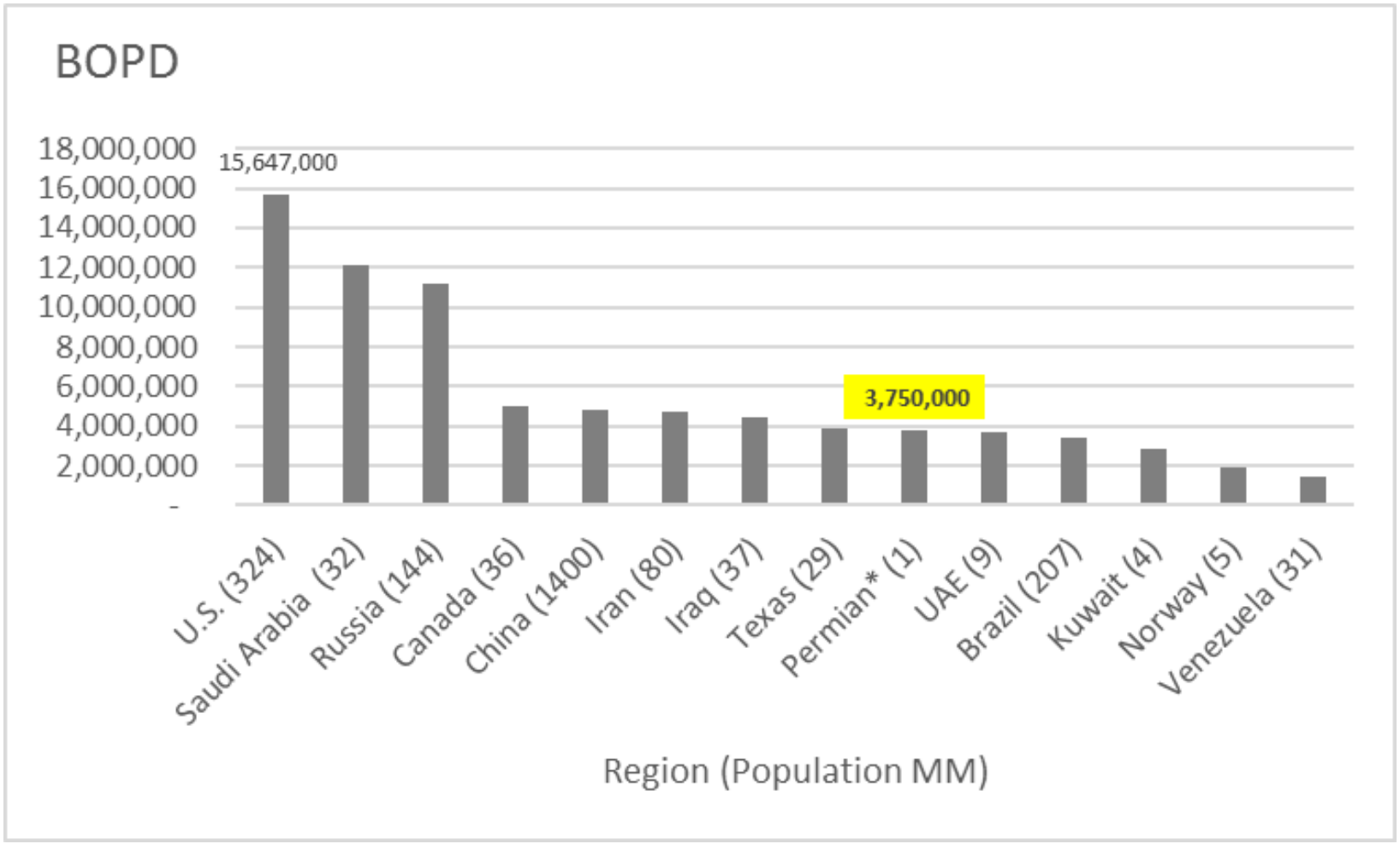
The San Andres Problem

Andrew N. Hunter, Chuck Pounds, and Scott L. Lowry

AAPG Permian Super Basin 1/23/19

If The Permian Was a Country It Would Rank #8 in Oil Production



Sources
https://en.wikipedia.org/wiki/List_of_countries_by_population_(United_Nations)
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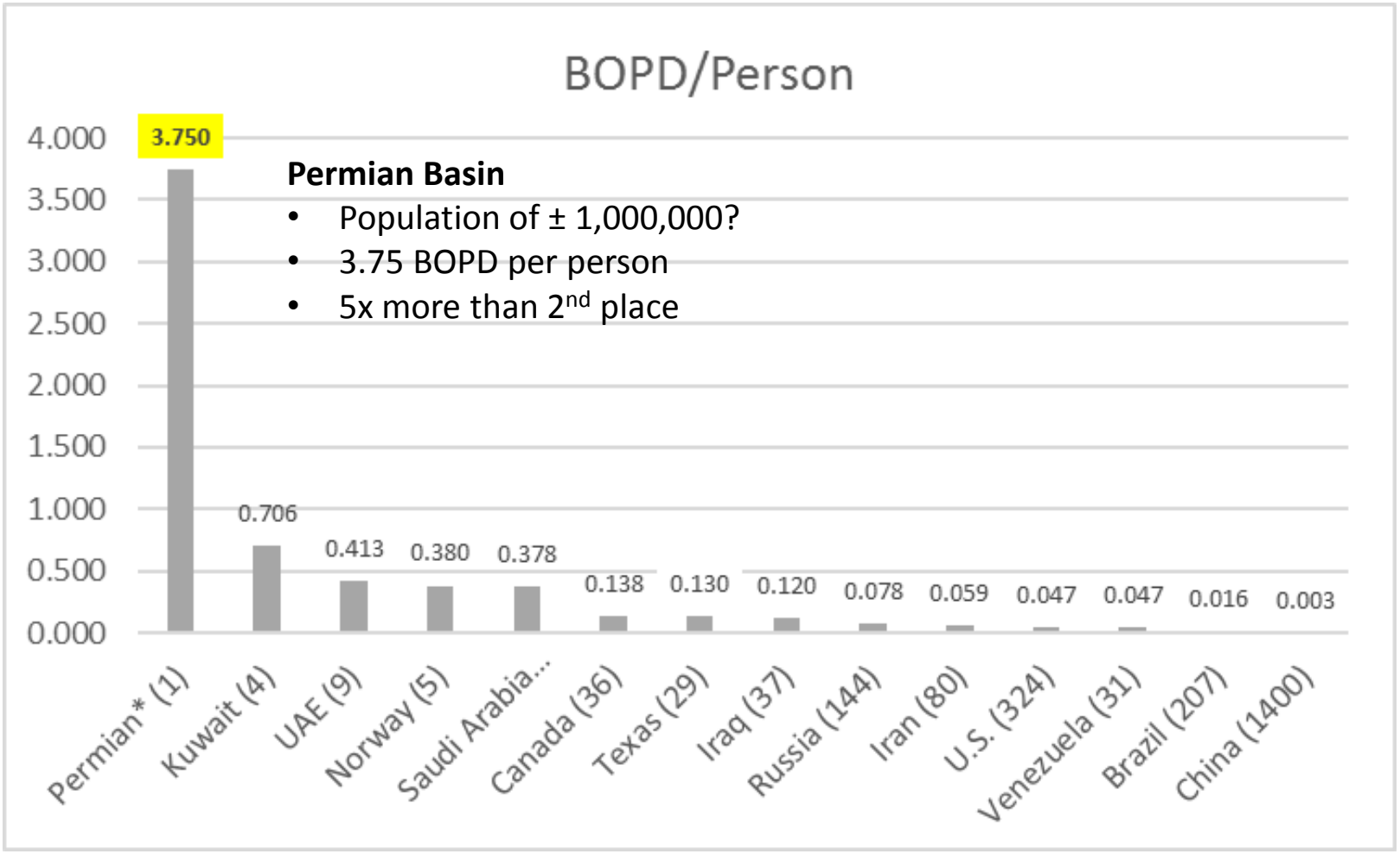
http://www.togetherweteach.com/TWTIC/uscityinfo/43tx/txpopr/43txpr.htm
*Permian Basin population estimate based on Midland + Odessa + San Angelo + Big Spring multiplied by 3

The "Country of Permian" Would Be The World Leader in BOPD Per Person



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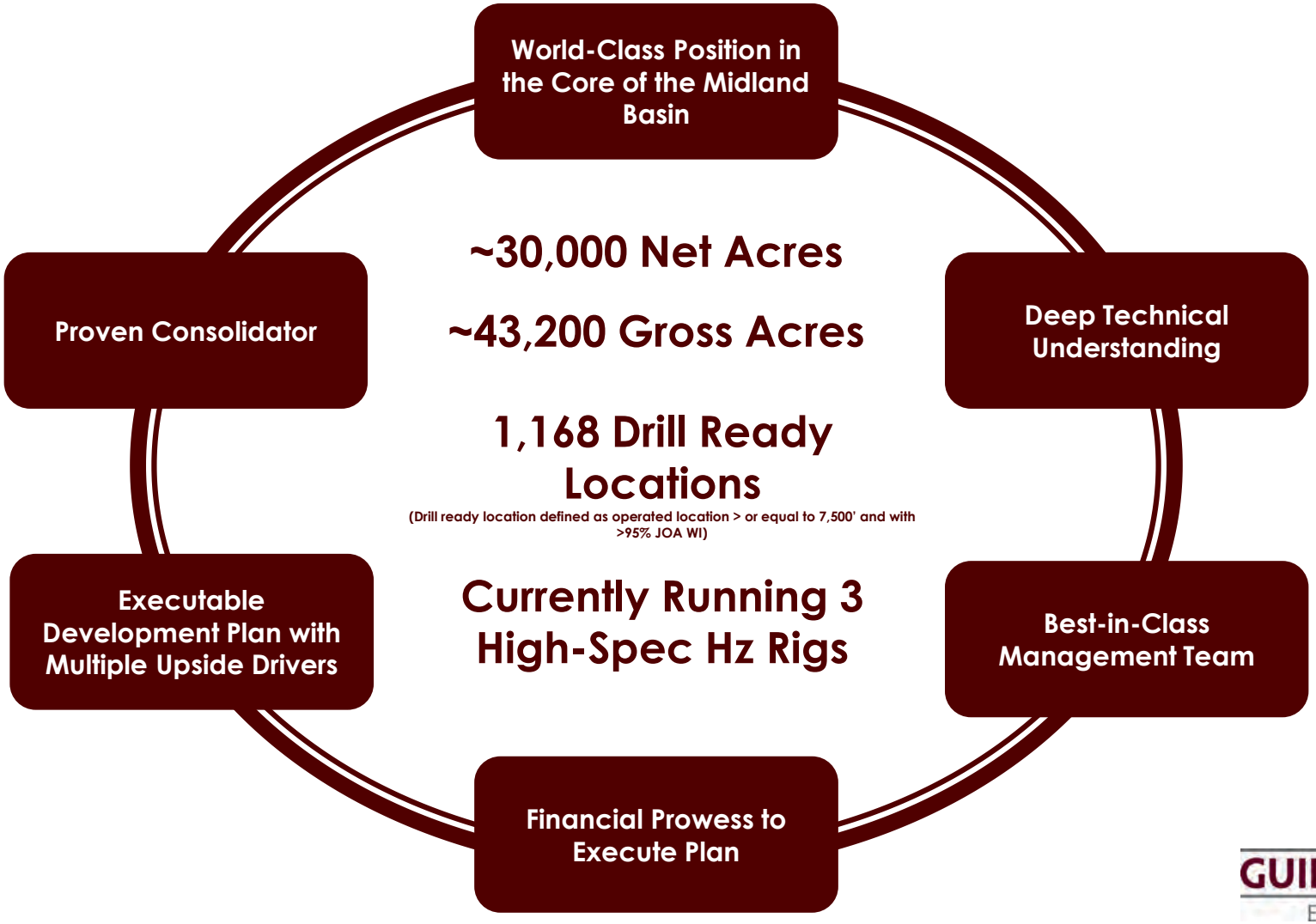
437 Hz Rigs x 15 wells/year x $8MM/well = ± $52 Billion/Year in Permian D&C

*As per Rig Data on 12/18/18, of the 480 rigs in the Permian Basin, 437 or 90% are drilling horizontal wells. 25 days per well = 15 wells per year.

