Efficient Industrial Scale Desalination and Economization of Permian Basin Produced Water

Joseph Alexander PhD PE
Circle Verde Water

CIRCLE VERDE
Zero Waste Petroleum

200 BBL/Day Pilot System

Performance – Freshwater Effluent

Conductivity – Less than 200 uSiemens/cm
- 3rd Party Analysis – 98 to 170 uSiemens/cm

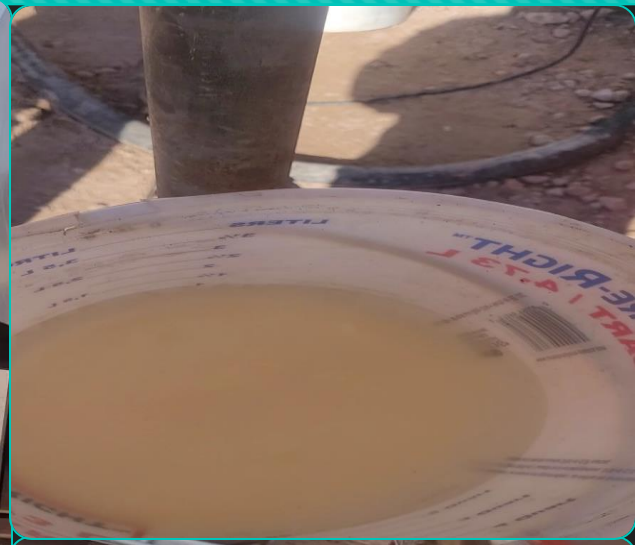
Turbidity of Freshwater: 1.4 NTU
- Inlet Raw Produced Water: 169 NTU

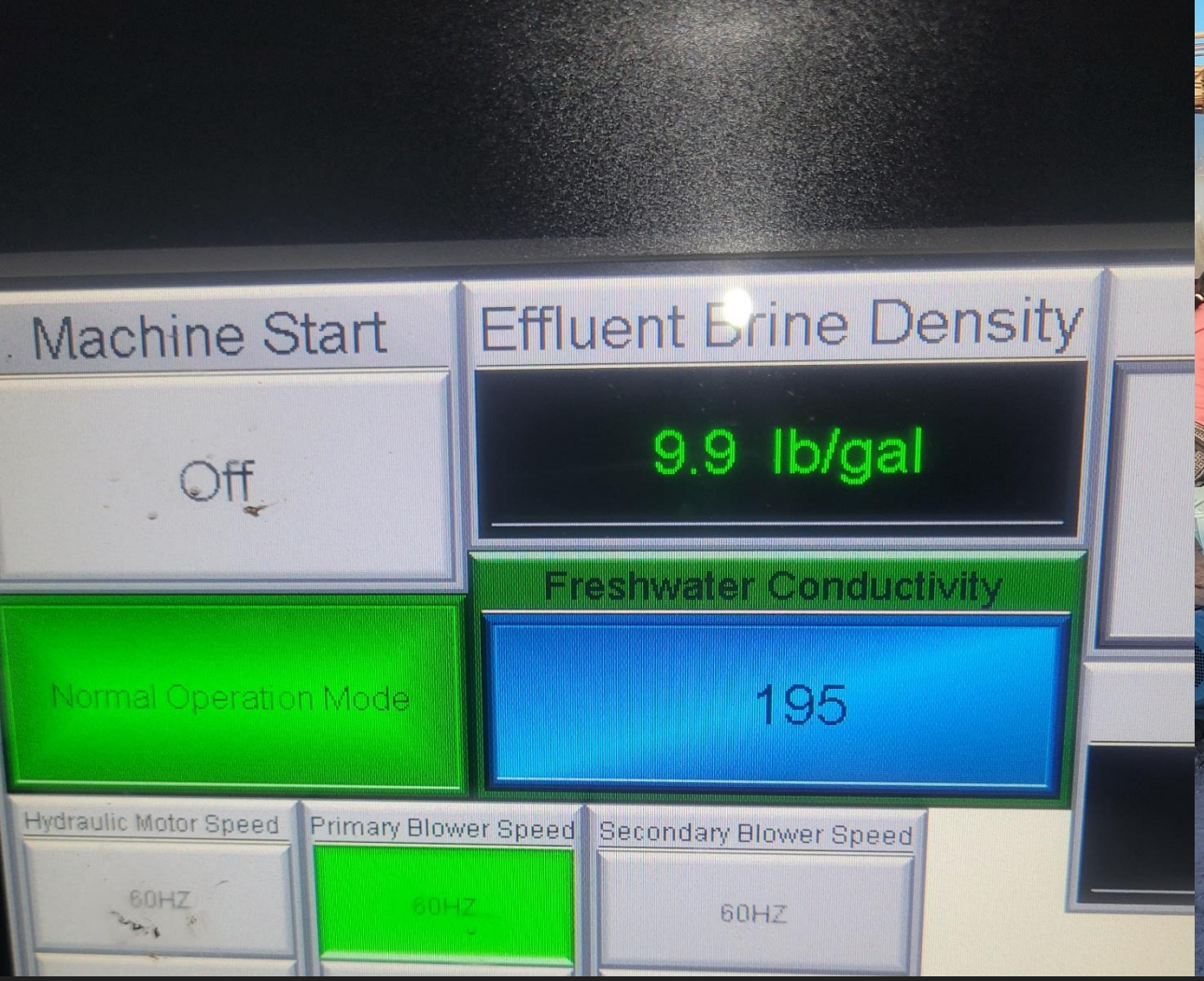
TSS of Freshwater Effluent: Below Detection Limit
- Inlet Raw Produced Water: 600 mg/l

TDS of Freshwater Effluent: 78 mg/l
- Inlet Raw Produced Water: 151,490 mg/l

Freshwater NH3 Concentration: 12.5 mg/l

TOC of Freshwater Effluent: Typically, Less than 10 mg/l





Pilot System – Demonstration and 3rd Party Evaluation

- Passed EPA WET Testing After Post-Treatment
- Processed Flowback During 3rd Party Evaluation

Freshwater Effluent Passed Multiple 3rd Party WET Testing After Post-Treatment

- Freshwater Post Treated
  - Activated Carbon
  - Ammonia Absorbents
- All 5 Organisms Showed **Zero Mortality** in 100% Freshwater Effluent After 96 Hours
- No Genetic Mutations/Damage Detected
- Results Confirmed By Second Laboratory

Raw Inlet Water Prior to Plant Contained

- Flowback/Frac Fluids
- Explosive Residues
- Corrosion Inhibitors

Maximum Contaminant Levels Observed

Inorganic Contaminants	Units	Max Allowable	Las Cruces	Midland	Santa Fe	Albuquerque	Circle Verde - Polished Fresh
Copper	ppm	1.3	0.2	0.258	0.37	0.15	ND
Lead	ppb	15	9	1.4	1.8	4	ND
Arsenic	ppb	10	8.1	8.29	1.9	9	8.2*
Barium	ppm	2	0.084	0.25	0.6	2	0.0017
Chromium	ppb	100	2	2.4	0.2	2	ND
Cyanide	ppb	200	6	146	0	0	8
Fluoride	ppm	4	1.13	0.5	0.39	0.73	ND
Nitrate	ppm	10	4.57	1.36	6.7	0.72	0.343**
Sodium	ppm	NA	590				28.9***
Selenium	ppb	50	3.7	0	21	0	12.5
Radioactive Contaminants							
Alpha Emitters	pCi/L	15	14	31	0.9	1.6	0.827*
Beta/Photon Emitters	pCi/L	50	21.6	31	3.9	0	1.25*
Radium	pCi/L	5	2.23	0	0.8	0.5	0.669*
Uranium	ug/l	30	38	26.8	2	6	0.000289*

*Concentration Below Detection Limit in Freshwater Effluent Stream Prior to Post-Treatment
**Concentration of 0.0871 mg/l In Freshwater Effluent Prior to Post-Treatment
***Concentration of 0.928 mg/l in Freshwater Effluent Prior to Post-Treatment

