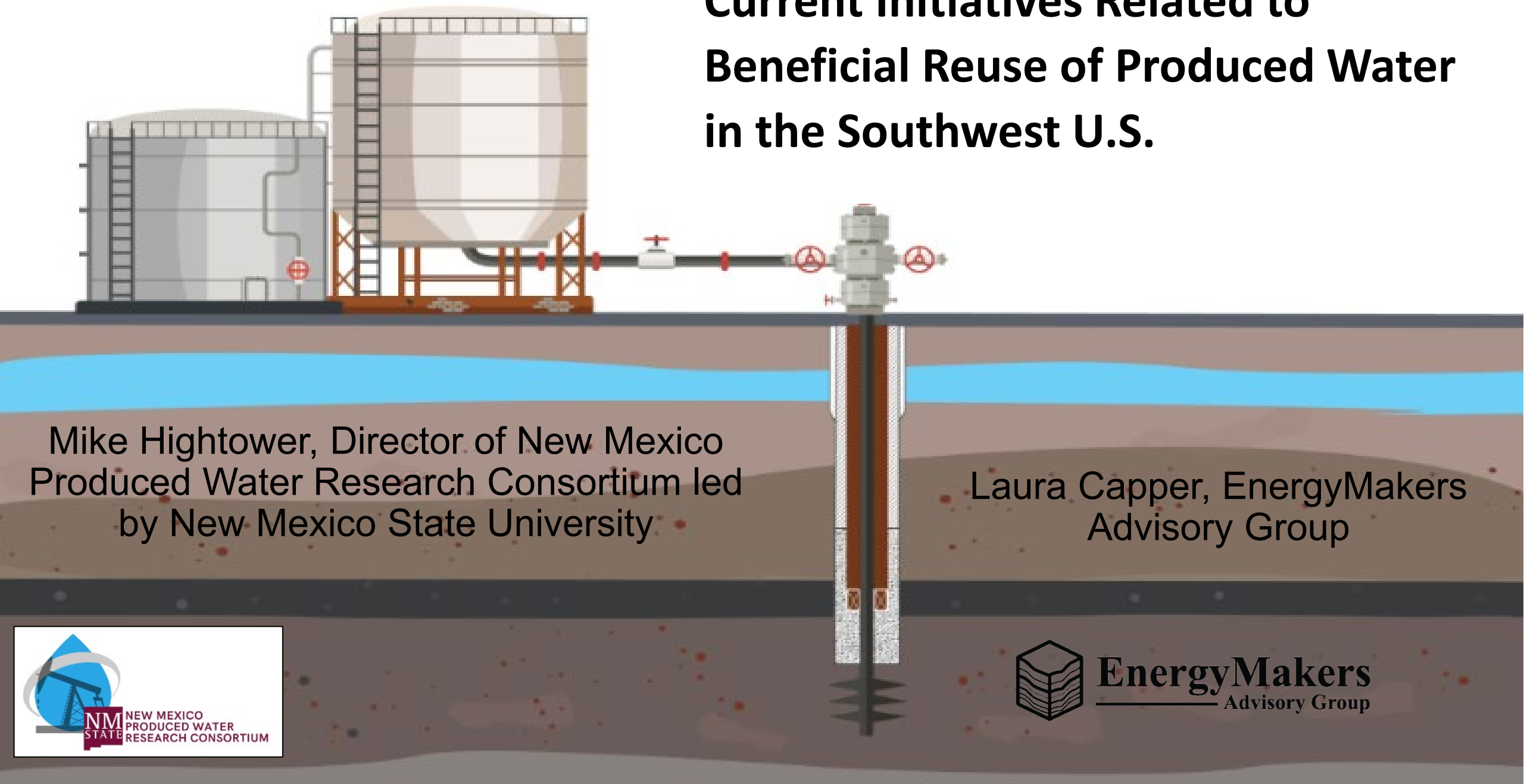
Current Initiatives Related to Beneficial Reuse of Produced Water in the Southwest U.S.



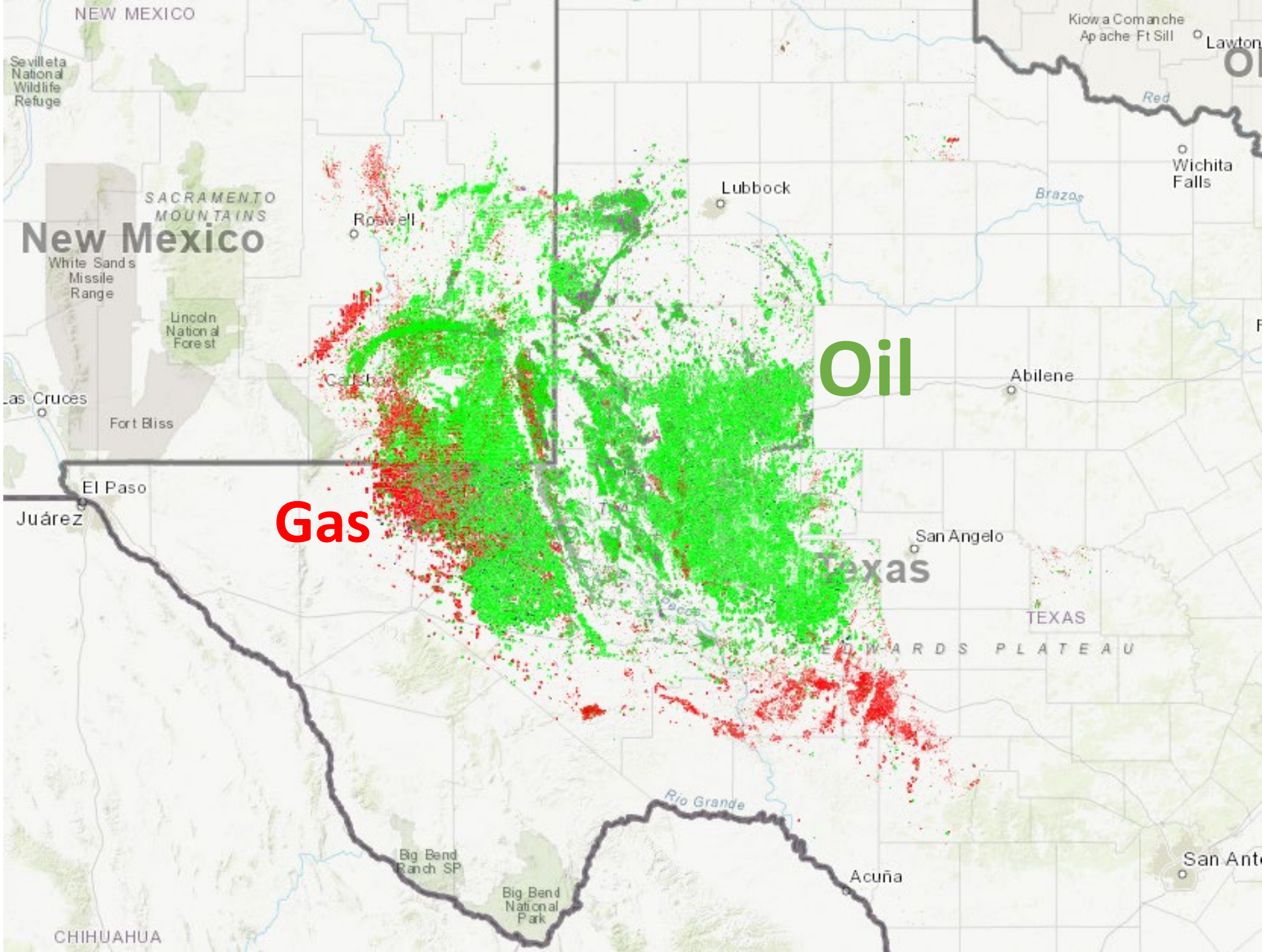
Mike Hightower, Director of New Mexico Produced Water Research Consortium led by New Mexico State University

Laura Capper, EnergyMakers Advisory Group

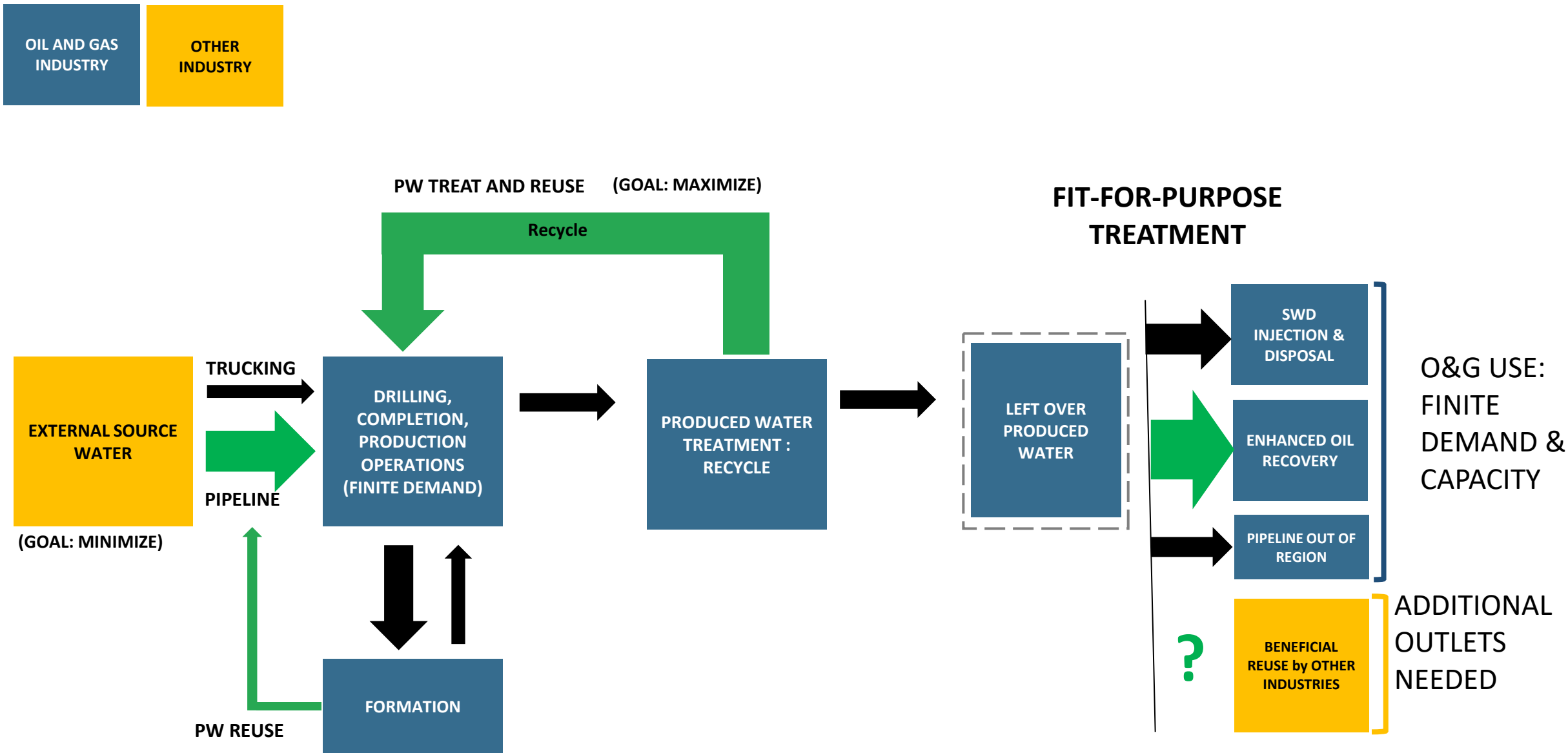
NM STATE NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM

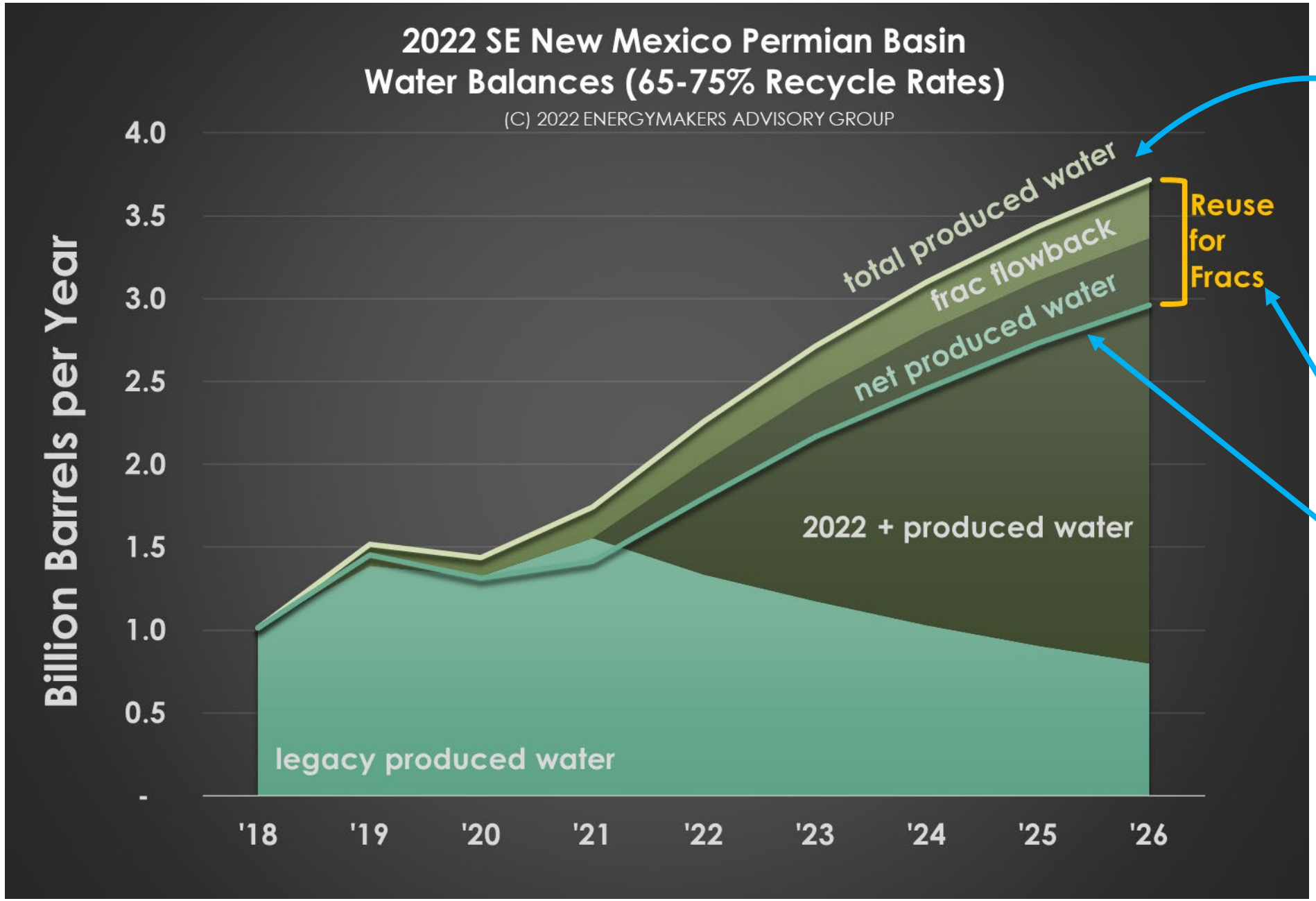
EnergyMakers Advisory Group

Permian Oil and Gas Production, 2022



Oil and Gas Water Management Cycle (not to scale)





"Wall of Produced Water" co-produced with Oil and Gas (O&G) in SE New Mexico

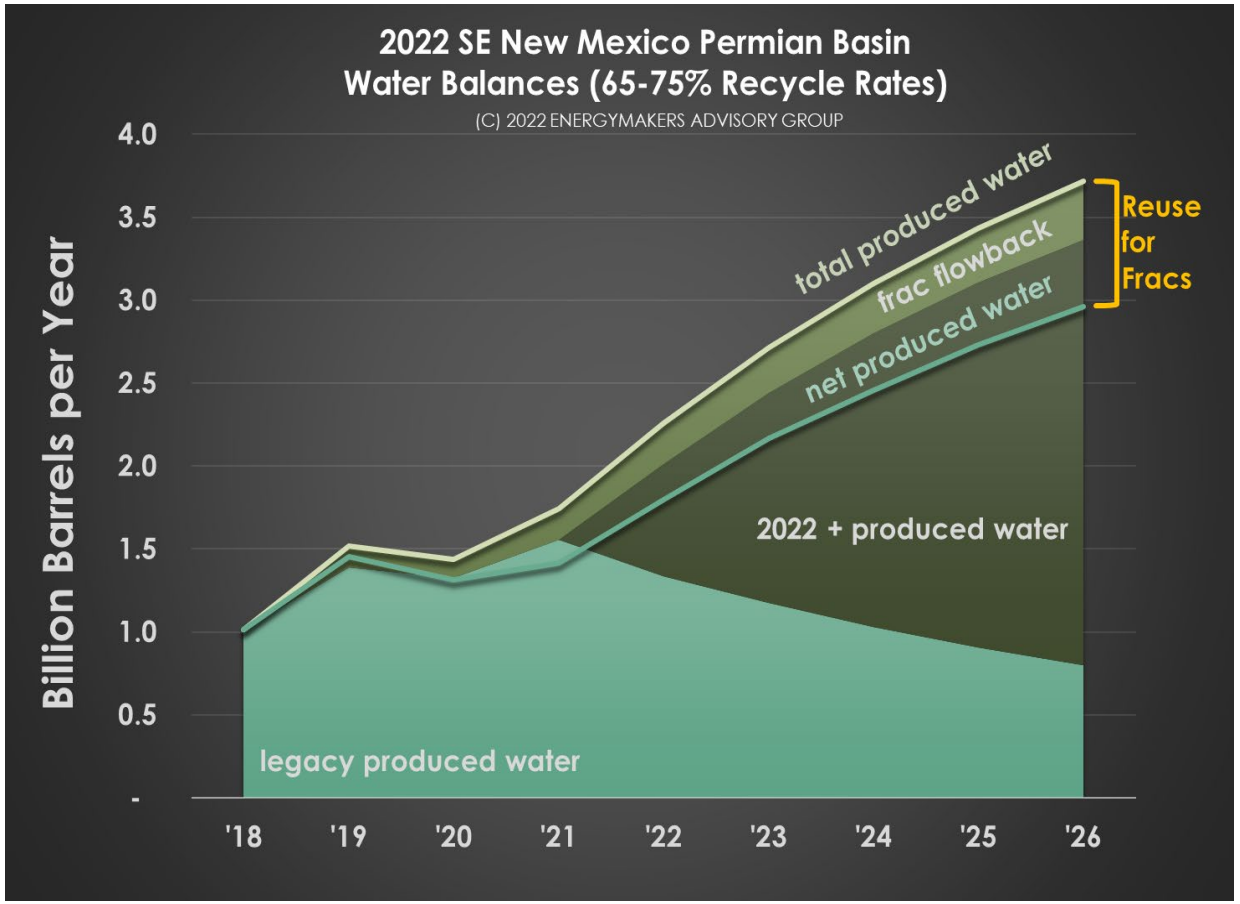
Recycling Reuse in O&G will consume ~ 20% of PW

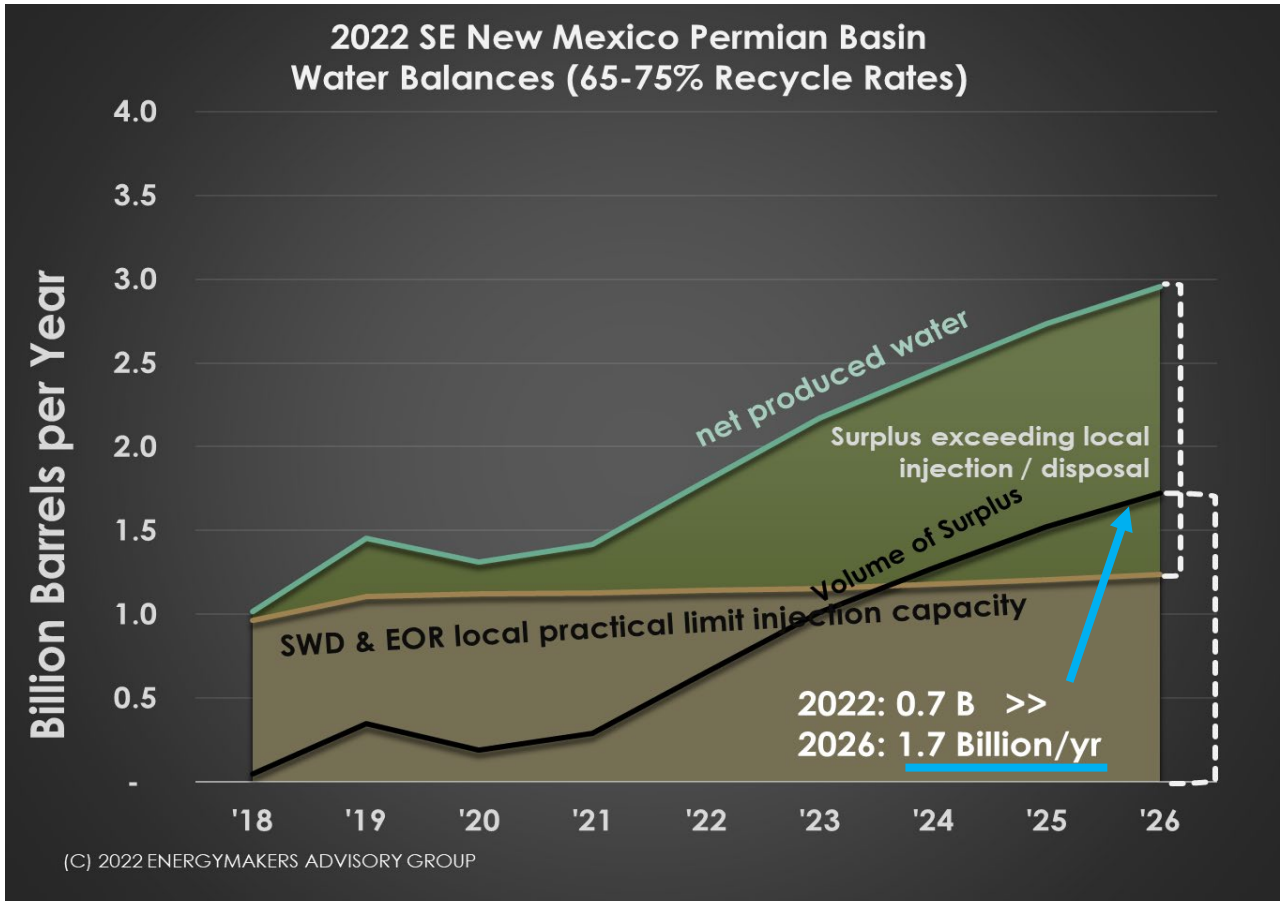
"Net Produced Water", after recycling, is surplus PW that must be:

- Injected Underground
- Piped out of Area
- Find an Alternate Beneficial Use

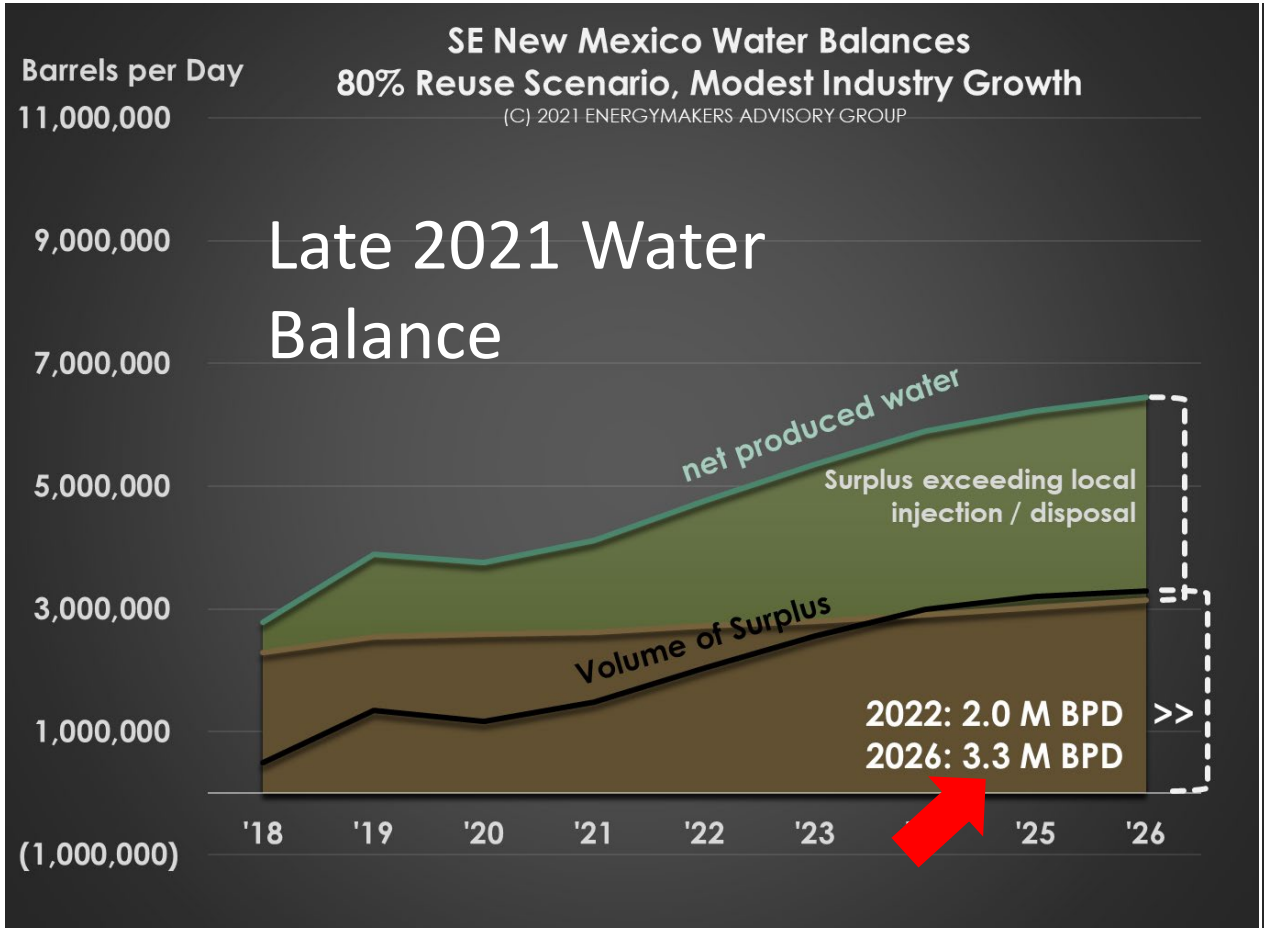
After we have recycled all we can use in Oil and Gas….

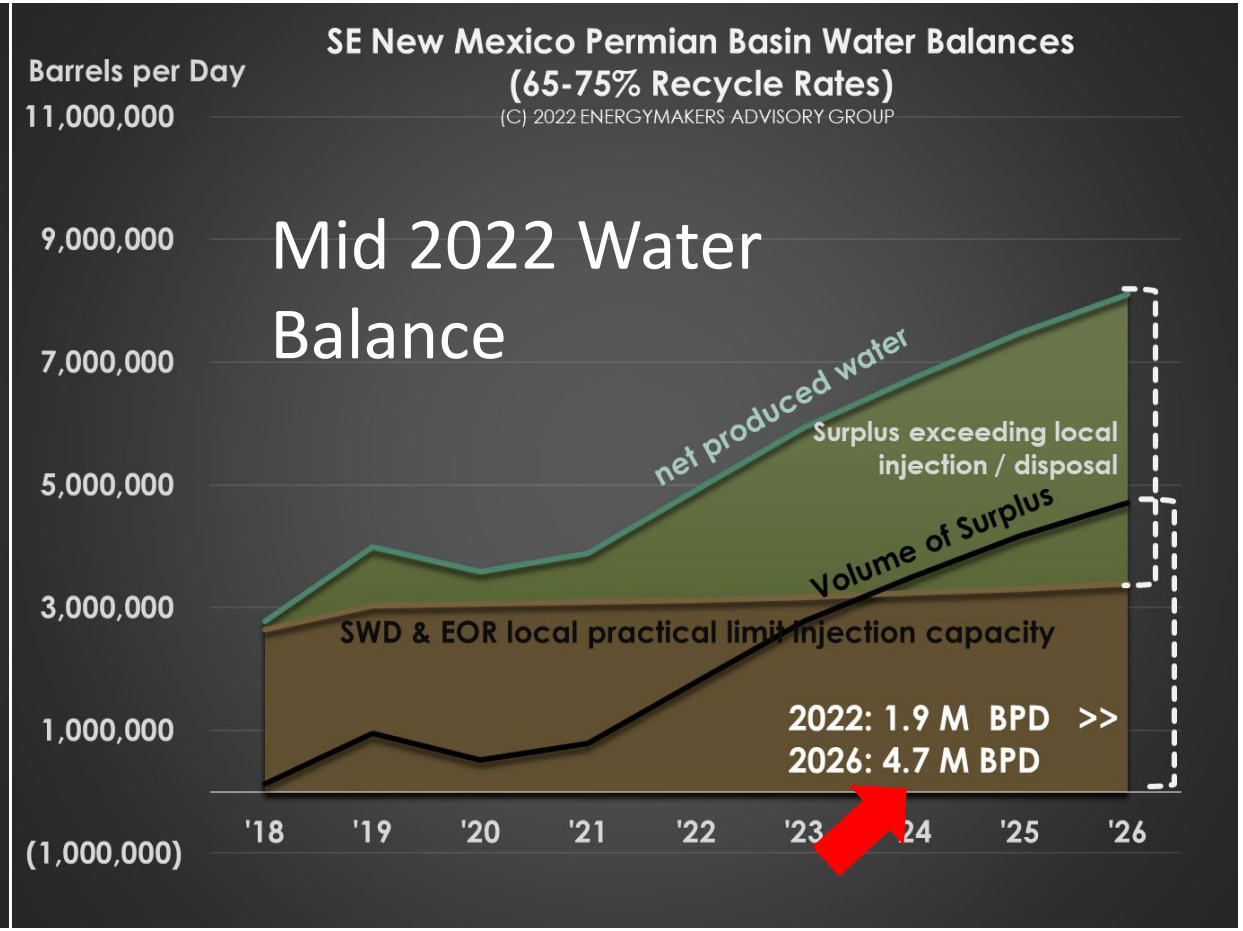
…the left over Net Produced Water (PW) needs an outlet. Currently, SWD & EOR injection are the primary outlet. SWD and EOR growth is increasingly limited, leaving a growing surplus (black line).

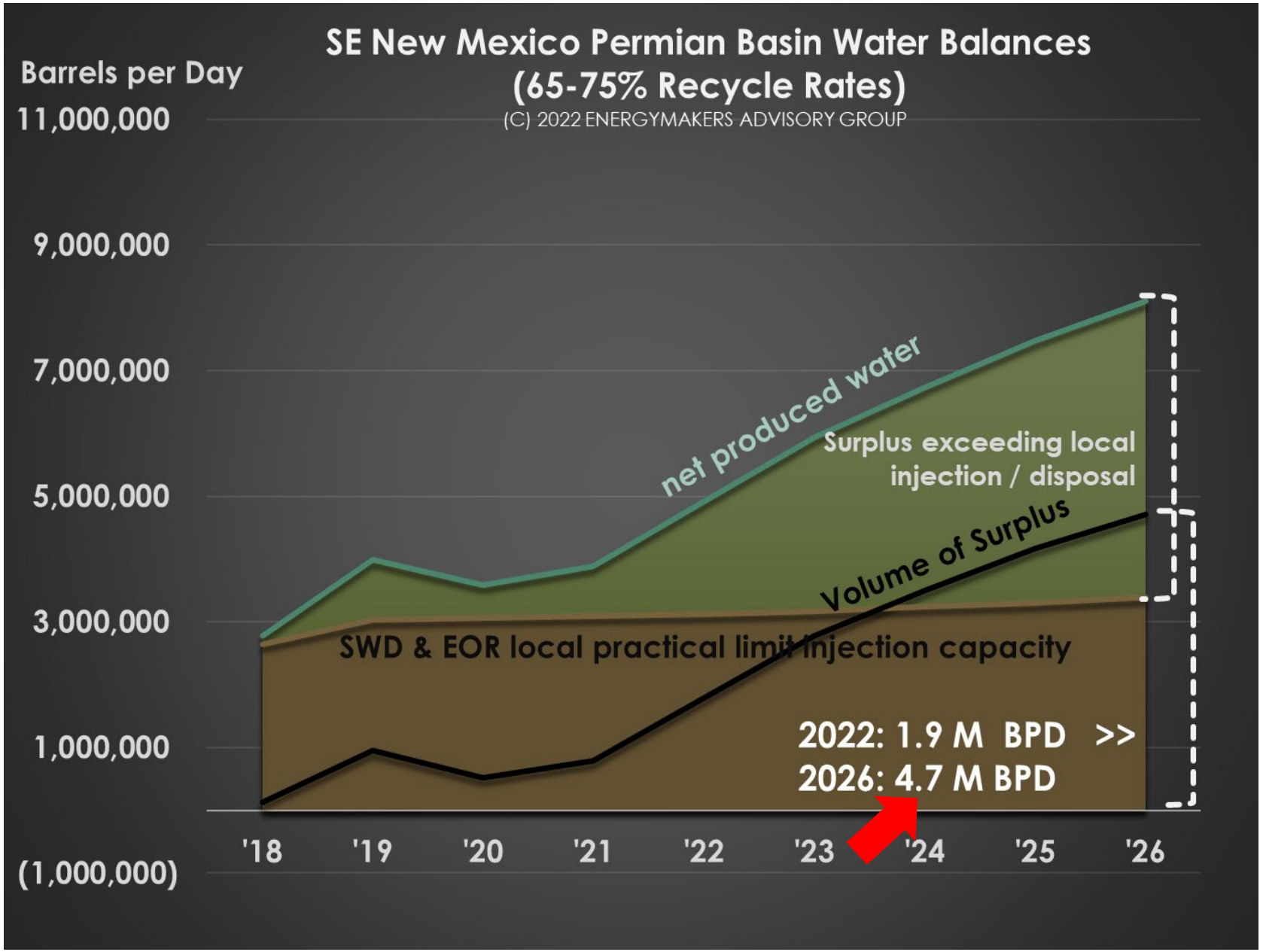




The Problem of Re-Allocating Surplus Produced Water is Growing :
(EnergyMaker's Estimates 2021-2022)







Unfortunately, only two options for Surplus water once we have

1) Recycled all we can, and
2) Disposed all we can.

