The Future of Geophysics for CCUS

David Alumbaugh
Staff Scientist and Carbon Storage Program Lead, LBNL

Preston Jordan and Julia Correa, *LBNL*

Brigitte Petras, *Battelle*

Bill Abriel, Orinda Geophysical

BERKELEY LAB

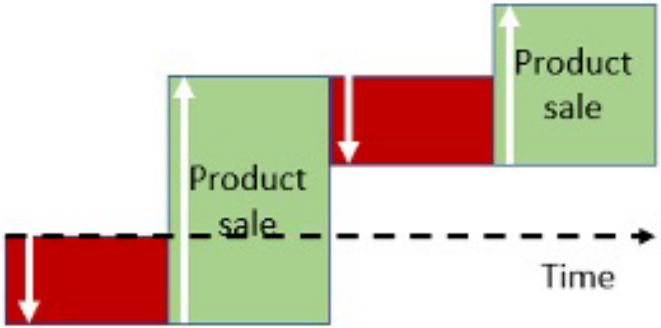
NATIONAL ENERGY TECHNOLOGY LABORATORY

BATTELLE

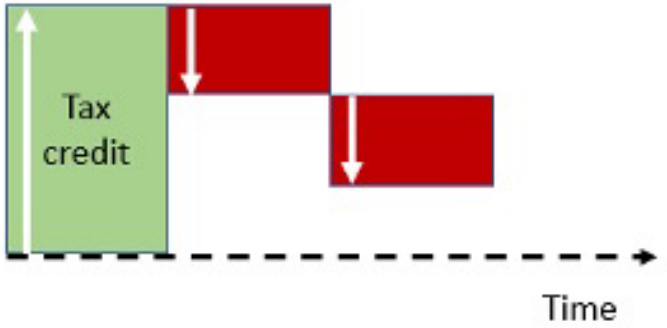
U.S. DEPARTMENT OF ENERGY

Investment: Producers versus Regulators Market

Producers market (e.g. mining)



Regulators market (e.g. CO2)



	45Q Tax Credit Amounts in 2018 FUTURE Act	New 45Q credits in IRA: **Industry & Power**	New 45Q credits in IRA: **Direct Air Capture**
For dedicated secure geologic storage of CO_2 in **saline or other geologic formations**	$50 per ton	$85 per ton	$180 per ton
For **carbon utilization projects** to convert CO or CO_2 into useful products (e.g., fuels, chemicals, products)	$35 per ton	$60 per ton	$130 per ton
For secure geologic storage of CO_2 in **oil and gas fields** through enhanced oil recovery	$35 per ton	$60 per ton	$130 per ton

BERKELEY LAB

NATIONAL ENERGY TECHNOLOGY LABORATORY

Class VI EPA Relevant Requirements

- Prepare, maintain, and comply with an AoR and Corrective Action Plan that includes all of the required elements of the plan [40 CFR 146.84(b)];
- Delineate the AoR using computational modeling and identify all wells that require corrective action [40 CFR 146.84(c)];
- Reevaluate the AoR throughout the life of the project [40 CFR 146.84(e)];
- AoR must be reevaluated at a minimum fixed frequency not to exceed five years, or when monitoring and operational conditions warrant [40 CFR 146.84(e)].
- Retain modeling inputs and data used to support AoR reevaluations for 10 years [40 CFR 146.84(g)].
- The suite of methodologies used will be site specific and vary based on project details, but it must include at least one direct method [40 CFR 146.90(g)(1)] and an indirect method, unless the UIC Program Director determines indirect methods are not applicable [40 CFR 146.90(g)(2)].

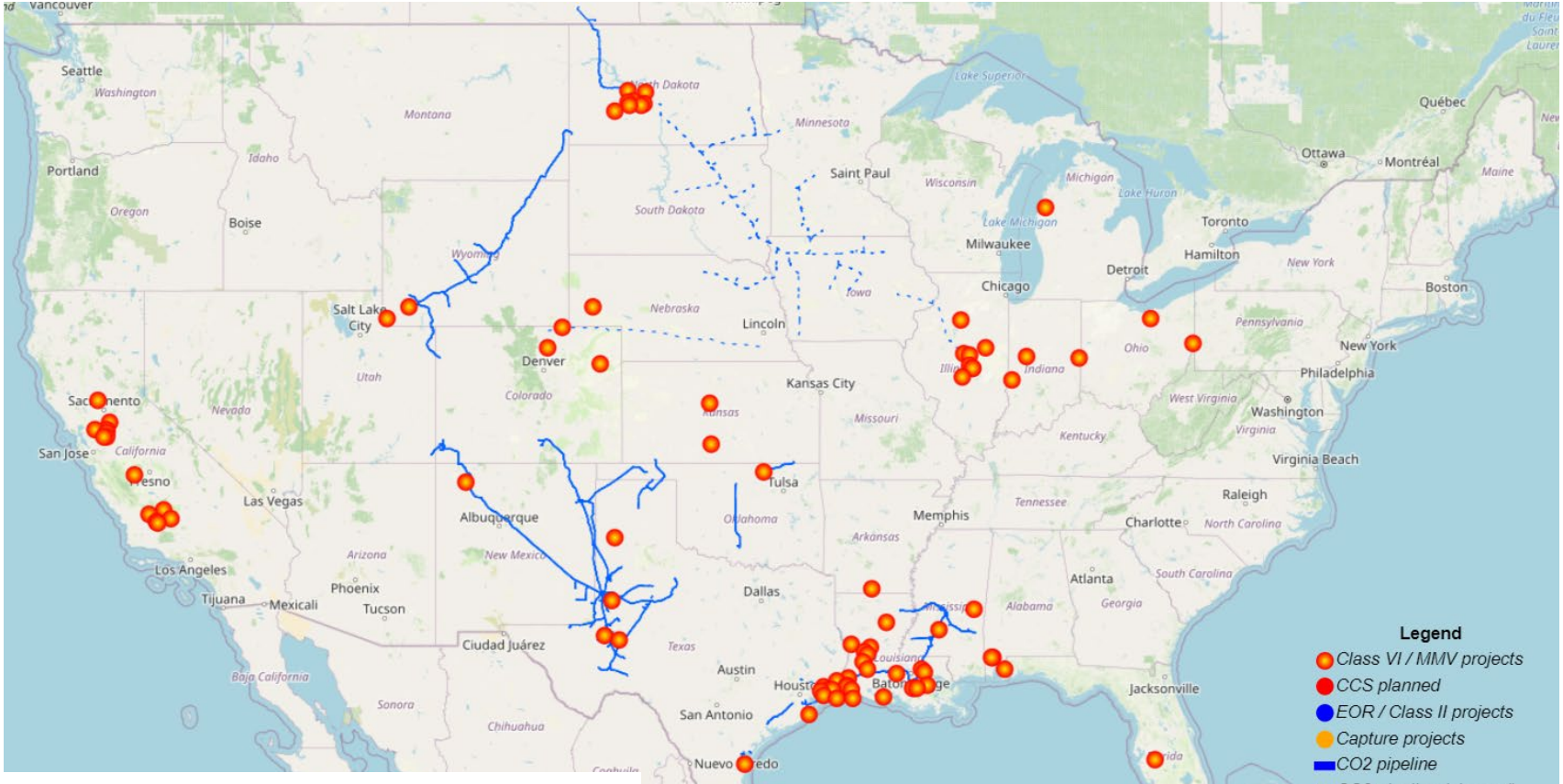
https://www.epa.gov/sites/default/files/2015-07/documents/epa816r13001.pdf

Class VI EPA Monitoring Requirements

Technology	Description	Class VI Rule	
		Requirement	Citation
Direct pressure monitoring	Measurement of in situ fluid pressure that may be achieved using transducers placed within monitoring wells in the injection zone, behind casing gauges, or through direct measurement of fluid depth through a perforation (see Section 5.2)	Required to track the presence or absence of elevated pressure within the injection zone	40 CFR 146.90(g)(1)
Indirect geophysical monitoring	Seismic, electrical, gravity, or electromagnetic techniques (see Section 5.3)	Required to track the presence or absence of elevated pressure within the injection zone and the extent of the carbon dioxide plume, unless the UIC Program Director determines that such methods are not appropriate	40 CFR 146.90(g)(2)
Direct carbon dioxide plume monitoring	Use of monitoring wells in the injection zone to substantiate the presence or absence of carbon dioxide by geochemical methods (see Section 5.4)	Required to track the extent of the carbon dioxide plume if the UIC Program Director determines that indirect methods are not appropriate	40 CFR 146.90(g)(1)
Computational modeling	Informing the development of field monitoring strategies and incorporation of measured data into a comprehensive mathematical model of the site	Computational modeling is required as a component of AoR delineation and reevaluation	40 CFR 146.84

