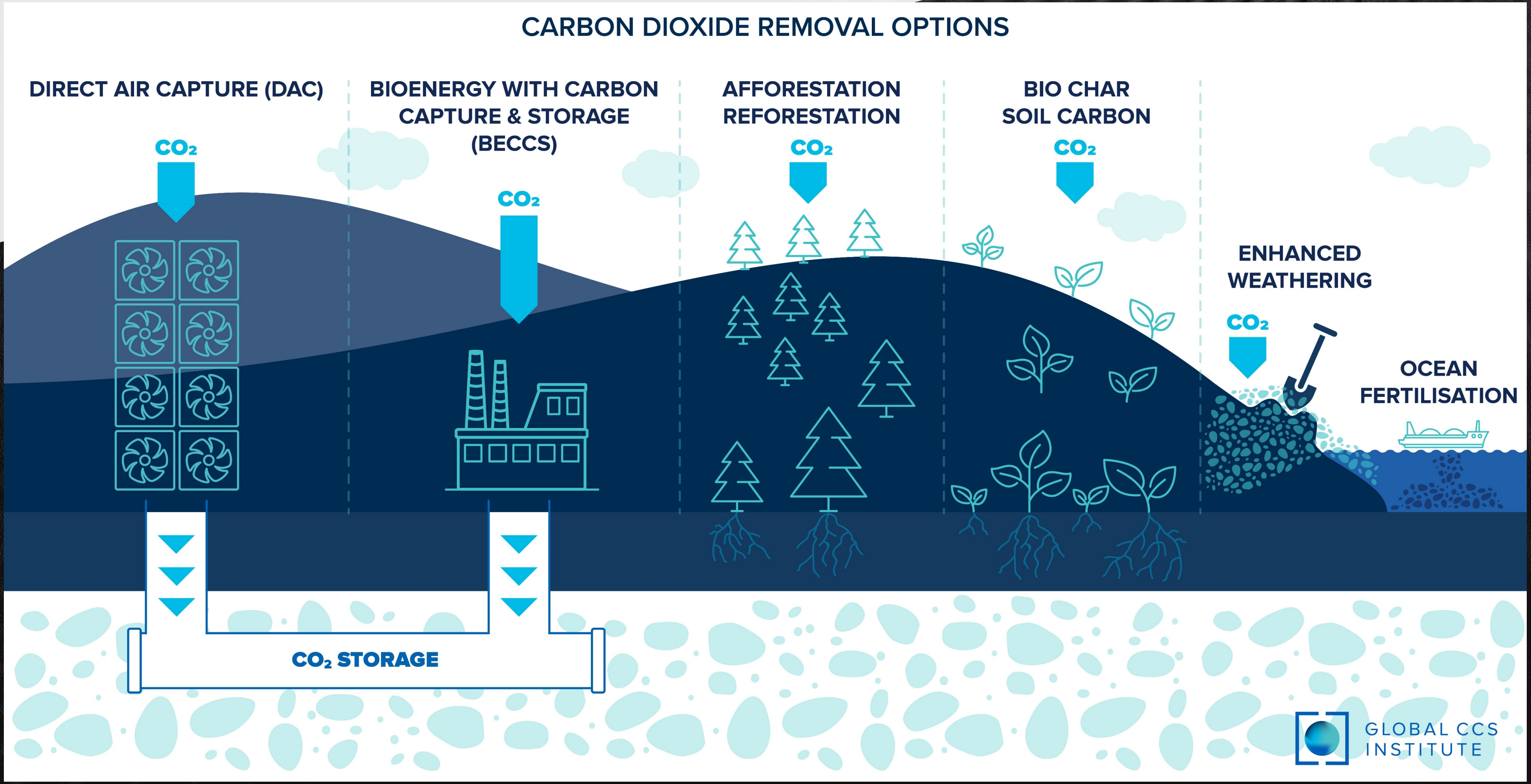
Getting to global net zero will require some amount of CO_2 removal



Credit: Global CCS Institute

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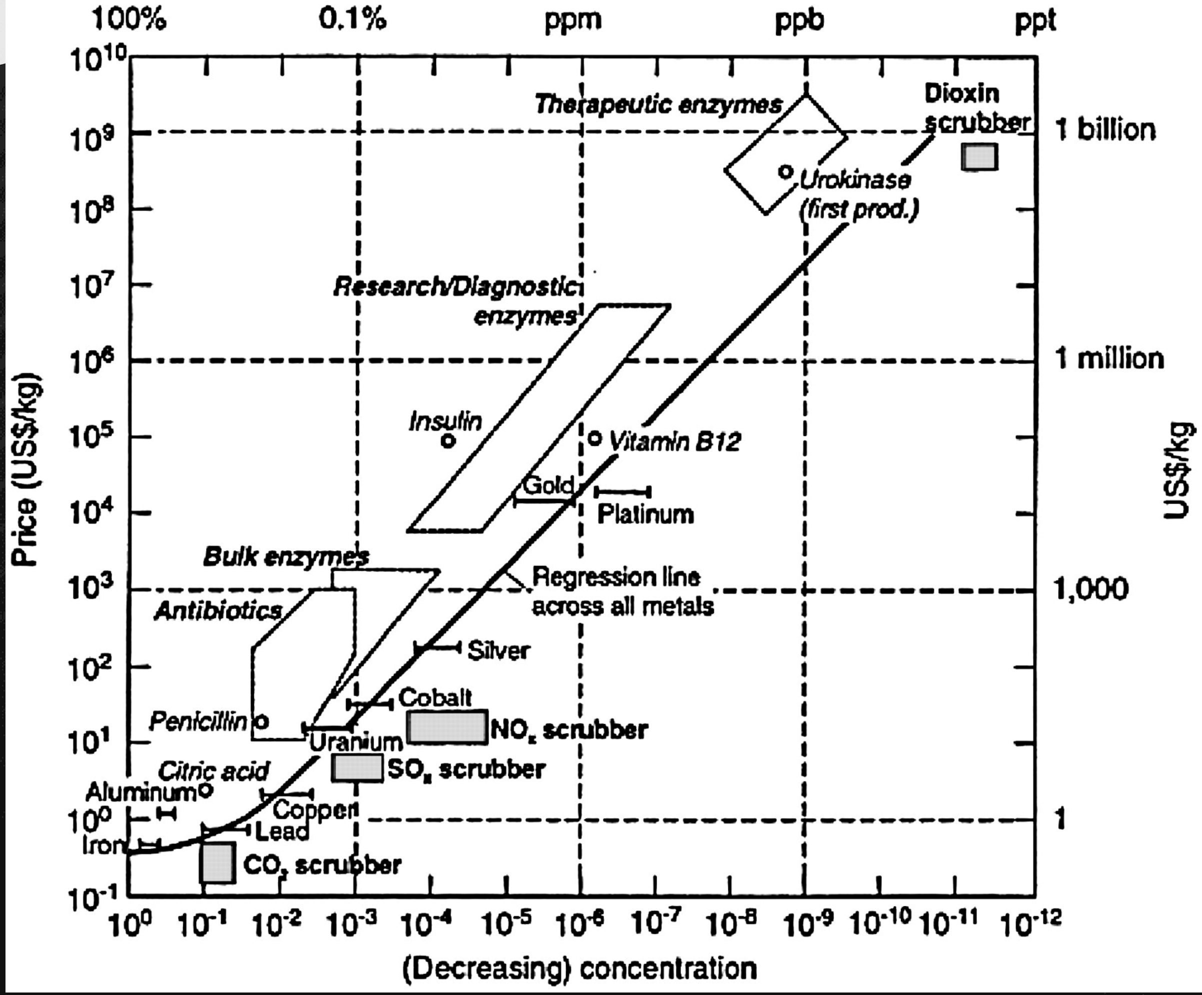
Compared to DAC, capturing CO_2 point source emissions is a bargain

