Stanford | Center for Carbon Storage

Development and Application of Site Selection Criteria for offshore carbon sequestration

2019

Multi-Stage Screening Process

Available Data

Stage 1
Screen many potential sites and eliminate those that do not meet qualifying criteria

- Published papers, public databases

Stage 2
Identify and score potential sites using readily available criteria

- USGS data, limited well log data, published papers, state geological survey data, public databases

Stage 3
Selection of suitable sites using detailed characterization

- Pilot test data, modeling studies, lab measurements, seismic data

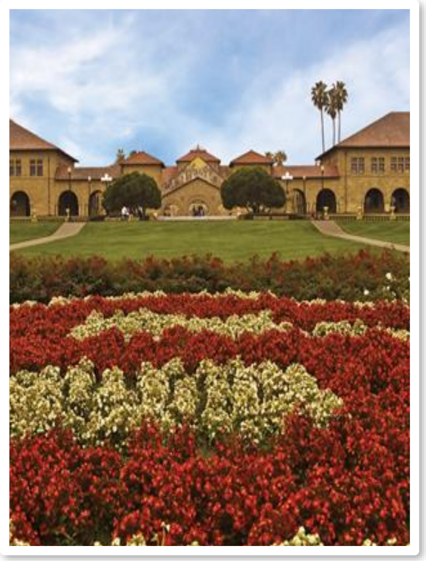
Optimal saline reservoir and depleted reservoir

Major Categories

Storage Optimization	• Finds a site that meets the necessary storage capacity and reservoir characteristics using favorable injection conditions
Risk Minimization	• Minimize the occurrence and potential impact of CO_2 migration and leakage from the site • Examines characteristics of top seal, potential leakage pathways such as faults in addition to other potential hazards to the storage site
Environmental Constraints	• Studies the potential impact to surface and subsurface environments
Consideration of Economic Aspects	• Considers economic factors that might make a site less economically attractive than another

Wei, N. et al. (2013)

Criteria for Depleted Oil and Gas Reservoirs



Stage 1: Disallowed Conditions for Depleted Reservoirs

Category	**Criteria**	**Disqualifying Threshold**
Storage Optimization	Compartmentalization	4 way closure; small compartments
	Top Seal	No top seal
	Secondary Confining Units	No secondary confining units
	Depth of Top of Formation	<800m
	Water Depth	>500 ft
	Permeability	<10 mD
	Porosity	<10%
	Reservoir Thickness	<4 m
	Pressure Buildup	Injection Pressure > Fracture Pressure
Risk Minimization	Top Seal Capillary Pressures	$P_c < P_{entry}$
	Top Seal Thickness	<25m
	Top Seal Continuity	Discontinuous
	Potentially Active Faults	<2 km
	Distance between outcrops & storage sites	<20 km
	Earthquake Record	$M \geq 5$ (< 10 km) & $M \leq 5$ (<5km)
Environmental Constraints	City Nearby	Within Cities
	Distribution of Natural Resources	<10 km
Consideration of Economic Aspects	City Nearby	Within Cities

Stage 2: Storage Optimization for Depleted Reservoirs

Criteria	J=1 (worst)	J=2	J=3	J=4	J=5 (best)
Compartmentalization	4-way closure; medium compartments	3-way closure	2-way closure	1-way closure	Infinite Acting
Depth of Top of Formation	800-1000m	Deep (>3,000 m)	1,000-1,500m	2,000-3,000m	1,500-2,000m
Size (Storage Capacity)	10 MT (7 km3)	50 MT (36 km3)	100 MT (71 km3)	200 MT (143 km3)	500 MT (357 km3)
Permeability	10-20 mD	20-50 mD	>500 mD	50-100 mD	100-500 mD
Porosity	10-15%	15-20%	20-25%	>25%	
Reservoir Thickness	10-20m	20-50m	50-100m	100-300m	>300m
In Situ Pressure (confined reservoirs)	0.9 psi/ft (Severe Overpressure)	>0.7 psi/ft (Overpressure)	>0.5 psi/ft (Mild Overpressure)	≈ 0.43 psi/ft (Hydrostatic)	<0.43 psi/ft (Underpressure)
Geothermal Gradient	Warm Basin (>40C/km)		Moderate (20-40 C/km)		Cold Basin (<20C/km)

