U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

An Overview of AMO Strategic Analysis

Joe Cresko - Advanced Manufacturing Office, DOE

AMO Program Peer Review
July 17, 2018
Washington, DC

ANL – Diane Graziano, Matt Riddle, John Murphy, Sarang Supekar, Nwike Iloeje

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

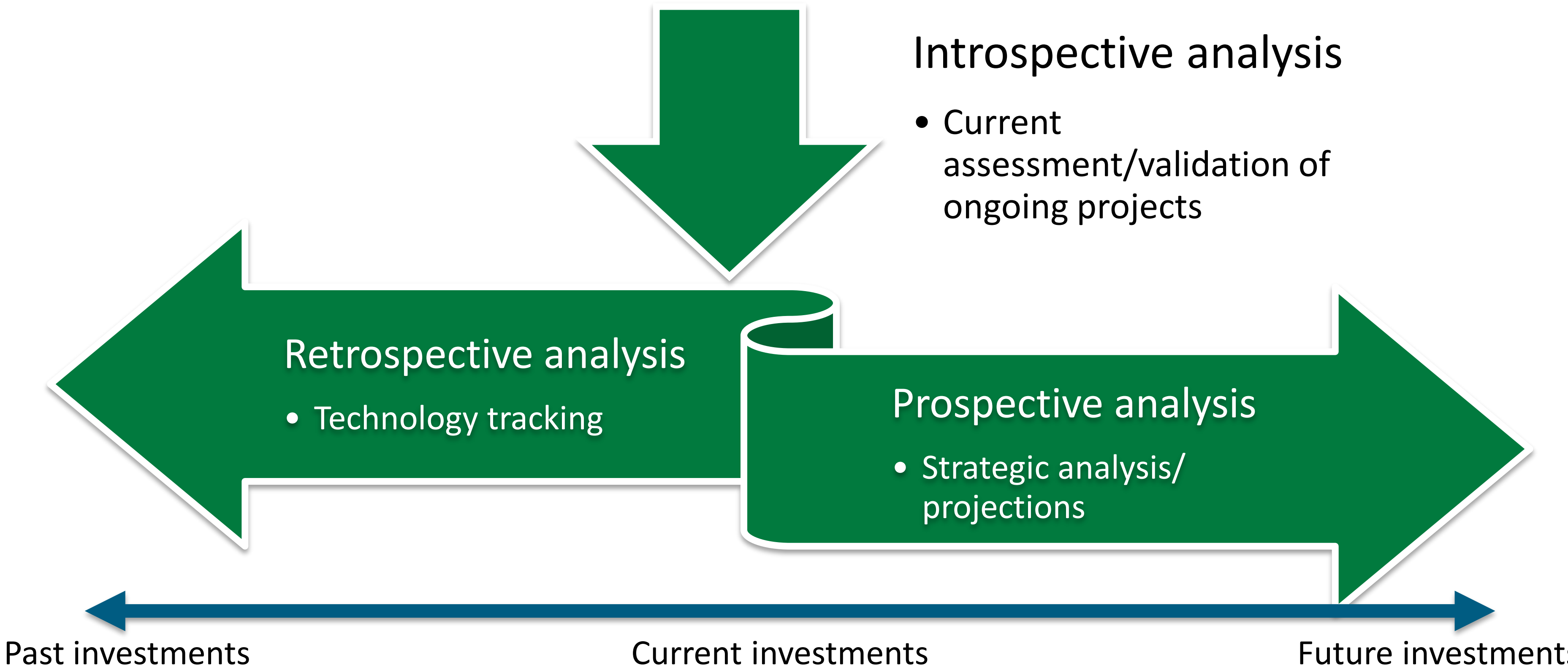
NREL – Alberta Carpenter, Rebecca Hanes, Samantha Reese, Scott Nicholson, James McCall, Matthew Ringer

ORNL – Sujit Das, Sachin Nimbalkar, Kristina Armstrong

Energetics – Sabine Brueske, Caroline Dollinger

AMO Analysis Approaches

- *Analysis Objective:* Provide independent and credible information to inform AMO decision making
- Cycle of prospective, introspective, and retrospective analysis helps AMO gain a sense of investment impacts across time

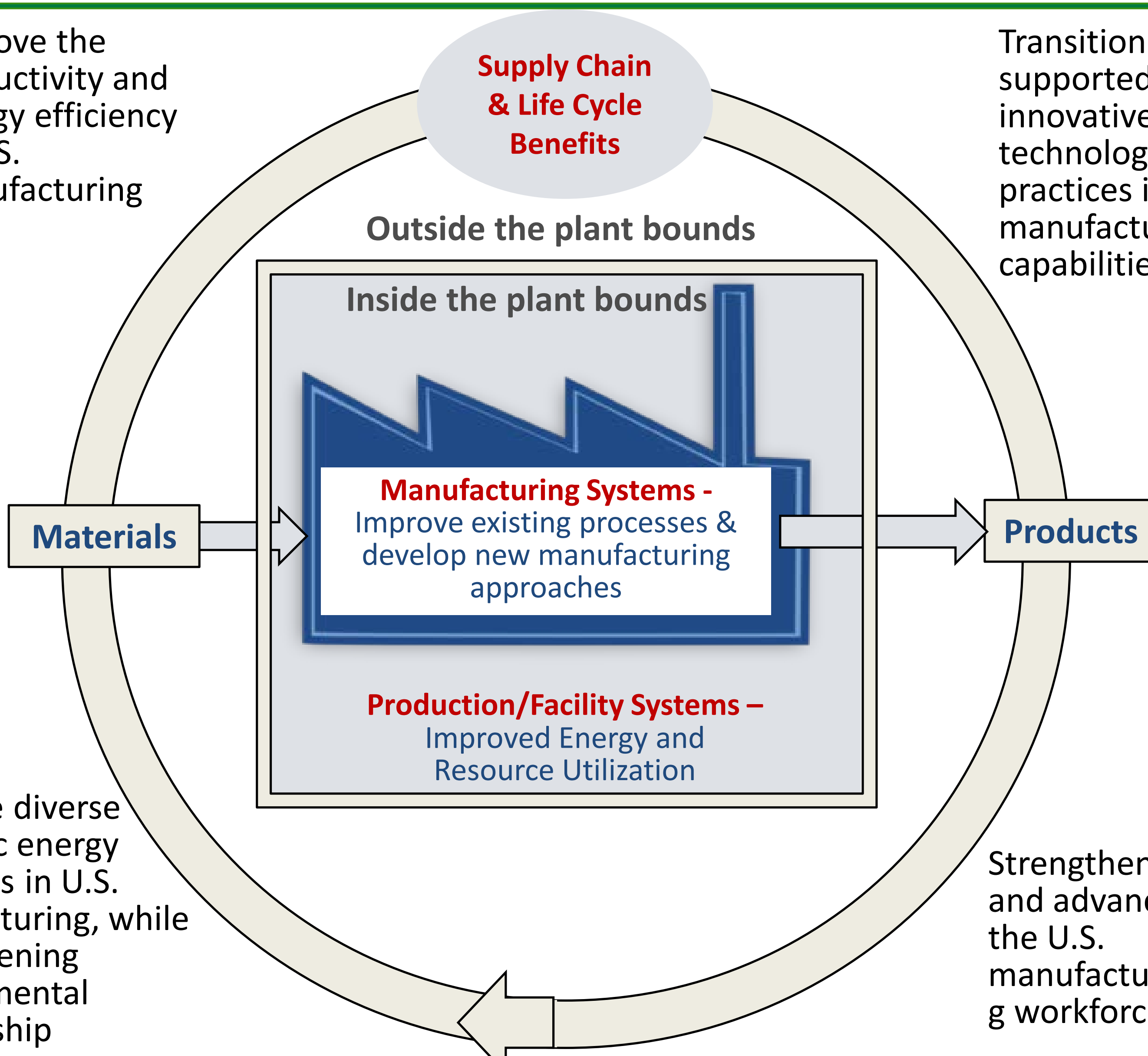


A framework to identify and quantify the opportunity space → AMO Strategic Goals

Improve the productivity and energy efficiency of U.S. manufacturing

Transition DOE supported innovative technologies and practices into U.S. manufacturing capabilities

Advance materials, critical materials, and rare earth elements to avoid supply chain disruptions for U.S. manufacturing

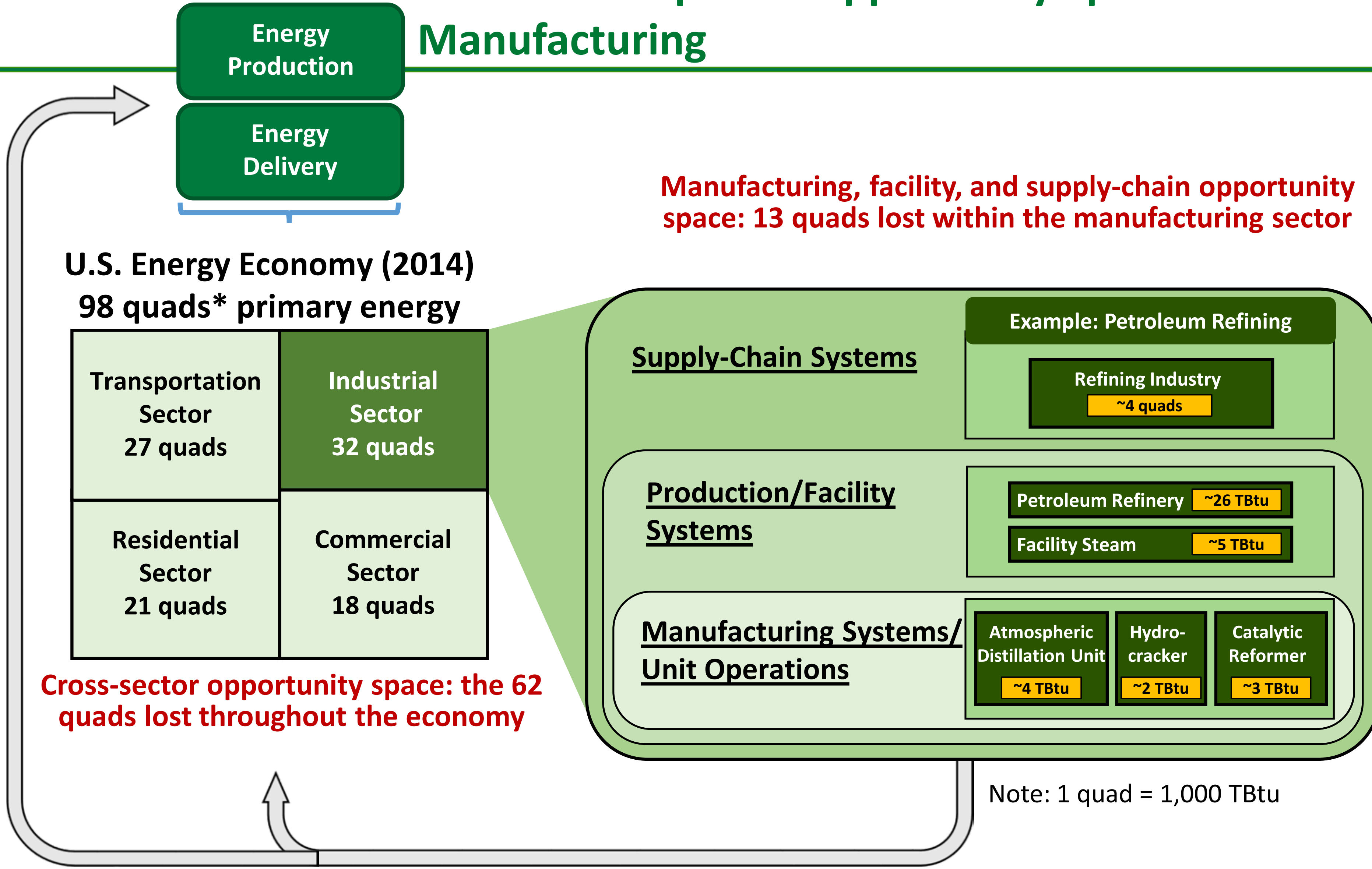


Reduce lifecycle energy and resource impacts of manufactured goods

Leverage diverse domestic energy resources in U.S. manufacturing, while strengthening environmental stewardship