Thomas K. Sherwood

Photo: University of Waterloo



after TK Sherwood, 1959

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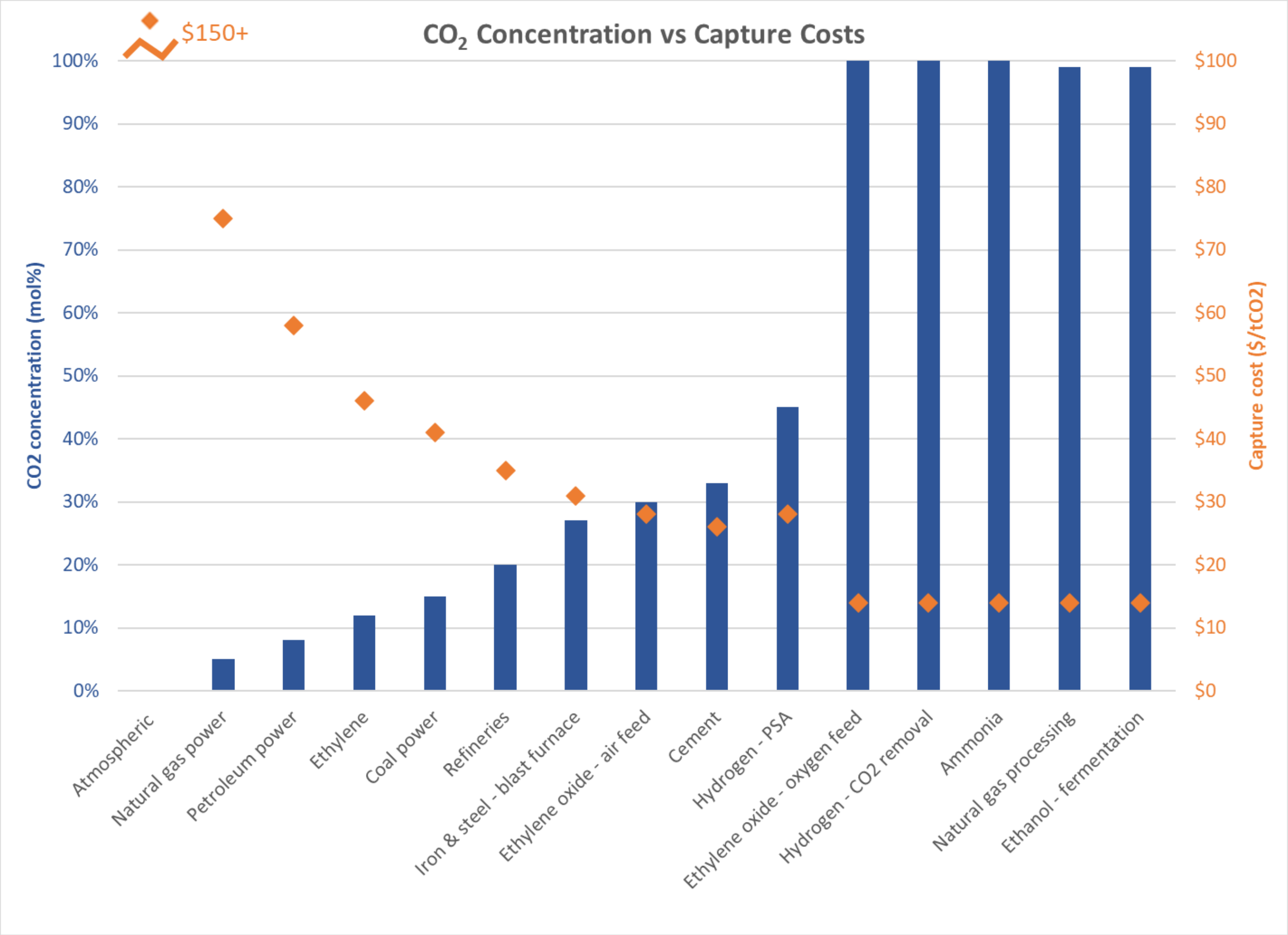
Compared to DAC, capturing CO_2 point source emissions is a bargain