Stage 2: Risk Minimization for Depleted Reservoirs

Criteria	J=1 (worst)	J=2	J=3	J=4	J=5 (best)
Primary Seal Formation	Seal by different lithology		Regional Seal Formation		Basin-scale seal formation
Top Seal Capillary Entry Pressure	P_{entry} (5-10 bars)		P_{entry} (10-100 bars)		P_{entry} (>100 bars)
Top Seal Clay Content	Low clay (≈ 20%)				High clay (>40%)
Top Seal Vertical permeability	>0.01 mD				< 100 nD
Bottom Seal/potential for pressure transmission to the basement	No seal		Seal with vertical permeability 1 µD		Seal with vertical permeability <100 nD
Secondary Confining Units	1 confining unit				2 confining units
Trapping Mechanism	Rollover anticline into growth fault, faulted anticline, fault trap (normal)		Stratigraphic		Anticline
Stacked Reservoir (Number of Layers)	1		2+		3+
Nature of Faults	Extensively faulted and fractured		Moderately faulted and fractured		Limited faulting and fracturing
Presence of Quaternary Faults at Reservoir Depth	<3 km from closest injection well		< 5km from closest injection well		10 km from closest injection well
Number of Existing/abandoned Oil and Gas Wells	Extensive		Moderate		Limited
Age of Existing Oil and Gas Wells/ available data	More than 40 years/ No data available		Between 10 and 40 years		Last 10 years/ good data available
Previous Resource in Reservoir	Depleted Oil		Depleted Oil + Gas Reservoir		Depleted Gas Reservoir

Stage 2: Environmental Constraints for Depleted Reservoir

Criteria	J=1 (worst)	J=2	J=3	J=4	J=5 (best)
Depth of natural resources currently being used or likely to be explored in future research	800-2,000m		200-800m		<200m

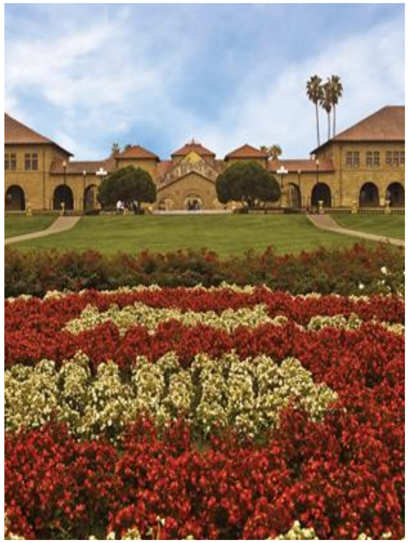
Stage 2: Consideration of Economic Aspects for Depleted Reservoir

Criteria	J=1 (worst)	J=2	J=3	J=4	J=5 (best)
City Nearby	<5 km	<10 km	<15 km	<20 km	>25 km
CO2 Sources	None	Few	Moderate	Major	
Proximity to Sources	Distant		Acceptable		Close
Permitting	Difficult		Moderate		Easy
Infrastructure	None	Minor	Major	Extensive	
Accessibility	Inaccessible	Difficult	Acceptable	Easy	

Stage 3: Detailed Reservoir Characterization for Depleted Reservoirs

Categories	Criteria	Narrative
Storage Optimization	Pressure Buildup	Pressure change cannot exceed the hydraulic fracture pressure of the reservoir or the top seal nor can it exceed the capillary entry pressure of the top seal.
	Number of Injection Wells Needed	The cost of the project increases with the number of wells that are needed for injection. However, there is an upper limit to how much can be injected into a single well. Furthermore, you don't want to inject too much into a single well in case you lose that well. Frictional losses can also be significant, which constrains the maximum injection rate per well.
	Vertical Heterogeneity	Higher pore space utilization at contrast ratios >50.
	Horizontal Heterogeneity	The plume will spread uniformly away from the injection well in a homogenous reservoir. It is easier to monitor due to a continuous plume.
Risk Minimization	Top Seal Continuity	The top seal needs to be continuous over the spatial extent of the plume to minimize leakage risk.
	State of Stress in Top Seal	A clay-rich ductile formation is highly preferred. Low-stress anisotropy reduces the tendency for faulting and increases the hydraulic fracturing pressure.
	Original Column Height	The buoyancy pressure associated with the original column height of oil and/or gas is an excellent indicator of top seal capacity.
	CO_2 Secondary Trapping Mechanisms (Residual, Solubility, Mineral)	Secondary trapping for CO_2 can make the CO_2 immobile and increases storage security. Mineral trapping is the most secure but takes the longest amount of time to occur.
	Dip of Formation	The dip of formation can influence the migration of CO_2.
	Fault Permeability	As a part of reservoir characterization, the permeability of any faults that are present (even those not likely to slip) as well as the permeability of any damage zones associated with the faults needs to be assessed as potential leakage pathways.
	Fault Juxtaposition	Fault juxtaposition of sands and shales can act as a barrier and limit the cross-fault flow.
	Age of Fault Displacement	Determination of the age of the most recent fault displacement can show whether a fault is potentially active.
	Potentially active small-scale faults	If high resolution geophysical data reveal the presence of potentially active faults, pressure changes should not exceed that which would be expected to induce slip on those faults.

