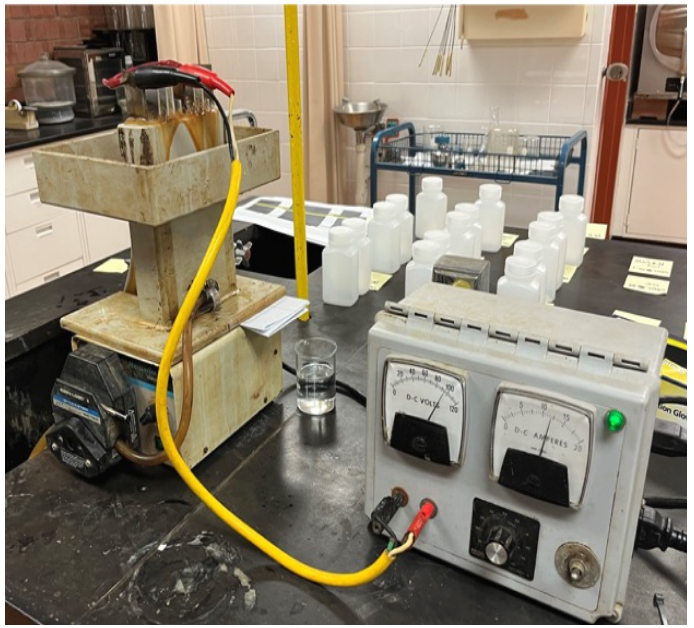


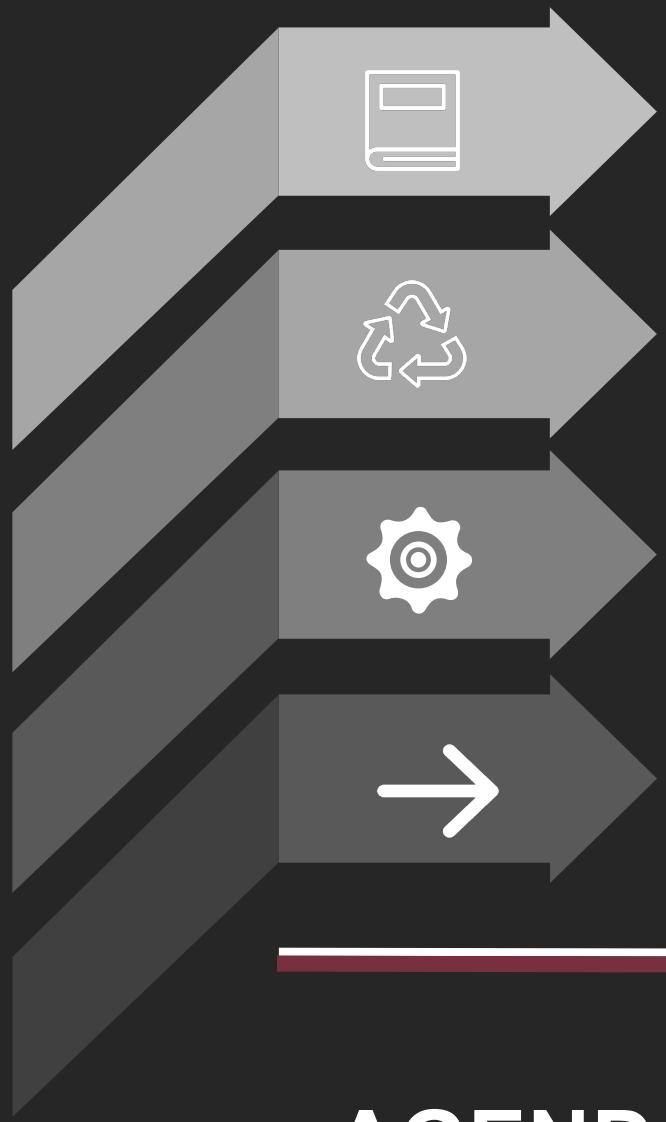


Water Reuse Advancements in Desalination and PFAS Research - Embracing the “Electrification” Concept

February 23, 2023

ERIC DOLE, PE, PSAP
WATER & ENERGY PRACTICE LEAD

YULIANA PORRAS-MENDOZA
ONE WATER PRACTICE LEAD



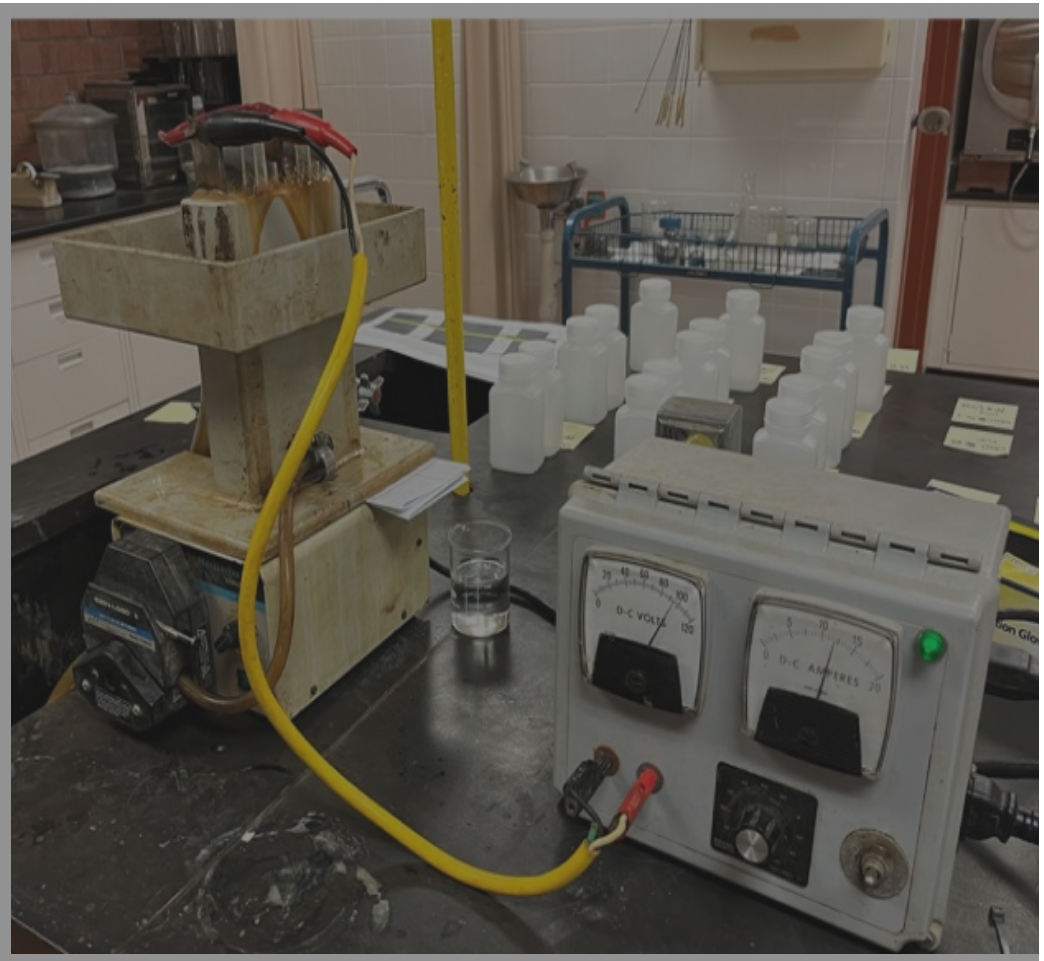
01
EC 101

02
PFAS Electrocoagulation Case Study for BGNDRF

03
Pitch to Pilot Desalination Research Summary

04
Regional Brine Management Concept for West Valley

AGENDA

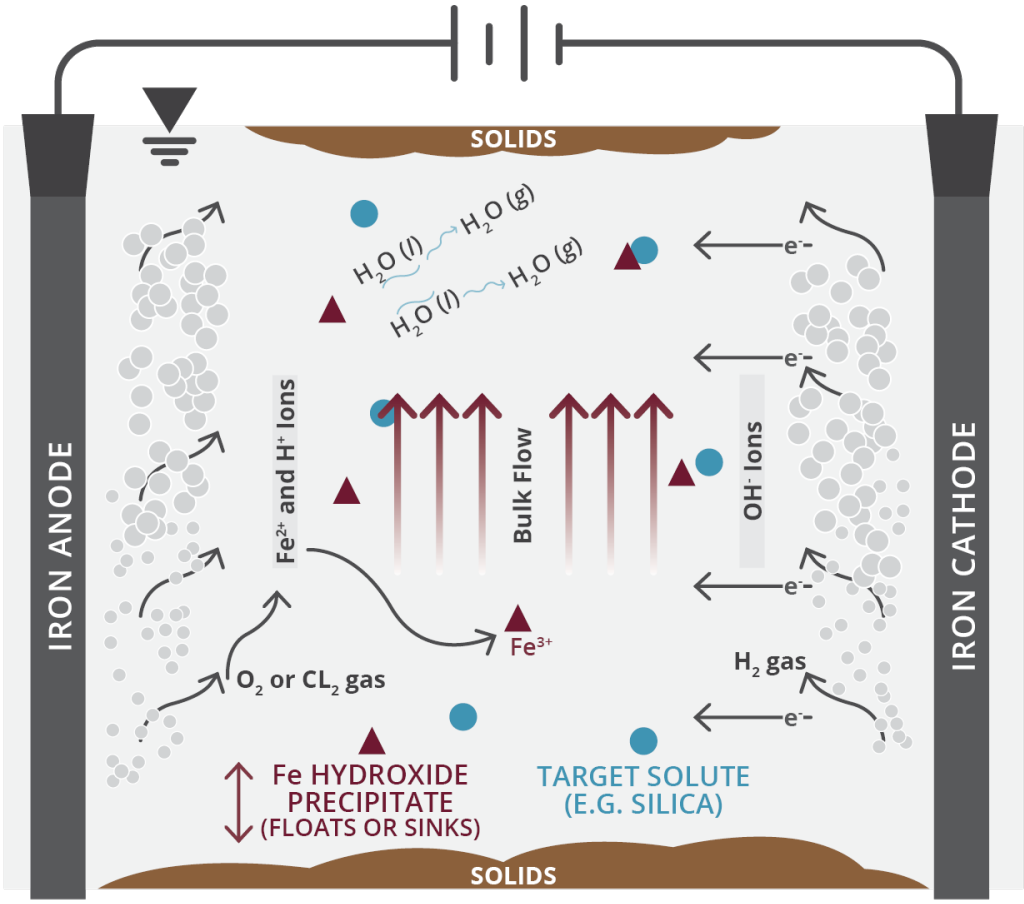


01
EC 101

EC Removal Mechanisms

Standard Configuration with *NO* chemical catalyst

EC Only (Fe Blades)