$52 Billion / Year Visualized

With Great Power Comes Great Responsibility

Guidon Highlights



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Guidon Energy: The Meaning of the Name

Frank McCarthy: "Buffalo Soldiers Advance as Skirmishes, Charge"

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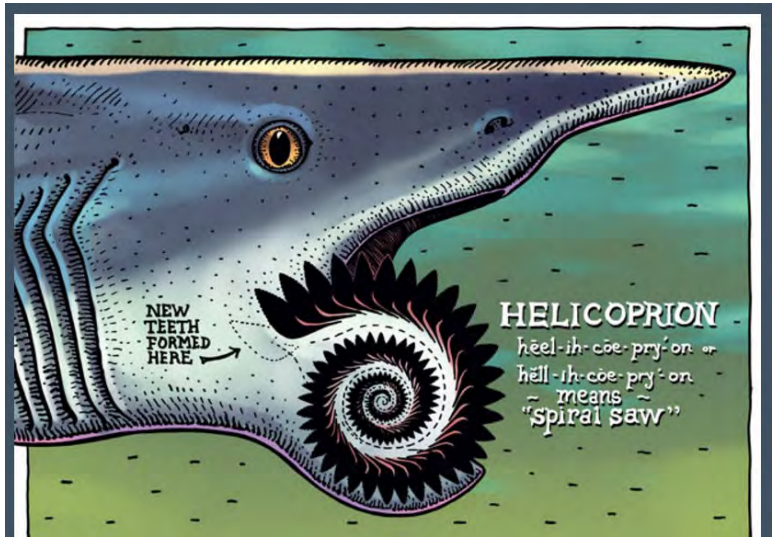
Permian Basin 260 Million Years Ago


The fishing was probably good back then…
Permian age shark (270 million years ago)

Helicoprion Shark Fossil in Wolfcamp Core



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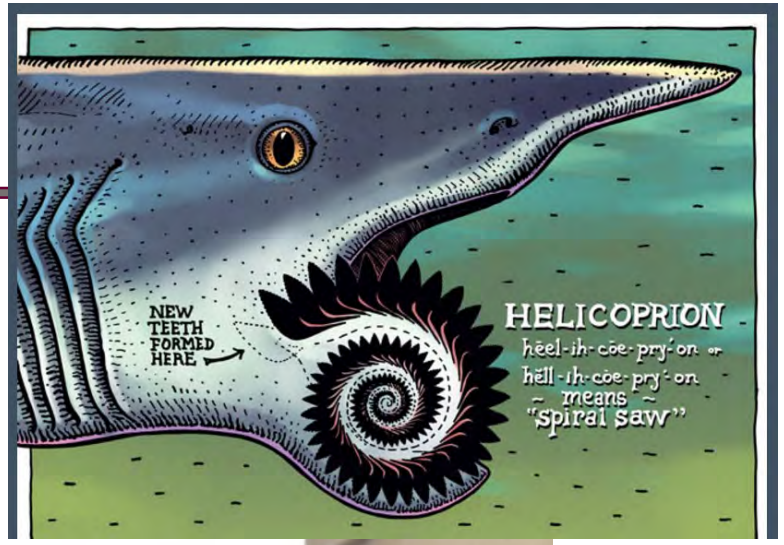

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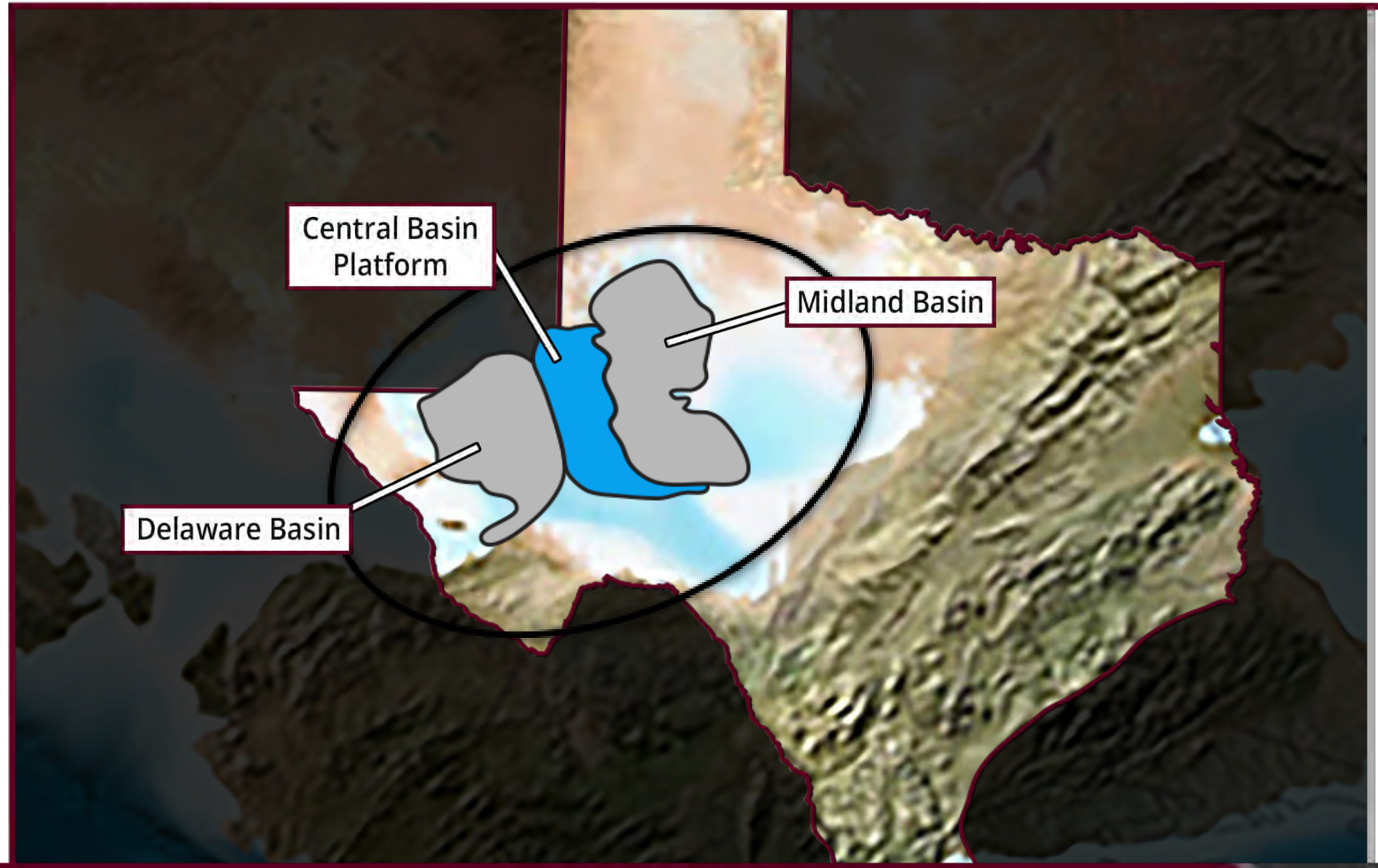
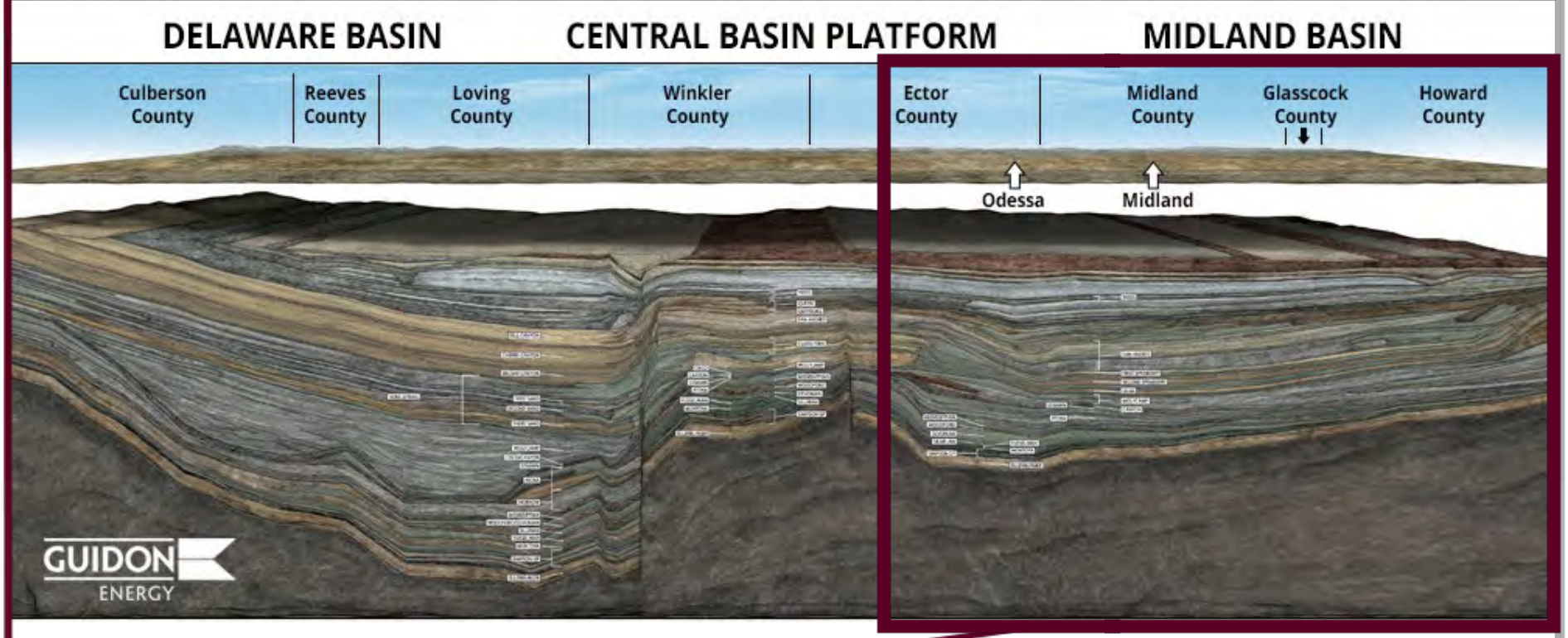
Permian Basin 260 Million Years Ago



Present Day - Permian Basin

Permian Basin Dimensions (Delaware/Central Basin Platform/Midland Basin)
163 miles E-W , 120 miles N-S or ~20,000 sq miles



← West

Midland Basin Only
86 miles E-W by 120 miles N-S or ~10,000 sq miles

East →

Santa Rita No. 1,

located in Section 2, Block 2, University of Texas lands in Reagan County (Midland Basin), came in on