Stage 2 Scoring



Scoring a Site

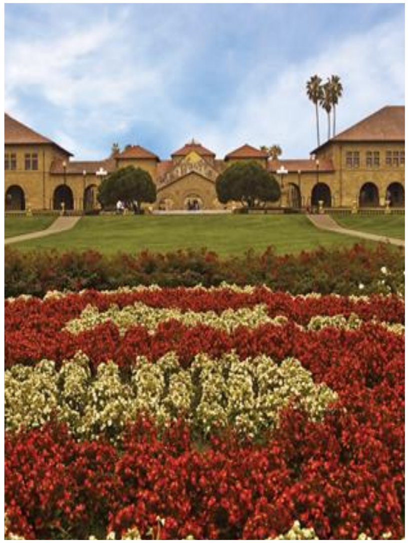
Level 2 Storage Optimization

	Criteria	*J=1 (worst)*	*J=2*	*J=3*	*J=4*	*J=5 (best)*	Weight
i=1	Compartmentalization	1	2	3	4	5	0.03
i=2	Depth of Top of Formation	1	2	3	4	5	0.05
i=3	Size (Storage Capacity)	1	2	3	4	5	0.05
i=4	Permeability	1	2	3	4	5	0.05
i=5	Porosity	1	1.67	3.3	5		0.03
i=6	Reservoir Thickness	1	2	3	4	5	0.03
i=7	In Situ Pressure	1	1.67	3.3	5		0.02
i=8	Geothermal Gradient	1		2.5		5	0.02
i=9	Salinity (for saline reservoirs)	1	1.67	3.3	5		0.02

To score this site:

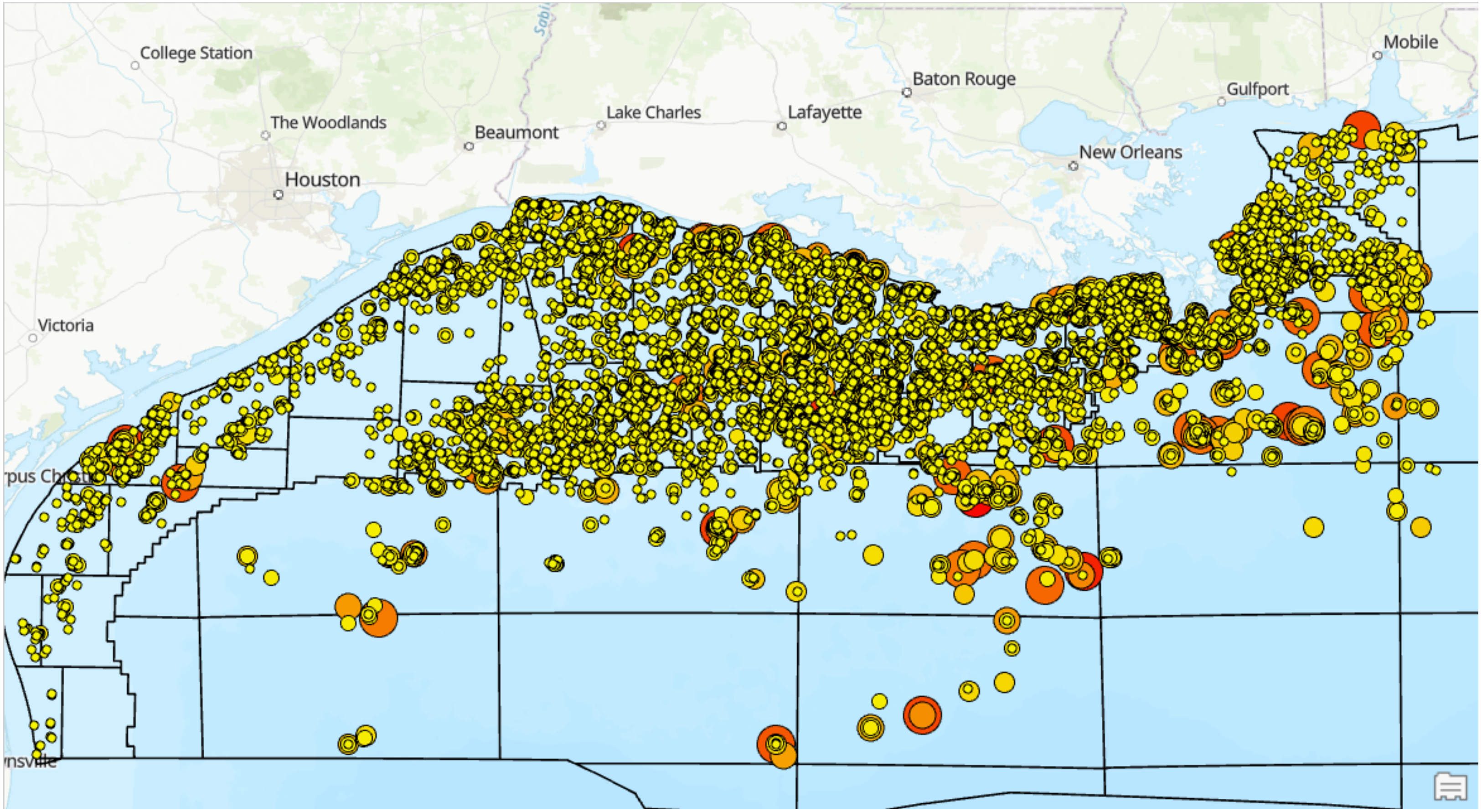
$$score = \sum_i^n w_i P_i^k = 0.956$$

BOEM Data Example



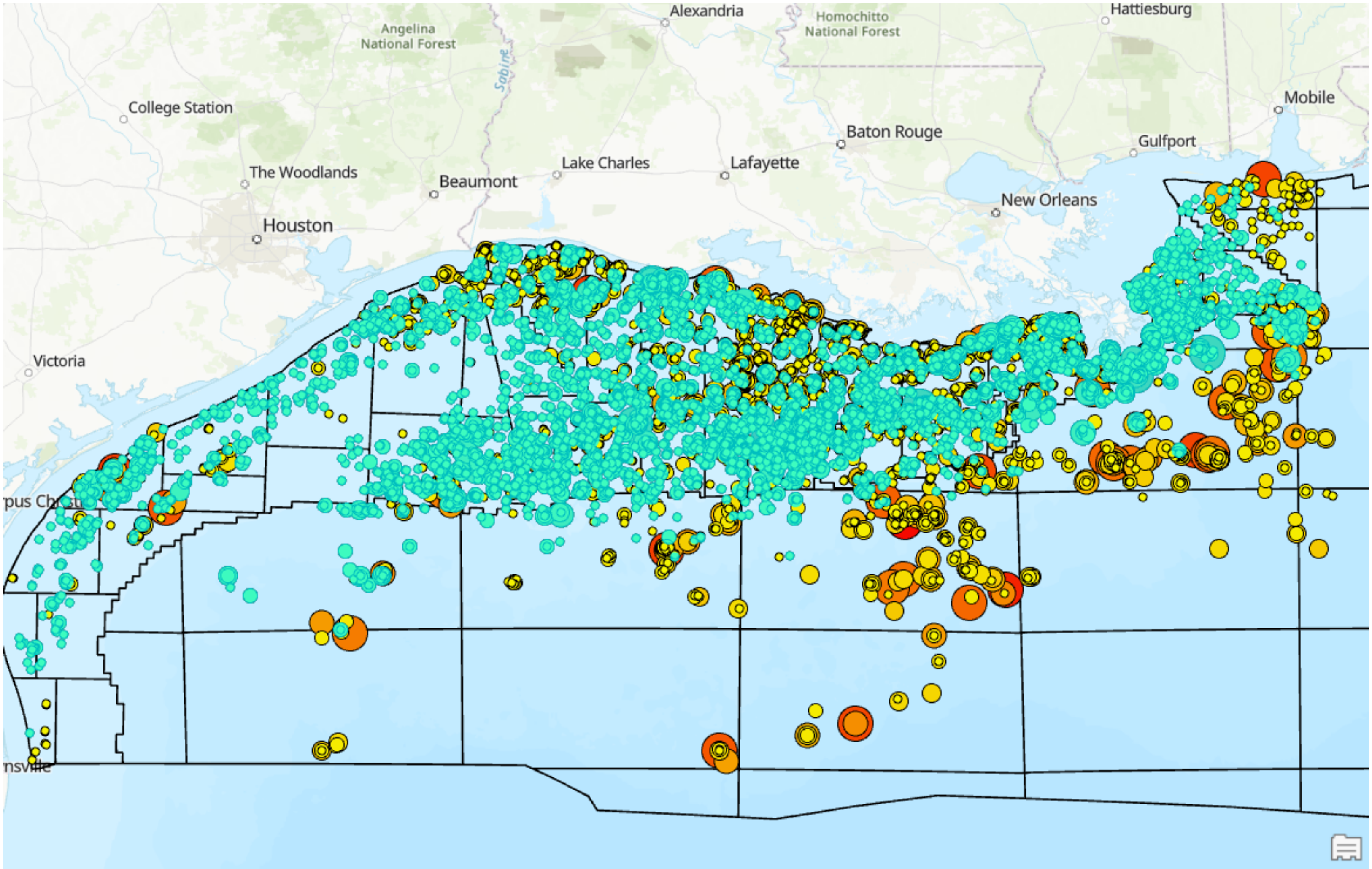
BOEM Dataset by Original BOE

13,381 total sands; 13,279 sands with complete data



