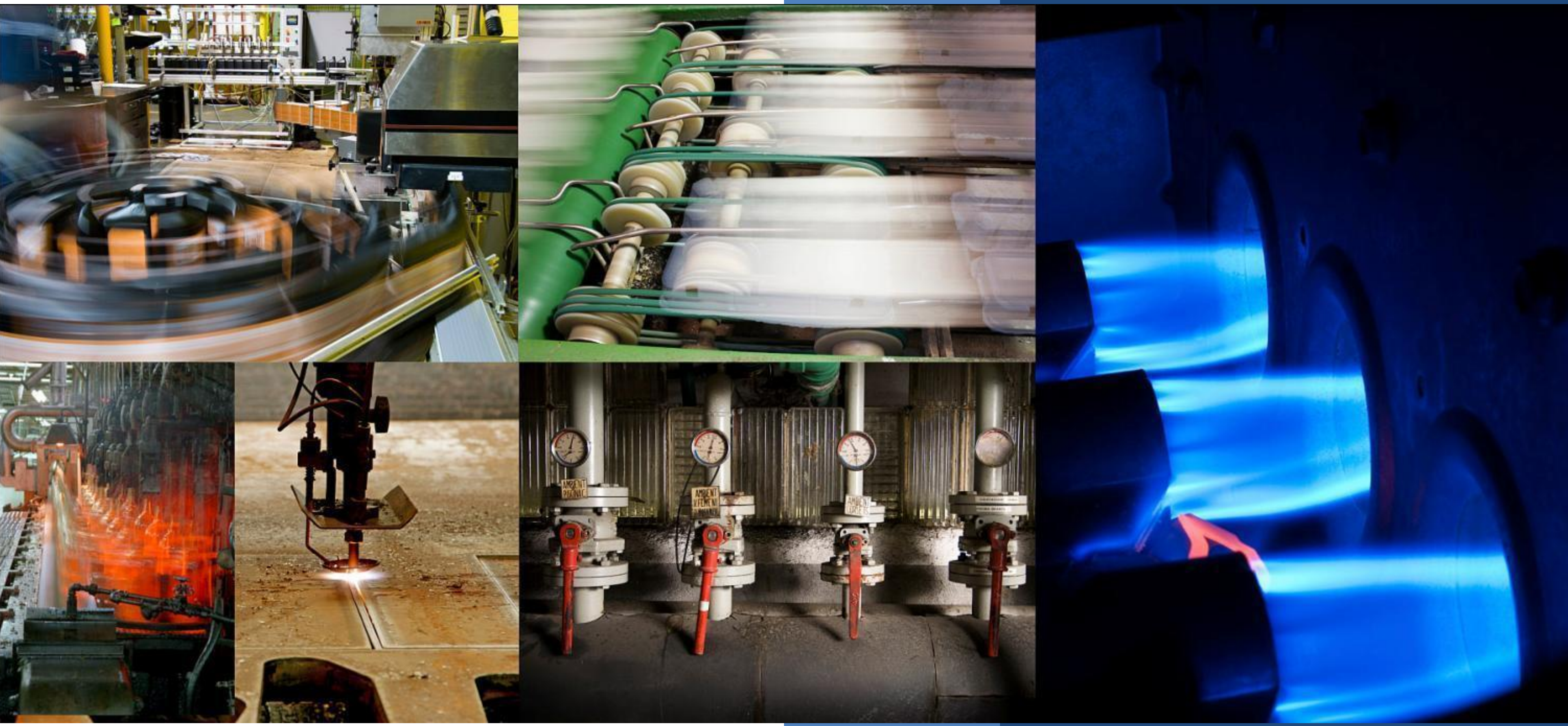
U.S. DEPARTMENT OF ENERGY



Energy Bandwidth Study of Desalination

Joe Cresko - Advanced Manufacturing Office, DOE

Brackish Groundwater National Desalination Research Facility
New Orleans, LA
September 19, 2018

AMO Strategic Goals

- Improve the productivity and energy efficiency of U.S. manufacturing.
- Reduce lifecycle energy and resource impacts of manufactured goods.
- Leverage diverse domestic energy resources in U.S. manufacturing, while strengthening environmental stewardship.
- Transition DOE supported innovative technologies and practices into U.S. manufacturing capabilities.
- Strengthen and advance the U.S. manufacturing workforce.

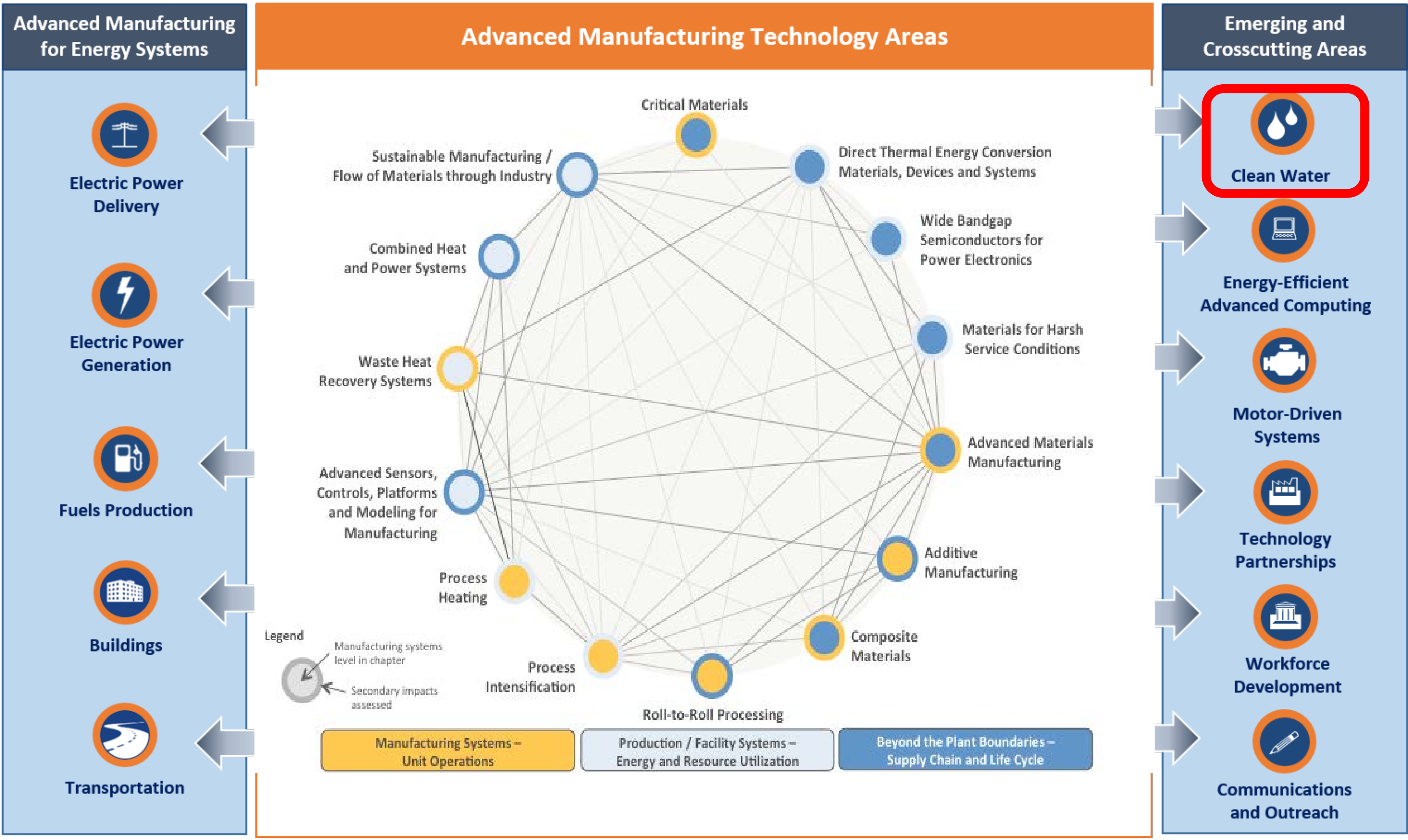
Multi-Year Program Plan

- Describes the Office mission, vision, and goals
- Identifies the technology, outreach, and crosscutting activities the Office plans to focus on over the next five years.

https://energy.gov/eere/amo/advanced-manufacturing-office

AMO Multi-Year Program Plan (MYPP) Framework and Clean Water

https://energy.gov/eere/amo/downloads/advanced-manufacturing-office-amo-multi-year-program-plan-fiscal-years-2017



Manufacturing Technology Assessments can be found here:

https://energy.gov/under-secretary-science-and-energy/quadrennial-technology-review-2015-omnibus#chap6ta

Issues with Water at Current State-of-the-Art

- **Water Processing Impacts:** The cost and energy associated with processing non-fresh water sources (brackish or seawater) is relatively high compared with fresh ground and surface waters.
- **Water Transport Impacts:** Cost and energy associated with water transport from a centralized facility is high (~$0.05/m^3 for 100 meter vertical lift or 100 kilometer of flat horizontal transport).
- **Underutilized Water Sources:** Regional non-fresh water sources are readily available and if utilized would reduce or eliminate the cost and energy demands of transporting clean water from one region to another
- **Suboptimal Energy Efficiency:** Current treatment centers and associated systems (whether centralized or distributed) are not as energy efficient with current technologies
- **Lack of Applications for Water Reuse:** Approx. 290 billion gallons of water a day is discharged back into the ocean or other surface water locations instead of being recycled back. Non-"reuse" volume represents near 95% of total.
- **Broader Systems Impacts**: All above impact energy demand, resiliency and robustness from watershed to water use.

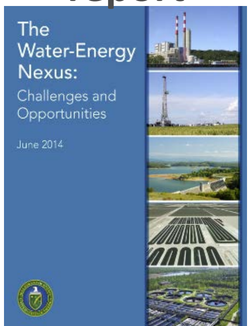
https://www.sierracollege.edu/ejournals/jsnhb/v6n1/null.html

"… untapped water resources could be utilized if key technical challenges are addressed, including processing and purifying water in a low cost and energy-efficient manner."

Advanced Manufacturing Office Multi-Year Program Plan

Examples of DOE/AMO Energy-Water Activities

DOE Water-Energy Nexus report



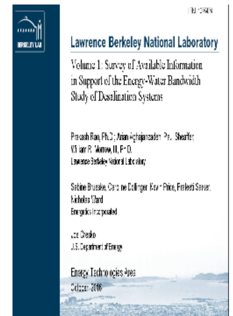
Better Plants Water and Wastewater Treatment Working Group

Better Plants® U.S. DEPARTMENT OF ENERGY

SEP Water and Wastewater Treatment Pilot

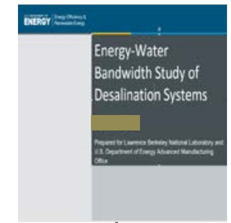
Superior Energy Performance® U.S. DEPARTMENT OF ENERGY

Desalination Data Study (Vol. 1)



Clean Water RFI

Desalination Bandwidth Study (Vol. 2)