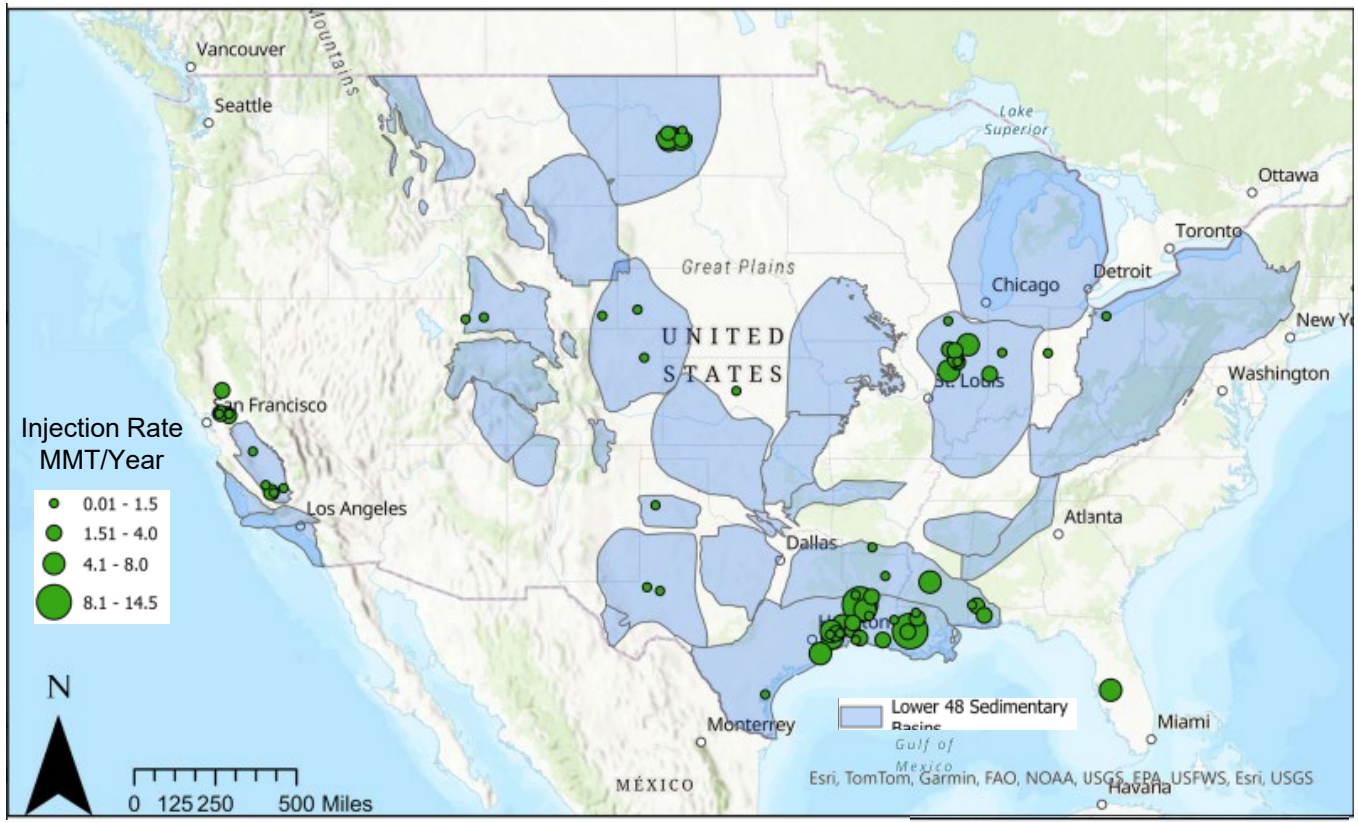
https://www.epa.gov/sites/default/files/2015-07/documents/epa816r13001.pdf

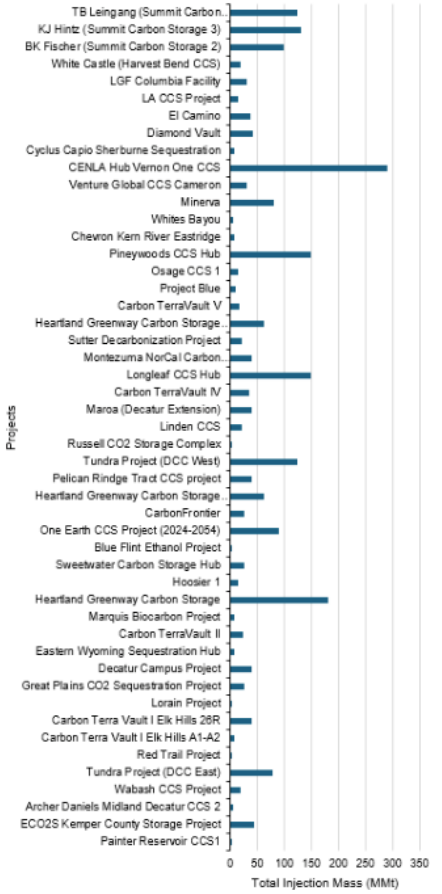
Class VI – Projects with Permits and Applications