Al (*s*) + 3e- → Al^{3+} Fe (*s*) + 2e- → **Fe^{2+}** $2H_2O + 4e \rightarrow O_2(g) + 4H^+$	Anodic reactions (Oxidation)
$2H_2O + 2e^- \rightarrow H_2(g)^* + 2OH^-$	Cathodic reactions (Reduction)

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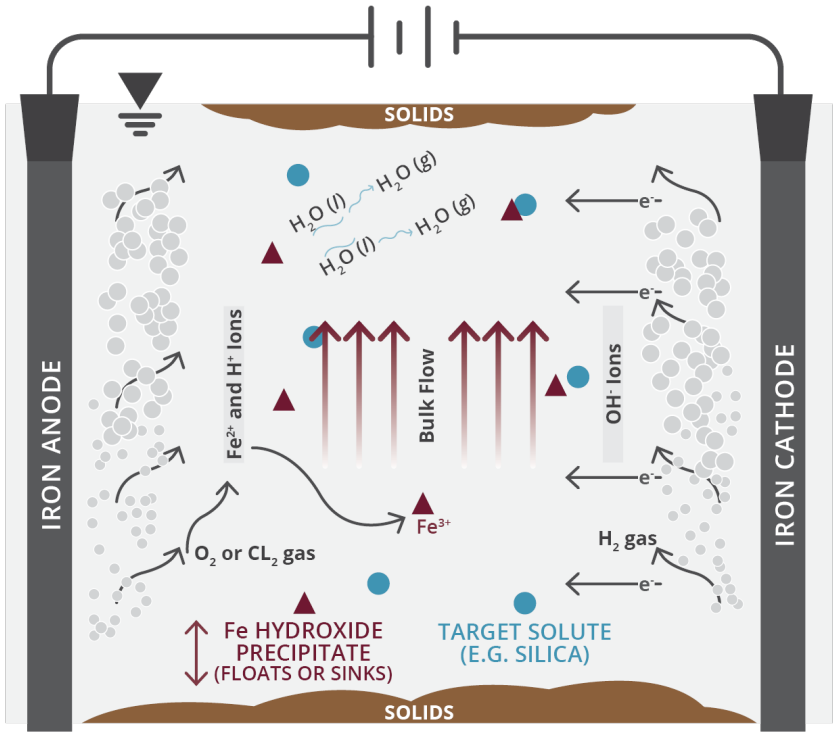
Advanced Oxidation Process

EC Removal Mechanisms….

Standard Configuration with H2O2 catalyst to drive E-Fenton Reaction

EC Only (Fe Blades) + Fenton (H_2O_2)



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$2H_2O + 2e^- \rightarrow H_2(g)^* + 2OH^-$	Cathodic reactions (Reduction)

\+

*$H_2(g)$ only generated if:
1.) Salt bridge > 8%; 2.) Polarity duration > 1.5 minute;
3.) Platinum or titanium electrode used

$$Fe^{2+} + H_2O_2 \longrightarrow Fe^{3+} + HO^{\bullet} + OH^-$$

$$Fe^{3+} + H_2O_2 \longrightarrow Fe^{2+} + HO^{\bullet}_2 + H^+$$

Electro-Fenton Reaction

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Courtesy: University of AZ Presentation “Electrocoagulation and Water Sustainability: Silica and Hardness Control” | June 26, 2008 | James C. Baygents and James Farrell

Electro-Coagulation vs. Chemical Coagulation

	Potassium Alum $KAl(SO4)_2 \cdot 12(H2O)$	Ferric Chloride $FeCl3 \cdot 6(H2O)$	Electro-coagulation Fe2+ or Al3+
-			

02

PFAS Electrocoagulation Case Study for BGNDRF

Background

Bureau of Reclamation owns and operates (BGNDRF) in Alamogordo, NM

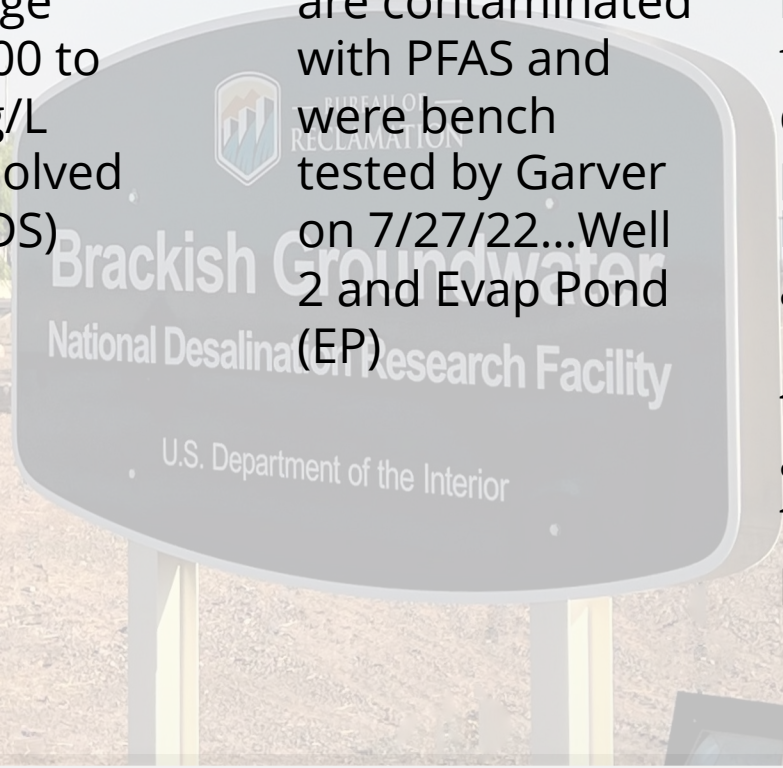
Four groundwater wells used for supply of brackish water to desal research trains and three evaporation ponds to store spent brine

Salinity of these wells range from 1,000 to 6,000 mg/L total dissolved solids (TDS)

2 of the 4 wells are contaminated with PFAS and were bench tested by Garver on 7/27/22…Well 2 and Evap Pond (EP)

Problem

Due to NM regulations the facility's discharge permit no longer allows any water with PFAS to enter the sewer adding stress to the evaporation ponds capacity



Why Test EC for PFAS removal?

We have tested it before on three types of challenging waters with successful results

BOR has seen the efficacy of EC (when performed correctly) in removing challenging contaminates in P2P Pilot train

BOR paid for exhaustive WQ analysis (including total organic fluorine) while Garver ran the bench tests in-kind