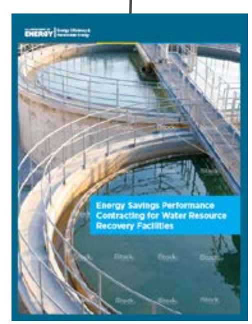


2014 | 2015 | 2016 | 2017 | 2018

Better Plants® CHALLENGE U.S. DEPARTMENT OF ENERGY

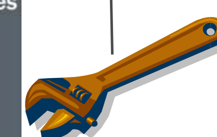
Water Savings Initiative

Energy Optimized Desalination Technology Development Workshop



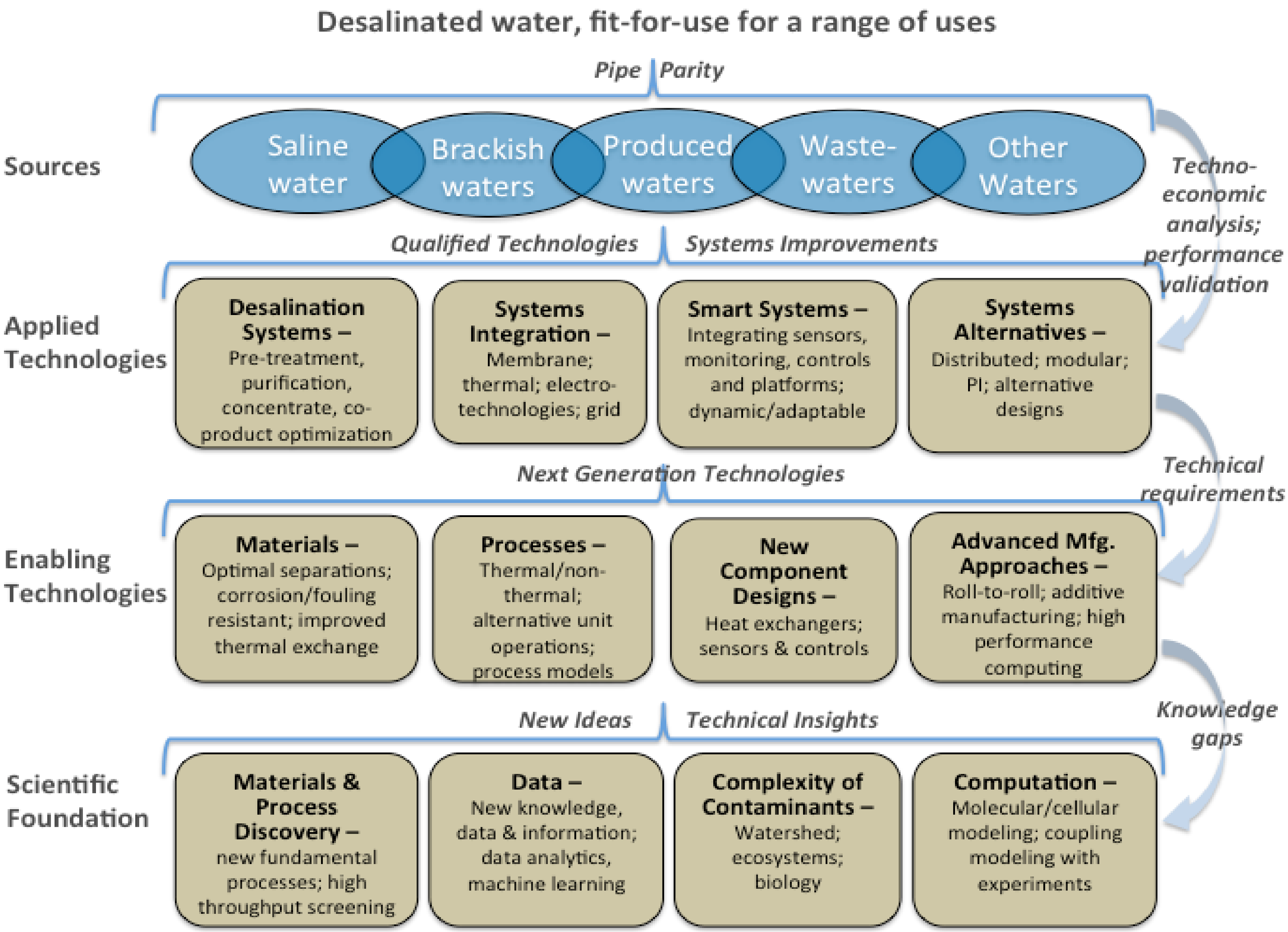
Wastewater Infrastructure Resiliency Accelerator

AMO Clean Water Workshops (Dallas, Cleveland)

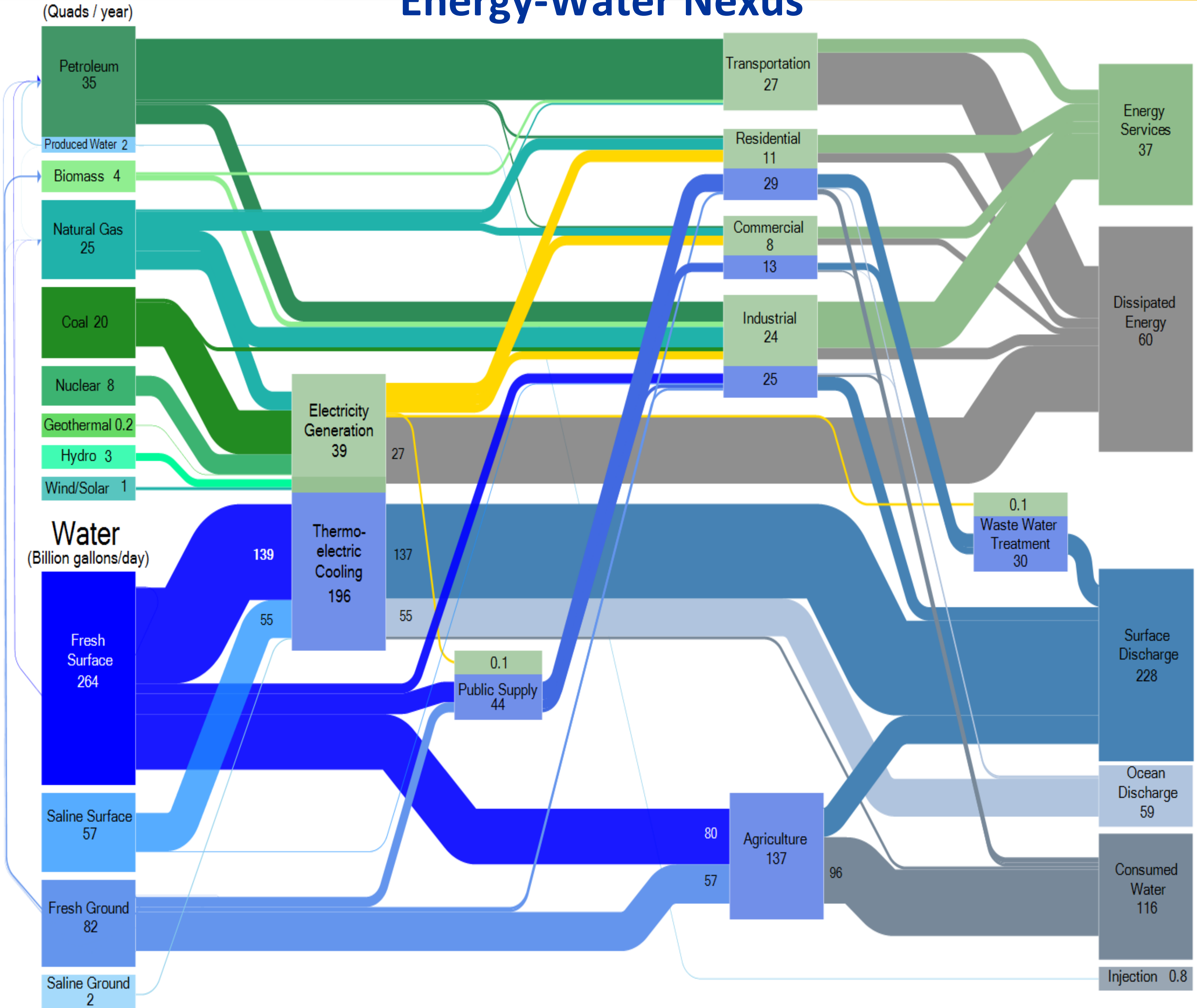


Plant Water Profiler Tool

Technology maturity and manufacturing scale for clean water



Energy-Water Nexus



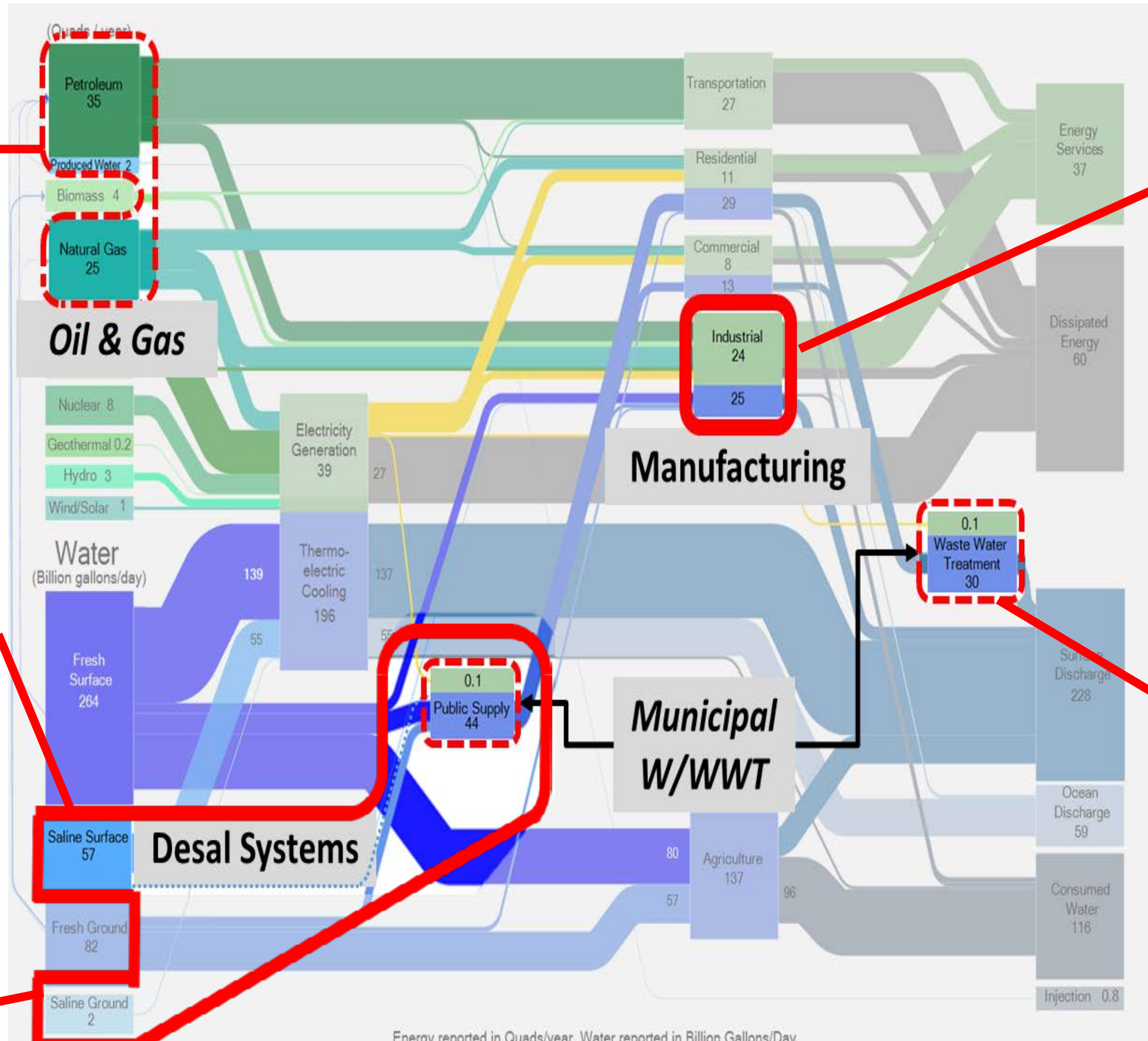
Energy reported in Quads/year. Water reported in Billion Gallons/Day.

What core technology improvements have targeted impacts, …

High Salinity feed water with variable contaminant mix to produce industrial/ag grade water w/ FO, RO viable candidates

Seawater for municipal potable water w/ RO, MSF, and MED candidates in focus

Brackish water for potable water w/CDI, EDR, MF/NF, RO as candidates



Reduce energy & water in specific sectors w/ sectors chosen in context with watershed impact

Reduce energy consumption of the water and wastewater sectors, including advanced resource recovery and reuse possibilities

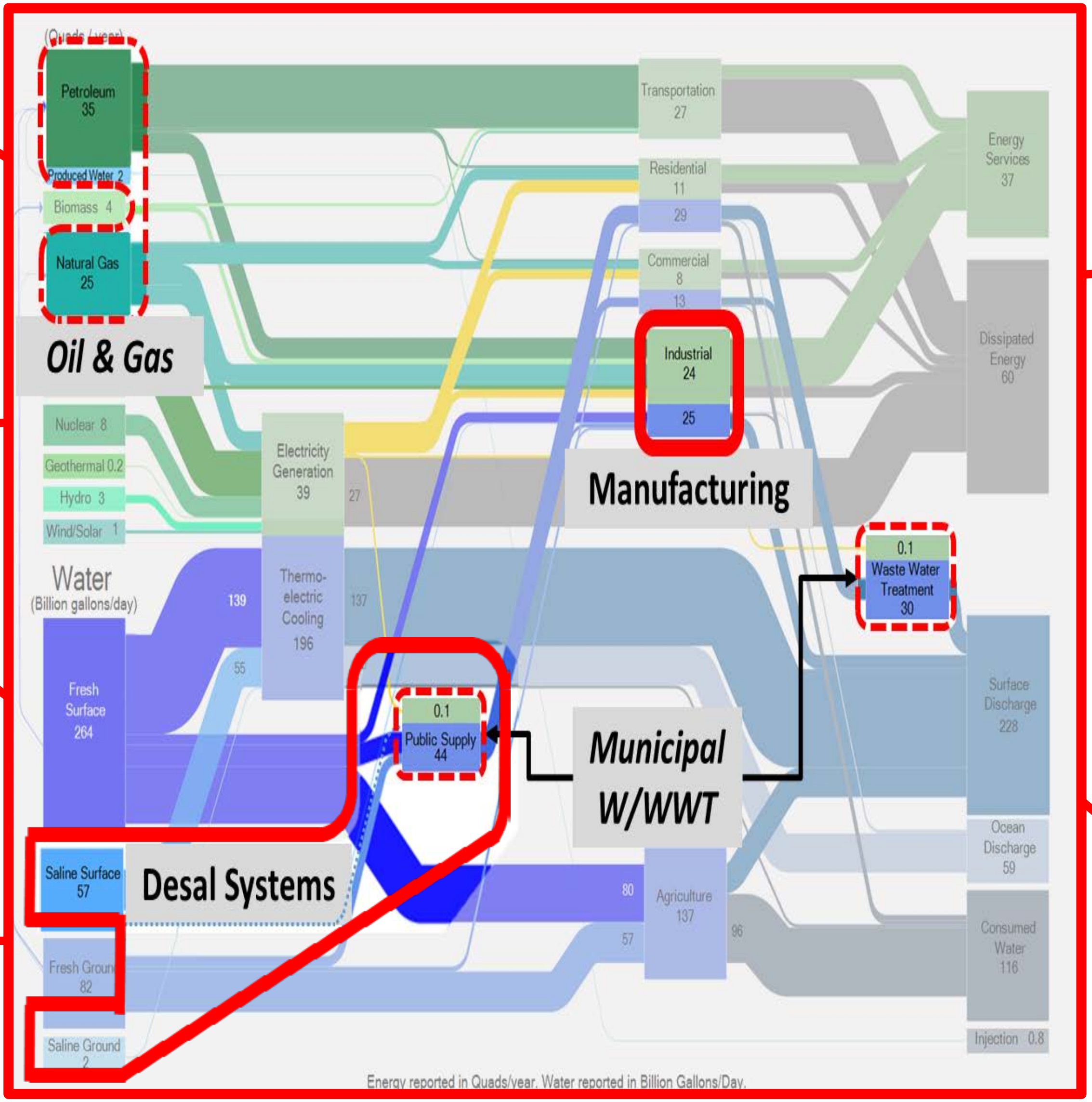
…and what cross-cutting technologies have pervasive impact?

