

# Assessment of Potential CO<sub>2</sub> Storage Sites in California

Nov. 5, 2020

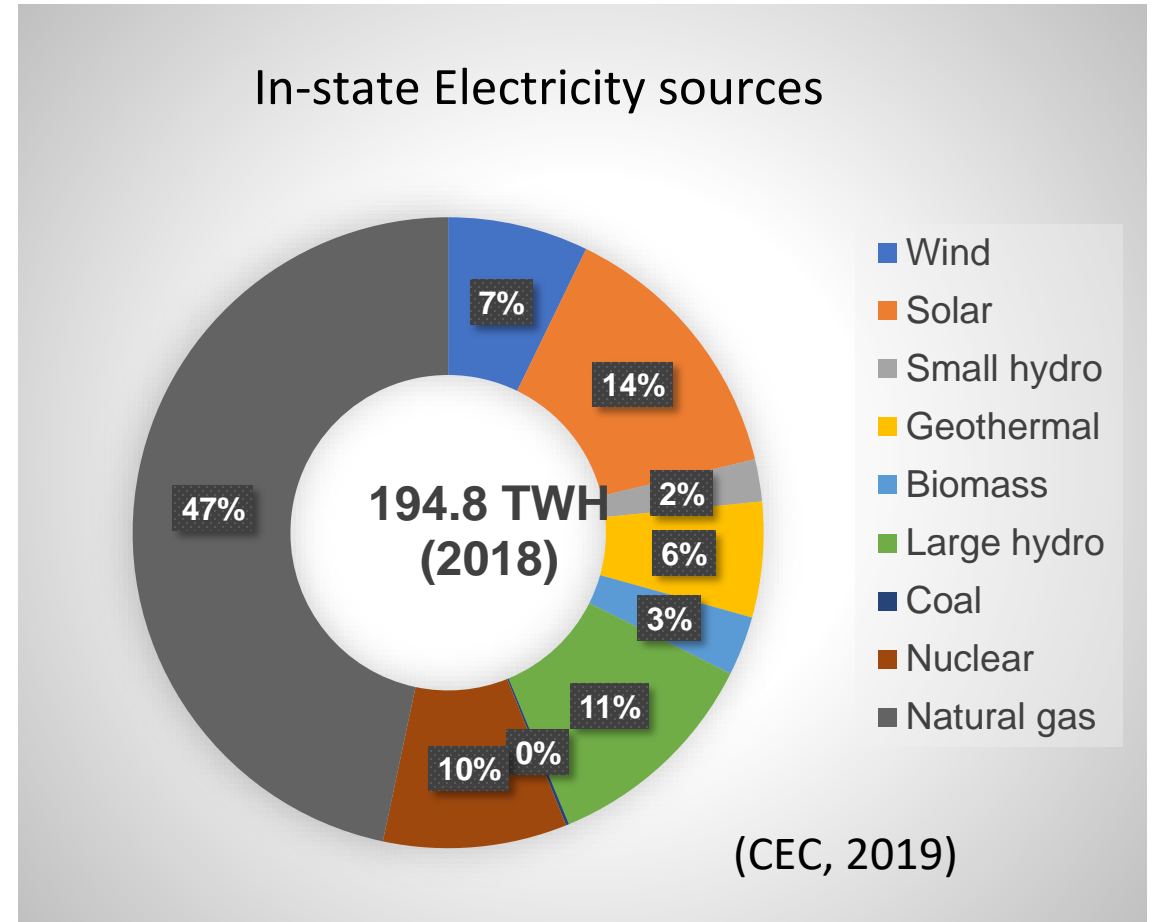
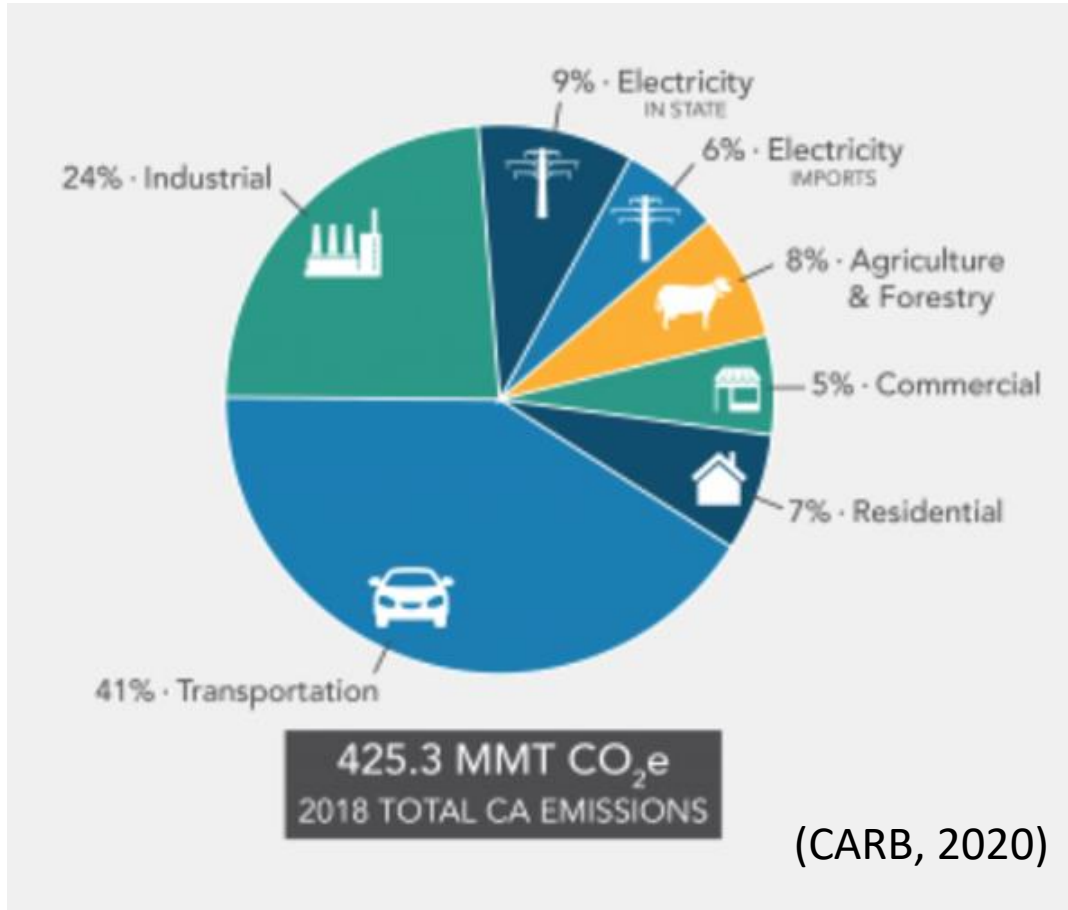
Tae Wook (Elliot) Kim, Sarah D. Saltzer, Ejeong Baik, Justin Bracci, Catherine Hay,  
Sally Benson, Mark Zoback, and Anthony Kavscek

# Content

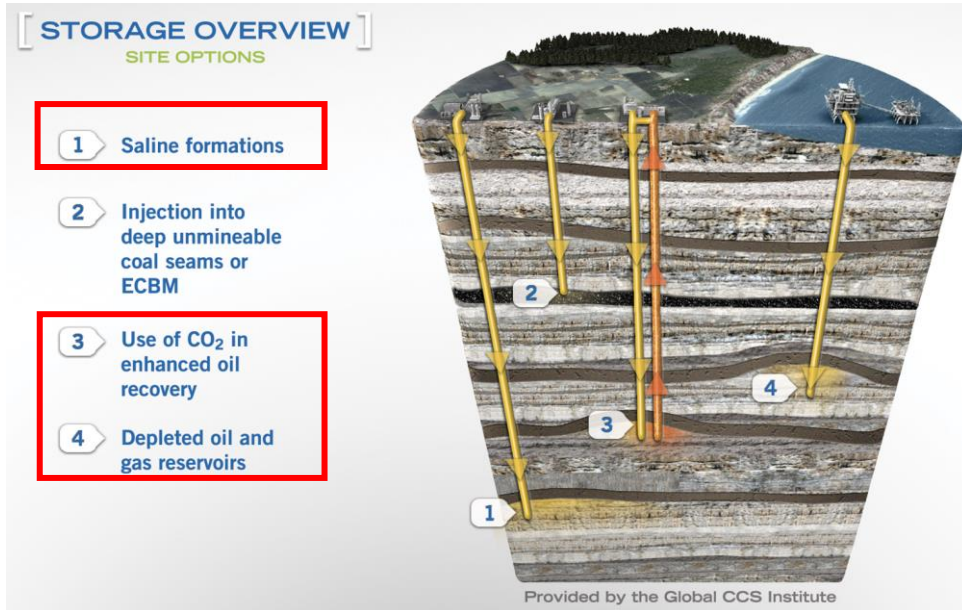
- Introduction
- Methodology
- Result
- Discussion
- Conclusion/Future directions
- Acknowledgement

# GHG Emissions in CA

- ❑ CO<sub>2</sub> emissions (2018) in CA: 1 % of global, 6.4 % of US (CARB, 2020)
- ❑ Industrial and electricity sectors: 39 % of the state’s GHG emissions.
- ❑ California’s non-CO<sub>2</sub> emitting electric generation categories: 53 % of electricity

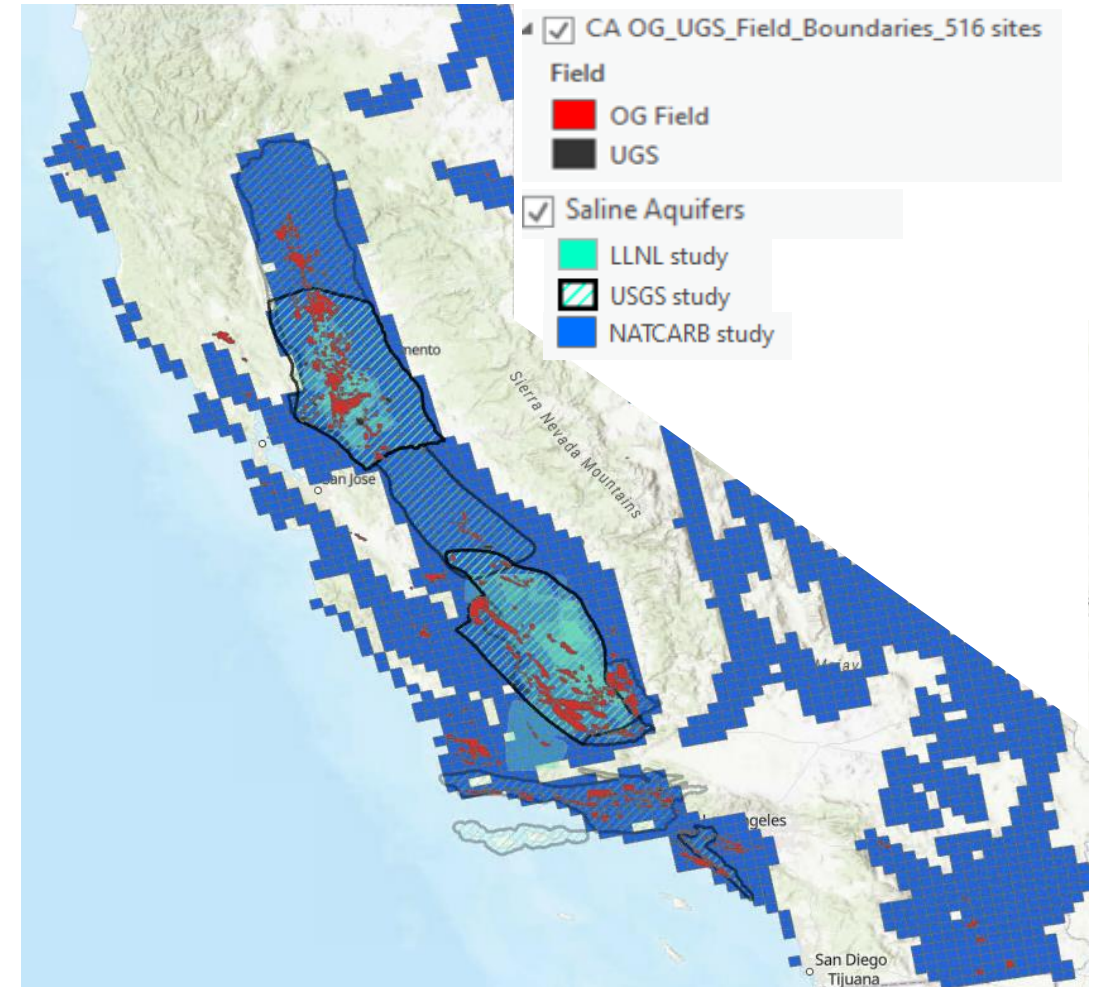


# Previous study of CA CO<sub>2</sub> storage sites



Source	Low	High
<b>O&amp;G and UGS sites</b>		
NATCARB (2015)	3.6 Gt	6.6 Gt
<b>Saline Aquifers</b>		
USGS (2013)	61 Gt	124 Gt
NATCARB (2015)	30 Gt	417 Gt
Teletzke et al. (2018, Exxon)	13 Gt	55 Gt
<b>OG/Saline (LLNL (2019))</b>	17 Gt	200 Gt