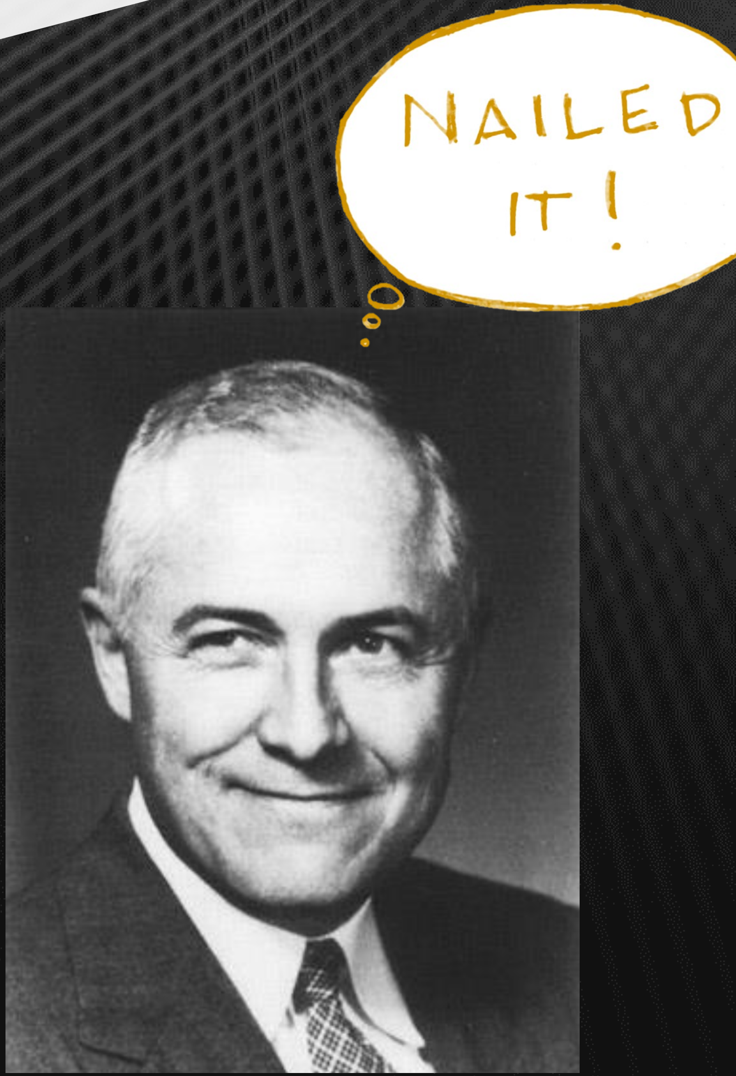


Photo: National Academy of Engineering

Data from Bains, Psarras & Wilcox. 2017. "CO2 Capture from the industry sector." *Prog Energy Combustion Science.* http://dx.doi.org/10.1016/j.pecs.2017.07.001

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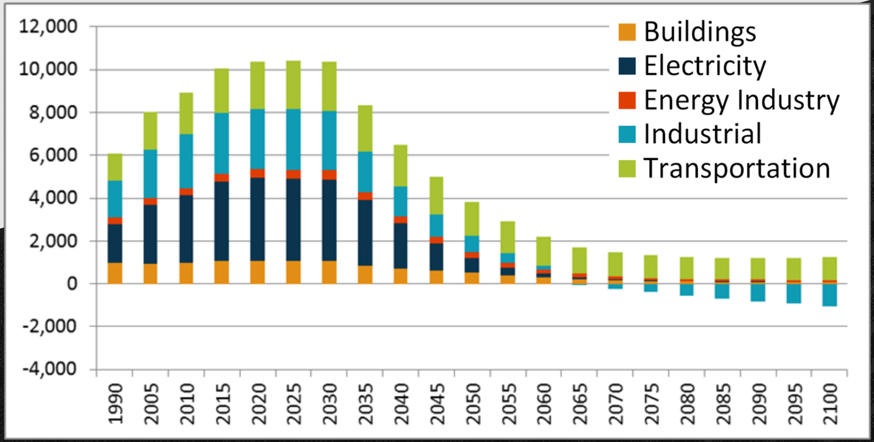
Meeting climate targets requires an “all of the above” approach

P2A-X



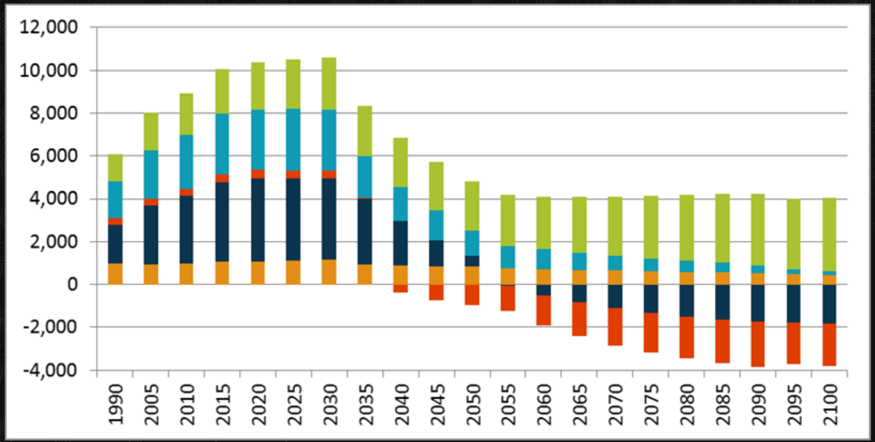
Without CCS

- Nuclear and renewable electricity become the cheapest mitigation options
- Most sectors reduce direct fuel use and switch to electricity
- Negative emissions options costly and limited, but required to offset irreducible emissions in the industry and transport sectors