Measurable Components in Polished Water But Undetectable in Raw Fresh Effluent

- Radium
- Uranium
- Cyanide
- Phthalates
  - All Found Trace Amounts

Chromatography/Mass Spectrometry

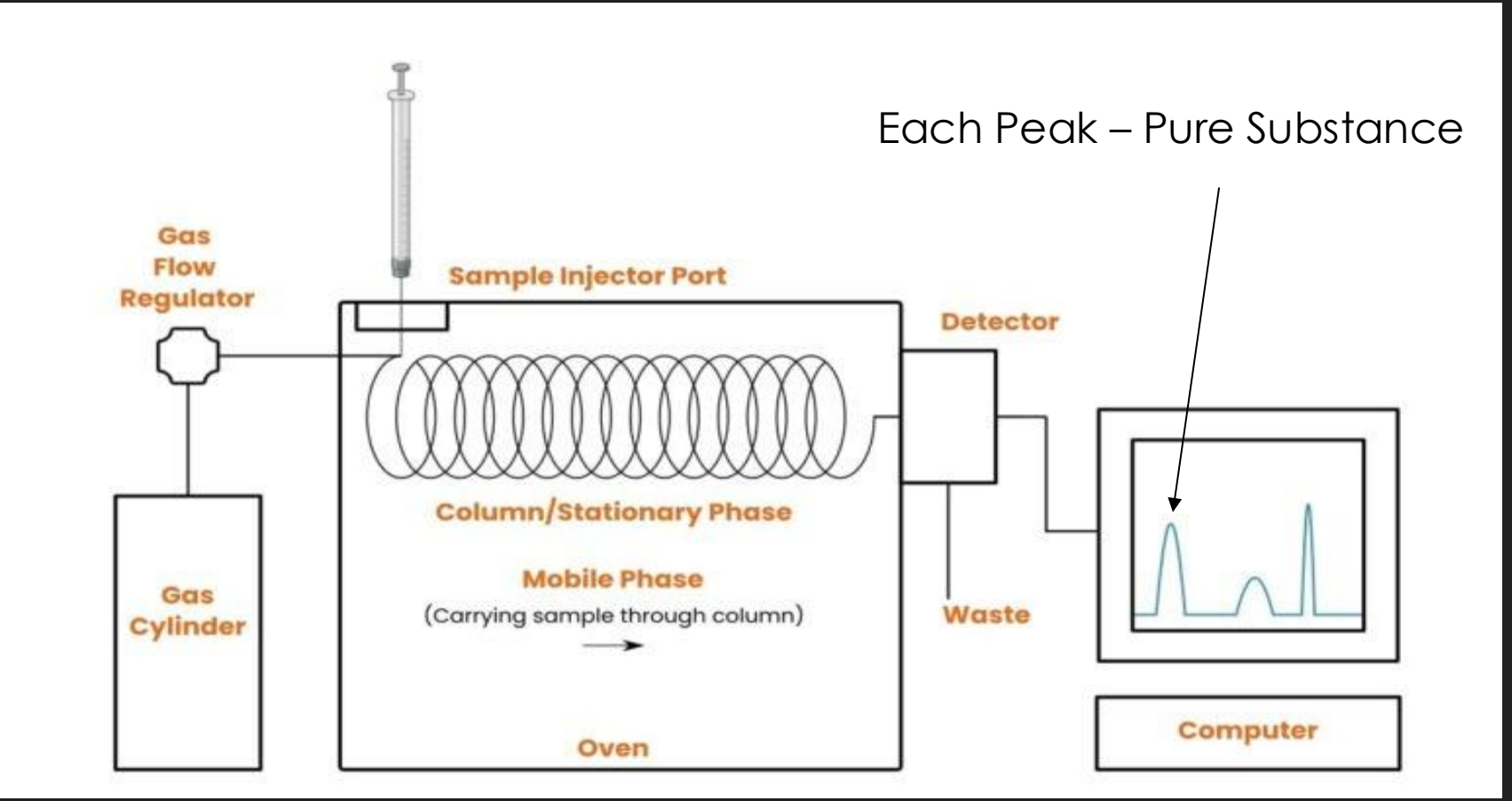
Chromatography

- Multicomponent Sample

Is Separated Into Pure Aliquots That Leave After Different Residence Times

- Chromatography Alone Does

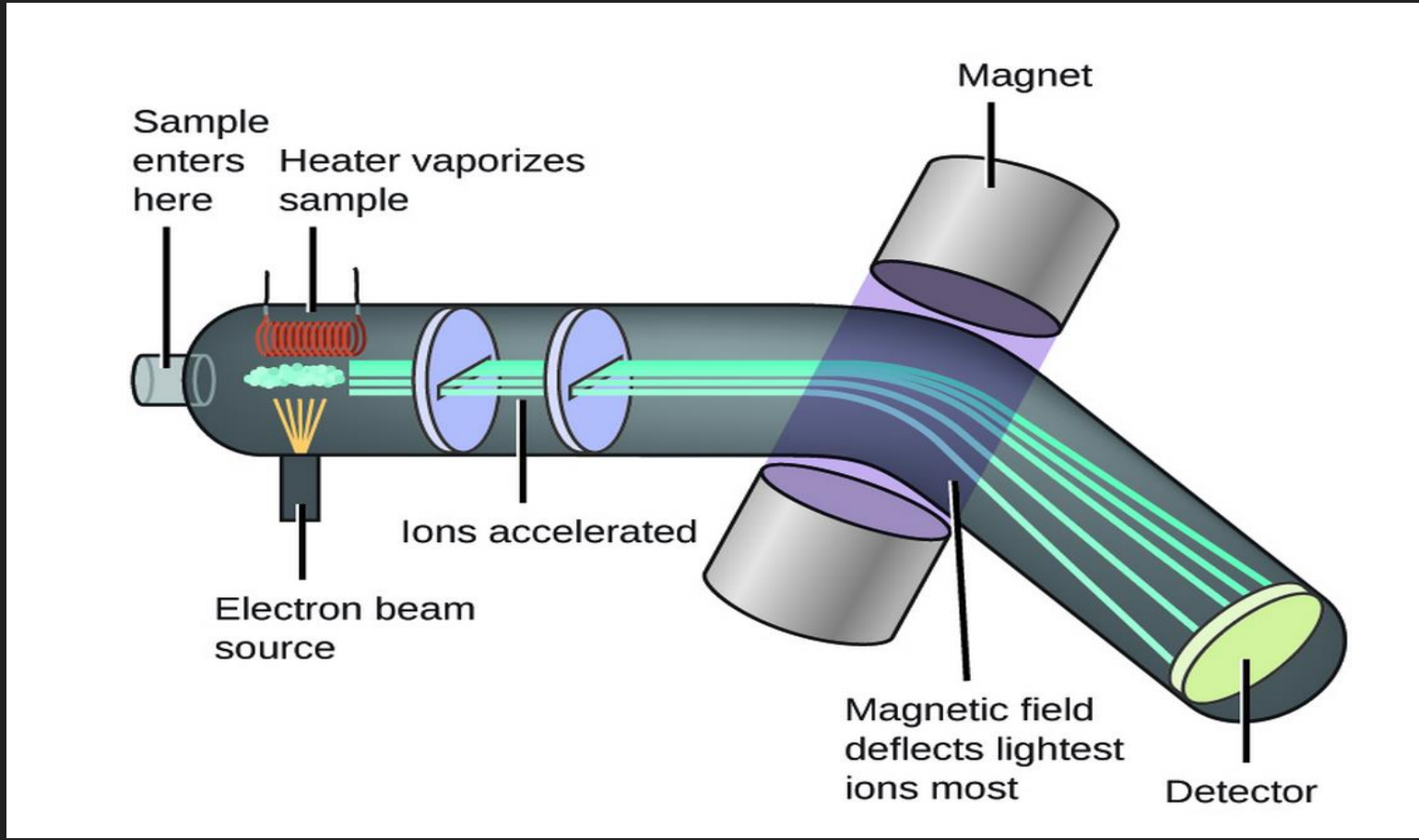
Not Provide Any Identification Information For Each Component Within Sample

