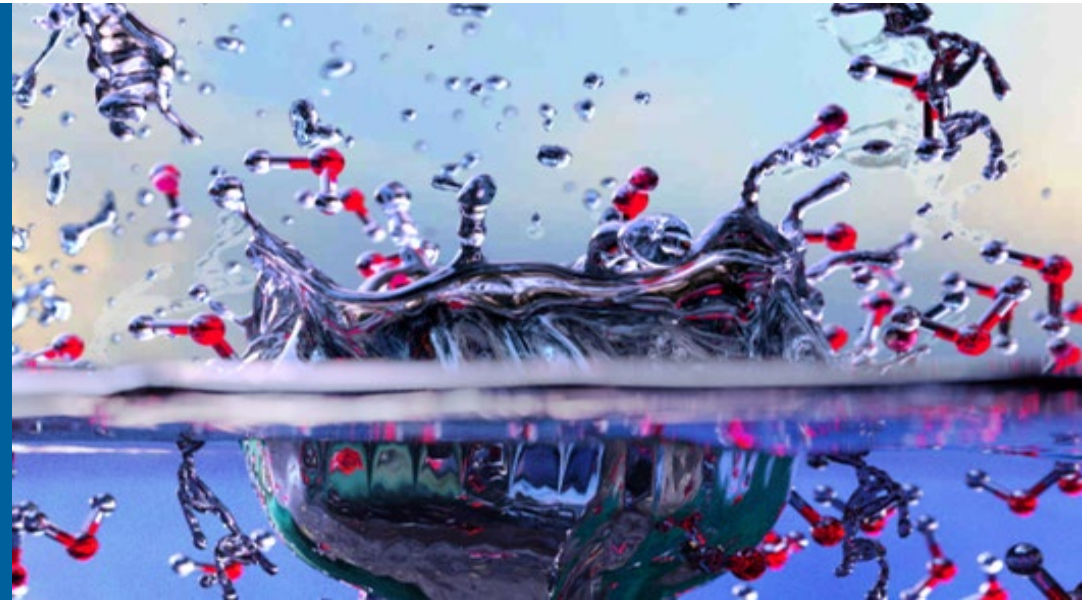
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
BIOENERGY TECHNOLOGIES OFFICE

Argonne NATIONAL LABORATORY

BIOENERGY TECHNOLOGIES OFFICE FY21 PEER REVIEW

Water Resource Management for Bioenergy and Bioproducts



May Wu
Miae Ha
Argonne National Laboratory

March 11, 2021
Analysis and Sustainability

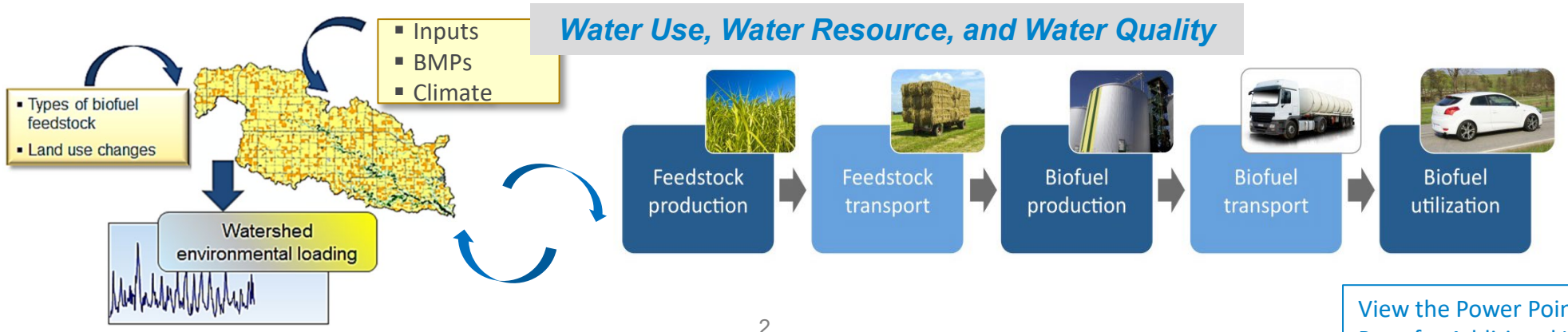
PROJECT OVERVIEW

Research Question: How can we produce bioenergy in a manner that increases water use efficiency, lowers regional water stress, and mitigates nutrient and sediment loss?

Goals: Develop science-based tools and metrics for improved understanding of the effect of feedstock and fuel production on regional freshwater availability and water quality, economic value, and implication of water reuse in the production.

Project cycle (FY18-20): This project develops an online model WATER[1] to illustrate water footprint and water resource impact of biofuels produced from conventional and advanced feedstock; analysis of biorefining water use[2]; and watershed models for evaluating the impacts of integrated landscape design with conservation practices on water quality[3].

***Project cycle** (FY21-23): Develop a framework incorporating GREET-SWAT-Century to quantify SOC, N, P in feedstock production; analyze institutional and infrastructural barriers for water resource conservation and reuse.*



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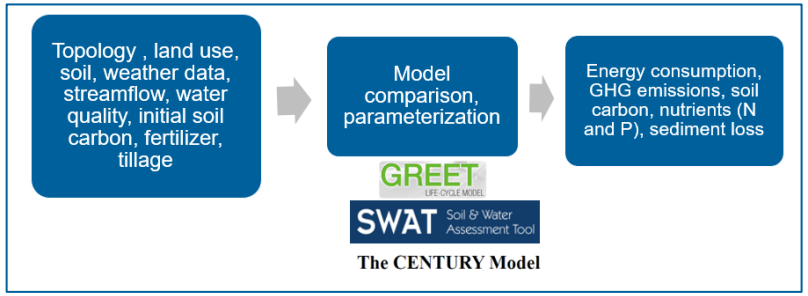
PROJECT OVERVIEW (CONT.)

1. **Water Resource and Water Footprint Analysis**
   - Design and develop water availability index (WAI) for feedstock production scenarios; analyze the effect of feedstock production on regional water resource. Assemble water resource inventory for renewable surface water, groundwater, rainwater, and reclaimed water.
   - Analyze water consumption intensity and water management of biofuel and baseline processes. Evaluate water use efficiency and conservation through reuse and recycle.
2. **Hydrologic Modeling and Value Proposition Analysis**
   - Develop SWAT model applications at agriculture watersheds in IOWA; simulate potential production landscape and BMP scenarios to estimate reduction of nutrient and soil loss.
   - Assess economic benefits of implementing multi-purpose buffer for feedstock at watershed scale.

Output

- **WATER** - Spatial-explicit model with regional water resource platform and production stage water footprint for bioenergy; *available online.*
- **SWAT** modeling and analysis of multiple river basins and watersheds.
- **Economic benefits** of reducing nutrients by biomass production in the watershed and river basin scale.