Generation in 2100: 450 EJ/y

- Nuclear, 37%
- Wind, 28%
- Solar, 28%
- Biomass, 0%
- Gas, 0%
- Coal, 0%

P2A-CCS



from Davidson et al., *EgyPro* 2017

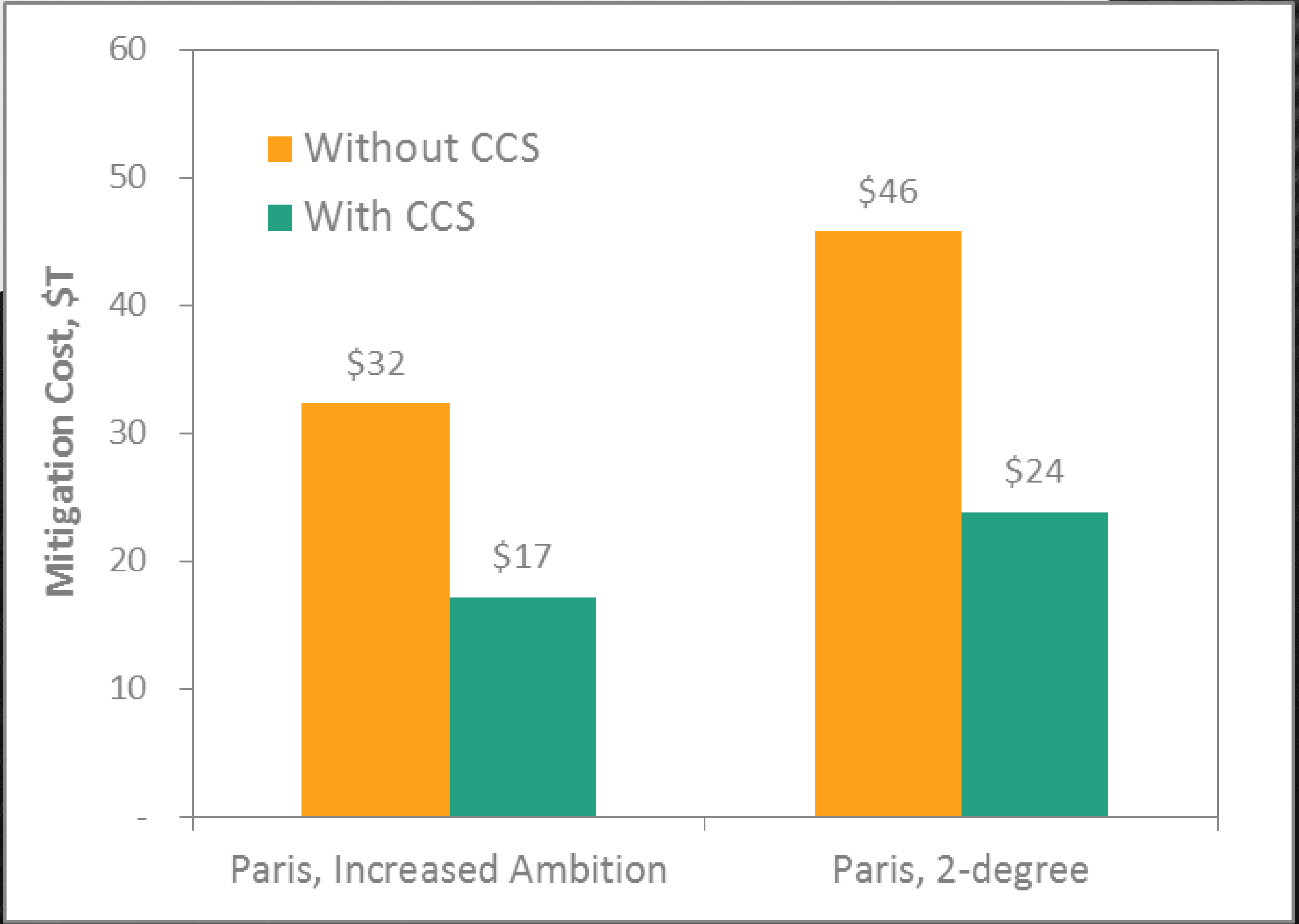
With CCS

- CCS-enabled fossil power and negative emissions from both bio-CCS generation and biofuels moderate transitions in buildings, industry, transport sectors

Generation in 2100: 390 EJ/y

- Nuclear, 21%
- Wind, 18%
- Solar, 17%
- Biomass, 10% (all with CCS)
- Gas, 16% (all with CCS)
- Coal, 9% (all with CCS)

The global cost of meeting Paris targets is halved by the availability of CCS



from CL Davidson et al. 2017. "The Value of CCS under Current Policy Scenarios: NDCs and Beyond." *EgyPro* 114:7521-27. https://doi.org/10.1016/j.egypro.2017.03.1885

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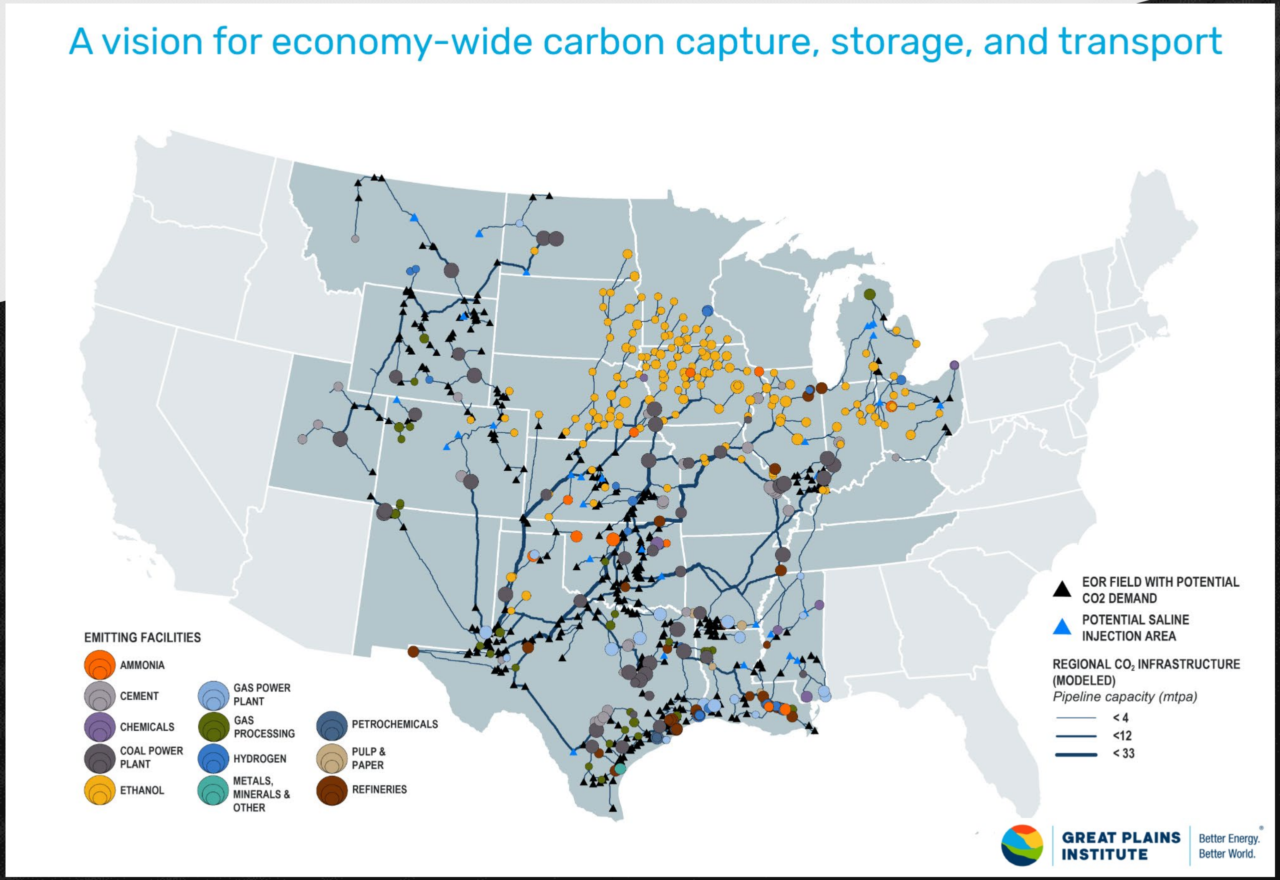
CO_2 CAPTURE AND GEOLOGIC STORAGE

Market-pull tech drivers



Graphic courtesy Great Plains Institute

45Q FEDERAL TAX CREDIT

[$35 to $50 per ton of CO_2]

STATE ENERGY STANDARDS

[renewable gas, hydrogen, low-carbon energy]