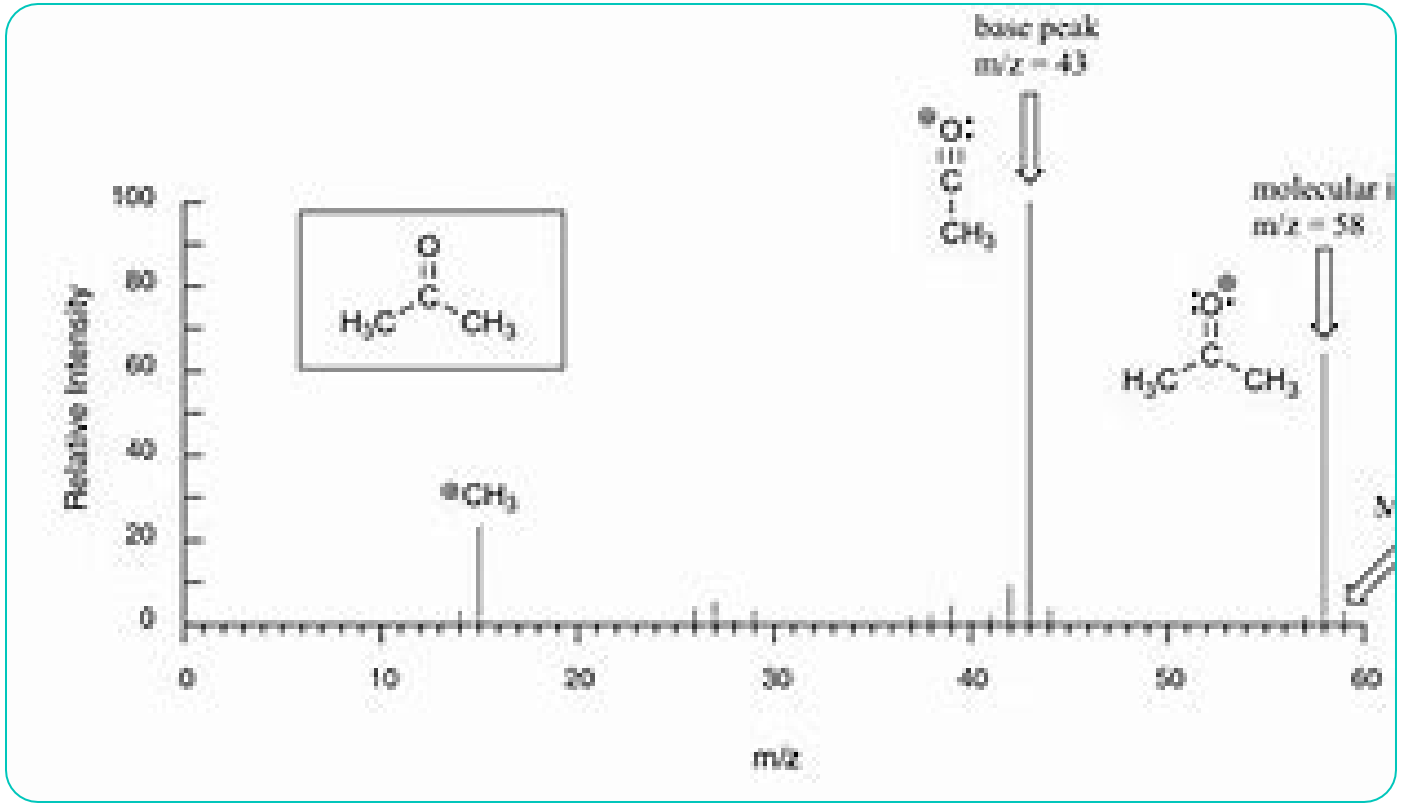


Chromatography/Mass Spectrometry

Mass Spectrometry

- Pure Sample Is Ionized and Accelerated Into Magnetic Field
- The Mass to Charge Ratio is Measured.
- Presence of Any Elements Detected
  - Isotopes Detected As Well
  - Used for Carbon Dating
- **Limitation – Cannot Accurately Analyze Multicomponent Sample**





Chromatography/Mass Spectrometry

- **Mass Spectrometry**
- Organic Compounds Break into Predictable Fragments
  - Allows Determination of Structure of Unknown Organic Compound
- NIST – National Institute of Standards
  - Maintains Library of Compounds

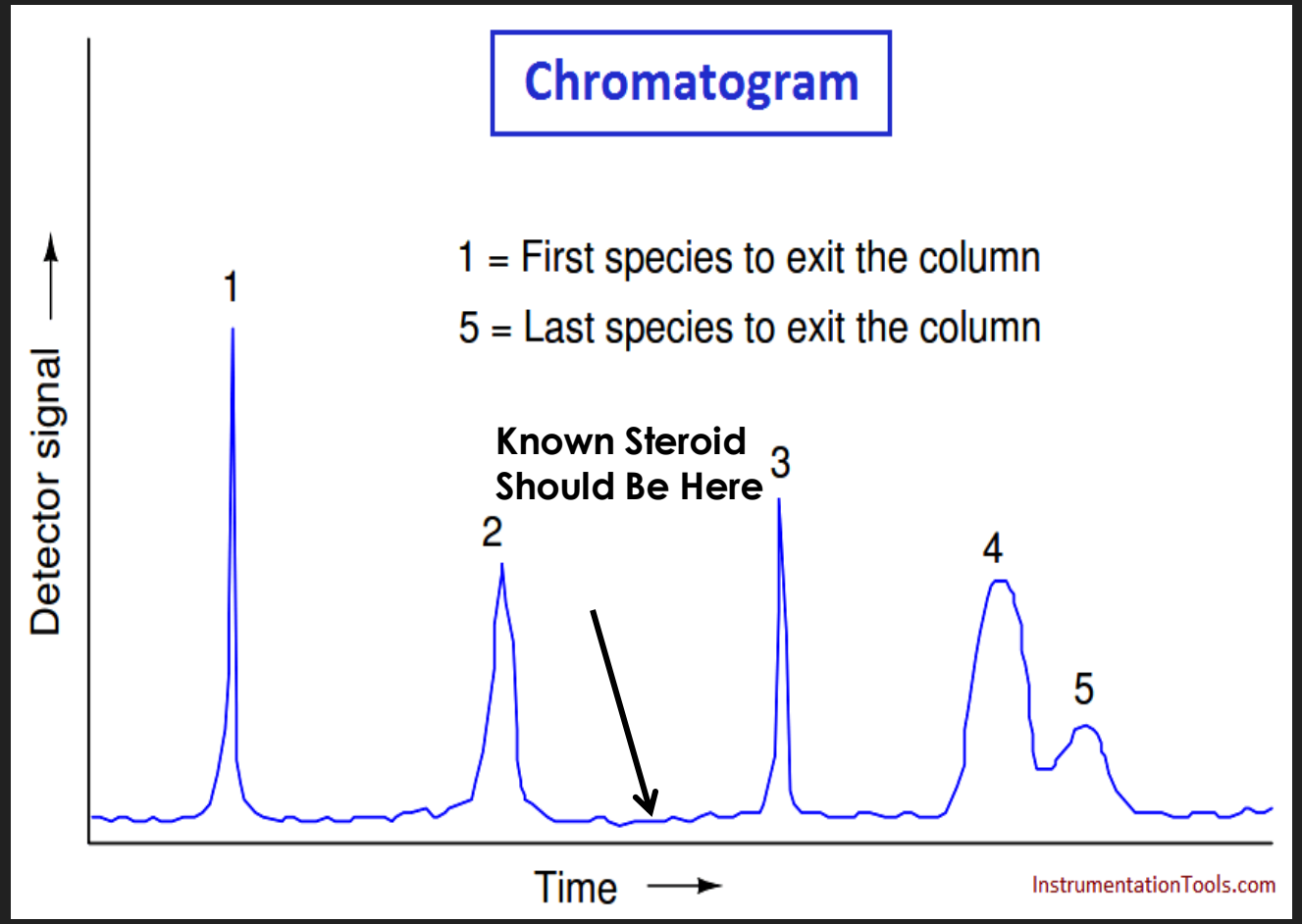
Chromatography/Mass Spectrometry

- **Widely Used Technique**
- Law Enforcement
  - Determination of Drug Presence
  - Detection of Accelerants in Arson Cases
  - Detection of Explosive Residues
    - Airports
- Athletics
  - Detection of Drugs/Steroids
- Commerce
  - Testing of Commercial Products
- Medicine
  - Determination of Drug Pathways/Residues/Purities
- **Results Widely Accepted In Court**