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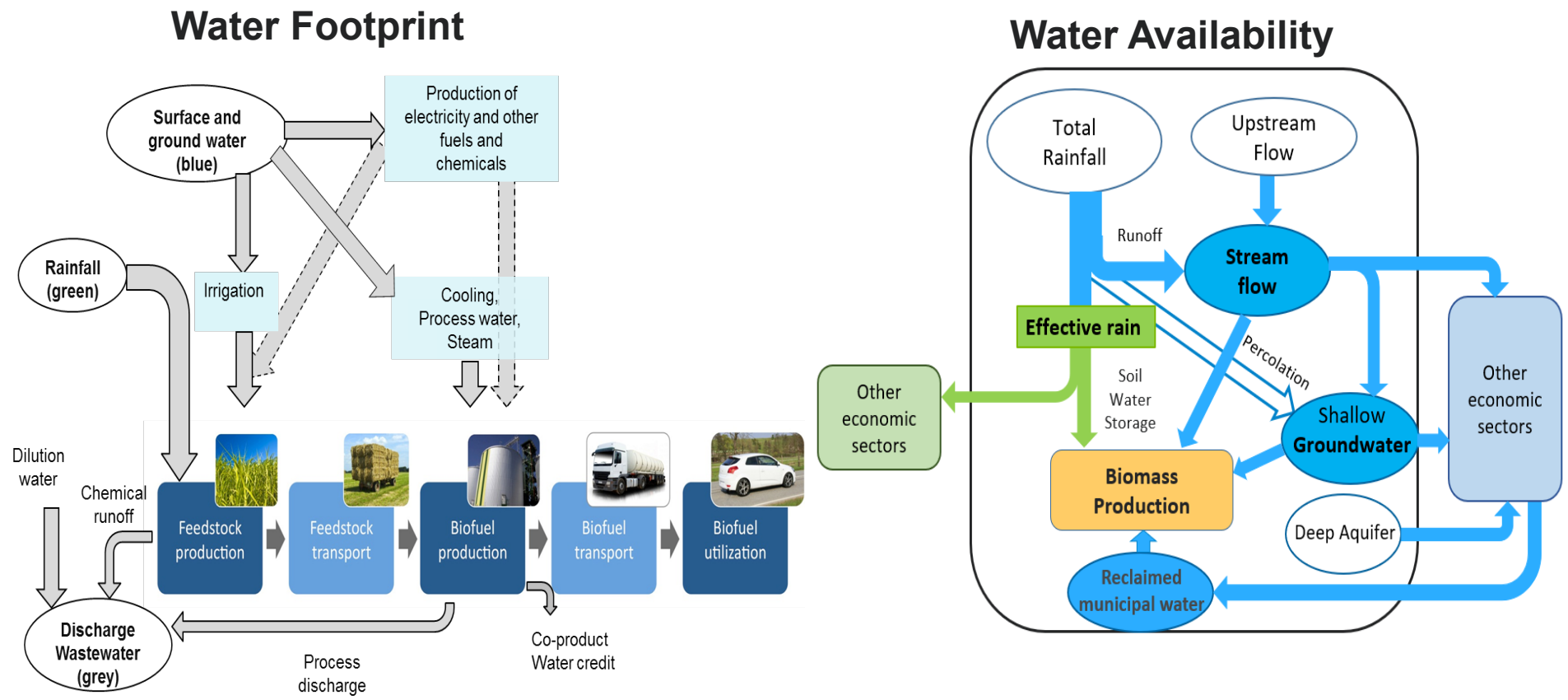
PROJECT OVERVIEW:

WATER RESOURCE MODELING AND ANALYSIS TOOLS

https://WATER.es.anl.gov



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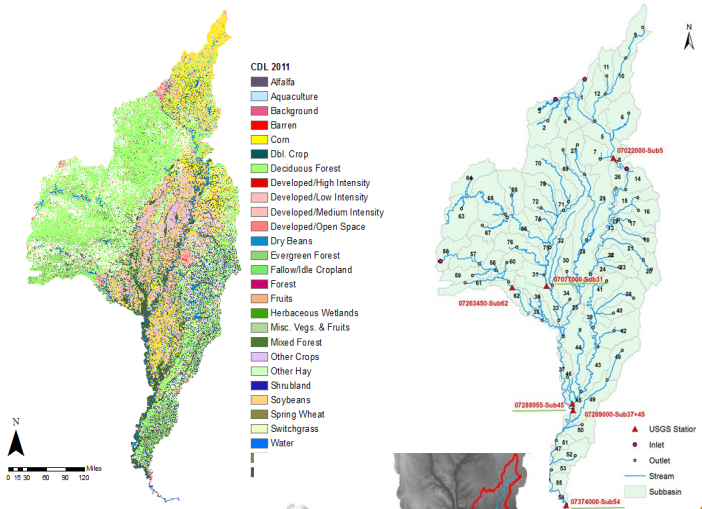
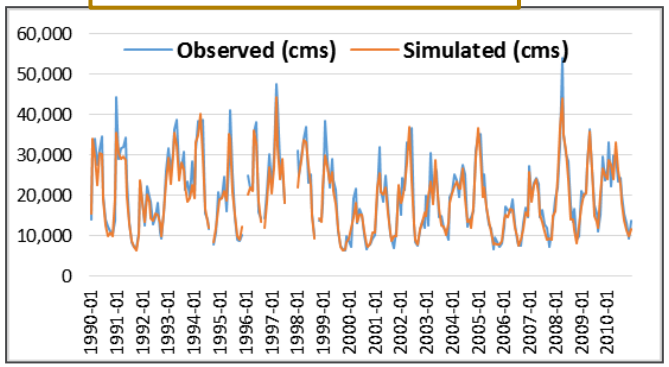
PROJECT OVERVIEW: WATER QUALITY MODEL



Land use, climate, stream network, soil, crop management, geospatial datasets

Hydrologic Modeling SWAT



Nitrogen, Phosphorus
Sediments, Flow

- Landscape design
- Potential biomass production scenarios

Conservation practices

Environmental and economic value proposition in watershed

Farming community

Drinking water supply

Ecosystem

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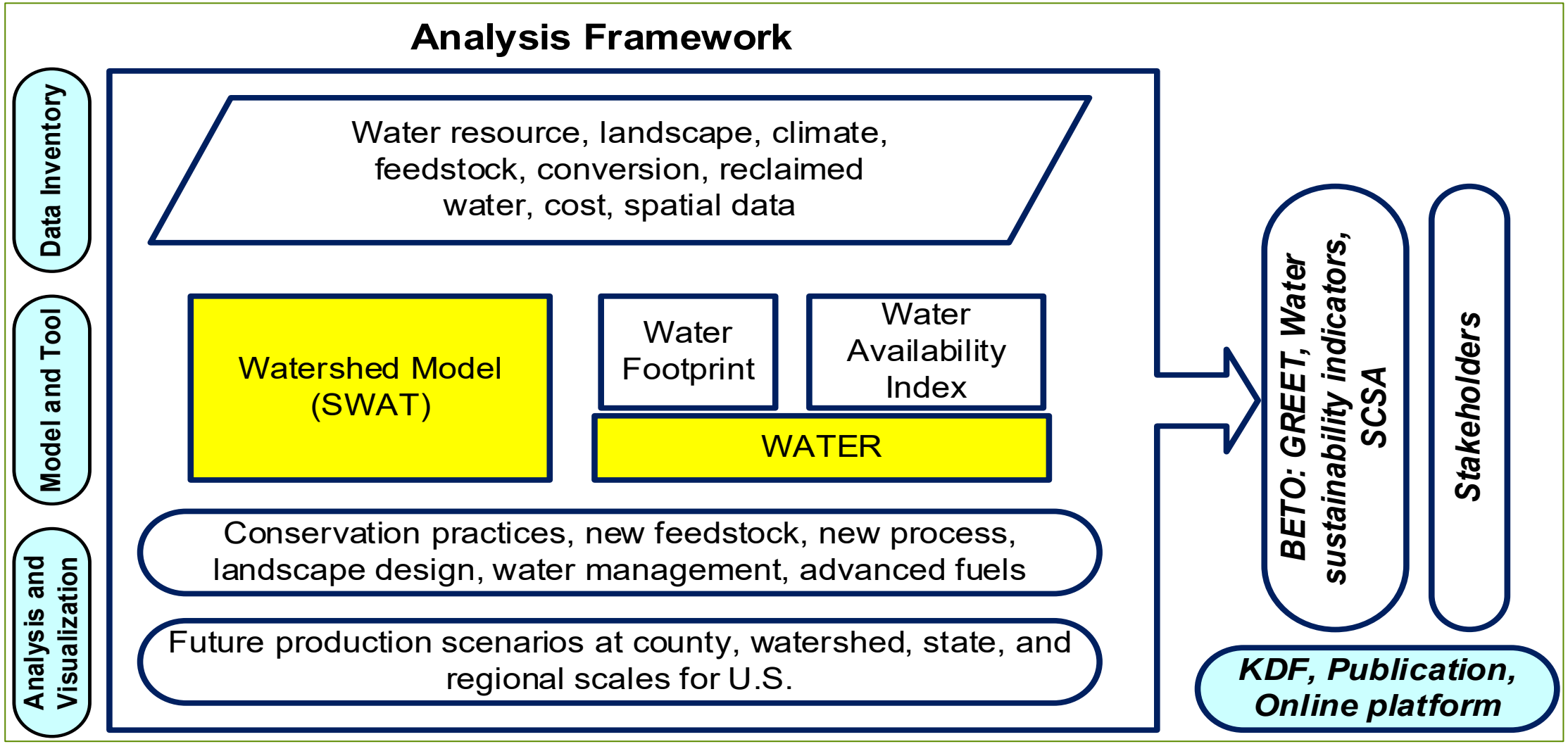
APPROACH



Land, Feedstock, Water Use and Resource, and Climate in a Single Framework

APPROACH

- **Success Factors**
  - Timely analysis for new technologies to address technology viability from a water resource perspective.
  - Capturing regional variabilities of water resource and feedstock.
  - Collaboration and partnership with multiple industries and agencies

Multi-disciplinary team including environmental engineer, hydrologist, and chemical engineer.