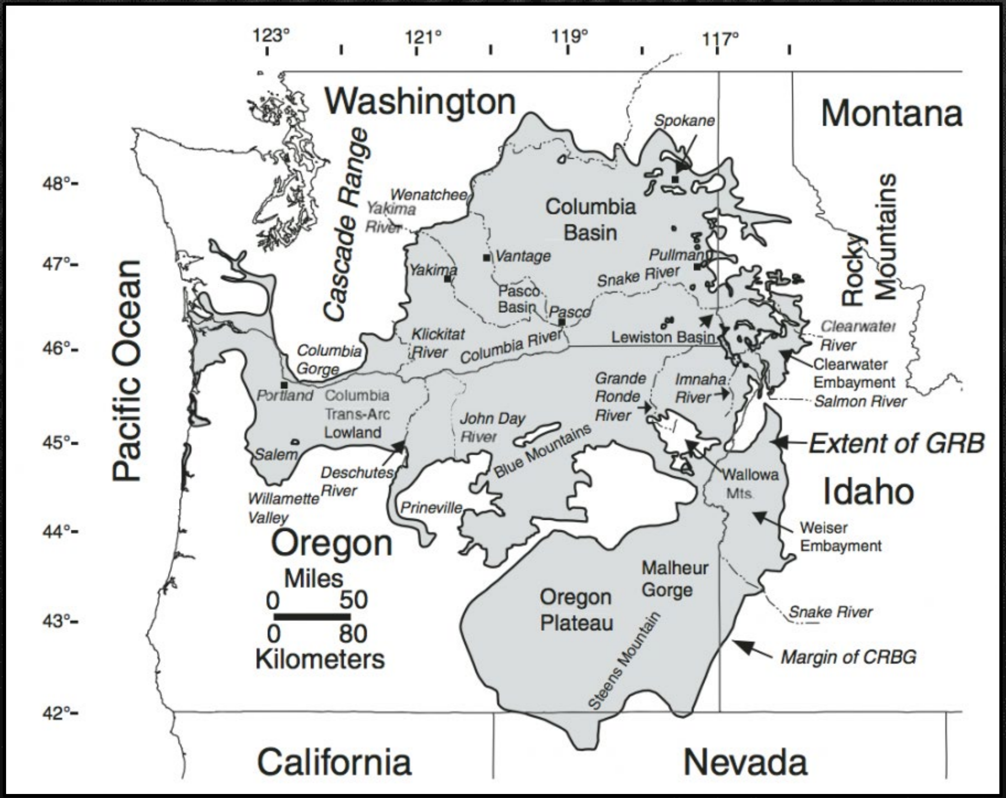
CLIMATE AWARE INVESTMENT

[risk mitigation, diversification, innovation]

REGIONAL CHALLENGES

[basalts needed to meet regional demand for these projects]

CO_2 storage resources can help attract regional cleantech projects



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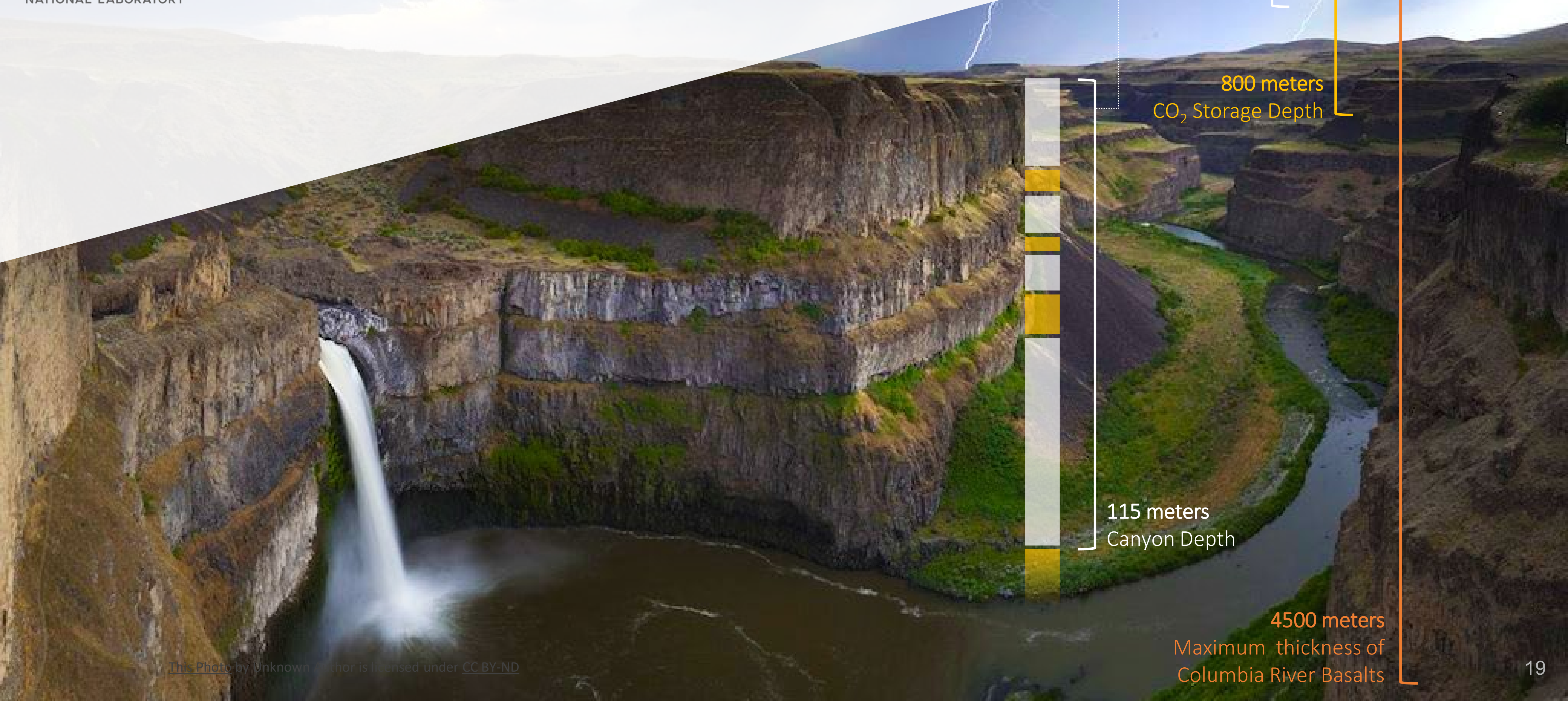
FLOOD BASALTS OFFER ACCELERATED MINERALIZATION FOR CO_2 STORAGE