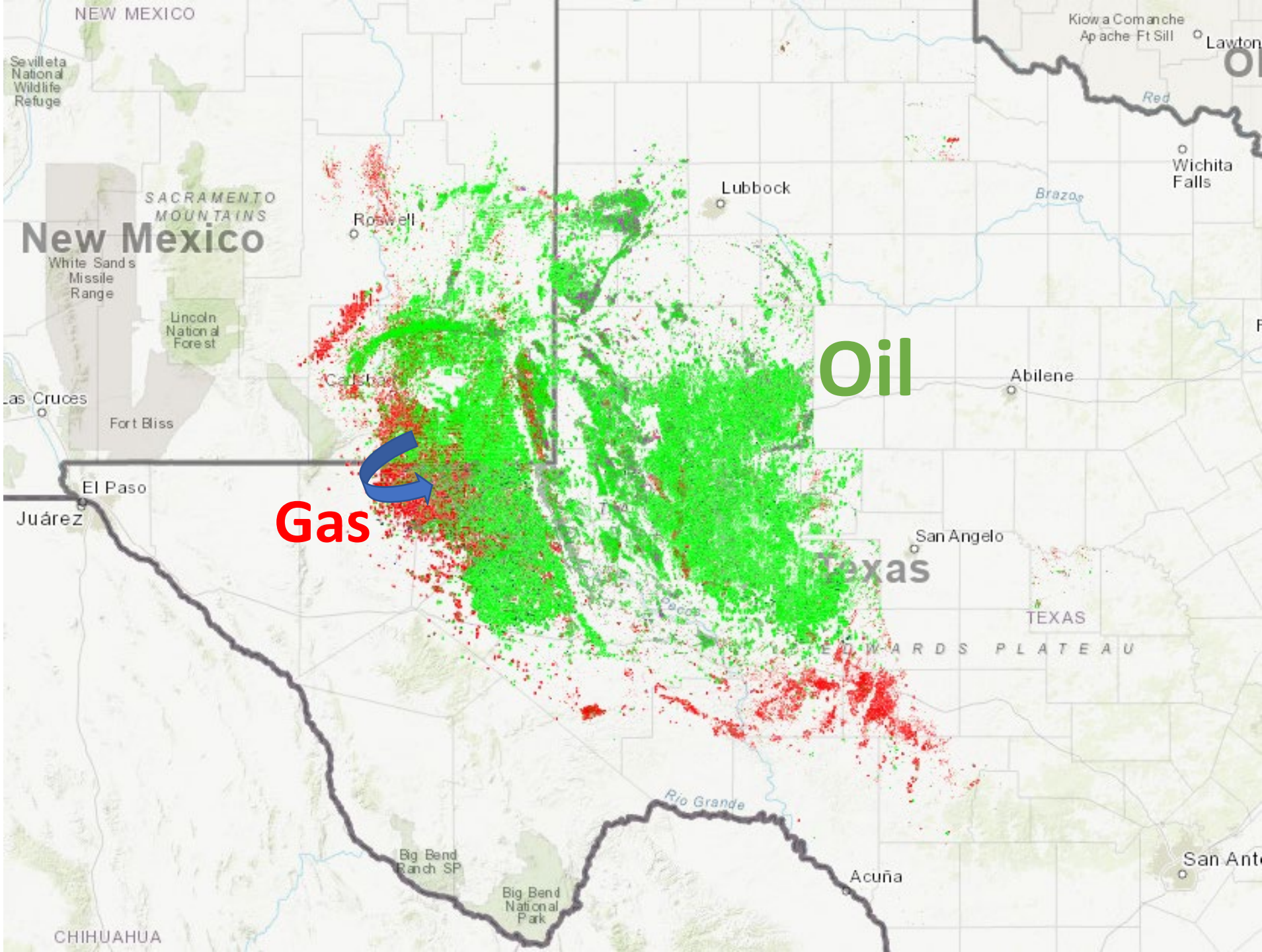
OPTION 1: Pipe Water out of State to receptive disposal wells (in Texas)

OPTION 2: Find an Alternate Beneficial Use for Treated PW

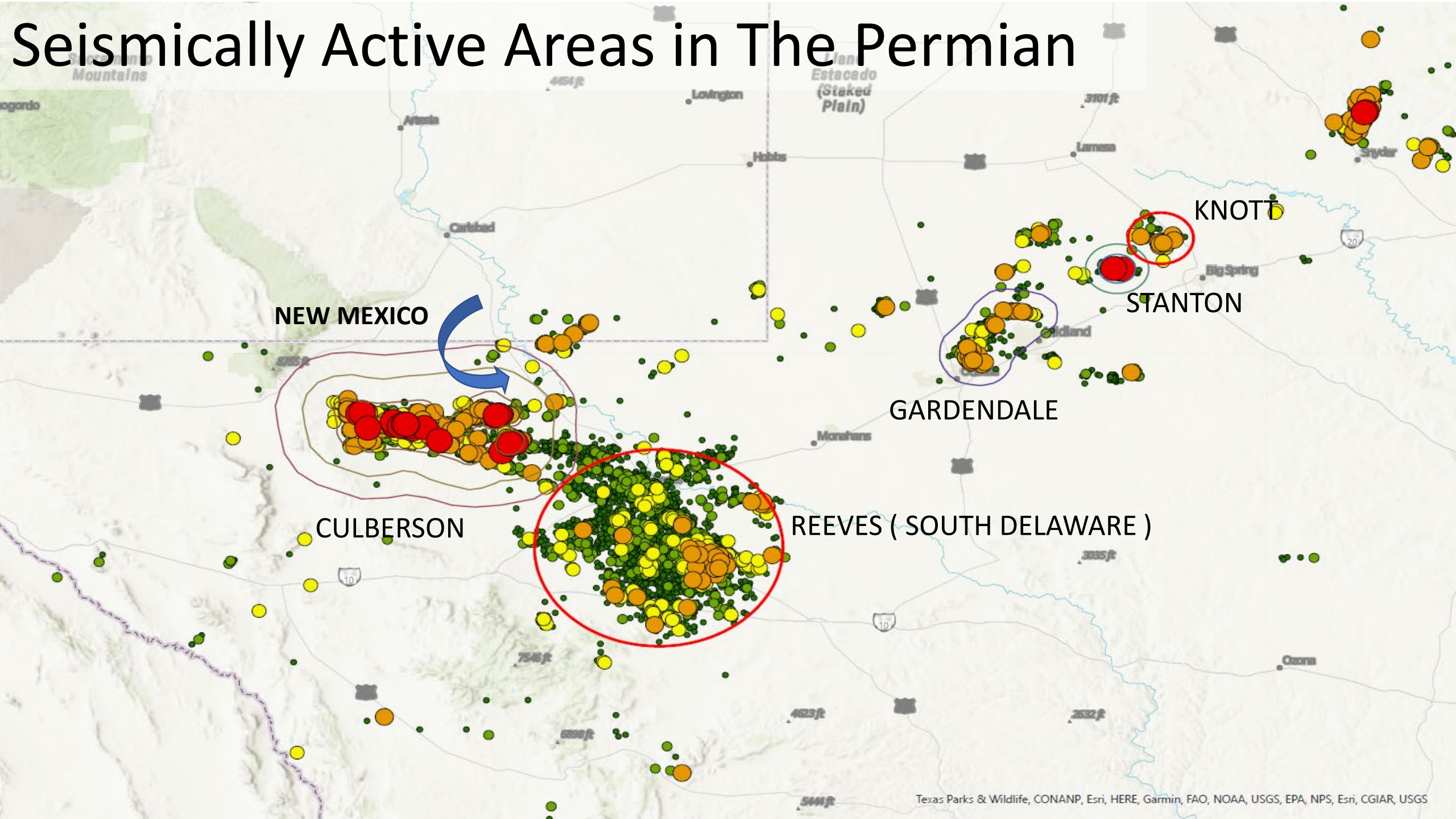
Currently, surplus Produced Water is being piped from New Mexico

– just across the border –

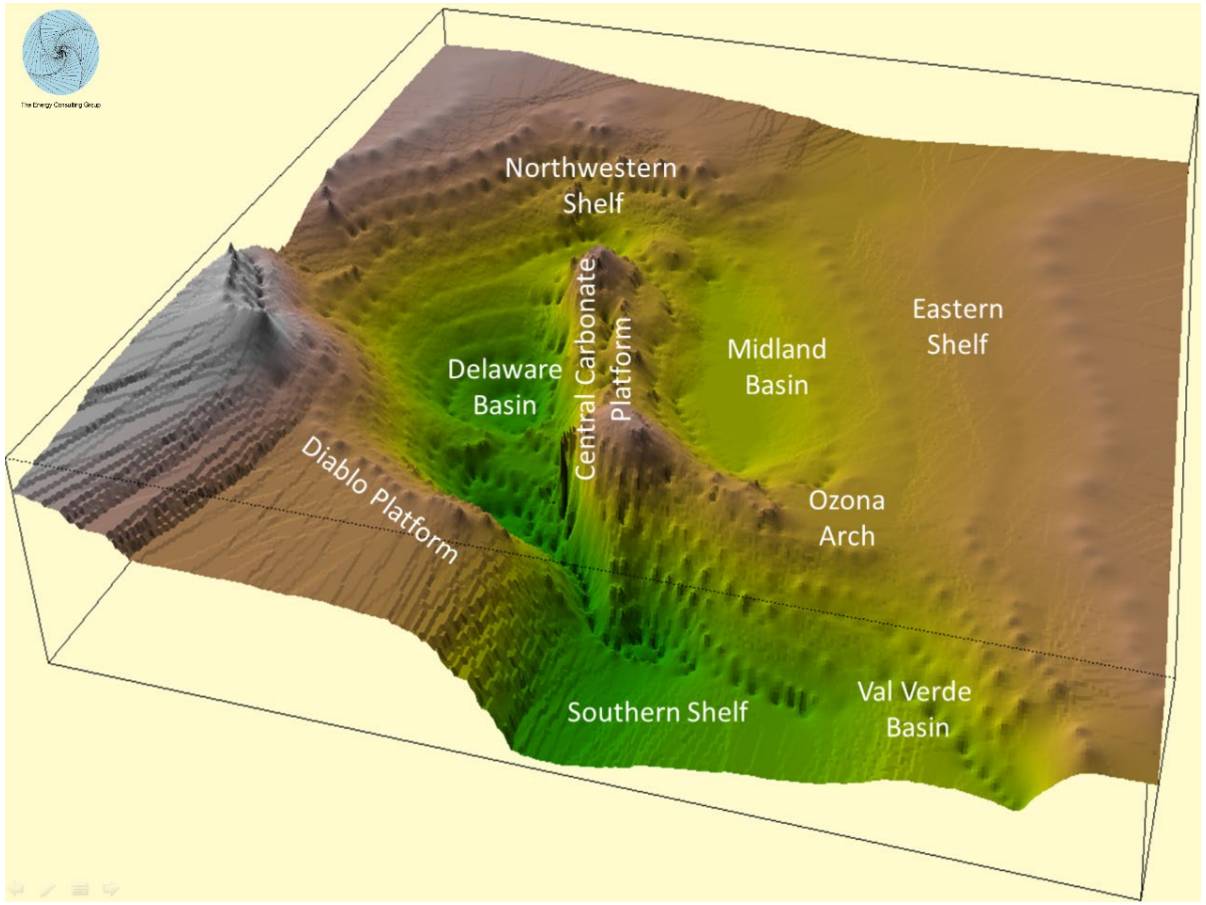
and into Texas where there is more disposal capacity



