

Pathway for Recovering Valuable Elements Of Interest from Subsurface Brines and Oilfield Produced Waters



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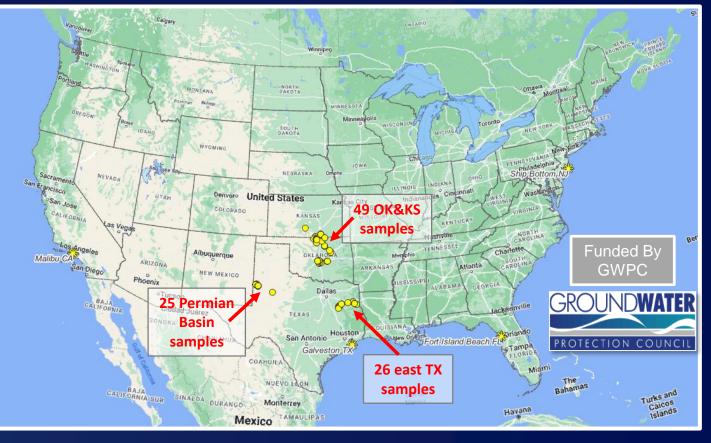


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Presentation Outline



- Motivation
- What are Elements of Interest (EOI)?
- Pathway for Recovering EOI from Produced Water (PW)
- Introduction to Gross Values (GV)
- GV Case Study: Permian Basin
- GV Case Study: Well OK 005



Motivation



Critical Minerals (CM) are elements that are critical to the U.S. economic and national security because they have important uses, no viable substitutes, are mostly imported, and face potential disruption in supply.

Mineral commodities are vital for economic growth, improving the quality of life, providing for national defense, and the overall functioning of modern society. Minerals are being used in larger quantities than ever before and in an increasingly diverse range of applications— from telecommunications (cell phones and computers), to renewable-energy generation (wind turbines, solar photovoltaics, and fuel cells), to clean forms of transportation (electric and hybrid cars).

USGS Professional Paper 1802, 2017 American Critical Mineral Independence Act of 2021 American Critical Mineral Exploration and Innovation Act

IM = Industrial Minerals

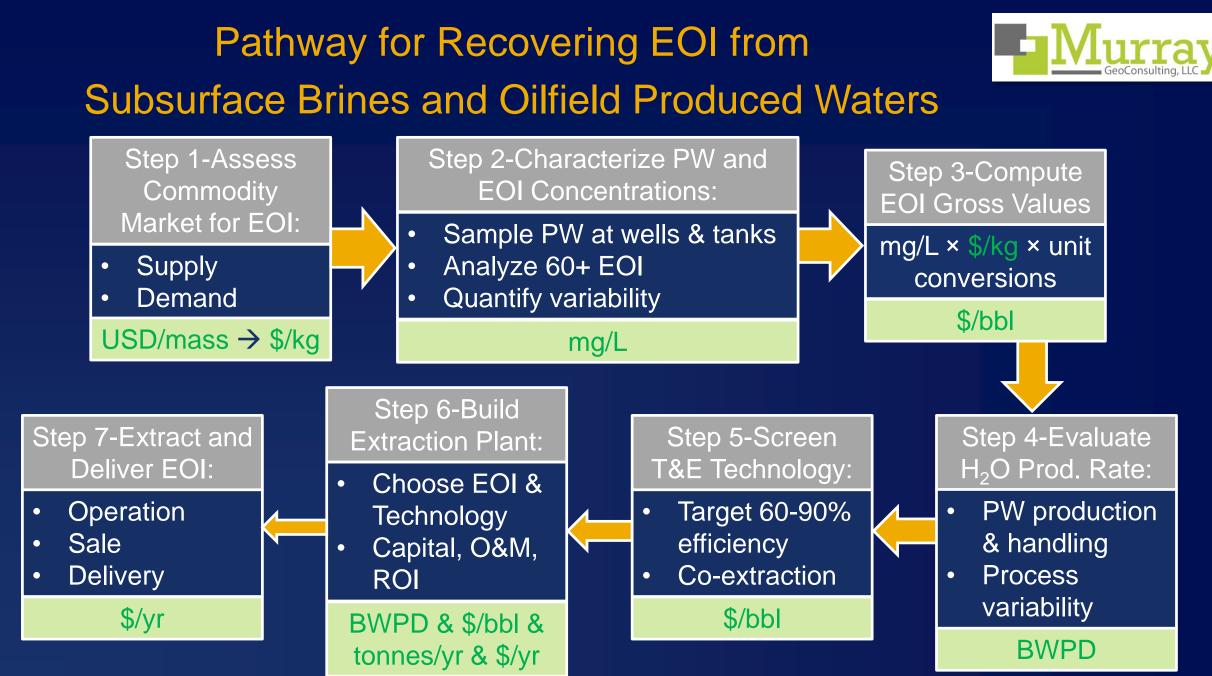


What are Elements of Interest (EOI)?