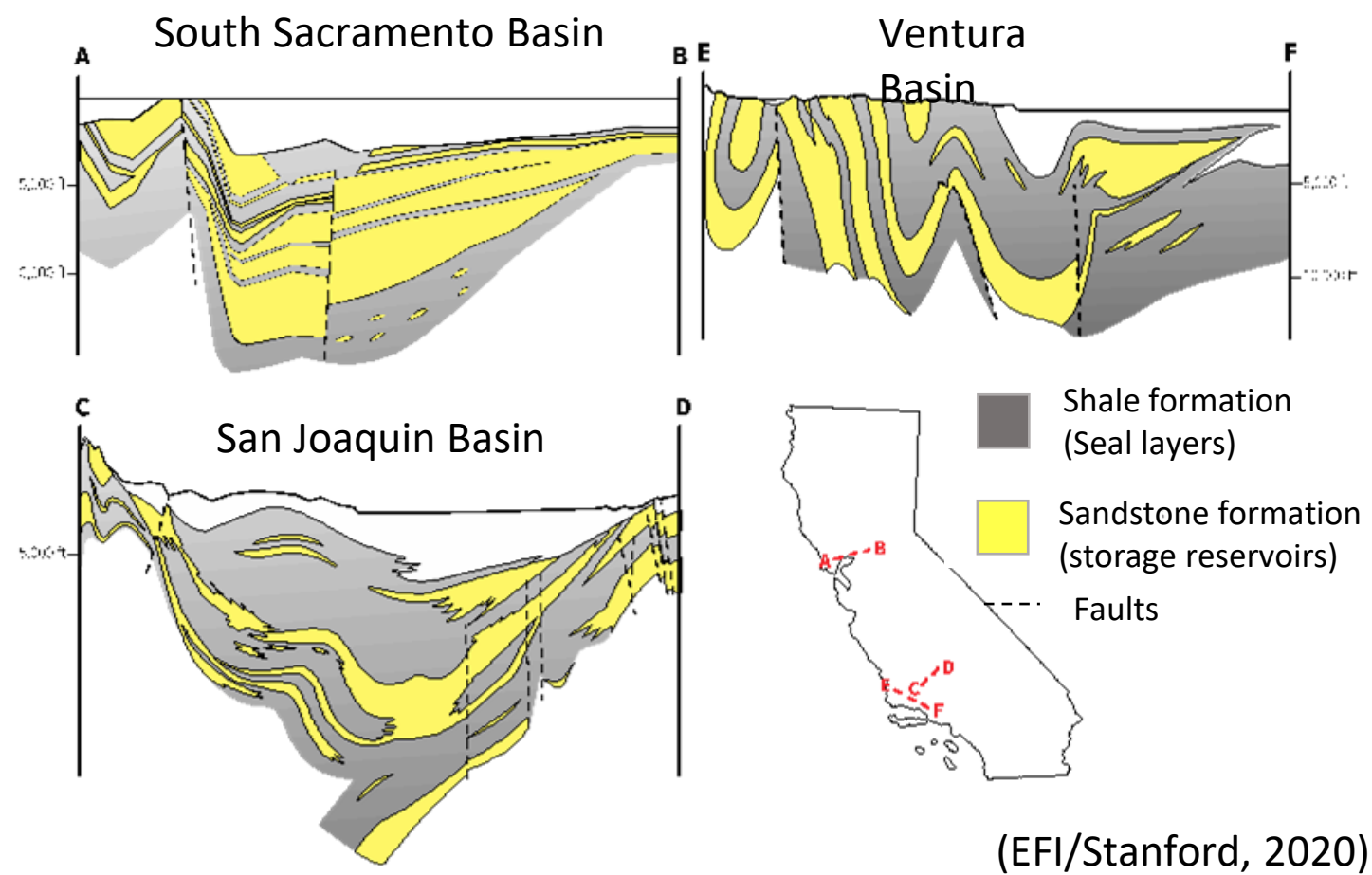
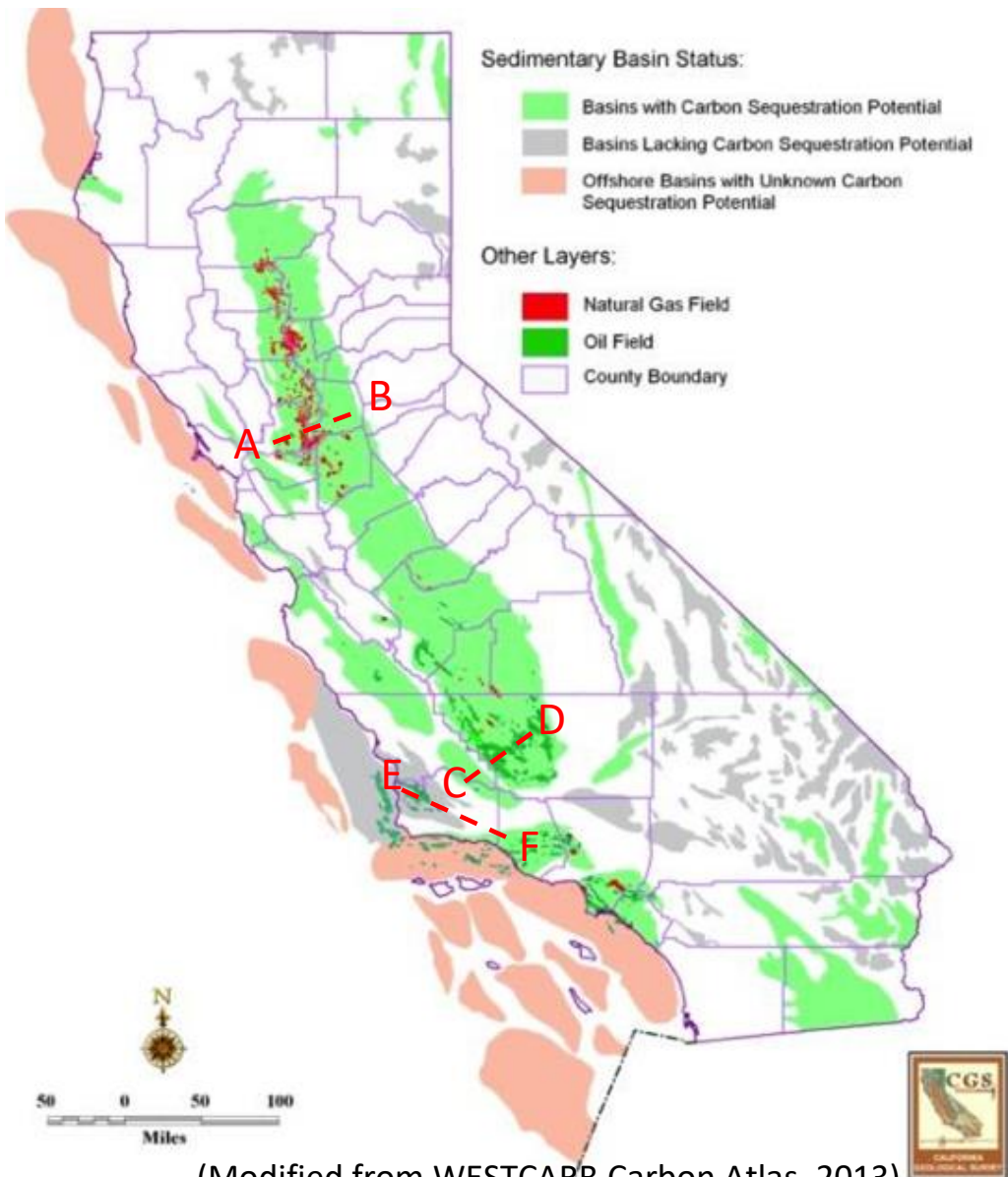
## All CO<sub>2</sub> storage sites in CA



# Objectives

- ❑ Screen CO<sub>2</sub> storage sites (oil/gas field, underground gas storage, and saline formation) in CA based on previous studies and criteria (EPA VI well and LCFS CCS protocol minimum siting criteria) with the consideration of exclusion zones.
- ❑ Link potential CO<sub>2</sub> storage sites to CO<sub>2</sub> emission sources to provide data for technoeconomic analysis.

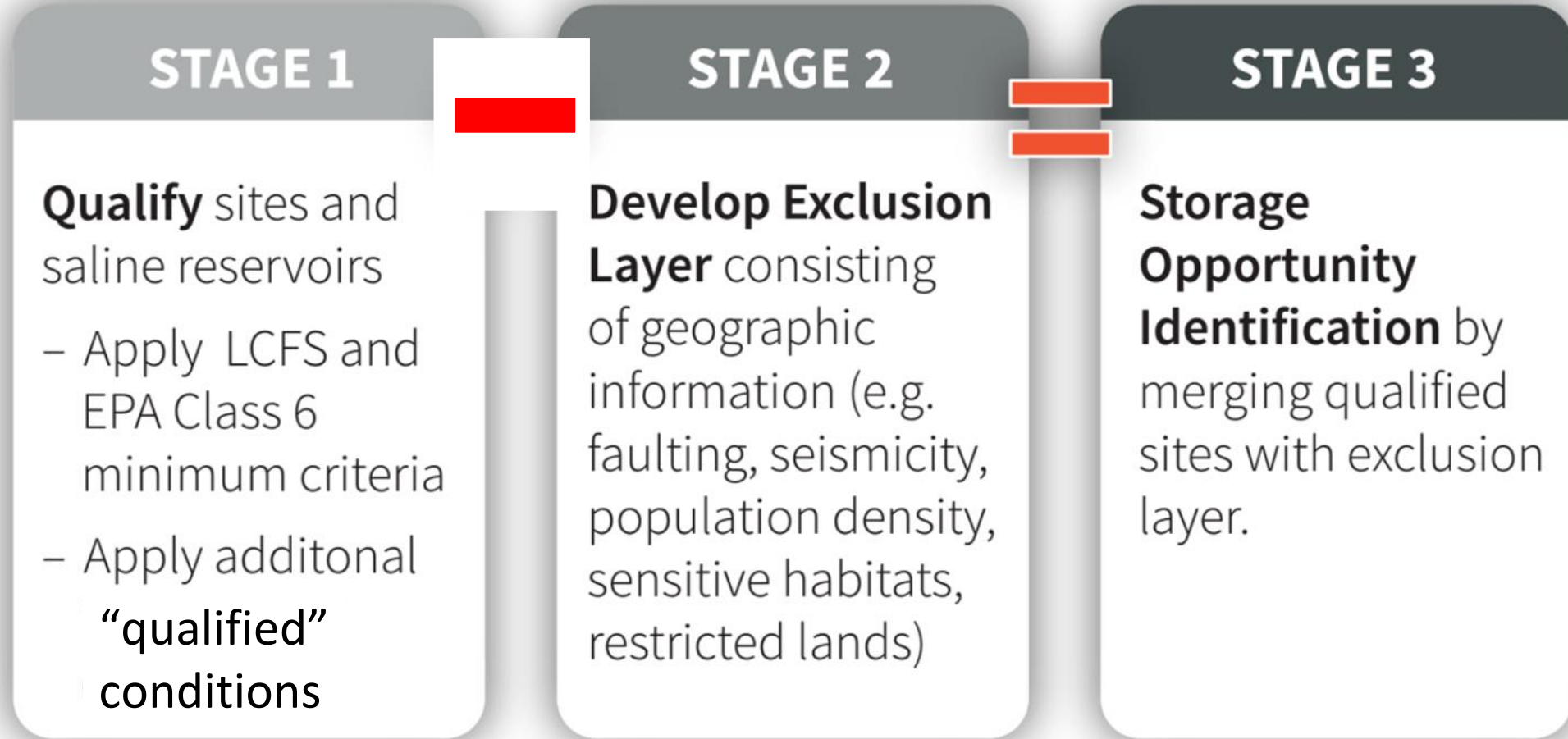
# California Geology



Schematic cross sections across the basins (note vertical scale is exaggerated)

(Modified from WESTCARB Carbon Atlas, 2013)

# Multi-Stage Screening Procedures



(modified from EFI/Stanford, 2020)

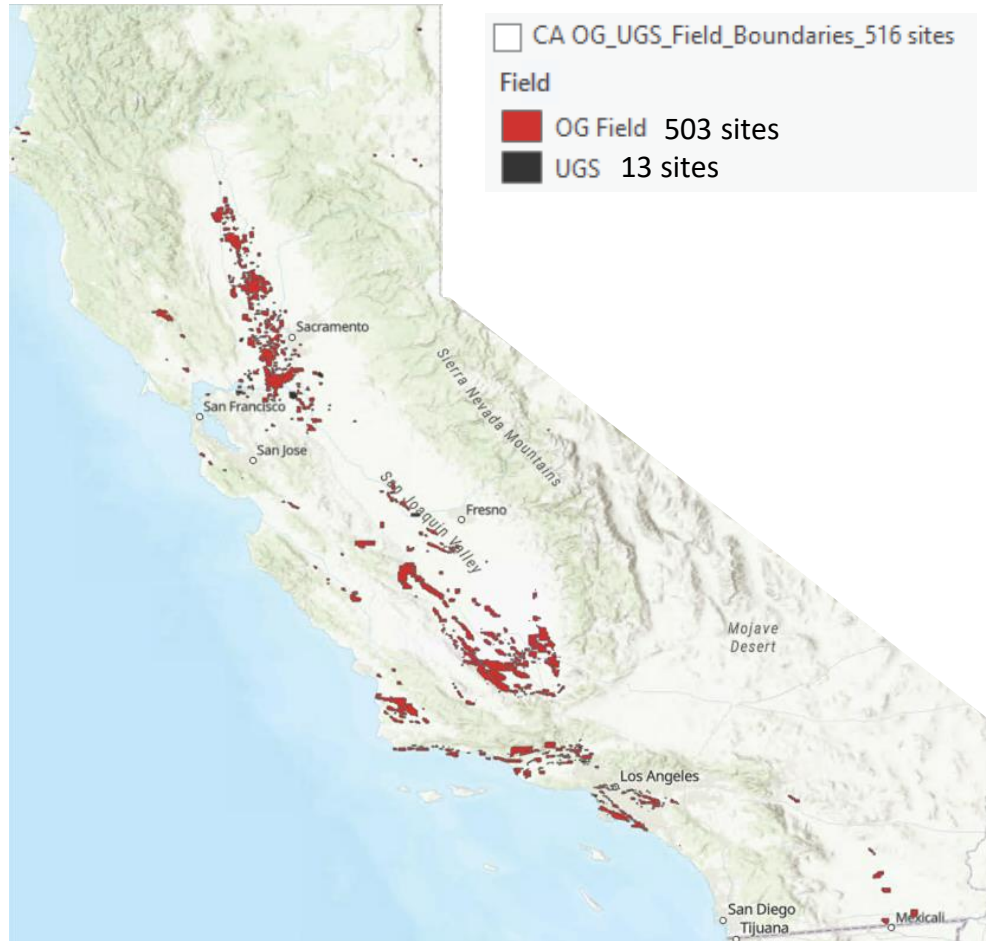
# Stage 1: Qualifying Criteria

Category	Criteria	Qualifying Threshold	EPA VI well Criteria	LCFS Minimum Criteria
Screening parameters	Storage Capacity	> 3 million metric tonnes CO <sub>2</sub>	“sufficient areal extent”	“sufficient volume”
	Depth (to top of formation)	> 800m		“deeper than 800m”
	Permeability	> 10mD	“sufficient permeability”	“sufficient permeability”
	Porosity	> 10%	“sufficient porosity”	“sufficient porosity”
	Reservoir Thickness	> 3m (one layer) or sum of layers > 10 m	“sufficient thickness”	“sufficient thickness”
	Salinity	> 10,000 TDS (only dry gas field, UGS, and Saline formation)	> 10,000 TDS	
	Sufficient Injectivity	Anything that suggests this could be an issue* (e.g. current pressure < 4000 PSI, Assume initial reservoir pressure < 5000 PSI)		“sufficient injectivity”