Strengthen and advance the U.S. manufacturin g workforce

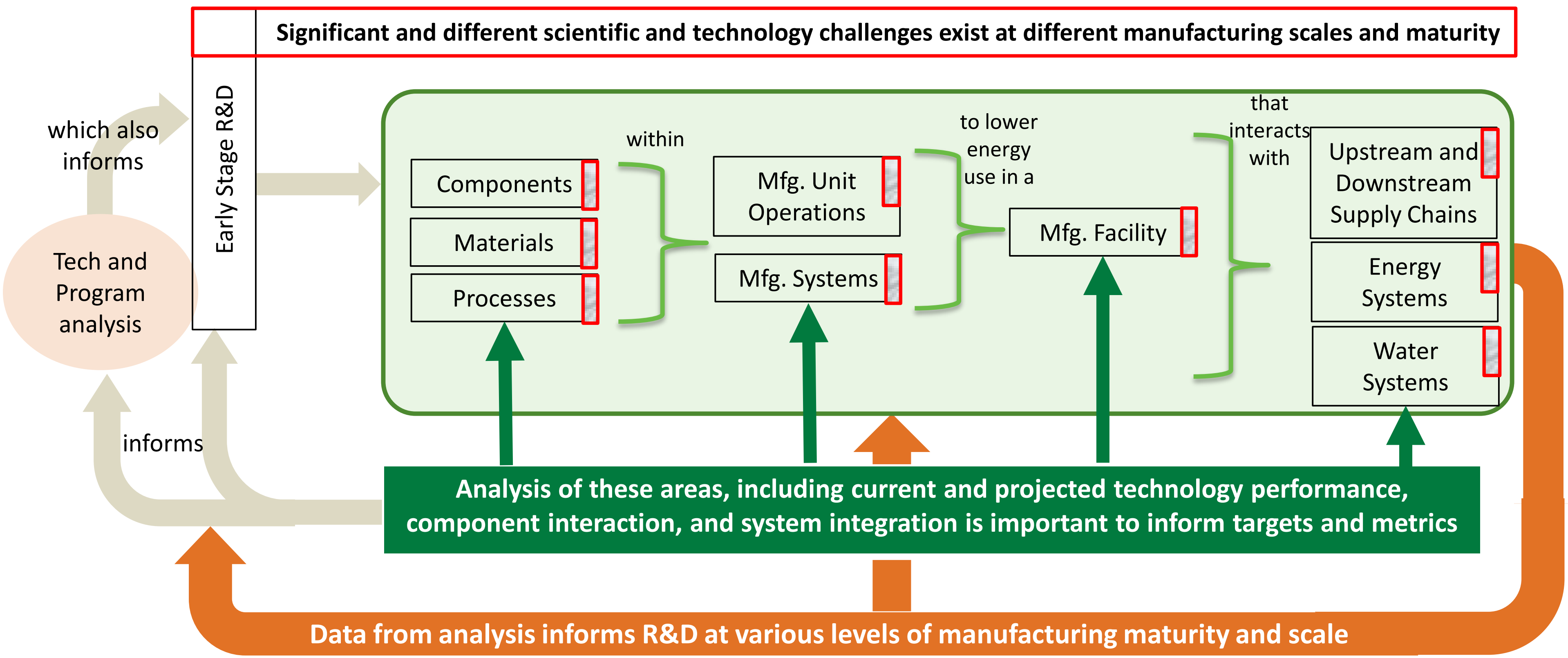
Overall and Specific Opportunity Spaces for Manufacturing



- *Technologies for clean & efficient manufacturing*
- *Technologies to improve energy use in transportation*
- *Technologies to improve energy use in buildings*
- *Technologies to improve energy production and delivery*

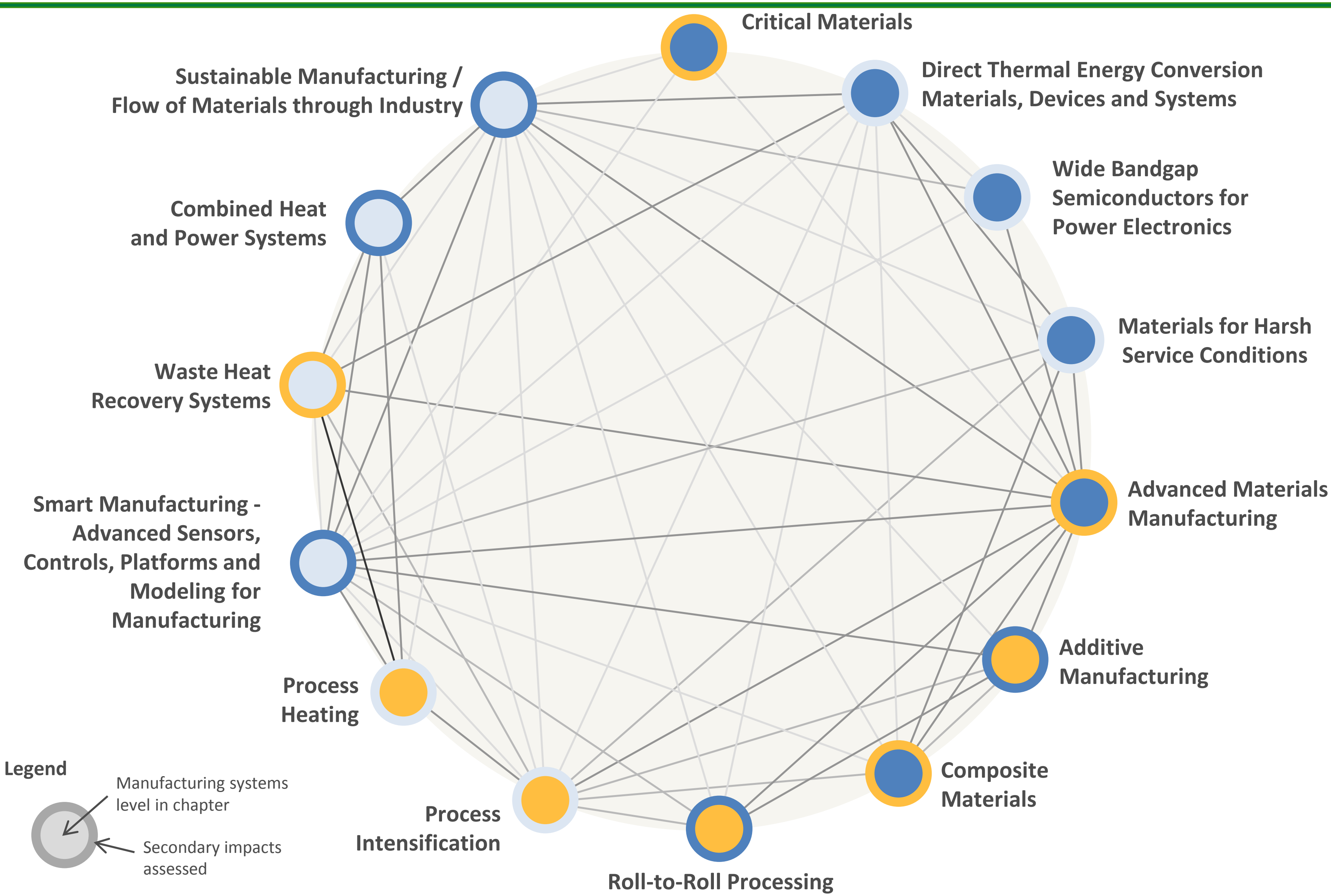
*EIA AEO and MER data

Analysis informs programmatic and technological progress, as well as early stage R&D



Core manufacturing technologies identified as impactful

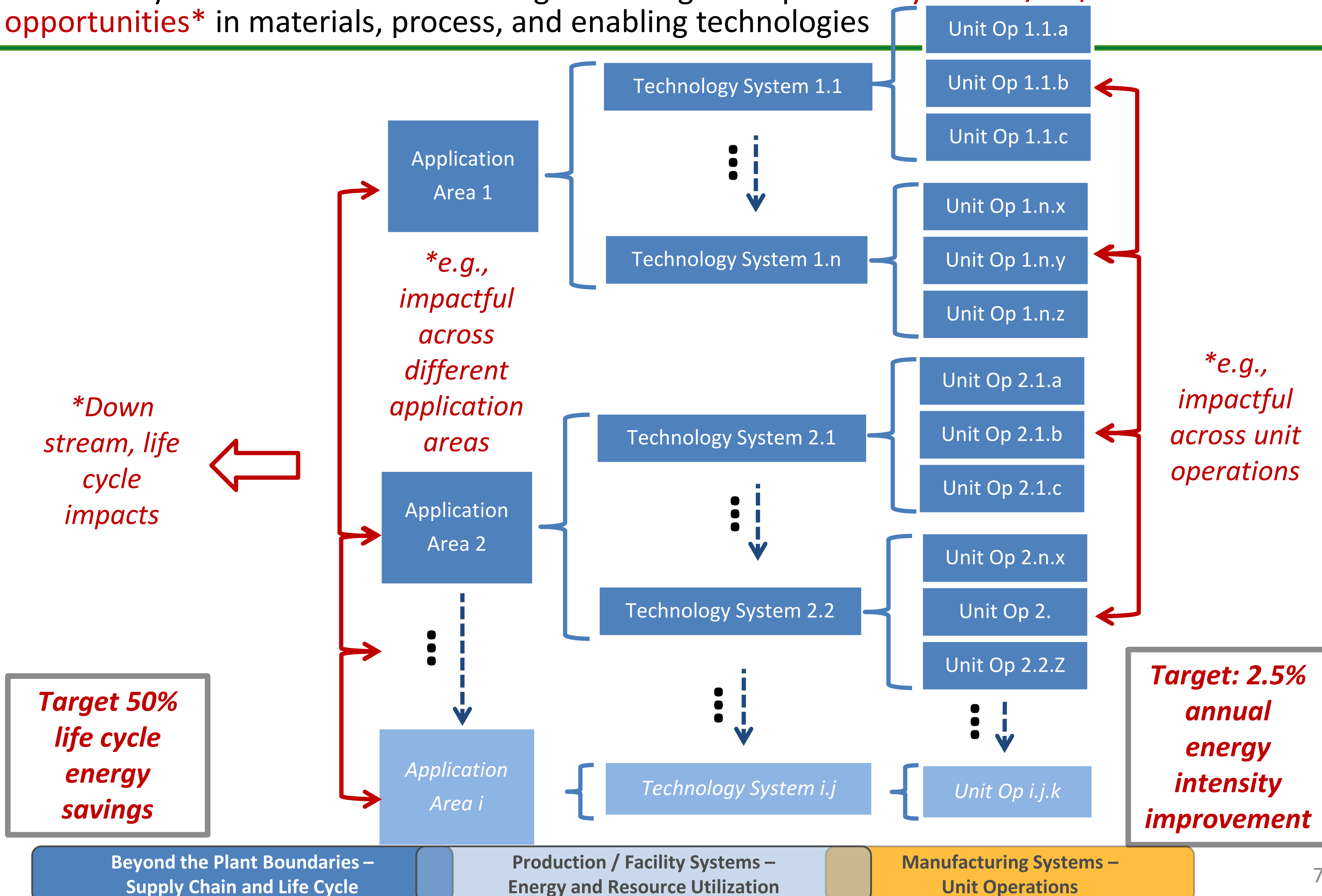
http://www.energy.gov/quadrennial-technology-review-2015



Manufacturing Systems – Unit Operations	Production / Facility Systems – Energy and Resource Utilization	Beyond the Plant Boundaries – Supply Chain and Life Cycle