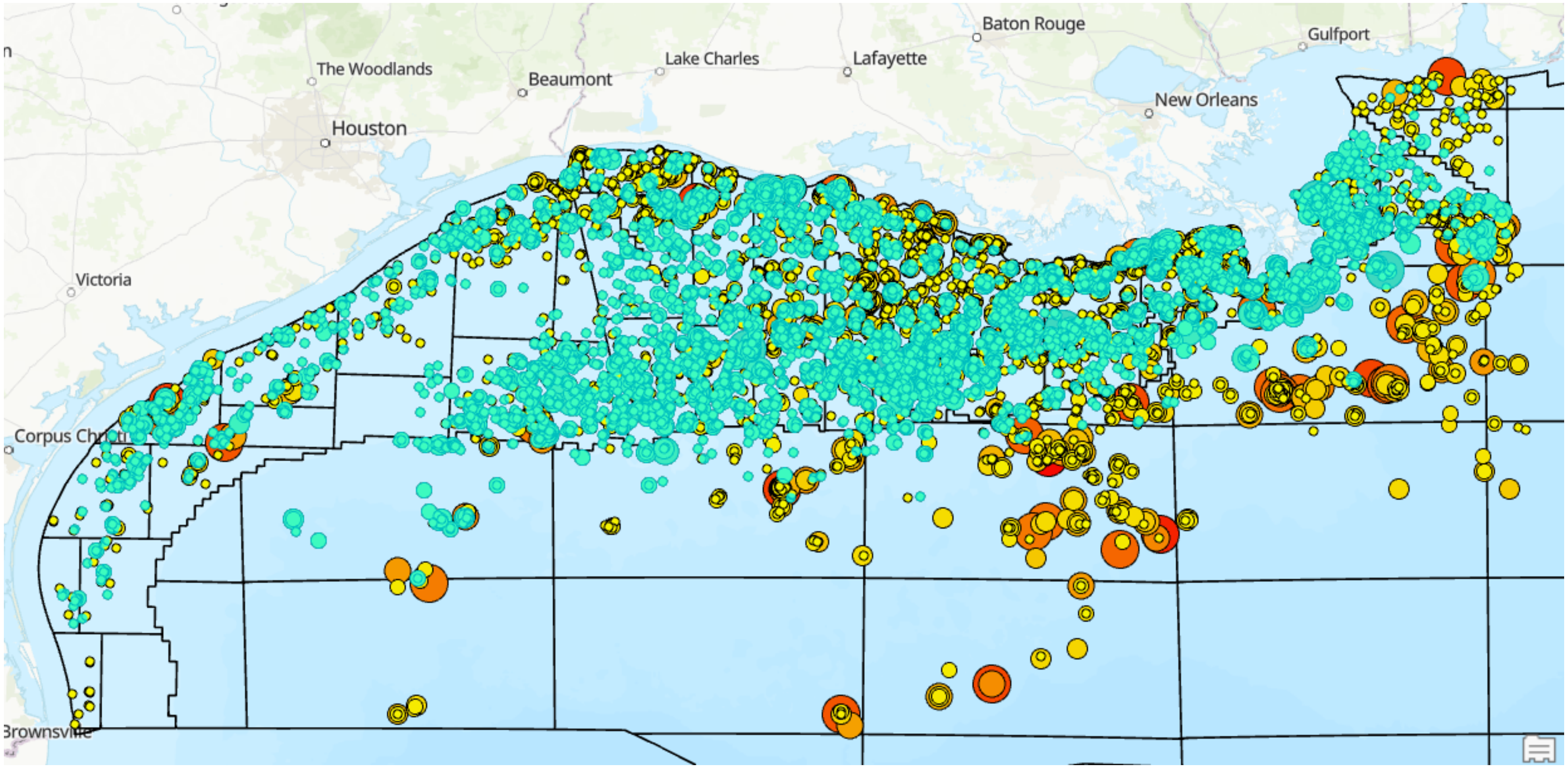
First Filter is Subsea Depth (≥ 2,264 ft & ≤10,000 ft)

13,279 sands → 8,258 sands (mostly deep reservoirs)



2nd Filter is Thickness (≥ 13 ft)