https://ccusmap.com/markers/map/

Class VI – Permits and Permit Applications – Size of Projects

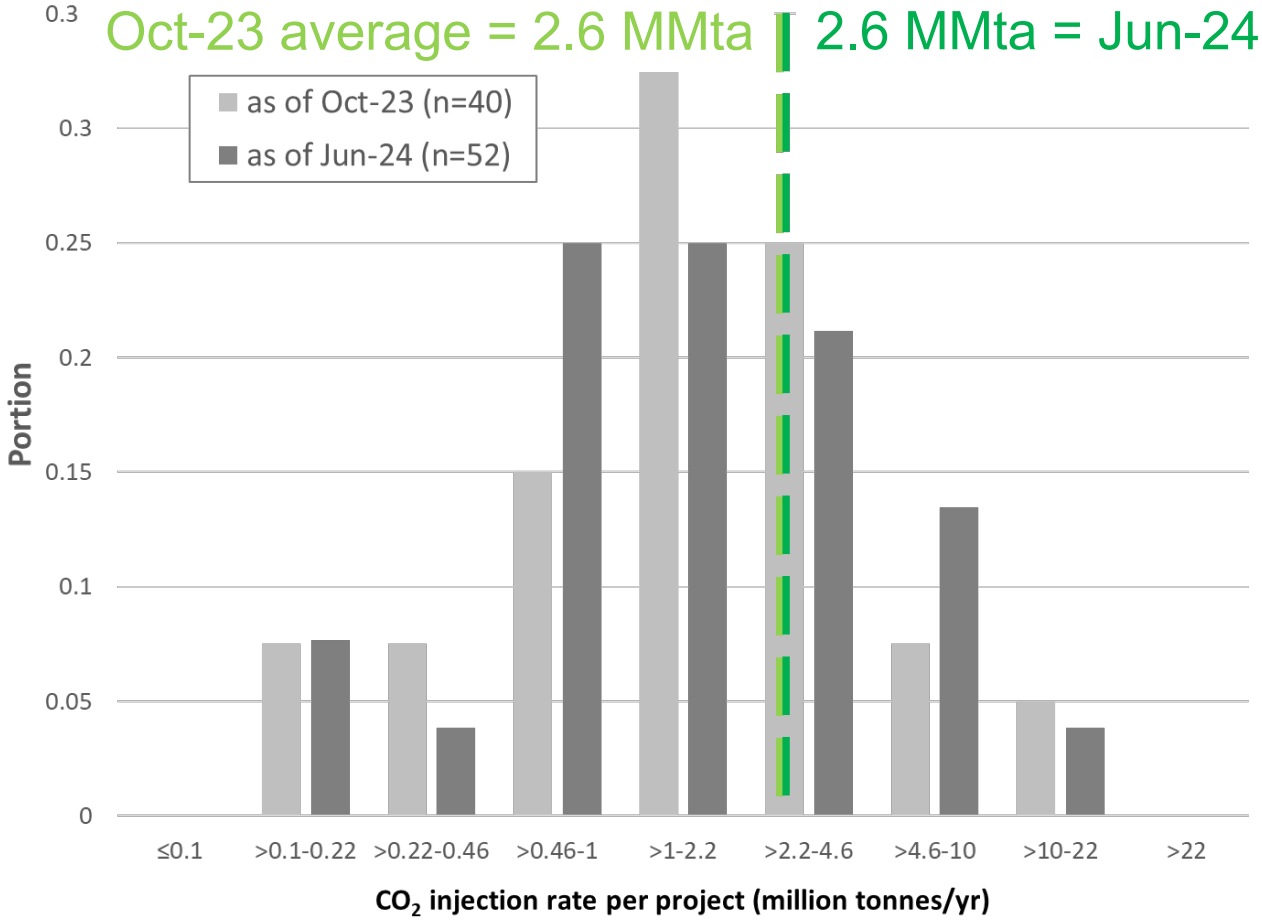




Created by: Jaelen Lewis Subsurface scientist/engineer

BATTELLE

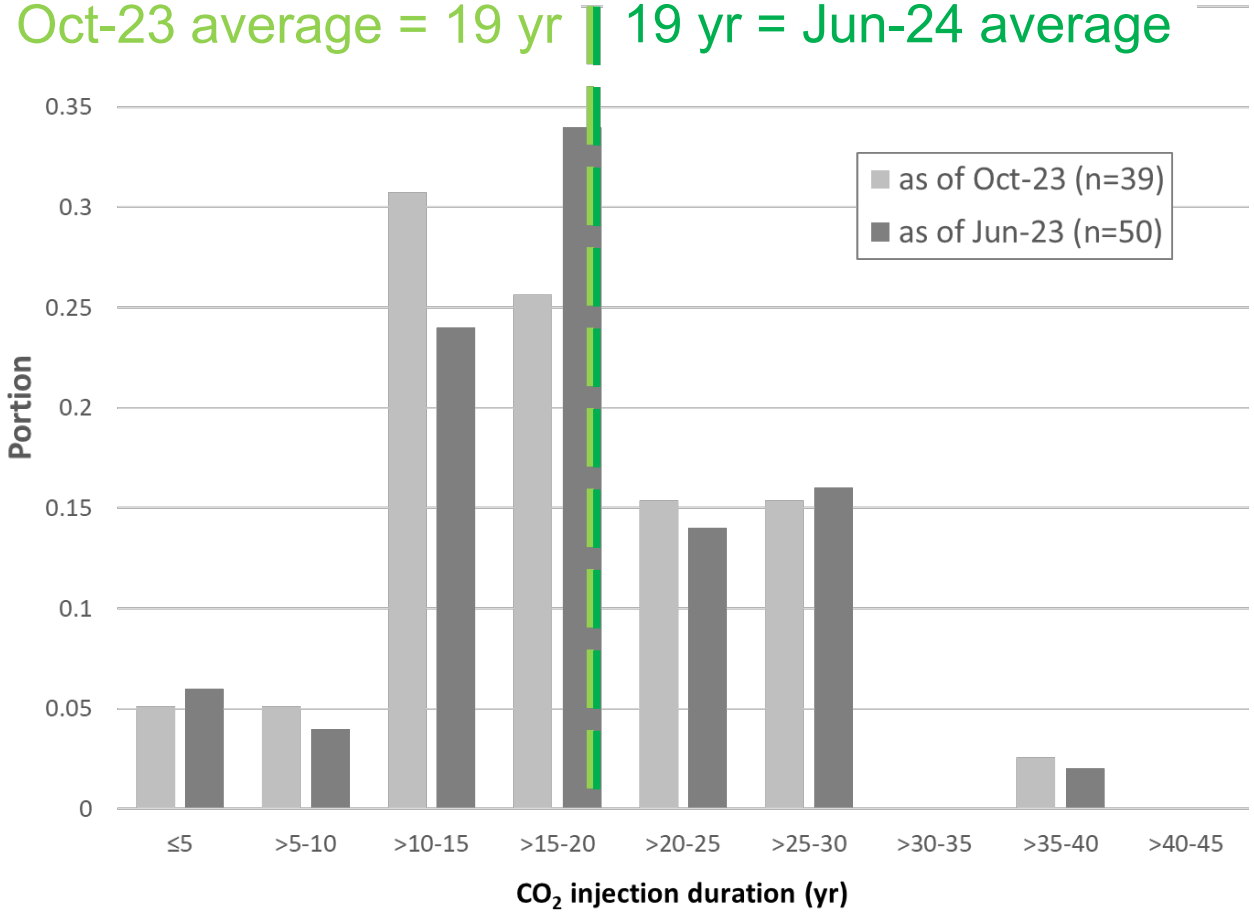
CO_2 Injection Rate Per Project



Average and median remain the same

Distribution is log normal

CO_2 Injection Duration Per Project



Average and median remain the same

Distribution of project injection durations normal

Distribution becomes less skewed (more normal)

GCS Projects/Injection Wells Forecast By NETL Supply Chain Study

Carbon Capture, Transport, & Storage

Supply Chain Deep Dive Assessment

U.S. Department of Energy Response to Executive Order 14017, "America's Supply Chains"

February 24, 2022

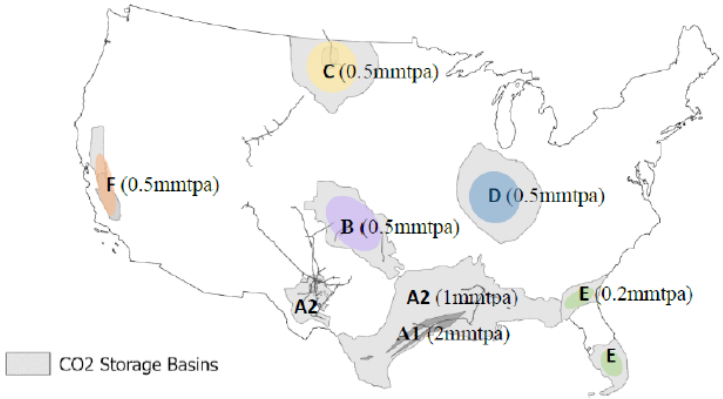


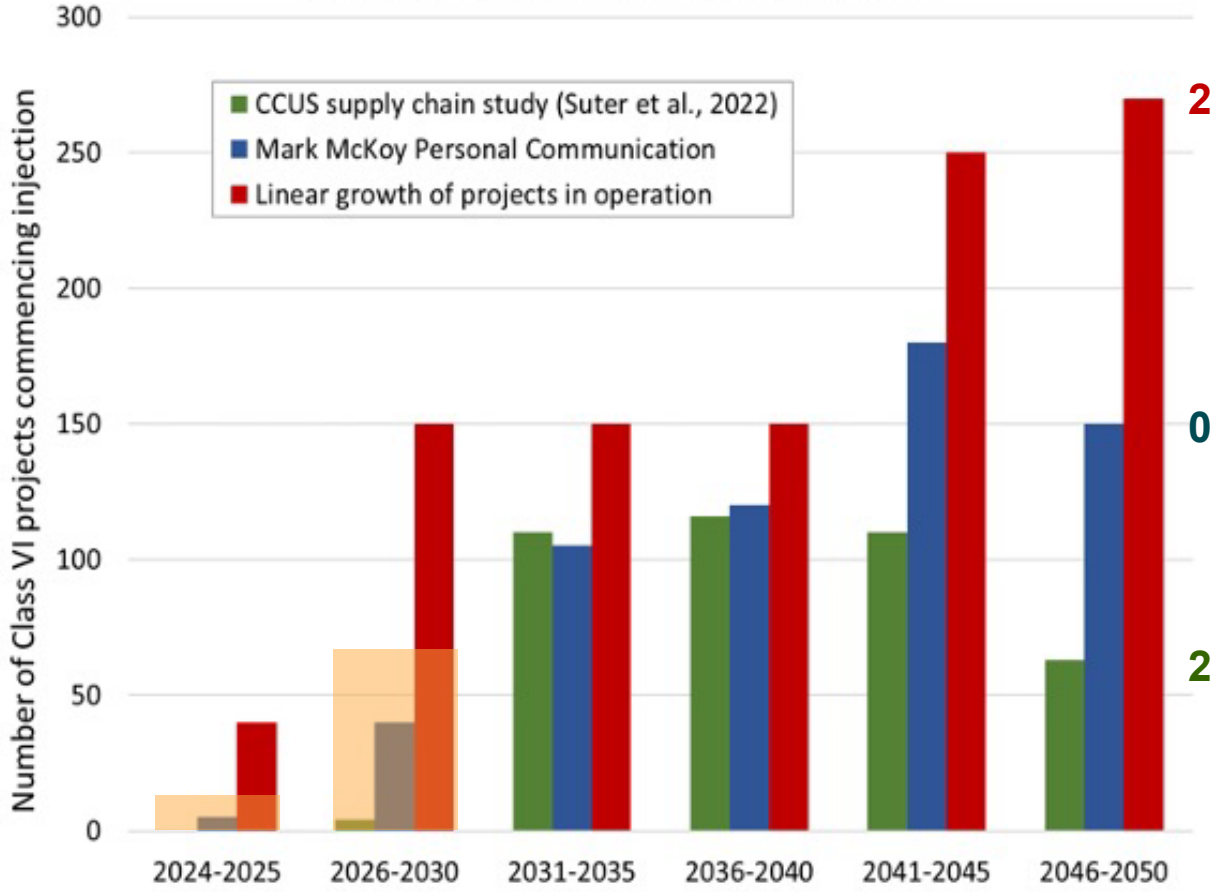
Figure 30: Map of NZA (and NETL analysis) basins for CO_2 storage, and per basin injection well mass flow rates