Strategic Planning – Informing topic development

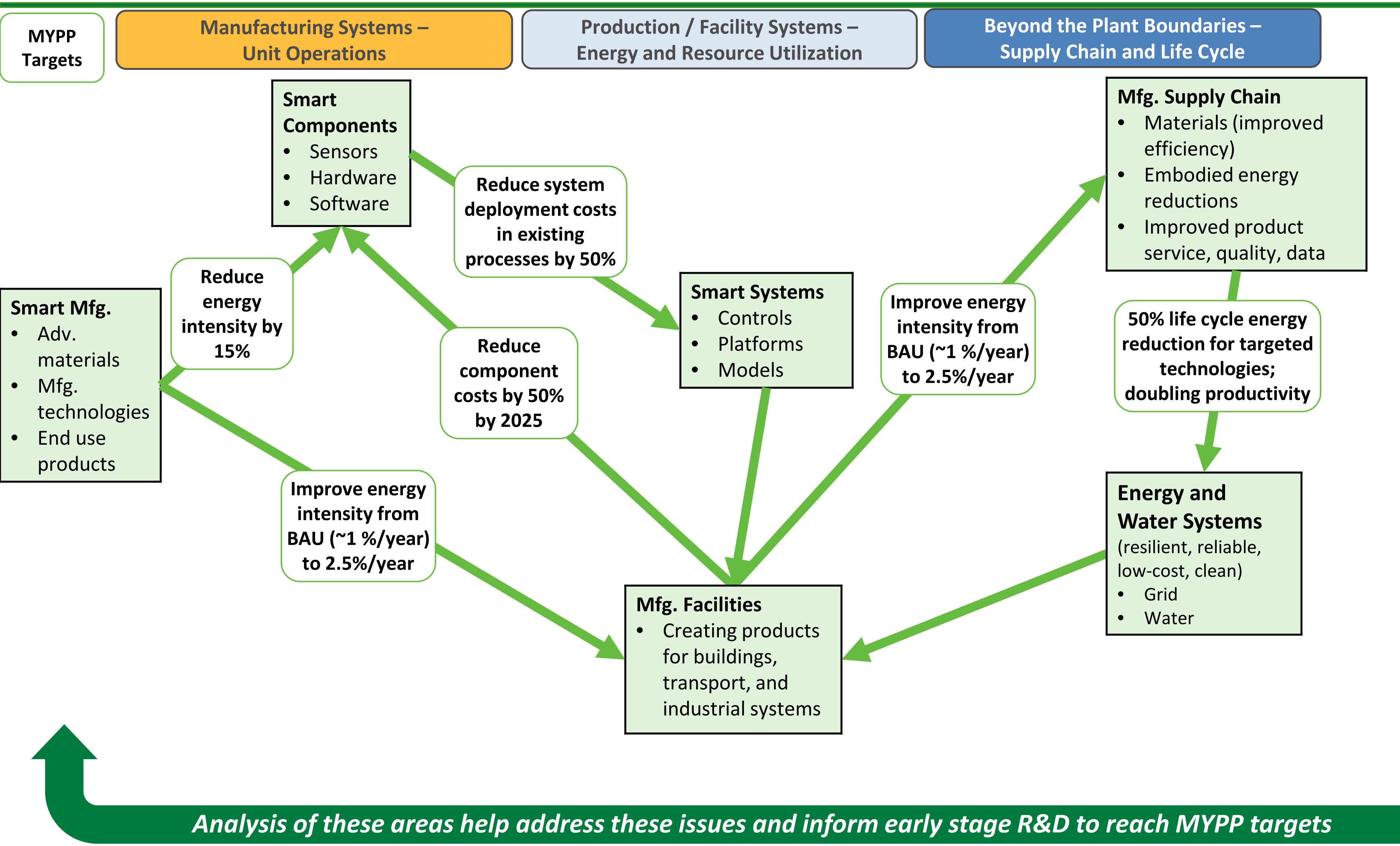
A taxonomy of advanced manufacturing technologies helps identify broadly impactful opportunities* in materials, process, and enabling technologies

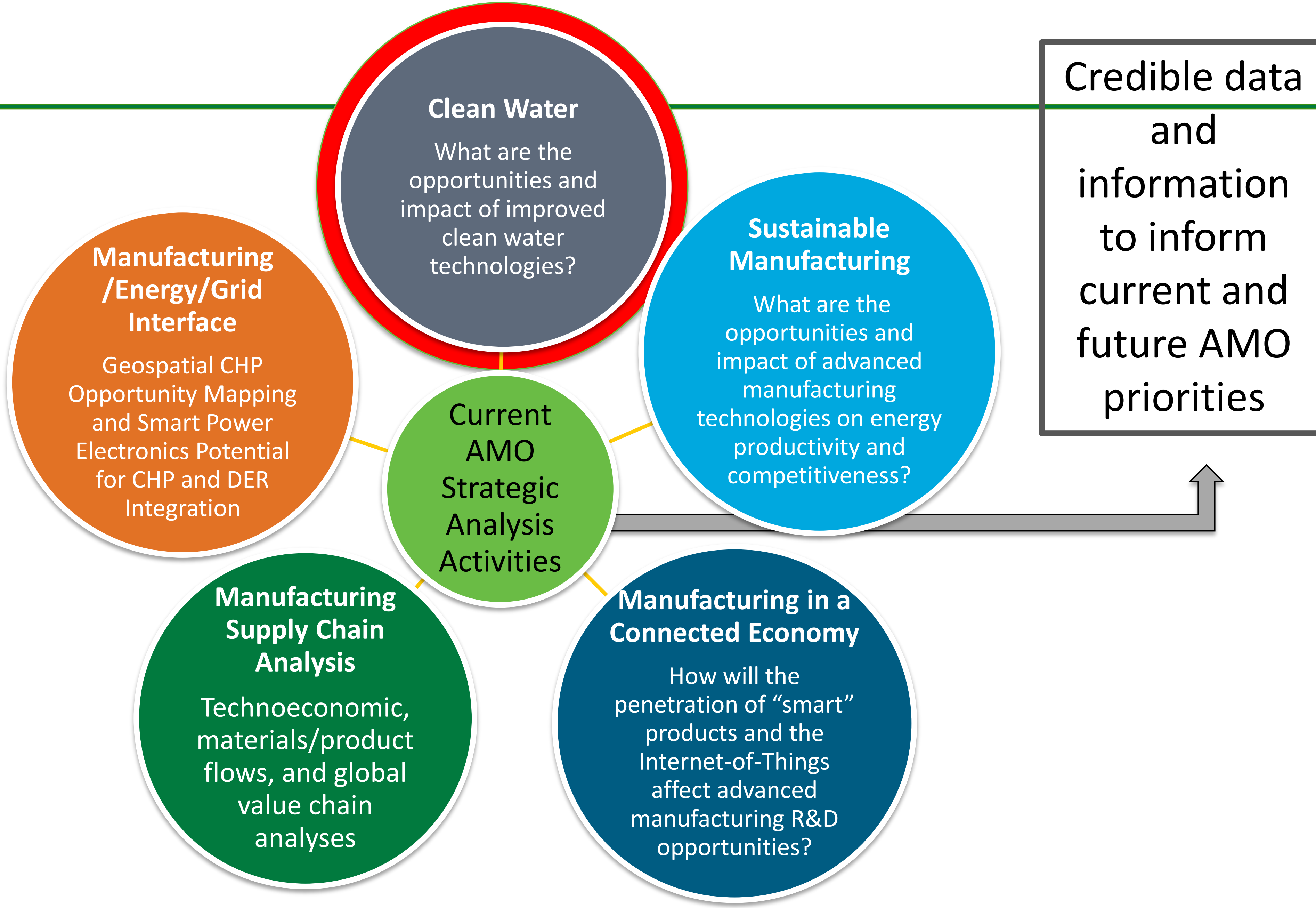


Technology Applications

Automotive 	• Lightweighting, leading to improved efficiency without sacrificing safety	• 10% vehicle mass reduction estimated to: • Increase fuel efficiency of internal combustion engine vehicles by 6-8% • Increase battery-electric vehicle range by 10%
Pressure vessels 	• Storage tanks for alternative (natural gas and fuel cell) vehicles	• Increase fuel economy through lightweighting as well as achieve longer driving distances between refueling
Wind 	• Enable longer, stronger, and lighter turbine blades & development of mid/lower-wind speed resources	• 2x turbine blade length can increase electricity generation by 4x

Analysis Impacts Example: Smart Manufacturing- Advanced Sensors, Controls, Platforms and Modeling for Manufacturing (ASCPMM)



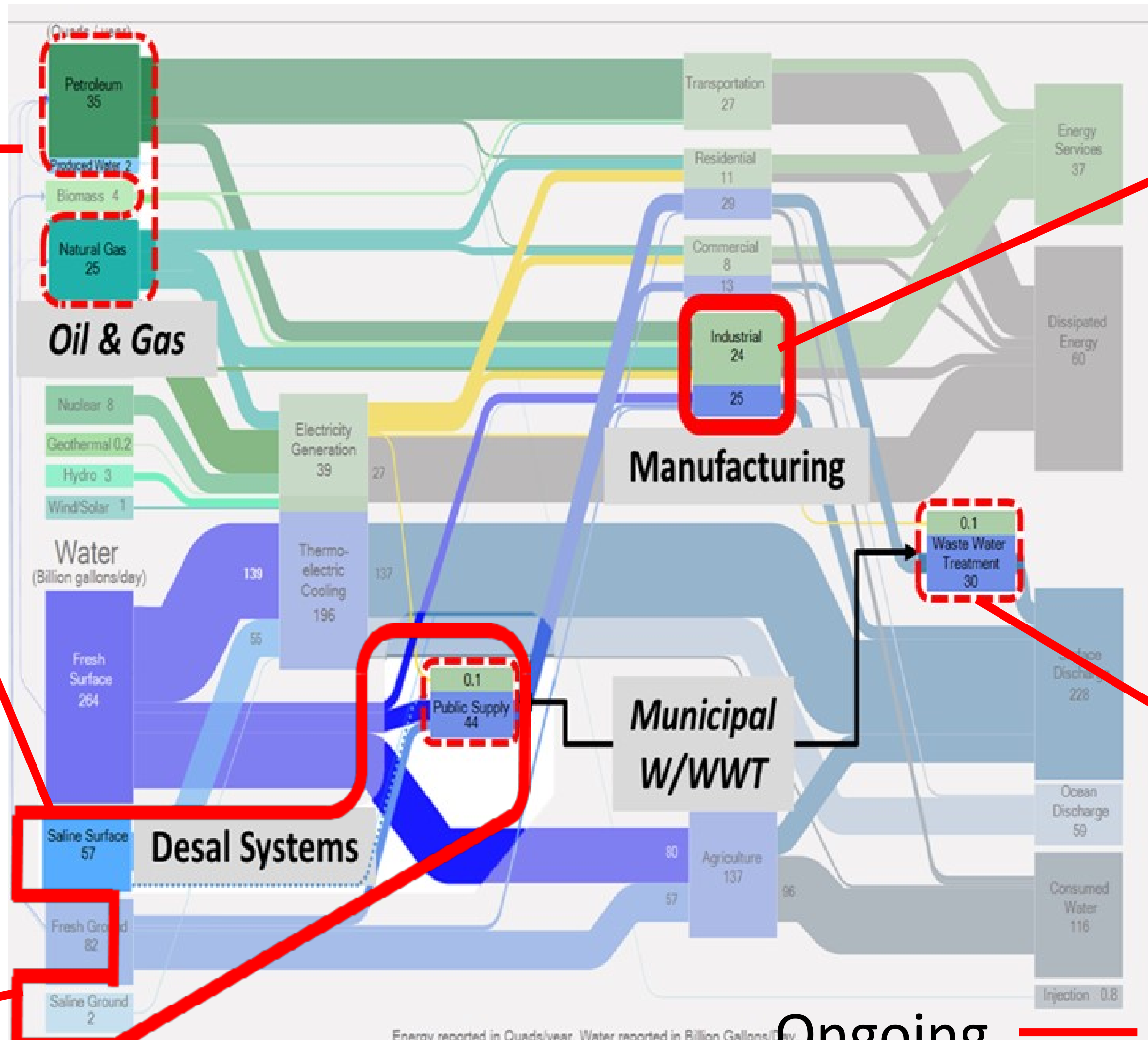

Clean Water
What are the opportunities and impact of improved clean water technologies?
Manufacturing /Energy/Grid Interface
Geospatial CHP Opportunity Mapping and Smart Power Electronics Potential for CHP and DER Integration
Current AMO Strategic Analysis Activities
Sustainable Manufacturing
What are the opportunities and impact of advanced manufacturing technologies on energy productivity and competitiveness?
Credible data and information to inform current and future AMO priorities
Manufacturing Supply Chain Analysis
Technoeconomic, materials/product flows, and global value chain analyses
Manufacturing in a Connected Economy
How will the penetration of “smart” products and the Internet-of-Things affect advanced manufacturing R&D opportunities?