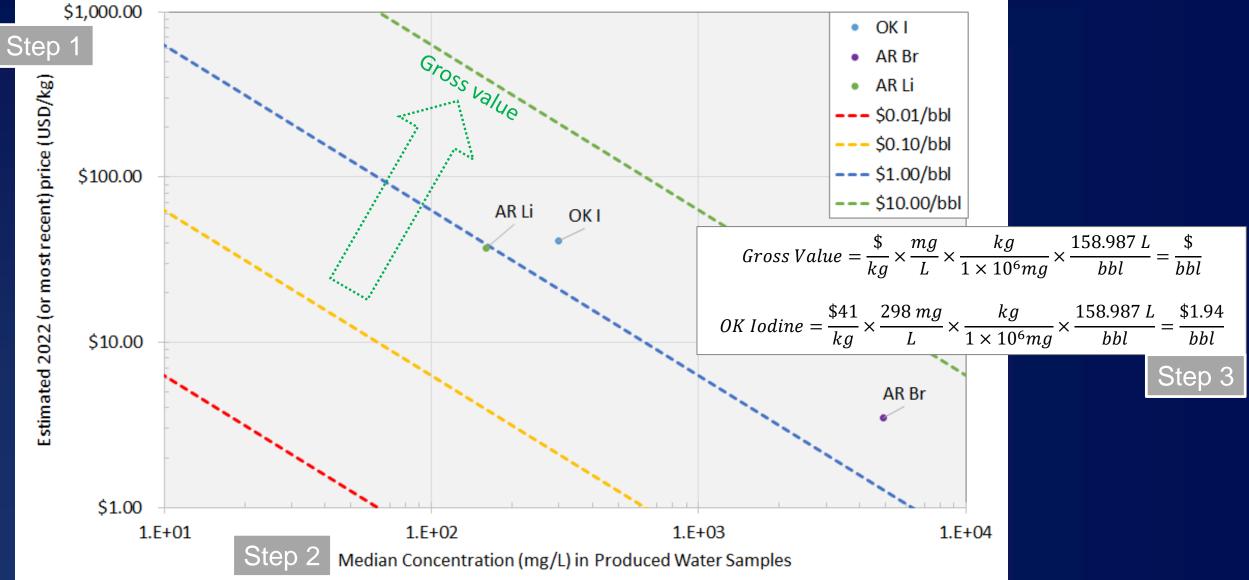
Elements of Interest (EOI) are elements that <u>may be</u> economically recovered from waters or solid wastes (i.e., \$ value > \$ extraction cost) .