How CO_2 injection and storage in basalts works

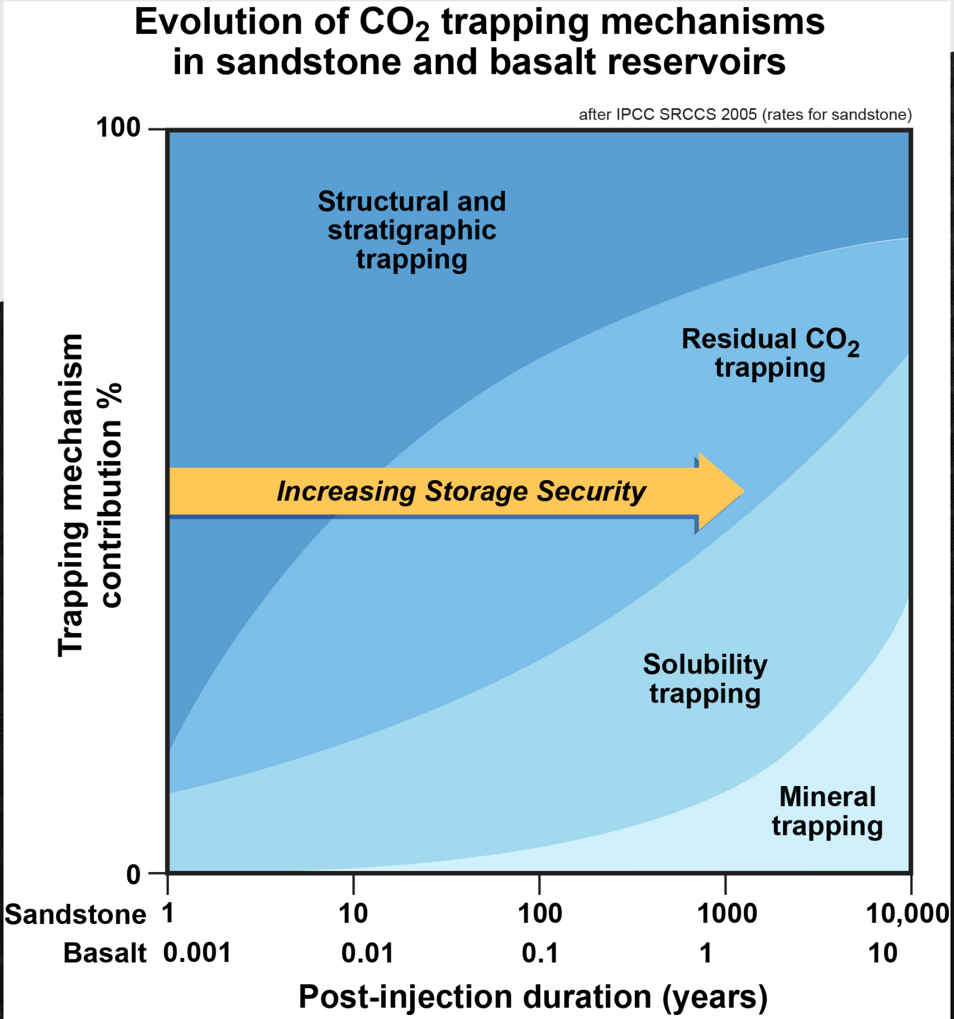
FLOOD BASALTS OFFER ACCELERATED MINERALIZATION FOR CO_2 STORAGE

Testing CO_2 injection at Wallula



Testing CO_2 injection at Wallula

Derisking rapid mineralization in basalt reservoirs



Basalts **convert CO_2 to solid minerals** much more rapidly than other rock types. Mineralized CO_2 is immobile and poses **no risk of leakage**.

Industry needs regulatory and technical support for **Class VI** permits that account for these risk reductions.

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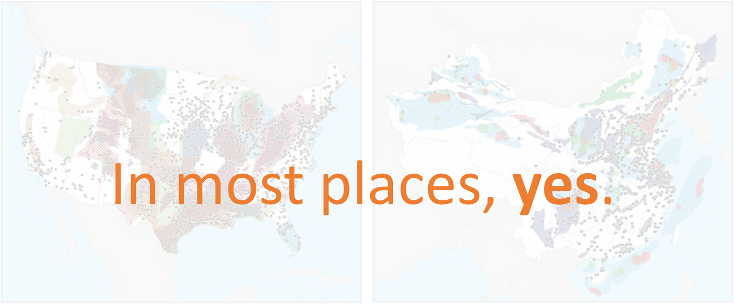
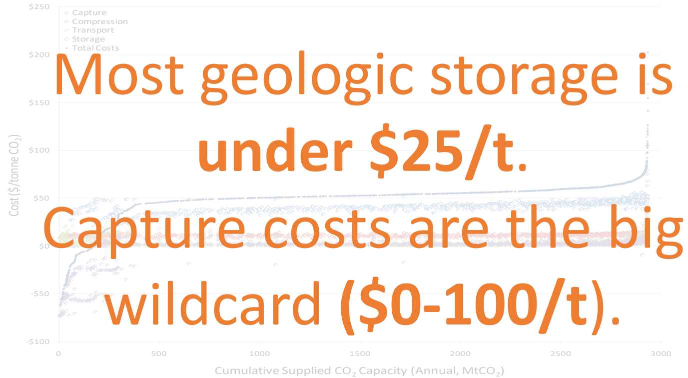
PNNL has helped address the old unknowns of CCS

Is there enough **storage capacity**?



In most places, **yes**.

How much could CCS **cost** globally?



Most geologic storage is **under $25/t**.

Capture costs are the big wildcard **($0-100/t)**.

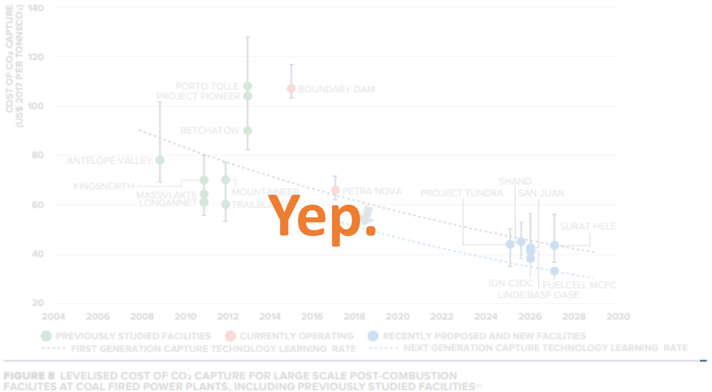
How do we **permit and verify** storage?

New regulatory standards adopted as UIC **Class VI** (SDWA).

Does capacity fit **potential demand**?

Across the U.S., **85%** of stationary CO_2 sources overlie potential storage.

Can R&D **reduce capture costs**?

