Manufacturing Water Use Characteristics and Opportunities for Increased Resilience

AMO Strategic Analysis (StA) Team

Poster Presenter:
James McCall, National Renewable Energy Laboratory

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Arlington, VA
June 11-12, 2019

Overview

- The multi-laboratory (Argonne National Laboratory, Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, and Oak Ridge National Laboratory) AMO Strategic Analysis (StA) Team provides independent, objective, and credible information to inform decision-making.
- The StA team submitted 6 posters for this year's Program Review; the research topics are ongoing and do not follow the typical poster format
- This poster, **"Manufacturing Water Use Characteristics and Opportunities for Increased Resilience"** includes information on multiple complementary ongoing analysis project areas:
  1. Determining manufacturing water use characteristic data
  2. Developing sub-facility level understanding of water use
  3. Incorporating water use risk into analysis
  4. Industrial water reuse opportunities
  5. Industrial wastewater treatment as an ancillary service
  6. Dry fabricated metals factories analysis

Project Objectives and Goals

Problem & Background: Water is an essential resource for most manufacturing processes, but is not currently a major concern for most manufacturers in the U.S.

- Water analysis/evaluation commonly conducted within facility's fence line, does not incorporate watershed considerations unless legally bound (e.g., permits)
- Resiliency to water risks critical to maintaining a competitive manufacturing sector (due to expected water shortages, increased water stress)
- Manufacturing water resiliency (as defined by the StA Team): mitigating and recovering from production impacts associated with realizing physical, regulatory, societal, and/or economic risks associated with use of a shared watershed

Analysis Goals: Establishing an understanding of manufacturing water use characteristics and risks, used to conduct analysis in support of water resiliency in manufacturing. Current analysis goals include:

- Establishing understanding manufacturing water use characteristics
- Understanding water-related risks facing manufacturers
- Evaluating advanced opportunities for water conservation to support resilience

Applying manufacturing water use analysis

Objective:
Help to harden U.S. manufacturing against current and future water issues using analysis

Challenges:
- Risk greater driver than economics
- Risks highly spatially and temporally dependent
- Lack of data and information

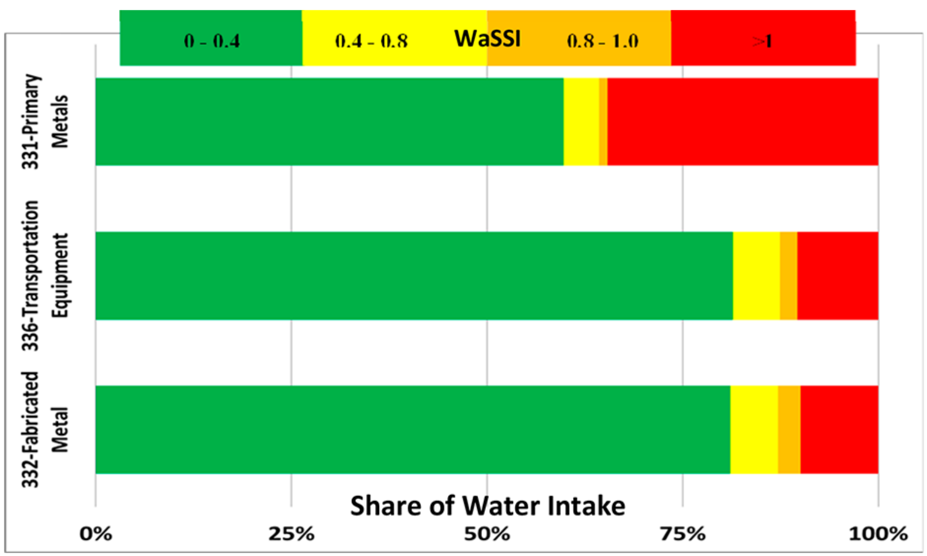
AMO StA approach:
- Characterize manufacturing water use
- Quantify risks and evaluate implications on U.S. manufacturing
- Evaluate technologies responsive to risks

Manufacturing water use characteristics: Filling in the unknown

Problems:

- Surveys on manufacturing water use discontinued in 1980s in the U.S.
- No current, comprehensive information on location, sources, quantities, end-uses of manufacturing water use
- Without this information, cannot conduct analysis on technology needs and impacts for increasing resiliency at the sector or national-level