Period		1 I A																			18 VIII A
1	1s	1 ±1 H hydrogen 1.008	2 II A				atom English eleme	atomic # \rightarrow nic symbol \rightarrow ent name \rightarrow	29 +2,1 Cu copper 63.55	← ions comr ← atomic ma	nonly formed uss (rounded)					13 III A	14 IV A	15 V A	16 VI A	17 VII A	2 He helium 4.003
2	2s	3 +1 Li lithium 6.968	4 +2 Be beryllium 9.012		Major	IM	СМ	CM- REE	CM- PGE						5 2p	+3 B boron 10.81	6 -4 C carbon 12.01	N nitrogen 14.01	O oxygen 16.00	9 -1 F fluorine 19.00	10 Ne neon 20.18
3	3s	Na sodium 22.99	12 +2 Mg magnesium 24.31		3 III B	4 IV B	5 V B	6 VI B	7 VII B	8 VIII B	9 VIII B	10 VIII B	11 I B	12 II B	3р	AI aluminum 26.98	Si silicon 28.09	P phosphorus 30.97	S sulfur 32.07	CI chlorine 35.45	18 Ar argon 39.95
4	4s	K potassium 39.10	20 +2 Ca calcium 40.08	3d	Sc scandium 44.96	22 +4,3,2 Ti titanium 47.87	V vanadium 50.94	Cr chromium 52.00	25 2,3,4,6,7 Mn manganese 54.94	Fe iron 55.85	Co cobalt 58.93	Ni nickel 58.69	29 +2,1 Cu copper 63.55	30 +2 Zn zinc 65.38	3 4p	Ga gallium 69.72	32 +4,2 Ge germanium 72.63	As arsenic 74.92	Se selenium 78.97	Br bromine 79.90	36 Kr krypton 83.80
5	5s	37 +1 Rb rubidium 85.47	38 +2 Sr strontium 87.62	4d	v	40 +4 Zr zirconium 91.22	41 +5,3 Nb niobium 92.91	42 +6,3,5 Mo molybdenum 95.95	43 +7,4,6 TC technetium 98	44 +4,3,6,8 Ru ruthenium 101.1	45 +3,4,6 Rh rhodium 102.9	46 +2,4 Pd palladium 106.4	47 +1 Ag silver 107.9	48 +2 Cd cadmium 112.4	4 5p	9 +3 In indium 114.8	50 +4,2 Sn tin 118.7	51 +3,5 Sb antimony 121.8	52 -2 Te tellurium 127.6	53 -1 iodine 126.9	54 Xe xenon 131.3
6	6s	55 +1 Cs cesium 132.9	56 +2 Ba barium 137.3	† 5d	1	72 +4 Hf hafnium 178.5	73 +5 Ta tantalum 180.9	74 +6,4 W tungsten 183.8	75 +7,4,6 Re rhenium 186,2	76 +4,6,8 OS osmium 190.2	77 +4,3,6 Ir iridium 192.2	78 +4,2 Pt platinum 195,1	2 79 +3,1 Au gold 197.0	80 +2,1 Hg mercury 200,6	8 6p	1 +1,3 TI thallium 204,4	82 +2,4 Pb lead 207,2	83 +3,5 Bi bismuth 209.0	84 +4,2 Po polonium 209	85 At astatine 210	86 Rn radon 222
7		87 +1 Fr francium 223	88 +2 Ra radium 226	‡6d	L e	104 Rf rutherfordium 267	105 Db dubnium 268	106 Sg seaborgium 271	107 Bh bohrium 272	108 Hs hassium 270	109 Mt meitnerium 276	110 Ds darmstadtium 281	111 Rg roentgentium 280	112 Cn copernicum 285	1 7p	13 Nh nihonium 284	114 Fl flerovium 289	115 Mc moscovium 288	116 Lv livermorium 293	117 Ts tennessine 292	118 Og oganesson 294
	_		n thanides n elements)	† 4f	La Ianthanum 138.9	140.1	Pr praseodymium 140.9	Nd	Pm promethium 145	62 +3,2 Sm samarium 150.4 94 +4,3,5,6	Eu europium 152.0	Gd gadolinium 157.3	65 +3,4 Tb terbium 158.9 97 +3,4	Dy _{dysprosium} 162.5	67 Ho holmiur 164.9	+3 68 EI n erbiu 167. +3 100	im thuliu .3 168.	um ytterbi	um		
			actinides			Th thorium 232.0	Pa protactinium 231.0	U uranium 238.0	Np neptunium 237	Pu plutonium 244	Am americium 243	Cm curium 247	Bk berkelium 247	Cf californium 251	einsteiniu 252	Fn	n Me um mendele	d No evium nobeli) um		



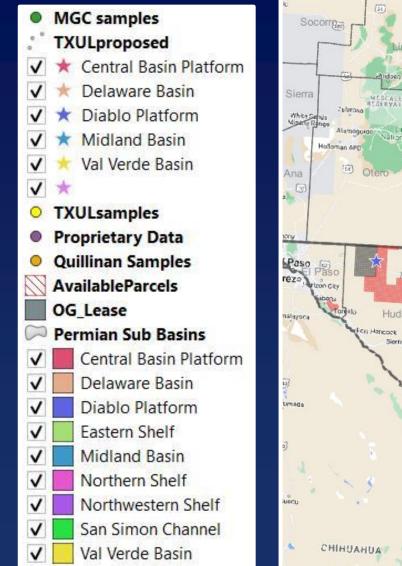
Introduction to Gross Values (GV) of EOI