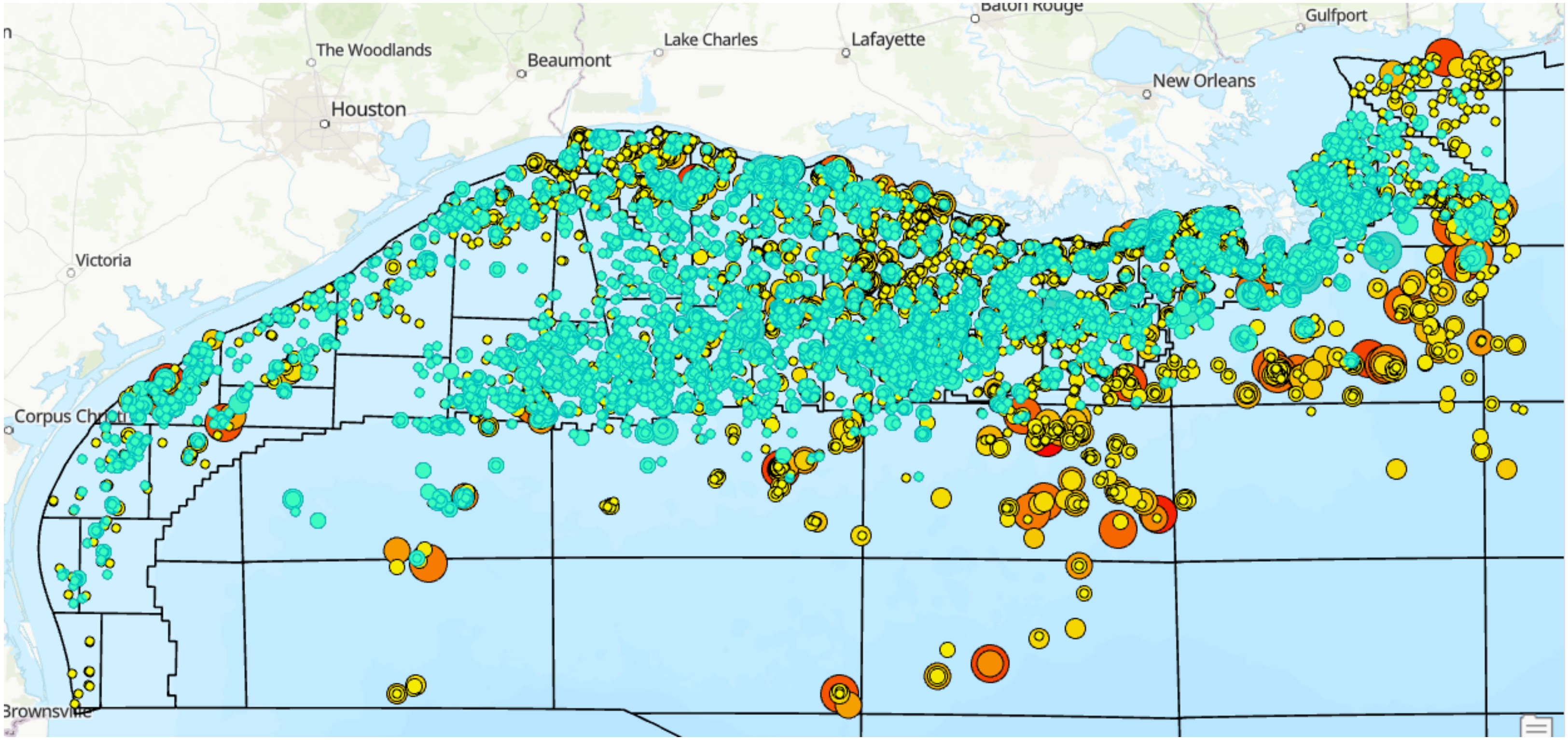
8,258 sands → 4,997 sands



BOEM Dataset by Original BOE

Next Filter is Porosity and Permeability (≥ 10% & ≥ 10 mD)