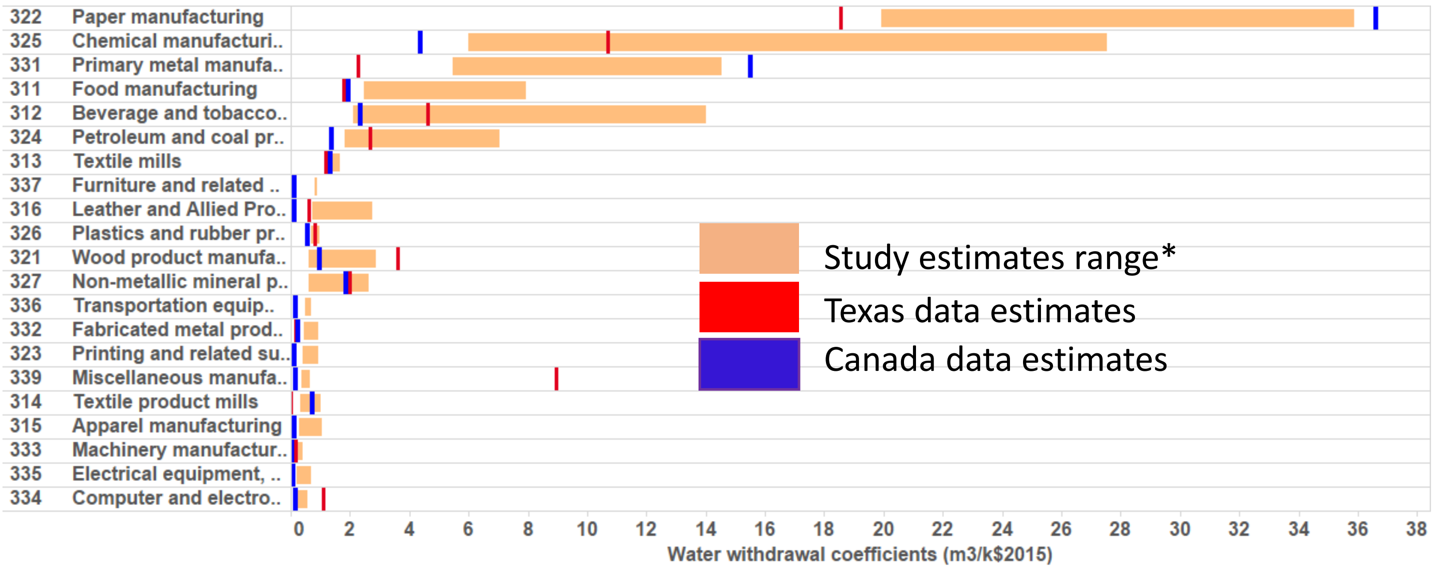
- **Current Solution:**
  - In absence of U.S. water data, Canadian manufacturing water use data can be applied to U.S. economic data to estimate water use characteristics for U.S. manufacturing
  - Hence single intensity metrics employed by AMO StA team:



(see left) Using employees as a normalizing factor, sectors at greatest risk of physical water shortages identified: primary metals, transportation equipment, and fabricated metals.
WASSI = Water Supply Stress Index. WaSSI of 1 serves as the demarcation for a
region withdrawing more water than is naturally replenished

Rao et al. 2019. Evaluation of U.S. Manufacturing Subsectors at Risk of Physical Water Shortages. Environmental Science & Technology.