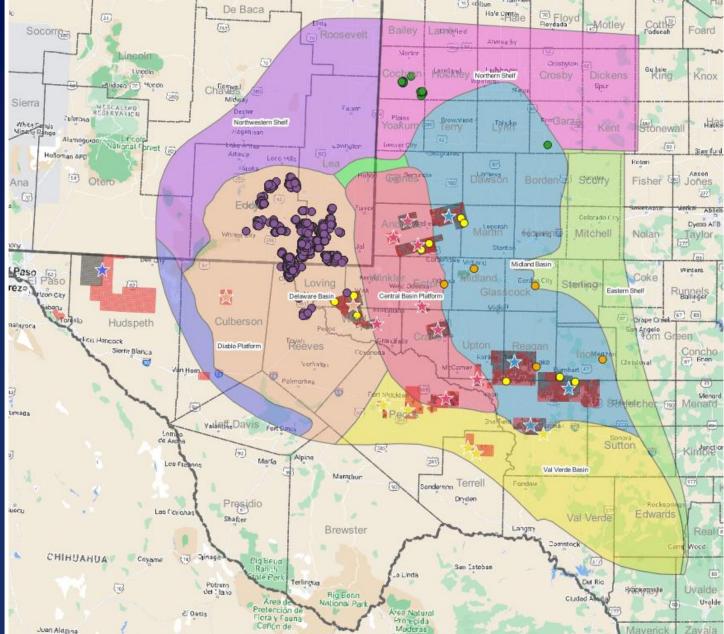




Case Study: MGC and other EOI Data in PB





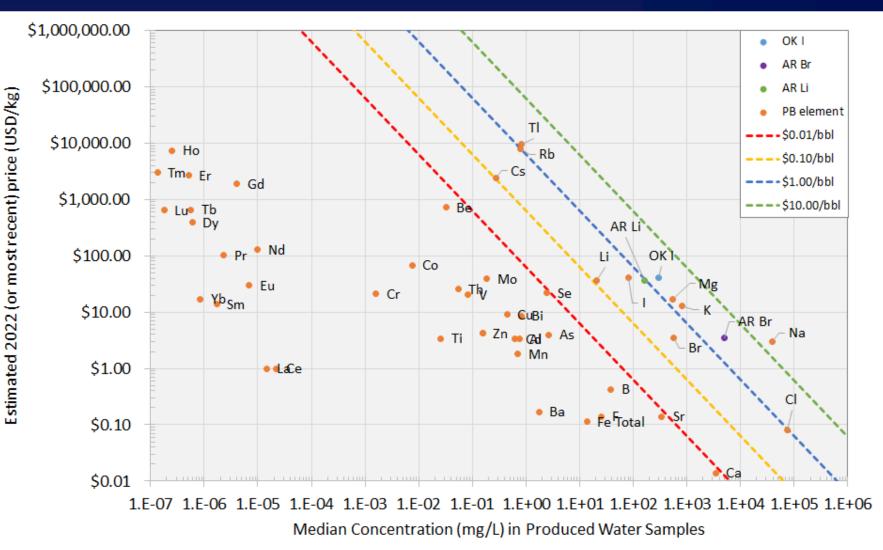


Case Study: 60+ EOI in Permian Basin



- 61 samples in the Permian Basin
- Top 5 highest priced elements detected (Tl, Rb, Ho, Tm, Cs, Be).
- Top 5 highest gross value elements (Na, K, Mg, Tl, Rb)

Cesium (Ce), Erbium (Er), Holmium (Ho), Rubidium (Rb), Scandium (Sc), Tellerium (Te), Thallium (Tl), Thulium (Tm)



Data from Jiang et al. (2022); Quillinan et al. (2018); Murray (2021-unpublished)