May 28, 1923

SANTA RITA No. 1

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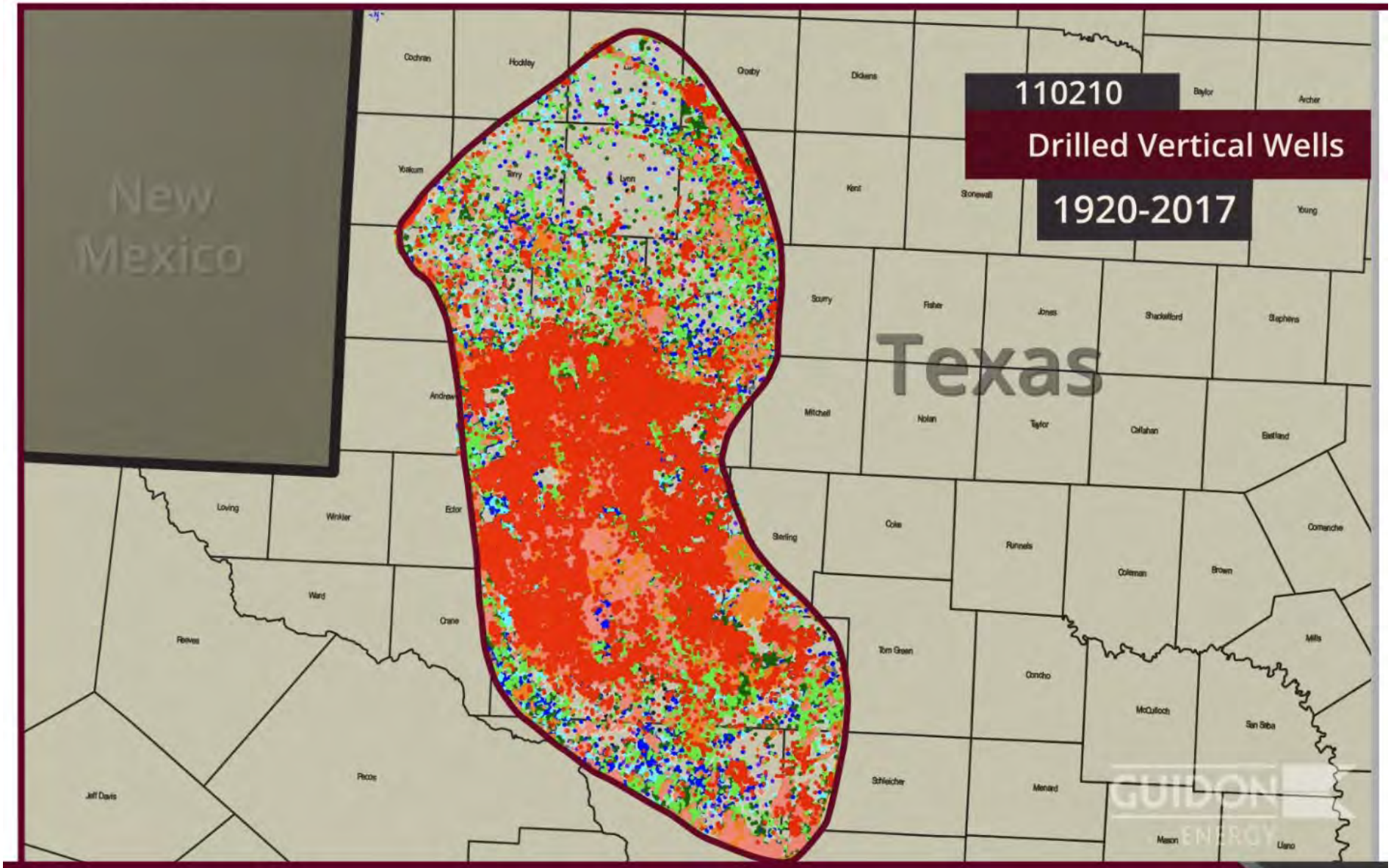
Vertical Well Development History of the Midland Basin



2,000+ Shallow SWD Wells in the Midland Basin

Midland Basin SWD Data Estimates

- Very rough estimates intended to show trend
- 6-county data set = 4,250 square miles
- Estimated daily oil production = ± 1,750,000 BOPD
- Estimated water cut = 2 bbl water produced for each bbl of oil (IHS)
- 2,281 active SWD wells
  - 89% or ± 2,000 are shallow disposal (upper perf < 6000')
  - 1 active shallow SWD every 2 square miles
  - Shallow disposal rate average = 1,250 bbl/day per well
- Current estimate of 2,700,000 bbl/day* shallow disposal basin wide
  - **7x** the pre-Hz daily annual disposal volume in 2010
- Projected Midland Basin production in 2025 = 3,600,000 BOPD**
- Projected shallow disposal in 2025 = 5,400,000 bbl/day
  - Equates to **15x** the pre-Hz annual disposal volume in 2010

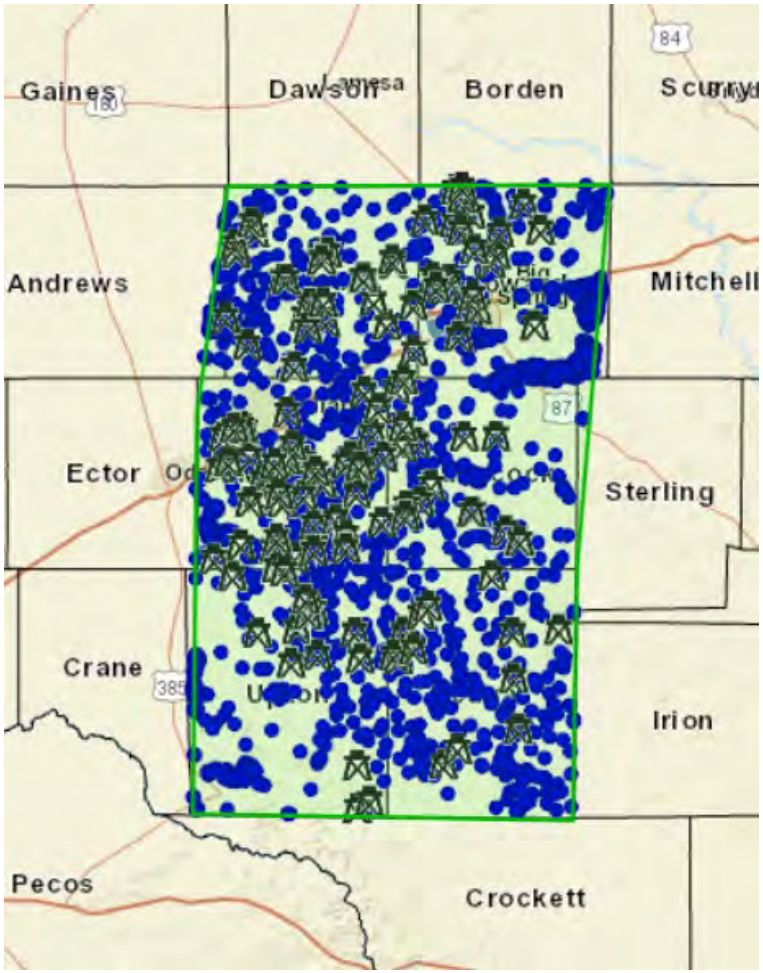
➢ **The current shallow disposal rate growth is not sustainable**

*SWD disposal rate assumes 2/1 oil/water ratio from IHS, 15% recycling, 10% goes to deep wells

**2025 Oil projection based on annual growth of 300,000 bopd (approx. 2017-2018 YOY growth)

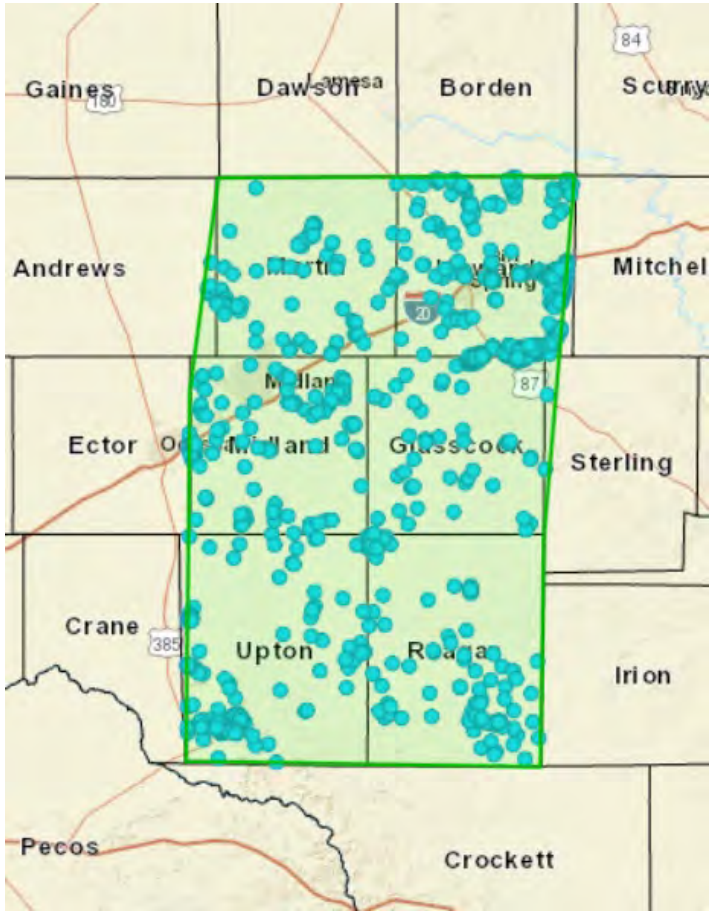
6 counties include Midland, Howard, Martin, Glasscock, Reagan, Upton

Martin, Howard, Midland, Glasscock, Upton, Reagan

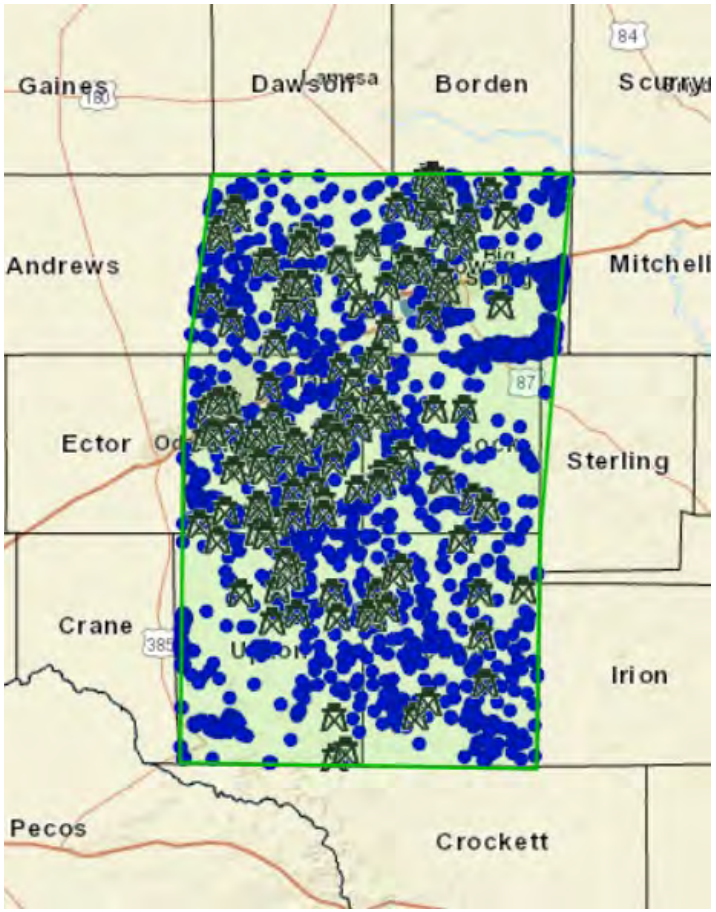


40% of SWD Wells Appear to be Commercial Wells

Commercial SWD (± 906) wells)