Example Use – MLB Doping Scandal

Prior to Scandal

- Chromatography Alone Used
- Extra Peaks – Not Identified
  - Ignored
  - Could Not Positively Identify Drug/Steroid Unless Sample Present In Control

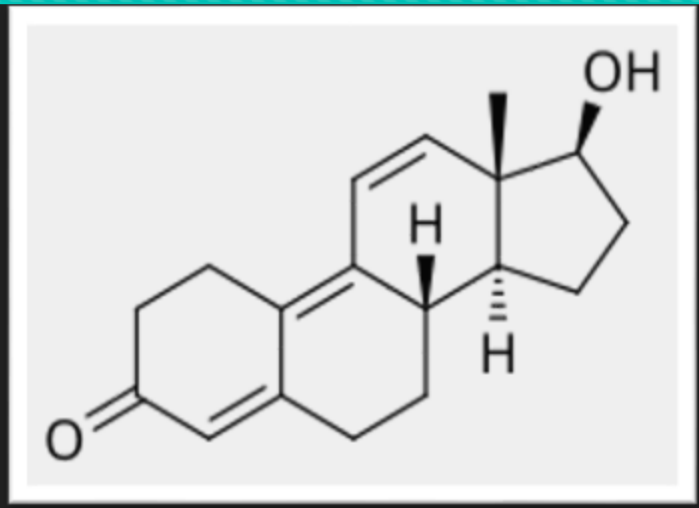


Example Use – MLB Doping Scandal

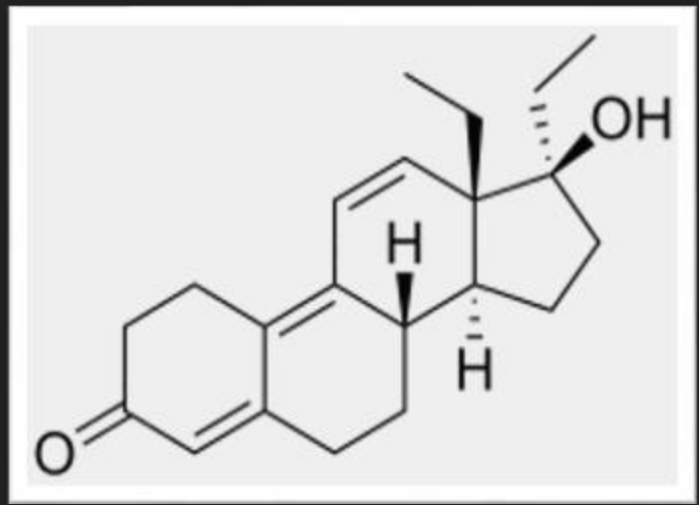
Scandal

- Chemist Slightly Modified Known Steroid
  - Different Residence Time And Peak Location
  - Undetectable with Chromatography Alone
- **Chromatography/Mass Spec Used For All Drug Tests Now**
  - Peaks of Unknown Compounds Are Analyzed

Trenbolone – Known Steroid

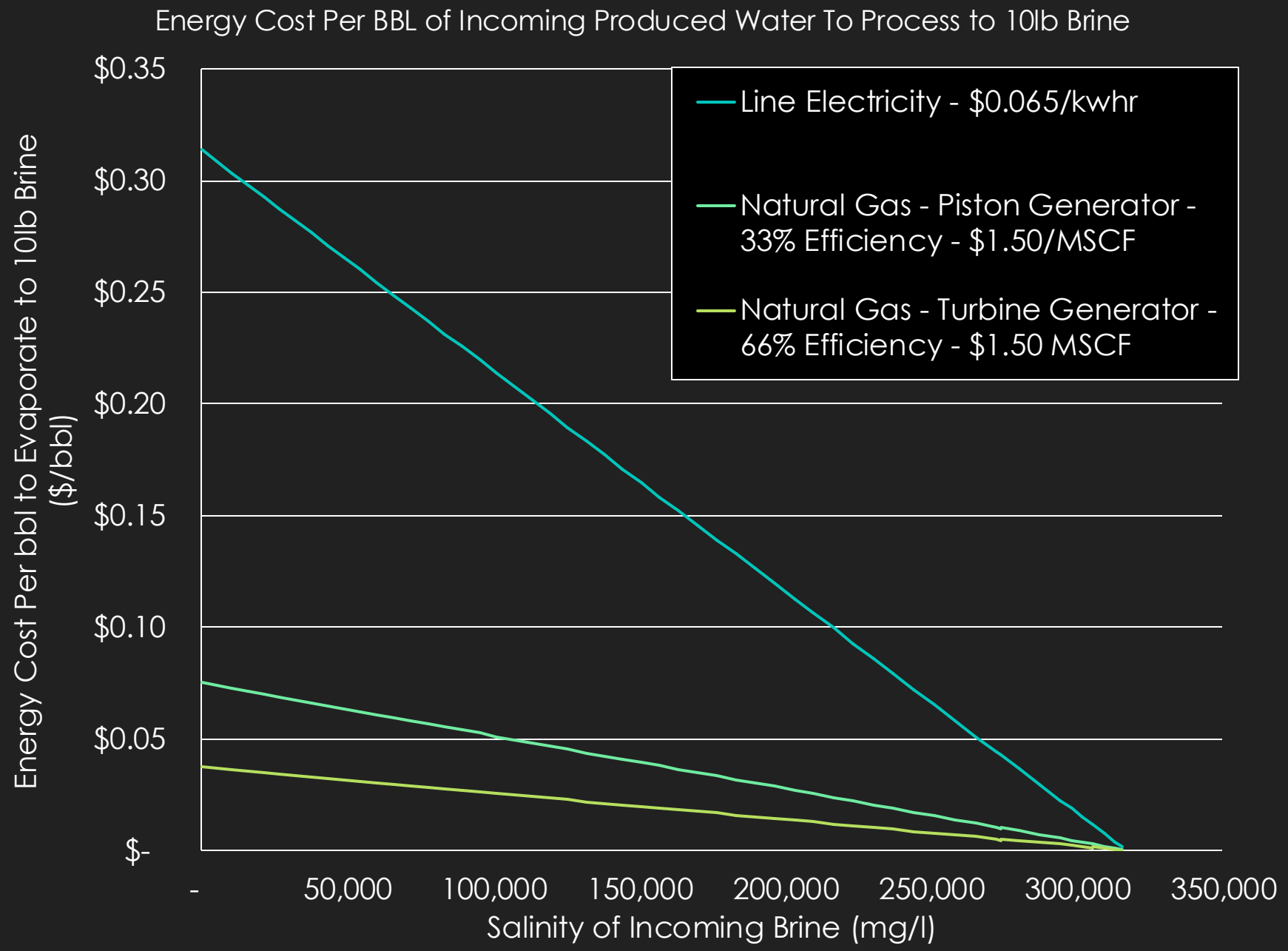


"The Clear" – Unknown Steroid



Normalized Energy Consumption

- Saturated Brine Production
- -Based on Pilot Experience/Outside Engineering Analysis
- - Energy Use per BBL of Incoming Raw Produced Water



Dry Salt Production

- Switch Between Concentrated Brine and Dry Salt Effluent Quickly
  - Salt Leaves Through Centralized Port, Falls Into Hopper, Auger/Belt Transports Away
  - Salt Effluent – Oily Consistency
    - Brief Processing Through Kiln –Dry/Free Flowing
  - Tests on Mentone Produced Water Showed No Increase in Hydrocarbon Levels in Freshwater Discharge