Overall Multi-year Water Analysis Strategy – 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



Ongoing

Planned

Reduce water & energy-related use with goal of enhancing resilience based on watershed impact

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

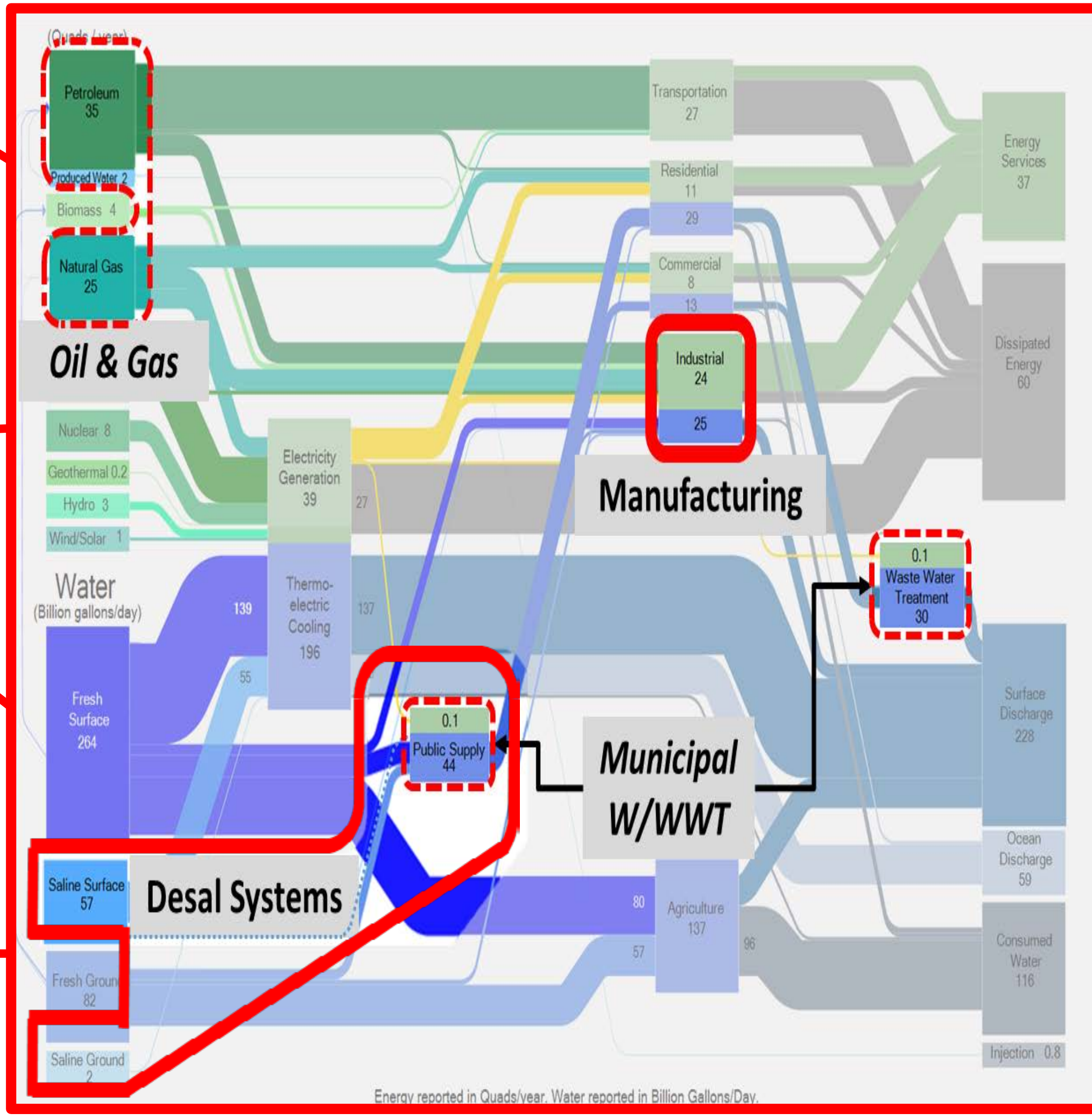
…and what cross-cutting technologies have pervasive impact?

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

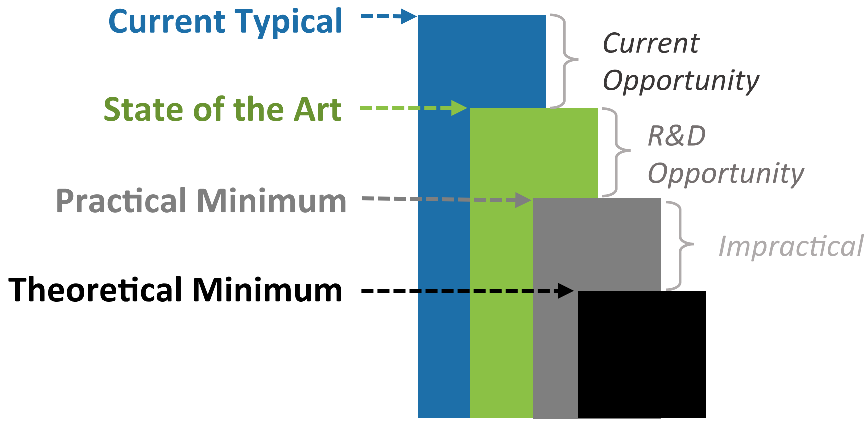
Energy Water Bandwidth Study of Seawater Desalination: 2 Volumes

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

Assess energy savings opportunities within manufacturing….

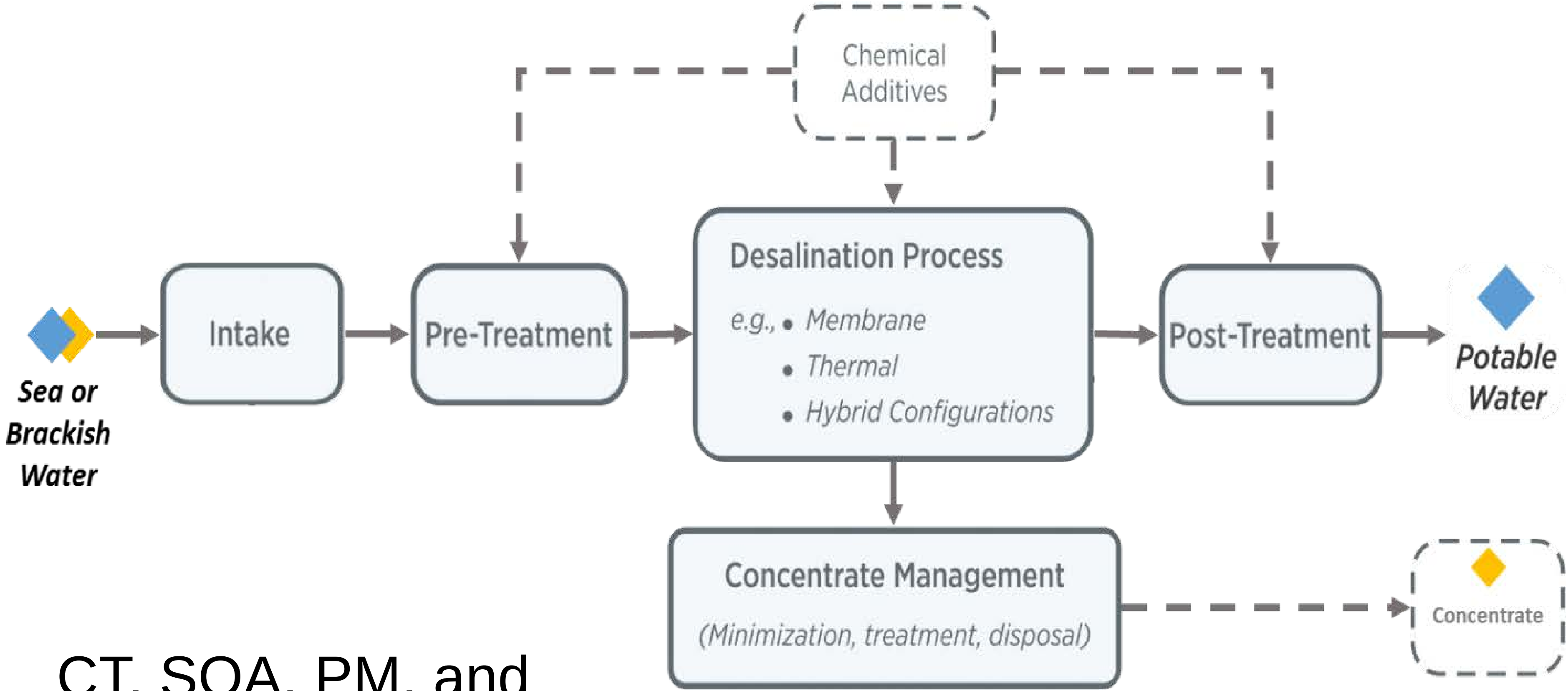
Energy bandwidth studies frame the range (or *bandwidth*) of potential energy savings in manufacturing, and technology opportunities to realize those savings.



Measures of energy intensity studied:

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

Desalination System Boundary



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

Many applications for water treatment through desalination

Intake

Alternate Water Sources

1 MGD - 250 MGD	NR	<1 MGD - 40 MGD	NR	100 MGD - 300 MGD	0.002 MGD (per oil & gas well)
Wastewater (Municipal)	Wastewater (Industrial)	Low Salinity Brackish Water	High Salinity Brackish Water	Seawater	High Salinity Water (i.e., brine or produced waters)
0.5-0.6% TDS	NR	0.05%-0.50% TDS	0.50%- 3.5% TDS	3.5% (Seawater) - 4.5% (Persian Gulf) TDS	>4.5% TDS

Pretreatment

Desalination

Desalination Technology Options

0.20%-7.5% TDS 0.1-180 MGD	0.10%-1.25% TDS NR	<0.5% TDS <40 MGD	0.2% TDS ~1 MGD	3.0%-10% TDS 5-160 MGD	3.0%-10%TDS 6-12 MGD	3.5% TDS 1-8 MGD	0.05%-3.5% TDS NR
RO Recovery 35-50%	**NF** Recovery 80-85%	**ED/EDR** Recovery 30-90%	**CDI** Recovery 70%	**MSF** Recovery 19-45%	**MED (w/ TVC)** Recovery 35-45%	**VC (TVC or MVC)** Recovery 23-41%	**Hybrid** (FO-RO or FO-MSF/MED) Recovery 96%
0.6%-7% TDS | <0.05% TDS	NR | 0.002% TDS	3.2% TDS | 0.05% TDS	0.67 TDS | 0.01% TDS	10% TDS | <0.001% TDS	4.5% TDS | <0.002% TDS	4.5% TDS | <0.001% TDS	NR | NR
0.1-90 MGD | 0.1-90 MGD	NR | NR	4-28 MGD | 12-36 MGD	~0.3 MGD | ~0.7 MGD	<100 MGD | <100 MGD	<10 MGD | <10 MGD	<5 MGD | <5 MGD	NR | NR

Concentrate Management and Disposal

Concentrate Disposal Options

0.1%-5% TDS	NR	NR	2.0%-10% TDS	<0.5% TDS
Ocean Discharge	Surface Water Discharge	Deep Well Injection	ZLD: Evaporation Ponds, etc.	Land Disposal/ Irrigation
NR	NR	>1 MGD	<1 MGD	NR