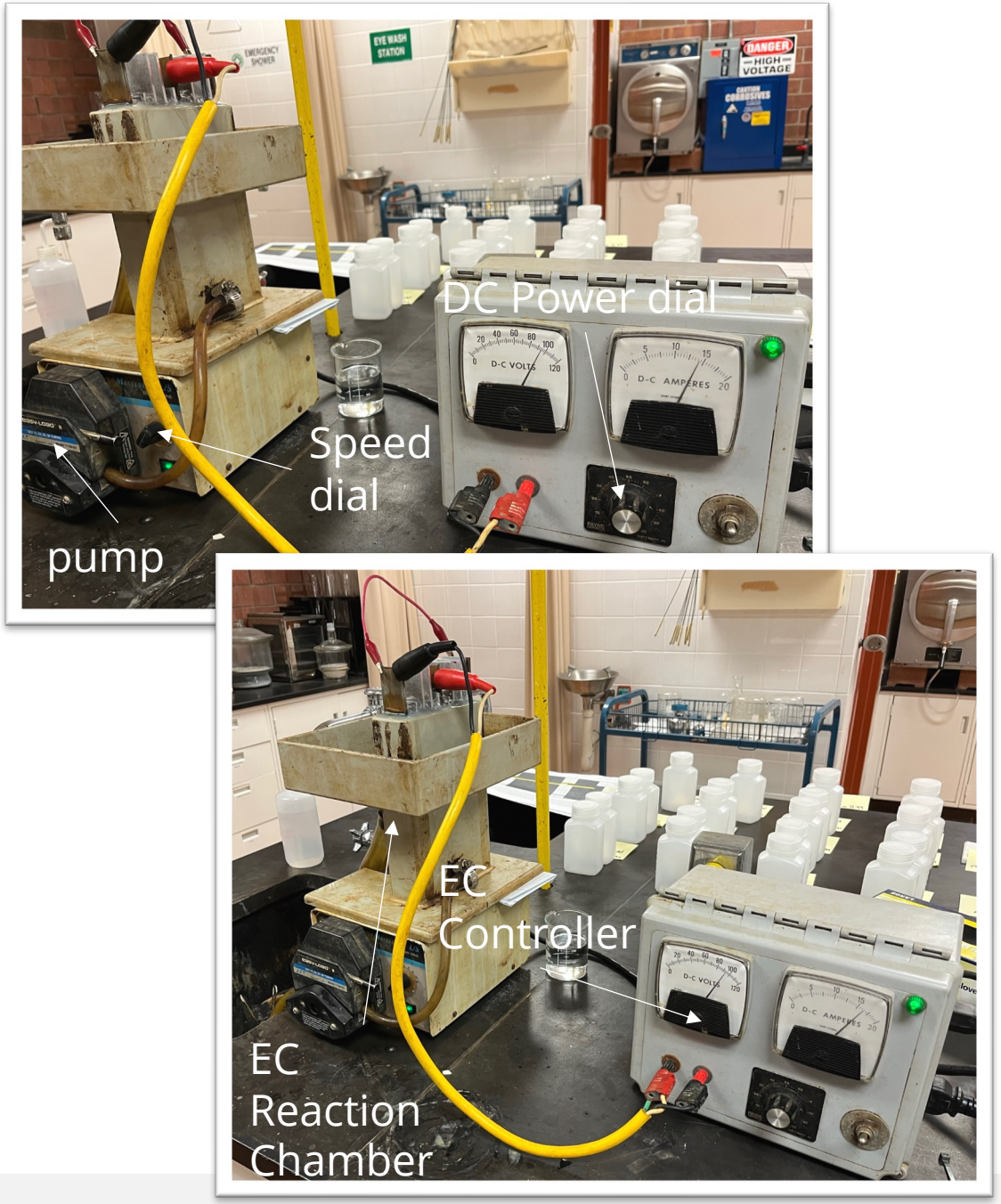
Determine the PFAS removal efficacy for 24 compounds and the fate of the residuals generated (destructive vs. non-destructive)

Solution

If EC proves to be a viable, destructive treatment tech, then further piloting / full scale design may ensue

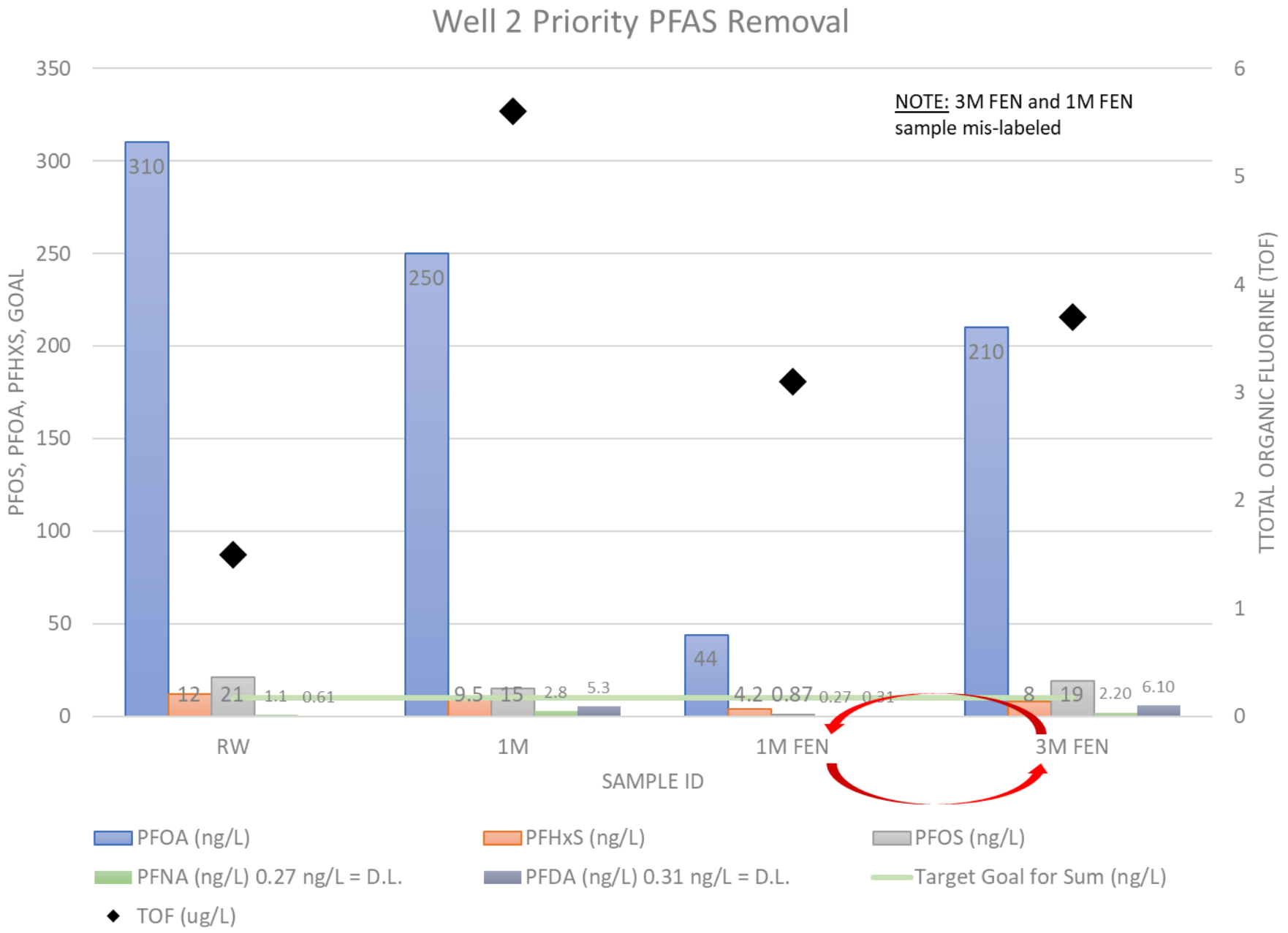
Well 2 1-min HRT | ambient pH

- Temperature of water rose 4°C quickly due to ohmic heating effect over 1.5 min process time
  - Higher the TDS, higher the temperature rise due to ohmic heating
- Chamber required jumping in high conductivity chamber b/c only 2.5-amps pulled due to lower TDS
  - Split in 2 equal chambers
- 96-V @ 15-amps (initial) to 94-V @ 17 amps (final) as metal was dissolved in solution



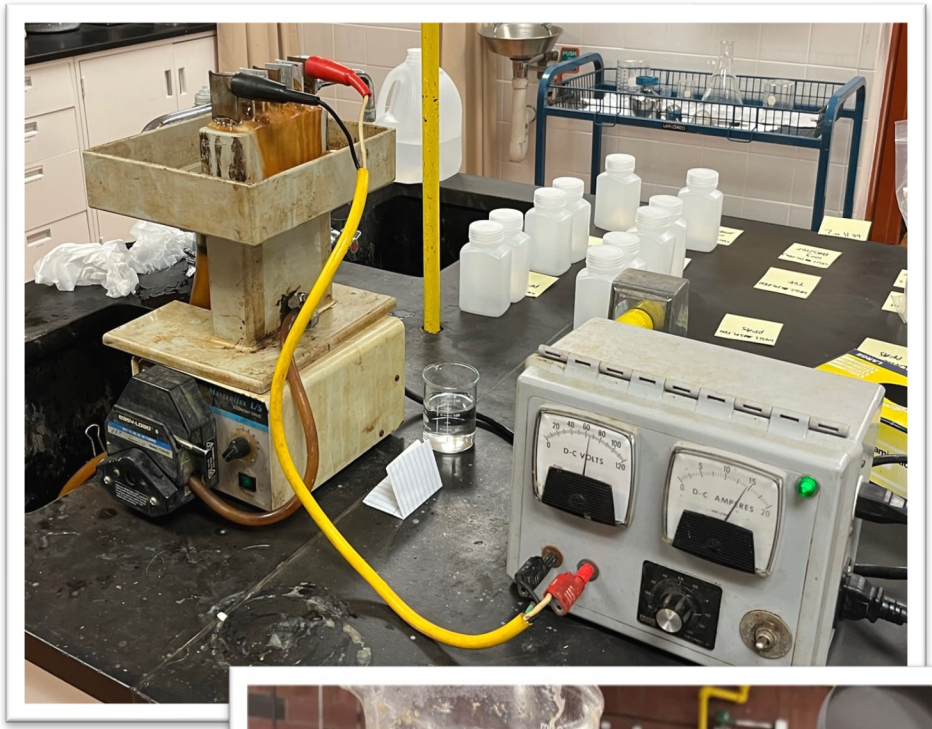
Well 2 – Lab Data

- 1M FEN and 3M FEN mis-labeled
- Longer, E-Fenton run time resulted in better removal for PFOA, PFOS, PFHxS, PFDA and PFNA
- 1M and 1M FEN led to 155% to 900% increase in PFNA and PFDA
- 3M FEN brought PFNA and PFDA back to ND
- TOF increase in all TW centrate samples may be indicator of C-F destruction