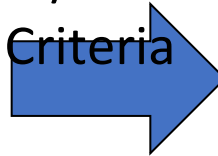
\*Additional disqualified sites: 50 sites (insufficient data) and 4 sites (offshore sites with no 45Q credit)

# Stage 1: Prospective OG/UGS fields and saline formations

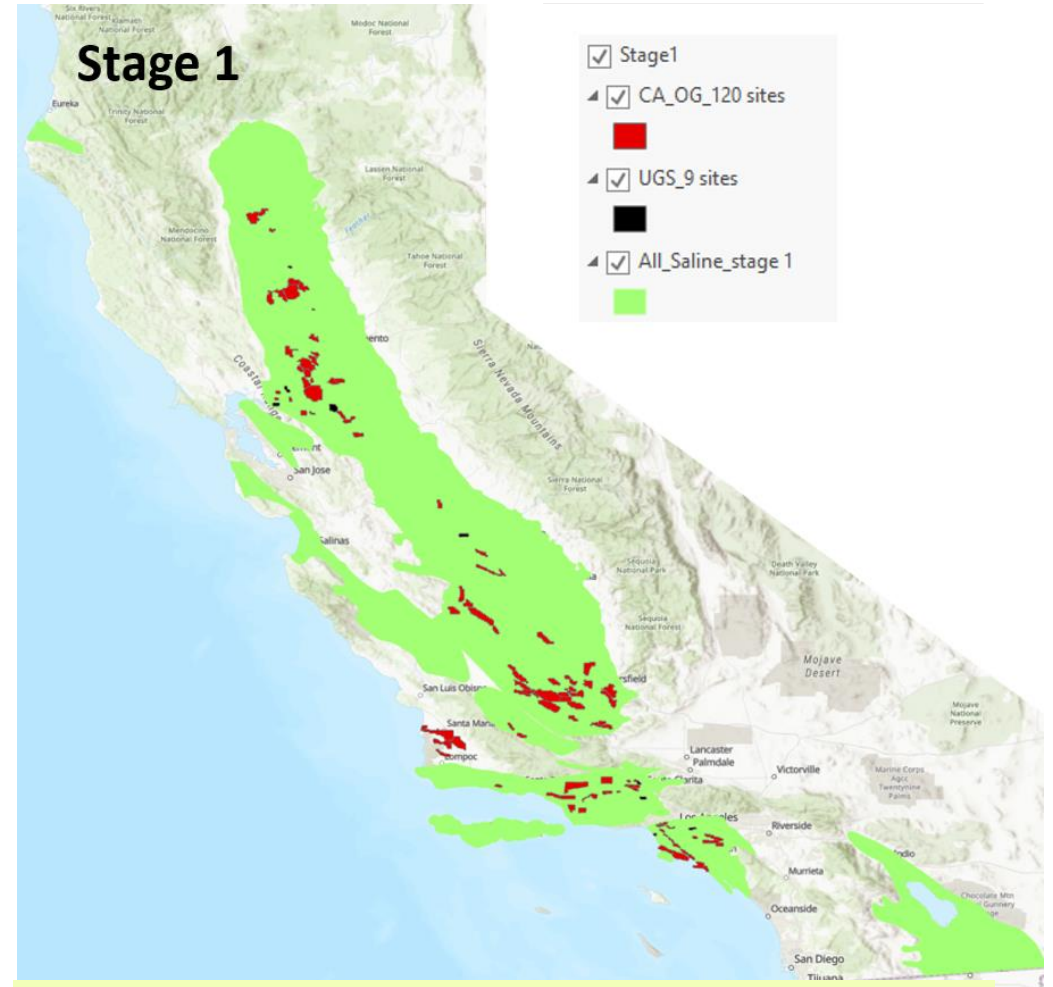
## Prospective sites



- CO<sub>2</sub> Storage Cap. > 3 MT
- EPA VI/LCFS Criteria



Add Saline Formation (USGS/NATCARB)



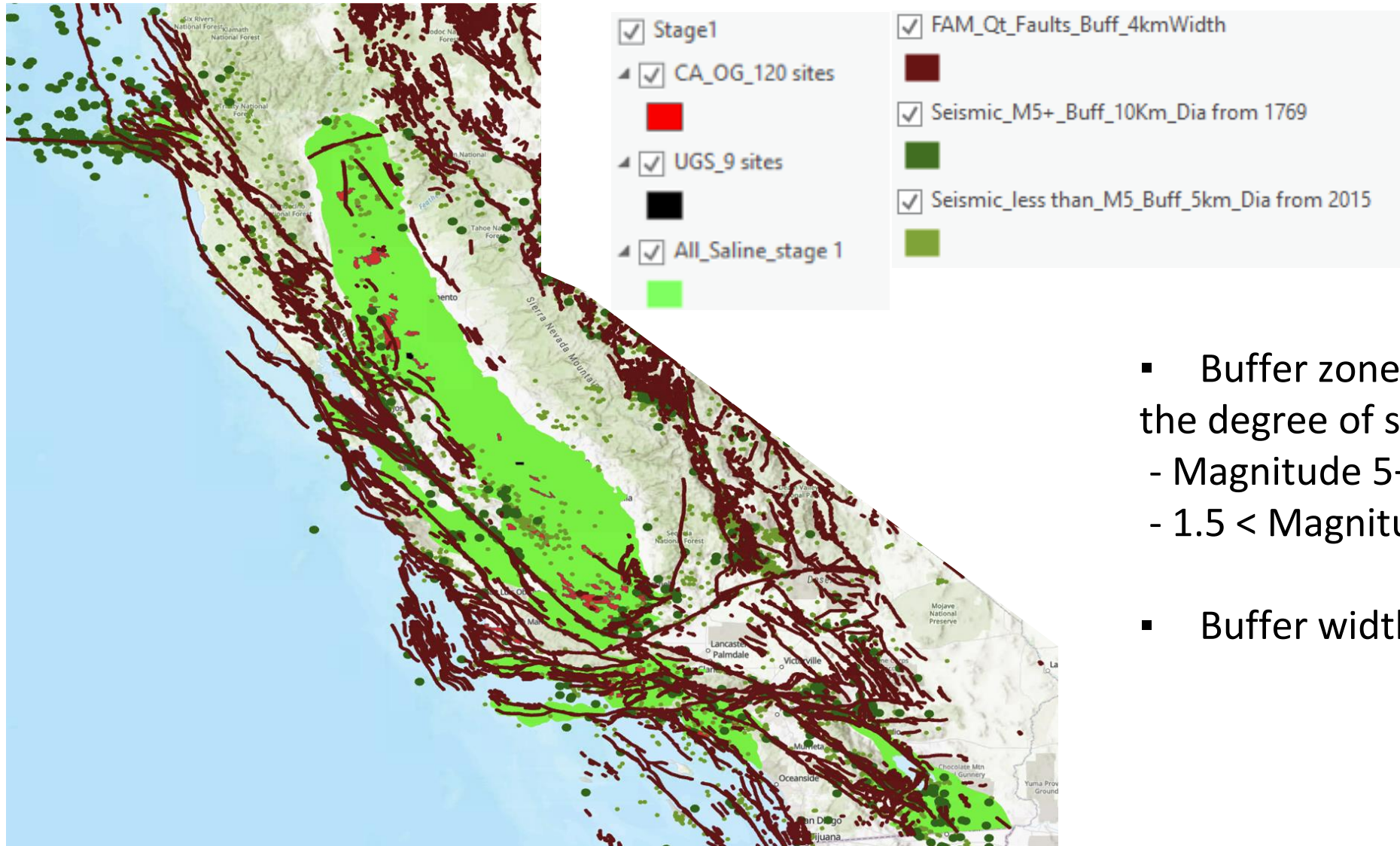
Total # O&G (503) and UGS sites (13): 516  
 Total capacity (NATCARB) of OG/UGS: 3.6 - 6.6 Gt CO<sub>2</sub>

Total # O&G (120) and UGS sites (9): 129  
 Total capacity of OG/UGS: 2.9 – 5.3 Gt CO<sub>2</sub>  
 Total capacity of Saline formation: 116 (mean) Gt CO<sub>2</sub>

## Stage 2: Criteria for exclusion

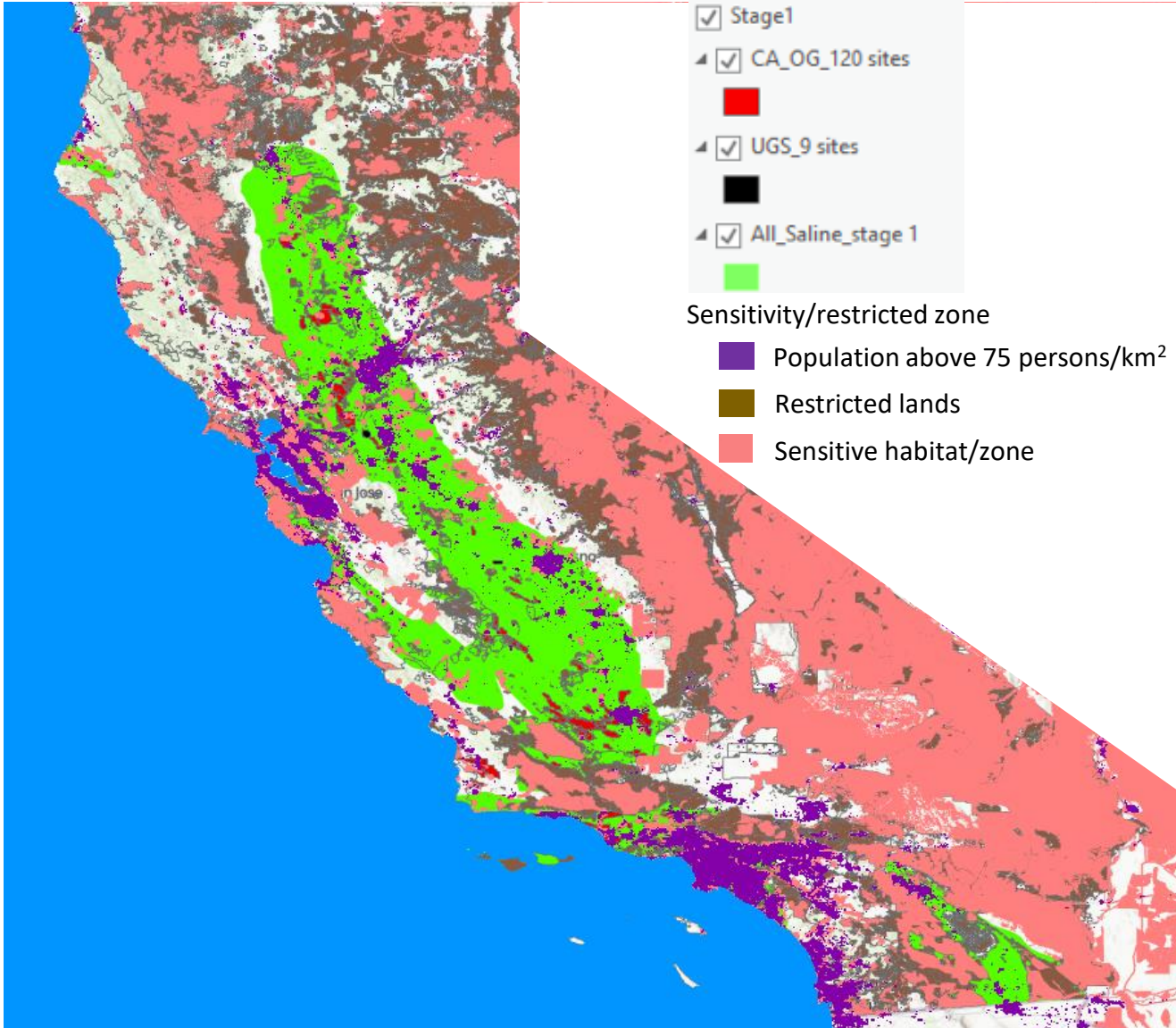
- Near Quaternary faults
  - 2km “buffer zone” each side of fault (4 km width)
- Seismicity activity (exclusion zone based on magnitude)
  - 10 km diameter for  $M > 5$  (from 1769 – present)
  - 5 km diameter for  $M < 5$  (from 2015 – present)
- Population density
  - Above 75 persons/ km<sup>2</sup>
- Land
  - ownership status (restricted lands)
  - sensitive habitats