- **Develop and Continue Collaborations**
  - NOAA and USGS: Surface and groundwater flow data and uncertainty analysis.
  - Texas A&M, Iowa State, and US Army Corp.: SWAT
  - USDA ARS: Watershed site-specific water quality monitoring and conservation practices tool ACPF[1].
  - Water industry: Waterworks water quality data, facility operation, and reclaimed water data.
  - Biofuel industry: Facility energy and water survey.
  - State and local agencies: Agricultural management, water re-use data.

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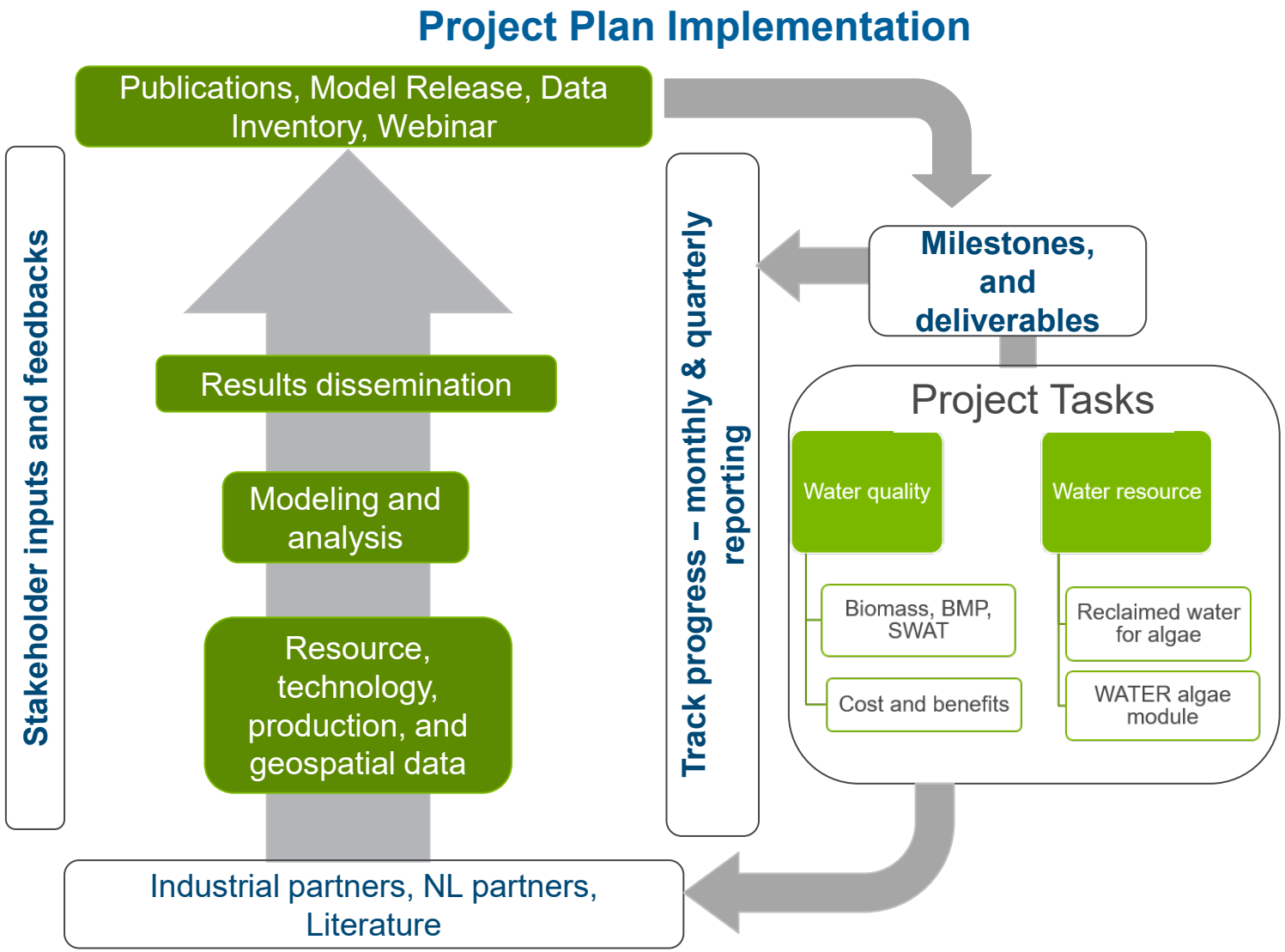
MANAGEMENT

Potential Challenges and Risks

- Incomplete temporal and spatial water resource data.
- Poor data quality; inconsistent estimates of water data by different data entities.
- Water use efficiency changes as technology/management advances.

Mitigation

- Collect **new industry data** that reflect current practices.
- Collect data from different agencies as **verification points**.
- Analyze sampling method and assess data reliability.
- Assess **uncertainty**.