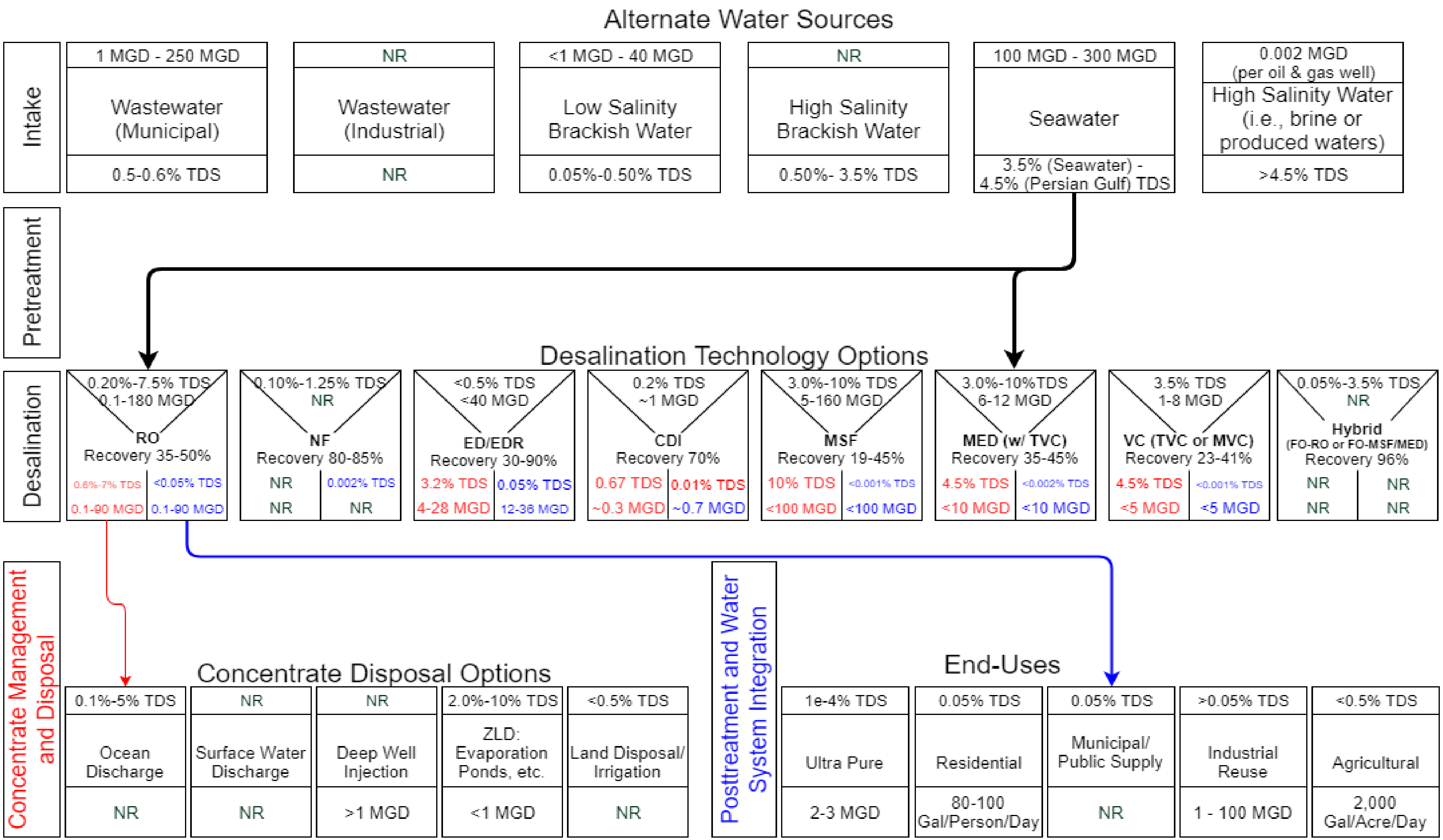
Posttreatment and Water System Integration

End-Uses

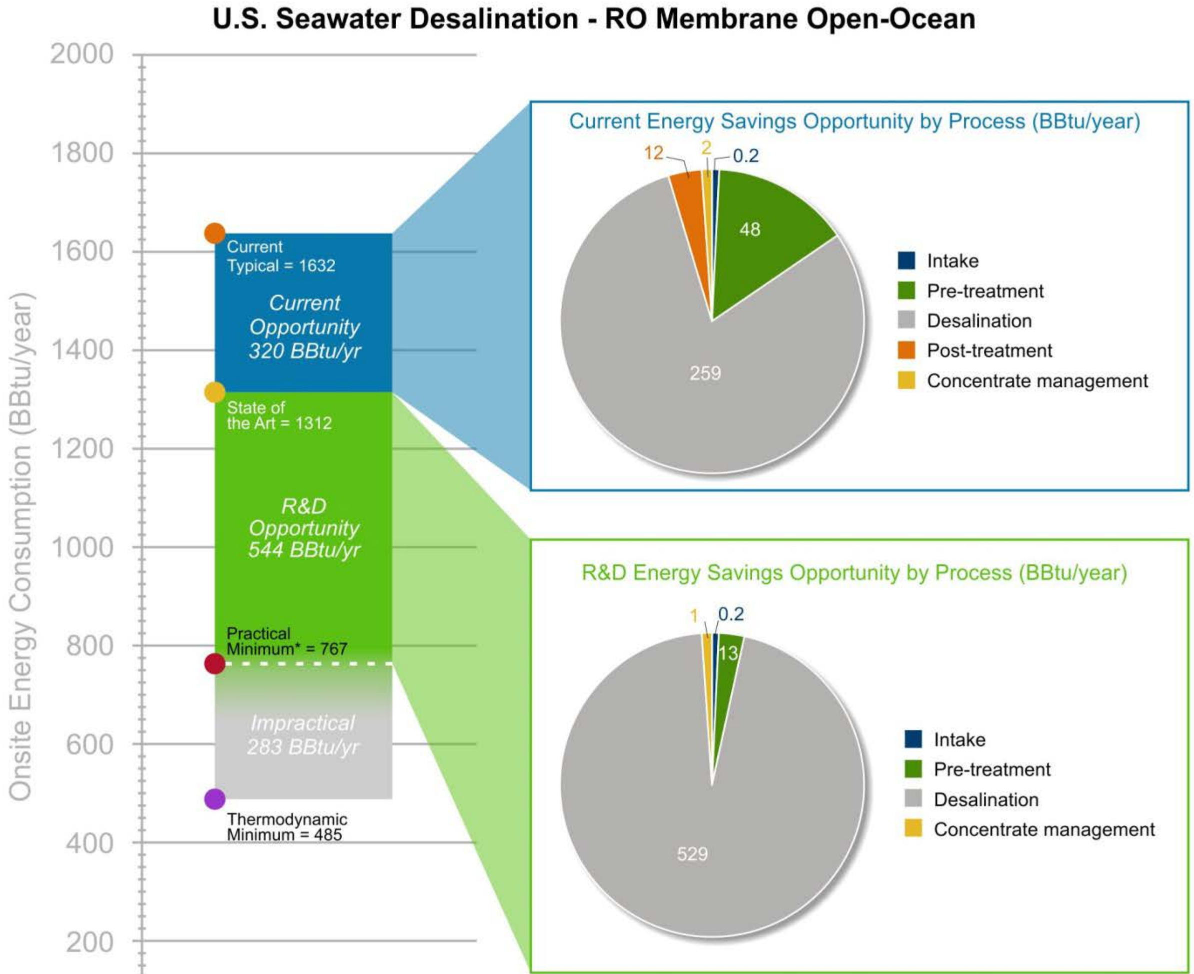
1e-4% TDS	0.05% TDS	0.05% TDS	>0.05% TDS	<0.5% TDS
Ultra Pure	Residential	Municipal/ Public Supply	Industrial Reuse	Agricultural
2-3 MGD	80-100 Gal/Person/Day	NR	1 - 100 MGD	2,000 Gal/Acre/Day

Seawater for Municipal Potable Water Pathways

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



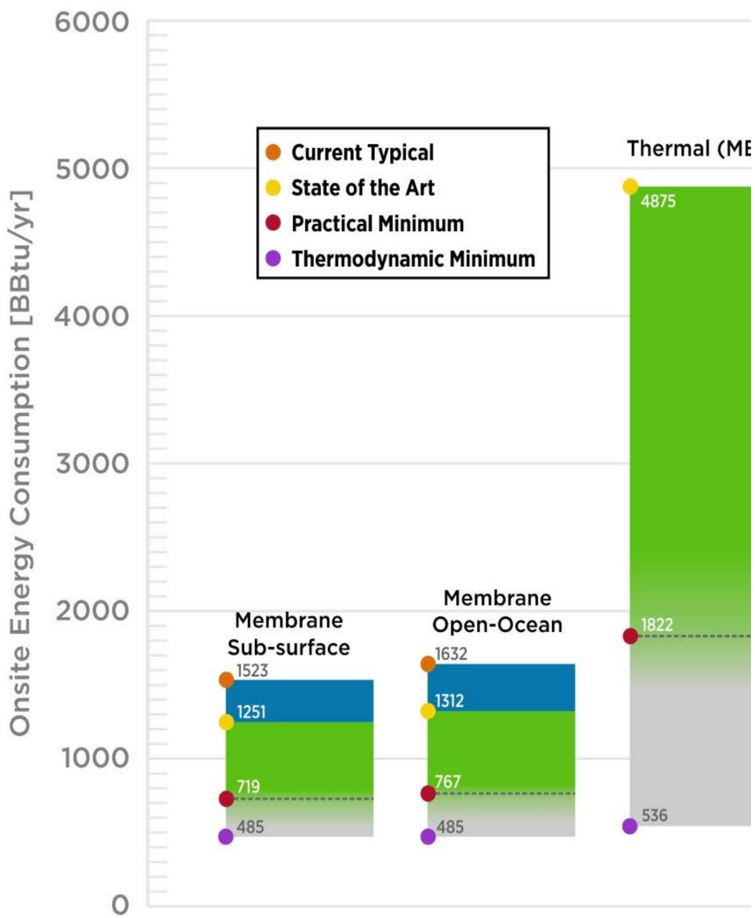
Seawater Desalination - Energy Savings Opportunity for RO system w/ Open Ocean Intake



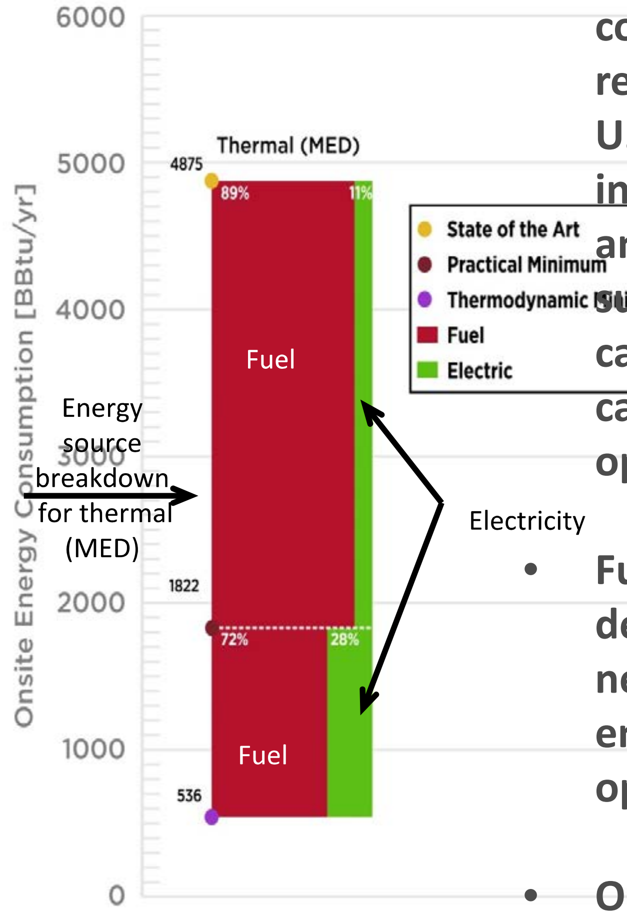
CT, SOA, TM operating conditions: RO-based system at 50% recovery of 500 ppm (0 ppm for TM) product water from 35,000 ppm feedwater. PM operating conditions: semi-batch RO-based system at 42% recovery of 379 ppm product water from 36,357 ppm feedwater.