# Risk identification: Faults, Seismicity



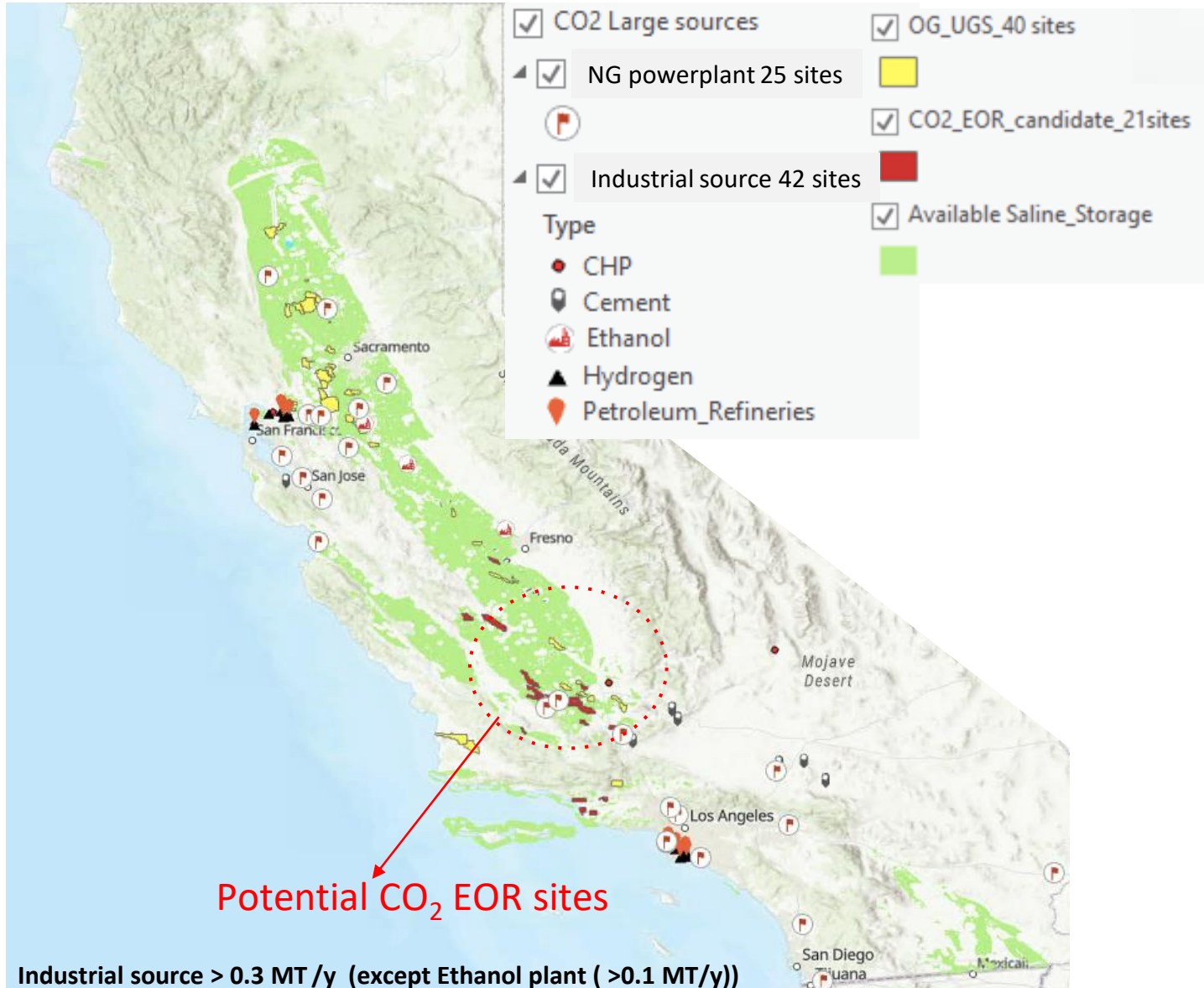
- Buffer zones are applied based on the degree of seismicity.
  - Magnitude 5+ : 10 Km Dia.
  - 1.5 < Magnitude < 5: 5 Km Dia.
- Buffer width of Faults zone: 4 km

# Sensitivity/restricted zone



<b>Restricted lands</b>	Federal, state land, American Indian, military installation
<b>Sensitive habitat/zone</b>	<ul style="list-style-type: none"> <li>- Cultural sites (national landmark, national register properties),</li> <li>- Ecology habitats (sharp tailed grouse, desert tortoise connectivity, and so on),</li> <li>- Wildlife habitat (wildlife allocation, national historic park/monument, wilderness study area, Conservation land, wildlife management area)</li> </ul>

# Stage 3: Potential CO<sub>2</sub> storage sites



Potential CO<sub>2</sub> storage sites  
 = Screened Oil/gas, UGS +  
 Saline formation - Exclusion layers

## Storage Capacity Estimates

Saline Reservoirs	Mean	
UGSG supplemented with NATCARB	116 Gt	
Qualified (end of Stage 1)	116 Gt	
Storage Opportunities (end of Stage 3)	69.1 Gt	
Oil and Gas Reservoirs	Low	High
NATCARB	3.6 Gt	6.6 Gt
Qualified (end of Stage 1)	2.9 Gt	5.3 Gt
Storage Opportunities (end of Stage 3)	1.1 Gt	2.1 Gt

# Comparison of 45Q vs. LCFS for CO<sub>2</sub> storage

## ❑ 45Q Tax credit

- Project type: Store CO<sub>2</sub> from any industrial/Direct air capture (DAC) unit in US
- Credit: Saline (Max \$50/tCO<sub>2</sub>), CO<sub>2</sub>-EOR Max \$35/tCO<sub>2</sub>
- Project condition: Above 0.1 MtCO<sub>2</sub>/year capture volume, 12 years after injection
- Construction must begin by Jan. 1. 2024

## ❑ LCFS (Low Carbon Fuel Standard) credit

- Geographic scope: Anywhere provided they sell fuel into CA
- Project type: Store CO<sub>2</sub>/CH<sub>4</sub>/Nox/VOC from any fuel production facility and DAC unit
- Credit: Market based credit (~ \$200/tCO<sub>2</sub>, current) during injection period
- There is no limitation of project capacity

**Both credits require permanent storage**

# Storage Optimization for OG/UGS field

Scoring criteria based on subsurface properties

Total score: 35

points

High:  $\geq 28$

Medium: 23 – 27

Low:  $\leq 22$

Criteria	J=1 (worst)	J=2	J=3	J=4	J=5 (best)
Storage Capacity	3-5 Mt CO <sub>2</sub>	5-10 Mt CO <sub>2</sub>	10-30 Mt CO <sub>2</sub>	30-50 Mt CO <sub>2</sub>	>50 Mt CO <sub>2</sub>
Bottom Seal	No seal				Yes-Seal
Depth of Top of Formation	800-1000m	Deep (>3,000 m)	1,000-1,500m	2,000-3,000m	1,500-2,000m
Permeability	10-20 mD	20-50 mD	>500 mD	50-100 mD	100-500 mD
Porosity	10-15%	15-20%	20-25%	25-30%	>30%
Reservoir Thickness	3-20m	20-50m	50-100m	100-300m	>300m
Geothermal Gradient (Geothermal favorability)	Warm Basin (>40 °C/km) Class1		Moderate (20-40 °C/km) (Class 2, 3, 4)		Cold Basin (<20 °C/Km) (Class 5)

(modified after Hay, 2020)

# Prospective OG/UGS CO<sub>2</sub> storage, Northern CA

☐ Potential CO<sub>2</sub>-OG sites (depleted OG) are mainly located in northern CA.

- CO<sub>2</sub> Large sources
- NG powerplant 25 sites
  - Industrial source 42 sites
- Type
- CHP
  - Cement
  - Ethanol
  - Hydrogen
  - Petroleum\_Refineries

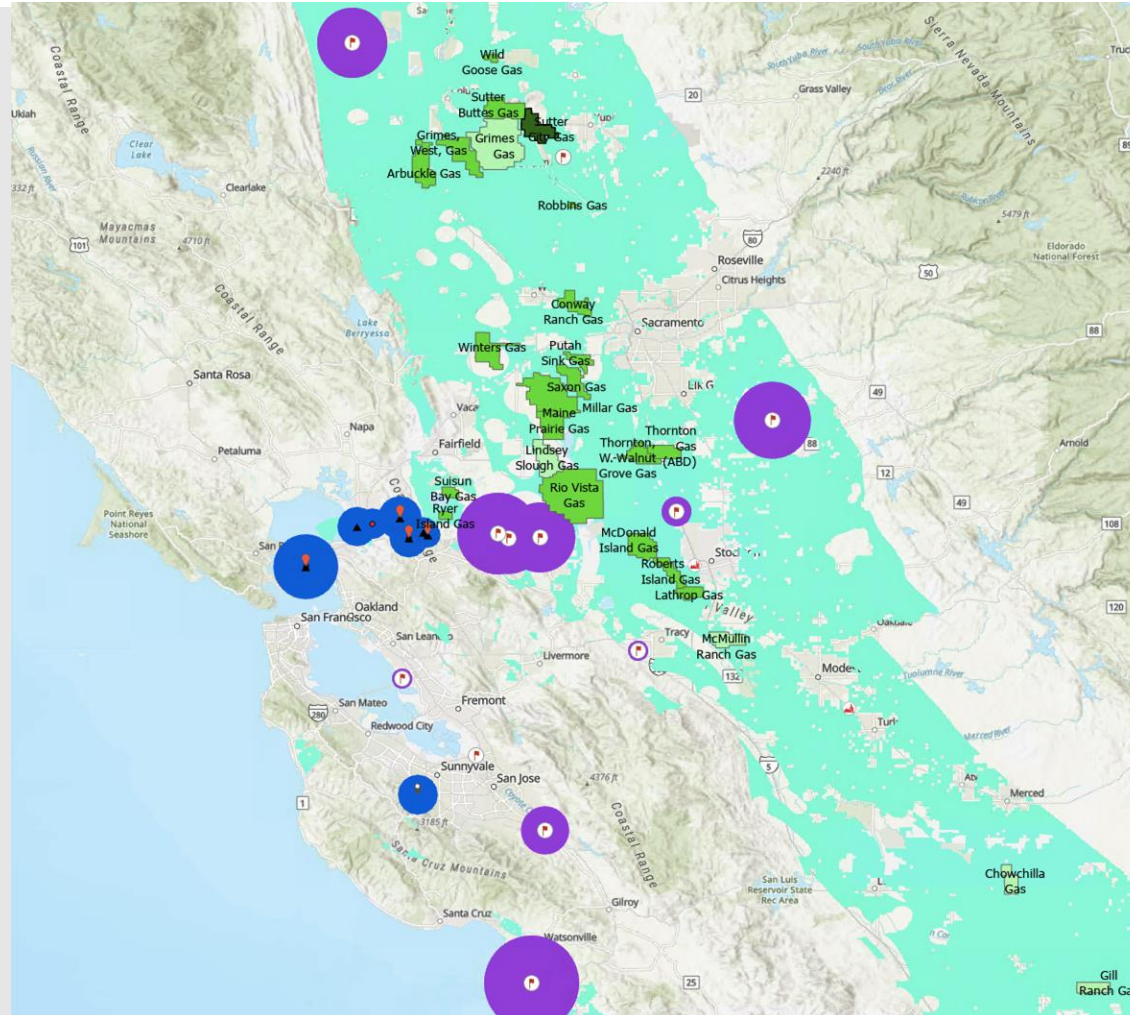
CO<sub>2</sub> EOR 21 sites

- High score, 6 sites
- Medium score, 11 sites
- Low score, 4 sites

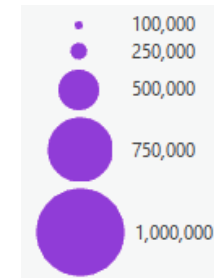
OG/UGS 40 sites

- High score, 2 sites
- Medium score, 26 sites
- Low score, 12 sites

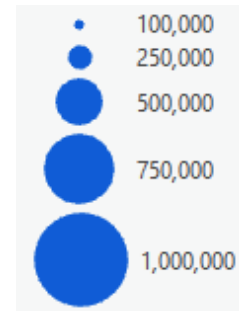
Available Saline\_Storage



NG Powerplant, emission CO<sub>2</sub>e tons/year



Industrial, emission CO<sub>2</sub>e tons/year



Industrial source > 0.3 MT/y (except Ethanol plant (>0.1 MT/y))

# Prospective OG/UGS CO<sub>2</sub> storage, Southern/Central CA

☐ Potential CO<sub>2</sub>-EOR sites are mainly located in southern/central CA.