Separations /treatment:
- Membranes
- Thermal

Fluids Pumping:
- Motor driven systems
- Materials

Heat transfer:
- Corrosion resistant materials
- Waste heat integration

Infrastructure:
- Piping
- Structural materials



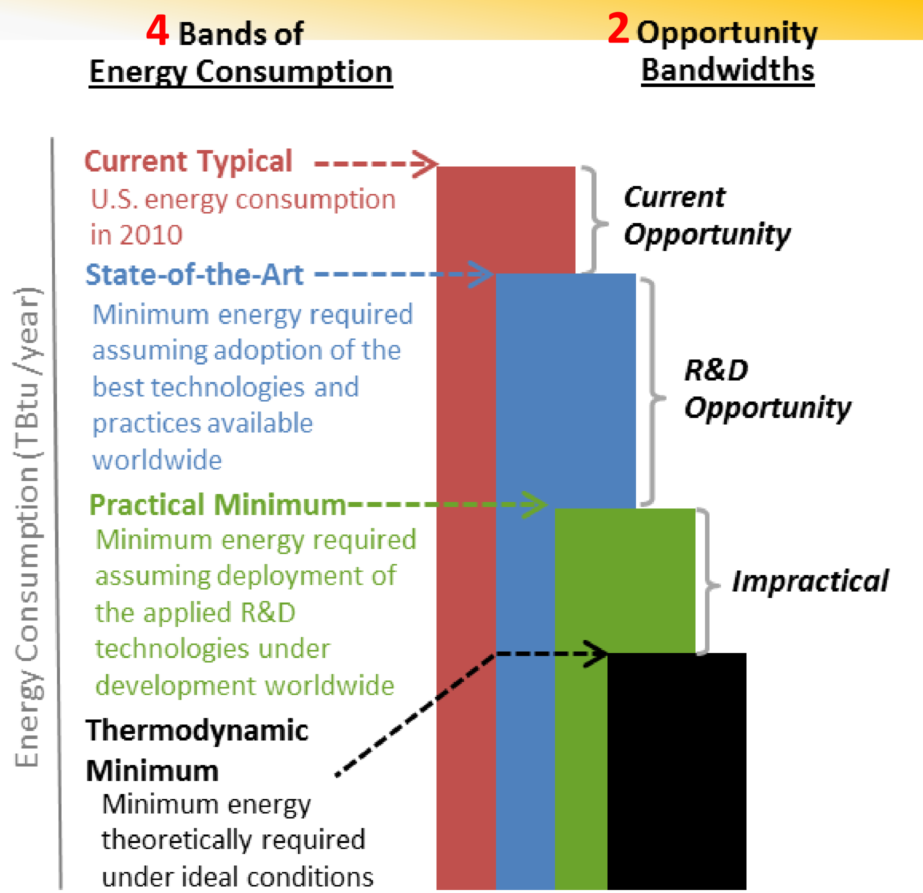
System integration:
- Smart technologies
- Modular designs
- Processes
- Joint energy grid/water system management

Sustainability:
- RE integration
- Consumptive water use
- Chemicals (alternatives)
- Life cycle water use
- Fit-for-use, reuse
- ZLD

Energy Bandwidth Studies

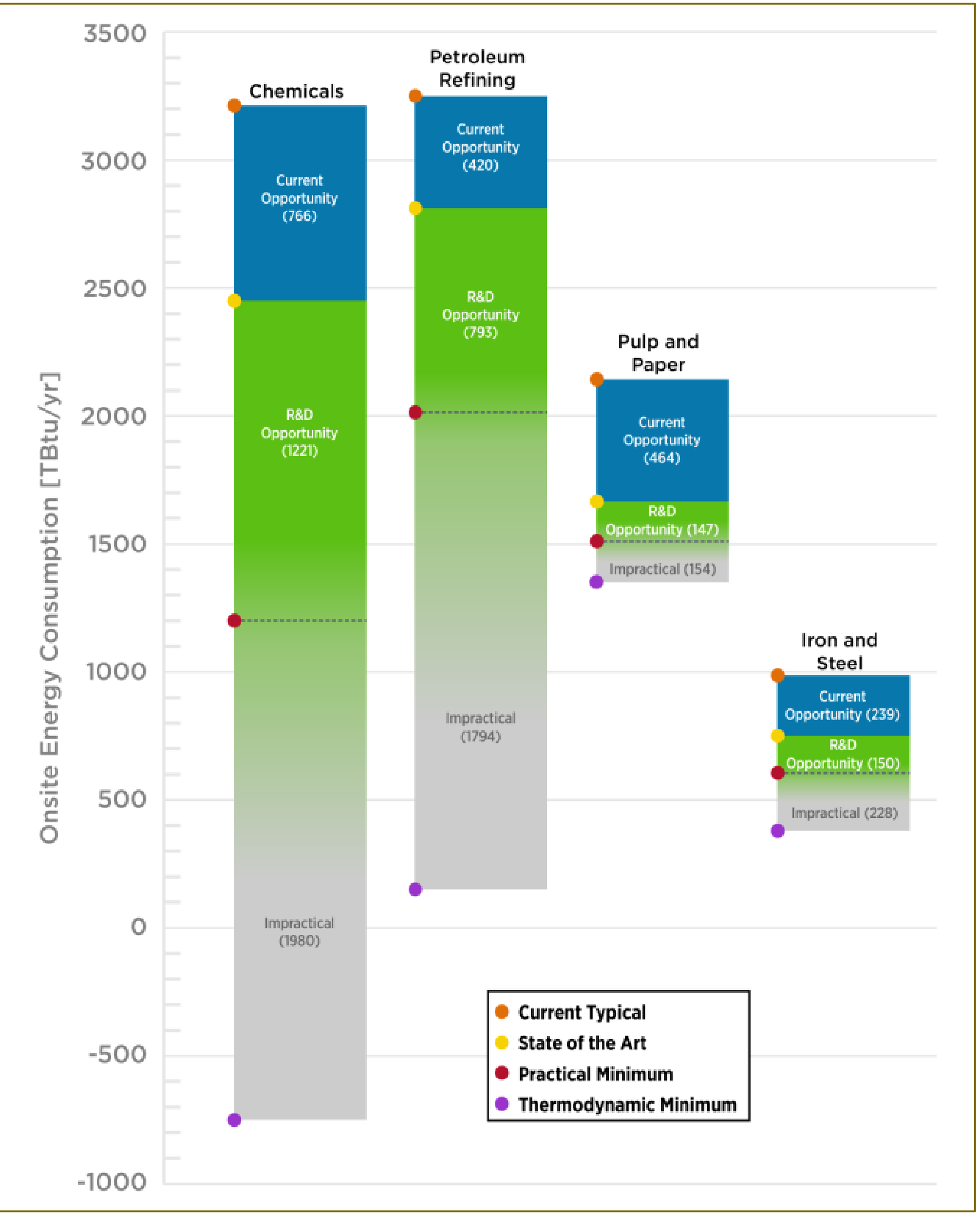
Comparison of energy consumption for defined industrial process areas to determine bandwidths of energy savings opportunity

These bands of energy consumption and bandwidths of opportunity are useful for identifying areas of R&D technology focus.



Current Typical (CT)	State of the Art (SOA)	Practical Minimum (PM)	Thermodynamic Minimum (TM)
Literature review and stakeholder outreach, based on current typical processes in the U.S.	Literature review and stakeholder outreach, based on the most energy-efficient technologies and practices available worldwide	Calculated based on plausible energy savings from identified R&D technologies under development worldwide	Calculated analytically using Gibbs free energy assuming ideal conditions

Recent Bandwidth Studies



https://energy.gov/eere/amo/energy-analysis-sector

<u>Published 2015:</u>

- Chemicals
- Petroleum Refining
- Pulp and Paper
- Iron and Steel

<u>Published 2016</u>:

Draft lightweight structural materials series:

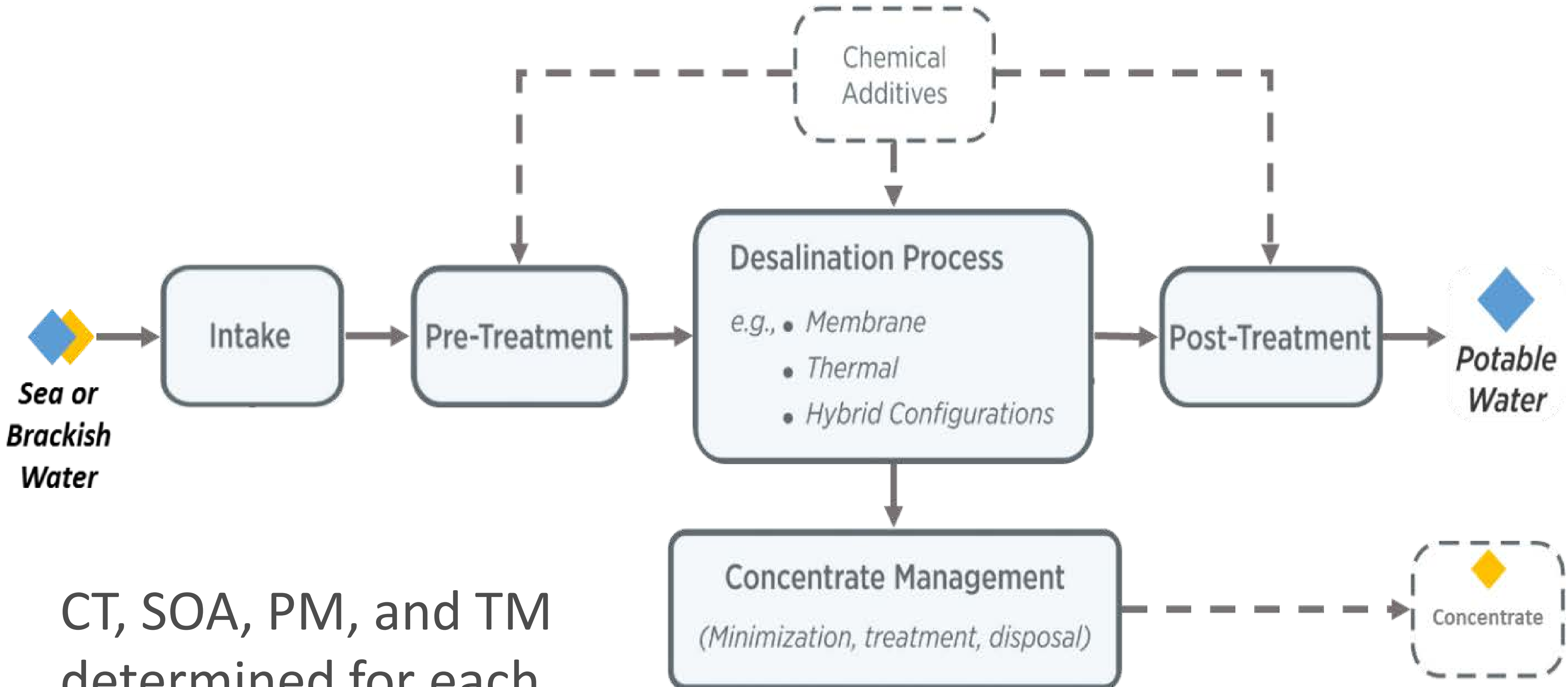
- Advanced High Strength Steel
- Aluminum
- Titanium
- Magnesium
- Carbon Fiber
- Glass Fiber

<u>Published 2017</u>:

- Cement
- Glass
- Plastics and Rubber Product
- Food and Beverage
- ***Seawater Desalination***