- This system chosen as best representative for U.S. for 2016 facilities and installed capacity
- 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

Seawater Desalination Energy Consumption and Savings Opportunity for 3 Systems



Membrane Sub-surface & Open-Ocean both implement RO desalination with t
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.

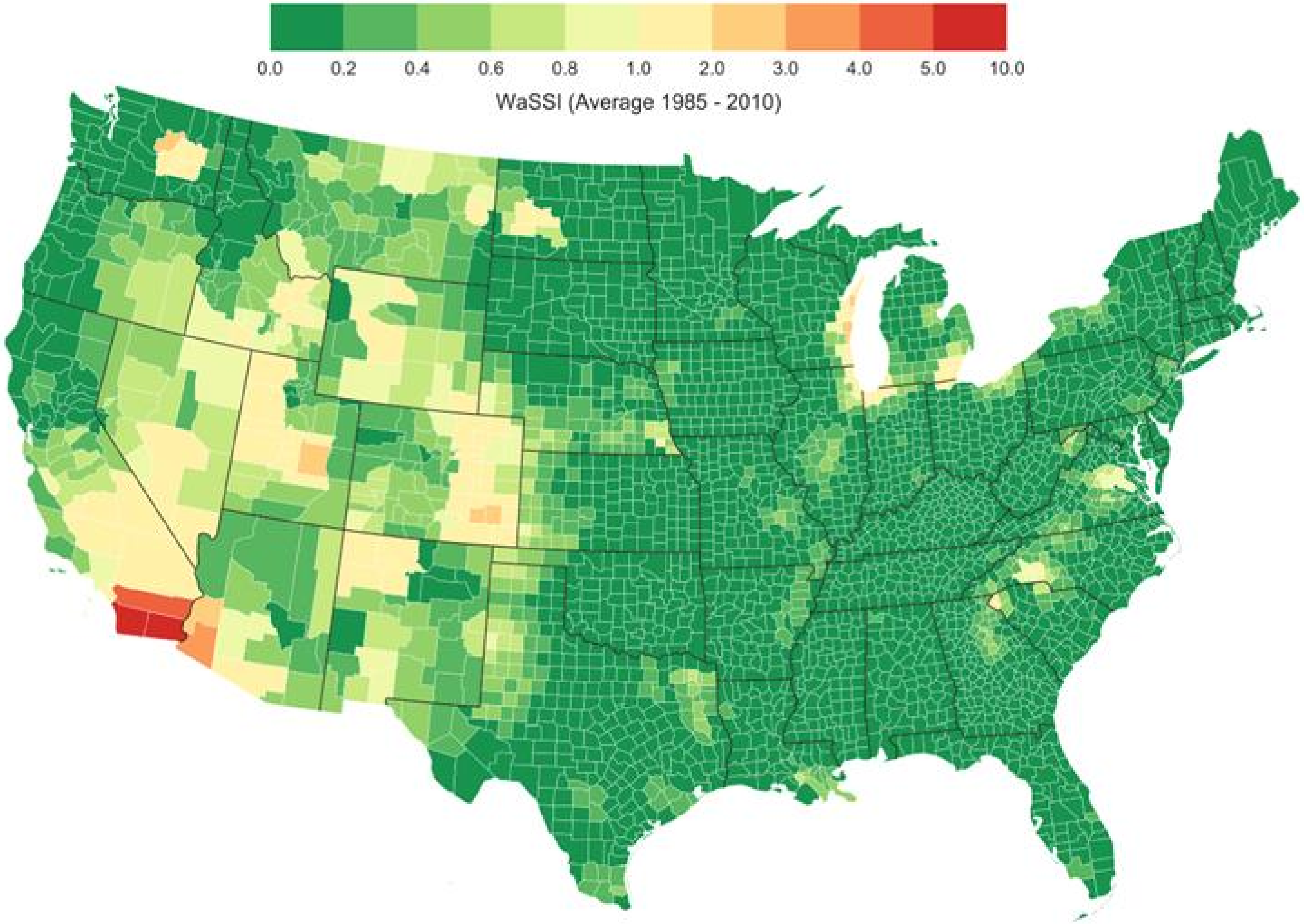


Thermal: MED-based system at 35% recovery of <25 ppm (0 ppm for TM) product water from 45,000 ppm feedwater

Thermal SOA, PM, TM operating conditions: MED-based system at 3
(35% average) recovery of <25 ppm (0 ppm for TM) product water from

- Membrane open-ocean considered best representative of 2016 CT U.S. consumption for installed capacity; thermal and membrane sub-surface values are calculated at same capacity as membrane open-ocean
- 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

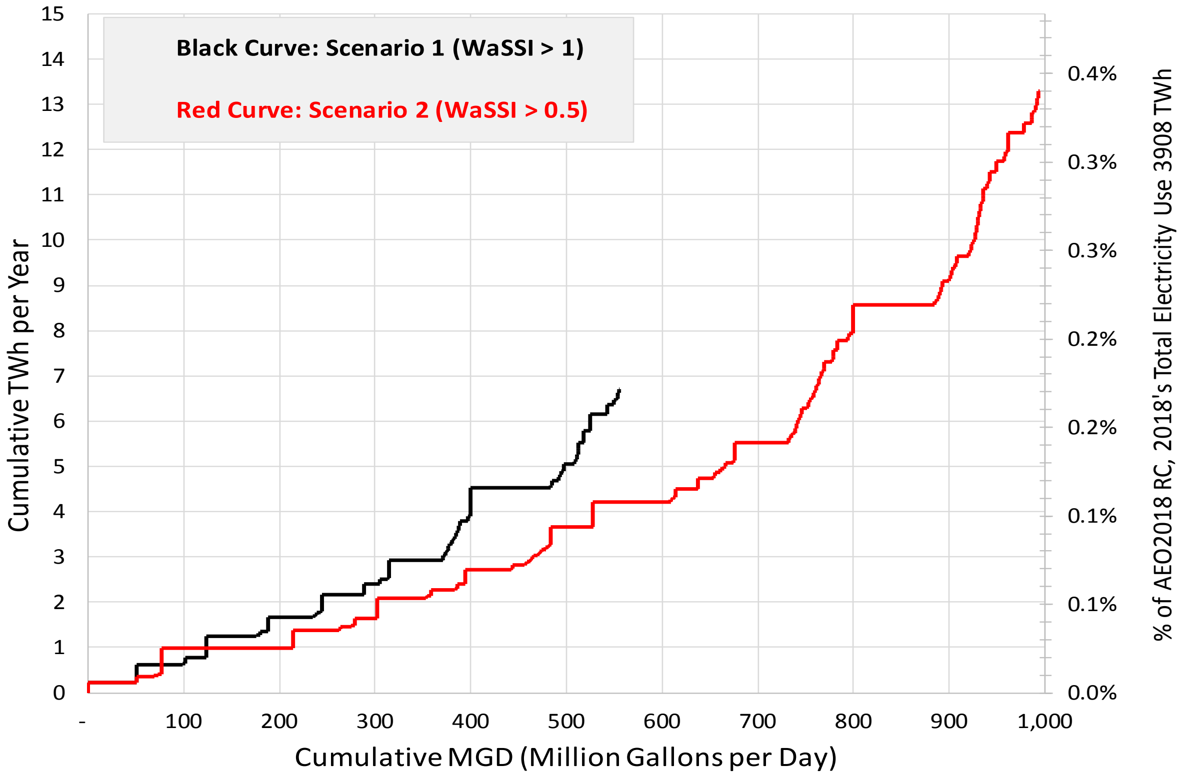
Water Supply Stress Index



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

Additional Desalination Scenario Analysis

- Goal: Identify science and technology opportunities for realizing energy and cost reductions in desalination systems



Energy impact from greater adoption of seawater desalination in US
(Rao, Morrow, et al., submitted to Desalination)

WaSSI = Water Stress Supply Index

Distributed Desalination: Small modular

Small distributed systems:

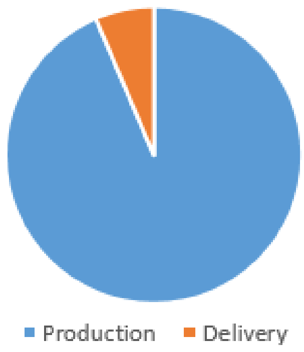
- 1000 – 660,000 gallons per day
- Local production
- Low maintenance/operation costs

Containerized
Seawater RO Plant

Large Central System:

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

Cost of producing and distributing RO desalinated seawater in a flat area



Cost of producing and distributing RO desalinated seawater in a mountainous area

Thank you.

joe.cresko@ee.doe.gov

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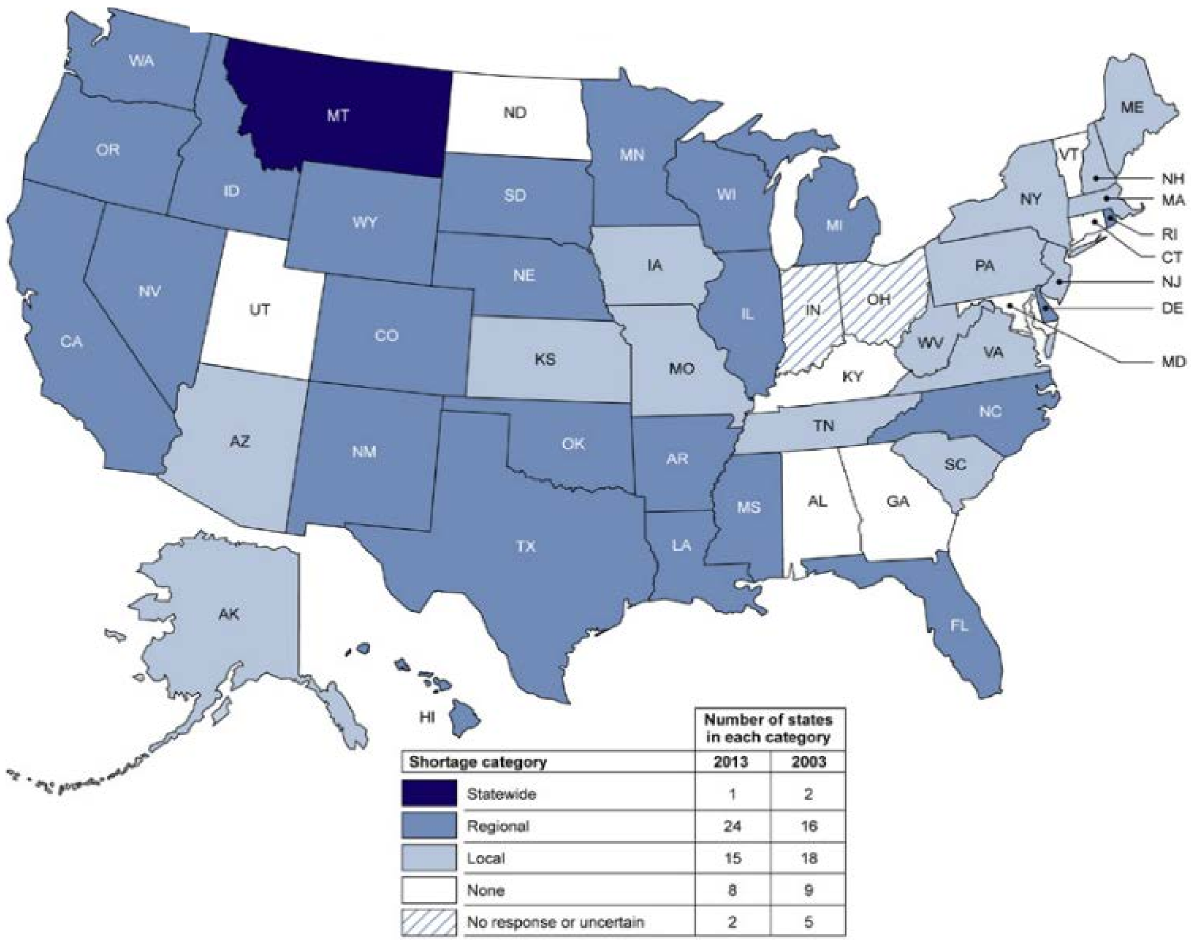
Back-up slides