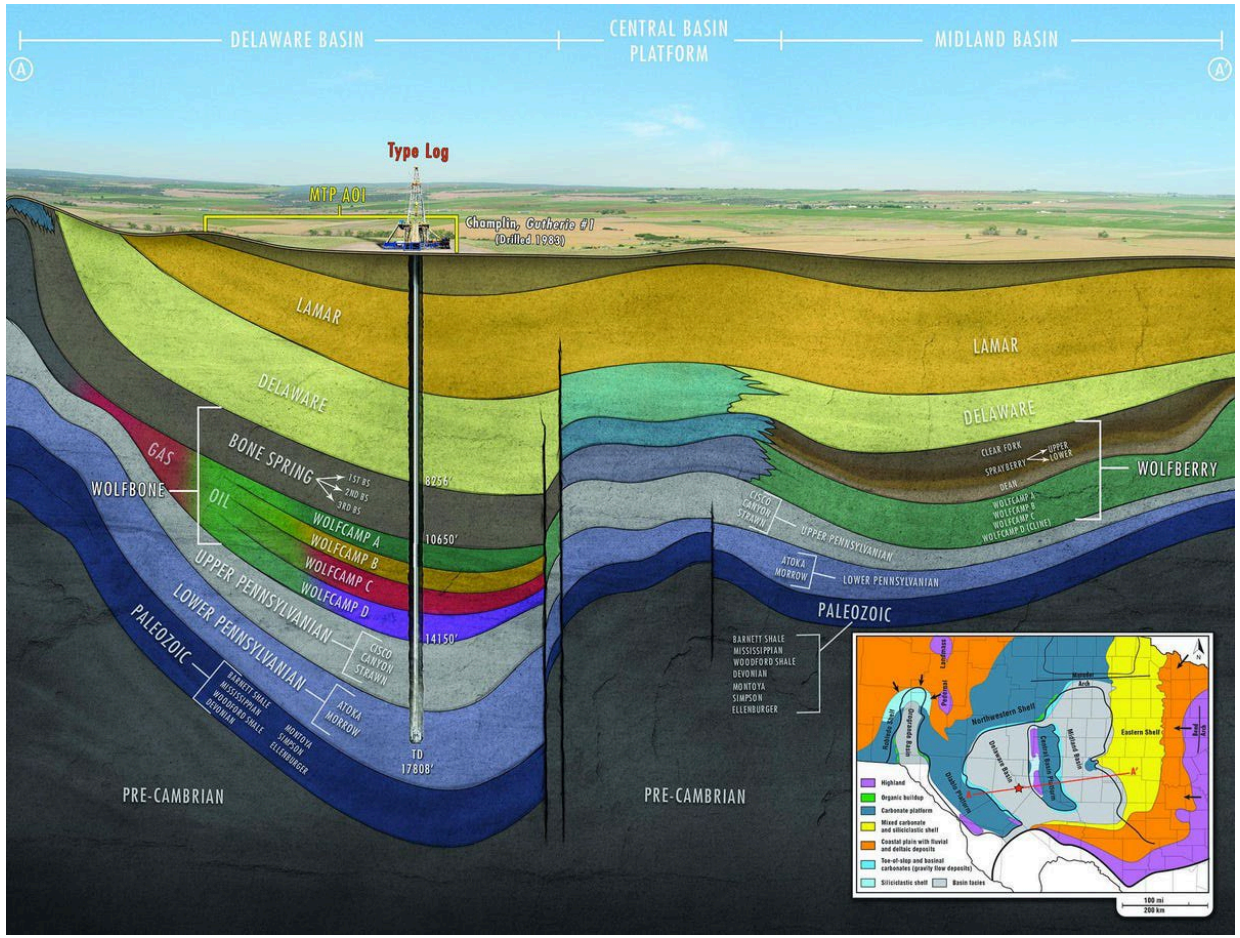
Seismically Active Areas in The Permian



1) Permian Geology Is <u>Complex</u>
2) Underground hydrogeologic flows are complex, much is unknown
3) Nature, gravity, natural tectonic shifts, geomechanics and rock quality, seasonal shifts, outcrops, rainwater, groundwater, production and extraction, drilling and completion, and subsurface injection <u>all</u> impact subsurface flows and pressures



http://energy-cg.com/USA/Permian/permianbasin.html



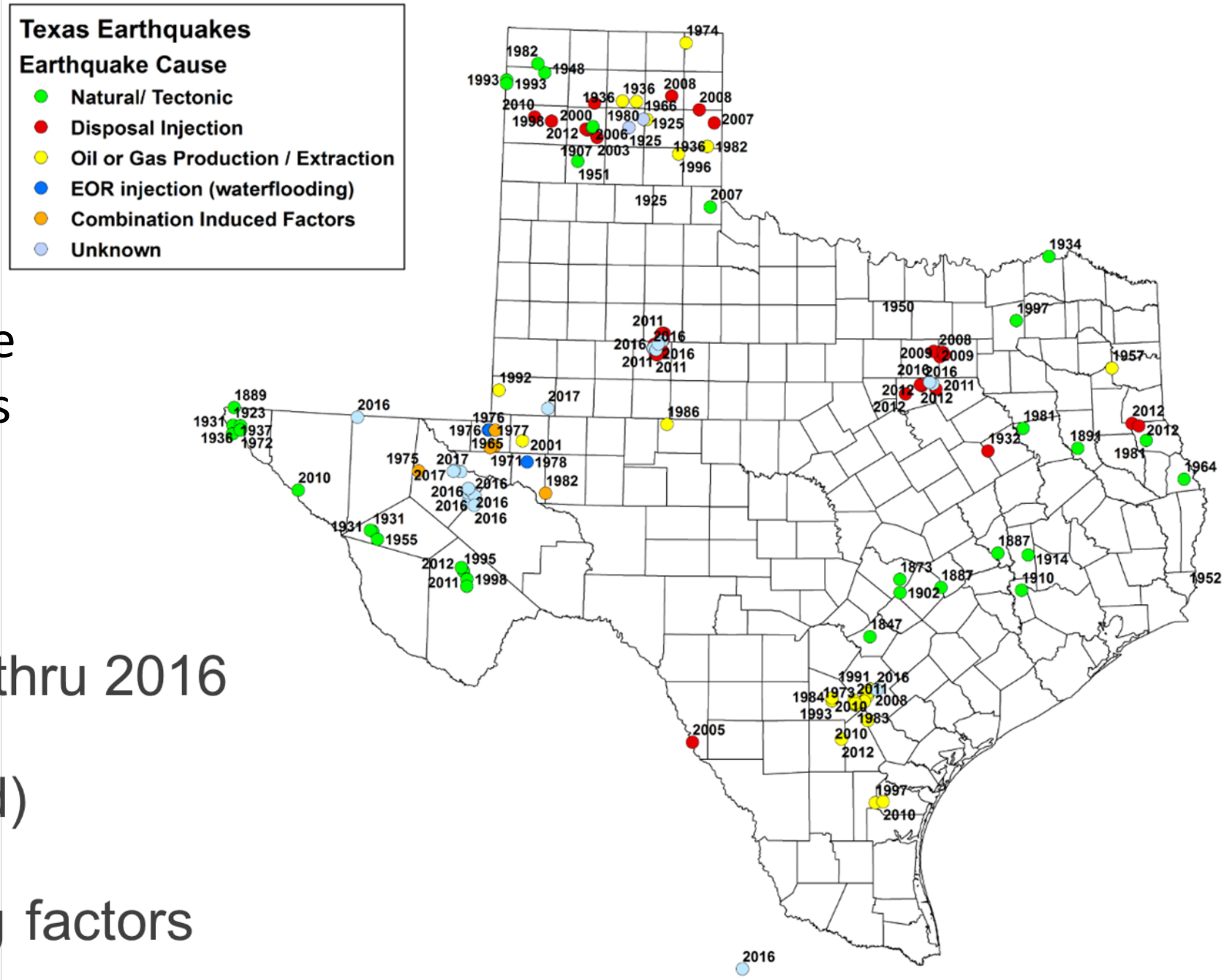
Forbes – Permian Basin Cross-Section

Therefore, Establishing the Root Cause of Seismicity is extremely complex.

Texas Seismic Activity thru 2016

(Before Texnet installed)

A variety of contributing factors



Challenges in Diagnosing Induced Seismicity

Complex Geology, Stratigraphy, Geomechanics and Hydrogeologic Influences

"It's all too new" – not **enough earthquake data** for researchers

Poor quality earthquake data – estimated earthquake locations can be off by thousands of feet (up to a mile or more, if monitoring systems are sparse)

Very limited comprehensive research completed in the Permian Basin on induced seismicity;

Most is "directed research" towards frac'ing and SWD

(at the expense of truly understanding all causal factors)

Recently Published Studies		Research Focus of Investigations / Correlations with Causation								
		Tectonic / Natural	SWD	Hydraulic Fracturing	EOR	CO2 Injection	Far Field Effects / Hydrogeologic Stress Flow	Production/ Extraction	Multiple Effects / Full Strata	Other
Widespread deep seismicity in the Delaware Basin, Texas, is mainly driven by shallow wastewater injection		?	?	?	?	?	?	?	?	?
Stability of the Fault Systems that Host-Induced Earthquakes in the Delaware Basin of West Texas and SE New Mexico										
On the Depth of Earthquakes in the Delaware Basin - A Case Study along the Reeves-Pecos county Line										
Recent water Disposal and Pore pressure evolution in the Delaware Mountain Group, Delaware Basin...										
Distinguishing the Causal Factors of Induced Sesmicity in the Delaware Basin - Hydraulic Fracturing or WasteWater Disposal										
Frequently Referenced Seismic Studies	Lomax and Savvaidis (2019)									
	Deng et al 2020									
	Savvaidis et al (2020)									
	Skoumal et al (2020)									
	Tung et al (2020)									
	Gao et al (2020_									
	Dvory and Zoback (2021a)									
	Zhai et al (2020)									
	Zhai et al (2021)									
	Skoumal and Trugman (2021)									

?

Tectonic / Natural
Saltwater Disposal Wells
Hydraulic Fracturing
Enhanced Oil Recovery (Water Flooding)
CO2 Injection
Hydrogeologic Flows/Far Field Effects
Production/Extraction
Multiple Effects
Other

Recently Published Studies		Research Focus of Investigations / Correlations with Causation								
		Tectonic / Natural	**SWD**	**Hydraulic Fracturing**	**EOR**	**CO2 Injection**	**Far Field Effects / Hydrogeologic Stress Flow**	**Production/ Extraction**	**Multiple Effects / Full Strata**	**Other**
Widespread deep seismicity in the Delaware Basin, Texas, is mainly driven by shallow wastewater injection								INCOMPLETE		
Stability of the Fault Systems that Host-Induced Earthquakes in the Delaware Basin of West Texas and SE New Mexico										
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	Gao et al (2020_									
	Dvory and Zoback (2021a)									
	Zhai et al (2020)									
	Zhai et al (2021)									
	Skoumal and Trugman (2021)									

Challenges in understanding / quantifying Formation Behaviors

Limited Water Data, Limited Oil and Gas Data. Examples:

- In many states, SWD Data may be 12-18 months old before it gathered and made public
- Fracturing schedules considered proprietary, not readily available

Poor understanding of Underground Pressures (Data), and how they relate to Seismicity or SWD Risk

- We Rely on Surface Pressures to "Police" injection activity
- Surface Pressures are very poor Proxies for Subsurface Pressures