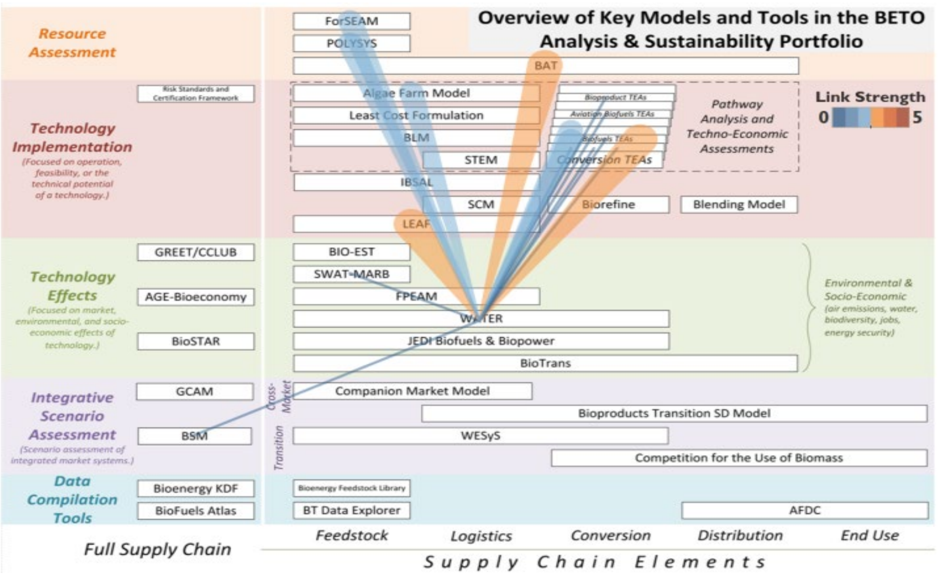


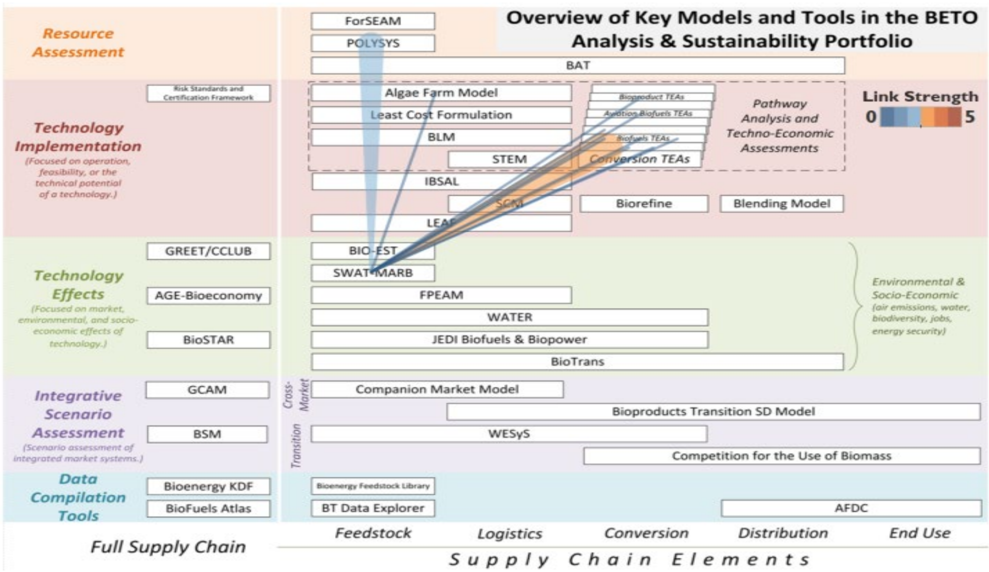
IMPACTS

WATER

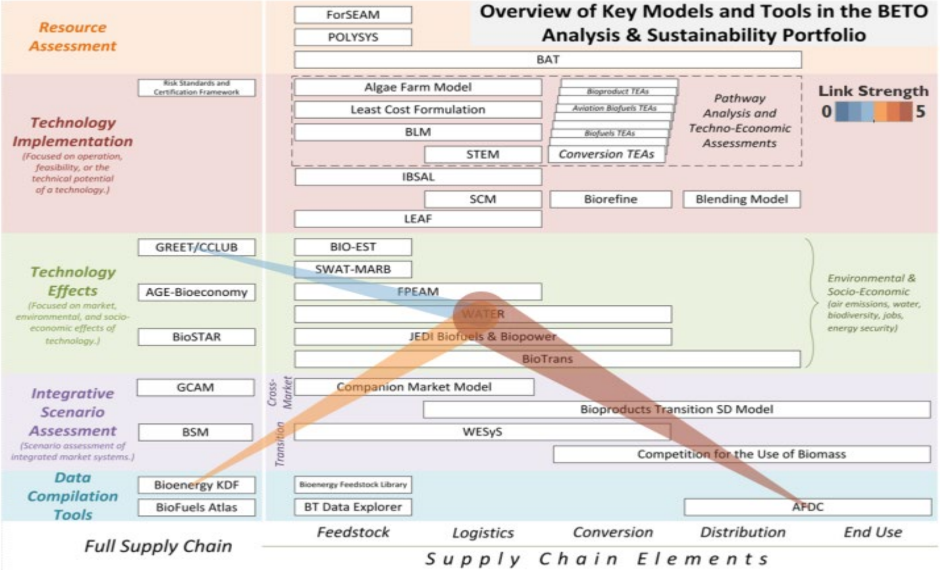
SWAT - MARB

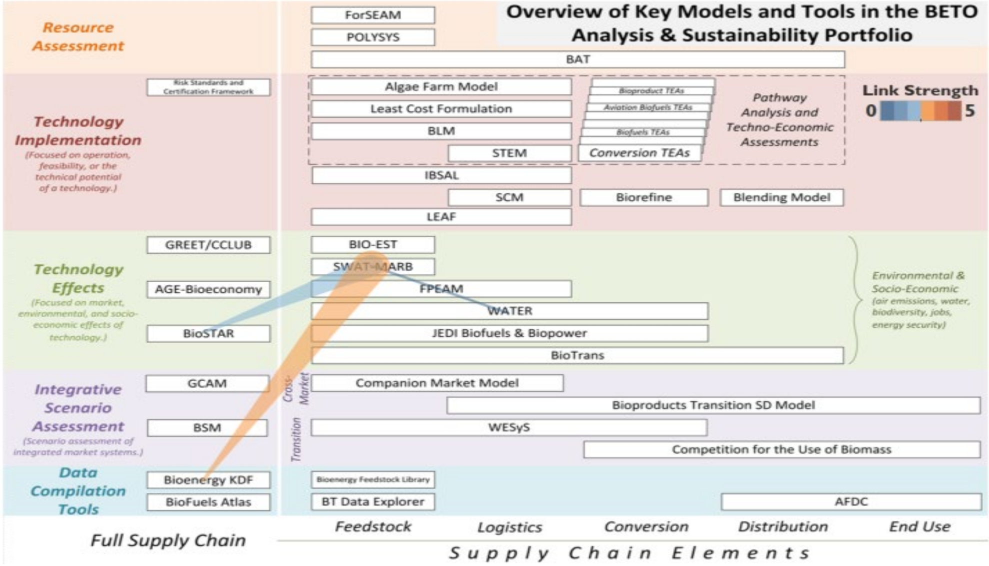
INPUT





OUTPUT





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IMPACTS

To BETO

- Addresses several BETO **technical barriers** and challenges, including[2]:
  - At-**B** Analytical Tools and Capabilities for System-Level Analysis
  - At-**C** Data Availability across the Supply Chain
  - At-**E** Quantification of Economic, Environmental, and Other Benefits and Costs
- Informs BETO's strategic thinking by evaluating the potential degree of impact of energy policies on water resources and identifying water-efficient technologies and scenarios.
- Provides a reliable platform and models/tools to examine water sustainability metrics.
- Provides inputs to other BETO projects:
  - Developing and simulating landscape design scenario for biomass production and evaluate water quality impact that supports ANTARES Landscape design project.
  - Sharing SWAT Raccoon River watershed model for water modeling task in the landscape TEA with BETO Integrated Landscape Management project.

To Stakeholders and broad community

- Improve understanding of trade-offs between production targets and water resource and quality.
- Inform decision-making for science-based data-driven feedstock production strategies; and develop technologically viable and water sustainable bioenergy applications.
- Contribute to feedstock decarbonization assessment tool in a joint effort with GREET-SWAT-Century.
- Communicate with water reuse projects with EPA, USDA, and other water agencies, state agencies across the U.S., contributing to national water conservation strategy.
- Products: journal publications, KDF[1], webinars, and presentations in major conference venues.