U.S. Water Shortages



Shortage category	Number of states in each category 2013	2003
Statewide	1	2
Regional	24	16
Local	15	18
None	8	9
No response or uncertain	2	5

- 40 of 48 responding state water planners anticipate water shortages in their state in the next ten years
- 42 anticipate water shortages in the next 10 to 20 years

Source: U.S. GAO (2014) *Freshwater Supply Concerns Continue, and Uncertainties Complicate Planning.*

Manufacturing subsectors at risk of water shortages

Manufacturing Sector	Estimated % water intake within each WaSSI* Bin	
	[0.8,1.0)	[1.0,inf)
Primary Metal	1	**35**
Fabricated Metal Product	3	**10**
Transportation Equipment	2	**10**
Petroleum and Coal Product	1	**9**
Plastics and Rubber Products	3	**9**
Non-metallic Mineral Product	7	**8**
Machinery	2	**8**
Food	3	7
Computer and Electronic Product	5	7
Beverage and Tobacco Product	2	6
Paper	1	6
Electrical Equipment	3	5
Textile Product Mills	2	3
Chemical	1	3
Textile Mills	6	2
Wood Product	6	2
Other Industries [315,316,323,337,339]	4	8

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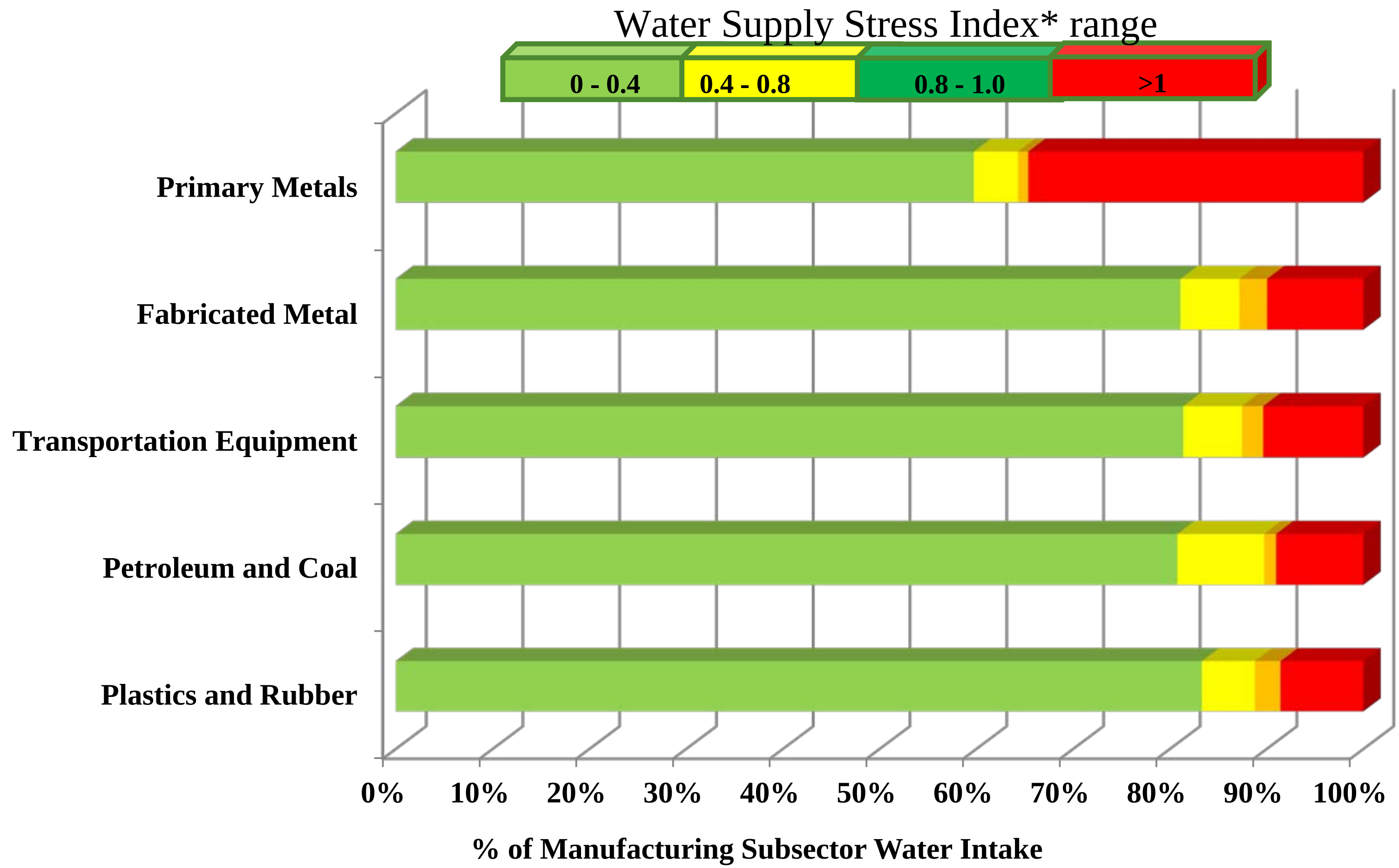
*WaSSI: Water Supply Stress Index, ratio of water demand to water replenishment rate within a watershed. Greater than 1 indicates greater demand than rate at which water is replenished

Estimates of manufacturing water intake developed by LBNL for each manufacturing subsector and county inferred from Canadian data and employment characteristics

U.S. Manufacturing Subsectors at Risk of Water Shortages



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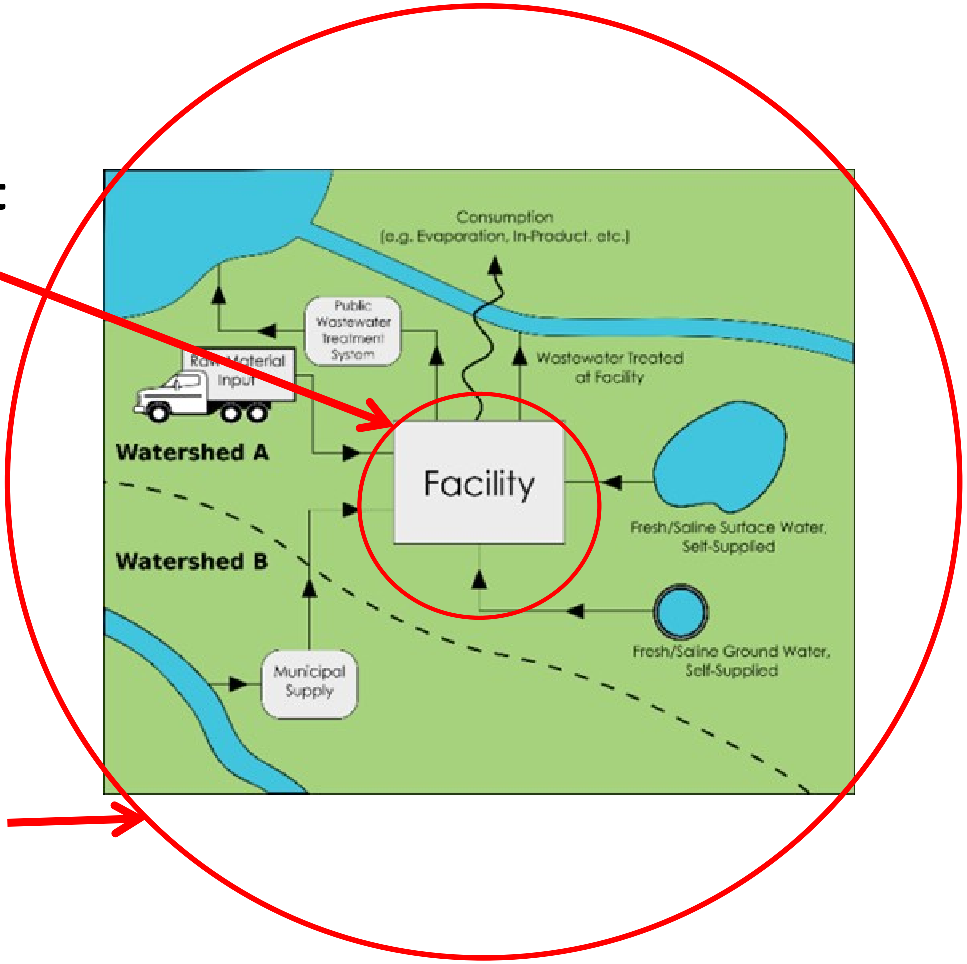
*Water Supply Stress Index, ratio of water demand to water replenishment rate within a watershed. Greater than 1 indicates greater demand than rate at which water is replenished.

Estimates of manufacturing water intake developed by LBNL for each manufacturing subsector and county inferred from Canadian data and employment characteristics.

Manufacturing Water Analysis: Overview

Within a facility, water is a low priority for most



Outside the facility, water use impacts the whole watershed creating a risk to resilience

Goals of StA team: Support US manufacturing resilience by:

1) Understanding manufacturing water use characteristics
2) Developing and evaluating advanced opportunities for water conservation and clean water tech. to support resilience

Major barrier to manufacturing analysis: data

- No national data collection or reliable state reporting
- Need estimation methods:

Berkeley Lab ≠ NREL ≠ Oak Ridge National Laboratory

Berkeley Lab

- Using Canadian water and employee data, estimated water intake by 3-digit NAICS by county
- Presented at results at ACEEE Summer Study

NREL

- Using EPA DMR data set quantified discharge
- Using state reporting, gathered intake for states as available

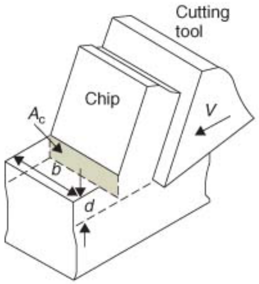
Oak Ridge National Laboratory

- Using Canadian water and revenue data, estimated water consumption by 3-digit NAICS by county
- Estimated water consumption for electronics industry using bottom-up estimates

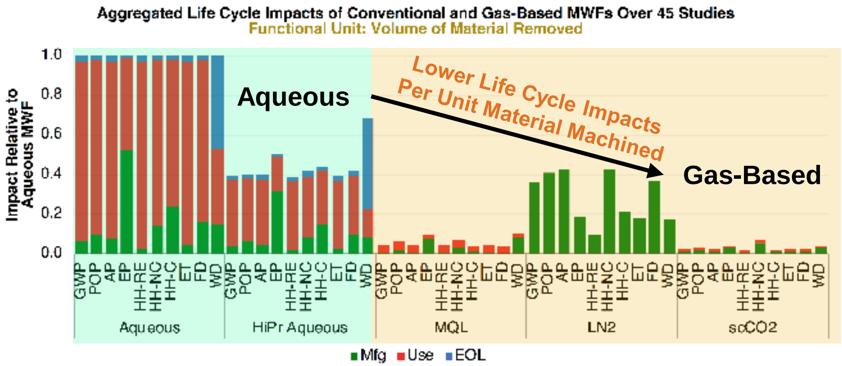
- Current activities: reviewing statistical reconciliation methods; reaching out to USGS, EPA, and others