Note: mmtpa = million metric tons per annum, or Mtpa

Table 26: Storage project and injection well count, by basin (NETL-NZA Model)

Basin	Injection Rate (Mtpa/well)	CO_2 storage capacity potential (Mtpa)	NETL-NZA Model			
			CO_2 Storage capacity used in 2050 (Mtpa)	Injection well count per storage project*	Total Storage Projects Deployed by 2050 (count)	Total injection well count in 2050
A1_Gulf shore	2.0	500	343	4	69	276
A2_Gulf shore	1.0	1700	1153	6	231	1386
B_Midcon	0.5	80	49	11	10	110
C_Williston	0.5	240	159	11	32	352
D_Illinois	0.5	220	147	11	30	330
E_Florida	0.2	60	37	26	8	208
F_California	0.5	200	112	12	23	276
TOTALS			**2000**	**-**	**403**	**2938**

Forecast Number of GCS Project Starts With Time



2 Gta in 2050

0.7-1.9 Gta in 2050

2 Gta in 2050

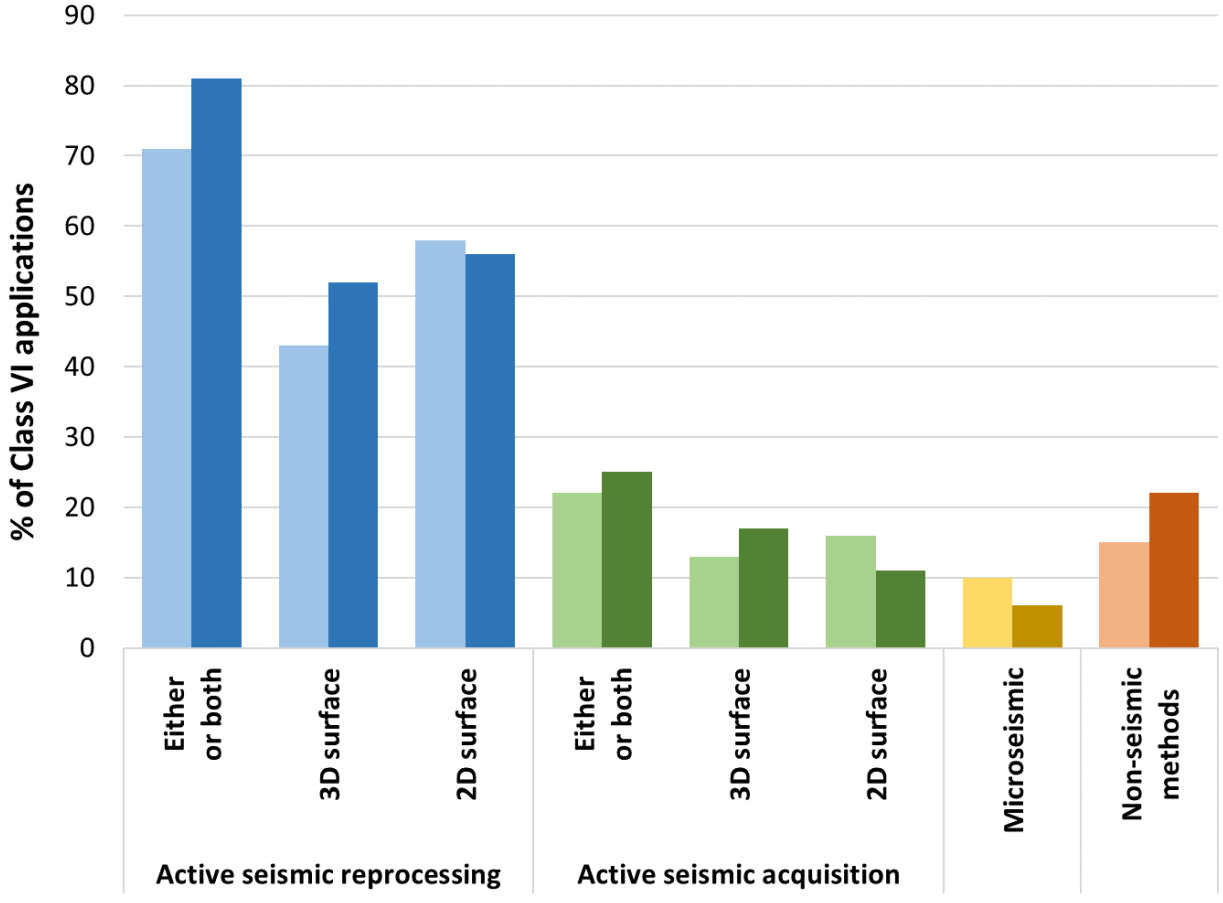
As of the end of June 2024 - Class VI active/in process

4	Operating/permit to inject
4	Permit to construct
1	Permit finalization
4	Public comment
57	Technical review
10	Completeness review
80	Total

Growth / Operational Uncertainties in Current Form of 45Q Tax Credits

- Current eligibility only for projects that start construction before January 1, 2033
- Tax credits only for 12 years