			Step 1	Step 2		Step 3
				OK 005		EOI Gross
EOI	EOI name	Ş	5/kg in 2022	mg/L	,	Value \$/bbl
Al	Aluminum	\$	3.31	1.4	\$	0.001
В	Boron	\$	0.43	11.9	\$	0.001
Ba	Barium	\$	0.17	3.5	\$	0.000
Br	Bromide	\$	3.50	996.0	\$	0.554
Ca	Calcium	\$	0.01	19580.0	\$	0.044
Cd	Cadmium	\$	3.30	0.001	\$	0.000
Cl	Chloride	\$	0.08	176,000	\$	2.295
Со	Cobalt	\$	68.34	0.0014	\$	0.000
Cr	Chromium	\$	21.00	0.0080	\$	0.000
Cs	Cesium	\$	2,394.00	0.0666	\$	0.025
Cu	Copper	\$	9.04	0.0200	\$	0.000
Eu	Europium	\$	30.00	0.0002	\$	0.000
F	Fluoride	\$	0.14	4.90	\$	0.000
Fe Total	Iron	\$	0.11	18.8	\$	0.000
Ga	Gallium	\$	640.00	0.0020	\$	0.000
1	Iodide	\$	41.00	71.80	\$	
In	Indium	\$	250.00	0.0006	\$	0.000
к	Potassium	\$	12.85	992.00	\$	2.027
La	Lanthanum	\$	1.00	0.0003	\$	0.000
Li	Lithium	\$	37.00	13.8	\$	0.081
Mg	Magnesium	\$	16.76	2520.0	\$	6.713
Mn	Manganese	\$	1.82	4.3	\$	0.001
Мо	Molybdenum	\$	39.25	0.0040	\$	0.000
Na	Sodium	\$	3.00	73000	\$	34.818
Ni	Nickel	\$	25.00	0.0120	\$	0.000
Rb	Rubidium	\$	7,770.00	1.9080	\$	2.357
Sb	Antimony	\$	13.89	0.0002	\$	0.000
Sc	Scandium	\$	137,000.00	0.0080	\$	0.174
Se	Selenium	\$	22.05	2.7600	\$	0.010
Sr	Strontium	\$	0.14	1470.0	\$	0.033
Те	Tellerium	\$	2,000.00	0.0200	\$	
тι	Thallium	\$	9,400.00	0.0043	\$	
Y	Yttrium	\$	43.00	0.0026	\$	0.000
Zn	Zinc	\$	4.19	0.2460	\$	0.000
			Total G	iross Value	\$	
			Economical	\$	47.063	

Example for Well OK 005



Step 1	
Step 2	
Step 3	
Step 4	

Assess Commodity Market for EOI (\$/kg) Characterize PW and EOI Concentrations (mg/L) Compute EOI Gross Values (\$/bbl) Evaluate PW Rate (BWPD)

			Ļ	Step 4
vol. prod. rate	units	\$/unit		\$/day
BWPD	700	\$ 49.61	\$	34,730.44
BOPD	106	\$ 100.00	\$	10,600.00
MCFPD	126	\$ 7.90	\$	995.40

In this example, Well OK 005, the gross value of the EOI in the produced water exceeds the value of the oil and gas.

BWPD = barrels of water per day BOPD = barrels of oil per day MCFPD = 1000s of cubic feet of gas per day

Frequently Asked Questions



- 1. What type of water analysis does MGC provide?
 - Over 60 Elements of Interest (EOI)
 - Low detection limits
- 2. What type of samples do you need and where should we take them?
 - Water that is gravity separated from oil produced water, SWD water, or solids
 - From locations where individual producing wells and formations can be discerned
- 3. How much does it cost for analysis?
 - With "local" travel, sampling & lab costs are about \$600 per sample for 60+ EOI
 - Data evaluation and resource assessment is \geq \$600 per sample
- 4. What do we get for deliverables from the analysis?
 - Presentation and report showing concentrations (mg/L) for 60+ EOI, gross values (\$/bbl) per EOI, per well, per formation, per play, and EOI yield (\$/day)
 - Recommendations for prospecting or extraction plant development
- 5. What are the next steps after the analysis is done? (this could be Step 1)
 - Use your data along with MGC data to complete an Exploratory Data Analysis (EDA) to prospect for "enriched brines" per EOI, per well, per formation, per play
 - Targeted sampling after EDA