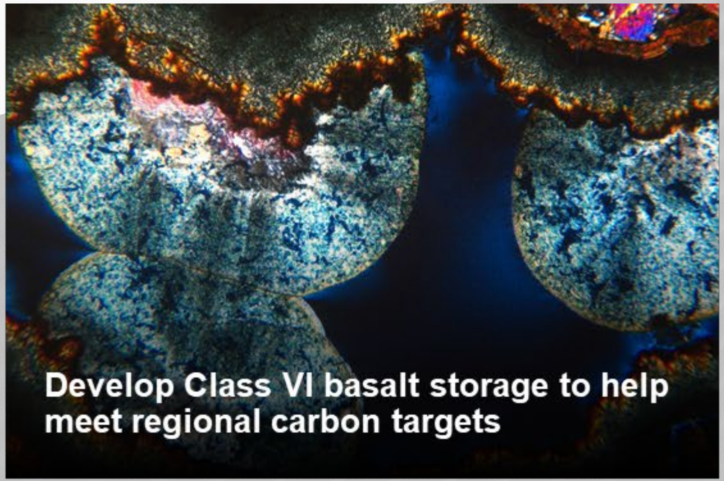


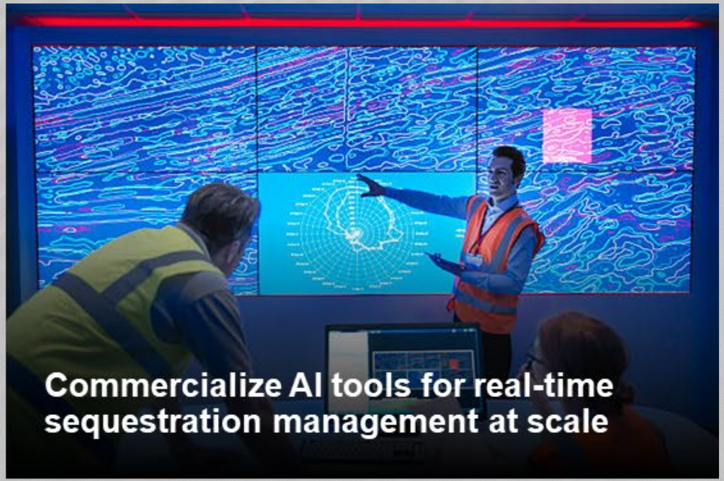
Yep.

Will it work in **diverse settings**?

It will.

CO_2RUS: Focusing on transformational outcomes





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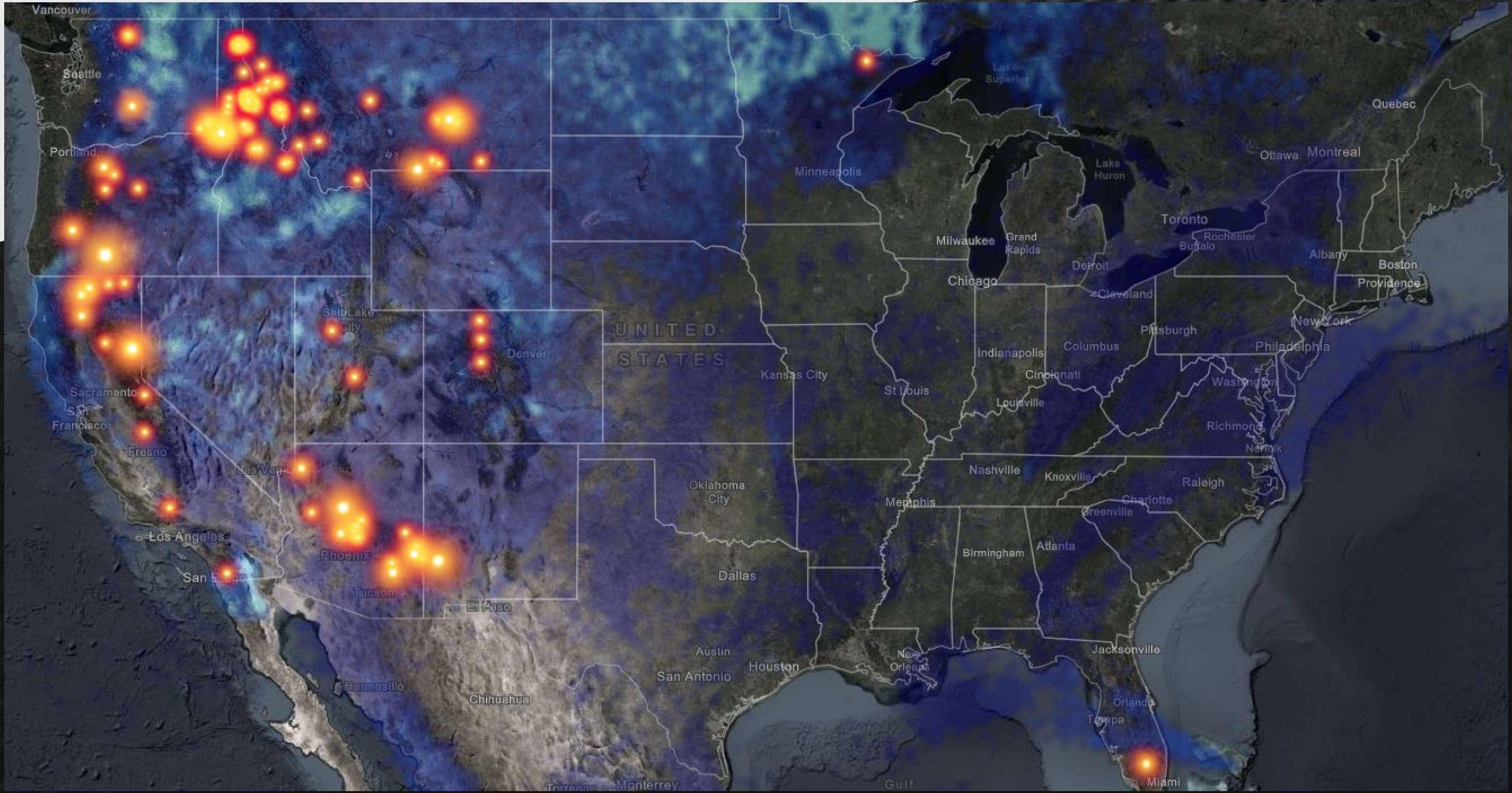
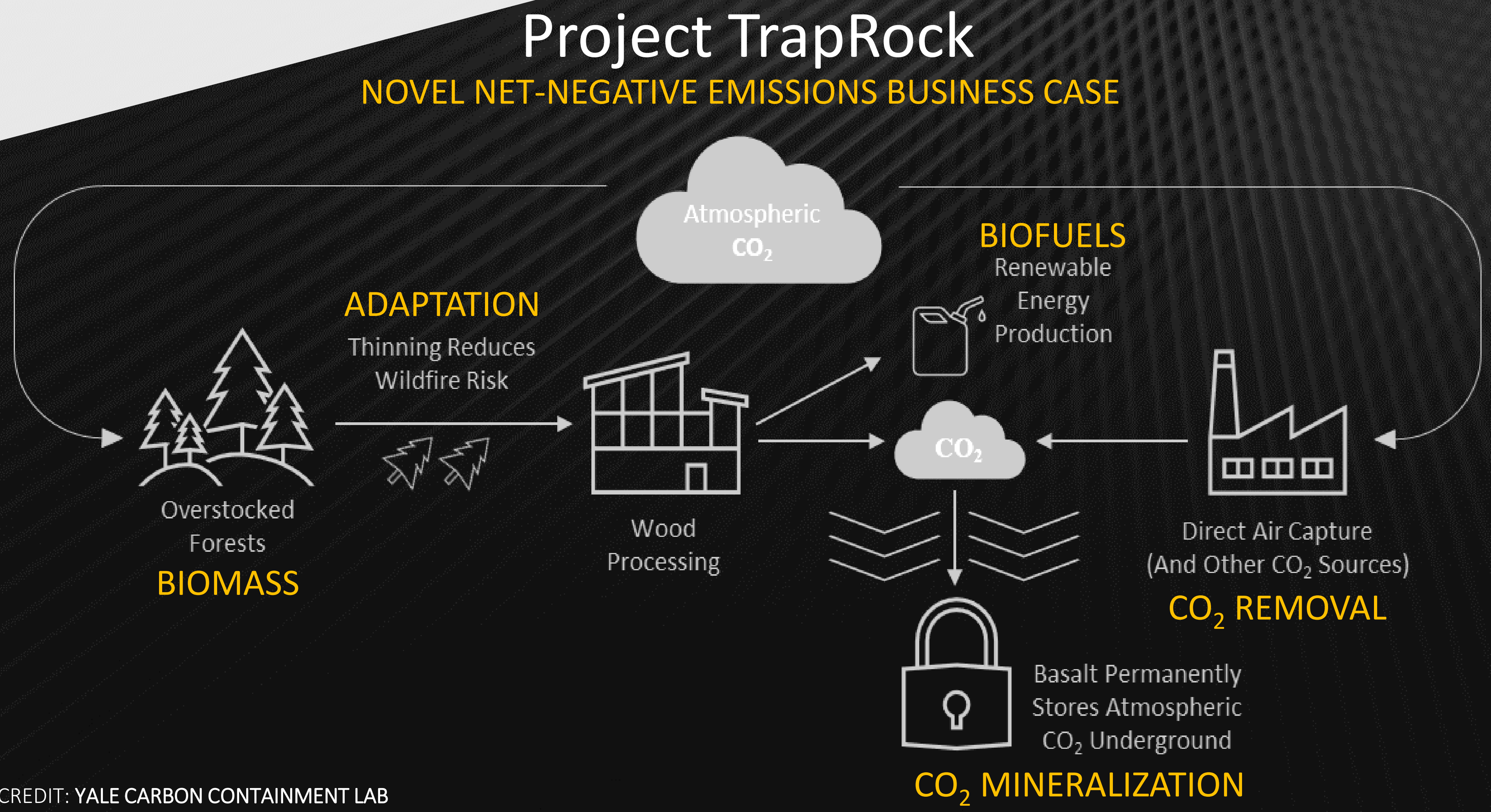
Collaborating to bring tech innovation to integrated business cases