## CO<sub>2</sub> Large sources

- NG powerplant 25 sites
  - Industrial source 42 sites
- Type
- CHP
  - Cement
  - Ethanol
  - Hydrogen
  - Petroleum\_Refineries

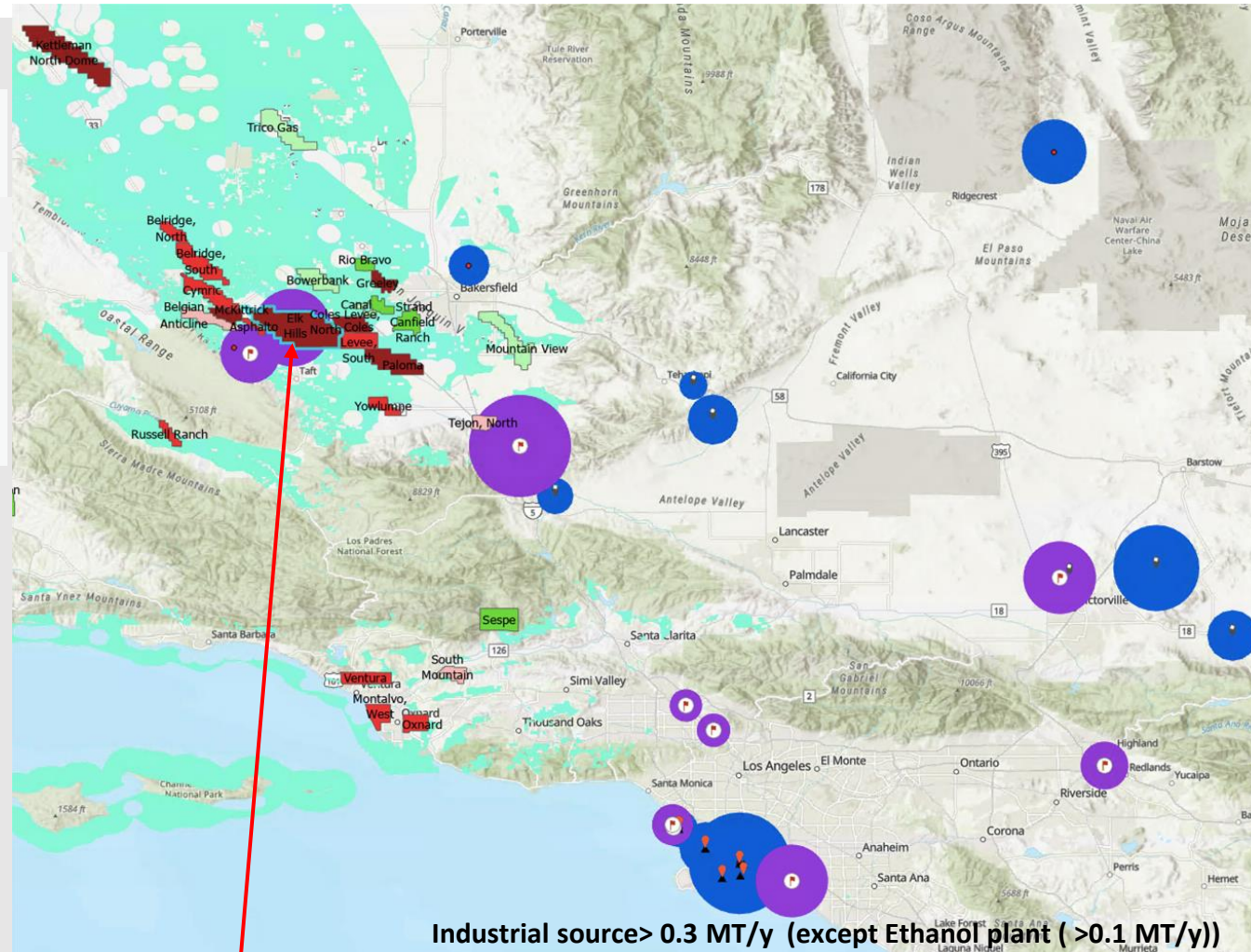
## CO<sub>2</sub> EOR 21 sites

- High score, 6 sites
- Medium score, 11 sites
- Low score, 4 sites

## OG/UGS 40 sites

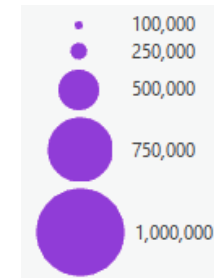
- High score, 2 sites
- Medium score, 26 sites
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Available Saline\_Storage

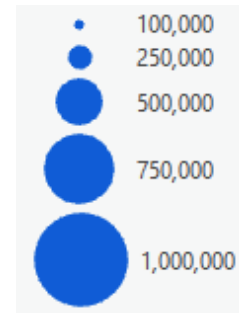


Industrial source > 0.3 MT/y (except Ethanol plant (>0.1 MT/y))

NG Powerplant, CO<sub>2</sub>e tons/year



Industrial, CO<sub>2</sub>e tons/year



Elk Hills field (Gas-power + EOR) is under development.

# Conclusion

- ❑ CO<sub>2</sub> storage sites in CA were qualified based on previous studies with rigorous screening criteria (EPA VI well and LCFS CCS siting criteria).
- ❑ Potential CO<sub>2</sub> storage sites in CA were assessed and conservative exclusion zone criteria applied
  - Oil/gas and underground gas storage sites: 1.1 -2.2 Gt CO<sub>2</sub>
  - Saline formation: 69.1 (mean) Gt CO<sub>2</sub>
- ❑ Scoring parameters can be applied to optimize the selection of oil/gas fields and underground gas storage sites.

# Future directions

- ❑ Storage optimization focused on technoeconomic analysis, scenario development, and risk assessment: SIMCCS, NRAP, and more.
- ❑ Observe CCUS projects with CO<sub>2</sub>-EOR and saline formation (Elk Hills field, potential gas-power + EOR).

State-of-Stress Assessment Tool

## State-of-Stress Assessment Tool - Main Page

**Enter Parameters**

**Generate**

A set of Python modules have been developed to assist in performing a geomechanical risk assessment for a carbon storage reservoir. The primary geomechanical risk considered here is the risk of induced seismicity.

Version: 2018.08-1.0  
Main Contact: Jeffrey Burghardt  
Email: [jeffrey.burghardt@pnnl.gov](mailto:jeffrey.burghardt@pnnl.gov)  
[Acknowledgements](#)  
[References](#)  
[User Manual](#)

**NRAP**  
National Risk Assessment Partnership

**NE TL** NATIONAL ENERGY TECHNOLOGY LABORATORY  
**BERKELEY LAB**  
**Los Alamos** NATIONAL LABORATORY EST. 1943  
**Pacific Northwest** NATIONAL LABORATORY

# CUSP (Carbon capture Utilization Storage Partnership)



- Update/create geological data for CCUS
- Development/validation of risk assessment w/NRAP tools
- Select/analyze the focused scenario (capture/store/monitoring)
- Development readiness indices to identify best sites for short and long-term CCUS project
- Network development/technology transfer

# Acknowledgement



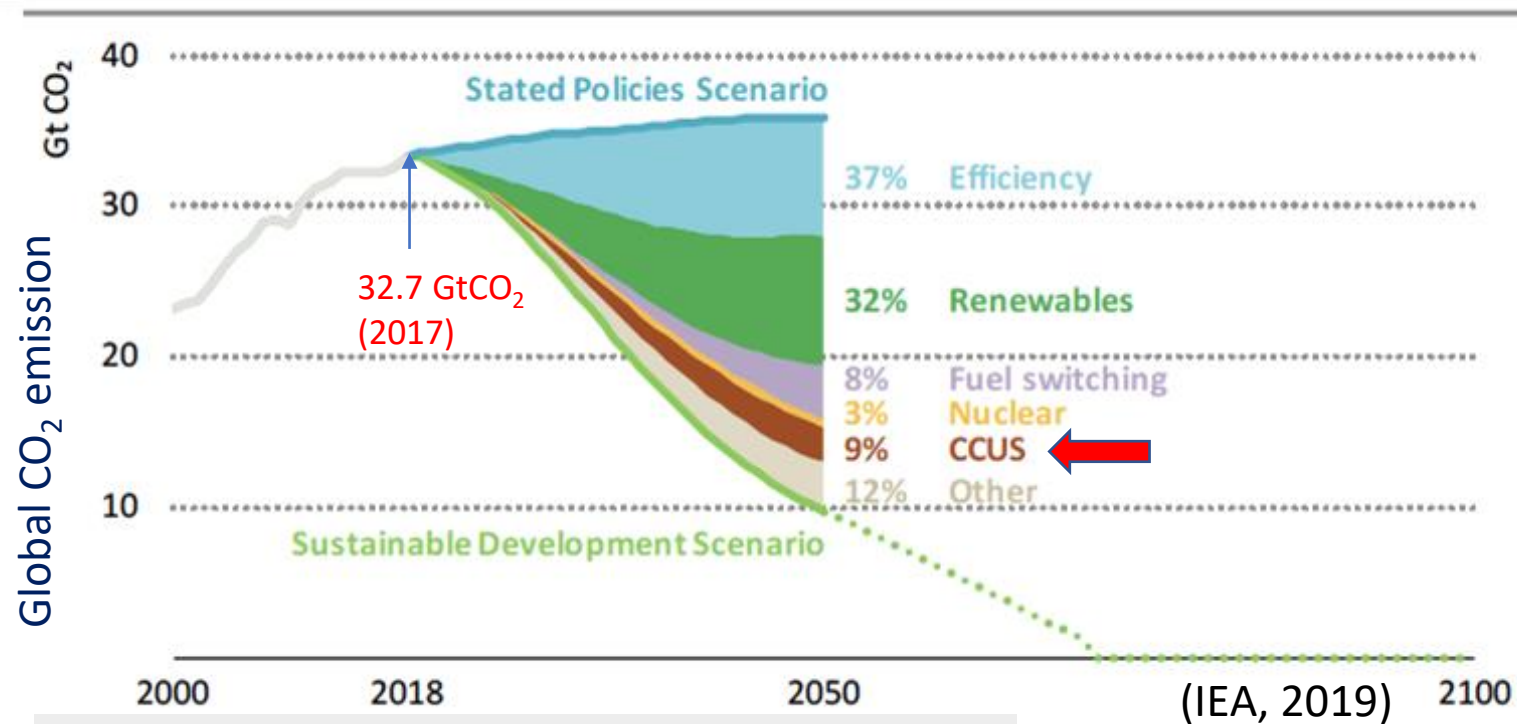
**Stanford** | Center for Carbon Storage



**Backup slides**

# CO<sub>2</sub> emission reduction scenario

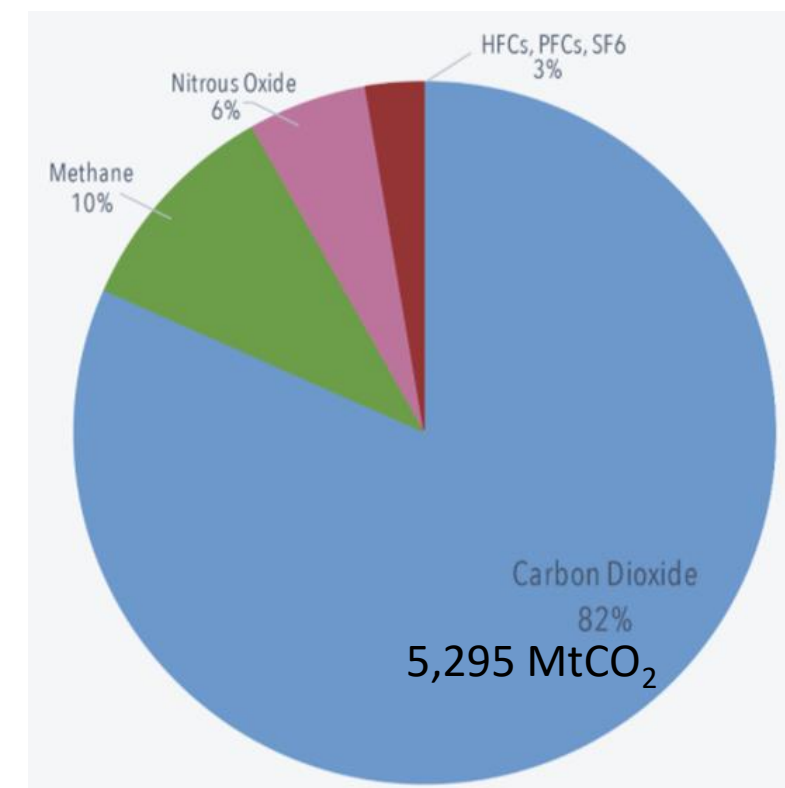
## Energy-related CO<sub>2</sub> emissions and reductions technology scenario