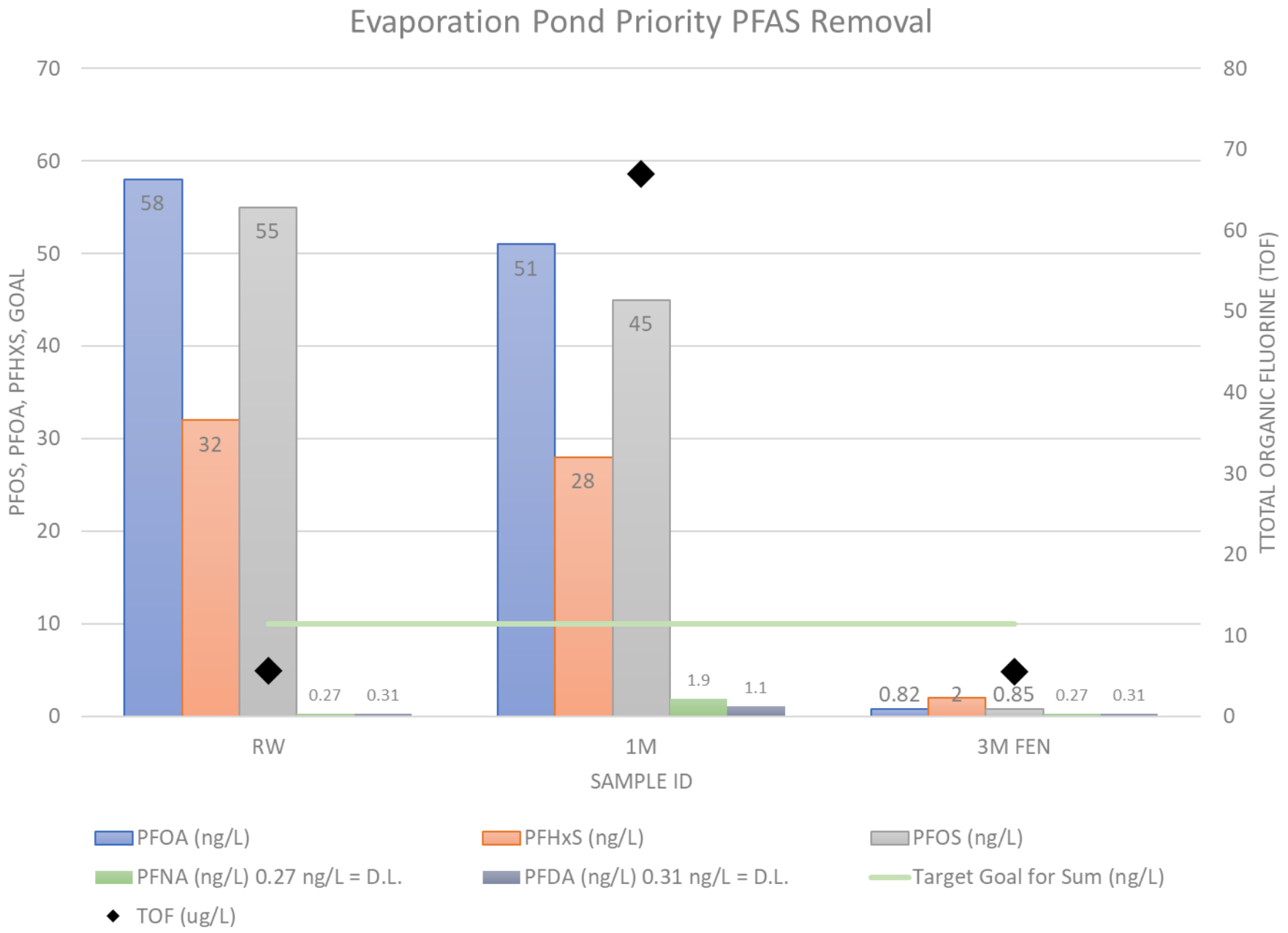
EP 3-min HRT | ambient pH | E-Fenton

- Highest temperature rise of all tests, but could not record temperature until centrifuged 2-hrs later
  - Allowed to cool
- Chamber did NOT require jumping due to high conductivity of EP sample
- 66-V @ 15-amps (initial) to 68-V @ 12.5 amps (final)
  - Significant quantity of bubbles generated during process caused the amperage to bounce between 10 and 15 amps
- Solids separated well, leading to clear filtrate



EP – Lab Data

- Longer, E-Fenton run time resulted in better removal for PFOA, PFOS, PFHxS, PFDA and PFNA
- 1M FEN led to 255% to 600% increase in PFDA and PFNA
- 3M FEN brought PFNA and PFDA back to ND
- TOF increase in 1M centrate samples may be indicator of C-F destruction



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ACE22

BOR Funded Desalination Pilot for Cooling Tower Blowdown - A Reuse Model for Challenged Waters

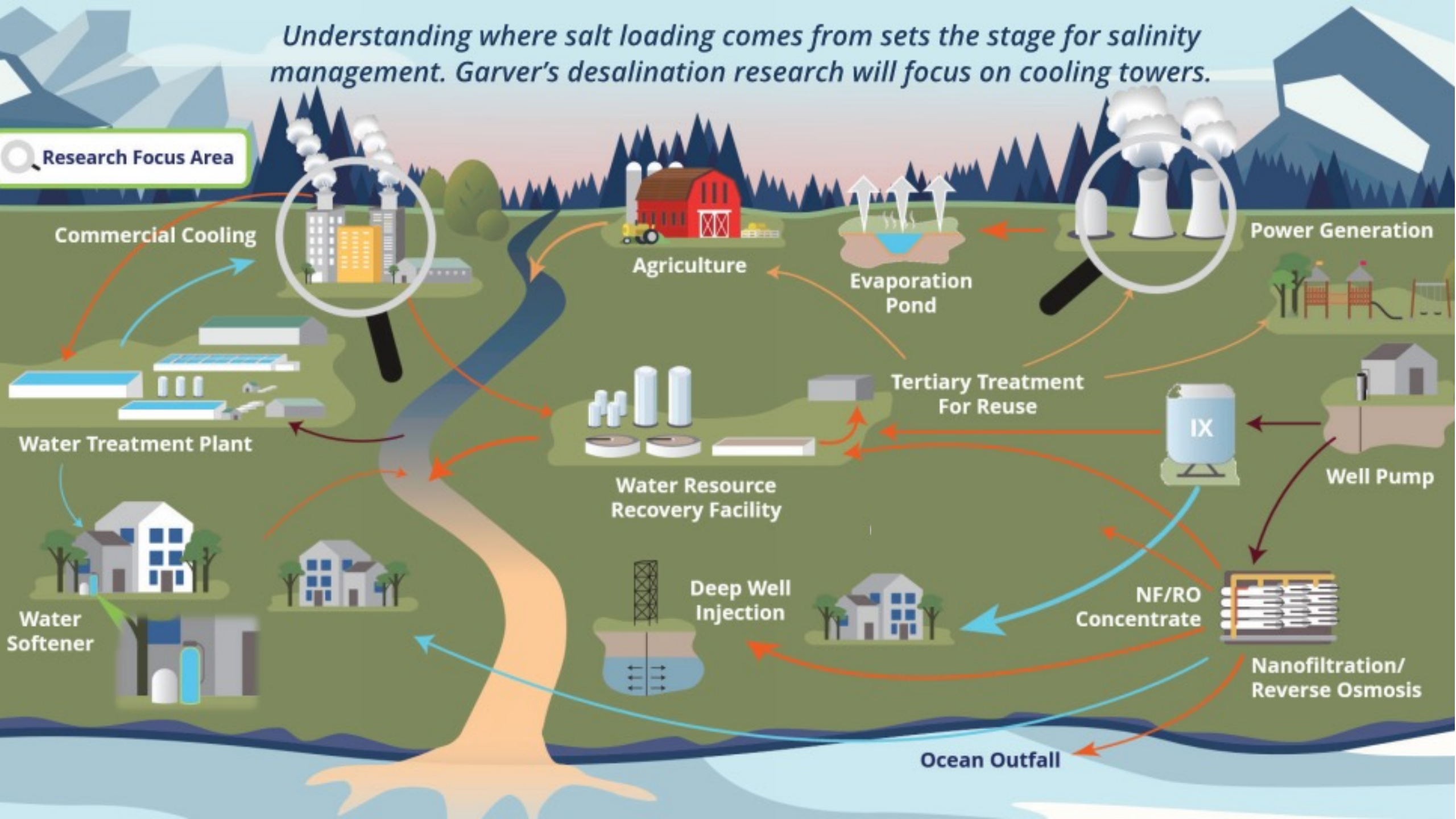
ERIC DOLE, PE, PSAP | GARVER
YULIANA PORRAS-MENDOZA | BOR