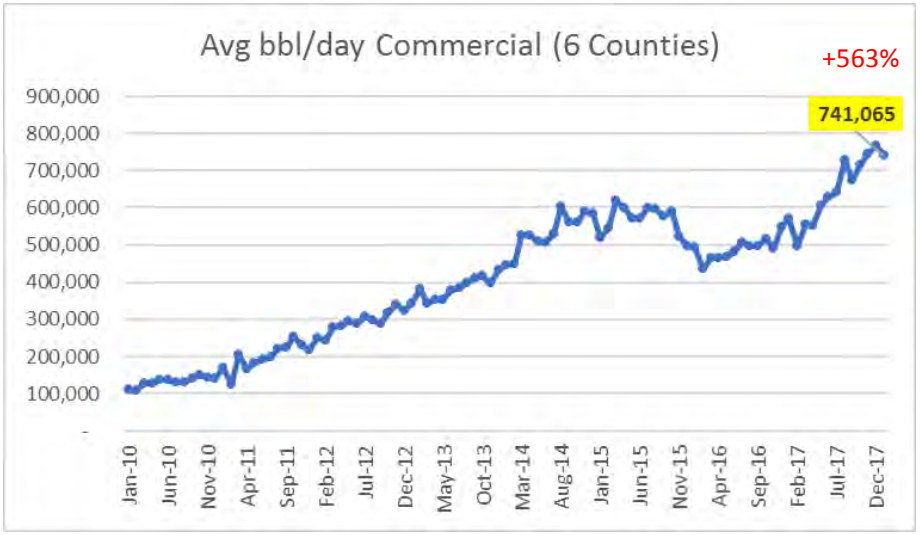


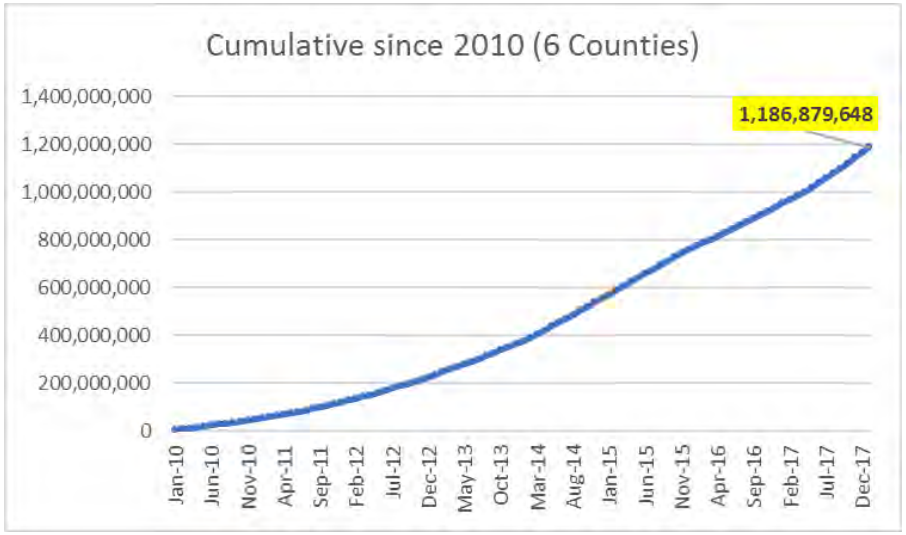
All Active Shallow Disposal Wells (± 2,039 wells)



- 3rd party SWD companies have different incentives; more water = more income and they're not drilling offset
- Even if I shut down my own shallow disposal I still get hit by other people's water sent to nearby commercial wells
- Operators control their own destiny *only* if they all work together in the same neighborhood
- 906 wells out of 2,281 appear to be commercial in Drilling Info

Commercial Disposal Has Increased 566% Since 2010

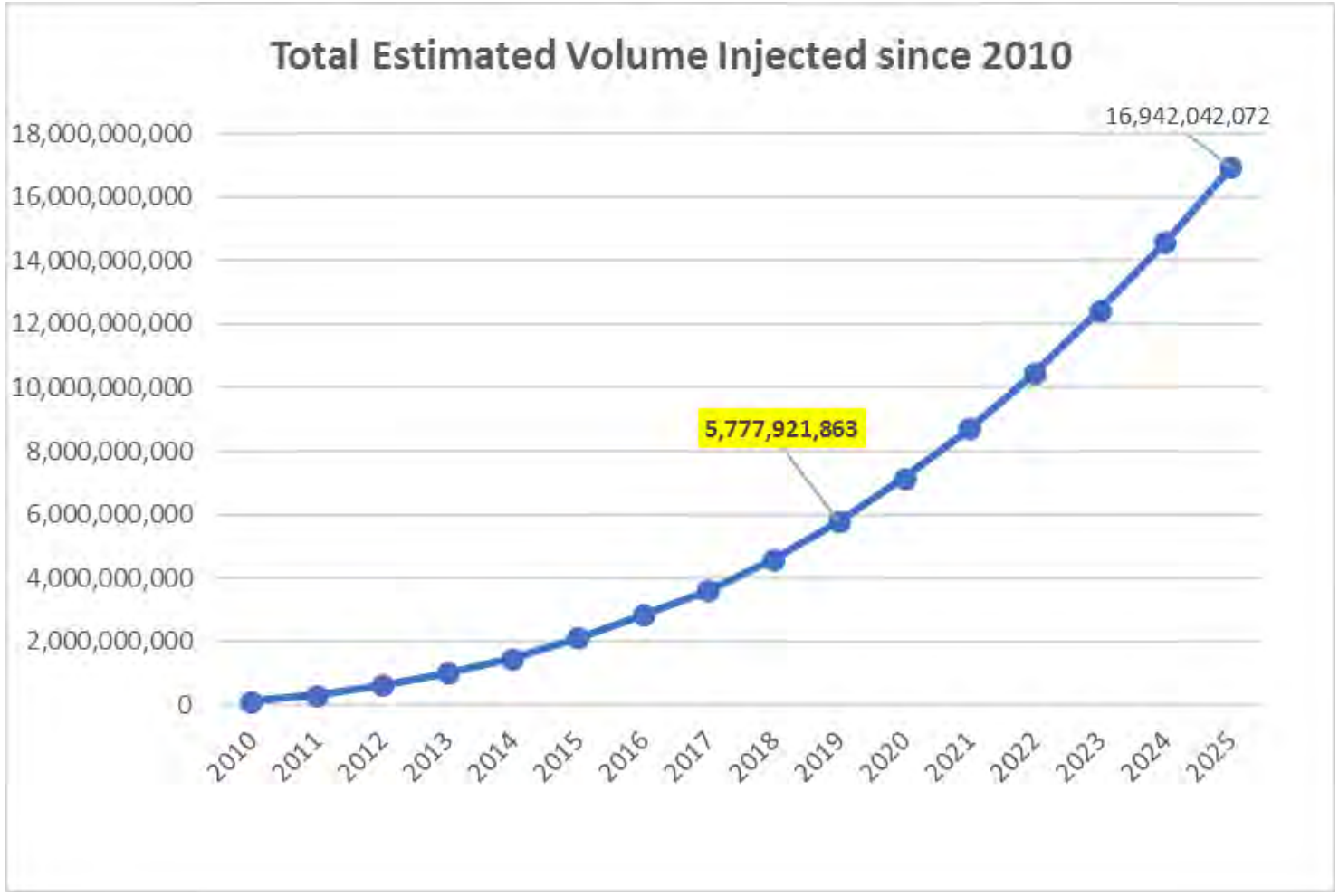




- 563% increase in commercial disposal volume since 2010
- 1.18 billion bbls injected since 2010
- ± 30% of disposal volume goes to commercial disposal wells*
- Public commercial disposal data supports rough estimate of growth based on total oil production and water cut (± 700% increase)
- Author has yet to find a way to query non-commercial disposal data by county
- Source: Commercial disposal into a nonproductive zone (W-14) for Midland, Howard, Martin, Glasscock, Reagan, Upton counties from 2010 to Jan 2018 H10 Search

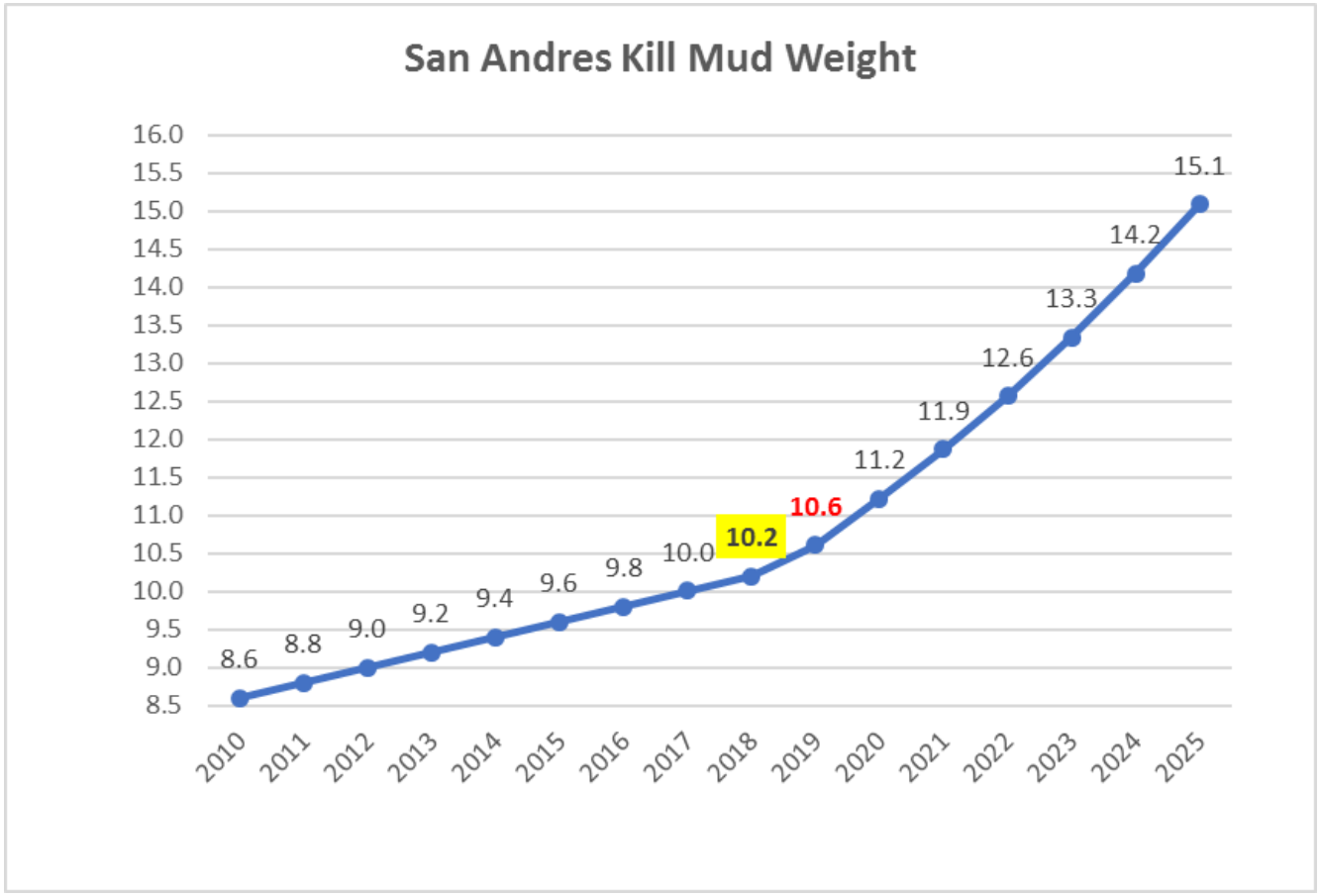
*Assumes 2/1 oil/water ratio, 15% recycling, and 10% goes to deep wells, drilling info data indicates 40% of SWD wells are commercial

± 5 Billion Barrels Disposed Shallow Since 2010



- Based on total oil production volume, 2/1 water/oil ratio, and 10% goes to deep disposal wells

What Happens When We Add 5 Billion Barrels to a Closed System?