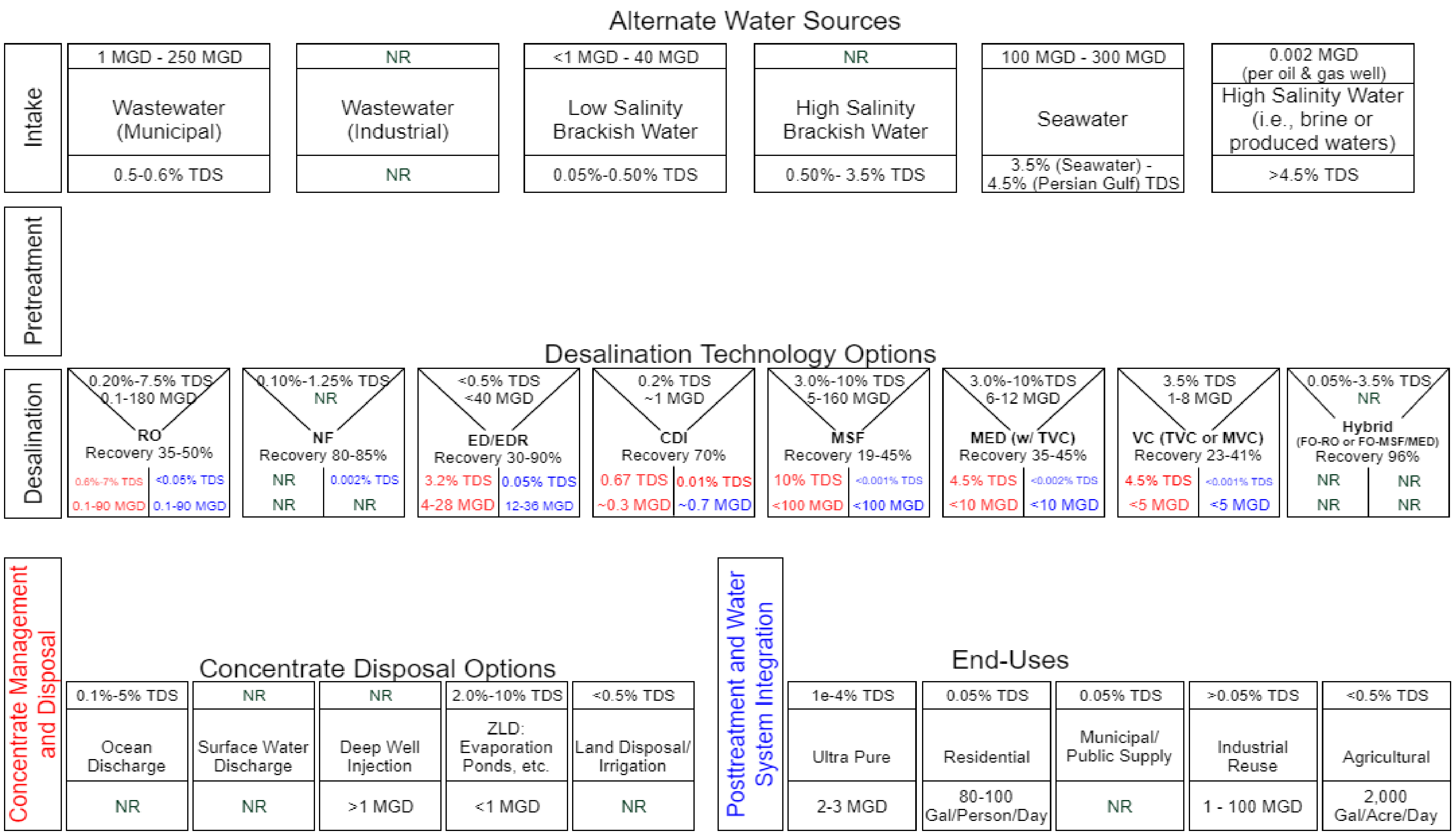
Seawater Desalination Analysis

Desalination System Boundary



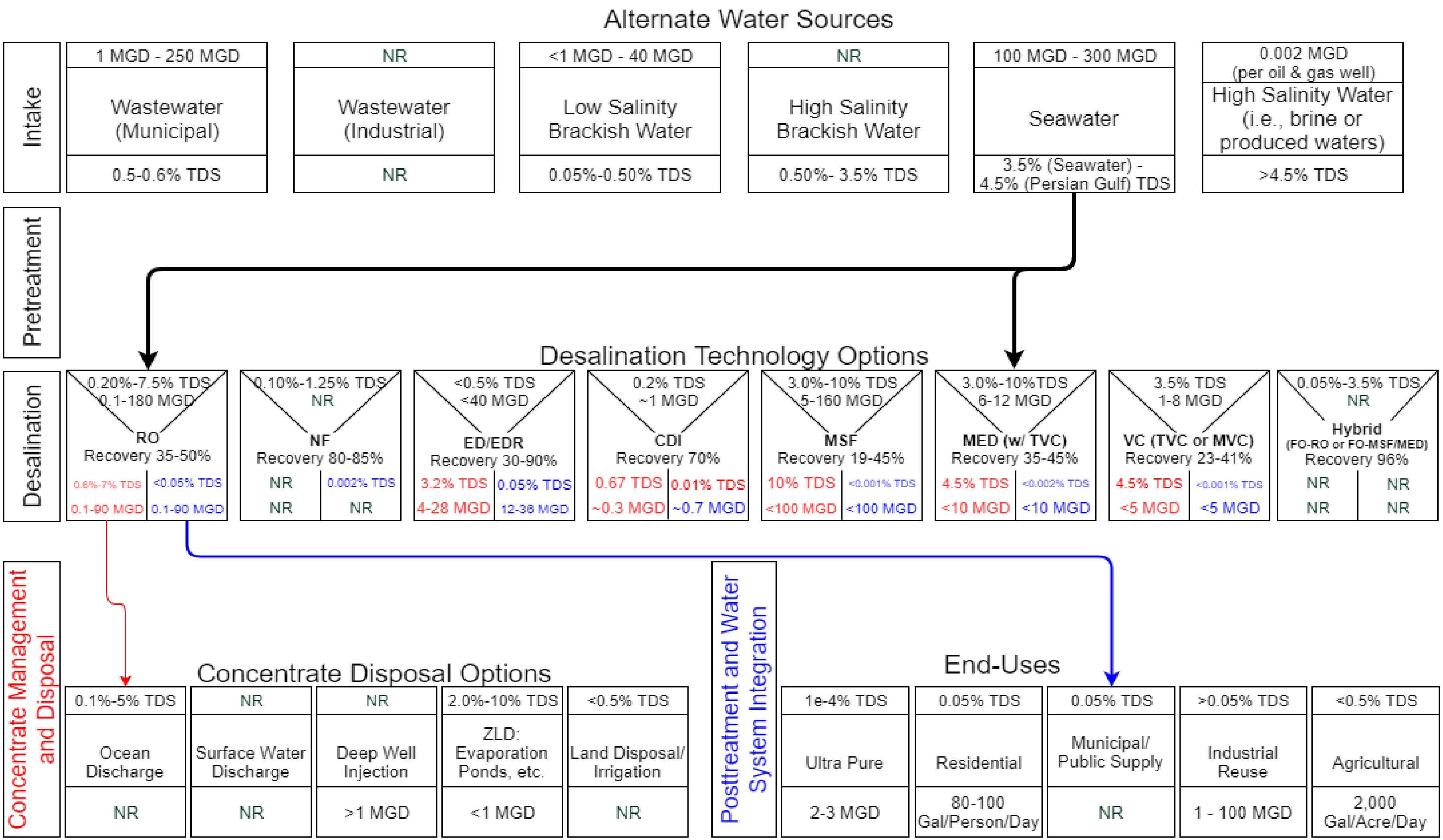
CT, SOA, PM, and TM determined for each unit operation

Many applications for water treatment through desalination



Seawater for Municipal Potable Water Pathways

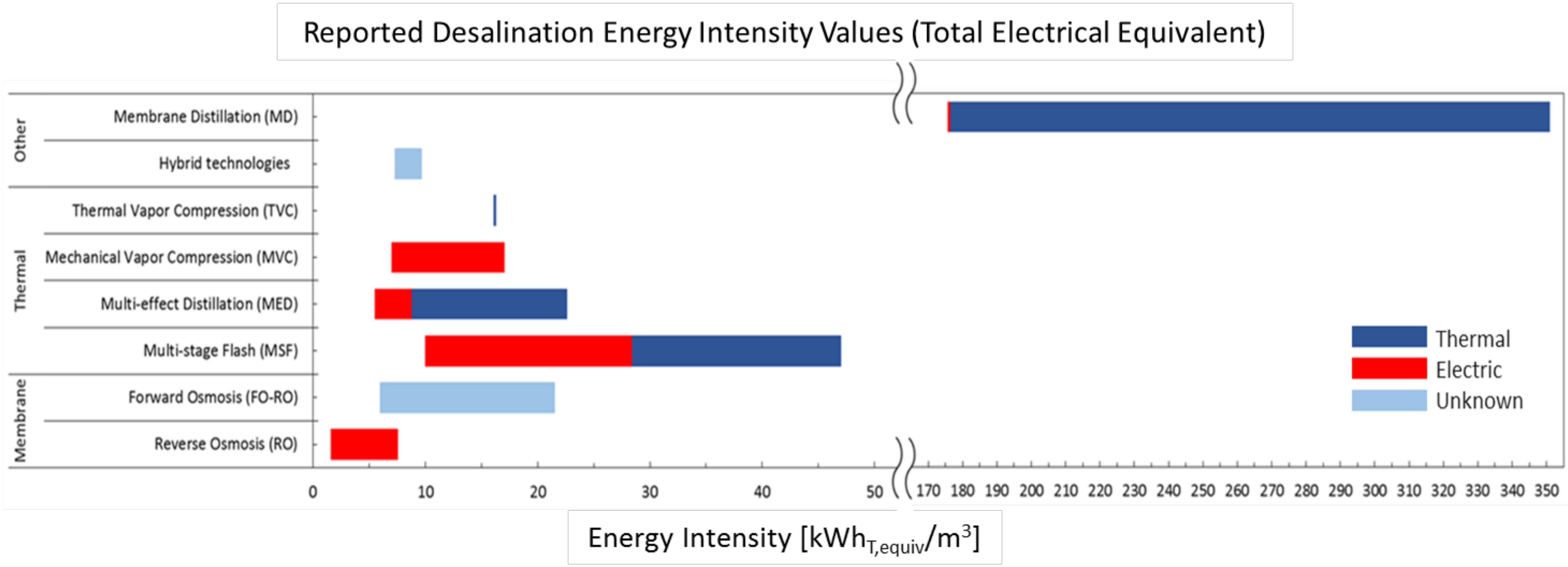
Analysis for seawater looks at two pathways for desalinating seawater into municipal potable water



Desalination Technologies Reviewed For Seawater Application

Intake	Pre-treatment	Desalination	Post-treatment	Concentrate
• Open-ocean intake - Screened • Subsurface intake - Beach wells - Offshore radial collector wells	• Membrane filtration - Microfiltration - Ultrafiltration • Media filtration • Sand filtration • Cartridge filtration • Disc filtration • Flocculation • Sedimentation • Chlorination • Dissolved air flotation	• Thermal vapor compression • Mechanical vapor compression • Multi-effect distillation • Multi-stage flash distillation • Reverse osmosis (RO) • Forward osmosis in combination with RO or a thermal technology	• Remineralization • Disinfection • Boron removal	• Surface water discharge • Zero liquid discharge - Brine concentration - Crystallization

Preliminary Energy Data (Seawater)



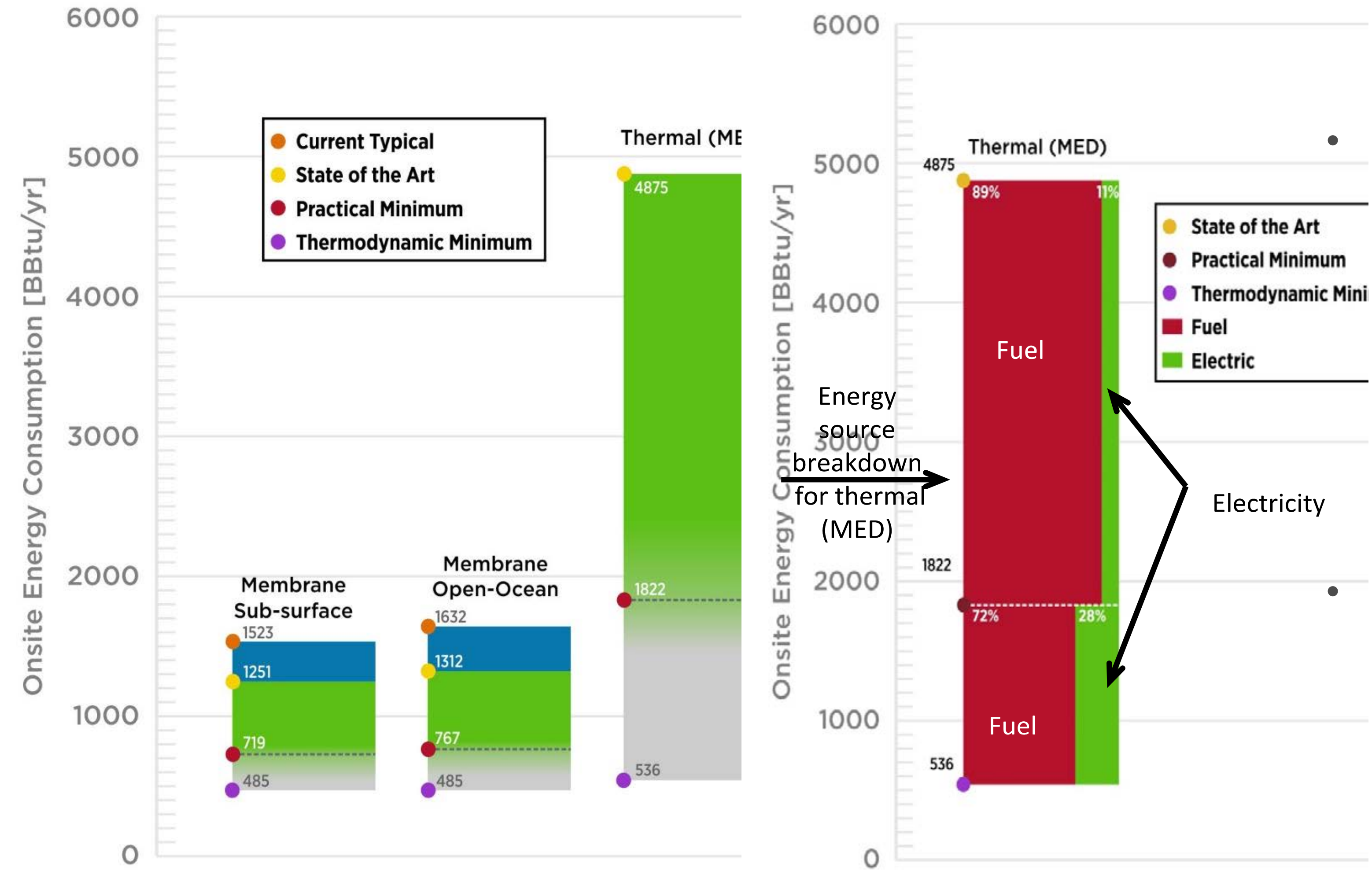
Reported energy data needed further refinement before being used:

- Values need to be reported with operational characteristics, *e.g. intake and product water flow rate, recovery and plant size, salinity, and temps (for thermal processes), desalination unit operation, use of energy recovery or waste heat.*
- Addition of electrical and thermal must account for generation losses associated with converting thermal energy to work.