Dry Salt Production

Normalized Energy Costs ($/bbl Inlet Brine)

- Grid Electricity: $0.31/bbl[1]
- Natural Gas-Powered Piston Generator: $0.075/bbl[2]
- Combined Cycle Turbine Generator: $0.037/bbl[2]

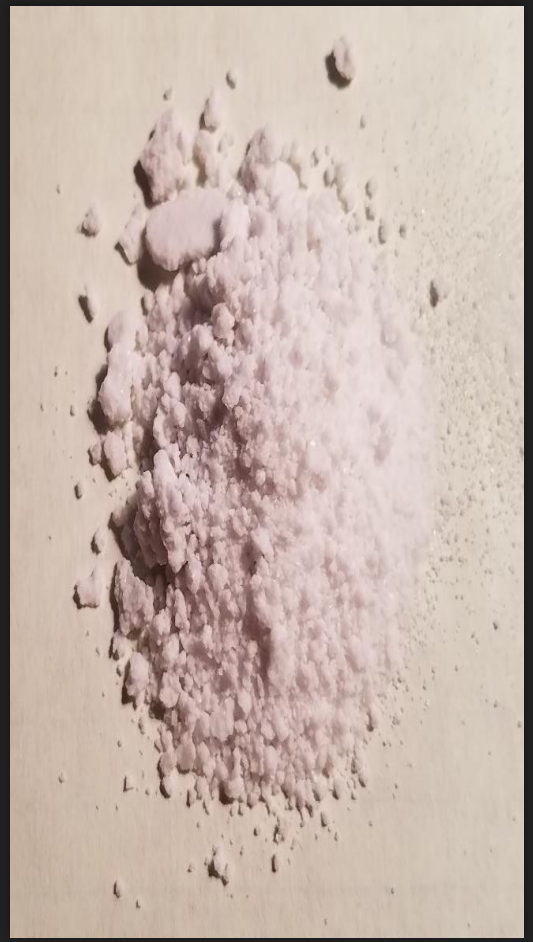
Efficient Mineral Extraction

- Lithium
- Potassium (Potash)