---

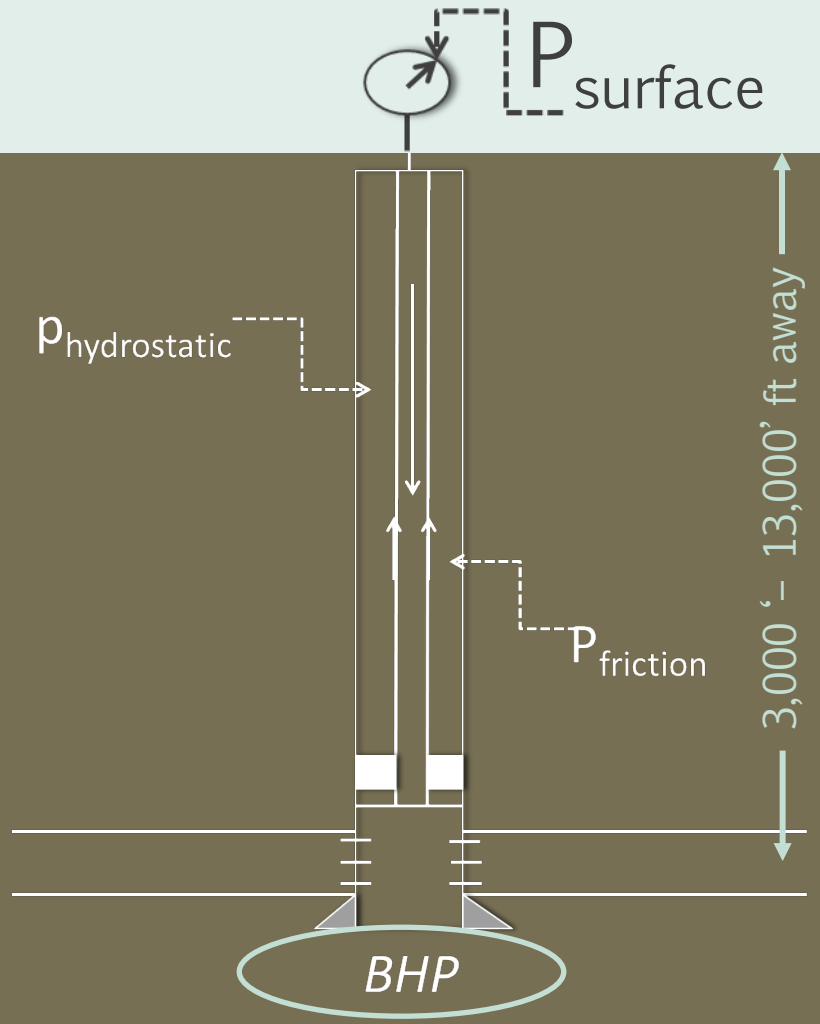
Better Approach – Incorporate Knowledge of Subsurface Pressures

(also termed Bottomhole Pressures, or BHP)

Surface Pressure Doesn't tell the Whole Story

$$BHP = P_{surface} + P_{hydrostatic} - P_{friction}$$

- Easily Measured (at the surface), **but very inaccurate**
- Measurement is thrown off (false positive data) depending on the rate that water is injected and the way the well was completed (tubing, etc.)
- Due to "Ease of Use", Regulators use surface pressure gauge readings to monitor subsurface well / formation health – albeit thousands of feet away



Bottom Hole Pressure

- **BHP – closer reflection of formation health;** where the action is
- Allows us to better understand the formation's reaction to injection
- Allows us relationships between seismicity, formation pressures, and well operations
- Much better indicator of well health
- Physical Measurement from downhole instruments very expensive, difficult to keep calibrated
- Advanced Modeling techniques provide effective means to "back into" or estimate BottomHole Pressures (EnergyMaker's specialty)

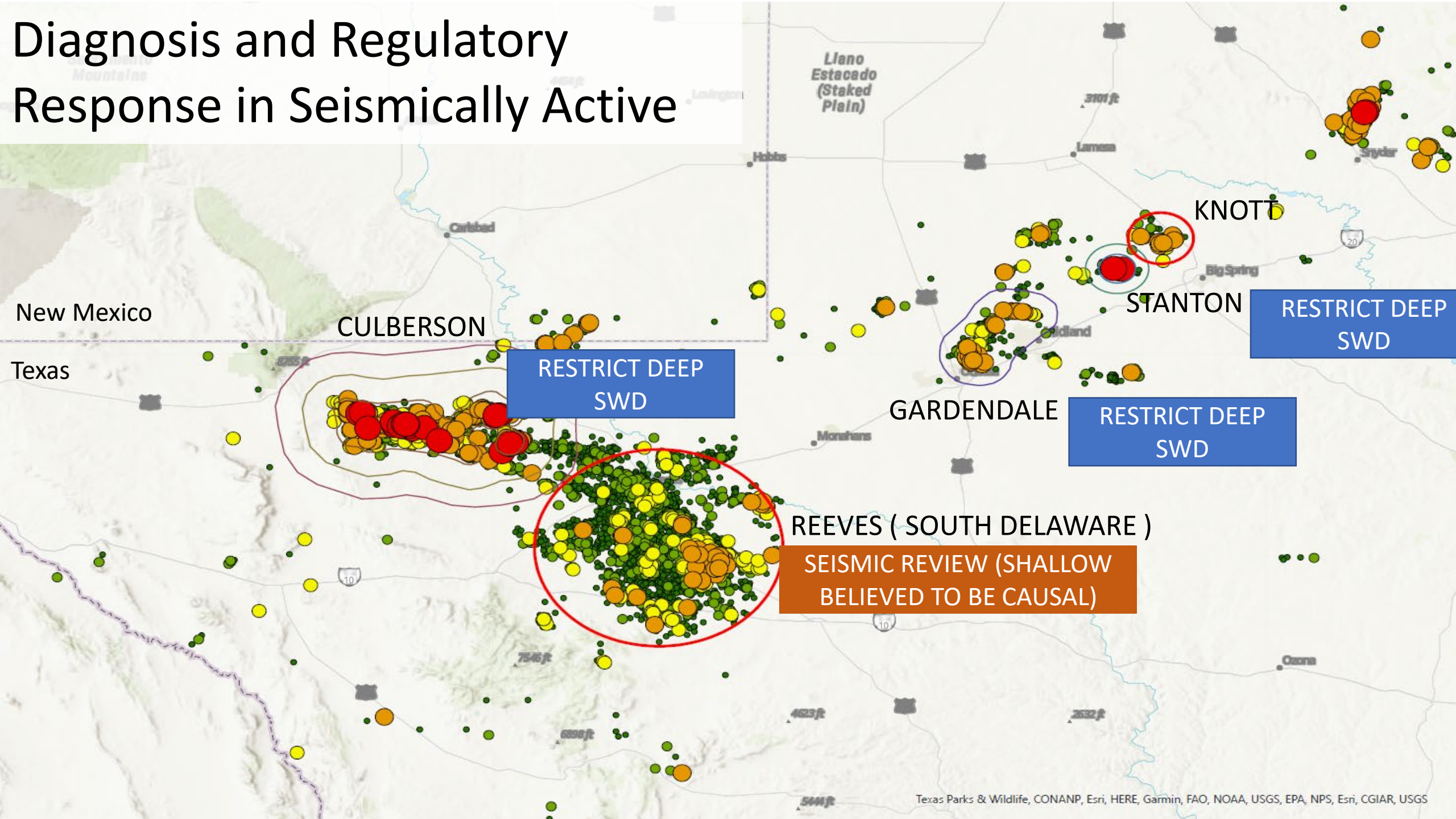
Potential Risks from inadequately diagnosing Induced Seismicity

If we are “barking up the wrong tree” or not fully guided by SCIENCE, we risk:

- Re-directing O&G operators to behaviors that may be associated with *higher* environmental risk

- Having to limit U.S. Oil and Gas production, because we can’t safely allocate the PW.
  - State Revenues (Down)
  - **State Education Funds (Down)**
  - Diminished Energy Independence (Down)
  - Weakened National Security and Defense (Down)
  - Increased Global Reliance on Middle East and Russian Energy Sources (Up)

Diagnosis and Regulatory Response in Seismically Active



Midland Basin BottomHole Pressures - 2017

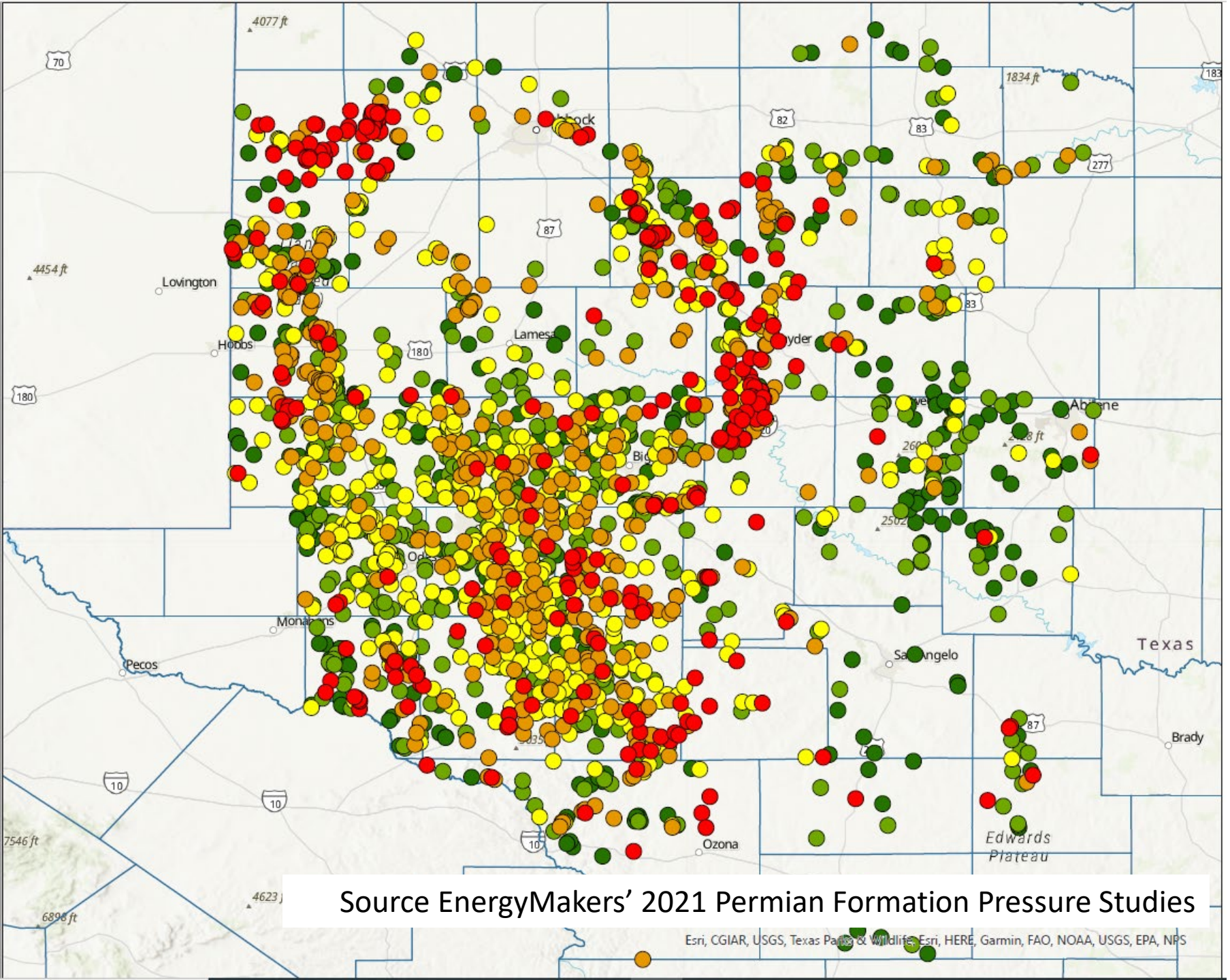
Injection Depth Range (ft)	County A	County B	County C	County D	County E	County F	County H	County I	County J	County K	County L	County M	County T	County U	County V	County W	County X	County Y	County Z	County A	County B	County C	County D	County E	County F	County G	County H	County I	County J	County K	County L	County M	County N	County O	County P	County Q	County U	County R
0-999				0.61	0.44	0.60	0.60												1.07	0.84															0.77	1.00		
1,000+				0.48	0.80	0.51	0.51					0.79	0.86	0.86	0.79	0.78	0.74	0.77	0.59										0.86					0.62	0.74		
2,000+	0.46		0.71	0.73	0.80	0.53	0.53		0.57		0.61	0.56	0.78	0.78	0.56	0.43	0.65	0.72	0.57	0.55			0.89					0.65	0.72	0.68	0.61	0.49		0.55	0.46	0.48	0.72	
3000+	0.48	0.70	0.69	0.62	0.68	0.57	0.57	0.81	0.45	0.65	0.64	0.65	0.69	0.78	0.53	0.55	0.64	0.74	0.26	0.60	0.67	0.66	0.59	0.76	0.63	0.63	0.54	0.56	0.64	0.78	0.54	0.52	0.46	0.51	0.61	0.63	0.65	0.54
4000+	0.58	0.60	0.66	0.56	0.57	0.57	0.5	0.73	0.61	0.62	0.59	0.6	0.72	0.75	0.49	0.62	0.81	0.77	0.50	0.64	0.65	0.65	0.57	0.78	0.66	0.66	0.64	0.61	0.71	0.67	0.60	0.58	0.56	0.49		0.49	0.63	0.47
5000+		0.57	0.57	0.55	0.59	0.54		0.72	0.64	0.57	0.62		0.68		0.46	0.48	0.57		0.49	0.56	0.60	0.65	0.49	0.63		0.64	0.58	0.61	0.60	0.77	0.57	0.77	0.54	0.53		0.51	0.47	0.46
6000+		0.61	0.59	0.71	0.49	0.4	0.66	0.69	0.66	0.57	0.4	0.47	0.61	0.71	0.55	0.48	0.57	0.53	0.35	0.51	0.56	0.53	0.44	0.63	0.61	0.67	0.76	0.53	0.51	0.73	0.51	0.56	0.61			0.51	0.56	0.46
7000+			0.57	0.71	0.52	0.51	0.51	0.56	0.60	0.51	0.54	0.51	0.72	0.61	0.44	0.53	0.65	0.71	0.46		0.48	0.57	0.60	0.60						0.51	0.46	0.57	0.47					0.45
8000+			0.52		0.57	0.52	0.52	0.48	0.47	0.45	0.60	0.50	0.66	0.60	0.43	0.53	0.69	0.61	0.57			0.45	0.64	0.55	0.53											0.62	
9000+					0.50	0.47	0.47	0.46	0.46	0.52	0.68				0.49			0.75	0.71	0.85	0.48		0.74														
10000+					0.45	0.48	0.48	0.46	0.49	0.45	0.61					0.45					0.50																
11000+								0.45	0.43		0.47									0.68	0.53	0.48															
12000+								0.45	0.53											0.63		0.48															
13000+								0.46	0.48												0.43															
14000+	0.50			0.47																																	