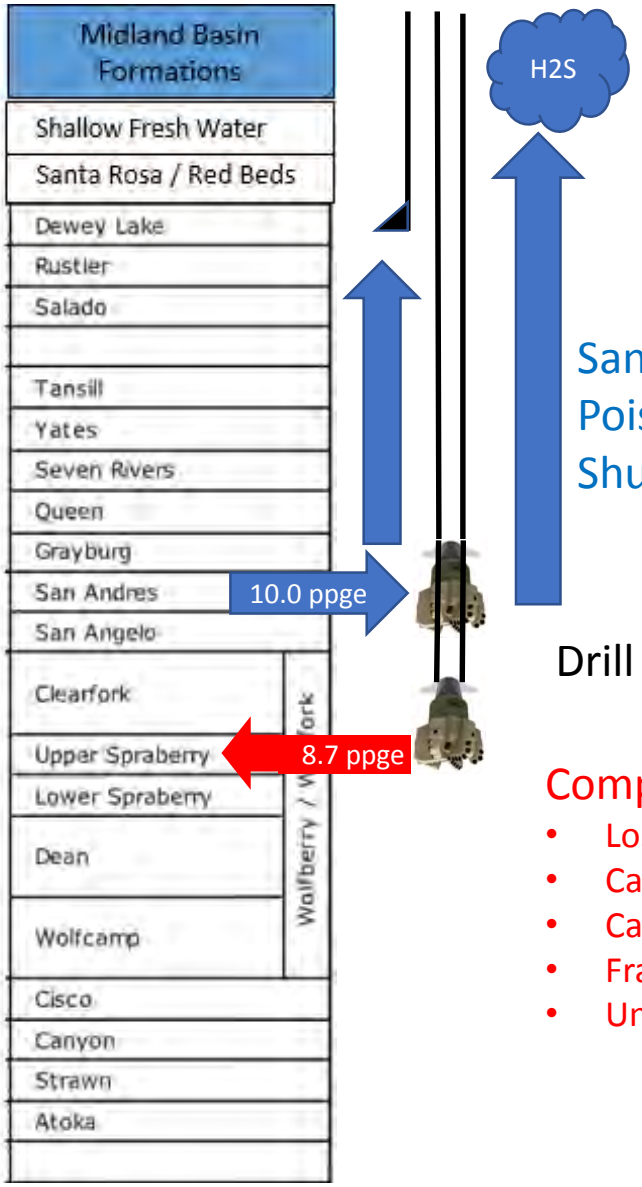


- Projection based on rough estimate of ppg increase per billion bbl injected since 2010 (0.3 ppg per MMMBW)
- At 10.2 ppg kill mud weight, we have already started to exceed the fracture gradient of the San Andres shale at 5900' TVD; lost circulation and differential sticking hazards increasing rapidly
- At 10.6 ppg kill mud weight we approach the fracture gradient of the Clear Fork lime, our primary 9-5/8" casing shoe
- Bottom hole pressure of San Andres does not appear to be regulated properly in the basin

Dumping the Leaves on Your Doorstep

Disposing in the San Andres is like raking up the leaves in your backyard…. and dumping them at your front doorstep.

Why is San Andres Injection Such a Drilling Hazard?



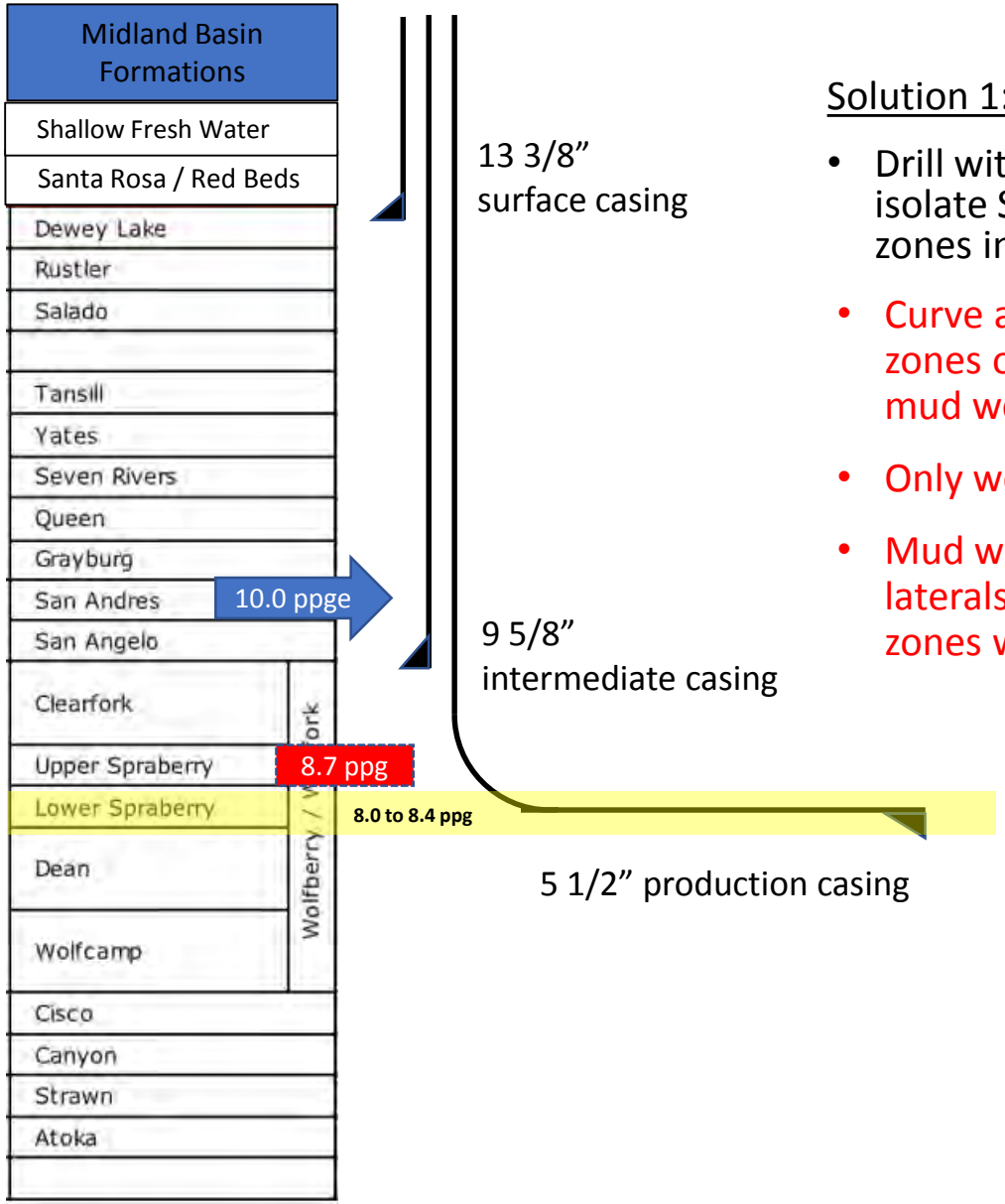
San Andres is over-pressured - Well is Flowing!
Poison H2S gas present
Shut in well, raise mud weight, and kill flow with 10.0 ppg

Drill Ahead with 10.0 ppg

Complete Losses in Upper Spraberry with MW > 8.7 ppg

- Loss of hydrostatic; well starts flowing again from San Andres
- Can't circulate kill weight mud with weak zone open
- Can't remove cuttings without flow; more difficult to drill ahead
- Fractured rock can become unstable; increased risk of stuck pipe
- Unsafe to trip with well flowing

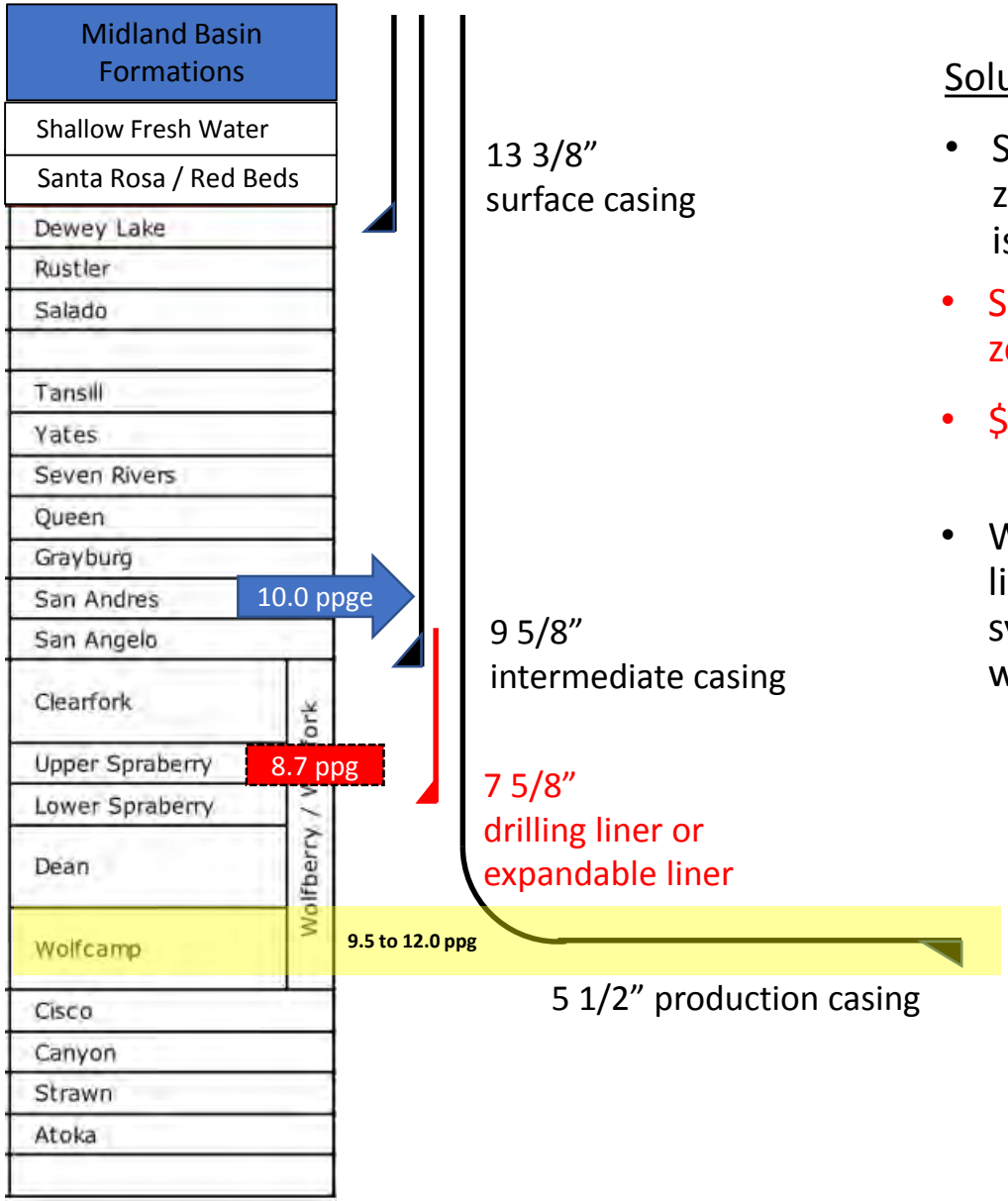
Modified 3-string Solution for Spraberry Targets



Solution 1: Modified 3-String Design

- Drill with kill weight mud, set 9 5/8" casing to isolate San Andres before drilling into the weak zones in Clearfork and Upper Spraberry
- Curve and lateral must be drilled with the weak zones open which limits your ability to increase mud weight to prevent wellbore collapse
- Only works reliably in the Spraberry horizontals
- Mud weight required to keep the Wolfcamp laterals open is higher than the open weak zones will hold