June 13, 2022

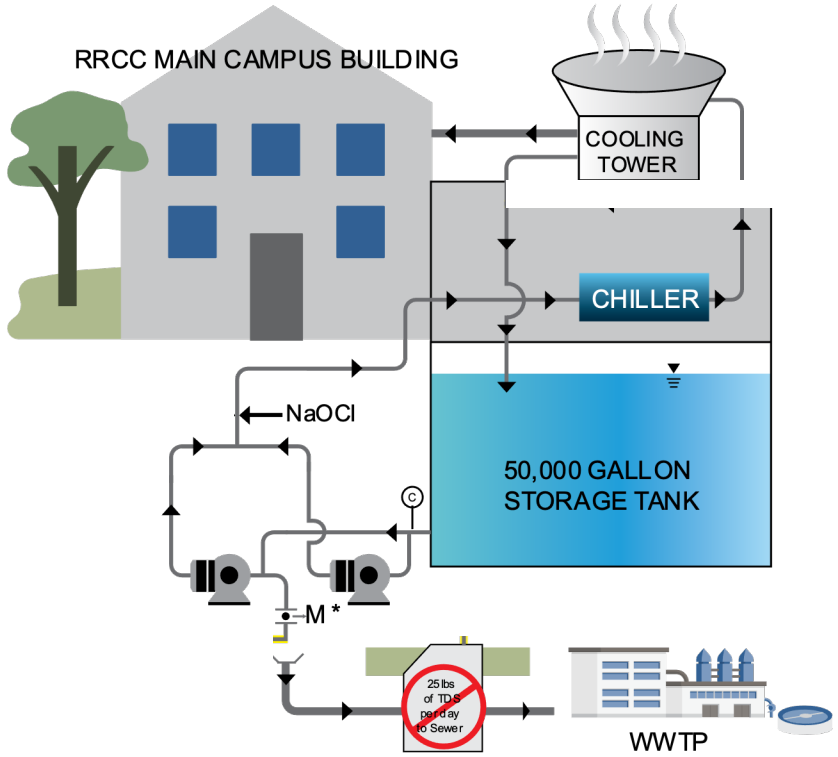
03

Pitch to Pilot Desalination Research Summary

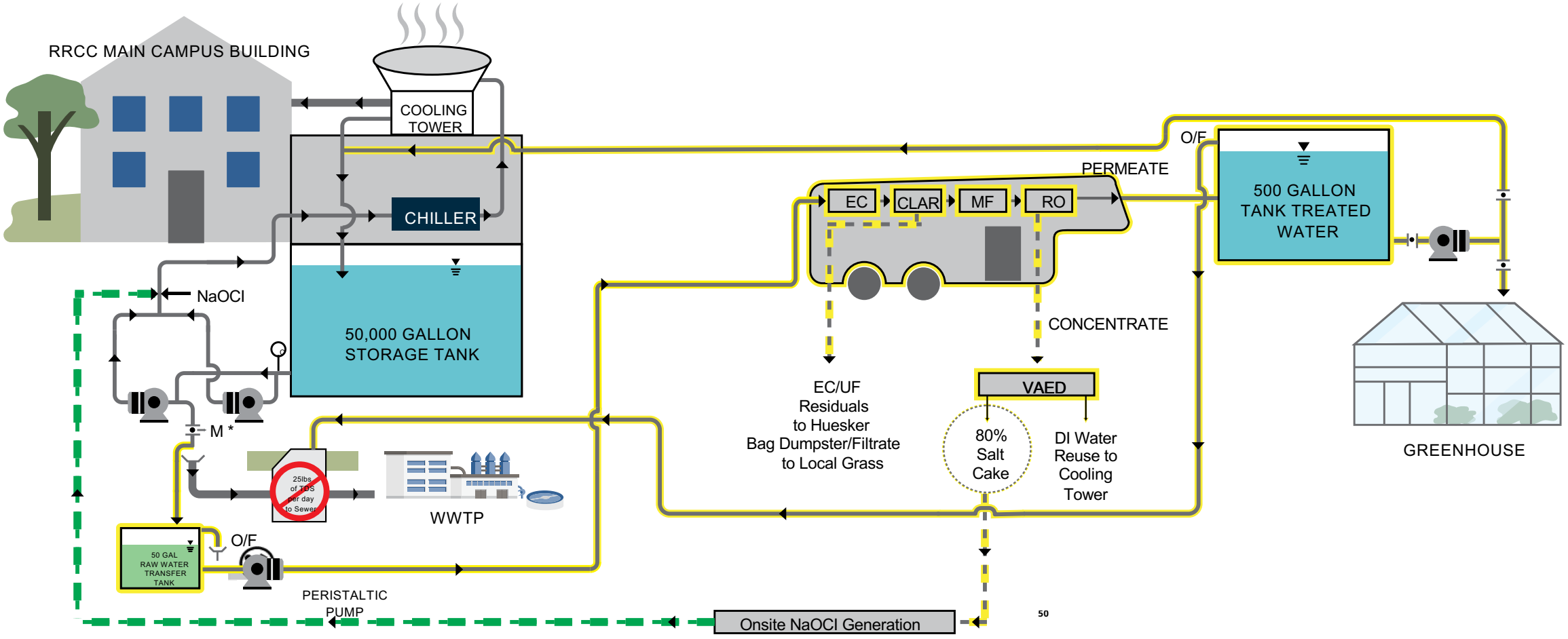
Understanding where salt loading comes from sets the stage for salinity management. Garver's desalination research will focus on cooling towers.



Cooling tower blowdown is a major contributor to salt loading of watersheds and should be considered especially if IPR or DPR is means to enhance water security.



Garver's team offers an innovative treatment train for cooling tower blowdown that prevents high salinity wastewater from entering the sewershed ***and*** eliminates the need for blowdown make up water ***while*** evaluating the salt slurry waste stream us as feedstock for chlor-alkali industry.



We were able to consistently produce high quality permeate without irreversible fouling ***due to removal of scale forming compounds***

TARGET CONSTITUENT	10th Percentile			Average			90th Percentile		
	Raw Water	Filtered EC Supernatant	Permeate	Raw Water	Filtered EC Supernatant	Permeate	Raw Water	Filtered EC Supernatant	Permeate
TH as CaCO3 (mg/L)	699.7	174.3	0.1	743.38	428.68	1.38	810.4	723.4	4.86
pH	8.1	7.9	7.1	8.3	8.8	8.8	8.7	9.3	9.9
TDS (mg/L)	1683	1515	5	2848.7	1686.2	11.4	1992	1966	21.2
Silica (mg/L)	15.61	0.30	0.3	17.7	1.39	0.3	19.4	3.24	0.3
TSS (mg/L)	5.0	5	5	5.3	12.5	5	5.3	17.8	5
Total Phosphate (mg/L)	0.11	0.05	0.05	0.16	0.06	0.05	0.19	0.05	0.05
TOC (mg/L)	5.79	4.84	0.5	6.38	5.18	0.51	7.34	5.46	0.5
*ORP (mV)	180	-141.8	-182.9	194.00	-112.40	-124.60	211	-70	-61.2
*Temperature (^{o}C)	15.86	13.19	12.86	18.09	16.99	16.96	19.94	21.23	21.33
Total Coli (mpn/100 mL)	1.0	1.0	1.0	1.18	1.67	1.0	1.0	1.0	1.0

OPERATING PARAMETER	10th Percentile	Average	90th Percentile
Energy Intensity (kWh/kgal)	39.6	44.9	51.4
Pressure (psi)	312	346	386
Permeat Flow (gpm)	0.72	0.80	0.86
Perm Flux (gfd)	11.9	13.2	14.3
Concentrate Flow (gpm)	0.80	0.88	0.97
% Recovery 3-stg RO	43%	48%	52%
**% Recovery Overall	49%	54%	59%

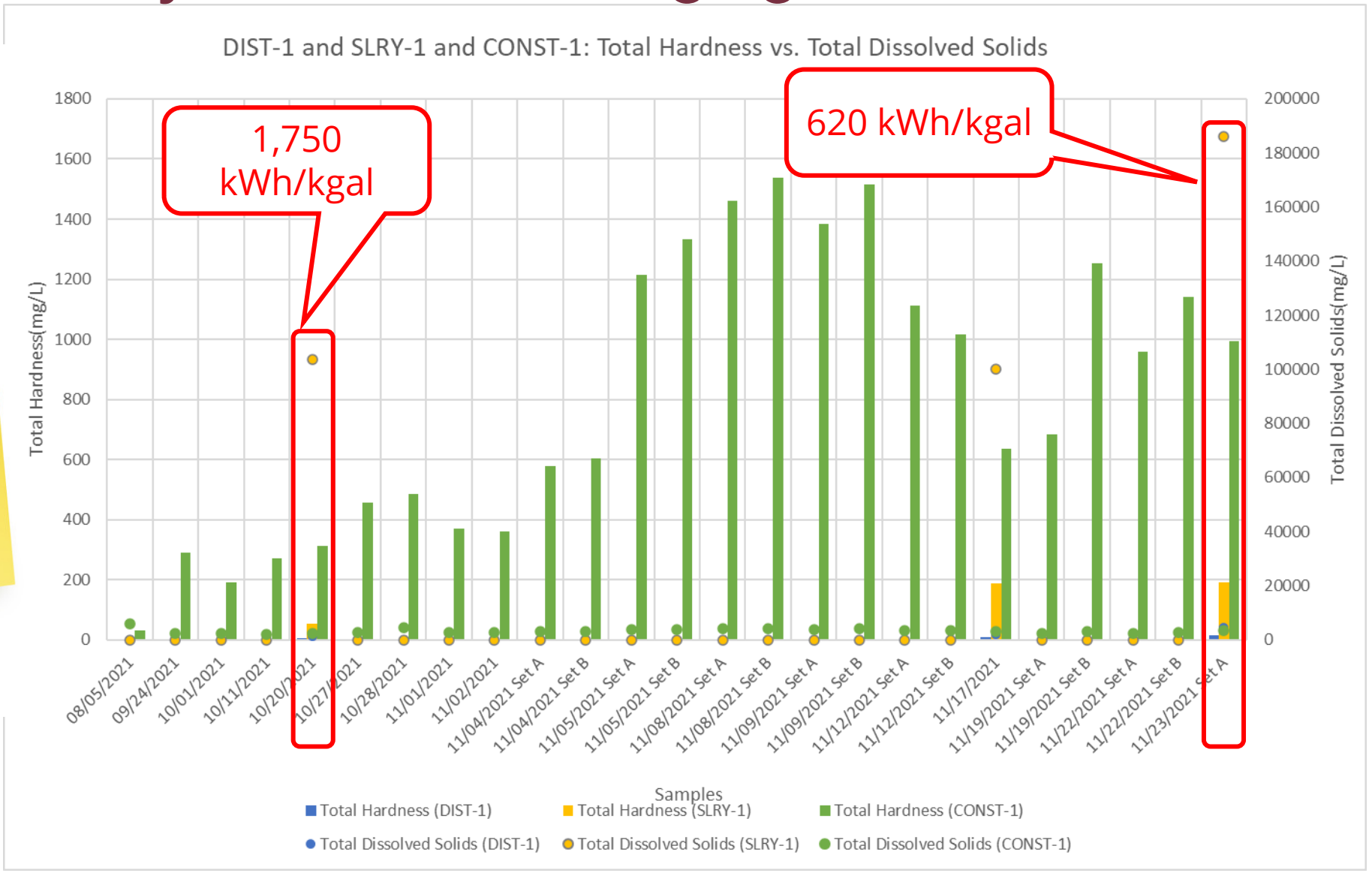
*As trended through in-line analyzers

**@ 400 ppm TDS w/ Blend

How did the VAED system do at managing the concentrate?