Geophysical Methods for Site Characterization

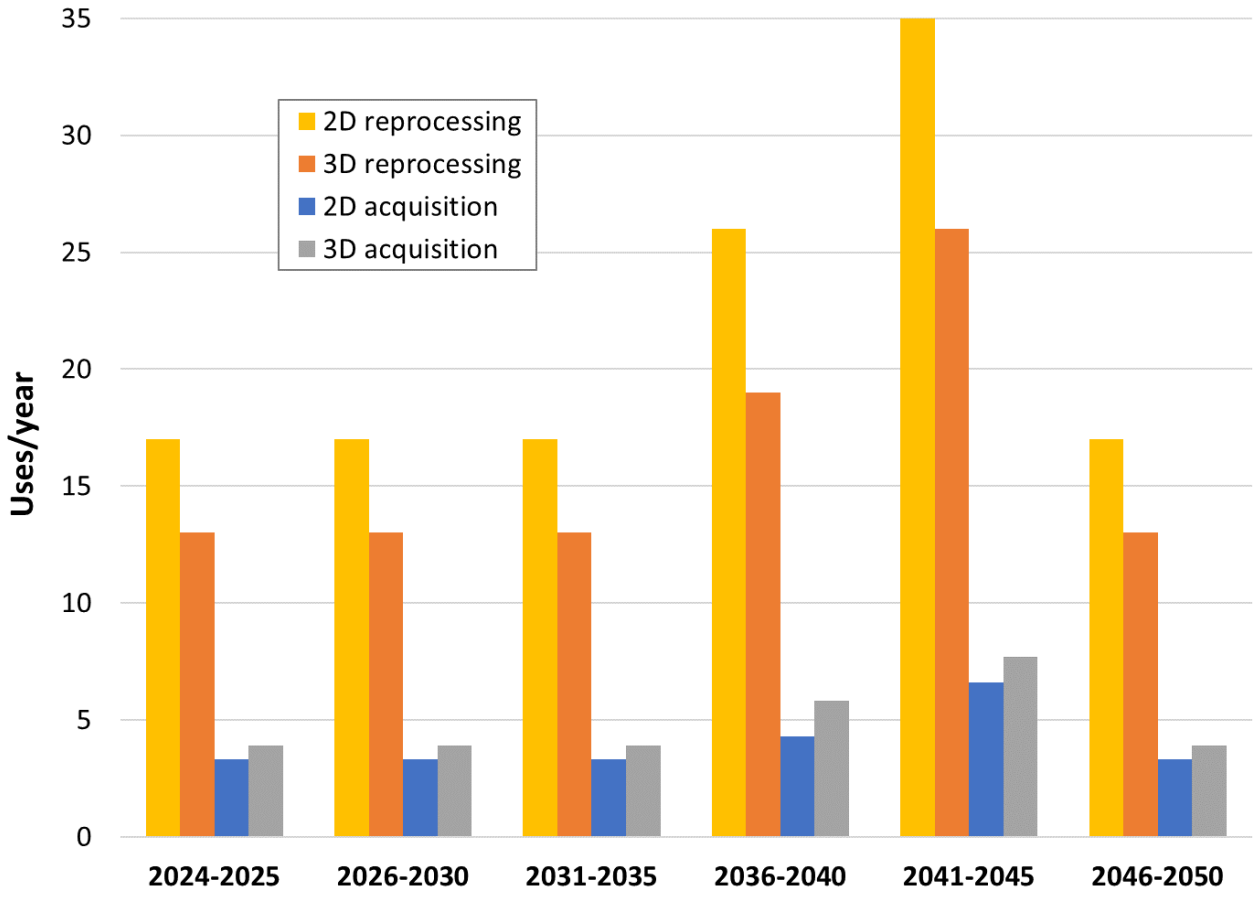


Share of projects using seismic increases

2D – Slightly less use of legacy and collection of new

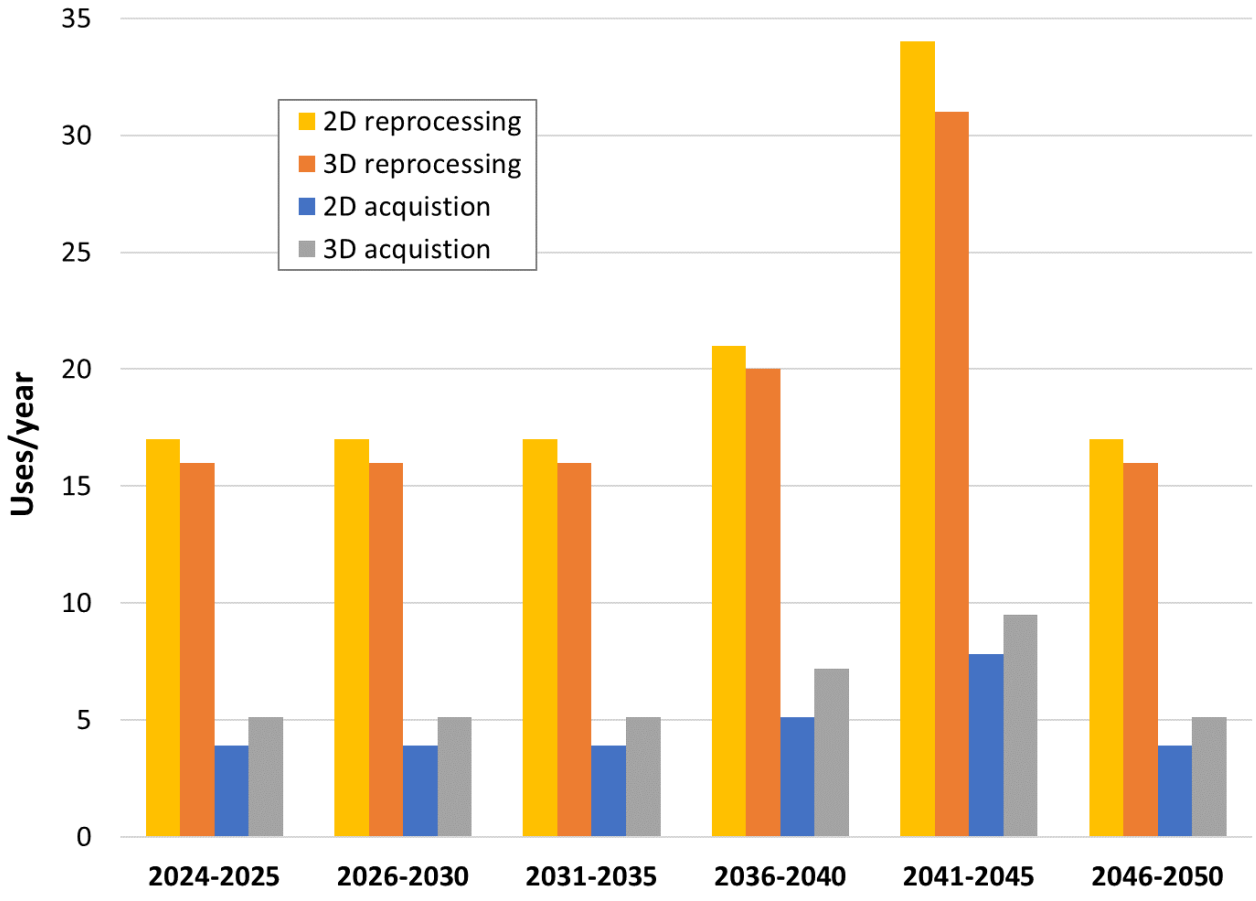
3D – more use of legacy and collection of new

Forecast of Seismic Reprocessing/Survey for Characterization



As of Oct-23 (n=38)

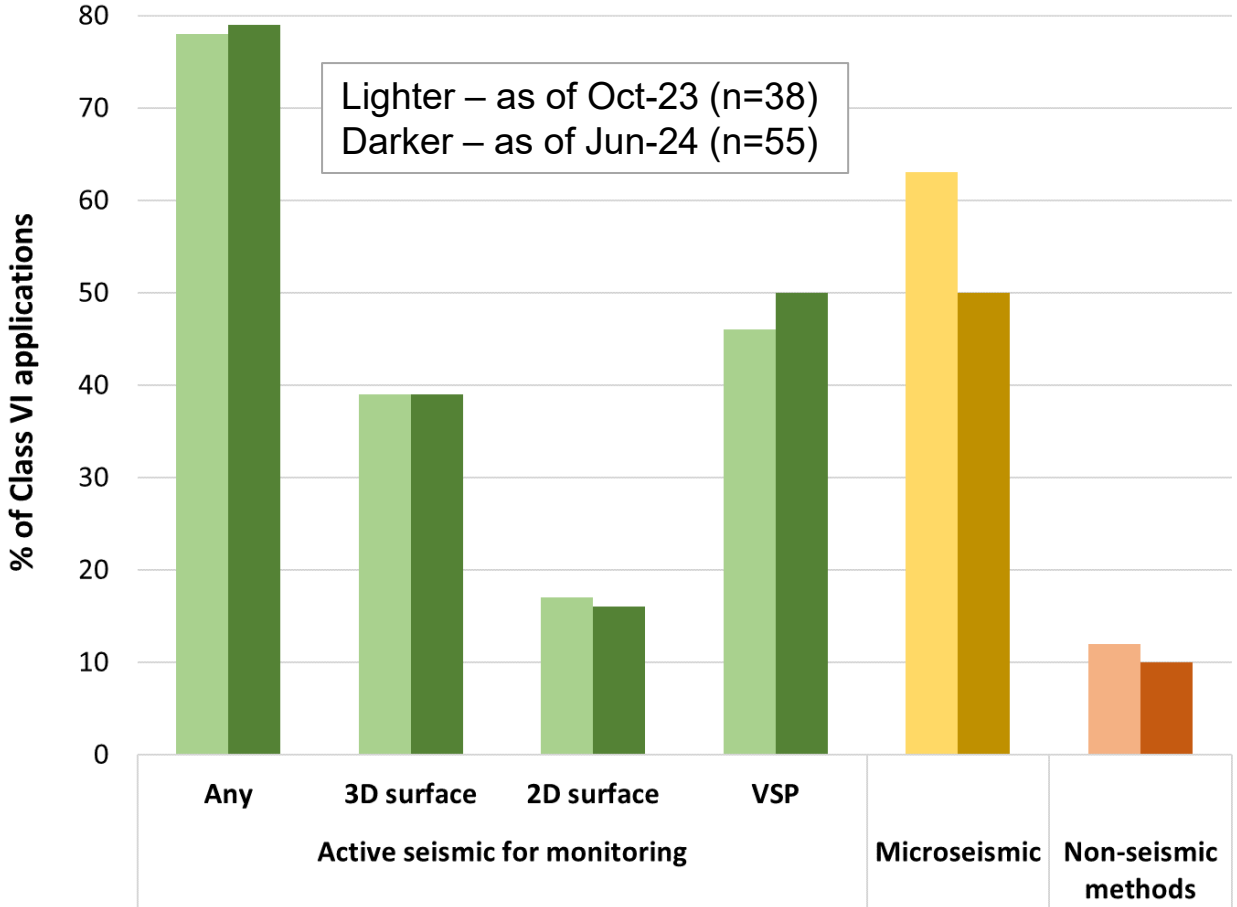
Forecast of Seismic Reprocessing/Survey for Characterization