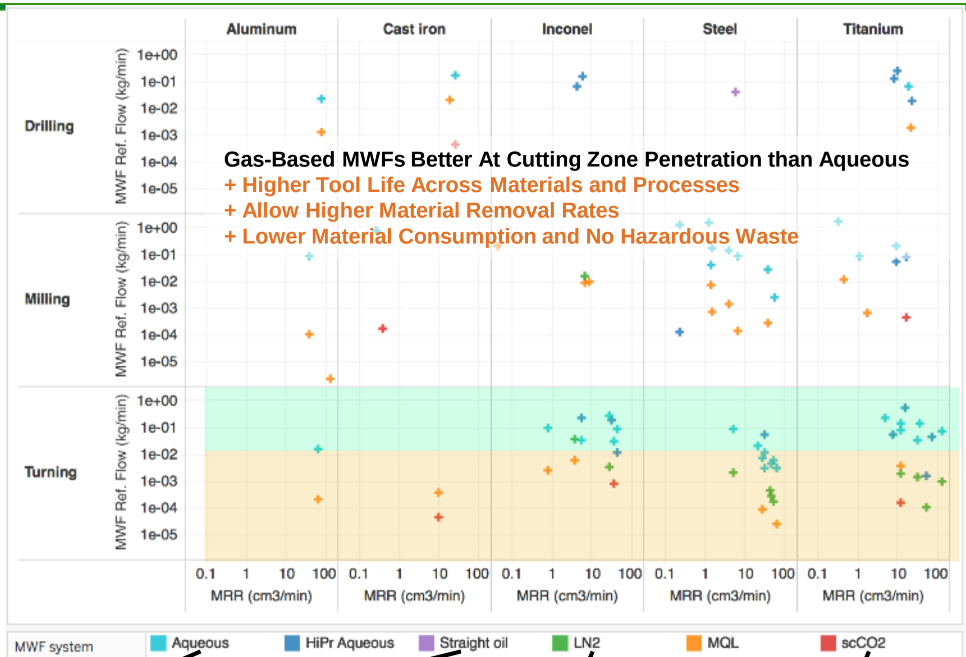
Manufacturing Water Conservation Analysis Underway: Dry Factories

Meta-Analysis of Published Literature to Assess Productivity and Life Cycle Impacts



Volumetric Material Removal Rate MRR (cm^3/min) = Chip area (cm^2) x Cutting speed (cm/min)







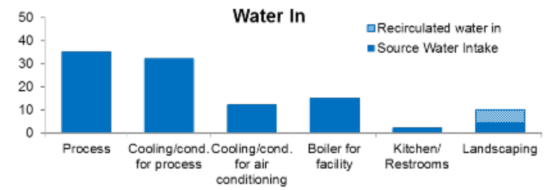

- Eliminating water use would also **eliminate occupational health concerns** associated with conventional MWFs
- Higher productivity per machine can be leveraged to further reduce energy use through fewer machines to produce a given output, or increase productivity by increasing output
- Gas can substitute water-based technologies in other manufacturing processes with a vision for energy-efficient **dry factories**

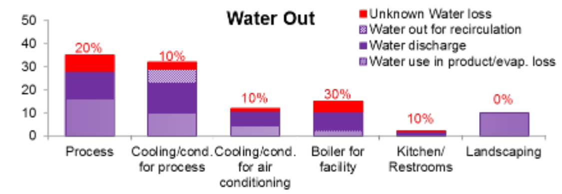
Manufacturing Water Conservation Analysis Underway: Plant Water Profiler tool

Plant Water Profiler

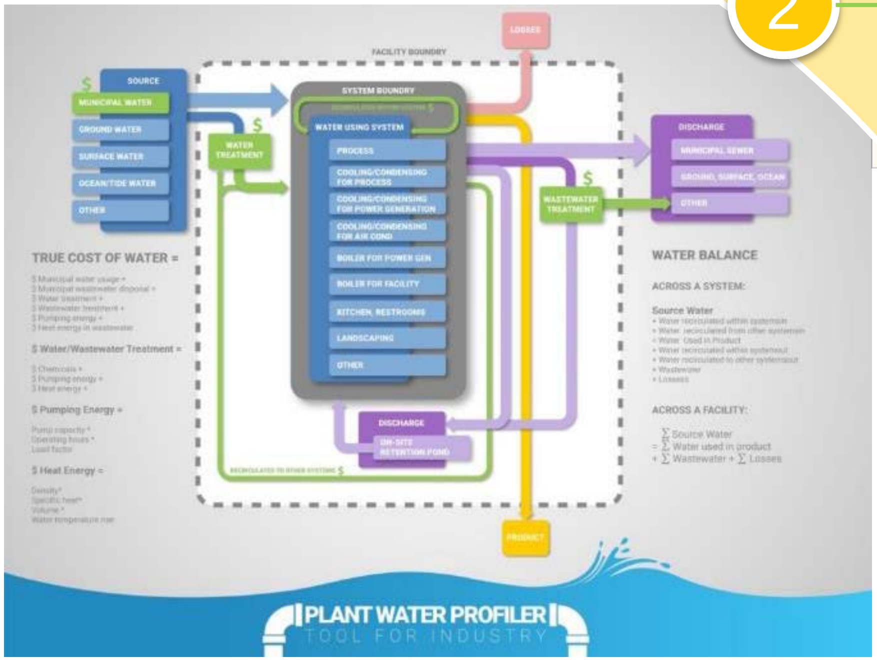
Oak Ridge National Laboratory

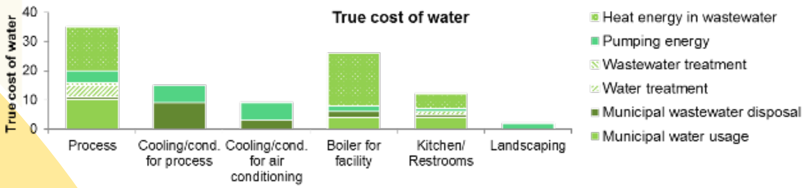
1 Baseline Water Use and Water Balance



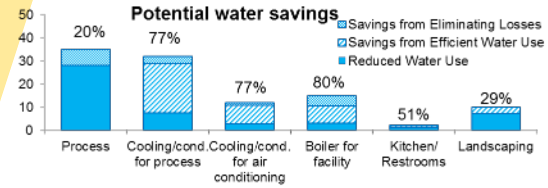


2 Determine True Cost of Water





3 Identify Water Efficiency Opportunities



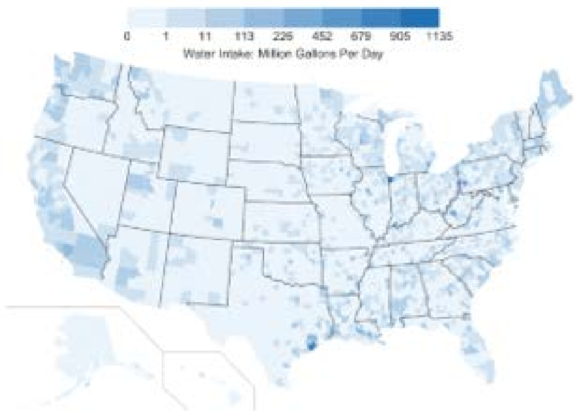
Clean Water for Manufacturing Analysis Underway

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. Nicholas Gilroy, August 28, 2017

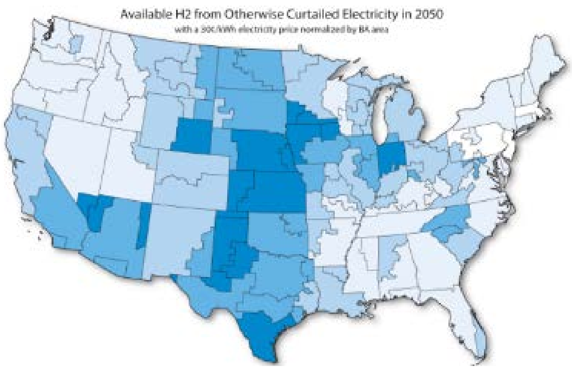
NREL NATIONAL RENEWABLE ENERGY LABORATORY

Industrial wastewater treatment for grid services

- Perform technoeconomic analysis of electricity cost savings for wastewater treatment using curtailed electricity
- Builds off of similar analysis done for H_2



Water use by county



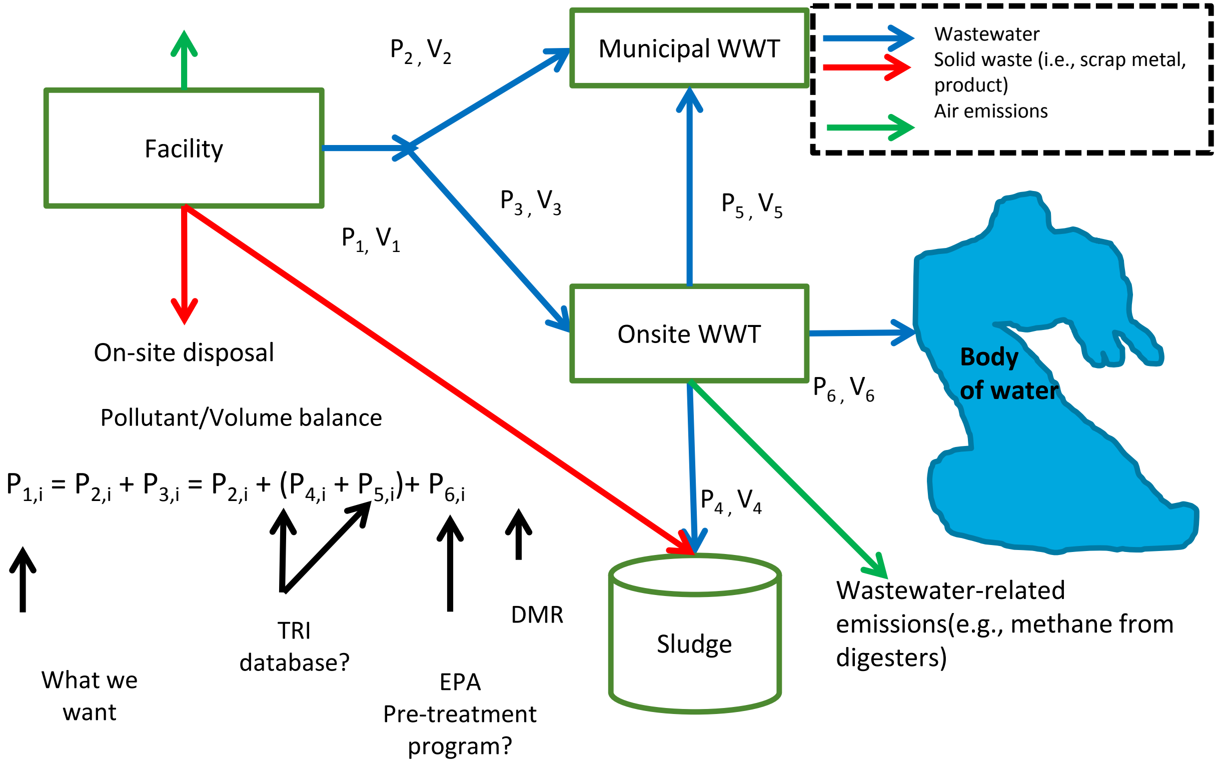
WWT management for grid services based on \$/kWh

Clean Water for Manufacturing Analysis Underway

BERKELEY LAB
Lawrence Berkeley National Laboratory

Sectors at risk of shortages and impact of water reuse

- Identified subsectors at risk of physical shortages (Rao et al., Environmental Science & Technology, in review)
- Evaluating energy consumption for industrial wastewater reuse



Putting manufacturing pieces together

Resilience (working definition): Mitigating and recovering from production impacts associated with the realization of physical, regulatory, societal, and/or economic risks associated with use of a shared watershed.

1

Understand manufacturing water use characteristics impacting resilience: quantities, locations, quality, end-uses, environmental impact, economic value

2

Identify critical water uses and consequences to subsector and US manufacturing at-large from losing water access

3

Conduct analysis on technologies/practices to support resilience: dry factories, cross-benefits, energy/water trade-off for reuse, others

AMO Strategic Analysis Team - presentations, journal articles and technical reports (2013-Present)

2018

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