Limitations of single intensity metrics



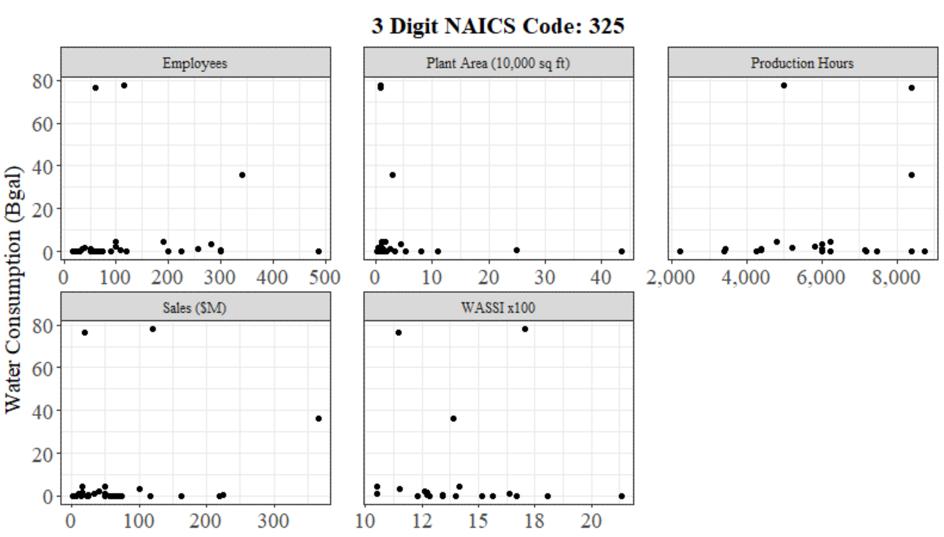
- Existing input-output (IO) methods to estimate water use by manufacturing sectors were analyzed
- These methods calculate water coefficients ($m^3/\$$) *(see figure above)* for sectors/subsectors using a single metric
- **Benefit:** IO method allows to compute direct as well as indirect water use associated with a sector
- **Limitation:** IO method assumes that water use by a sector is dependent on gross output only; good regional level estimations not available
- Variations in the value of water use coefficients among the IO Studies suggest that using single metrics to estimate water use leads to unknown uncertainty

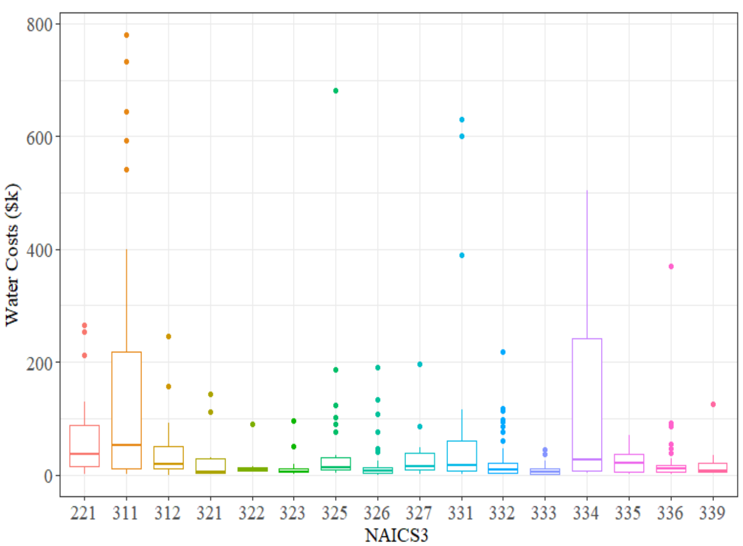
Needed: A more comprehensive model for water use estimation that quantifies its dependence on parameters like weather, employees, risk, etc. in addition to gross economic output

* Studies referred for this analysis are: 1. Yang, Y., W. Ingwersen, T. Hawkins, M. Srocka, AND D. Meyer. USEEIO: a New and Transparent United States Environmentally Extended Input-Output Model. JOURNAL OF CLEANER PRODUCTION. Elsevier Science Ltd, New York, NY, 158:308-318, (2017). 2. Blackhurst, Michal, Chris Hendrickson, Jordi Sels i Vidal. Direct and Indirect Water Withdrawals for U.S. Industrial Sectors Environmental Science & Technology 2010 44 (6), 2126-2130DOI: 10.1021/es903147k