As of Jun-24 (n=58)

- Less 2D and more 3D

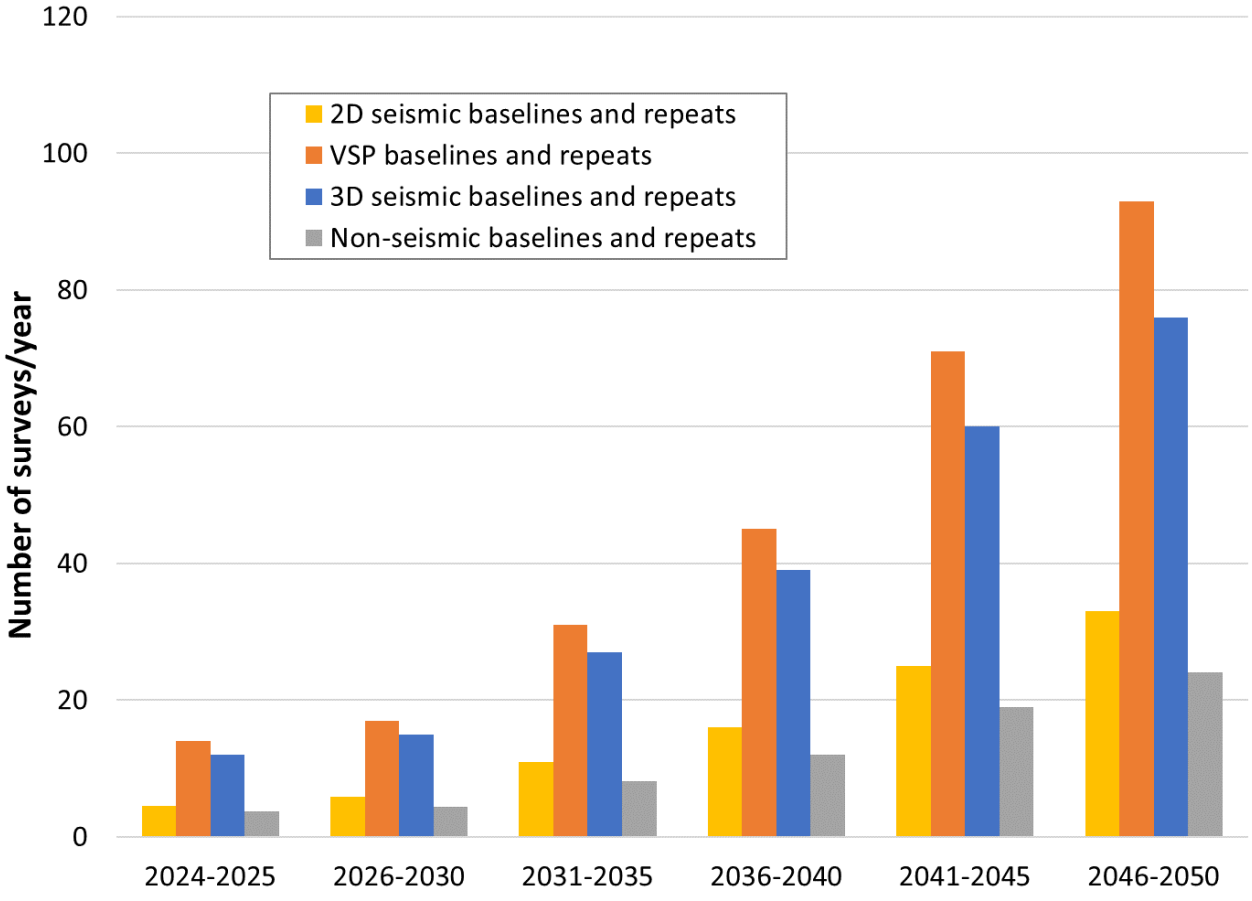
Geophysical Methods for Monitoring



Little change in share proposing active seismic and non-seismic

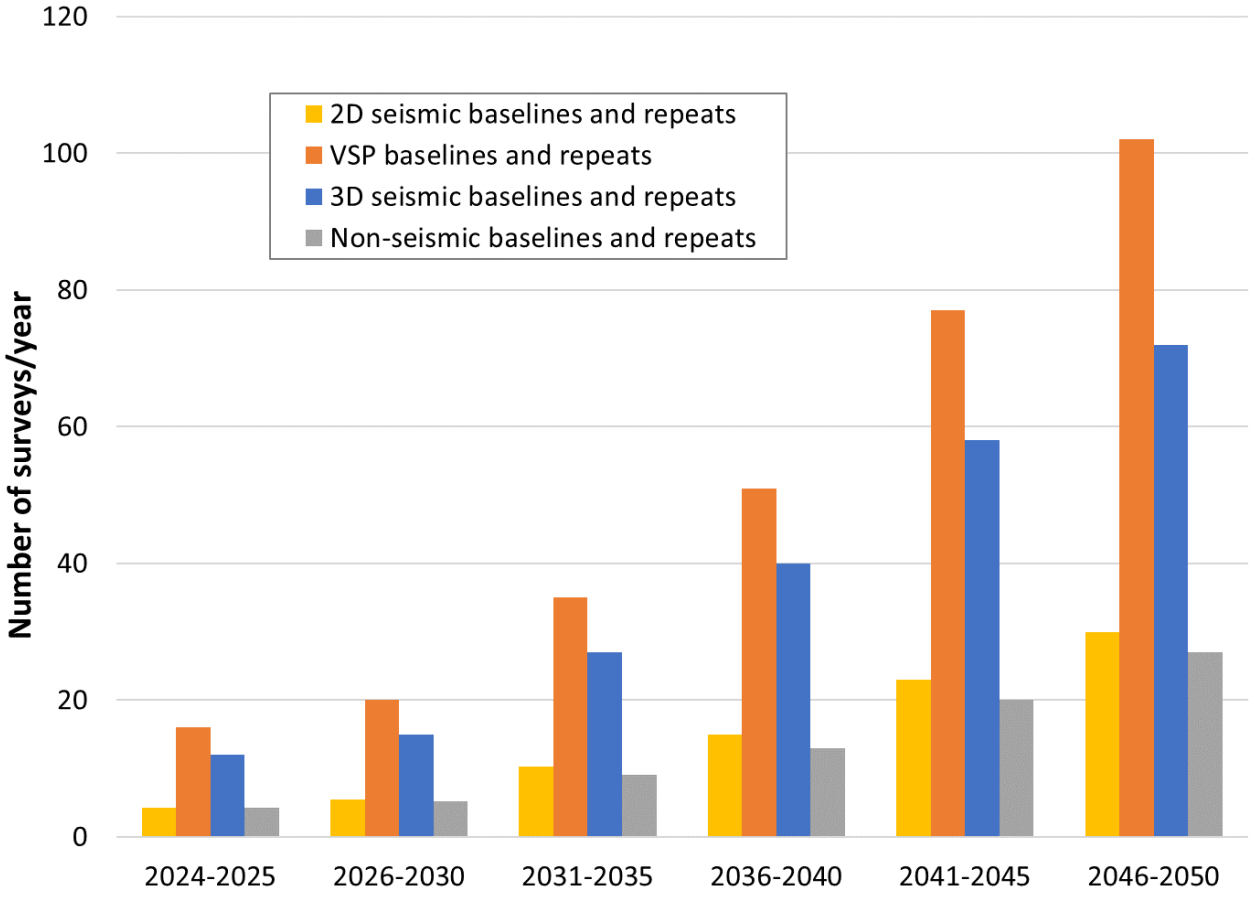
Reduction in share using passive seismic