Opportunities to reduce energy consumption for each unit operation

Unit Operation	Membrane Systems	Thermal Systems
Intake	Opportunities largely driven by improving pump and motor operating efficiency; site specific opportunities related to reducing total dynamic head may exist	
Pretreatment	Significantly impacted by intake design with subsurface lower than open ocean	On par with subsurface intake membrane systems
Desalination	Newer plants implementing SOA for membrane, and semi-batch RO identified as PM	MED-TVC identified as SOA, with designs that can reduce steam pressure requirements identified as PM
Post-treatment	Not a significant factor	Not a significant factor, though higher than membrane system
Concentrate Management	Opportunities largely driven by improving pump and motor operating efficiency	

Desalination looked at membrane and thermal systems

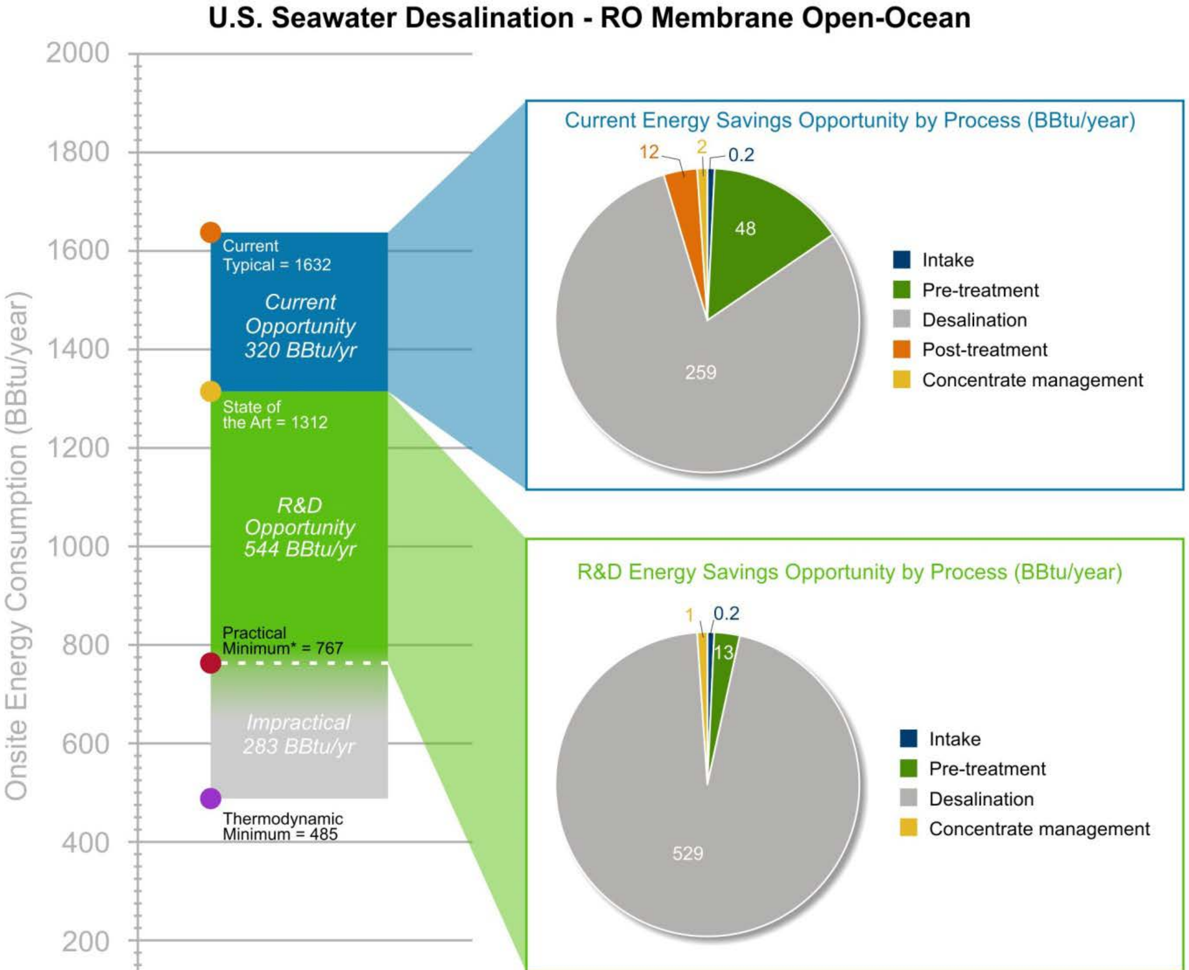


Membrane Sub-surface & Open-Ocean both implement RO desalination with ...
post-treatment and concentrate management, but utilize different intake and pre-t...
Sub-surface system involves sub-surface intake and Open-Ocean system uses open-...
Membrane Sub-surface & Open-Ocean CT, SOA, TM operating conditions: RO-based ...
50% recovery of 500 ppm (0 ppm for TM) product water from 35,000 ppm feedwater.

Thermal: MED-based system at 35% recovery of <25 ppm (0 ppm for TM) product water from 45,000 ppm feedwater

- Fuel sources in thermal desalination accounted for nearly all of the total energy savings for the R&D opportunity
- Opportunity for Waste Heat or Renewable Thermal Energy to Offset Direct Fuel Use in Thermal MED

Energy Savings Opportunity for RO system w/Open Ocean Intake



CT, SOA, TM operating conditions: RO-based system at 50% recovery of 500 ppm (0 ppm for TM) product water from 35,000 ppm feedwater. PM operating conditions: semi-batch RO-based system at 42% recovery of 379 ppm product water from 36,357 ppm feedwater.

- **91% of the energy saving opportunity is in the desalination operation**
- **Pretreatment offers the next largest opportunity (7%)**
- **Much of U.S. production already operating at SOA conditions**

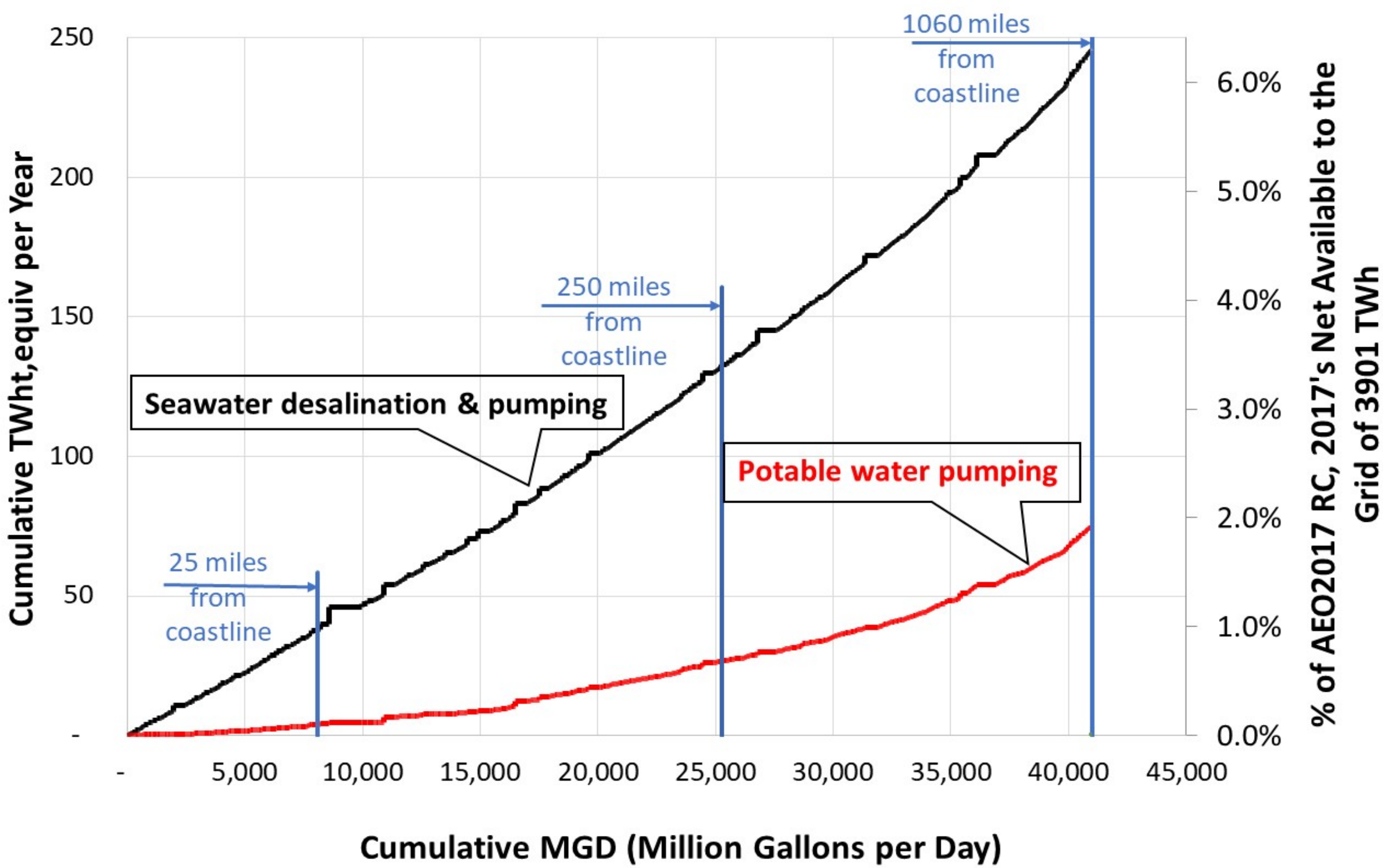
Scenarios: Potential Impact Under Greater Adoption

- Saline water (sea and brackish water) is a very small source of municipal water in the U.S. on the order of 0.1% → Hence, the impact on U.S. energy consumption is small at current uptake levels

- Potential impact of greater uptake:
  1) Scenario 1: supply all continental U.S. county's public water demand with desalinated water from U.S. coastal areas, and
  2) Scenario 2: supply all water stressed regions of the continental US with desalinated water from U.S. coastal areas

- Evaluated using open ocean intake RO system operating at SOA conditions with water demand equivalent to 2010 public water demand (from USGS)