CCUS = Carbon Capture, Utilization, and Storage

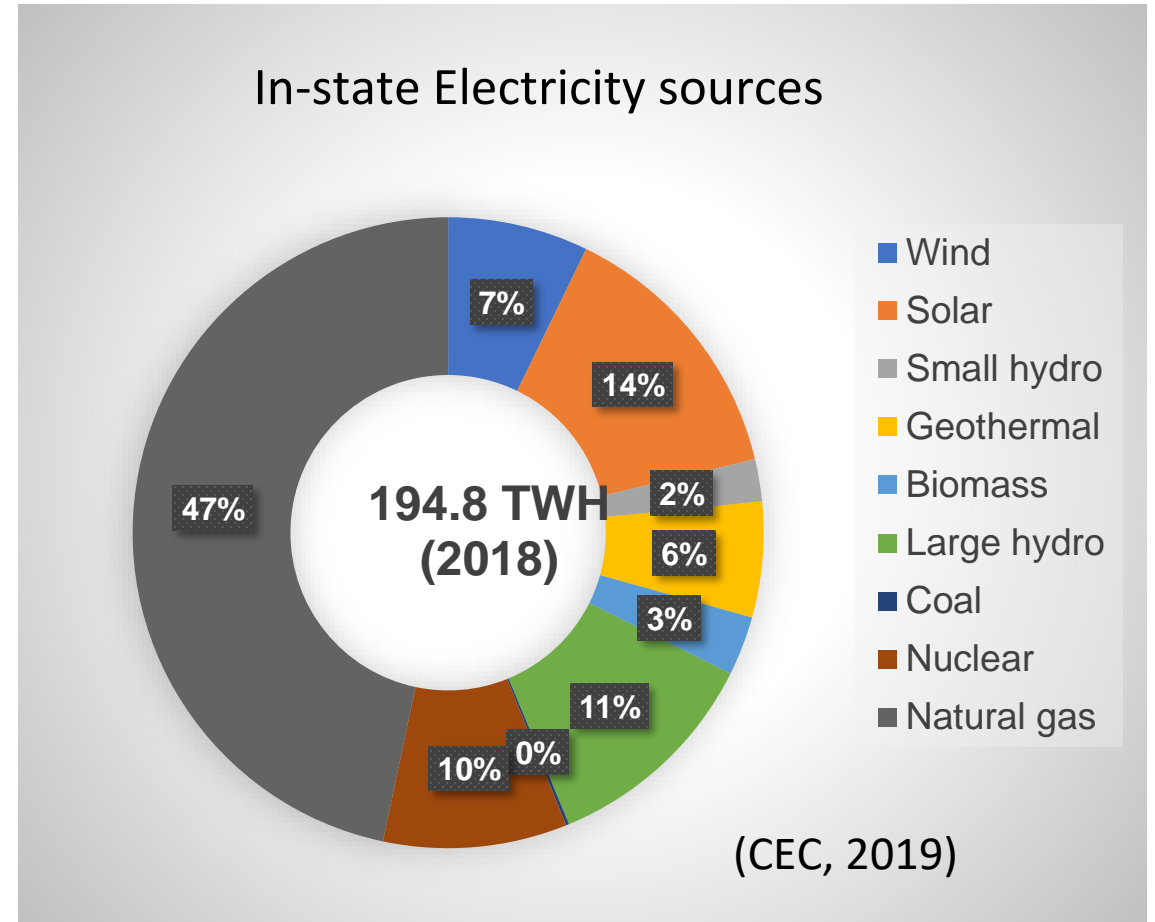
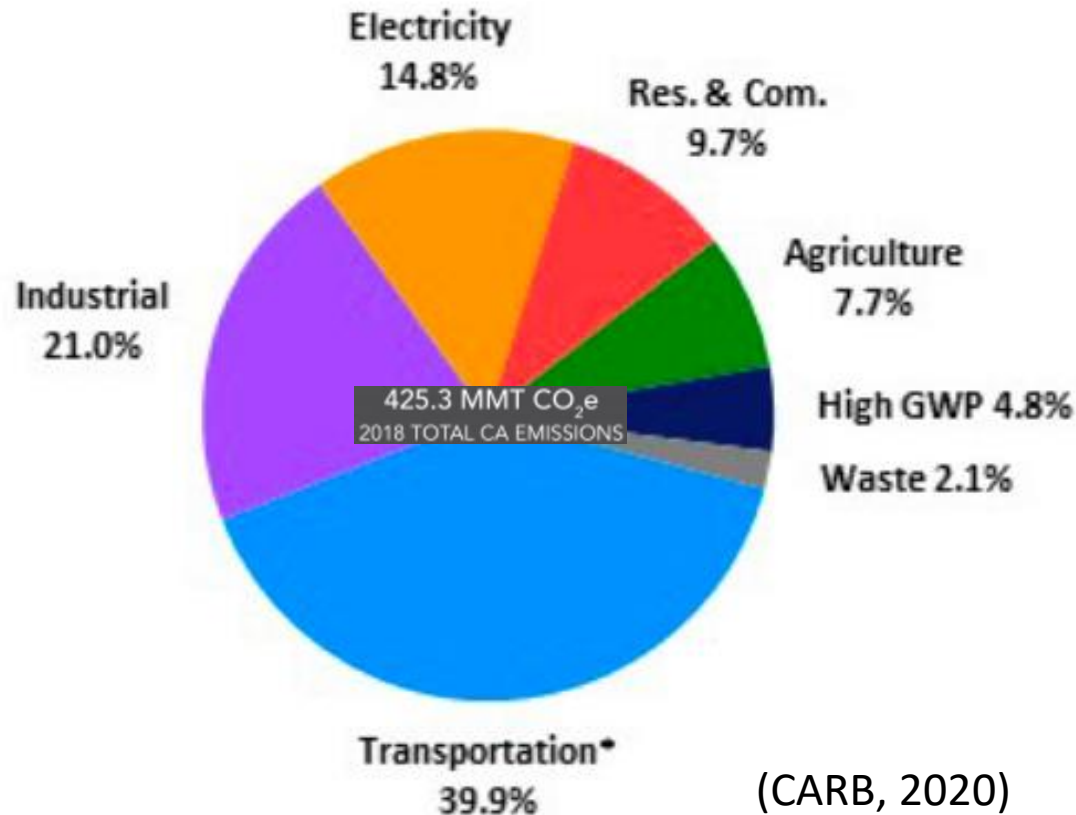
MtCO<sub>2</sub>: million metric tons of CO<sub>2</sub>  
GHG: Greenhouse gas  
CO<sub>2</sub>e: CO<sub>2</sub> equivalent

## Total US GHG Emissions (6,457 MtCO<sub>2</sub>e) by gas in 2017 (EIA, 2019)

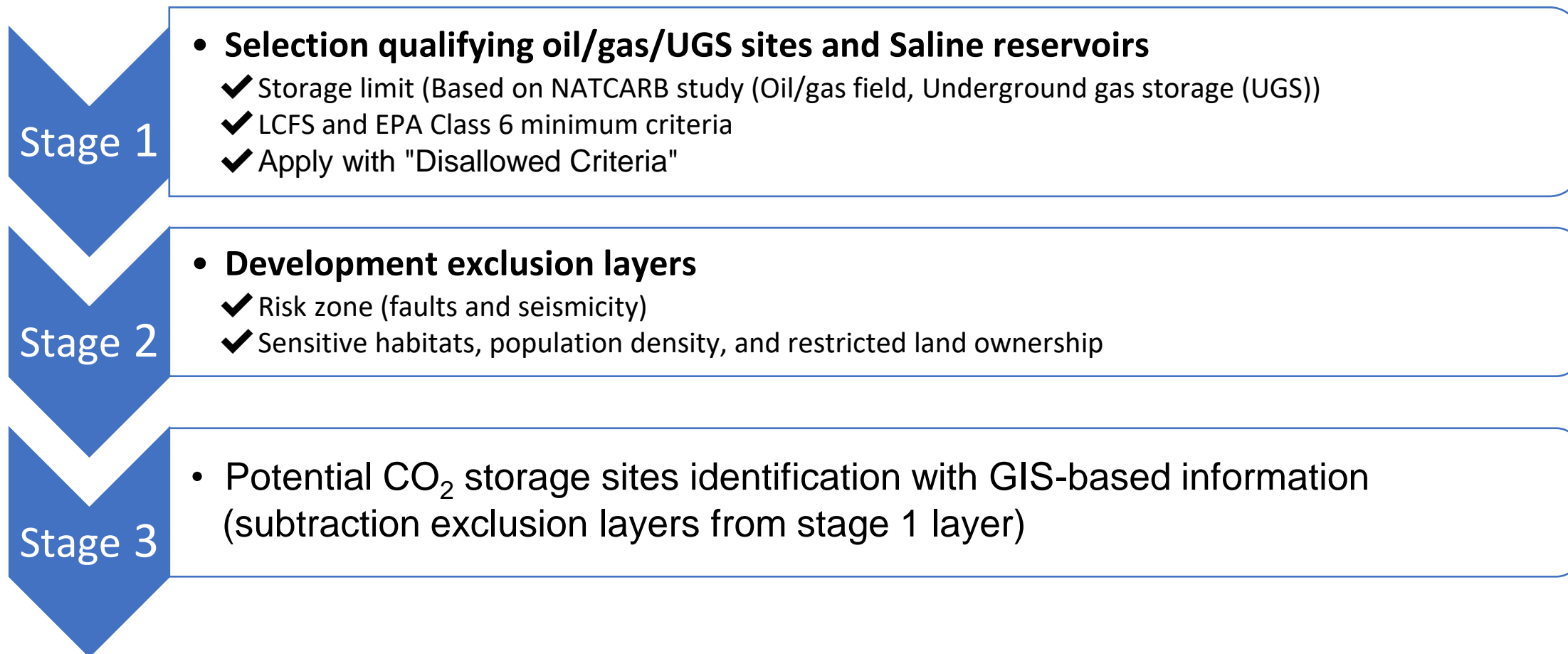


# GHG Emissions in CA

- ❑ CO<sub>2</sub> emissions (2018) in CA: 6.4 % of US, 1 % of global (CARB, 2020)
- ❑ Industrial and electricity sectors: 36 % of the state’s GHG emissions.
- ❑ California’s nonCO<sub>2</sub> emitting electric generation categories: 53 % of electricity



# Reference: Multi-Stage Screening Procedures



# Stage 1: Disallowed Criteria

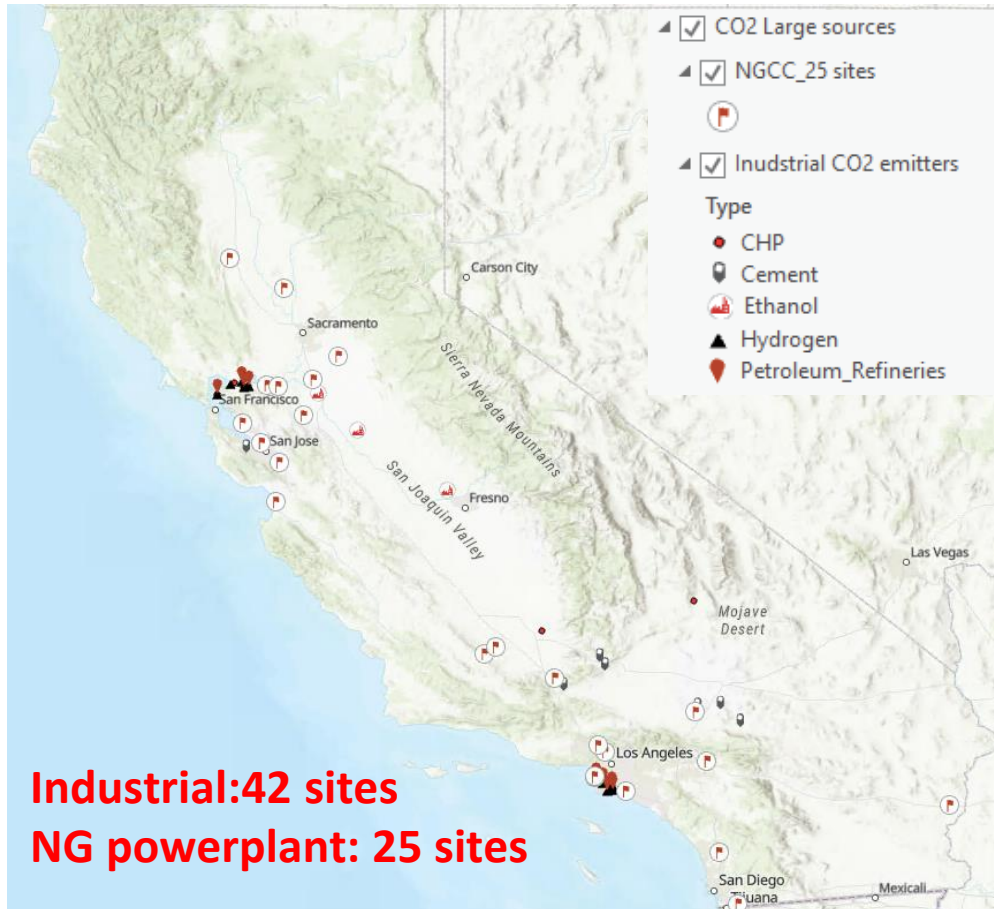
Category	Criteria	Disqualifying Threshold	Disqualified OG/UGS field	EPA IV well Criteria	LCFS Minimum Criteria
Screening parameters	Storage Capacity	< 3 million metric tonnes CO <sub>2</sub>	306 sites	“sufficient areal extent”	“sufficient volume”
	Depth (to top of formation)	<800m	12 sites		“deeper than 800m”
	Permeability	<10mD	2 sites	“sufficient permeability”	“sufficient permeability”
	Porosity	<10%	-	“sufficient porosity”	“sufficient porosity”
	Reservoir Thickness	<3m (one layer) or sum of layers < 10 m	2 sites	“sufficient thickness”	“sufficient thickness”
	Salinity	<10,000 TDS (only dry gas field and UGS)	10 sites	EPA requirement	
	Sufficient Injectivity	Anything that suggests this could be an issue* (e.g. current pressure > 4000 PSI, Assume initial reservoir pressure > 5000 PSI)	1 sites		“sufficient injectivity”

\*Additional disqualified sites: 50 sites (insufficient data) and 4 sites (offshore sites with no 45Q credit)