1. Grid Electricity Price: $0.065/kwhr
2. Natural Gas Price: $1.50/MMBTU

Oily Effluent

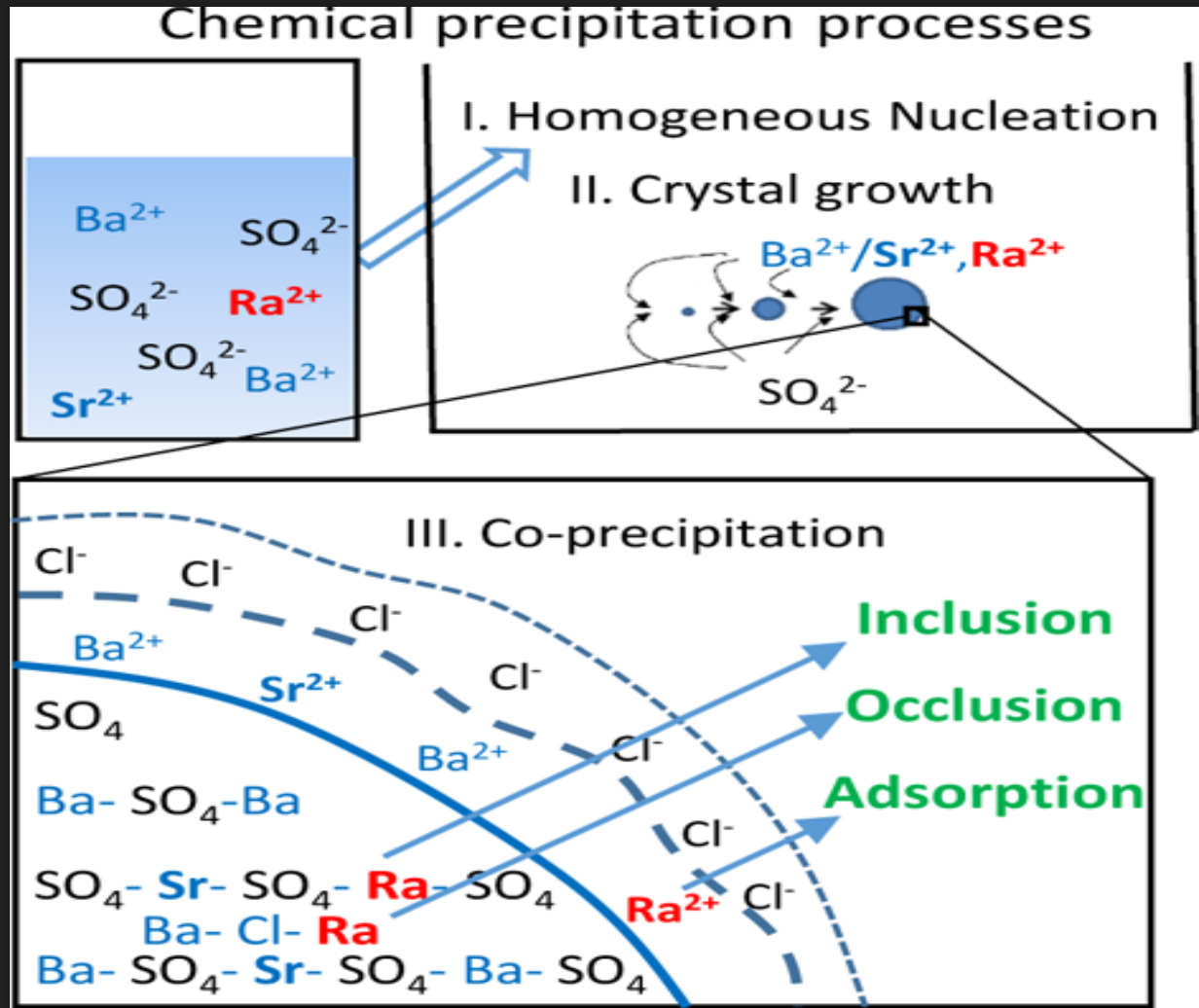
After Kiln



Radium Removal – Barite Precipitation

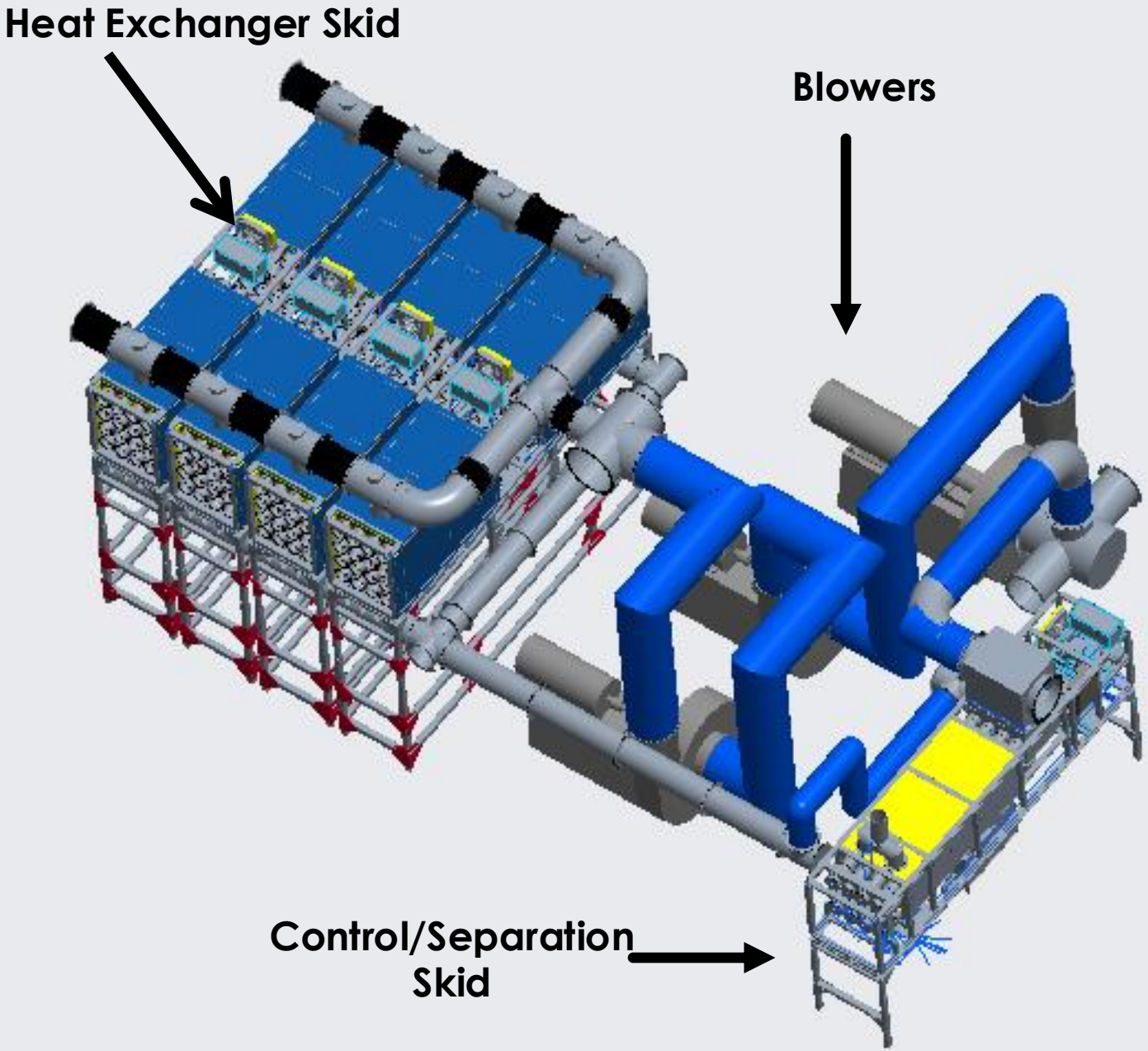
Tieyuan Zhang, Kelvin Gregory, Richard W. Hammack, and Radisav D. Vidic
Environmental Science & Technology **2014** *48* (8), 4596-4603
DOI: 10.1021/es405168b

- Effective
  - 99.99% Removal
- Inexpensive
  - Less than $0.03/bbl
- Safe
  - Precipitated Sludge Is Not Classified As Radioactive – Permian Water
  - Radium Locked Into Insoluble Form
- Accepted
  - Widely Used to Treat Wastewater From Uranium Mining
- Conducive To Desalination
  - Radium Removal Prior To Desalination Eliminates it in Brine/Salt Effluent.