PROGRESS AND OUTCOMES: OVERVIEW

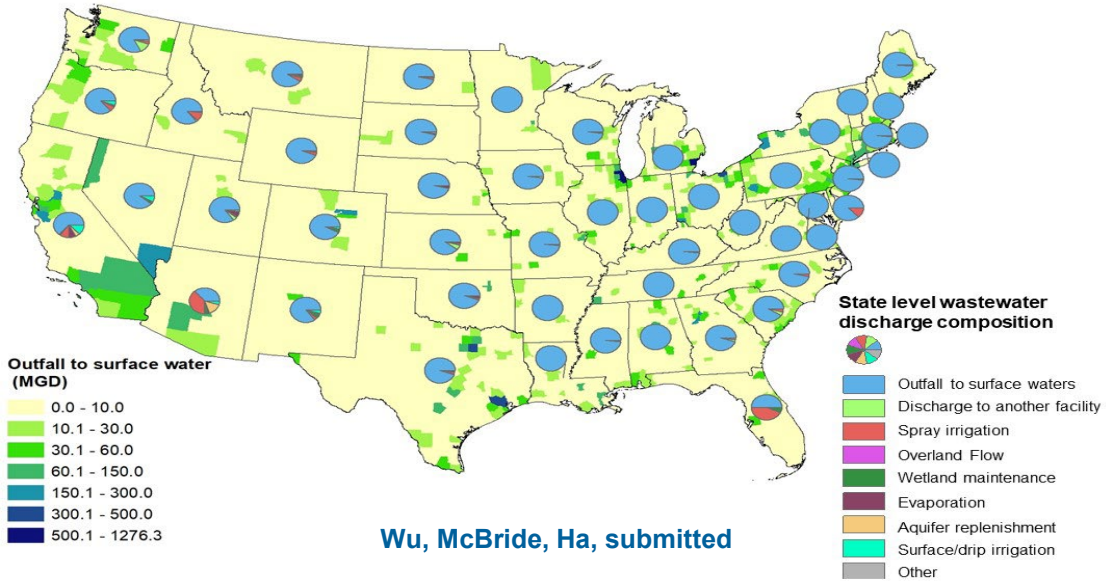
Since 2019 Peer Review

- Assessed water quality benefits of landscape design with conservation practices using **ACPF – SWAT**, contributing to the final report of ANTARES *Landscape Design* project. ★
- Developed a calibrated SWAT model for Raccoon River watershed, simulated water quality changes under multipurpose buffer using switchgrass, and developed **cost benefit analysis**. ★
- Analyze nutrients reduction **cost benefits** of riparian buffer to **drinking water supply** in Raccoon River watershed. ★
- Co-authored Water Quality chapter and Water Availability chapter of **EPA's** 3rd triennial Report to Congress (RTC3, draft under review). ★
- Contributed to a retrospective study of carbon intensity evolution in the biofuel industry.
- Developed three **reclaimed water for algae production** scenarios with geospatial analysis to estimate production potential algae-based renewable biodiesel blend at county level for the U.S. ★
- Released an analysis of 2018 **biorefinery survey** that summarizes facility-level energy and water use, providing an industrial benchmark. ★
- Implemented an algae production pathway, reclaimed water-based algae scenarios, and an algae database in the WATER model. ★
- Released **WATER 4.0** with a regional platform-WAI module capable of simulating future scenarios; updated petroleum water intensity. ★
- Developed a state-level survey of reclaimed municipal water reuse in various sectors.

★ Milestone

QUANTIFY RECLAIMED WATER FOR ALGAE BIOMASS

- Focus on reclaimed water currently discharged to surface water, which is available for reuse.
- Select counties in which reclaimed water can meet partially or fully the water demand for algae.
- Conduct geospatial screening followed by temporal screening to down-select facility locations.

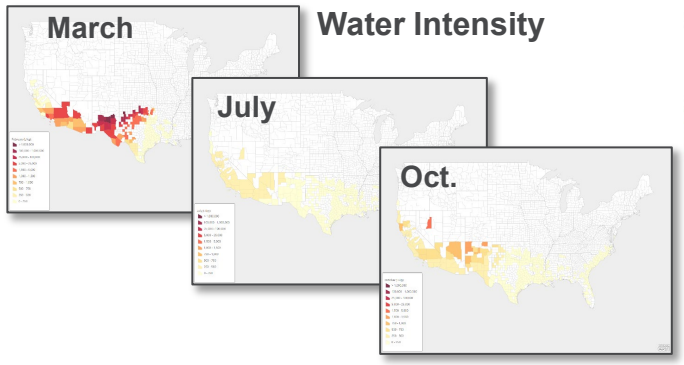


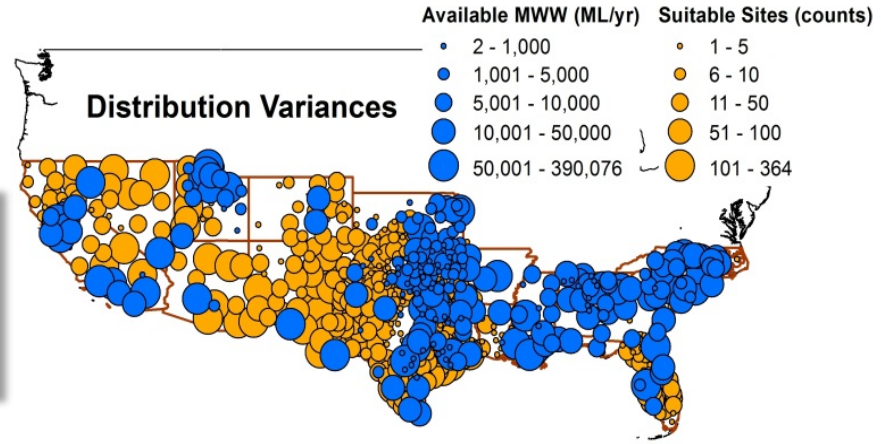
Wu, McBride, Ha, submitted

Algae water demand:

Location of pond facilities in 7075 sites in lower 17 states were selected by using 33 years climate and algae growth model and land down−selected for potential CO_2 supply.

- ***Collaboration with PNNL: Coleman and Wigmosta***.





Chiu and Wu, 2013, BioFPR

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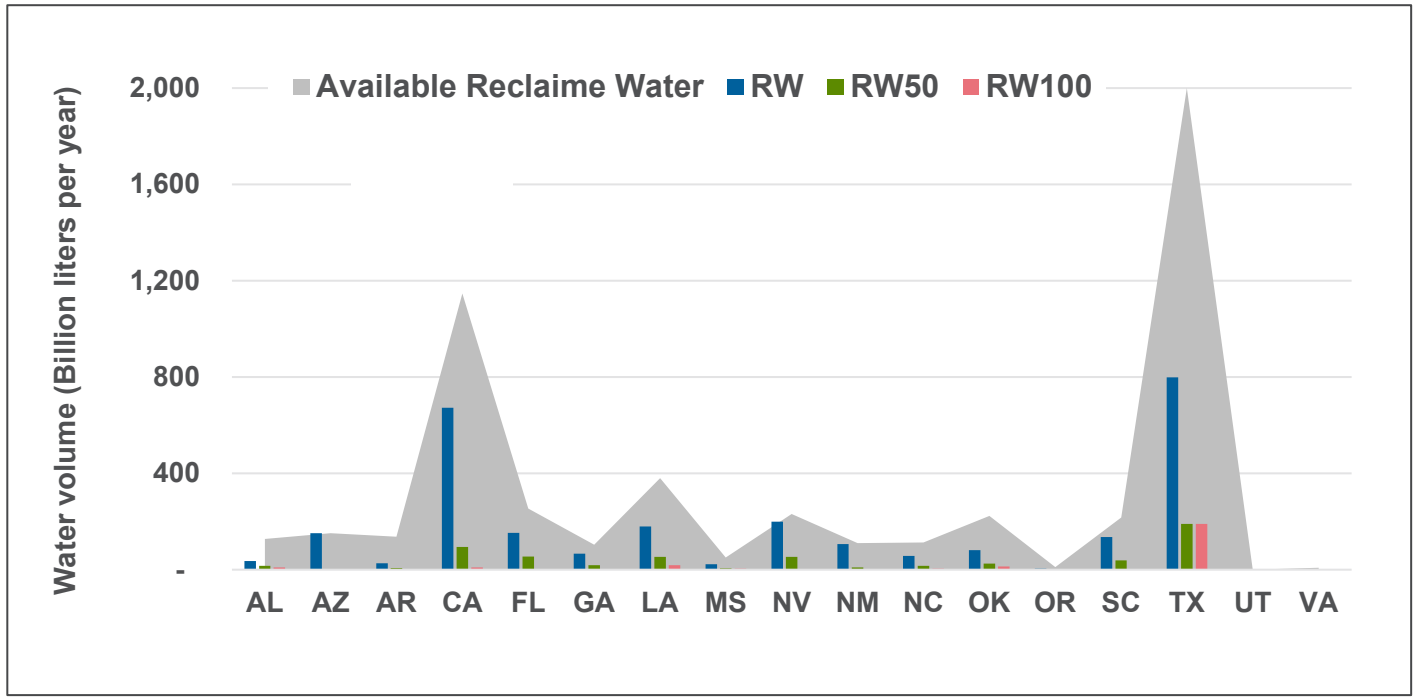
AVAILABLE RECLAIMED WATER IN ALGAE PRODUCTION REGIONS