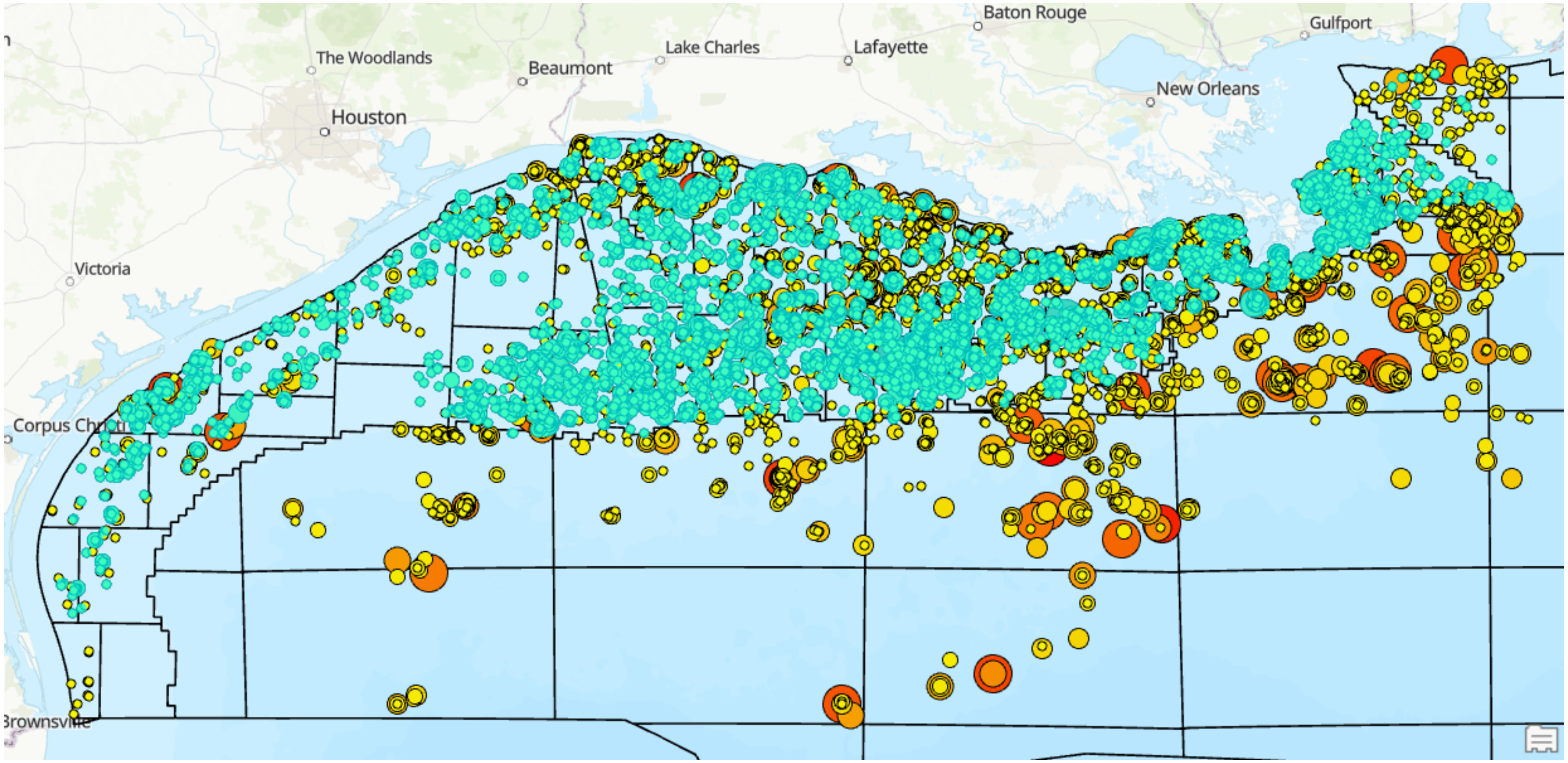
4,997 sands → 4,952 sands



BOEM Dataset by Original BOE

Next Filter is Water Depth (≤ 500 ft)

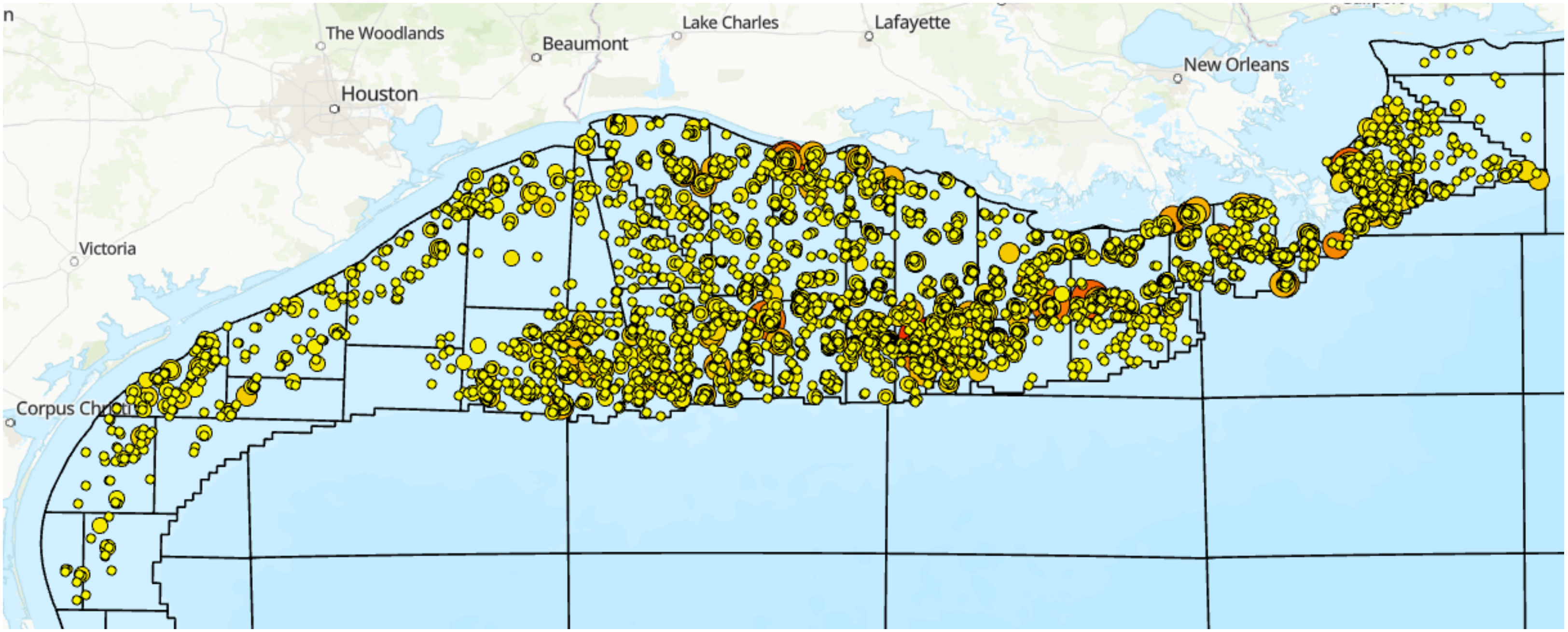
4,952 sands → 4,663 sands



BOEM Dataset by Original BOE

End of Stage 1 Filtering

Total 4,663 sands



BOEM Dataset by Original BOE

Capacity Estimates

CSLF Phase III Report by Stefan Bachu (2008)

CSLF-Proposed Methodology. Consistent with the resource-reserves pyramid concept, both theoretical and effective CO_2 storage capacities are calculated according to:

$$M_{CO2t} = \rho_{CO2r} \times R_f \times (1 - F_{IG}) \times OGIP \times [(P_s \times Z_r \times T_r) / (P_r \times Z_s \times T_s)] \quad (5)$$

for gas reservoirs, and by:

$$M_{CO2t} = \rho_{CO2r} \times [R_f \times OOIP / B_f - V_{iw} + V_{pw}] \quad (6)$$

for oil reservoirs.