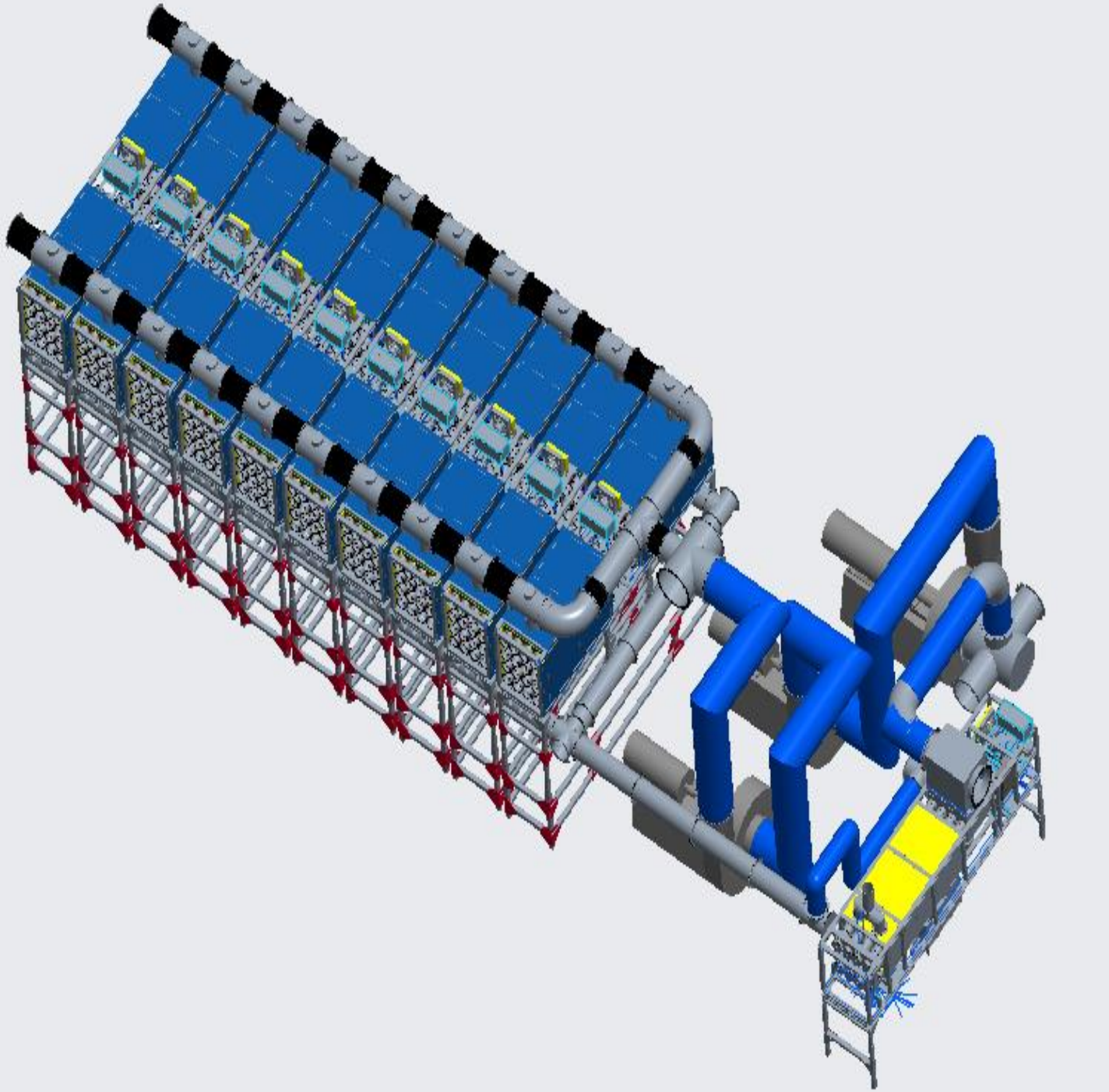
5,000 bbl/Plant

Commercial Facilities



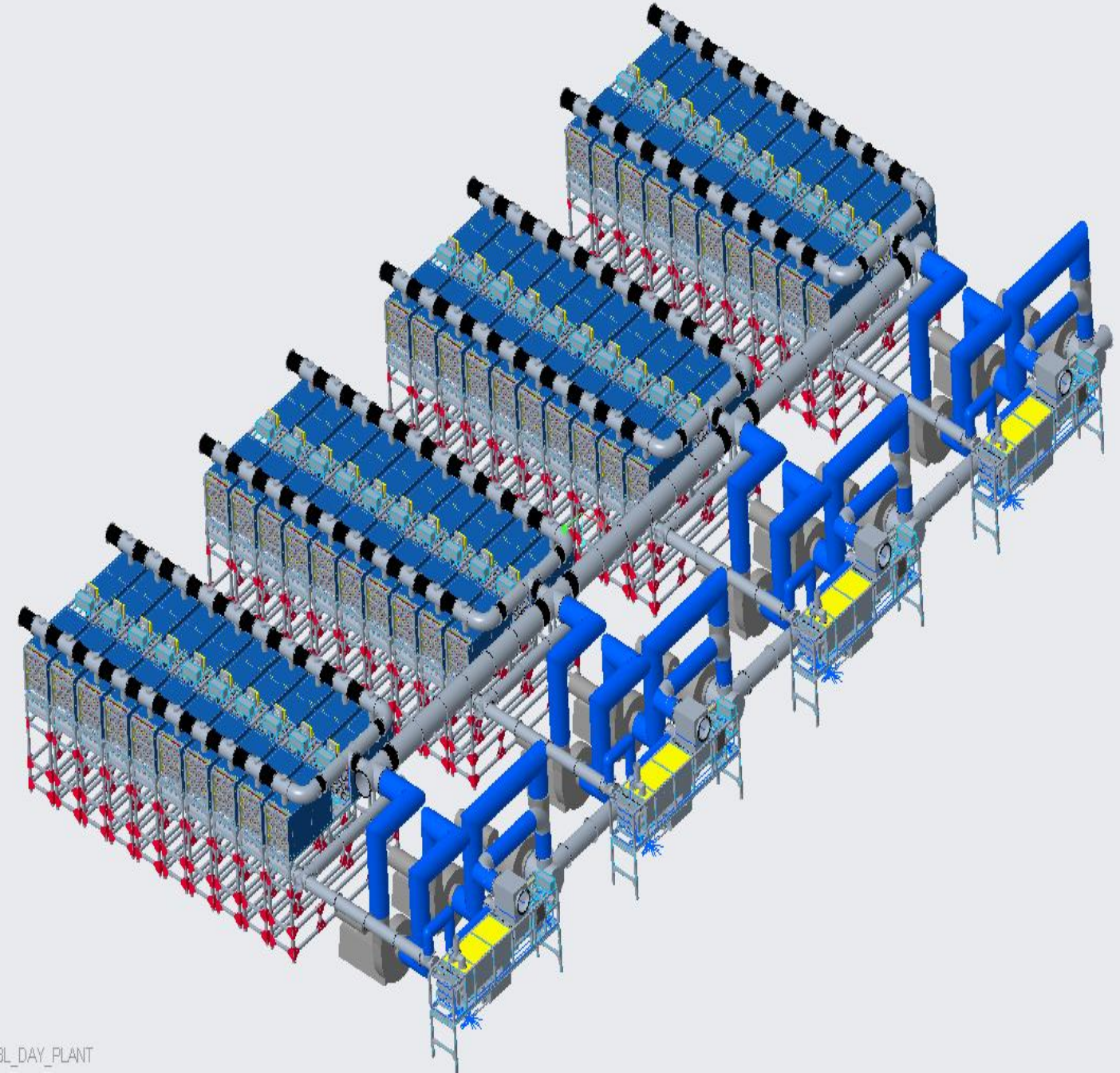
10,000 bbl/Plant

Commercial Facilities



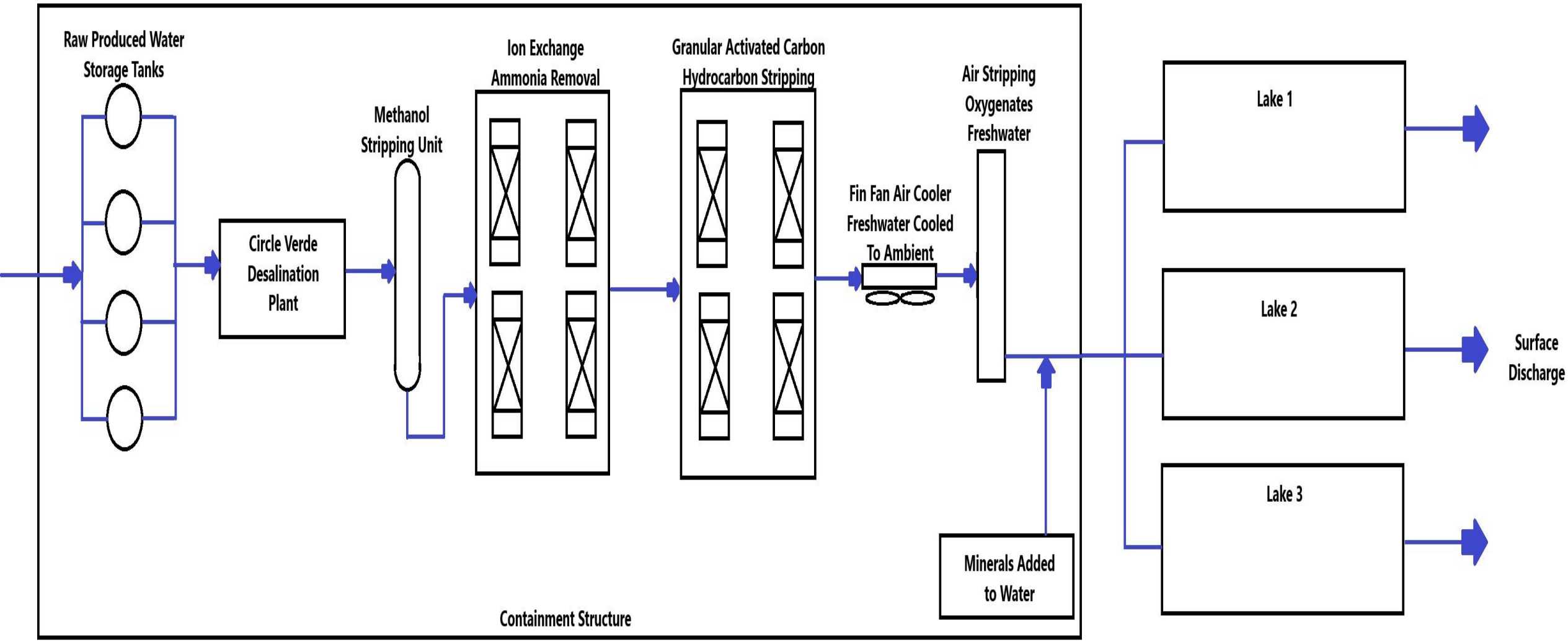
60,000 bbl/Plant

Commercial Facilities



Flexibility

- Turndown Ratio: Greater than 90%
- Increase Capacity by Connecting Additional Modules
- Small Plant May Be Scaled Without Interruption
- Damaged Modules Replaced Quickly
- Maintenance
  - Individual Components Repaired Without Stoppage
- Plants May Be Installed, Commissioned or Relocated in a Few Days
- Adaptable to Changing Water Chemistry



Pathway to Surface Discharge

- Redundant/Parallel/Orthogonal Sensors
- Batch Testing/Control

Safety of Freshwater Discharge

GOAL

- Dissolved Organic Carbon Less than 3 mg/l
  - Obtained After Polishing of Freshwater Effluent From Pilot
    - Total Petroleum Hydrocarbons 1.15 mg/l
  - Flowback Inlet