Live wildfire map, July 2021. Source: ESRI

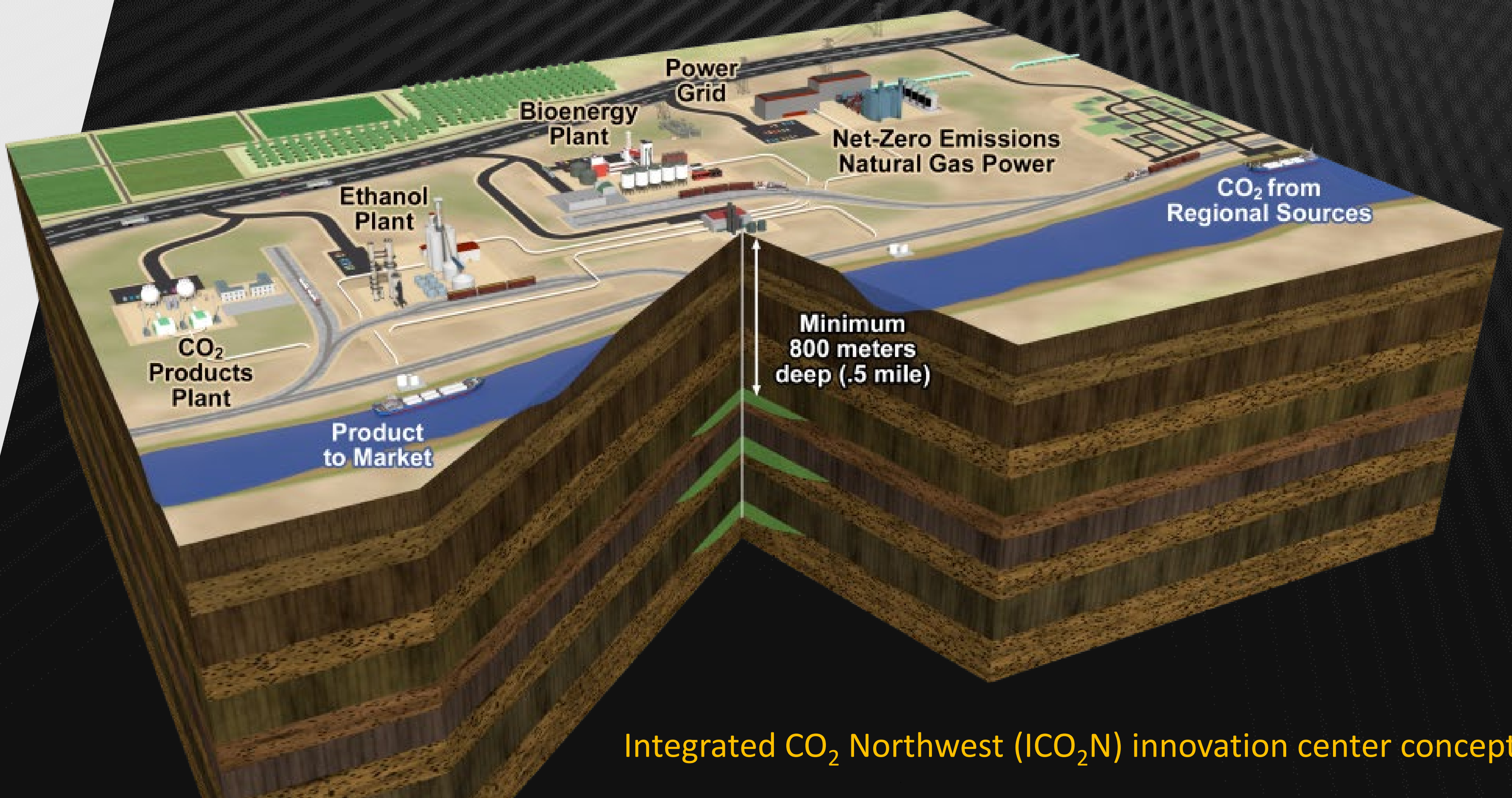
Creative integration offers unique regional business cases and value



CREDIT: YALE CARBON CONTAINMENT LAB

MOVING BEYOND NET-ZERO

Envisioning a net-negative future for the Pacific Northwest



Integrated CO_2 Northwest (ICO_2N) innovation center concept

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Casie Davidson
e: casie.davidson@pnnl.gov
o: 509/372-6259
m: 509/308-8522