2 things going on in Midland:

1) Some seismic risk, and
2) Some high BHPs in shallow formations (shown in Red/Orange).

Much of the basin is overpressured (red), not underpressured (green).

Many operators are completing SWDs back to shallow formations due to Seismic Restrictions



Source EnergyMakers' 2021 Permian Formation Pressure Studies

MIDLAND BASIN

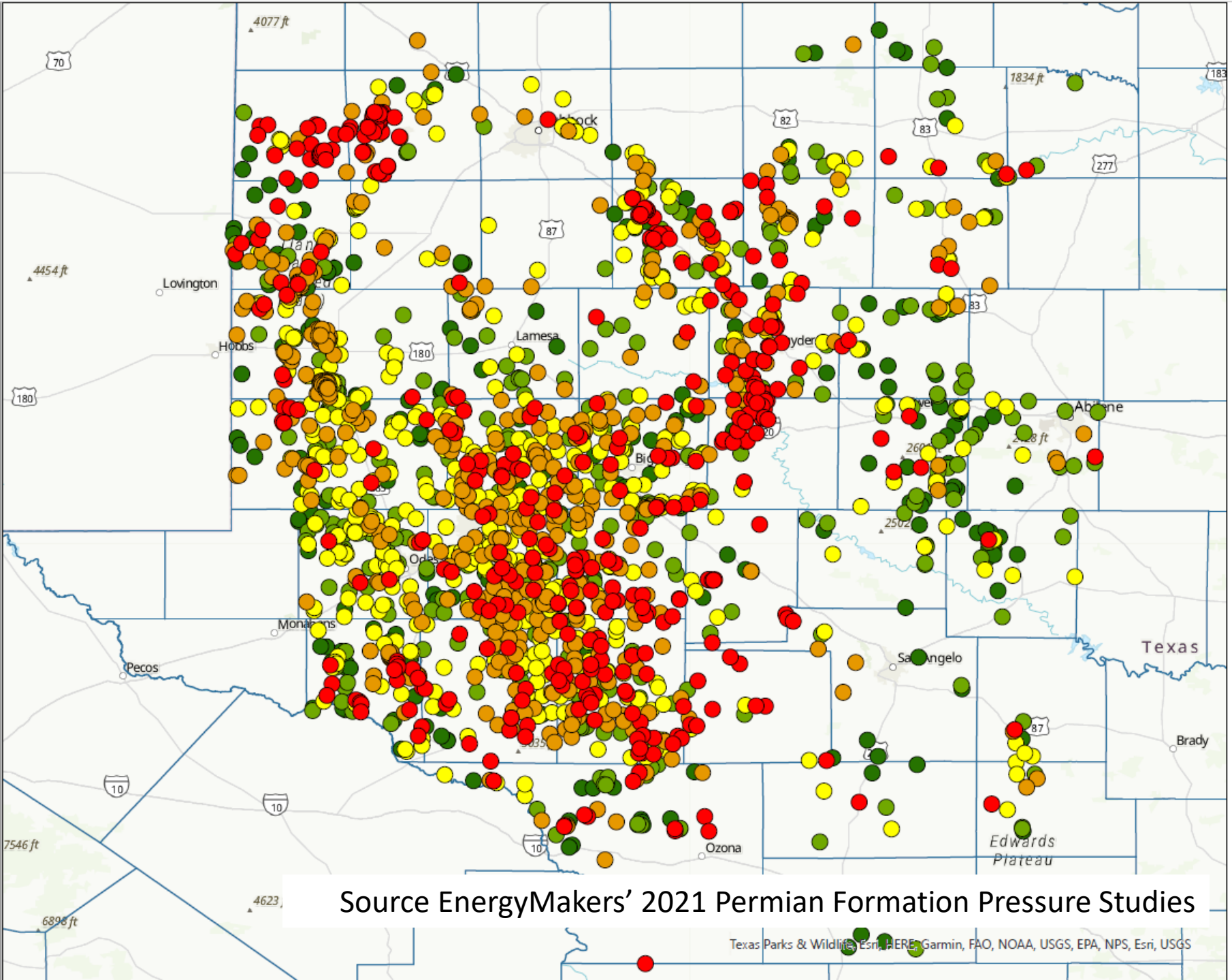
SHALLOW SWD WELLS

2018

ENERGYMAKERS
FORMATION PRESSURE
(INJECTION PRESSURE GRADIENT)

Psi/ft

- 0-0.50
- 0.51-0.60
- 0.61-0.70
- 0.71-0.80
- 0.80+



Source EnergyMakers' 2021 Permian Formation Pressure Studies

MIDLAND BASIN

SHALLOW SWD WELLS

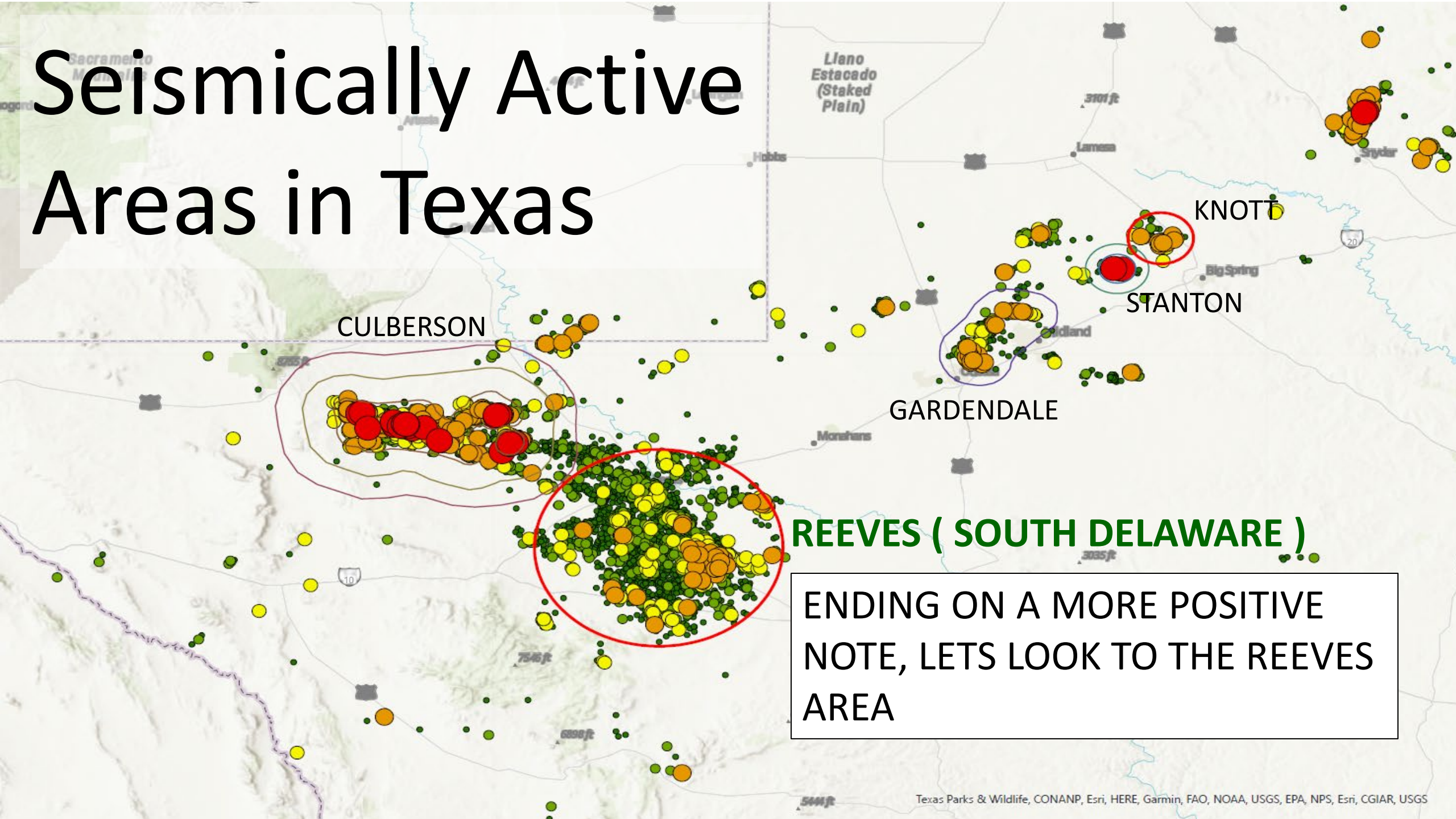
2020

ENERGYMAKERS
FORMATION PRESSURE
(INJECTION PRESSURE GRADIENT)