4-String Solution for Wolfcamp Targets

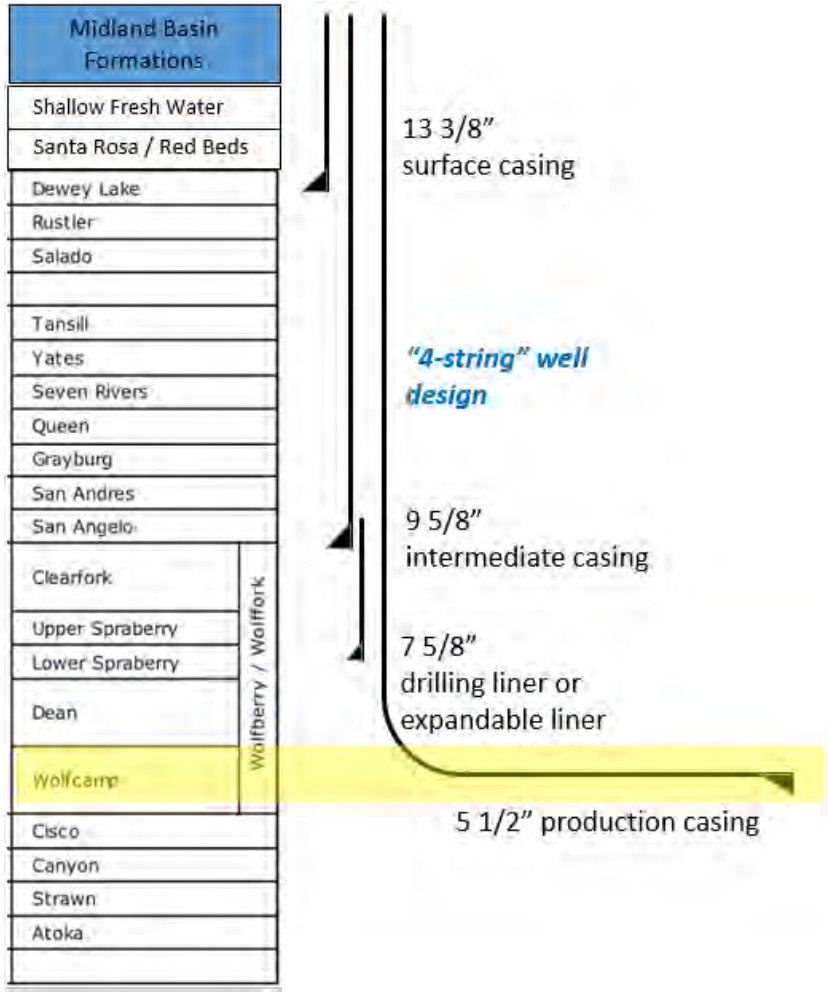


Solution 2: 4-String Design

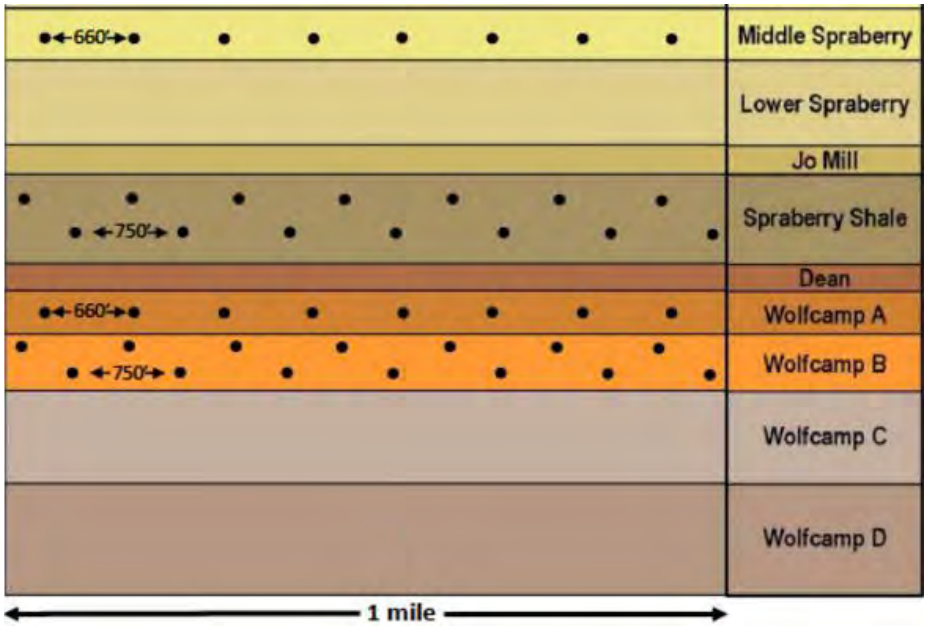
- Set 9 5/8" casing shallower, above weak zones in Clearfork and Upper Spraberry to isolate over-pressured San Andres
- Set 7 5/8" drilling liner to isolate weak zones in Clearfork and Upper Spraberry
- $600K additional cost

- With weak zones isolated by the drilling liner, we're now able to weight up our mud system to prevent Wolfcamp targets wellbores from caving in

San Andres Pressure Costs $13 Million Every 2 Square Miles



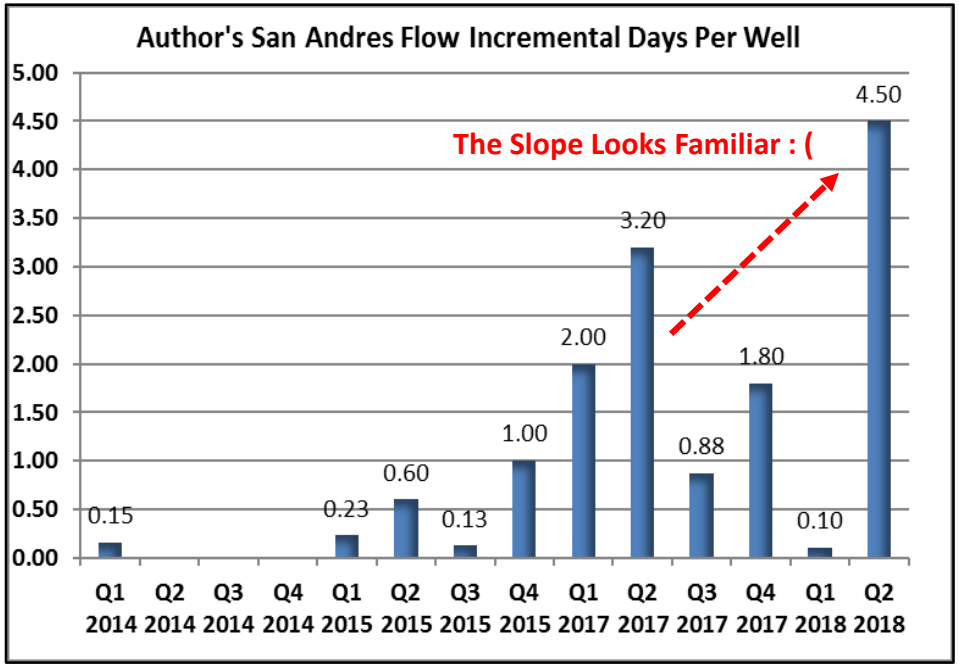
Spacing Assumptions

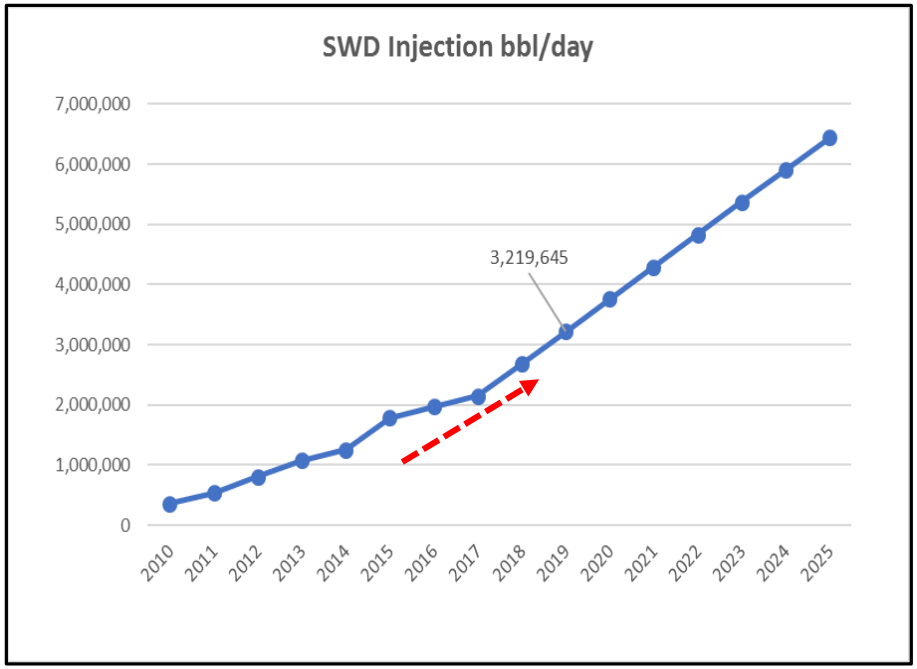


Target	Wells Per Section	Liner Cost Per Bench
WCA	8	$4,800,000
WCBshale	7	$4,200,000
WCBcarb	8	$4,800,000
Total per 1 mile wide unit		**$13,800,000**

- Incremental cost due to Drilling Liner = $13.8 MM every 2 sections/2 mi^2 (assuming 10k laterals)
- Full 6 County Basin Development 4,250 mi^2 x $13.8 MM every 2 mi^2 = $29.3 Billion incremental costs

San Andres NPT Trend Very Concerning





- In one current development area, well flows at 10.1 ppg with up to 300 ppm at the shakers. Losses and differential sticking with mud weights greater > 10.2 ppg.
- As of Dec 2018, five out of 47 wells have experienced losses at 10.1 ppg kill mud weight and subsequent differential sticking (stuck-pipe) events; able to free with 2,000 gals of 7.5% HCL.
- When the San Andres kill mud weight exceeds the fracture gradient of the formations below it we are in deep $%*#!

Path Forward

- **Continue "business as usual" and spend $600k per well on drilling liner**
  - Over-pressure is getting worse with time… where will this lead us?
  - San Andres pressure compounds almost every other drilling hazard
  - Inconsistent with commitment to maintaining a safe working environment
- **Continue "business as usual" and just let the well flow while drilling**
  - Goes against conventional well control training
  - Increased risk to life-threatening exposure to H2S
  - Will it eventually lead to a Macondo-like event?
- **Continue "business as usual", kill the San Andres and "dry-drill" without returns to normal casing point**
  - Where do all the cuttings go?
  - Increased risk of stuck pipe events and expensive lost-in-hole charges (± 20% failure rate according to major area operator)
  - Unplanned events wreak havoc on scheduling, forecasting, and production targets
- **Inject all produced water into deep zones**
  - Must invest in geoscience to properly characterize the reservoir
  - Non-starter for all 3rd party owners/operators/investors of shallow injection wells (unless you buy them out)
  - Doesn't fix the areas with existing over-pressure and doesn't work if your neighbors keep injecting shallow
  - Concerns with tectonic events in other basins related to injection
- **Reuse all produced water and use deep injection only as necessary – Guidon Energy's Strategy**
  - Several operators have recently reported that the current economics work and they've actually saved money with reuse
  - Higher up-front investment in infrastructure
  - More manpower, more planning
  - New challenge for frac fluid design

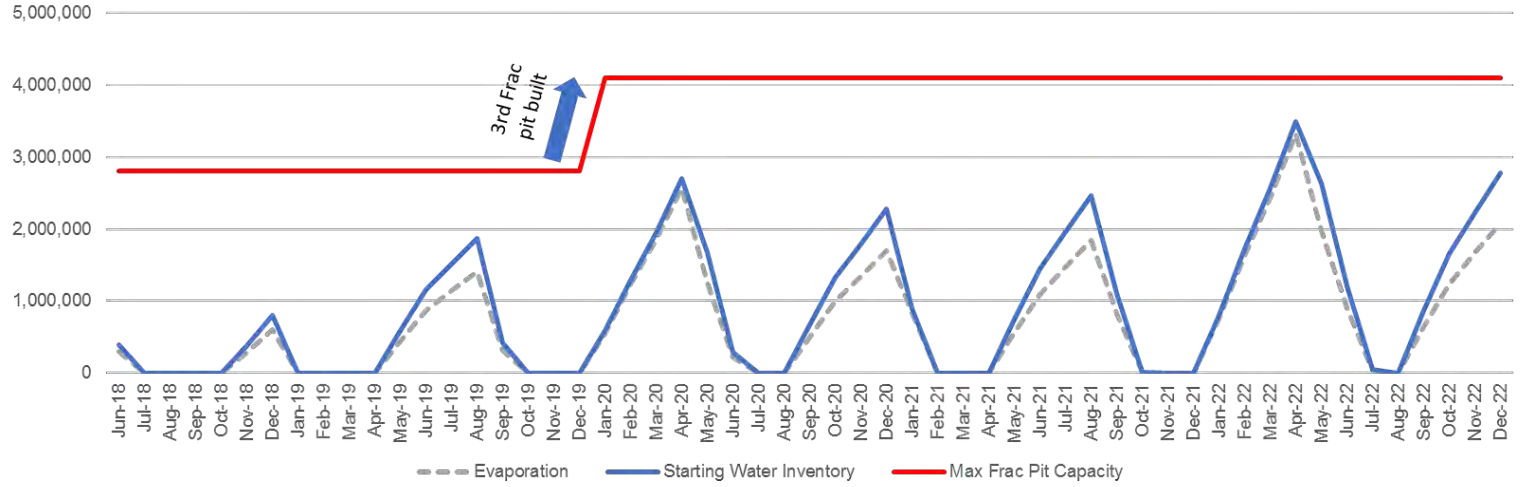
➢ **We need to study the San Andres reservoir in detail to understand the problem and to guide the path forward (ex. Laura Capper)**