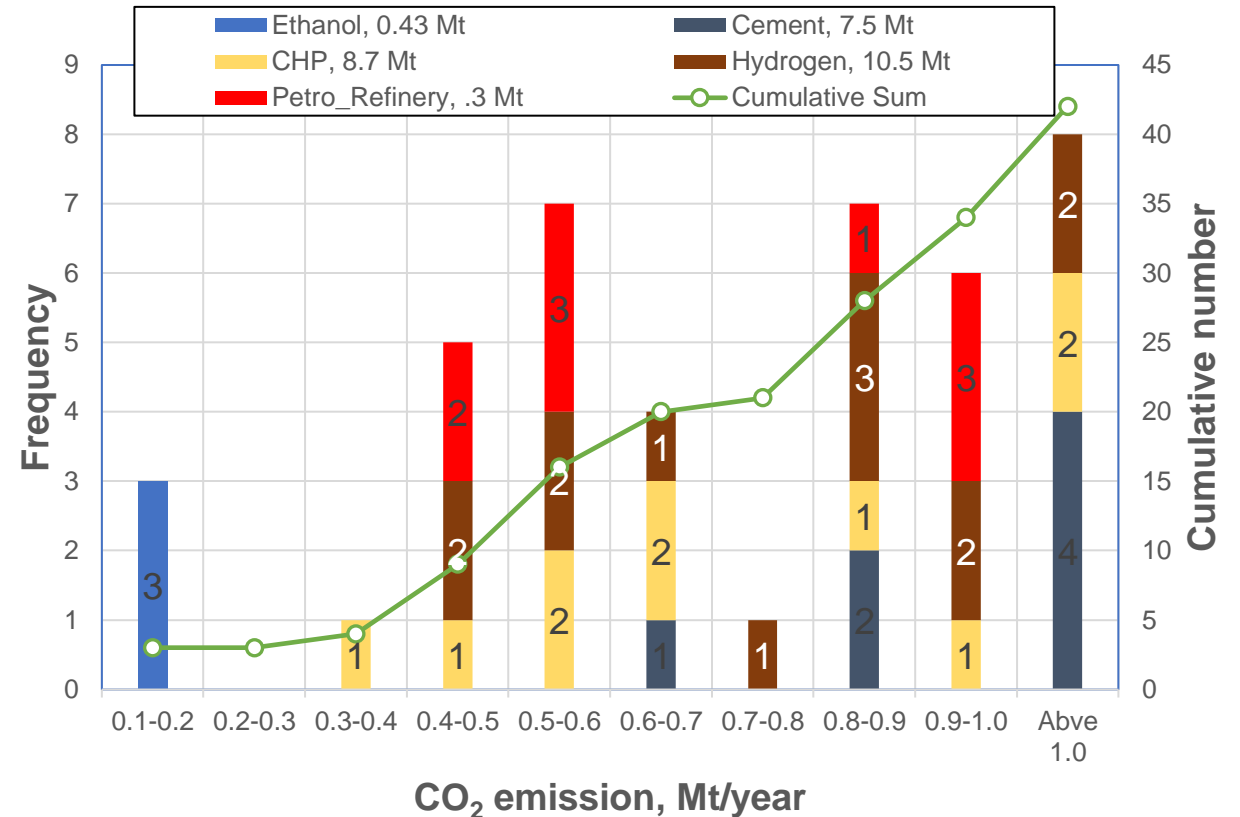
# Reference: CO<sub>2</sub> emitters in CA

## Selection Criteria

- Industrial: Emission amount (EPA 2018) > 0.3 MT<sup>1</sup>/y except Ethanol plant (>0.1 MT/y), total 33.3 MT CO<sub>2</sub> equivalent emission
- NG powerplant: CO<sub>2</sub> capturable amount > 0.5 MT<sup>1</sup>/y (EFI report, 2020), total 27.5 MT CO<sub>2</sub> equivalent emission



## Industrial sources: 42 sites



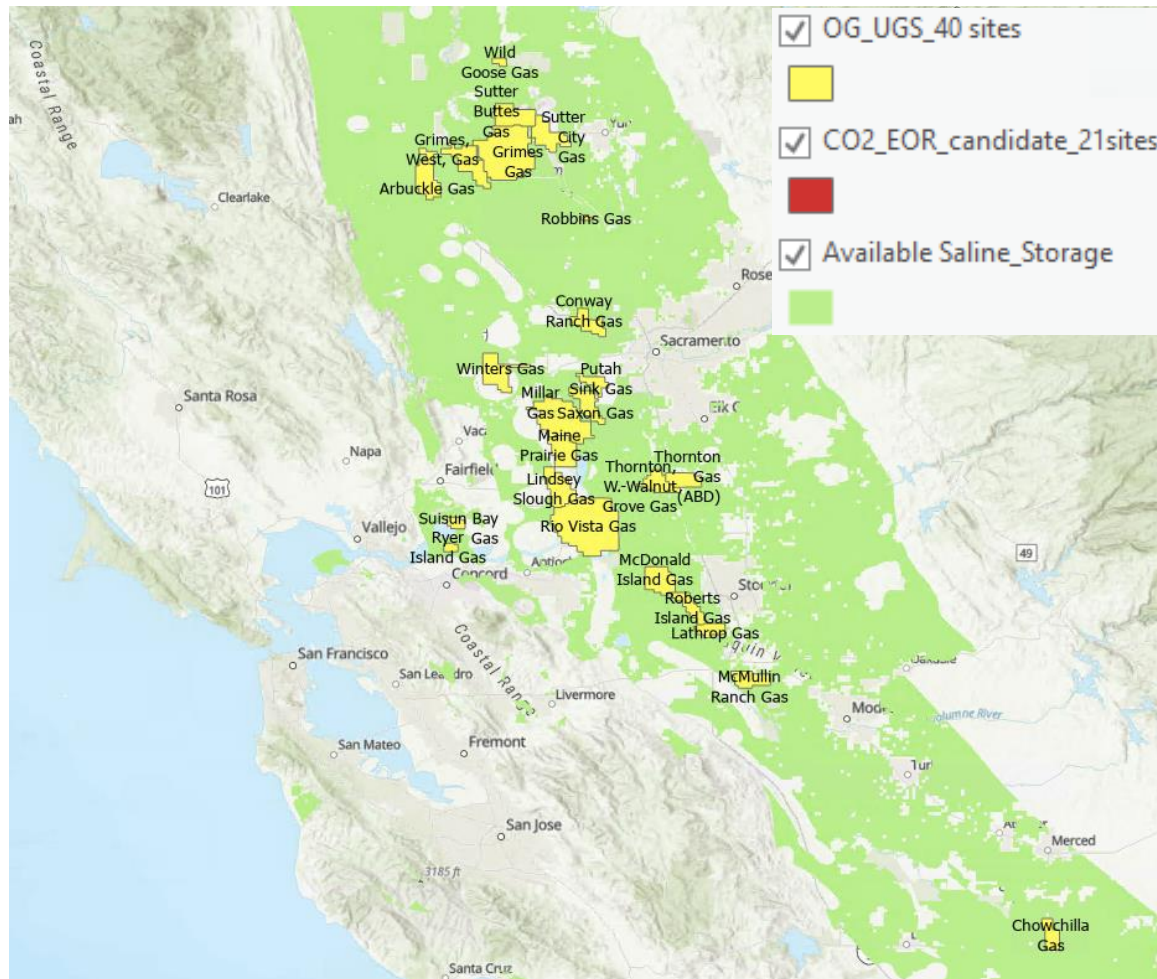
<sup>1</sup>MT: Million metric

# Comparison of 45Q vs. LCFS

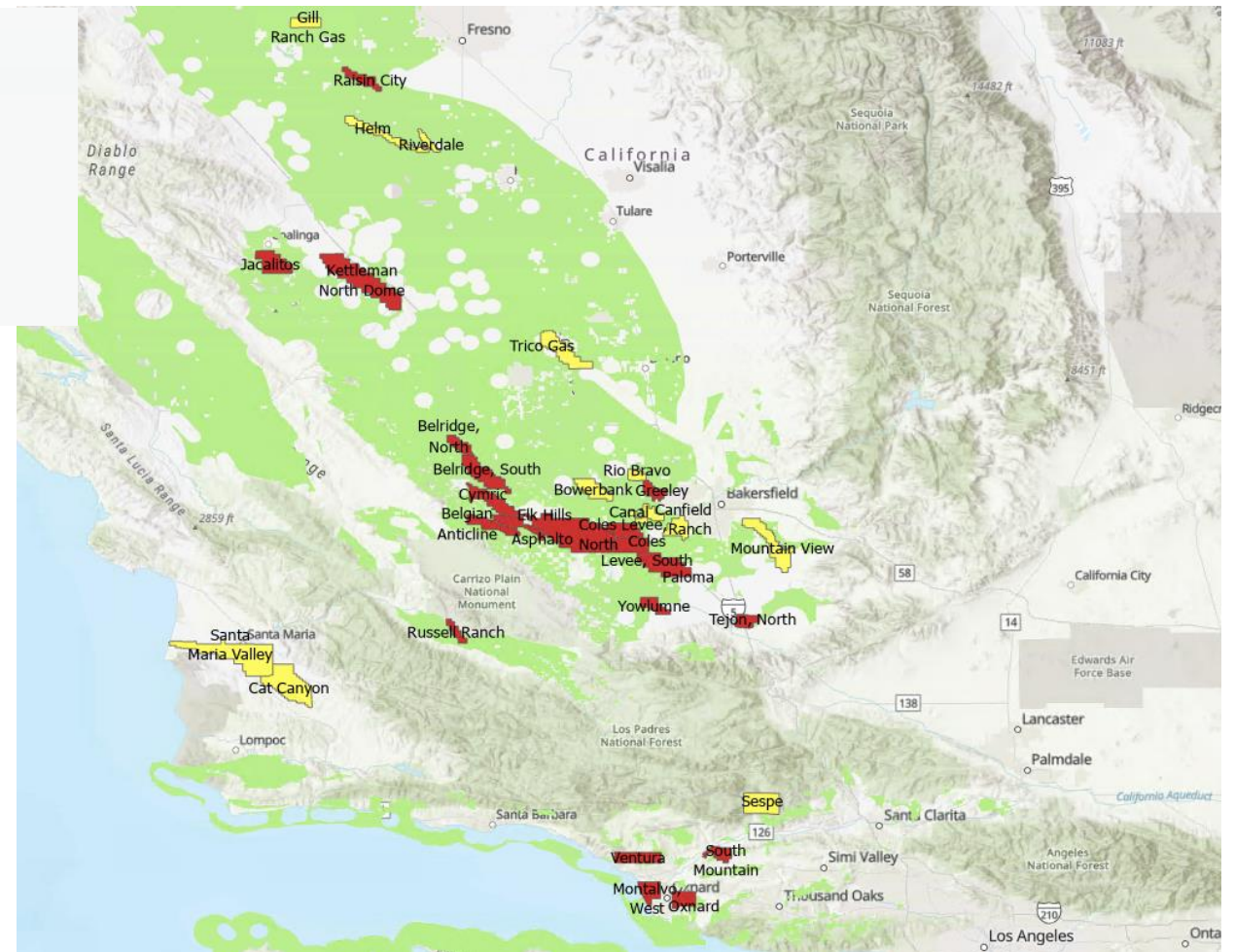
	LCFS	45Q
GEOGRAPHIC SCOPE	Anywhere provided they sell fuel <u>into California</u> (with exception for DAC projects)	Anywhere in the US Saline: Max \$50/Tones of CO <sub>2</sub> CO <sub>2</sub> -EOR: Max \$35/Tones of CO <sub>2</sub>
TYPES OF CCS PROJECT	Any fuel production facility or DAC facility that captures and either stores CO <sub>2</sub> or injects for CO <sub>2</sub> -EOR onshore	Any industrial or DAC facility that stores CO <sub>2</sub> or uses it for EOR or other utilisation purposes
MINIMUM PROJECT SIZE	<u>None</u>	Minimum thresholds for all projects exist (0.1 MMtCO <sub>2</sub> )
EMISSIONS COVERED	<u>CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, VOCs and CO</u>	Carbon oxide
QUALIFICATION PERIOD RESTRICTIONS	None	Construction must begin by 1 Jan 2024
CREDIT GENERATION DURATION	<u>Duration of injection</u>	<u>12 years</u>
CREDIT BUFFER & INVALIDATION	CCS projects must contribute to the Buffer Account	IRS is currently consulting on the approach to the recapture of tax credits in the event of leakage
PERMANENCE REQUIREMENTS	Demonstrated through receiving and maintaining Permanence Certification under the LCFS	IRS is currently consulting on the permanence requirements