Highlights:

- Significant reduction of hardness and TDS
- Higher conductivity = lower kWh/kgal
- Significant room for energy efficiency improvement
- Cooling is key - modifications identified to significantly improve performance



What NAWI thinks of our research

> **This demo is an EXCELLENT opportunity to see the sort of small-scale, distributed desal system NAWI seeks to develop and advance with both its pilot program and our overall baselining and roadmapping.**
>
> Dr. Peter Fiske
> *Executive Director, NAWI*

NAWI
National Alliance for Water Innovation

Ideas for NAWI's $10M Supplemental Funding

March 4, 2021

Peter Fiske

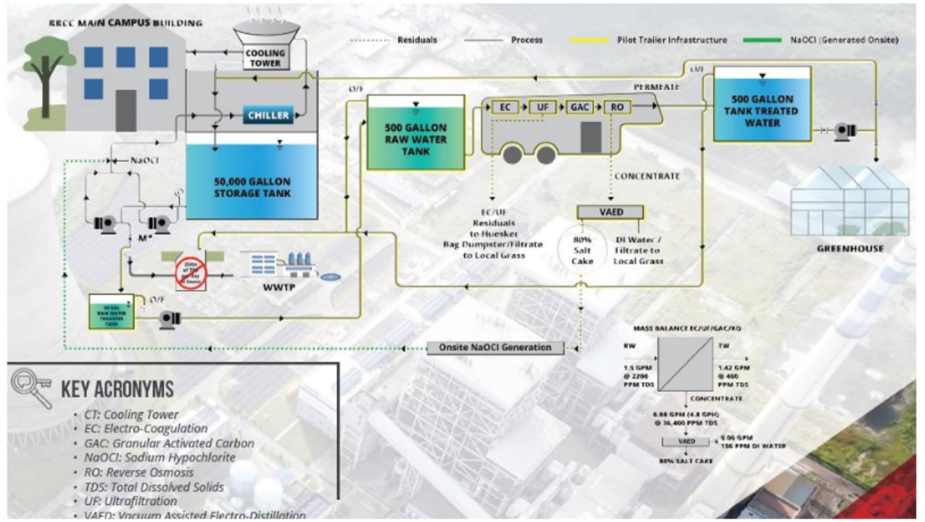
Executive Director – NAWI

Our industry partners put this as their TOP priority…

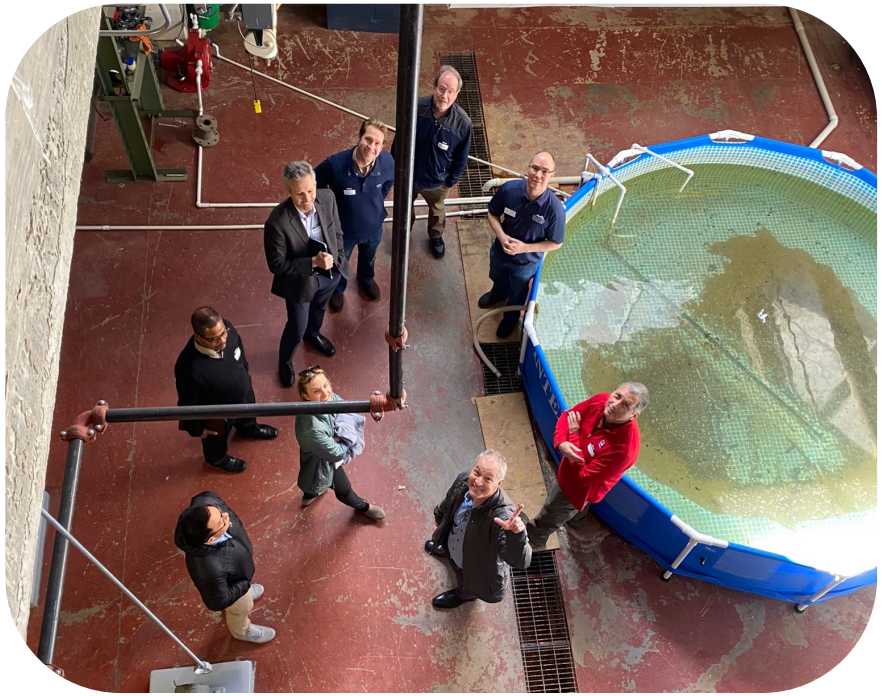
- Funding for demos is scarce
  - USBR's Pitch-2-Pilot is highly effective, but very small
  - Piloting in commercial settings is a cost often borne by the technology developer
- Successful pilots often stimulate a wave of commercial opportunities
- DWR in particular lists this as a critical need for California
- NAWI's vision of distributed desalination and water reuse is completely dependent on a succession of pilots and demos
- There are existing trial sites and demo facilities funded by ReNUWIt and USBR – these can be valuable leverage points for our pilots

What does one of these systems look like?

Garver's Pitch-2-Pilot demo of a ZLD blowdown treatment system



On 3/23/22 NAWI, DOE, NREL, Lawrence Berkley Labs, Oakridge Labs and APS participated in a tour



On 5/24/22 The BOR's Water Treatment Interagency Working Group also toured the P2P

BUREAU OF RECLAMATION

US Army Corps of Engineers

DARPA

USDA

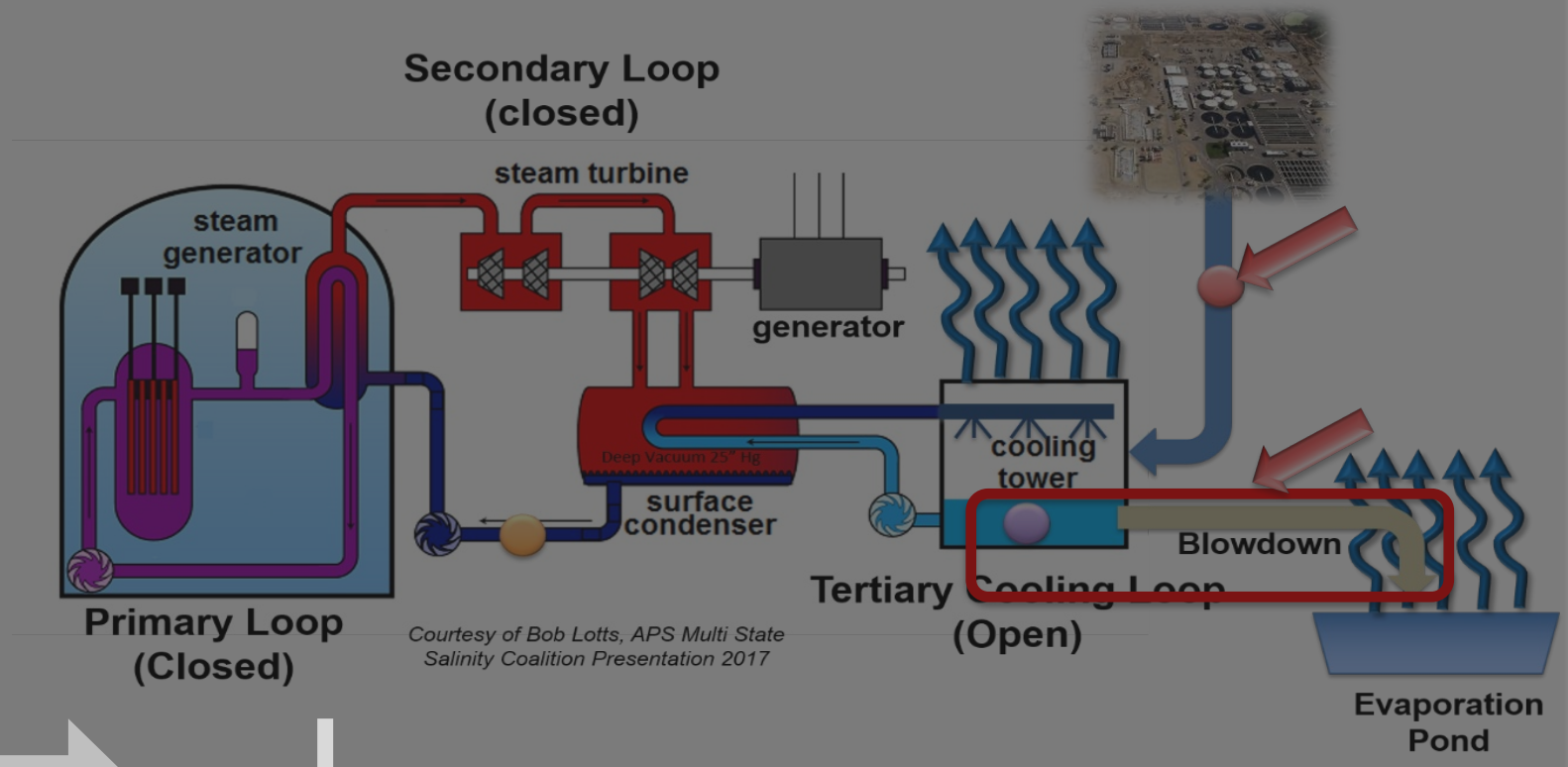
NIST National Institute of Standards and Technology U.S. Department of Commerce