Water Reuse Summary

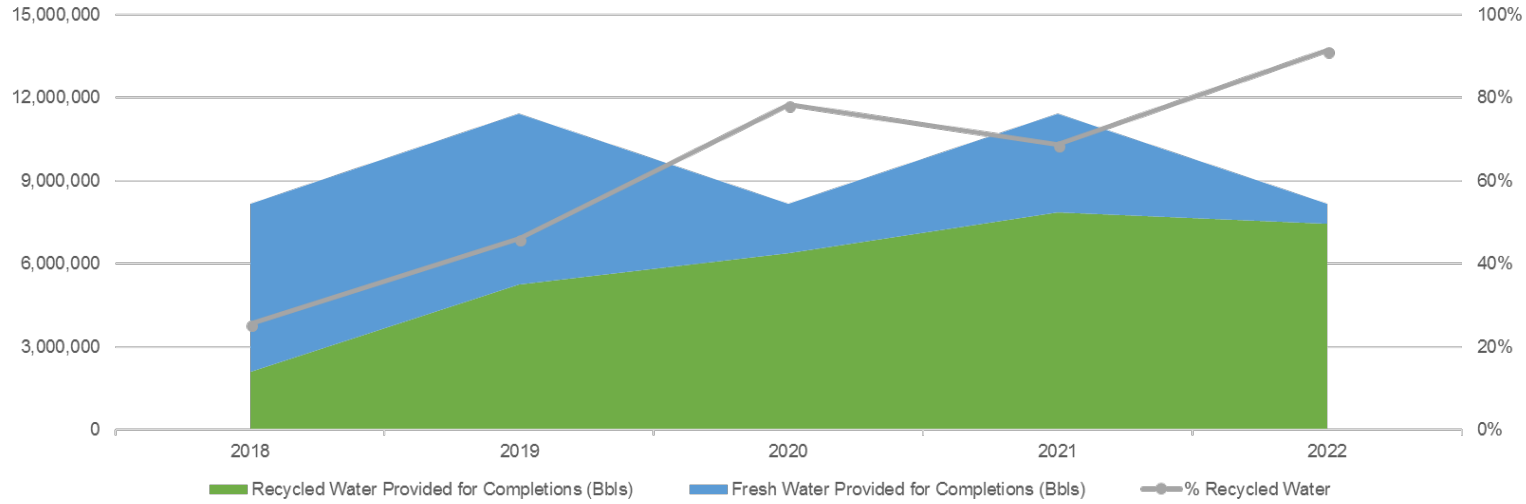
- Developed a produced water reuse standard based on bacteria, iron, sulfides, pH and total suspended solids (TSS)
- Oxidation used for bacteria, iron and sulfide control – specifically using Hydrozonix's portable ozone system
- After a successful ozone test under a service contract, purchased two fully automated ozone systems to further reduce costs
- Primary pit designed as a settling basin with sloped pit and central suction line to remove solids
- Aggressive aeration in secondary storage pit to maintain quality of the treated water
- Simple approach of oxidization and settling reduces the overall costs while meeting the established water treatment reuse objectives
- Recycling 100% of horizontal produced water
- Sharing water systems with Encana, FANG, XTO
- Roughly 60% of our current frac design volume is slickwater which allows the use of recycled produced water.
- The other 40% of the job is hybrid (gel/X-link) which requires freshwater to allow the fluids to yield
- Requires the use of two independent water supply lines for the frac (1 fresh, 1 recycled) to accommodate both fluid systems
- Connect development areas via pipe to enhance ability to use larger % recycled water, and achieve savings on a larger portion of volumes
- Model water production and frac use over time to determine pit volume requirements and water mix to ensure frac design can be accommodated
- Recently partnered with Waterfield Midstream

Modeling Water Inventory is Critical

Water Inventory Progression (bbls)

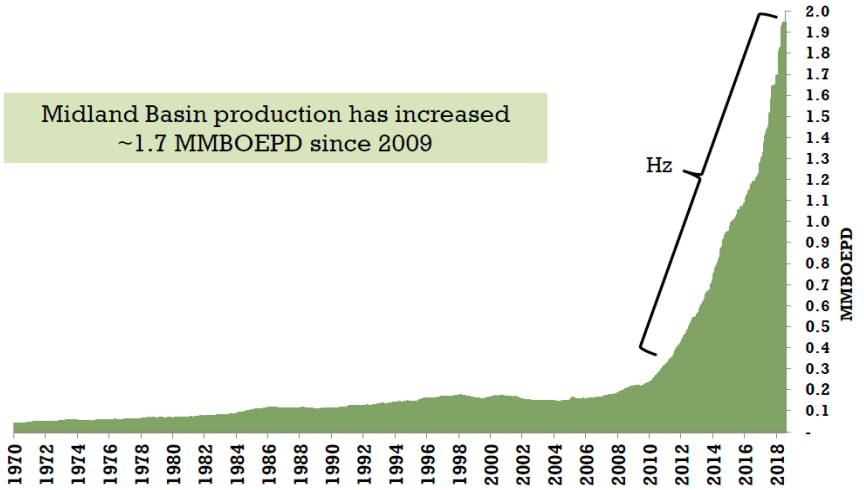


Fresh vs. Recycled Water Used in Completion (bbls I %)

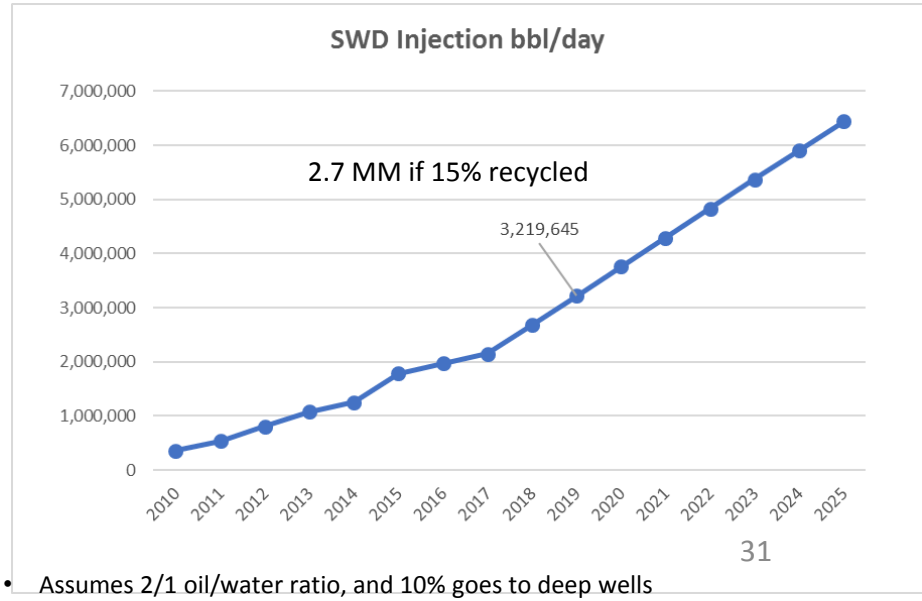


It Is Possible to Re-Use All Produced Water in the Basin

- Current estimate shallow disposal rate of 2.7 MM bbl/day
- Currently ± 155 rigs running in Midland Basin
- Assuming 1 frac fleet every 2 rigs = ± 75 fleets in Midland
- Assume each fleet pumps 6 stages/day
- Each stage = ± 7,500 bbl
- 75 fleets x 6 stages/day x 7,500 bbl/stage =
  - ± 3.3 MM bbl/day of frac water
- Assuming 60/40 mix = 2 MM bbl/day could be easily reused with hybrid frac designs
- We would have to use 80/20 mix to eliminate shallow disposal
- **It can be done… but**
  - **fluid designs have to be modified**
  - **requires a tremendous amount of infrastructure to store water and to connect development areas**
  - **inventory and usage must be modeled**



- From 2009 to 2012, production growth primarily attributable to increased vertical activity
- Post 2012, production growth driven by horizontal activity



- Assumes 2/1 oil/water ratio, and 10% goes to deep wells

Takeaways

- Current shallow disposal rate of 2.3 MM bbl/day
  - 7x the disposal rate in 2010
  - Projects to 5.4 MM bbl/day by 2025 (15x 2010 rate)
- San Andres bottom hole pressure is increasing in direct correlation with oil production growth and disposal rate. We need to study the reservoir to understand the problem.
- Drilling hazards and costs are increasing rapidly. San Andres liner contingency costs $13.8 MM every 2 sections or $29 billion across the basin.
- Current frac spreads require ± 3.3 MM bbl/day of frac water and we would have to use 80% recycled water to eliminate shallow disposal
- Shallow disposal can be eliminated but it will require a tremendous amount of infrastructure and planning
- As an industry we need to solve this problem ourselves before new regulations force our path

We are sitting on the 2nd biggest oilfield in the world… lets try not to screw this up

Backup

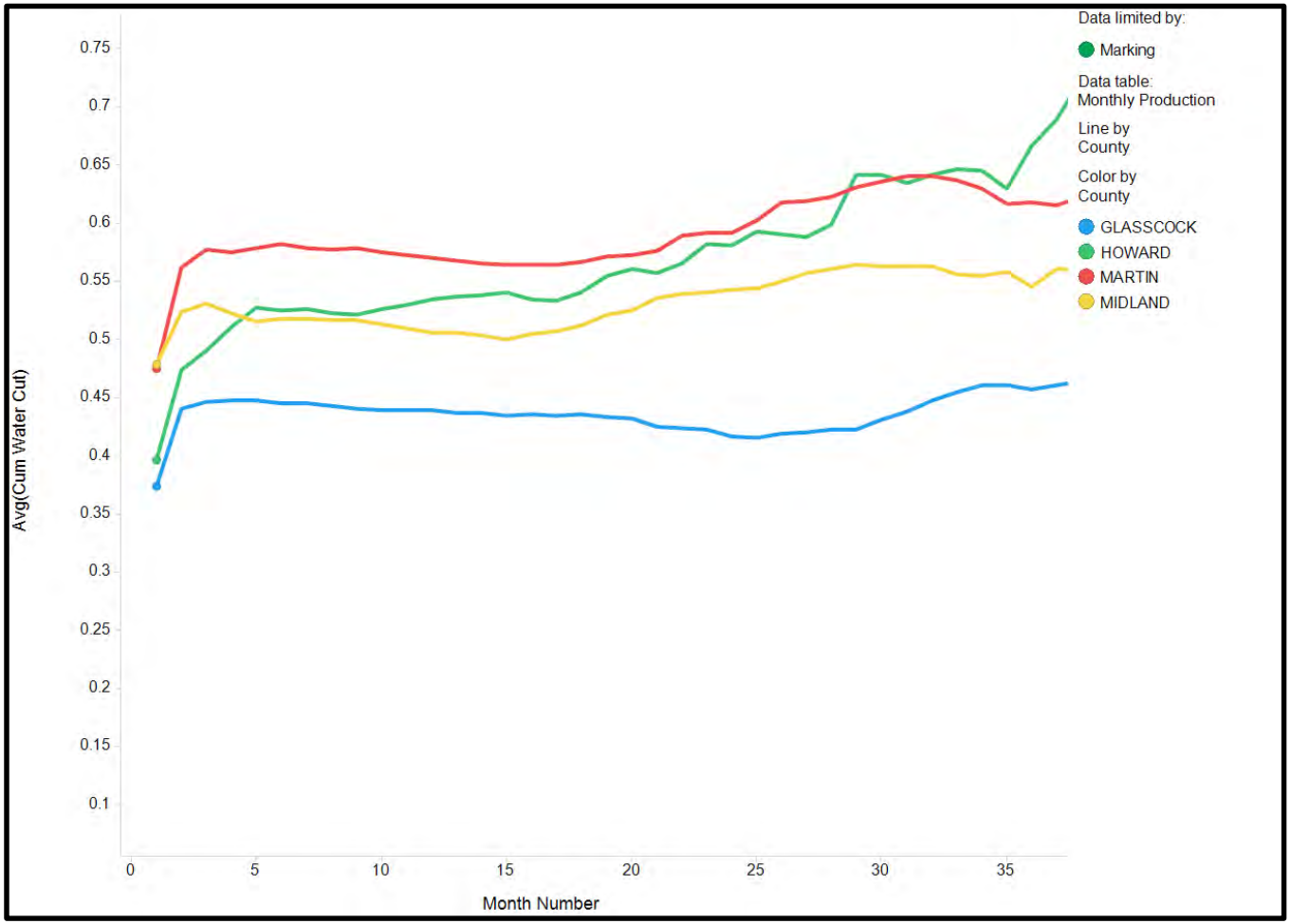
The San Andres is Poisonous

Worker Exposure Limits
NIOSH REL (10-min. ceiling): 10 ppm
OSHA PELs: General Industry Ceiling Limit: 20 ppm General Industry Peak Limit: 50 ppm (up to 10 minutes if no other exposure during shift) Construction 8-hour Limit: 10 ppm Shipyard 8-hour limit: 10 ppm
NIOSH IDLH: 100 ppm
IDLH: immediately dangerous to life and health (level that interferes with the ability to escape) (NIOSH)
PEL: permissible exposure limit (enforceable) (OSHA)
ppm: parts per million
REL: recommended exposure limit (NIOSH)