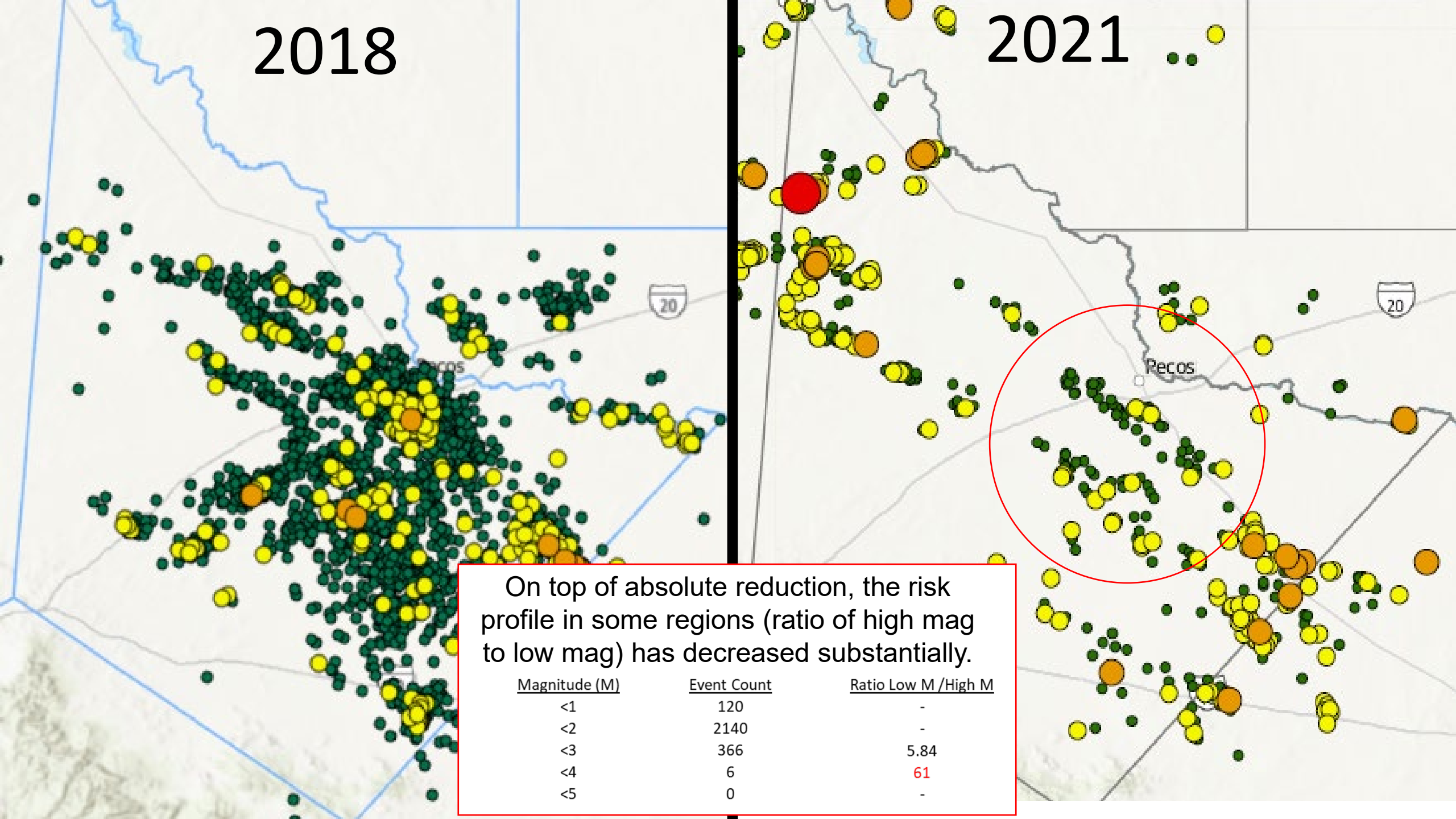
Psi/ft

- 0-0.50
- 0.51-0.60
- 0.61-0.70
- 0.71-0.80
- 0.80+

Seismically Active Areas in Texas

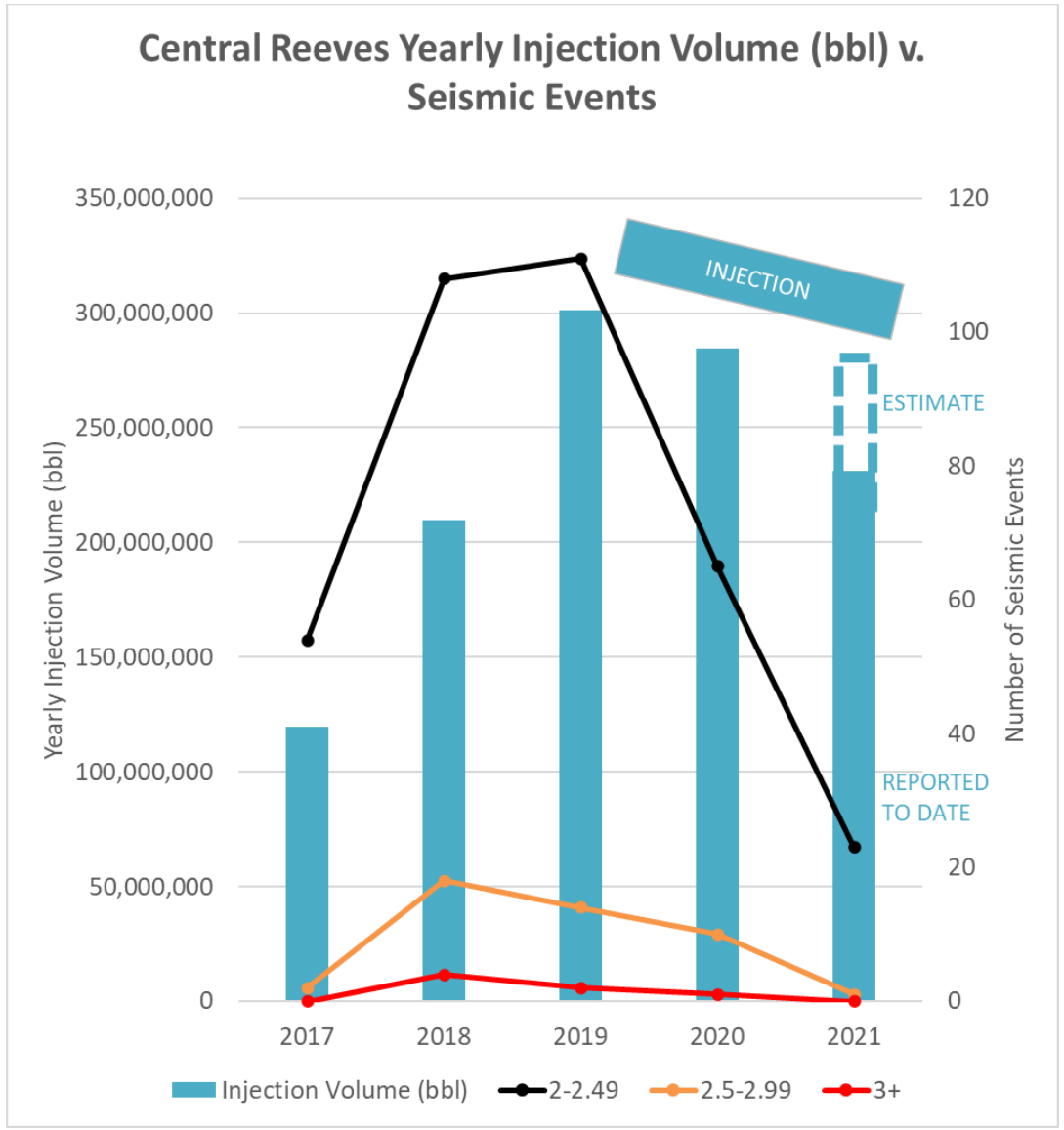


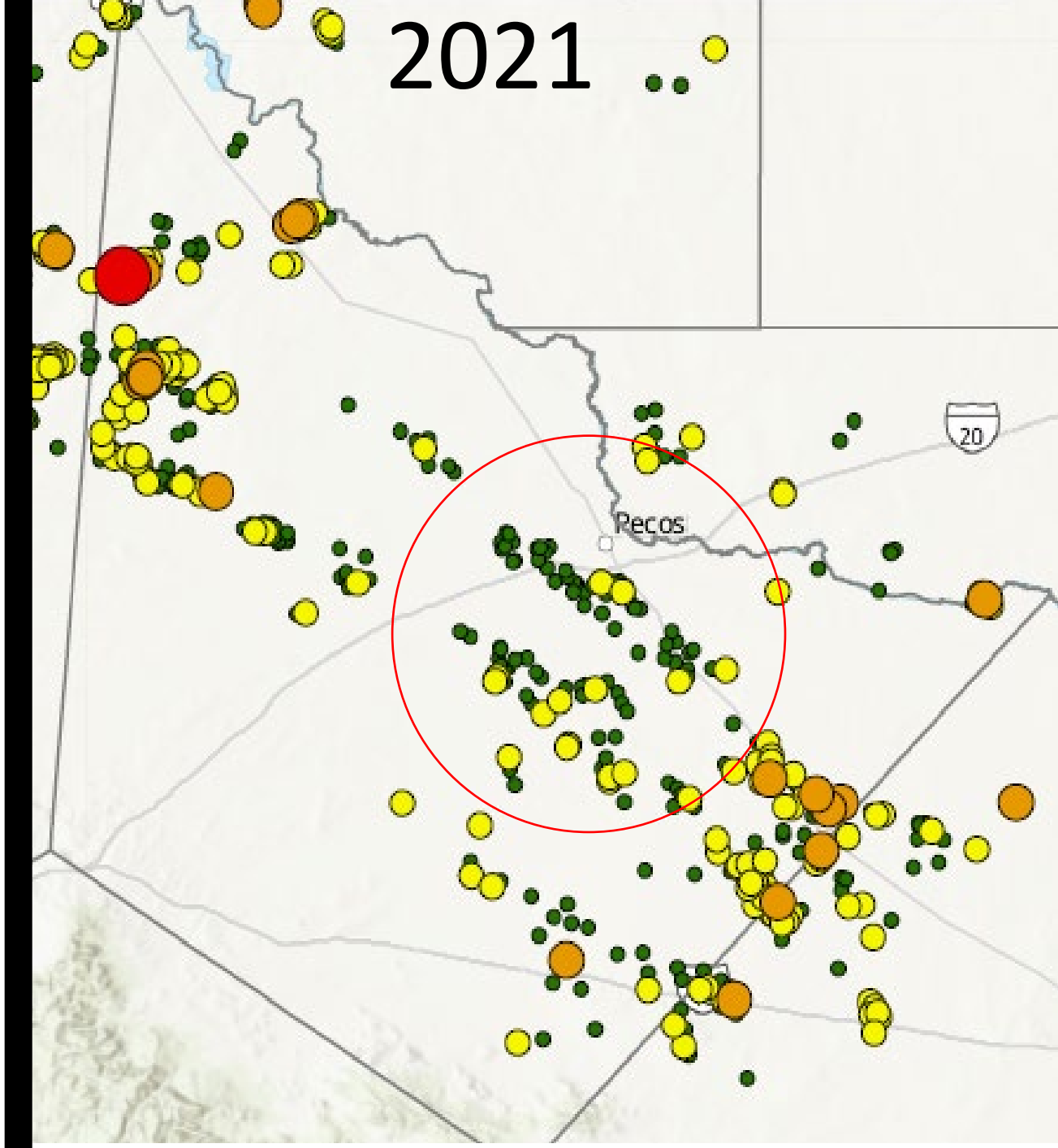
ENDING ON A MORE POSITIVE NOTE, LETS LOOK TO THE REEVES AREA



On top of absolute reduction, the risk profile in some regions (ratio of high mag to low mag) has decreased substantially.

Magnitude (M)	Event Count	Ratio Low M /High M
<1	120	-
<2	2140	-
<3	366	5.84
<4	6	61
<5	0	-


Central Reeves Yearly Injection Volume (bbl) v. Seismic Events
350,000,000
300,000,000
250,000,000
200,000,000
150,000,000
100,000,000
50,000,000
0
Yearly Injection Volume (bbl)
120
100
80
60
40
20
0
Number of Seismic Events
INJECTION
ESTIMATE
REPORTED TO DATE
2017
2018
2019
2020
2021
Injection Volume (bbl)
2-2.49
2.5-2.99
3+


2021
Pecos
20

Concluding thoughts

- The United States is potentially on a “Collision Course” related to “best” allocation of produced water
- Beneficial Reuse of Produced Water will be required (not optional) to maintain energy production
- Beneficial Reuse timelines need to be accelerated

- Role of hydrogeologic flows, quantification of water balances, and understanding subsurface (BHP) pressures is essential to managing subsurface risk. To manage we must quantify and monitor.
- Timely and better data collection by the States is essential to timely analysis and an actionable planning.
- “Ditto” – as we move to a Hydrogen Economy and support Carbon Sequestration Initiatives – each of which also require reliable, sustained injection capacity