Perspective

- Hydrogen Cyanide Safe Level
  - 10 mg/l

Aquaculture in Discharge Ponds

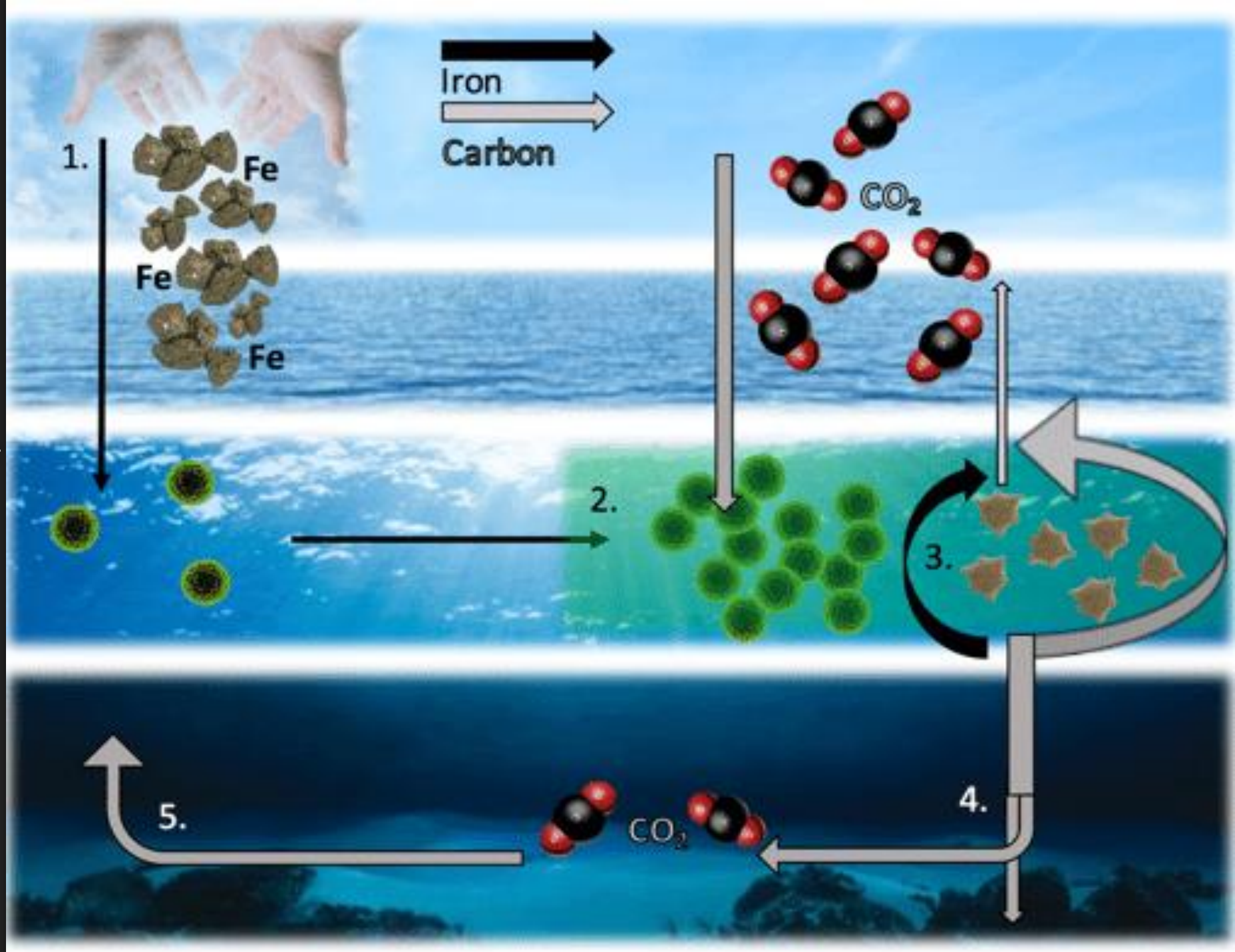
- Floating Cages
- Fish in Treated Produced Water for 7 Days+ Prior to Surface Discharge
- Real Time WET Testing
- Tertiary Containment
- Lakes Provide Storage For Other Uses Potentially Including:
  - **Fracking**
  - **Irrigation**

CO2 Sequestration Iron Fertilization

- Viability of Using Dried/De-Oiled TDS from Produced Water For Oceanic Fertilization
  - Partners
    - National Labs/DOE
    - Oceanographic Institutions
    - Universities

Oceanic Iron Fertilization

- Iron is Missing Micronutrient in Offshore Oceans
- Dry Salt From Complete Evaporation of Produced Water – Ideal Fertilizer



Large Scale Experiments Conducted

- 300 to 10,000 Square Miles of Ocean
- Each Gram of Iron Sequesters 1K to 100K Grams of Carbon

Limiting Factor – Other Nutrients Are Consumed

- Phosphorous
- Potassium
- Calcium
- High Levels of All In Produced Water Dissolved Solids

Potential - Dry Salt Production - Permian

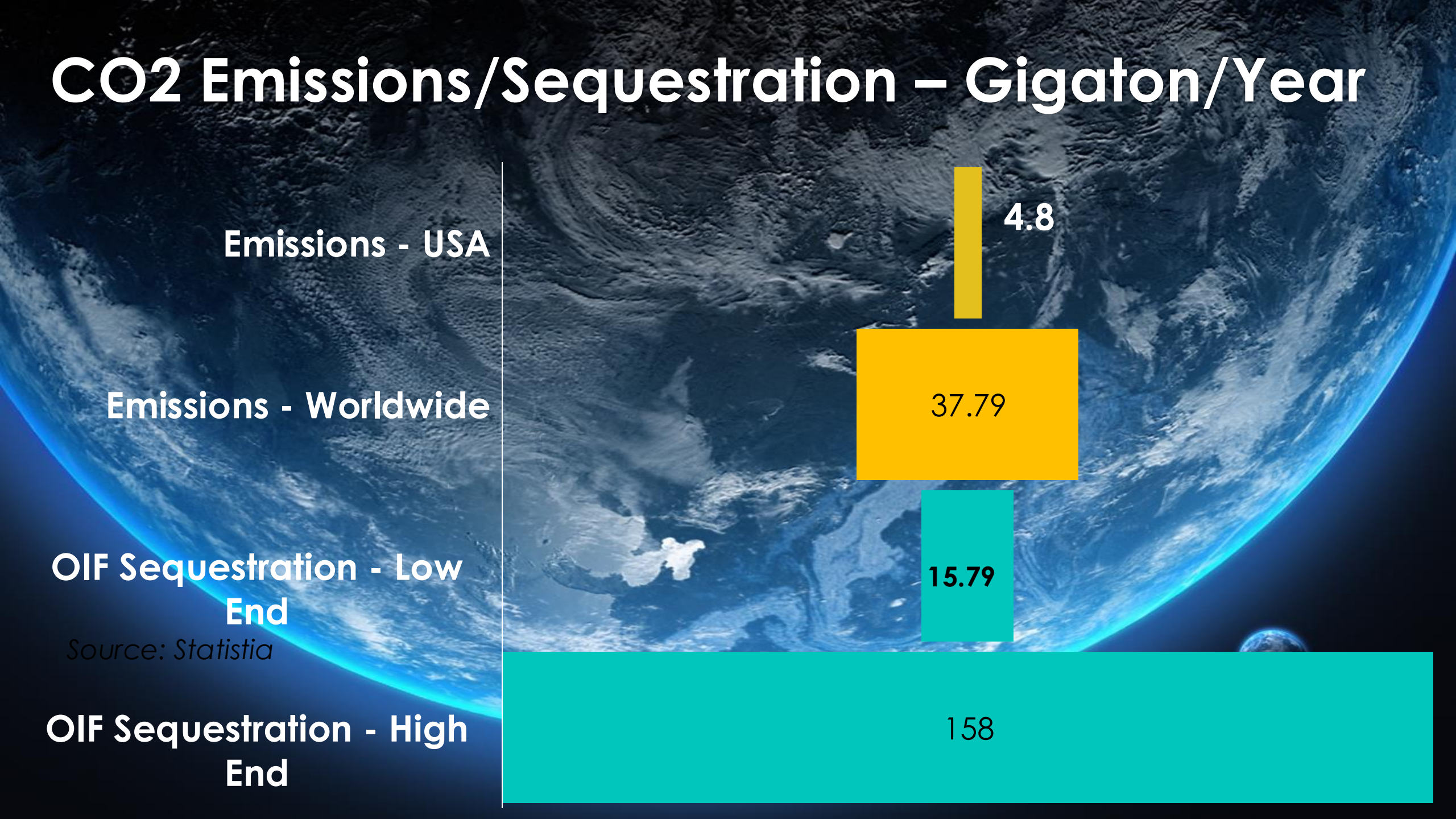
- 426,000 yd3/day of Salt
- 6,000 Rail Hopper Cars/day
- 1.35 Ore Carrier Ships/day

Permian Basin – Water Production

- 37 mg Fe/liter with 20MM bbl/day Production
- Potential to Sequester 15.794 Gigaton Carbon/year

1,000 gram CO_2 Sequestered/Gram Iron Fertilizer

CO2 Emissions/Sequestration – Gigaton/Year



Source: Statistia

Profound Realization

Contact Us

Email: info@circleverde.com

Website: www.circleverde.com