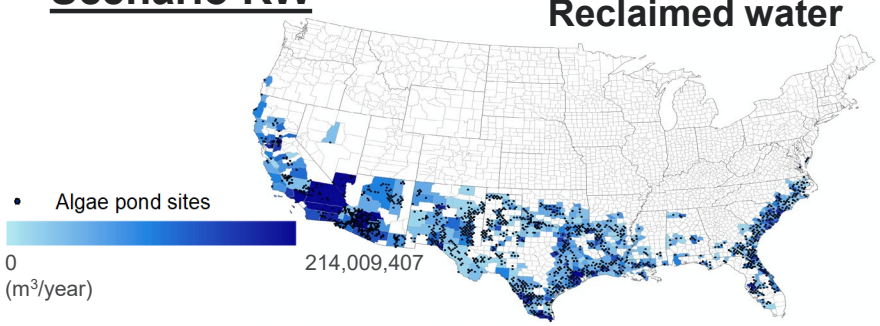
Developed three scenarios

- *RW* − Reclaimed water meets partial or full water demand for the production facilities in a county.
- *RW50* − Reclaimed water meets 50% of water demand for the production facilities in a county.
- *RW100* − Reclaimed water meets 100% of water demand for the production facilities in a county.

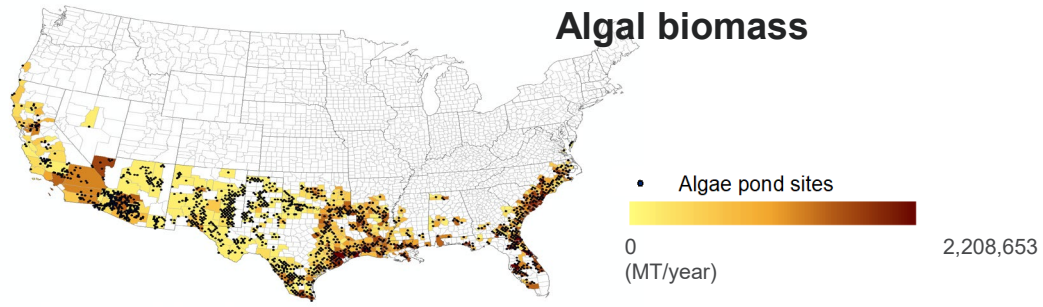


Scenario RW

Reclaimed water



Algal biomass



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RECLAIMED WATER FOR ALGAL BIOFUEL: KEY FINDINGS

Scenario	Reclaimed Water Volume Can Be Used For Algae	Number of Counties Affected	Algal Biomass Produced from Reclaimed Water	Renewable Biodiesel Equivalent via HTL from Algae
	BGY		Million Metric Ton	BGY
RW	712	455	42.2	7.7
RW50	154	290	14.0	2.6
RW100	67	33	4.4	0.8

- Counties can grow algae: 576
- Our nation currently use approximately 700 BGY of reclaimed water. Implementing reclaimed water for algae would double this figure.

Key Take-away: Domestic reclaimed municipal water would be able to support a significant amount of algal biofuel to meet BETO's production goal of **5 BGY**.

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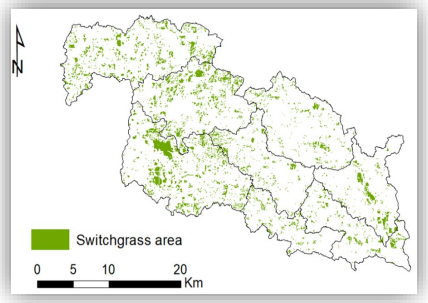
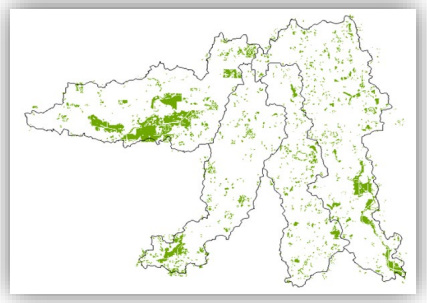
WATER QUALITY MODELING FINDINGS

SFIR

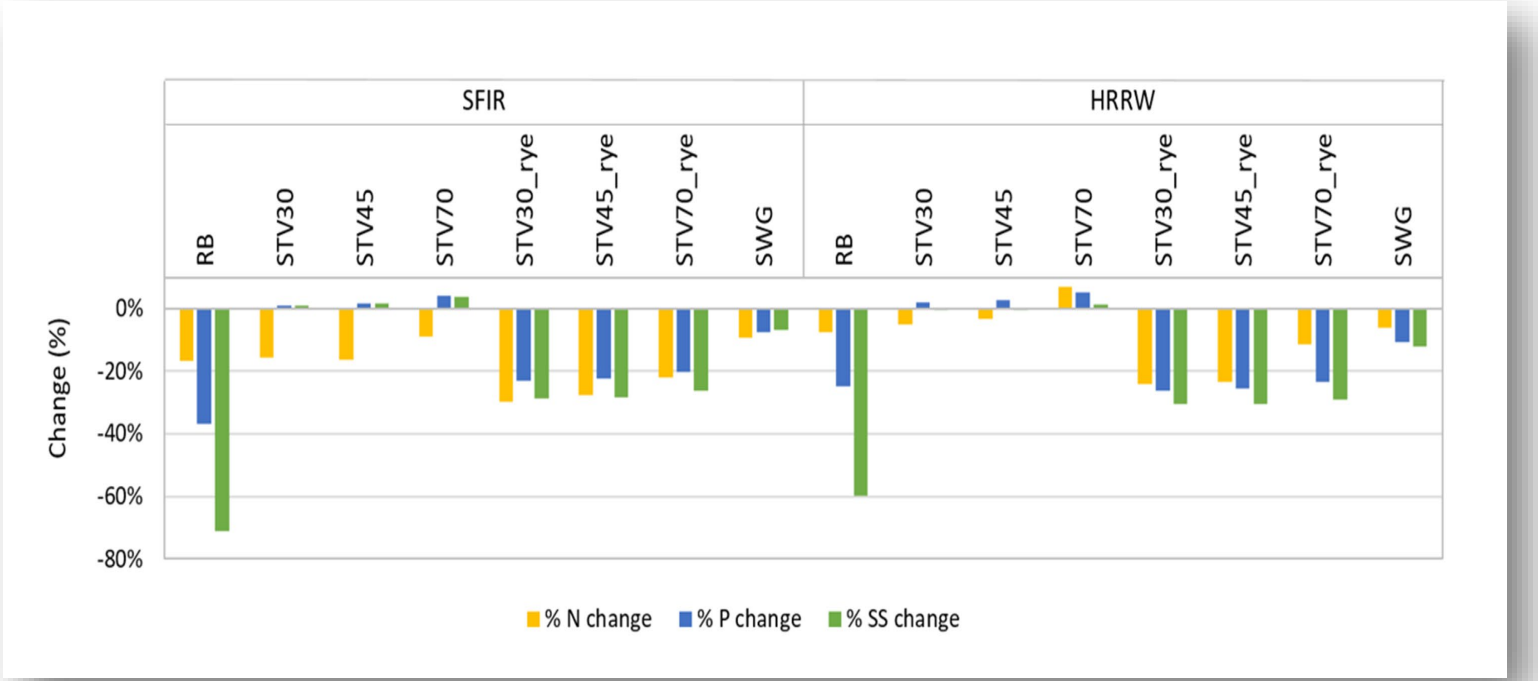


HRRW



- SFIR – Southfork of Iowa River watershed
- HRRW – Head water of Raccoon River watershed

Nutrient and soil loss reductions



Key take-away:

- Riparian buffer contributes to significant reduction of soil and phosphorus loss while cover crop has greater effect in reducing nitrogen loss.[1]

- RB – Riparian buffer.
- SWG – Landscape design with switchgrass.
- STV30, 45, 70 – stover removal at 30%, 45%, 70%.
- STV30_rye, STV45_rye, STV70_rye – stover removal with cover crop rye.
- SS – suspended sediments (soil erosion)

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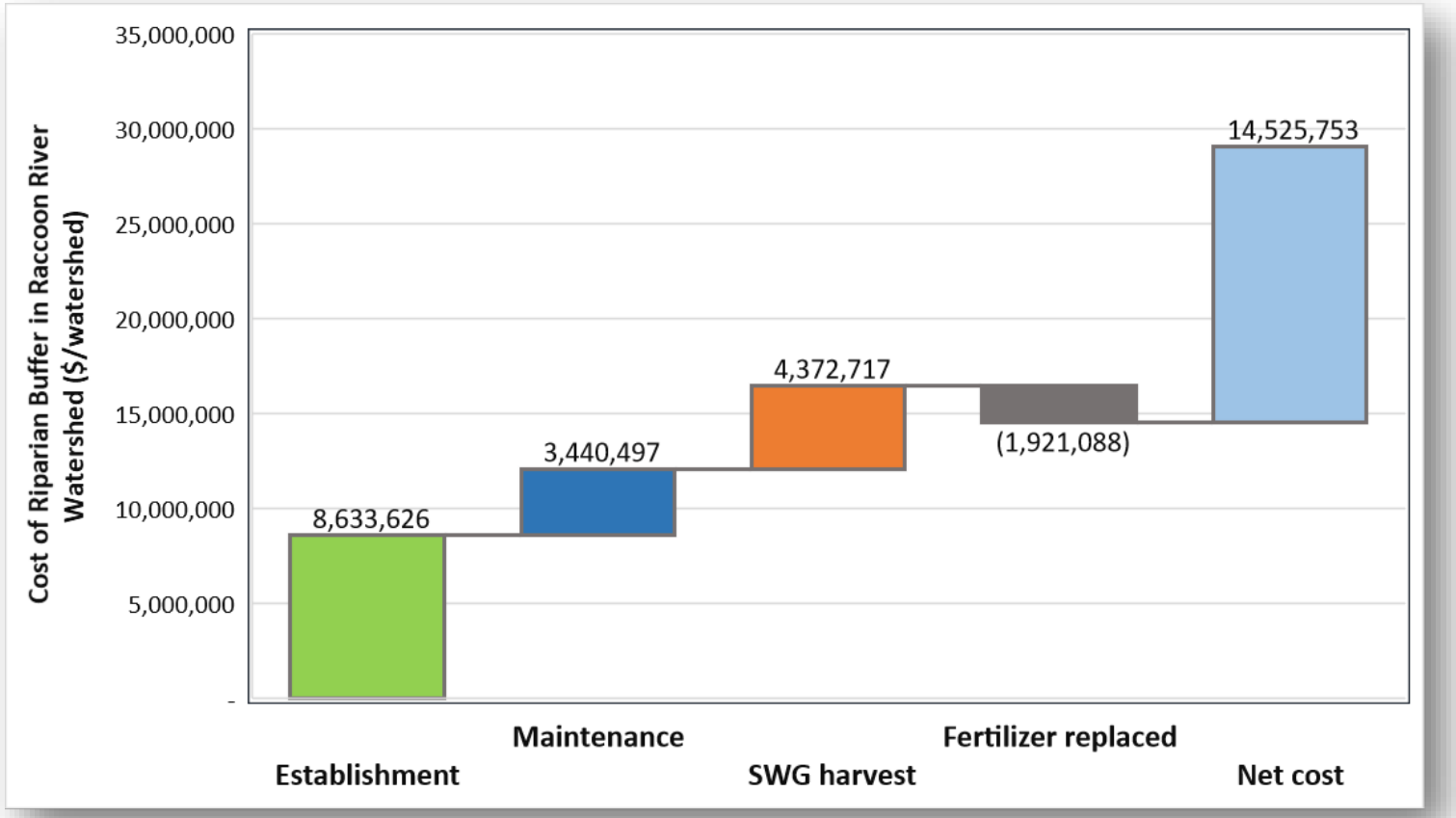
NUTRIENT VALUATION FINDINGS



- Cost benefit analysis of installing riparian buffer and use the nutrients trapped in riparian zone to grow biomass at Raccoon River Watershed.
- Nutrients trapped in the riparian zone account for 12% of the buffer cost.
- Further analysis revealed that the net return is sensitive to foregone income and SWG price.

Manuscript in preparation

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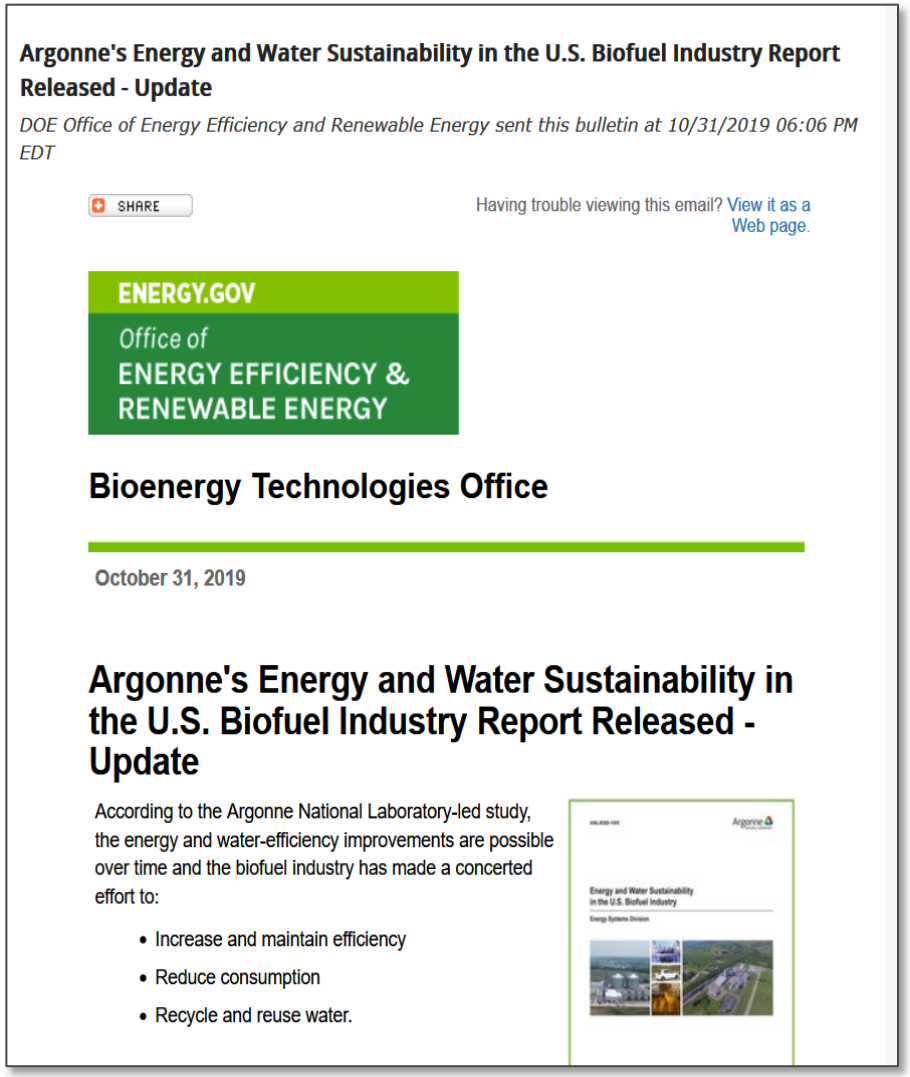
RELEASE OF BIOREFINERY SURVEY REPORT

Featured at ABLC Panel 2019 Oct.