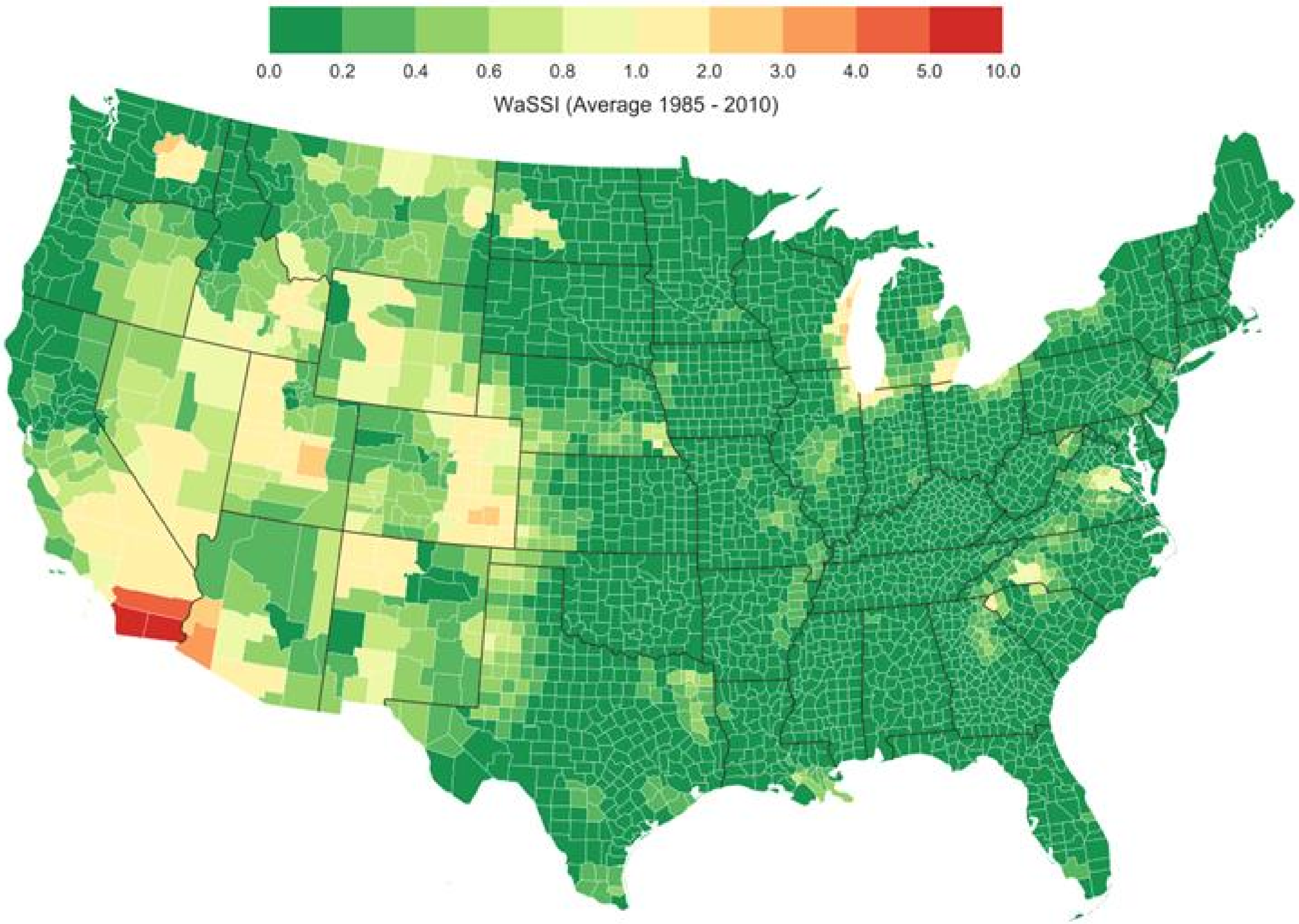
Scenario 1: Supplying All Municipal Water



Though impractical, sourcing all U.S. municipal water from seawater would represent ~**6% of projected 2017 electricity production**.

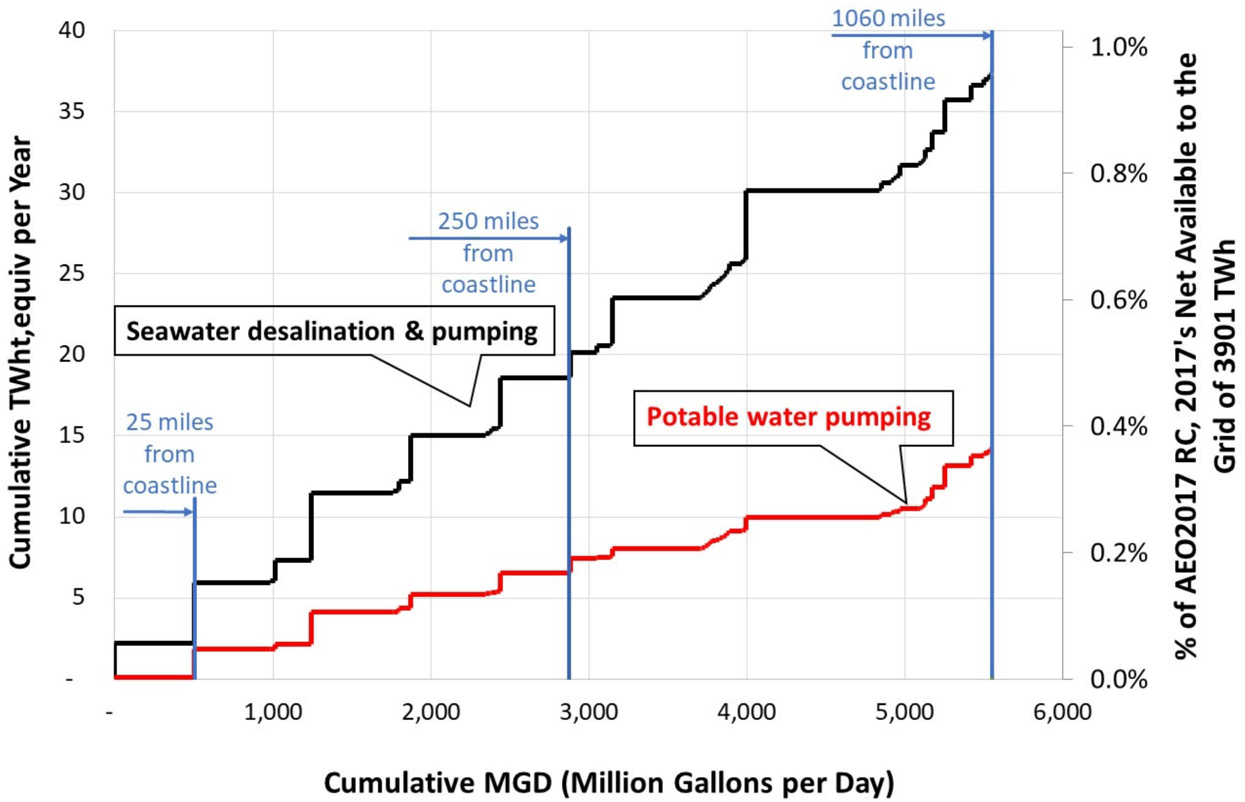
Provides an upper bound for seawater desalination impact on electric grid

Water Supply Stress Index



WaSSI estimated using *WaSSI Ecosystems Services Model* by NC State, USDA, and US Forest Service

Scenario 2: Supplying Water Stressed Counties



Supplying public water for counties with WaSSI > 1 and 250 miles from a coastline would require **0.5% of projected 2017 electricity production**

More likely that these counties would diversify water sources and some could meet a portion of their public water demand from seawater.

Distributed Water Systems: Desalination

<u>Small distributed systems:</u>

- Eg. Pure Aqua (American) or BWT (Denmark)
- 1000 – 660,000 gallons per day
- Local production
- Low maintenance/operation costs

<u>Large Central System:</u>

- Eg. Carlsbad CA
- 50m Gallons per day
- Large capital cost; high operations and maintenance costs
- Long pumping distances

Containerized Seawater RO Plant

ISO 9001 ISO CERTIFIED

MADE IN USA

GENERAL ARRANGEMENT DRAWING

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Santa Ana, CA 92704 USA
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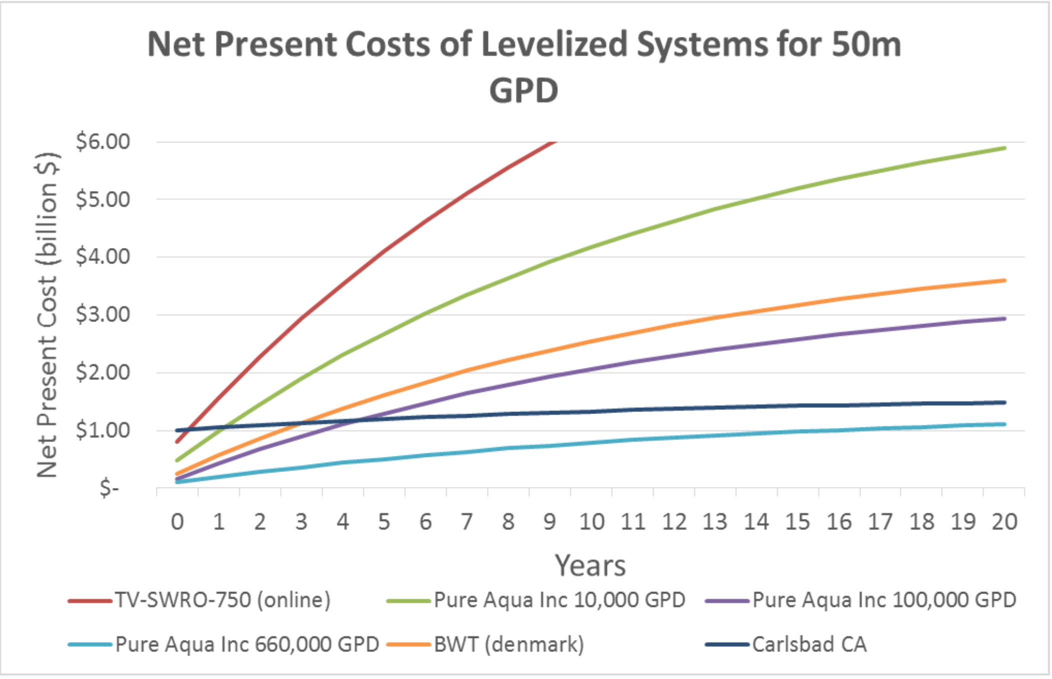
Fax: (714) 432-9898
www.pureaqua.com

SWI Series

Industrial SWRO



Manufacturing Water Use Analysis

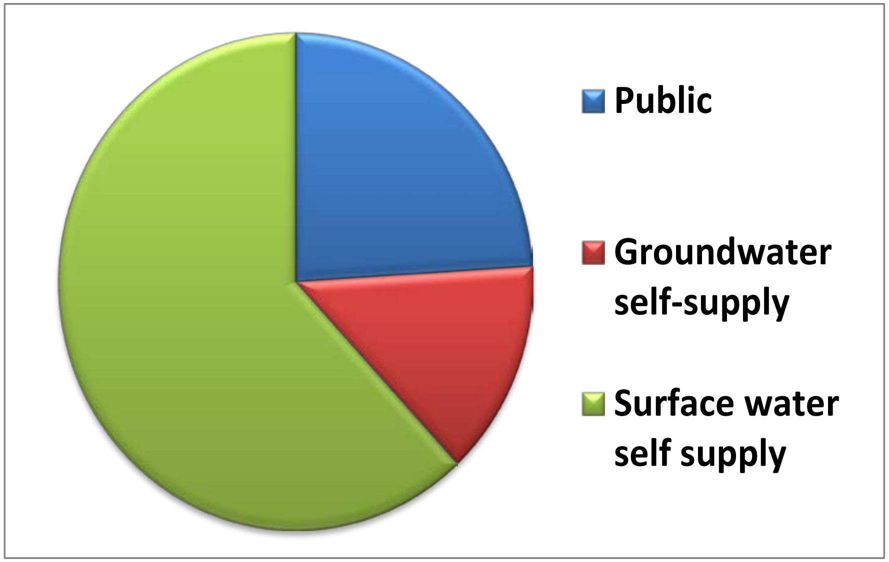
Industrial water use in 2010

75% (~16,000 MGD) is estimated to be self supplied (e.g. onsite surface or ground)

- Mostly freshwater; only 6% saline
- Down 12% from 2005
- Down 38% from 1985

25% (~5,000 MGD) is estimated to be supplied from public supply

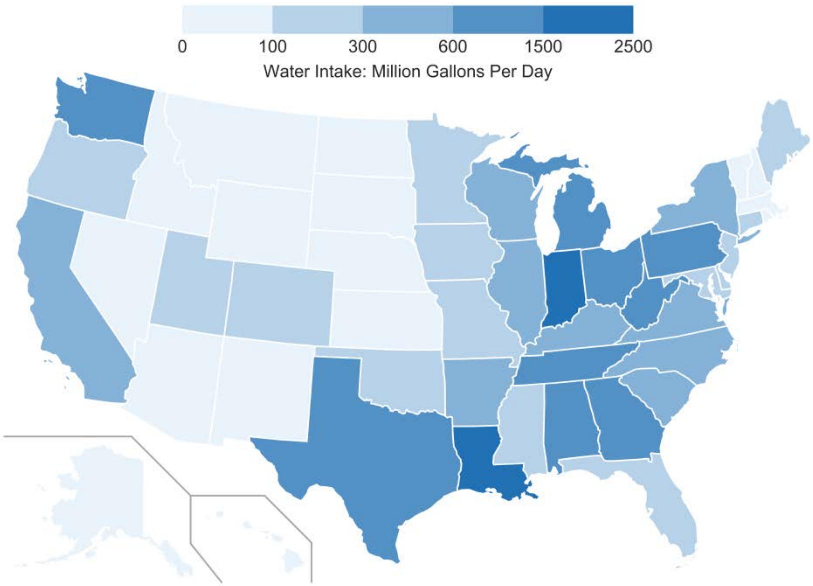
- USGS stopped estimating public supply by end use sector after 1995
- Assumed, based on 1995 estimates, that 12% of public supply is for industry



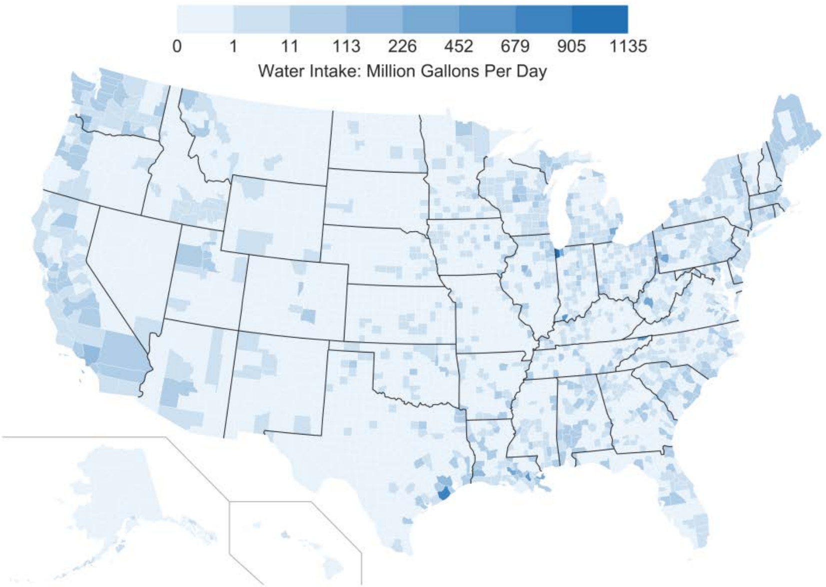
Estimates based on USGS data

Geographic Spread of U.S. Manufacturing Water Withdrawal (Estimated)