ARMY MEDICINE

NASA

NSF

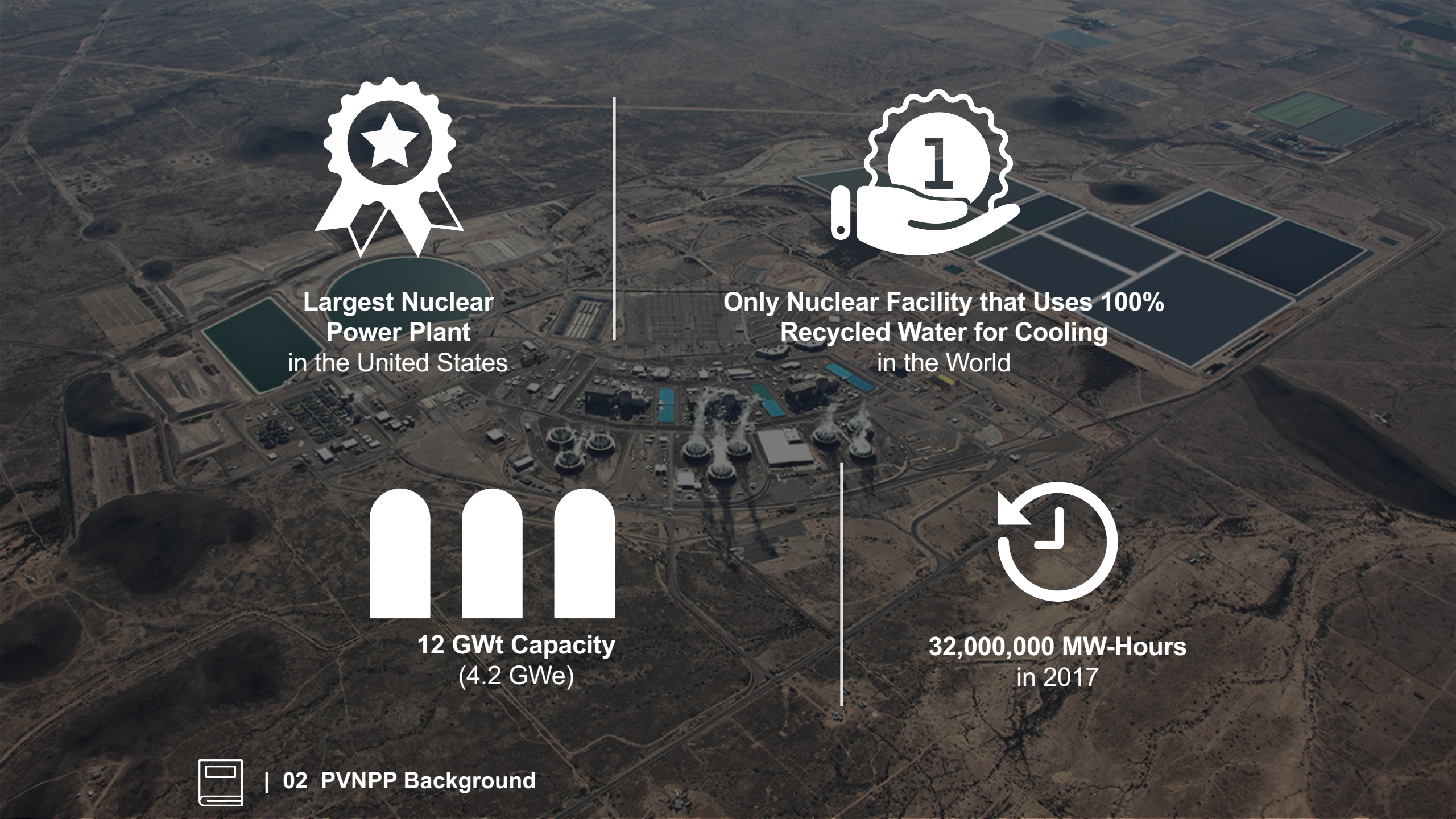
USAID FROM THE AMERICAN PEOPLE



Courtesy of Bob Lotts, APS Multi State Salinity Coalition Presentation 2017

04

Regional Brine Management Concept for West Valley



Largest Nuclear Power Plant
in the United States

Only Nuclear Facility that Uses 100% Recycled Water for Cooling
in the World

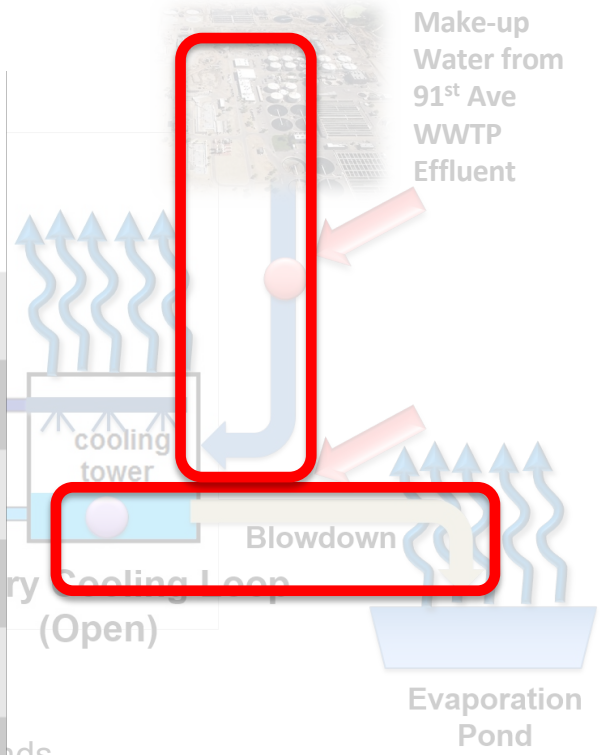
12 GWt Capacity
(4.2 GWe)

32,000,000 MW-Hours
in 2017

The Opportunities:
EC Based Treatment Solutions at PVGS

Palo Verde Water Quality

Parameter	WRF Influent (mg/l)	WRF Reservoir (mg/l)	Cooling Towers (mg/l)
Ca	200	100	2500
Mg	150	25	750
PO_4	10	1	10
SiO_2	20	5	150
Cl	350	350	5,500 – 10,000
TDS	1000	1000	25,000



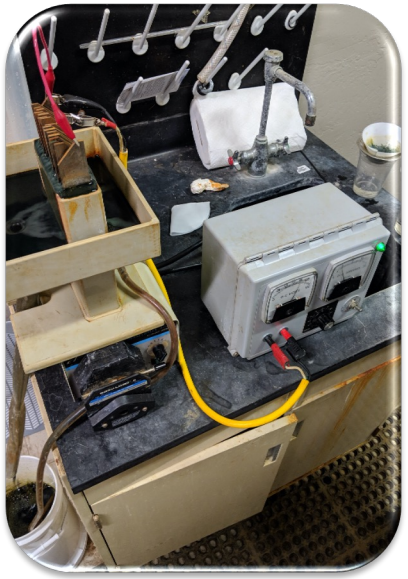
- Sulfuric acid + chlorine added to sump – blowdown to ponds
- Chemical softening + trickling filters for tertiary treatment of 91st Ave WW - ~ 100 tons/day

A Problem:

Upcyling of salt in Valley directly impacts PVNGS

Garver's EC Demo at PVGS on 1/25/19

Source: PVGS Make-up Water / 91st Ave. WWTP Secondary Effluent



High conductivity bench top EC unit processing sample water. Clear 11 um filtrate in plastic cup bottom. Filtrate sent to PVGS Lab for analysis

Ferrous hydroxide sweep floc settling after 1 minute

Ferrous hydroxide sweep floc settling after 5 minutes

Garver's EC Demo at PVGS on 1/25/19

Results – APS Email

Rafael.Balderrama@aps.com | Dole, Eric J.; Jeffrey.Brown@aps.com; Odegard-Begay, Andrea M.; Watts, Michael J.; Robert.Lotts@aps.com; Richard.Lange@aps.com | 2/26/2

RE: Checking In

You forwarded this message on 2/26/2019 8:42 AM.

Bing Maps + Get more ap

Eric –

We have in fact, received and reviewed the chemistry results for the samples processed on January 25th. The results suggest a significant decrease in hardness and silica. There was, however, an increase in chlorides and we assume that this would be exacerbated by the addition of HCl when added to adjust pH. All considered, a very successful test.