Developing multivariable estimation models

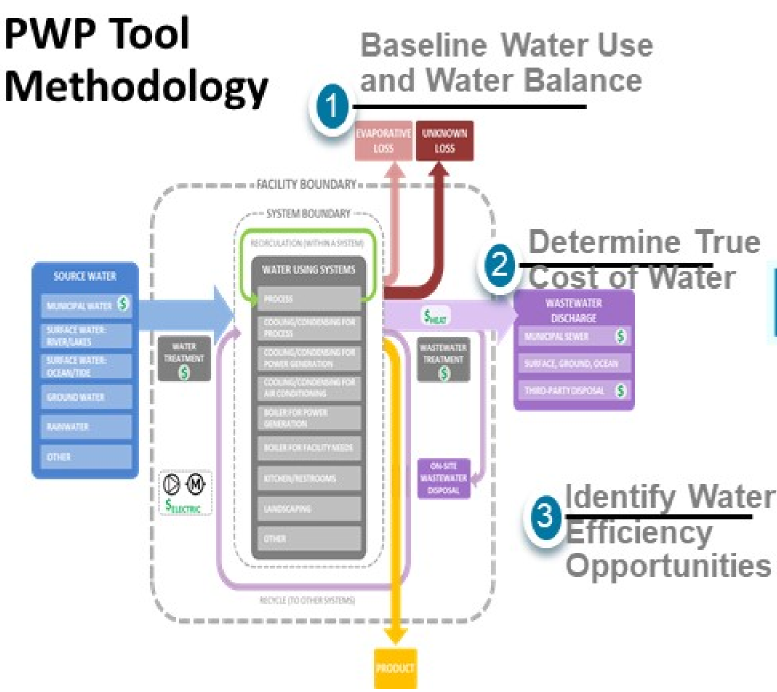
- **Top-down method developed/executing:** estimates U.S. manufacturing water use by county at 3-digit NAICS code-level that considers multiple influences: employees, economic output, number of establishments, weather
  - Will generate error statistics providing confidence in estimates
  - Uses Canadian manufacturing water use and economic survey data, U.S. economic survey data, and state-level manufacturing water use date where available
  - Should smooth out data variability found in previous models (below)
- Limitations of previous predictive water use (bottom left) and cost (bottom right) models using Industrial Assessment Center (IAC) data
  - NAICS codes' water use and cost *(right)* had very high standard deviations and showed more variation within the NAICS code than between them
  - Several issues with data were also identified: potential confusion regarding proper units when entering data (e.g., kgal vs. gal), only reporting purchased water, homogeneous water use across small facilities