Prediction of Future Geophysics Use for Characterization



As of Oct-23 (n=38)

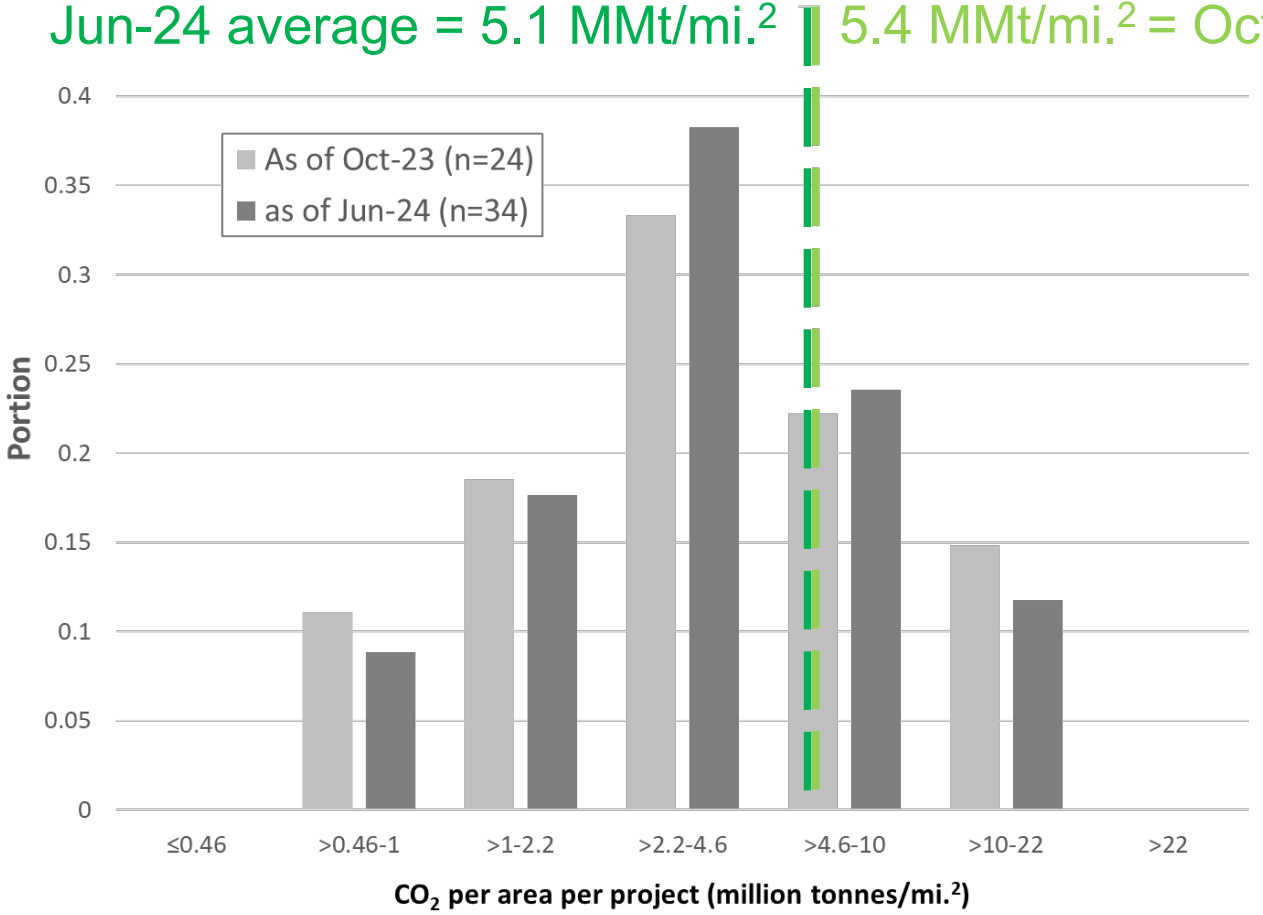
Prediction of Future Geophysics Use for Characterization



As of Jun-24 (n=58)

- Less 2D and more 3D

Forecast CO_2 Footprint Area

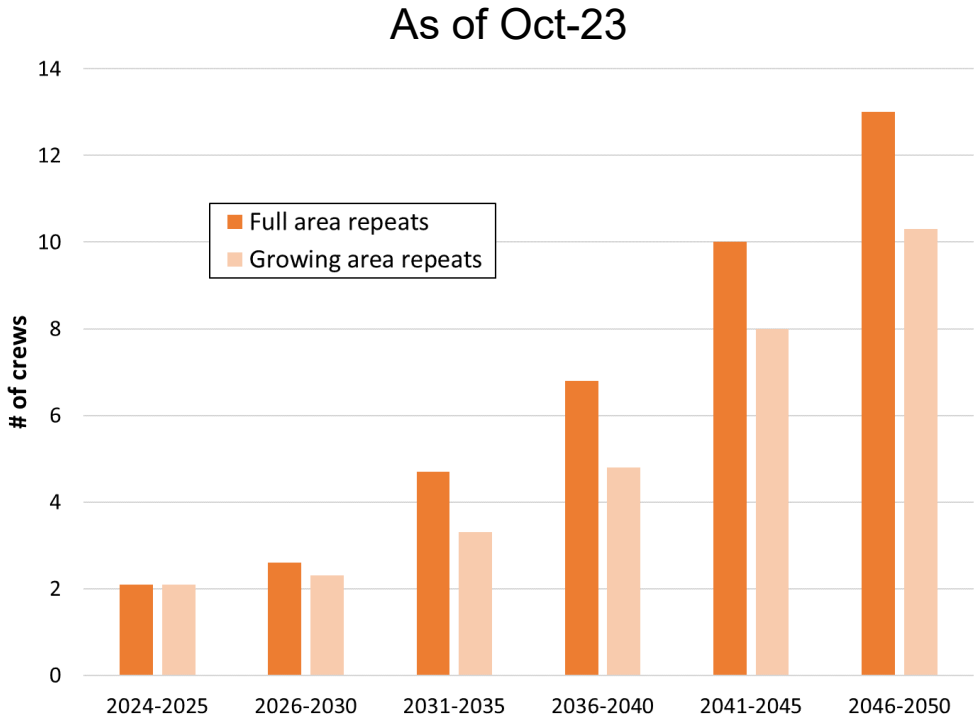


Average forecast CO_2 sequestration per unit area of footprint from permit applications available Oct-23 to Jun-24 declines slightly.