Given these results, we have prepared an Net Present Value (NPV) assessment based on some order of magnitude assumptions and attached the results for a proposed EC rebuild of the PV Water Resources tertiary system. The following assumptions were made:

- Design and large scale demonstration = $1M
- Facility re-design and construction = $64M over 4 years
- 33% increase in cycles of concentration in non-summer months (with a corresponding reduction in effluent from the SROG) based on the chemistry results for the bench-scale demo.
- 40% reduction in operating costs – no chemicals but engineers, operators, and maintenance remain
- $100K per year increase in OPEX for plate replacement (no basis for this one).
- Discount rate of 10.2%

These assumption were iterated on to produce a model that achieved the required ROI. You can see that the EC option becomes less expensive (i.e., achieves the discount rate) in 2045 which is the extent of the current licensed life for Unit 1.

More realistic inputs would include transition time. There would be a point at which power generation would be impacted by available cooling water if system start-up and swap-over didn't occur in 12 days. Also, I really believe that the CAPEX would be much higher than $64M and the project would need to be accelerated to a shorter time frame. I have no idea of what the cost would be to change chemistry and we also would need to assess the impacts on the CW chemistry if we're to add more HCl to the process, which raises our chloride concentration factor (we already blowdown on this). It will then come down to coming up with a program on how to manage solids.

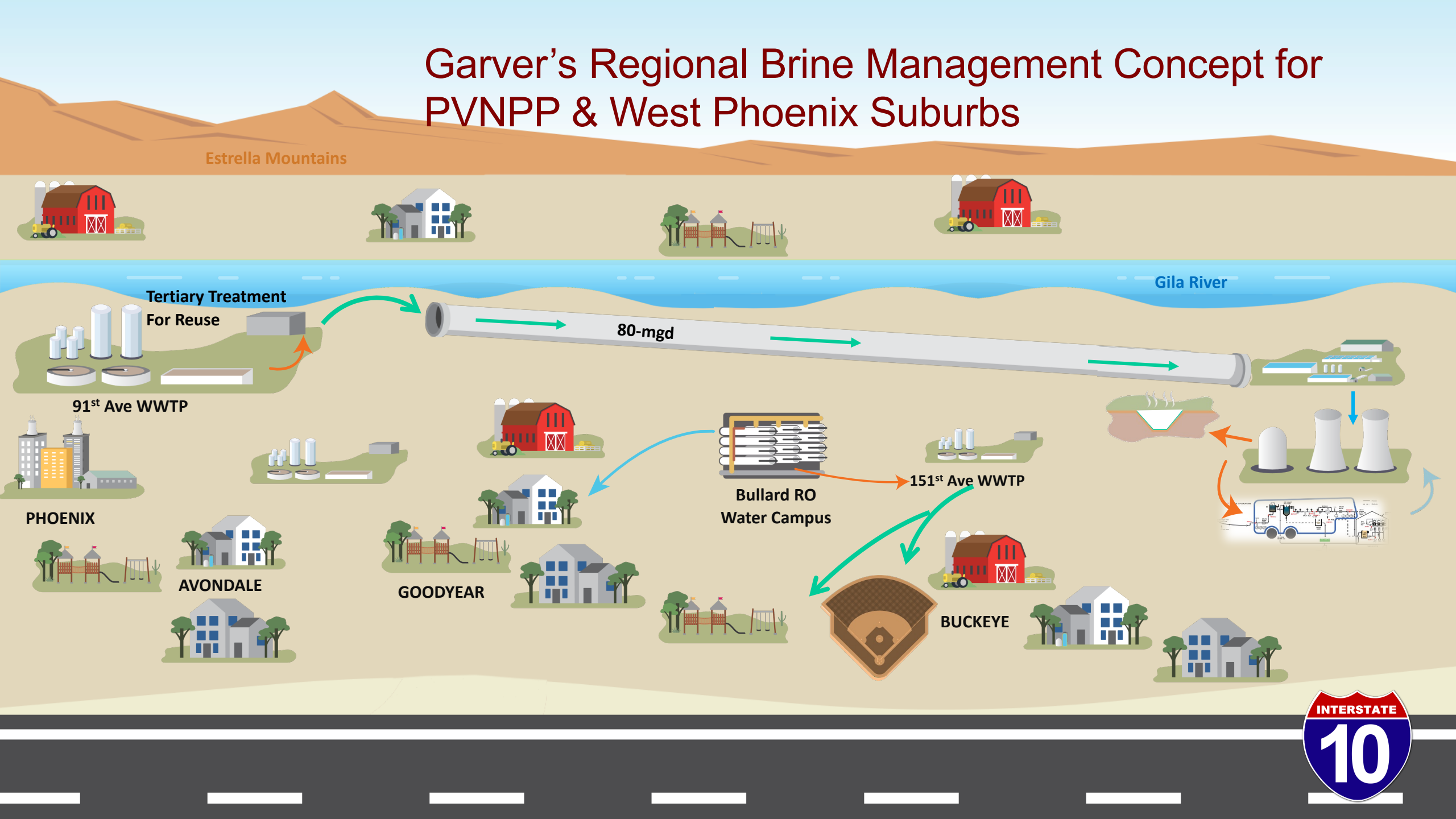
Again, the above scenario likely under-estimates the capital cost. Wholesale replacement of the tertiary plant is not feasible. However, if Garver is willing to provide more realistic capital and operating cost estimates for a specific application, such as a smaller scale installation to take a side slip stream of water that either heads to a reservoir or an evap pond, this technology may be an alternative to the RO process now considered to support municipal concentrate management. We'd be happy to discuss additional details if you wish.

Thanks – Rafael

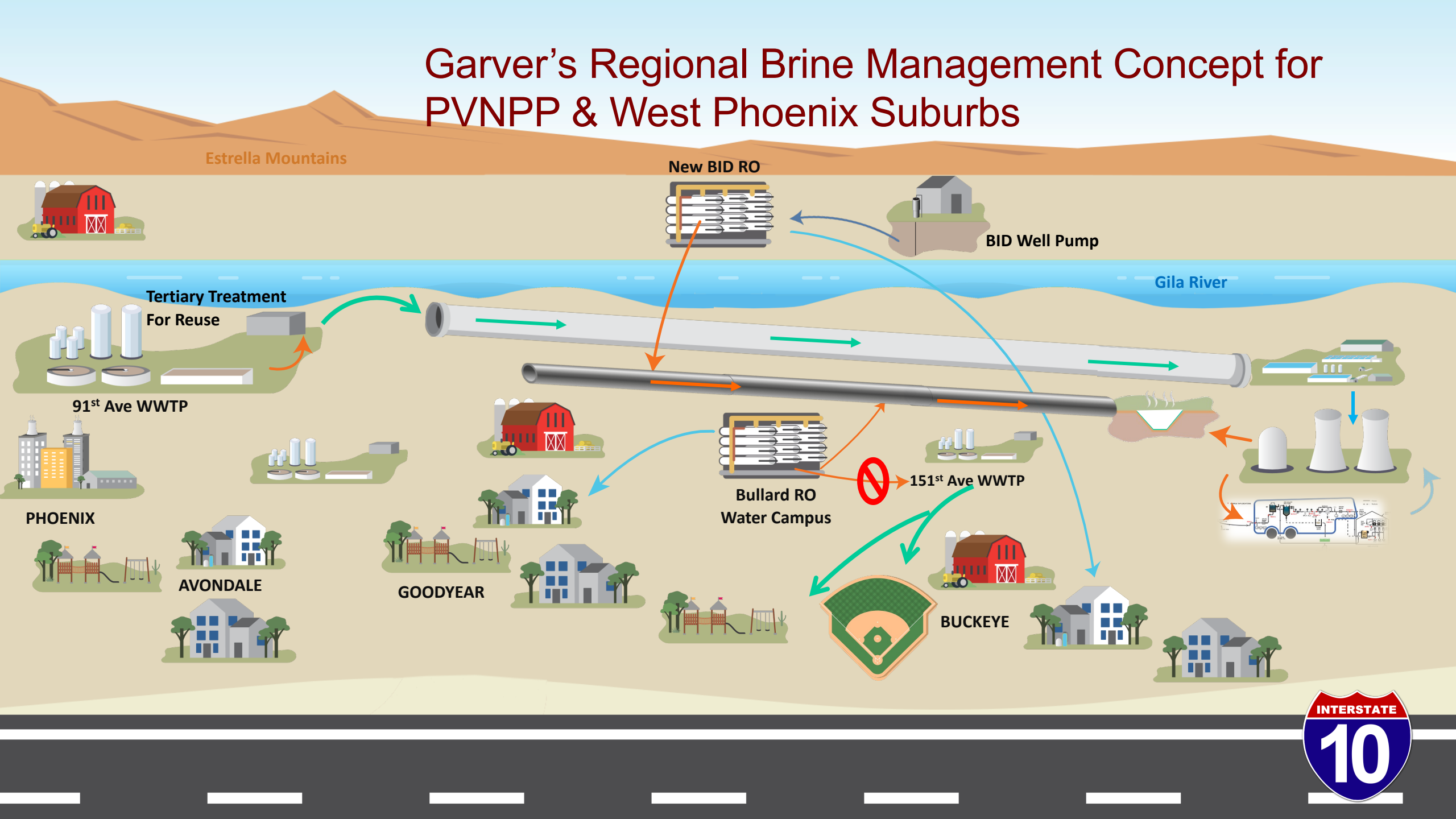
Highlights:

- Significant reduction of hardness and silica
- 33% more COC with EC than existing treatment
- 40% saving in OPEX – no chemicals
- Increase in chlorides
- Prelim ROI still high
- ROI assumptions need refinement

Garver's Regional Brine Management Concept for PVNPP & West Phoenix Suburbs



Garver's Regional Brine Management Concept for PVNPP & West Phoenix Suburbs



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Q&A

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