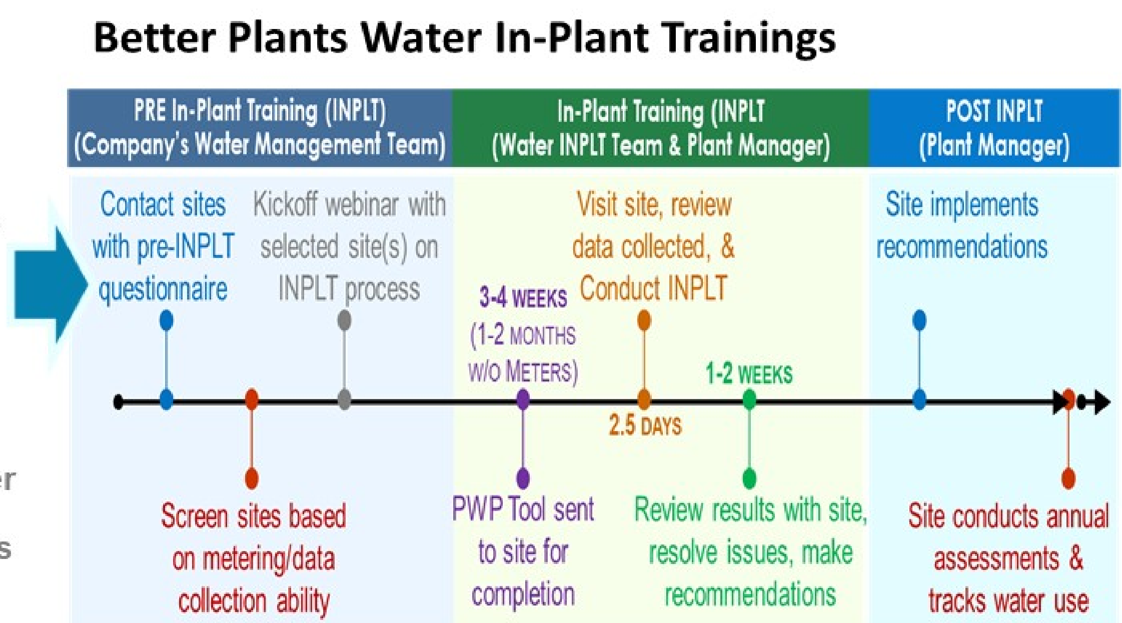




Developing sub-facility level understanding of water use

- **Need:** Understanding of water use at the process-level will help to conduct manufacturing-specific risk and technology assessments
- **Solutions:** Plant Water Profiler (PWP) tool *(bottom left)* helps facilities understand sub-facility water use by: streamlining water data collection process, conducting water balance, establishing water use and 'true cost of water' baselines, and identifying 'water use and true cost-intensive systems' to target for prioritizing water efficiency measures
    - PWP tool is now being leveraged by the DOE's Water In-Plant Training (*bottom right)* offered through the Better Plants program to: conduct a facility water use assessment, identify water savings opportunities, and make the business case for identified water saving projects.
    - Lessons learned from Better Plants partners would help Team develop in-depth facility-level case studies addressing water use in manufacturing sector and water-related risks



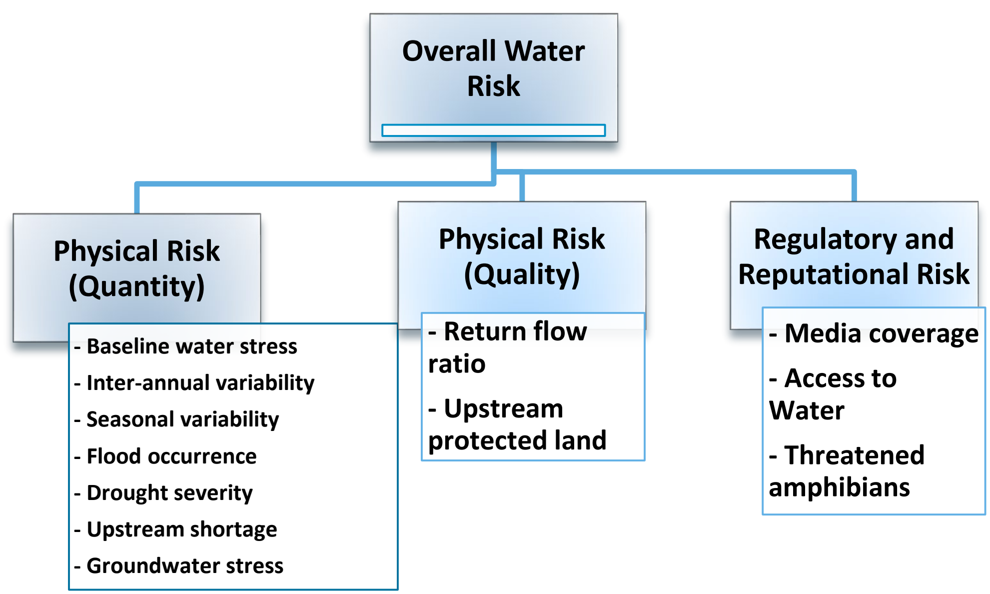


Incorporating risk into AMO StA analysis

- Coupling understanding of water use with risks will help identify where to focus future analysis efforts for promoting resiliency
- AMO StA team identified main water risks – physical, regulatory, reputational, natural disasters, and quality
- Tradeoff of cost vs risk: manufacturers identify risks from water resources, but low cost of water (<1% of expenses often) reduces incentive to upgrade water systems
- Natural disasters (floods, hurricanes, etc.) often main focus – high potential impact
- Tools currently used by manufacturers to quantify risks (WRI Aqueduct, WBCSD Global Water) focus on surface water stress rather than groundwater, and on supply and not quality. More robust tools could identify regions to focus improvements

Members of the AMO StA team visited the ArcelorMittal-Burns Harbor facility to understand water risks facing the world's largest steel producer and actions they take to improve resilience