Collaboration with Operators

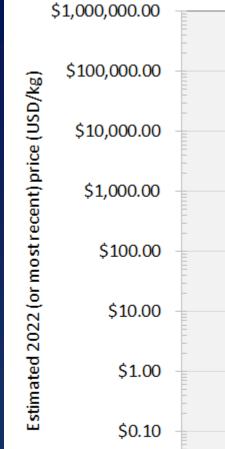


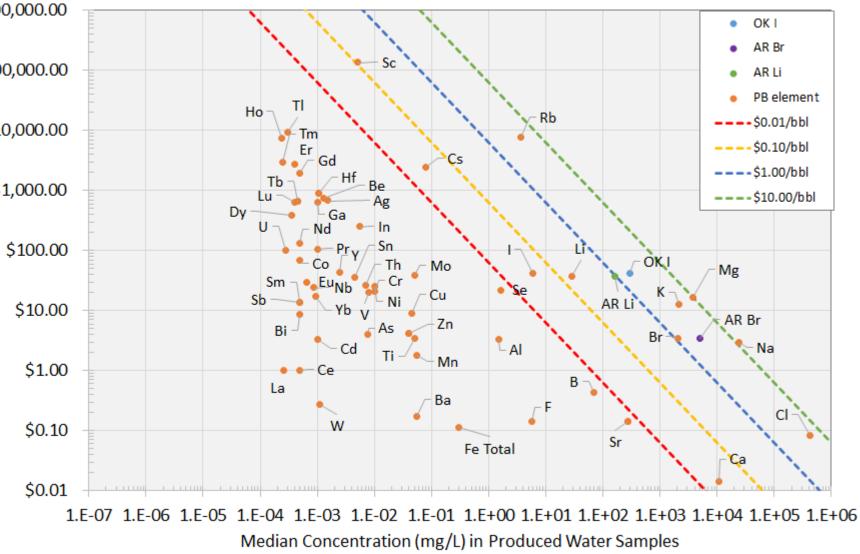
- 1. Agree on well access, data sharing/publication or confidentiality
- 2. Coordinate with MGC to sample from producing or SWD wells, or solids/sludge
- 3. Support costs for EOI sampling and analyses
- 4. Share info with MGC for producing formation and water vs. oil production rates
- 5. Provide other relevant data (e.g., produced water quality data)



Case Studies: 60+ EOI in Permian Basin







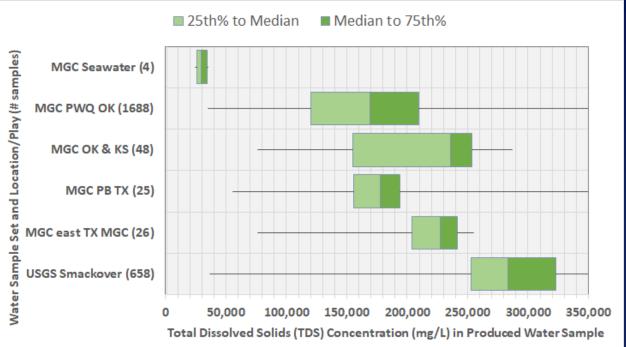
Compute Gross Values for EOI in 25 Permian Basin PW samples

	TDS (mg/L)
min	55,800
25 th %	156,000
median	178,000
75 th %	193,000
max	537,000

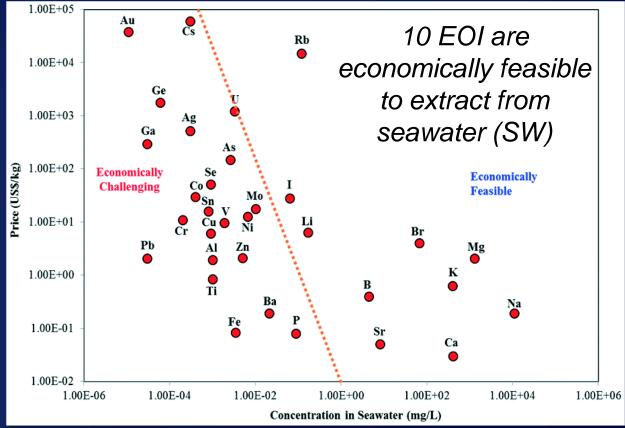
Murray (2023-in preparation)

Economically Feasible?



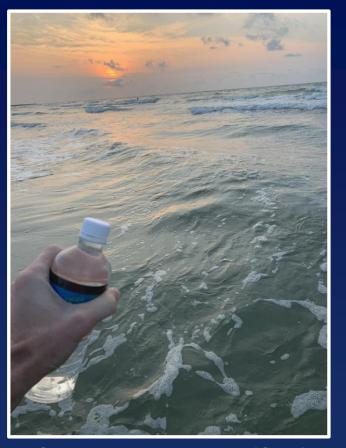


Data collected & compiled by MGC Total Dissolved Solids (TDS) concentrations (mg/L) of seawater vs. subsurface brine or produced water samples Figure 2 from Loganathan et al (2017) Screening of elements that can be economically extracted from seawater based on 2015 USGS mineral commodity summaries.



Case Studies: Sampling Points



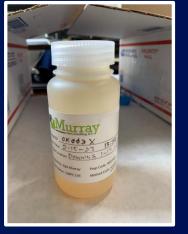


Sample seawater (SW) at shoreline or in the surf



Best Case: Sample PW from storage tank after gravity separation





Worst Case: Sample PW from wellhead and allow for gravity separation in the field

H₂O Sample for Analyses at Laboratory