State



County



Estimates based on USGS data

Issues with U.S. Manufacturing Water Data Availability

- Water use conservation driven by risk mitigation within the manufacturing sector

- Little to no data on U.S. manufacturing water use and related characteristics
  - Limited to USGS 5-year estimates
  - Some data at individual state level or by sector

- Water use issues and risk are a local phenomena requiring data at the watershed level
  - Research based on broad national data may not target at-risk industries

Need for better data

How to handle gaps in the U.S. data …

Leverage existing data sets to:

Quantify manufacturing water withdrawals and consumption at the national, state, and county-levels broken down by sector using Canadian water and economic data, USGS data, and U.S. Economic Census data

↓

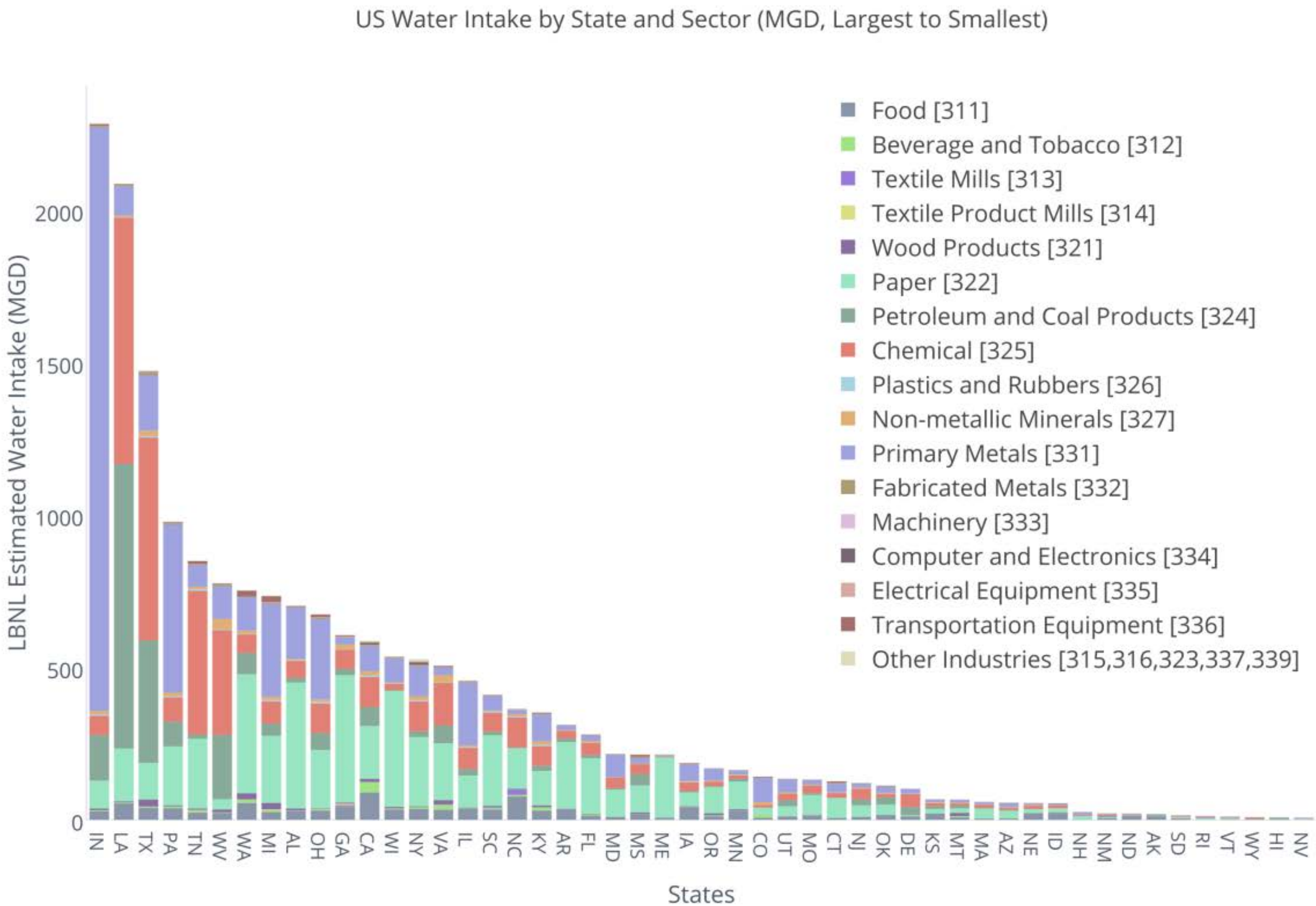
Identify sectors at-risk, defined as those sectors with large footprints in areas with long-term over-usage of locally available water supplies

↓

Use the results from to identify sectors for subsequent studies and other manufacturing water use-related research

For further details on methods and results for estimates presented on slides 36-38, see: Rao, P., Sholes, D., Morrow, W.R., and J. Cresko. 2017. “Estimating U.S. Manufacturing Water Use”. American Council for an Energy Efficient Economy Summer Study on Energy Efficiency in Industry. Denver, CO. August 16 – 18.

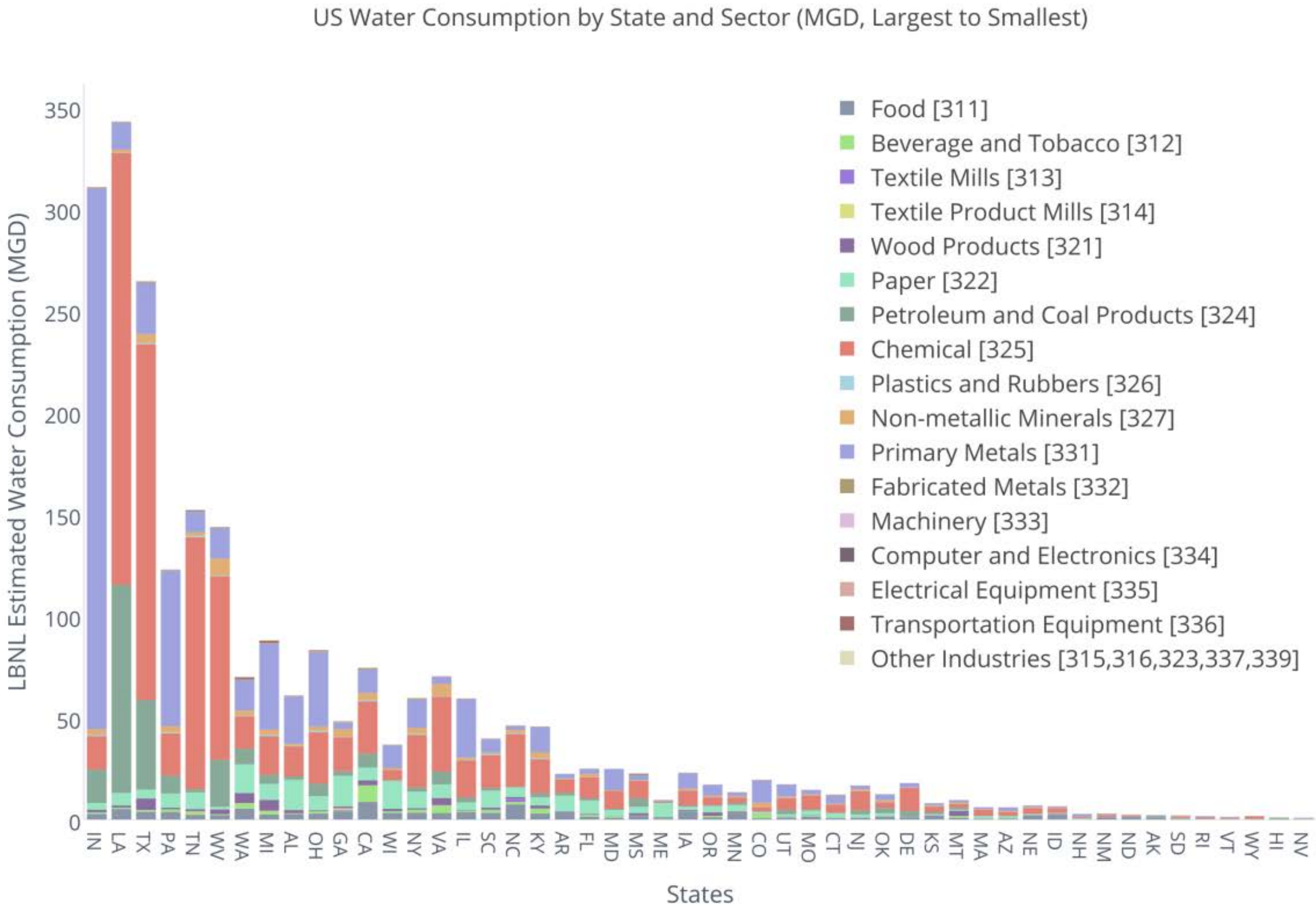
U.S. Manufacturing Water Withdrawals by Sector and State



Allows for better understanding of water use distribution:

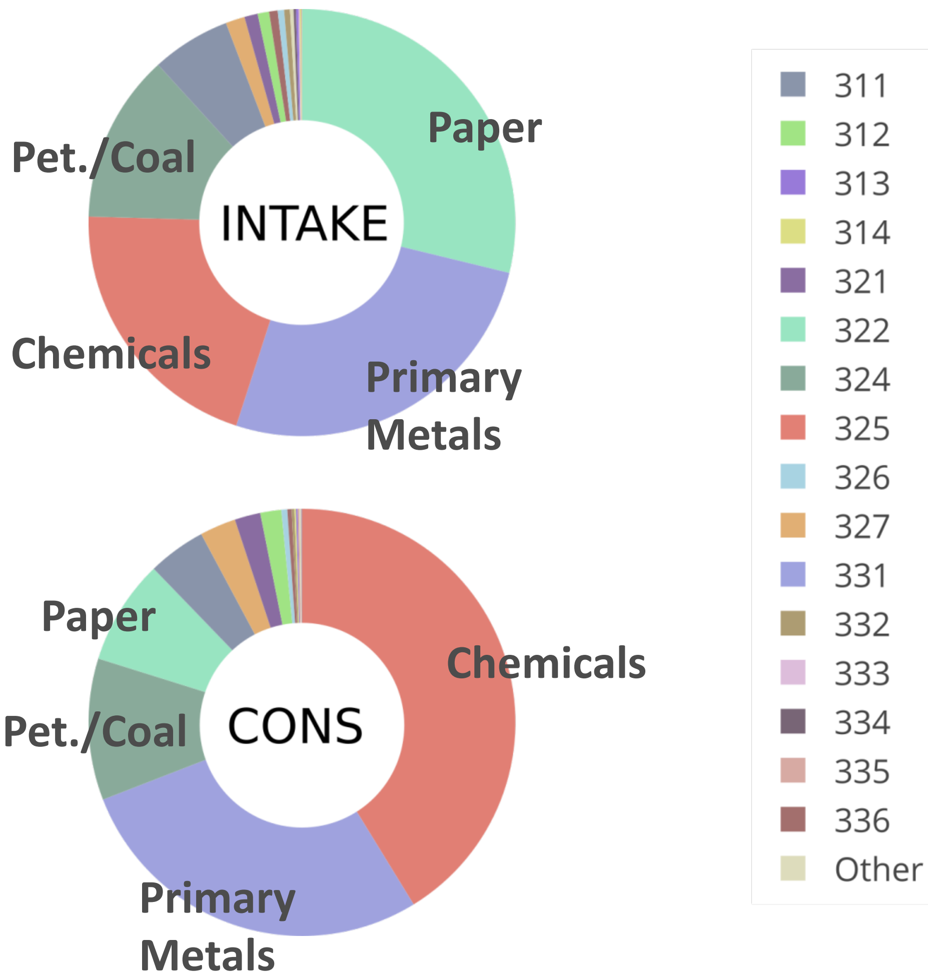
- IN and LA estimated to have the largest annual withdrawals
- Withdrawals in some states dominated by single industry (i.e., primary metals in IN, paper & pulp in ME)
- Other states have more diversity in their water withdrawals (e.g., MI, TX, NC)

U.S. Manufacturing Water Consumption by Sector and State



- Consumptive use will have greater impact on operational risk than withdrawals
- LA has highest amount of consumptive use
- Two of the top ten states in terms of consumption are drought prone (CA and TX)