Framework to identify risk in WRI Aqueduct Tool



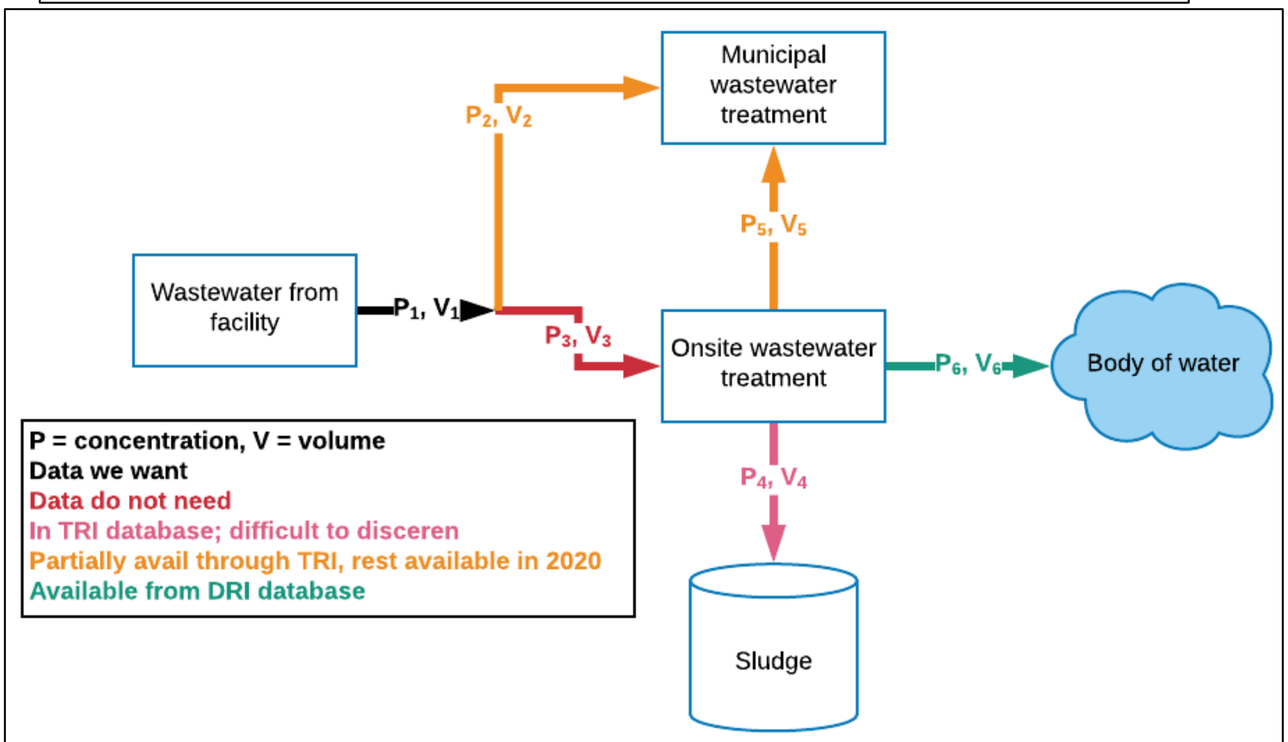
Industrial water reuse opportunities

Background: Water reuse can enhance a facility's resiliency and lessen watershed impact by reducing reliance on outside resources. Currently, energy/chemical trade-off associated with many industrial wastewater treatment options is unknown.

Goals:

1. Identify typical contaminants in industrial wastewater by subsector using EPA datasets (Discharge Monitoring Report (DMR), Toxic Release Inventory (TRI), and National Pretreatment Program (NPP))
2. Define, identify, and quantify "emerging" contaminants in industrial wastewater
3. Identify current and emerging technologies for treating contaminants identified in previous steps
4. Evaluate energy requirements for treatment technologies identified in 3

Tracking manufacturing wastewater flows and data availability



Using DMR, TRI, and EIA Annual Energy Outlook, the most common contaminants in 2016 were determined and the same list projected for 2035

Projected contaminants known (by 2035)
Solids, total dissolved
Sulfate
Chlorides & sulfates
Solids, total
Solids, total suspended
Chloride
Hardness, total (as CaCO3)
Chemical oxygen demand (C OD)
BOD, 5-day, 20 deg. C
Total Organic Carbon
Oil and grease
Residue, tot fltrble (dried at 105C)
Nitrogen
Nitrate Compounds
Iron

Industrial wastewater treatment as an ancillary service

Goal: Examine ability of manufacturing plants to use curtailed electricity for wastewater treatment and to provide ancillary electricity services

Initial Analysis Findings (cost savings possible)