An alternate equation for calculating the CO_2 storage capacity in oil and gas reservoirs is based on the geometry of the reservoir (areal extent and thickness) as given in reserves databases:

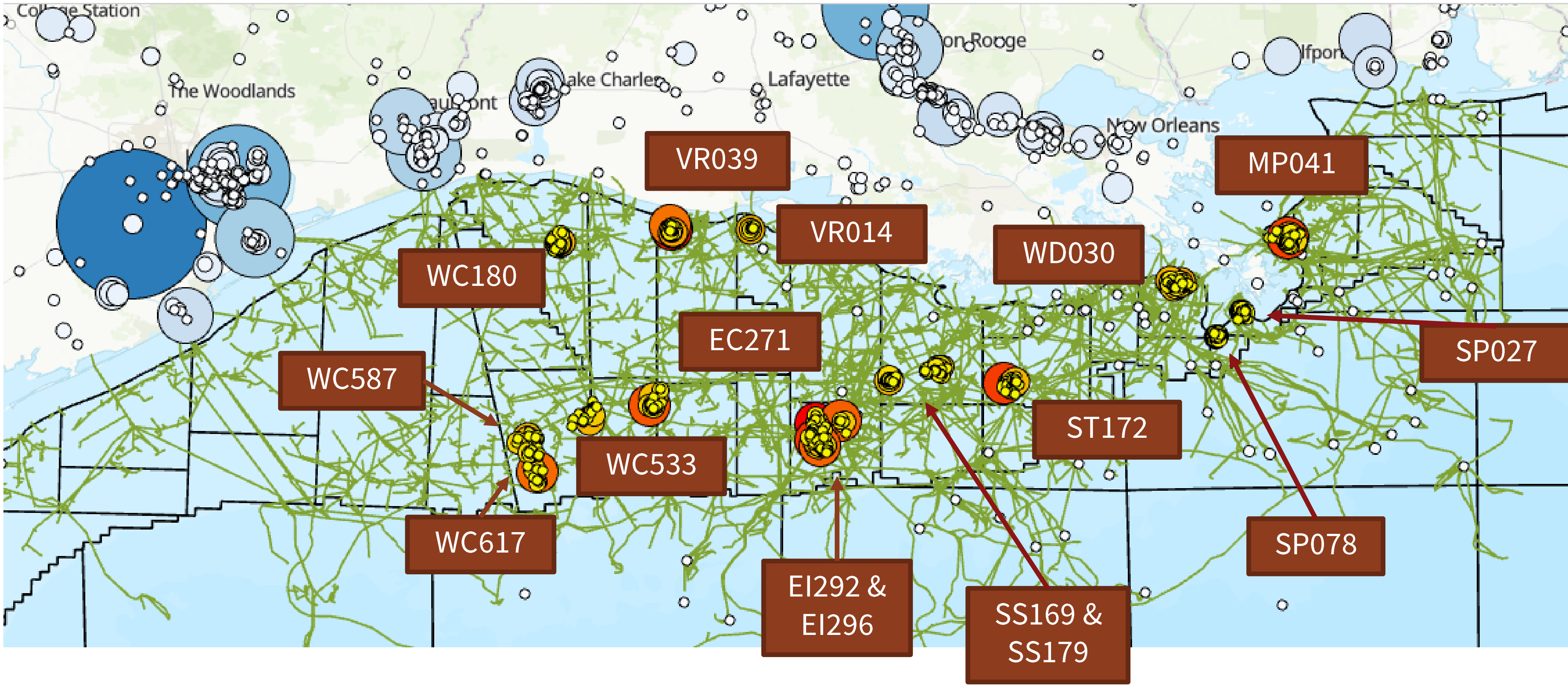
$$M_{CO2t} = \rho_{CO2r} \times [R_f \times A \times h \times \phi \times (1 - S_w) - V_{iw} + V_{pw}] \quad (7)$$

R_f is the recovery factor
F_{IG} is the fraction of injected gas
P,T,Z denote pressure, temp., and gas compressibility factor
B_f is the formation volume factor
V_{iw} and V_{pw} are the volumes of injected and produced water

Top Fields from CO_2 Capacity Estimates

Rank	BOEM Field	CO2 Capacity Estimate Range
1	EI 330	224 - 312 MT
2	VR 039	220 - 247 MT
3	MP 041	182 - 239 MT
4	EI 292	189 - 204 MT
5	ST 172	168 - 169 MT
6	WC 180	146 - 147 MT
7	SS176	115 - 134 MT
8	WD030	96 - 126 MT
9	EC271	112 - 120 MT
10	SS 169	71 - 116 MT
11	WC 587	113 - 115 MT
12	TS000	94 - 110 MT
13	WC 533	109 MT
14	SP 027	71 - 106 MT
15	EI 296	104 MT
16	SP 078	80 - 101 MT
17	WC 617	99 MT

Fields with Capacity > 100 MT



Thank You for listening

We acknowledge ExxonMobil for their support of this work