# Reference: Potential CO<sub>2</sub> storage sites

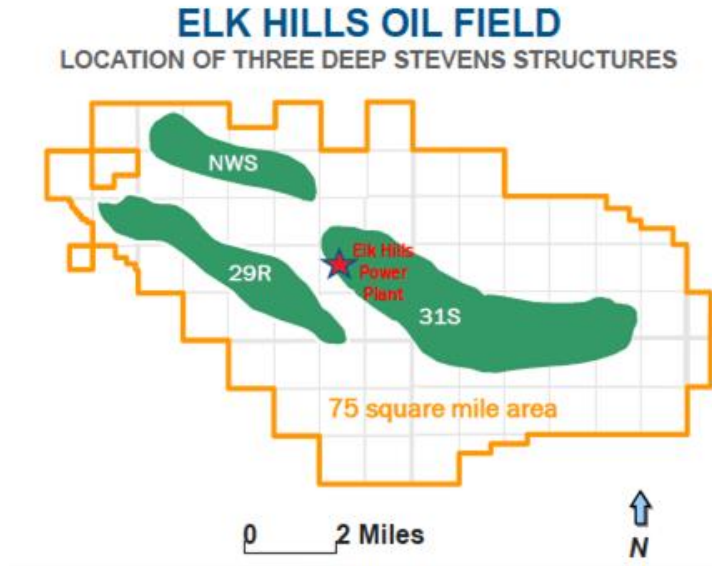
Northern CA



Central/Southern CA

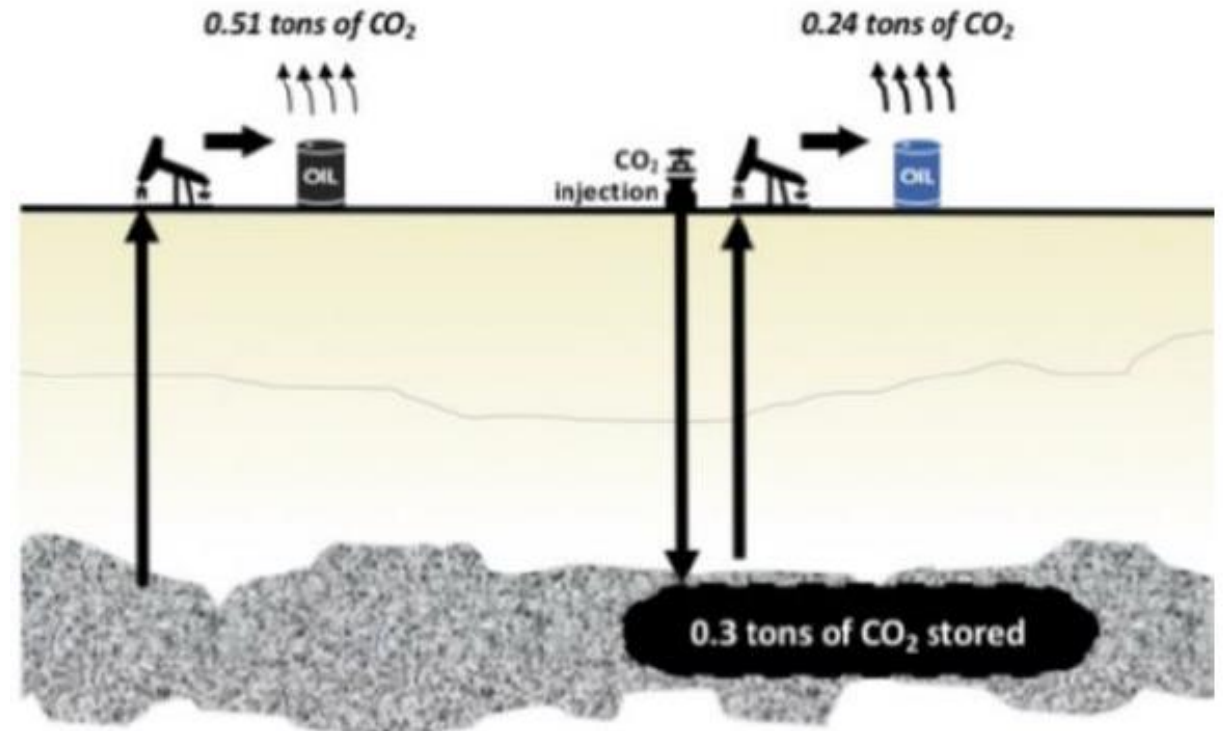


# Reference: Elk Hills Field for CCUS



Conventional Oil Production  
emits 0.51 tons of CO<sub>2</sub> per barrel

Enhanced Oil Recovery  
emits 0.54 tons per barrel. But, it also  
stores 0.30 metric tons of CO<sub>2</sub>  
underground. Thus, net emissions are 0.24  
tons per barrel.



CO<sub>2</sub> sources: Elk Hills Power Plant



(Haney,  
2020)

# Reference: Brea-Olinda OG field

□ Bridge Energy is considering to conduct CO<sub>2</sub>-EOR with the CO<sub>2</sub> source from landfill gas.

- ☑ CO2 Large sources
  - ☑ NGCC\_25 sites
  - ☑ Industrial CO2 emitters
- Type
- CHP
  - 📍 Cement
  - 🏭 Ethanol
  - ▲ Hydrogen
  - 🛢️ Petroleum\_Refineries

CO<sub>2</sub> EOR 22 sites

- High score, 7 sites
- Medium score, 11 sites
- Low score, 4 sites

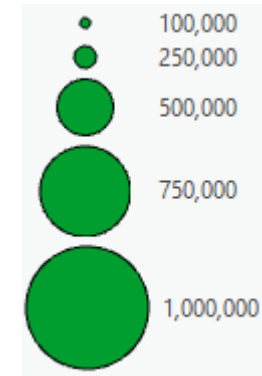
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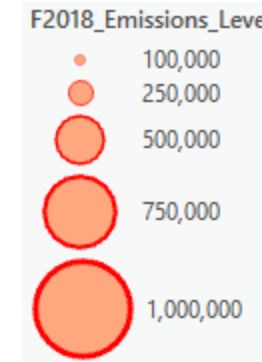


Brea Olinda field is located near the faults area.

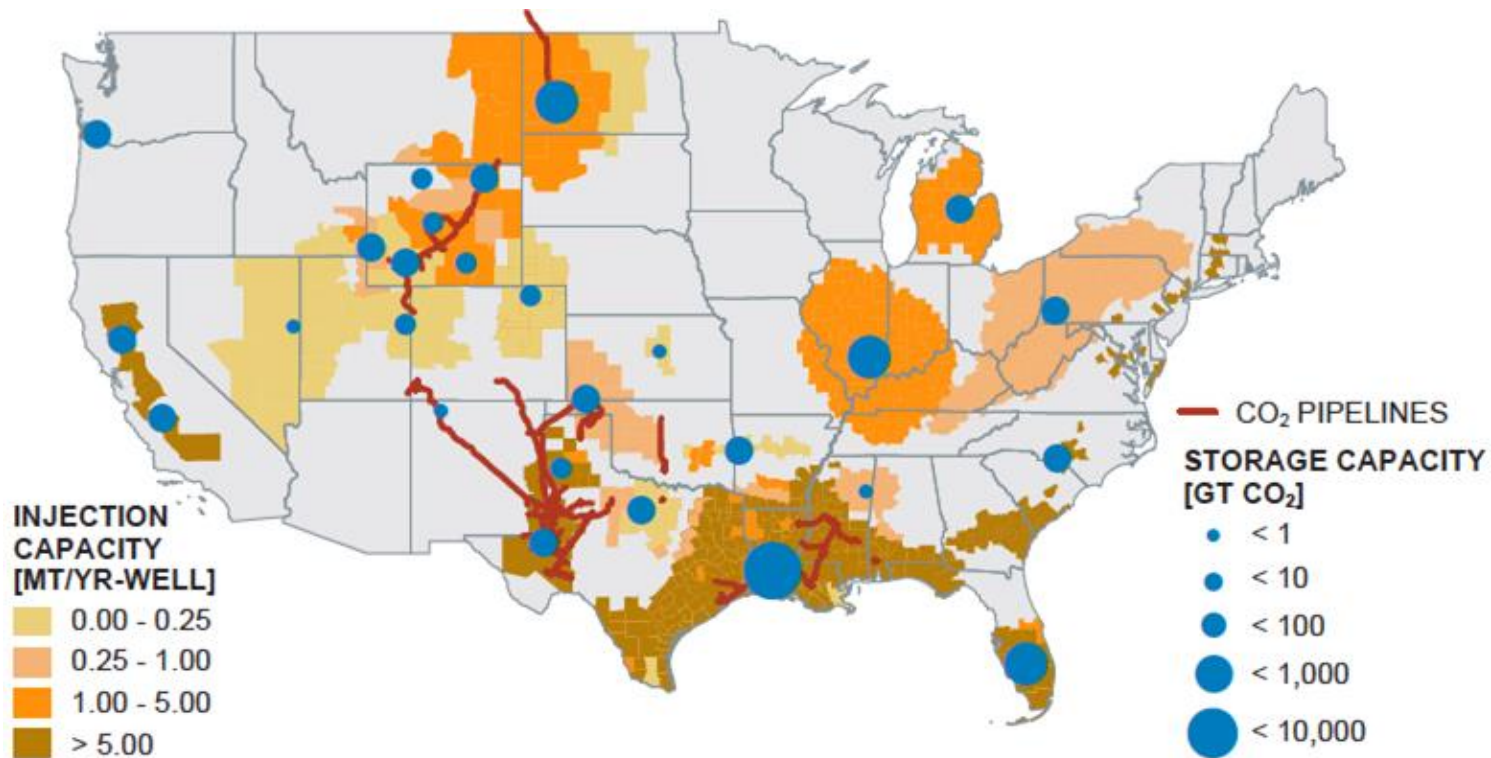
NG Powerplant, CO<sub>2</sub>e tons/year



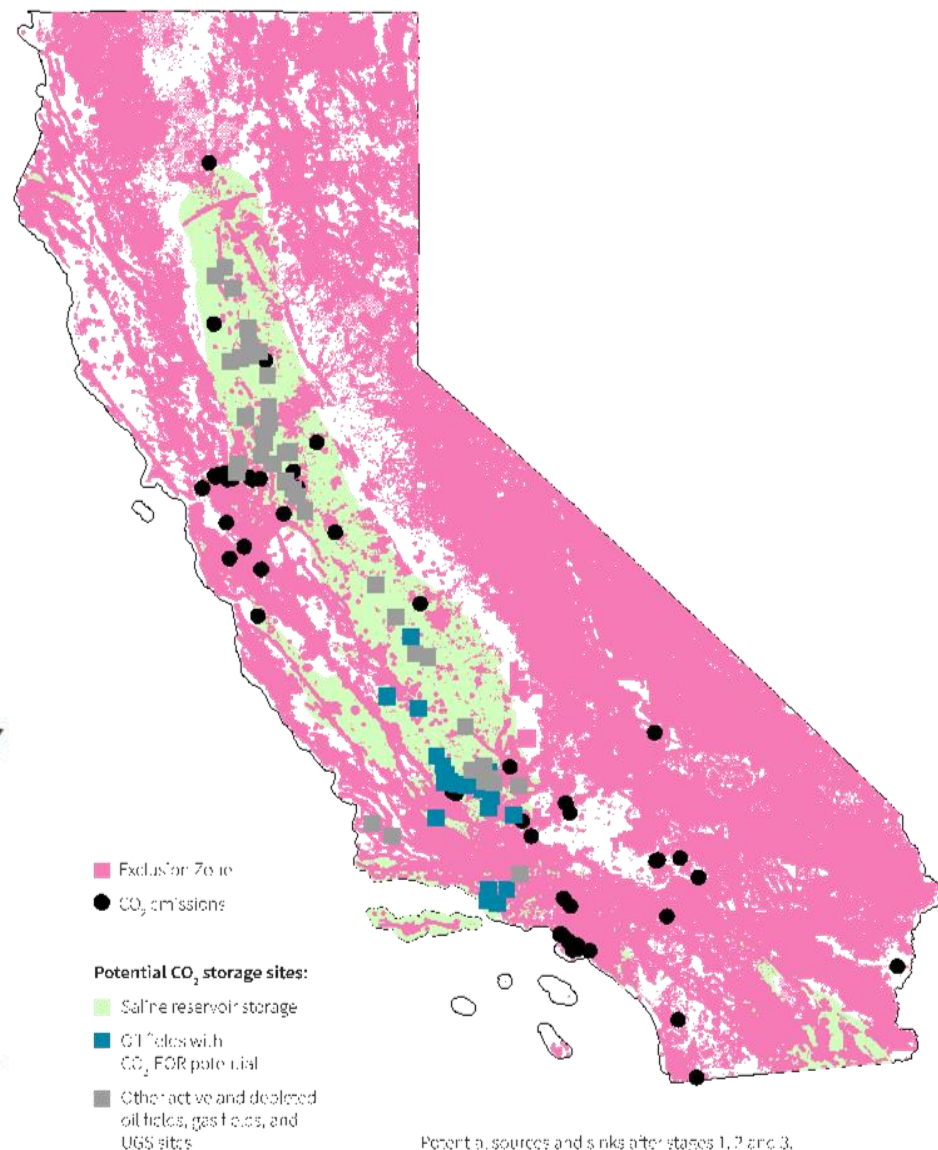
Industrial, CO<sub>2</sub>e tons/year



# Reference: Injection capacity Potential Sink and sources



Source: Baik, E., et al. (2018). "Geospatial analysis of near-term potential for carbon-negative bioenergy in the United States." Proceedings of the National Academy of Sciences, 115(13), 3290-3295.



(EFI/Stanford, 2020)

# Reference: CO<sub>2</sub> storage: Saline formation

$$G_{CO_2} = A_t h_g \phi_{tot} \rho E_{saline} \quad E_{saline} = E_{An/At} E_{hn/hg} E_{\phi_e/\phi_{tot}} E_A E_L E_g E_d$$

Parameters for saline formation efficiency.

Term	Symbol	<i>P</i> <sub>10</sub> / <i>P</i> <sub>90</sub> values by lithology			Description
		Clastics	Dolomite	Limestone	
Geologic terms used to define the entire basin or region pore volume					
Net-to-Total Area	<i>E</i> <sub>An/At</sub>	0.2/0.8	0.2/0.8	0.2/0.8	Fraction of total basin or region area with a suitable formation.
Net-to-Gross Thickness	<i>E</i> <sub>hn/hg</sub>	0.21/0.76 <sup>a</sup>	0.17/0.68 <sup>a</sup>	0.13/0.62 <sup>a</sup>	Fraction of total geologic unit that meets minimum porosity and permeability requirements for injection.
Effective-to-Total Porosity	<i>E</i> <sub>φ<sub>e</sub>/φ<sub>tot</sub></sub>	0.64/0.77 <sup>a</sup>	0.53/0.71 <sup>a</sup>	0.64/0.75 <sup>a</sup>	Fraction of total porosity that is effective, i.e., interconnected.
Displacement terms used to define the pore volume immediately surrounding a single well CO <sub>2</sub> injector.					
Volumetric displacement efficiency	<i>E</i> <sub>V</sub>	0.16/0.39 <sup>a</sup>	0.26/0.43 <sup>a</sup>	0.33/0.57 <sup>a</sup>	Combined fraction of immediate volume surrounding an injection well that can be contacted by CO <sub>2</sub> and fraction of net thickness that is contacted by CO <sub>2</sub> as a consequence of the density difference between CO <sub>2</sub> and <i>in situ</i> water.
Microscopic displacement efficiency	<i>E</i> <sub>d</sub>	0.35/0.76 <sup>a</sup>	0.57/0.64 <sup>a</sup>	0.27/0.42 <sup>a</sup>	Fraction of pore space unavailable due to immobile <i>in situ</i> fluids.

<sup>a</sup> Values from IEA GHG (2009).

(Goodman et al., 2011)