- Based on initial analysis, there is technical potential to use curtailed electricity for water treatment
- Previous NREL 'otherwise curtailed electricity' analysis considered power system buildout if price signal was sent to curtailed electricity
- If curtailed electricity price is $30/MWh, curtailments are projected to be 3,869 TWh in 2050
- This price below average industrial electricity prices; if manufacturing facilities can purchase cheap otherwise curtailed electricity and provide flexible water treatment operations, **cost savings can be achieved**
- Energy required to treat wastewater = 361 TWh in 2017 (based on DMR data/standard water treatment)

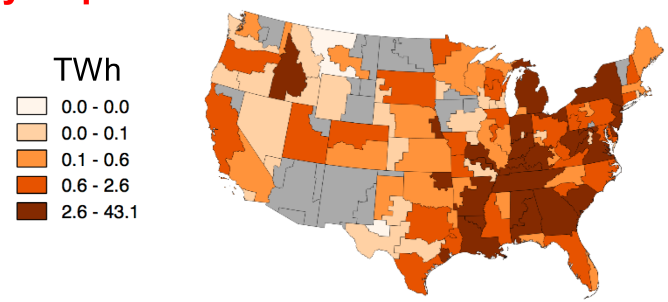
Next Steps (analyze energy/costs by sector)

- Differentiate treatment intensity by manufacturing sector
- Incorporate water treatment prices and electricity price savings achievable
- Estimate feasibility and value of incorporating flexible water treatment in manufacturing operations and discuss needed operational changes
- Discuss competition for curtailed electricity (hydrogen production, etc.)

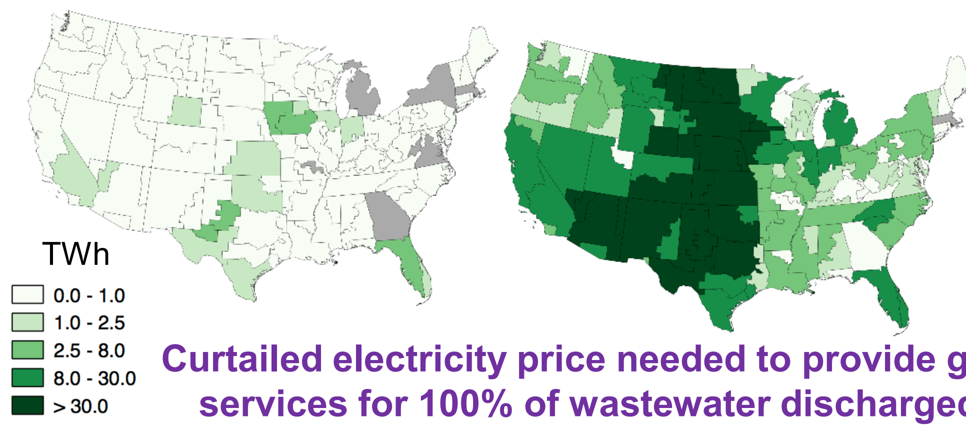
Initial analysis results show geographic variability in possible curtailed electricity for wastewater treatment

Energy required to treat wastewater

Total wastewater discharged (2017) and treatment energy intensity

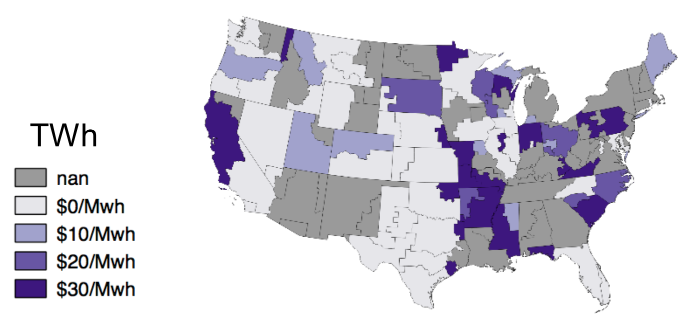


Curtailed electricity available: $0/MWh (L), $30/MWh (R)



Curtailed electricity price needed to provide grid services for 100% of wastewater discharged

Price signal needed to provide enough curtailed electricity to treat wastewater



Reducing health/water concerns in Dry Fabricated Metals Factories

Background:

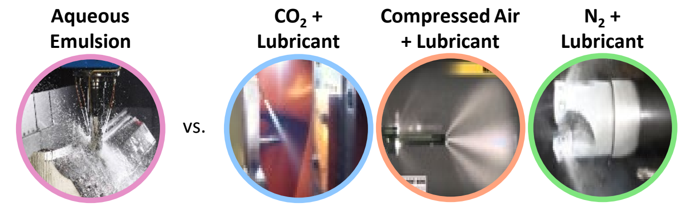
- Annual U.S. consumption of MWFs estimated at 90 MG – poses significant health, toxicity, and water pollution concerns
- Gas-based Metal Working Fluids (MWF) (N_2,CO_2 compressed air) eliminate use phase health and water concerns but shift energy and water use upstream

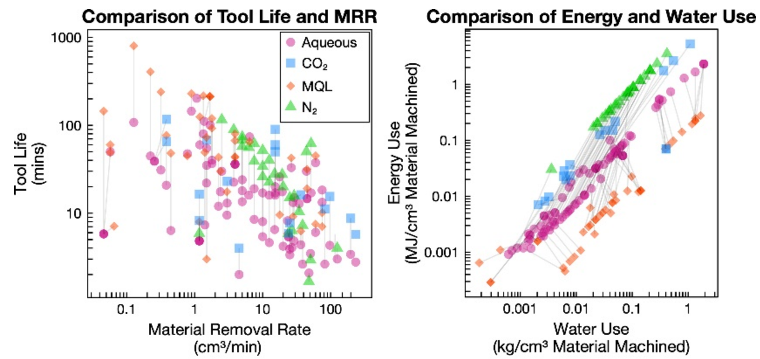
Analysis Goals: Provide better heat removal and lubricity to conventional aqueous MWFs, reducing environmental and health impacts by using gas-based MWF

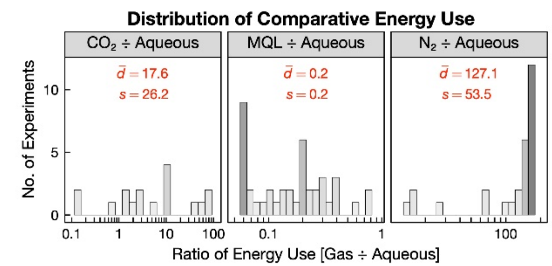
Method: Machining & MWF data compiled from 86 experiments in 29 peer-reviewed studies to estimate and compare energy and water use associated with the production and delivery of aqueous vs. gas-based MWFs

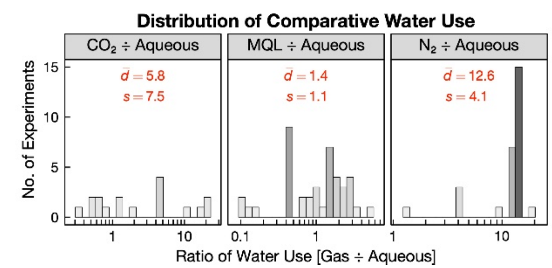
Findings:

- Despite reported improvements in tool life, **energy-intensive production processes for N_2 and CO_2** lead to higher overall energy and water use per unit of material machined relative to water-based MWFs – key difference is gas-based MWFs are 100% **consumptive** (no recirculation)
- Achieving **higher material removal rates** and throughput compared to aqueous MWF (not just improved tool life) can reduce energy & water use of gas-based MWFs
- **Optimizing flow rates** and delivery of CO_2 and N_2 MWFs to precisely meet cooling and lubrication needs can also reduce energy and water use of gas-based MWFs
- System expansion to include **reduced tool use, fewer machines** to meet target production, reduced cutting forces, and elimination of cleaning steps can further reduce energy and water use of gas-based MWFs









Example of StA Analysis informing DOE R&D

- Previous analysis conducted by the StA team played a major role in the planning of DOE's forthcoming Energy-Water Desalination Hub
- Reports and a peer-reviewed journal paper were developed to understand:
  - Synthesis of relevant science and latest research and development on energy for desalination systems
  - Analysis on the energy savings potential of seawater desalination systems by unit operation
  - Projections of energy-related impacts associated with increased uptake of seawater desalination
- Analysis was used in FOA

(Right): The AMO StA team developed a study, "Bandwidth Study on Energy Use and Potential Energy Savings Opportunities in U.S. Seawater Desalination Systems", that evaluated the energy and energy savings opportunities for seawater desalination systems in the U.S. This served as an example of the detail the Hub will need for conducting energy/technology evaluations of other non-freshwater sources