- San Andres flows commonly contain poisonous H_2S gas in concentrations that are immediately dangerous to life
- 20 – 50 ppm is common
- Have seen up to 200-300 ppm (deadly)
- Thankfully West Texas winds often help to dissipate gas from working areas and rig camp

Concentration (ppm)	Symptoms/Effects
0.00011-0.00033	Typical background concentrations
0.01-1.5	Odor threshold (when rotten egg smell is first noticeable to some). Odor becomes more offensive at 3-5 ppm. Above 30 ppm, odor described as sweet or sickeningly sweet.
2-5	Prolonged exposure may cause nausea, tearing of the eyes, headaches or loss of sleep. Airway problems (bronchial constriction) in some asthma patients.
20	Possible fatigue, loss of appetite, headache, irritability, poor memory, dizziness.
50-100	Slight conjunctivitis ("gas eye") and respiratory tract irritation after 1 hour. May cause digestive upset and loss of appetite.
100	Coughing, eye irritation, loss of smell after 2-15 minutes (olfactory fatigue). Altered breathing, drowsiness after 15-30 minutes. Throat irritation after 1 hour. Gradual increase in severity of symptoms over several hours. Death may occur after 48 hours.
100-150	Loss of smell (olfactory fatigue or paralysis).
200-300	Marked conjunctivitis and respiratory tract irritation after 1 hour. Pulmonary edema may occur from prolonged exposure.
500-700	Staggering, collapse in 5 minutes. Serious damage to the eyes in 30 minutes. Death after 30-60 minutes.
700-1000	Rapid unconsciousness, "knockdown" or immediate collapse within 1 to 2 breaths, breathing stops, death within minutes.
1000-2000	Nearly instant death

Average Water Cut = 0.6 for Hz Wells Since 2010



- Estimated average water cut including flowback = .667 (± 2 bbls of water produced for every 1 bbl of oil)

Total Disposal Rate Projections

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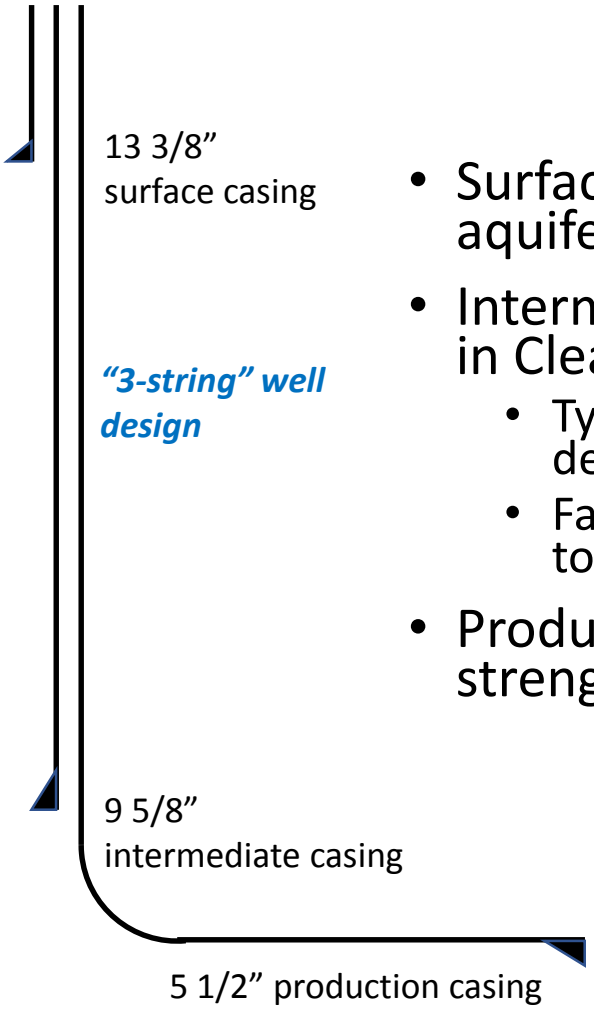
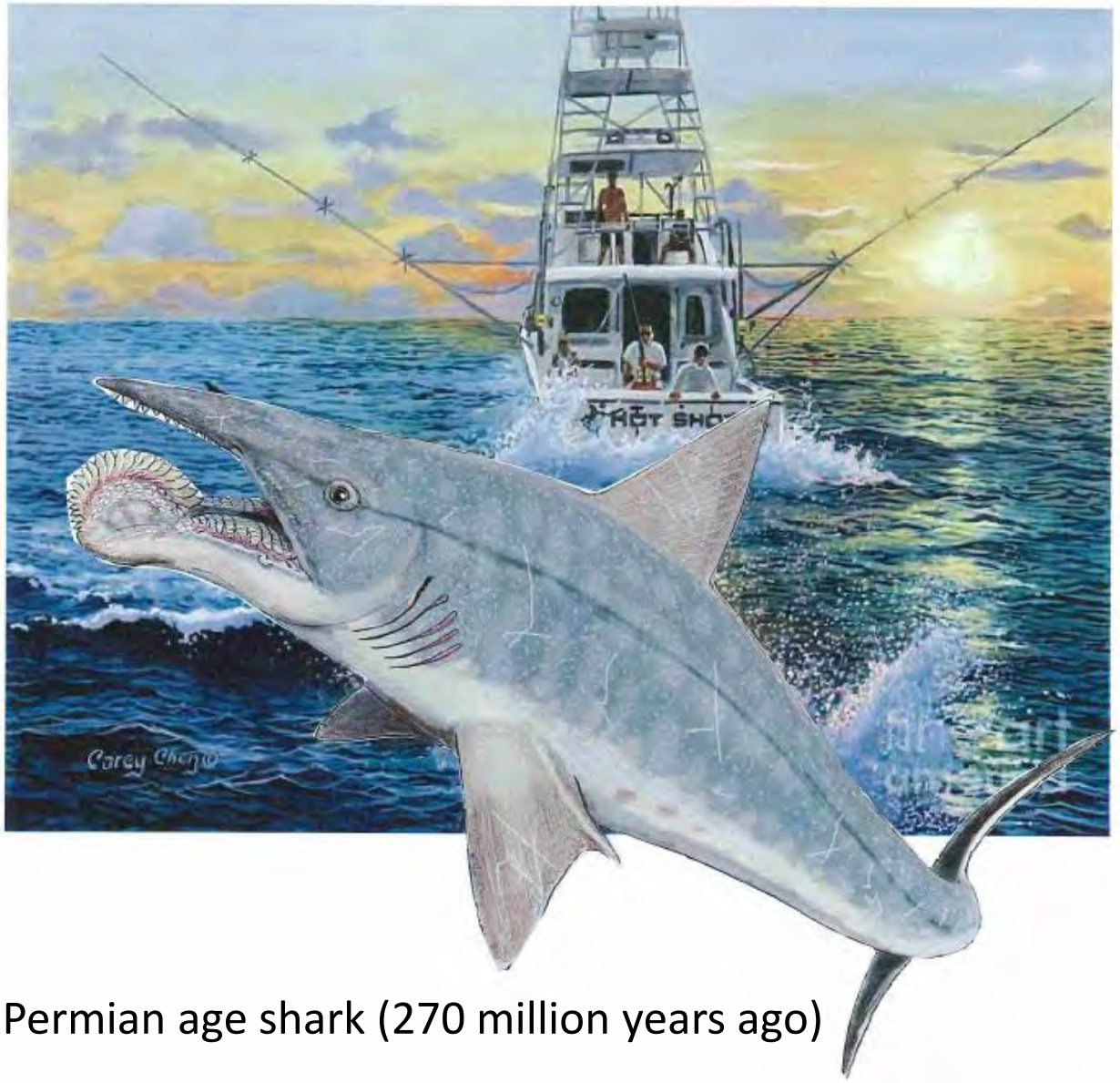
Year	BOPD	SWD Injection bbl/day	SWD Injection bbl/year	Total Estimated Volume Injected since 2010	% YOY Increase injection volume	% increase annual injection vs. 2010 volume	San Andres Kill Mud Weight	Increase in Kill Mud Weight	ppg increase / MMMBO injection volume
2010	200,000	357,738	130,574,505	130,574,505	n/a		8.6		
2011	300,000	536,608	195,861,758	326,436,263	50%	50%	8.8	0.2	0.612677
2012	450,000	804,911	293,792,637	620,228,901	50%	125%	9.0	0.4	0.644923
2013	600,000	1,073,215	391,723,516	1,011,952,417	33%	200%	9.2	0.6	0.592913
2014	700,000	1,252,084	457,010,769	1,468,963,185	17%	250%	9.4	0.8	0.544602
2015	1,000,000	1,788,692	652,872,527	2,121,835,712	43%	400%	9.6	1.0	0.47129
2016	1,100,000	1,967,561	718,159,780	2,839,995,492	10%	450%	9.8	1.2	0.422536
2017	1,200,000	2,146,430	783,447,032	3,623,442,524	9%	500%	10.0	1.4	0.386373
2018	1,500,000	2,683,038	979,308,790	4,602,751,314	25%	650%	10.2	1.6	0.347618
2019	1,800,000	3,219,645	1,175,170,548	5,777,921,863	20%	800%	10.6	2.0	0.347618
2020	2,100,000	3,756,253	1,371,032,306	7,148,954,169	17%	950%	11.2	2.6	0.367261
2021	2,400,000	4,292,860	1,566,894,065	8,715,848,234	14%	1100%	11.9	3.3	0.375206
2022	2,700,000	4,829,468	1,762,755,823	10,478,604,056	13%	1250%	12.6	4.0	0.379068
2023	3,000,000	5,366,076	1,958,617,581	12,437,221,637	11%	1400%	13.3	4.7	0.381196
2024	3,300,000	5,902,683	2,154,479,339	14,591,700,976	10%	1550%	14.2	5.6	0.382482
2025	3,600,000	6,439,291	2,350,341,097	16,942,042,072	9%	1700%	15.1	6.5	0.383314

Where We Began: Base Well Design



- Surface casing protects fresh water aquifers
- Intermediate casing isolates weak zones in Clearfork and Upper Spraberry
  - Typically set 800' TVD above target zone depth
  - Facilitates higher mud weights required to drill Wolfcamp laterals
- Production casing provides high-strength conduit for frac job

Permian Fishing Concept



Permian age shark (270 million years ago)