Distribution log normal

Kurtosis reduces slightly

Forecast 3D Seismic Crew Demand for GCS



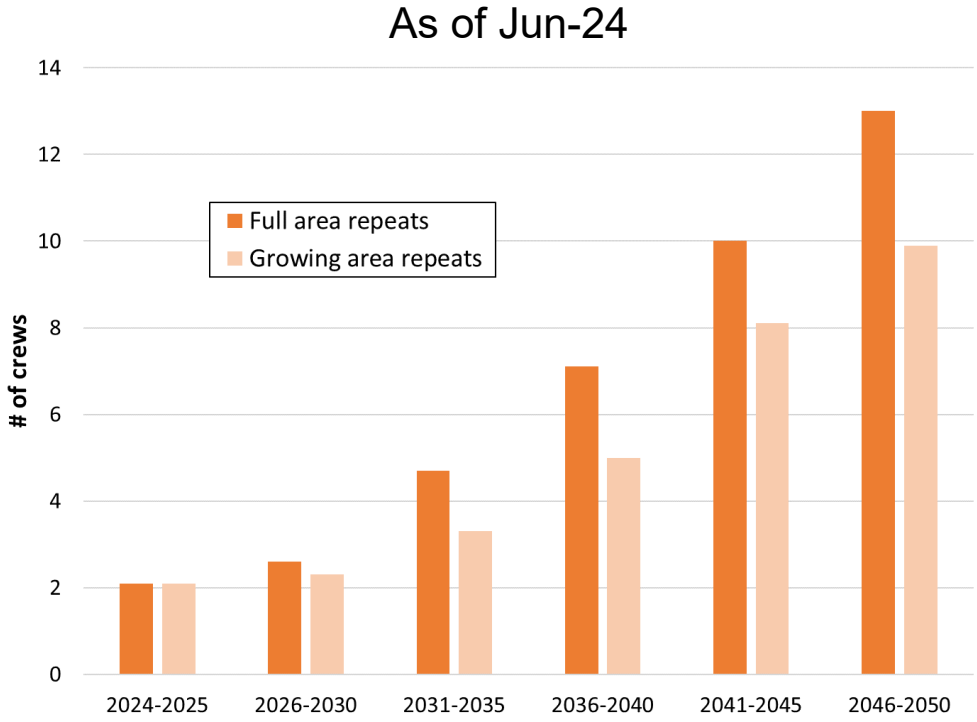
BERKELEY LAB

NATIONAL ENERGY TECHNOLOGY LABORATORY

BATTELLE

U.S. DEPARTMENT OF ENERGY

Forecast 3D Seismic Crew Demand for GCS



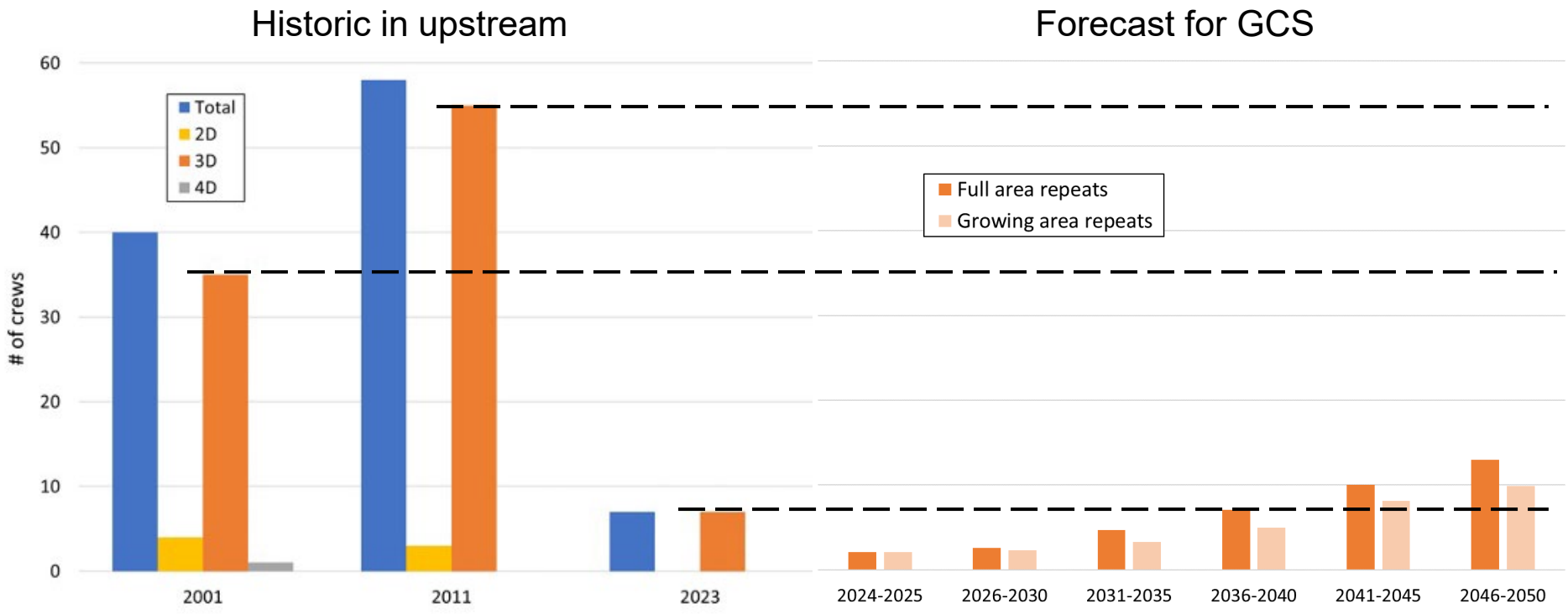
BERKELEY LAB

NATIONAL ENERGY TECHNOLOGY LABORATORY

BATTELLE

U.S. DEPARTMENT OF ENERGY

Forecast 3D Seismic Crew Demand for GCS



BERKELEY LAB

NATIONAL ENERGY TECHNOLOGY LABORATORY

BATTELLE

U.S. DEPARTMENT OF ENERGY

My Conclusions & Discussion Topics at Workshop

NATIONAL ENERGY TECHNOLOGY LABORATORY

Conclusions

- GCS is not going to provide the next applied geophysics 'boom' cycle
- Regulator driven market, so low-cost solutions are priority
- Small changes in basic monitoring techniques over 6 months (outside of passive seismic) suggest 'state of practice' is taking hold of new industry

Discussion Topics

- Will 5-year AOR updates cause issues with projects going forward?
- Will geophysical data be made public?
  - What level of data (raw, processed, interpretation only) should be released?
  - Public is going to be wanting transparency so the answer should be **yes!**
  - Possible legal issues associated with this might preclude this from happening
- Current fears of 'Pandora's Box' regarding permits being reopened are limiting testing of new technologies
  - Will regulators provide easy modification of permit monitoring techniques in future?
  - Are operators allowed to test recently developed methods without regulatory approval?
- What happens if 'permit approved' monitoring technique(s) don't work?

½ of This Talk Originally Given at This Workshop

Work-Shop Takeaways

- **Dominantly Service Companies and Universities Attending**
  - 4 majors present(CVX,SHL,ARAM, XOM), 2 big (SLB, HAL) and many smaller service companies
  - ~13 universities present
  - LANL and LBNL only labs, USGS, EPA and State Agencies with Primacy represented
- **Discussions around economics and cost of monitoring**
  - Only profitable capture scenarios are natural gas processing, ammonia and hydrogen production, ethanol production, and these are barely profitable
  - Power plant capture very expensive
  - Geophysical monitoring is the ’last cost’ in play when designing a site and thus often bare minimum as directed by EPA regulations is being proposed
- **Main Perceived Danger is Induced Seismicity due to injection near basement**
  - Some controversy regarding if its excess pressure or volume of CO_2 causing seismicity
  - Some controversy on how low of magnitudes need to be monitored for
  - Basin-scale pressure front threat recognized both from an induced seismicity point of view as well as pore-space rights
- **Both ML based and Physics based processing and interpretation being pursued**
  - Some skepticism on how applicable ML will ultimately be for certain topics

Work-Shop Takeaways

- **3D/4D Surface Seismic (and VSP) Assumed Dominant Method for Conformance and Leak Monitoring on Land**
  - Some talks on repeat noise problems associated with 4D seismic, one of which led to some controversy
  - Some discussion of permanently buried geophones, DAS, SOV's to alleviate noise issues
  - Two talks/one poster on EM methods for monitoring, two(?) talks regarding gravity methods
- **Cheap 'sparse nodal' monitoring mentioned several times**
  - Concerns of some sparse technologies overselling their applicability and usefulness
- **Rock-physics needs more research**
  - Gasman's expression often not viewed as 'valid'
  - How to validate rock physics models?
- **Other recognized threats**
  - Legacy wells leaking CO2
  - Public perception of operations (NIMBY) and what is held confidential
  - Very little concern over brine leakage into base of USDW and how to monitor for this
- **EPA would love more states getting primacy**

Acknowledgments

- Funding at LBNL to support the work presented here was provided by the U. S. Department of Energy, National Energy Technology Laboratory, CCSMR program, under U.S. DOE Contract No. DE-AC02-05CH11231
- Funding at Battelle to support the work presented here was provided by the U. S. Department of Energy, National Energy Technology Laboratory, through the Midwest Regional Carbon Initiative (MRCI) under U.S. DOE Contract No. DE-FE0031836
- Mark McKoy of NETL for insightful discussions