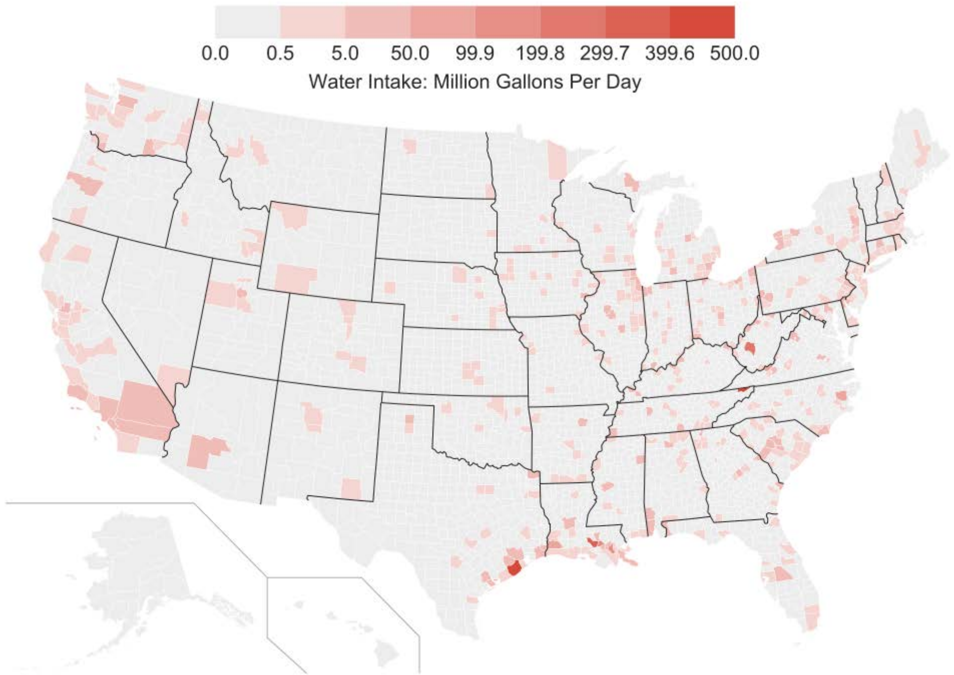
U.S. Manufacturing Water Withdrawals and Consumption



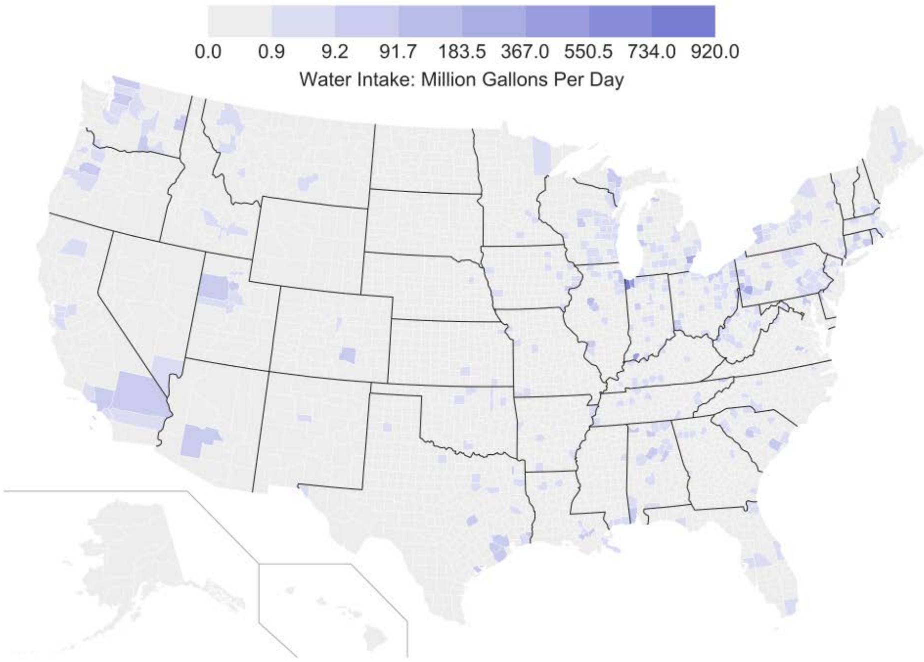
311	Food manufacturing
312	Beverage and tobacco product manufacturing
313	Textile mills
314	Textile product mills
321	Wood product manufacturing
322	Paper manufacturing
324	Petroleum and coal product manufacturing
325	Chemical manufacturing
326	Plastics and rubber products manufacturing
327	Non-metallic mineral product manufacturing
331	Primary metal manufacturing
332	Fabricated metal product manufacturing
333	Machinery manufacturing
334	Computer and electronic product manufacturing
335	Electrical equipment, appliance and component manufacturing
336	Transportation equipment manufacturing
Other	Other Industries

Water Withdrawals by Sector and County

325 - Chemicals



331 – Primary Metals



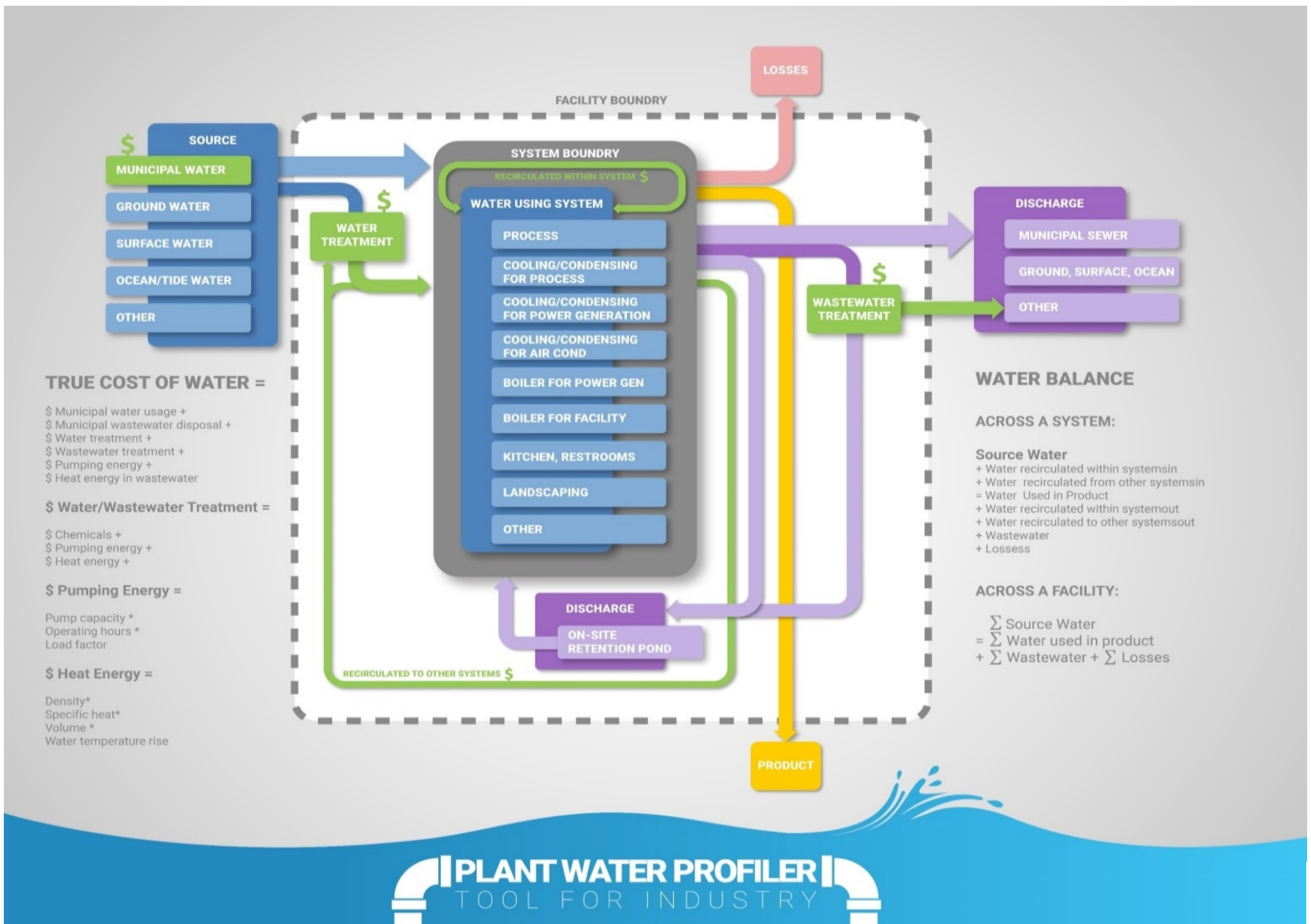
Evaluation of Sector Water Use "At-Risk"

Sectors in red are those that have the highest share of their water use in locations with WaSSI > 1 (i.e., locations where total water use exceeds local supplies)

Manufacturing Sector	Estimated % Water Intakewithin each WaSSI Bin				
	[0.0,0.2)	[0.2,0.4)	[0.4,0.8)	[0.8,1.0)	[1.0,inf)
Food	72	11	7	3	7
Beverage and Tobacco Product	71	9	11	2	6
Textile Mills	80	9	4	6	2
Textile Product Mills	88	5	2	2	3
Wood Product	84	6	3	6	2
Paper	79	8	5	1	6
Petroleum and Coal Product	52	29	9	1	**9**
Chemical	66	25	5	1	3
Plastics and Rubber Products	71	13	5	3	**9**
Non-metallic Mineral Product	68	11	6	7	**8**
Primary Metal	52	8	5	1	**35**
Fabricated Metal Product	68	14	6	3	**10**
Machinery	70	15	6	2	**8**
Computer and Electronic Product	68	13	8	5	7
Electrical Equipment	76	12	5	3	5
Transportation Equipment	72	9	6	2	**10**
Other Industries [315,316,323,337,339]	74	10	3	4.	8

Plant Water Profiler (PWP) Tool for Industry

- Identify how water is being procured and consumed at facilities,
- Quantify true cost of water used in different systems,
- Quantify potential water savings and cost savings,
- Feed information back to inform R&D



Thank you.

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ANL – Diane Graziano, Matt Riddle, Sarang Supekar

LBNL – Arman Shehabi, William Morrow, Sarah Smith, Prakash Rao

NREL – Alberta Carpenter, Maggie Mann, Rebecca Hanes, Samantha Reese, Kelsey Horowitz, Timothy Remo

ORNL – Sujit Das, Sachin Nimbalkar, Pablo Cassorla, Kristina Johnson

Energetics – Sabine Brueske, Heather Liddell, Caroline Dollinger, Hani Hawa

Back-up Slides

Energy Water Bandwidth Study of Seawater Desalination: 2 Volumes

Volume	Contents
Volume 1: Survey of Available Information in Support of the Energy-Water Bandwidth Study of Desalination Systems	• Boundary Analysis Framework • Energy Intensities for Five Unit Operations of Desalination • Framework for Desalination Uptake Scenarios

Volume 2: Bandwidth Study of Energy Use and Potential Energy Savings Opportunities in Seawater Desalination Systems	• Energy Consumption and CO_2 Emissions for Several Sea-to-Potable Water Uptake Scenarios Evaluated at:
	  • *Current Typical (CT)*
	  • *State-of-the-Art (SOA)*
	  • *Practical Minimum (PM) Intensity*
	  • *Thermodynamic Minimum (TM)*
	• Energy Consumption and CO_2 Emissions for Brackish Water to Potable Water at CT Energy and CO_2 Intensity
	• Current and R&D Energy Savings Opportunity

2016 Uptake for Seawater Desalination in the U.S.

Energy Consumption (Billion Btu/yr) =
Energy Intensity ($kWh_{total\ electrical\ equivalent}/m^3$) x **Current Uptake** ($m^3$/yr) x **C** (Billion Btu/kWh)

- In the U.S., annual municipal potable water production capacity from seawater desalination was 128,000,000 m^3 for 2016
- Since largely dominated by Carlsbad facility and other RO systems, broad assumption that this is at 50% recovery
  - *255,000,000 m^3 for intake annually*
- Assuming 16.5:1 concentrate dilution ratio for discharge, based on calculation
  - *2,231,000,000 m^3 pumped annually for discharge*
- For reference: energy consumption to source all currently desalinated seawater in the U.S. from fresh and ground water sources (excludes distribution): *127 Billion Btu*
  - *Assumes national average energy intensity for providing municipal water from freshwater of 0.29 kWh/m^3*
  - *Higher in some regions: Southern California: 1,136 Billion Btu*

What is 'Pipe Parity' for Water?

Potable Water Target => 200 – 600 mg/L (500 mg/L is realistic limit)

Agriculture Water Target => 200 – 2,000 mg/L (varies on crop)

Industrial Water Target => 50 – 20,000 (targets need further defining)

Proposed Energy Intensity Targets for 500 mg/L TDS:

- Fresh Water => less than 0.5 kWh/m3
- Brackish Water => less than 1.5 kWh/m3
- Seawater => less than 2.5 kWh/m3

Range of Inputs for "desalination":

Source	Quality (TDS)	Application	Quality (TDS)
Fresh Water	≤1000 mg/L	Drinking Water	≤500 mg/L
		Agriculture	≤750 -2000 mg/L
		Industrial	≤500 mg/L
Brackish Water	~10,000 – 30,000 mg/L	Drinking Water	≤500 mg/L
		Agriculture	≤750-2000 mg/L
		Industrial	Application specific
Seawater	35,000 – 47,000 mg/L	Drinking Water	≤500 mg/L
		Agriculture	N/A
		Industrial	Cooling (primarily)
Produced Water (from oil/gas)	Up to ~100,000-200,000 m/L	Drinking Water	≤500 mg/L
		Agriculture	≤750-2000 mg/L
		Industrial	Application specific

Cost Target?:

Approximate $\$0.50/m^3$