- This survey is the **first of the kind** to present a comprehensive recording of *water resources, water use, and water and wastewater management* in addition to production and energy consumption for the commercial-scale ethanol plants at the facility level.
  - Data gathered helps to establish **industrial benchmarks**.
- Water intensity has decreased **by 54% in the 19 years** between 1998 and 2017.
- **36% of facilities achieved Zero liquid discharge** (ZLD) by implementing in-plant water reuse and recycling.
- The survey has demonstrated a continuous improvement of yield and a diversified product portfolio, leading to improved process economics and environmental benefits.
  - **14% of the facility extracted a CO_2 stream**. CO_2 export from ethanol plants made up about 40% of the North American merchant market in 2017.



Argonne's Energy and Water Sustainability in the U.S. Biofuel Industry Report Released - Update

DOE Office of Energy Efficiency and Renewable Energy sent this bulletin at 10/31/2019 06:06 PM EDT

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Bioenergy Technologies Office

October 31, 2019

Argonne's Energy and Water Sustainability in the U.S. Biofuel Industry Report Released - Update

According to the Argonne National Laboratory-led study, the energy and water-efficiency improvements are possible over time and the biofuel industry has made a concerted effort to:

- Increase and maintain efficiency
- Reduce consumption
- Recycle and reuse water.

https://water.es.anl.gov/documents/EW%20survey%20report%20final%20ANL.pdf

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WATER (Water Analysis Tool for Energy Resources)

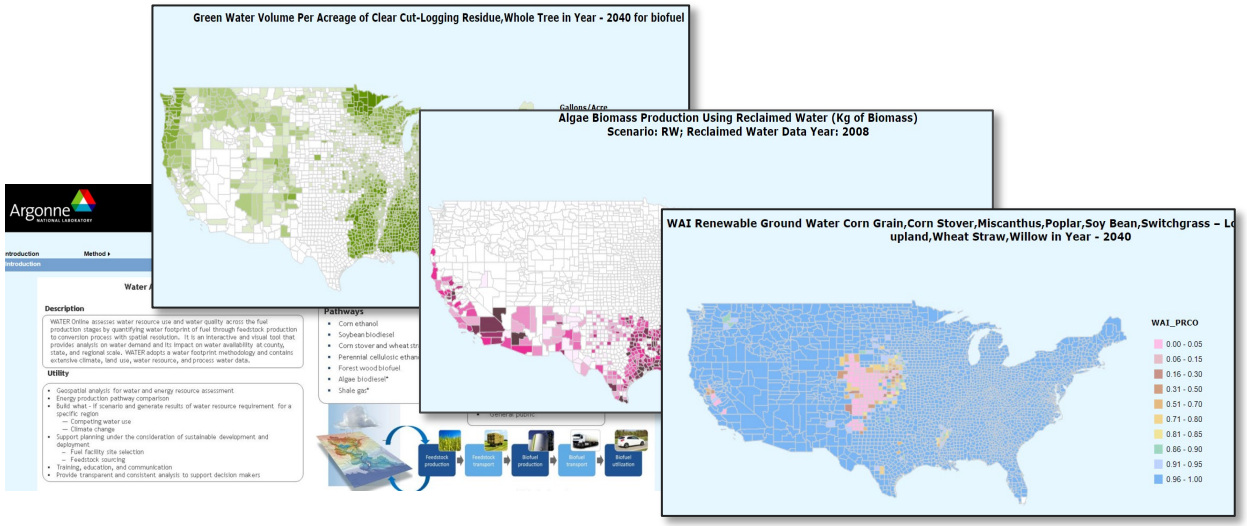
https://WATER.es.anl.gov

Biofuel pathways

- Ethanol, biodiesel, renewable diesel blend, renewable hydrocarbon, mixed alcohol
  - Corn (grain, fiber, stover), soybean, wheat straw
  - Switchgrass and Miscanthus
  - Forest wood (hard, soft, mixed) residue
  - SRWC (willow, hybrid poplar)
  - Micro-algae (reclaimed water)

Water intensity of other fuels and energies

- Petroleum - Domestic onshore oil
- Electricity - Fossil, renewable, nuclear, geothermal, hydro



Features

- Water footprint of biofuel production pathways
- Water availability for feedstock production scenarios
- Feedstock production and conversion stages
- Surface water, renewable groundwater, rain, reclaimed municipal wastewater
- Metric: water consumption intensity, water availability indices
- County, state, and regional level in the U.S.

Application

- Assess water resource impact of future scenarios.
- Evaluate production pathways.
- Enable compatible spatial resolution with POLYSYS, LEAF, FAPRI, and other models/tools.
- Support BETO with spatial-explicit water analysis, allowing analysis of the interplay among policy, economics, and environmental factors with granularity.

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EPA'S 3RD TRIENNIAL REPORT TO CONGRESS

- Contributed to two chapters of EPA's 3rd triennial report to congress (RTC3):
  - Water Quality
  - Water Availability
- Authored five sessions
  - Water availability in future biomass production scenarios
  - Water use in commercial-scale ethanol plants
  - Biofuel comparison with petroleum in water consumption footprint
  - Water quality modeling of biofuel production in Mississippi River Basin tributaries
  - Water quality impact of biomass production integrated with conservation practices
- **Collectively this is a cumulative of more than ten years of work supported by BETO**.

STAKE HOLDER ENGAGEMENT & COLLABORATIONS

- Joined Road Mapping Broad Team of **NAWI** (national alliance of water innovation – a water hub established by AMO[1]), contributed **unconventional water resource use and R&D priority** workshops and Road-mapping.
- Reached out to **EPA's WRAP** (water reuse action plan) program and water industry partners, seeking synergy in the area of water reuse among agencies. This project will be listed as an action item of WARP.
- Interacted with **Renewable Fuel Association and biorefineries** on bench marking and implications.
- Collaborated with **Des Moines Waterworks** on water quality impact on plant operations.
- Collaborated with **USDA ARS** on ACPF-SWAT work.
- Interacted with **state agencies** on **reclaimed water reuse** guidelines and process (CA, FL, TX, NM, AZ, and others); and nutrient reduction strategy (IL).

Key take-away:

- Broad engagement with stakeholders to keep track of the water resource conservation, water use efficiency, and improve water quality by using biomass.

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SUMMARY

Overview

- Develop an online WATER model to illustrate water footprint and water resource impact of biofuels produced from conventional and advanced feedstock; an analysis of biorefinery energy-water use; and watershed models (SWAT) to evaluate the effects of integrated landscape design with conservation practices on water quality at feedstock production regions.

Approach

- Collaborate with water and agriculture agencies, partner with public and private sectors, seek input from stakeholders, and capture the most recent industry data available.
- Develop well-defined framework, consistent methodology, and rigorous calibration; incorporate geospatial and temporal resolution with national coverage.

Impacts

- Provide BETO leadership with models, tools, and analyses that are science-based, robust, and high quality to support strategy development.
- Provide DOE stakeholders with quantifiable economic and environmental value proposition analysis to inform decision-making.

Key Technical Accomplishments

- Developed three reclaimed water for algae production scenarios with geospatial analysis to estimate production potential of algal biofuel at county level for the U.S.
- Released WATER 4.0 containing a regional platform that is capable of simulating WAI of future scenarios. Implemented an algae production pathway, reclaimed water-based algae scenarios, and an algae database in WATER model.
- Released an analysis of 2018 biorefinery survey that summarizes facility level water use and conservation practices, and areas critical to improved water use efficiency.
- Published a study on water quality benefits of bioenergy production based on landscape design and conservation practices integrating ACPF and SWAT in two watersheds in Iowa.
- Developed a SWAT model for Raccoon River watershed to simulated water quality changes under multipurpose buffer and developed cost benefits of nutrient reduction.
- Co-authored Water Quality chapter and Water availability chapter of EPA's 3rd triennial Report to Congress (under review).

Geospatial Analytical Framework for Water Sustainability

Quad Chart Overview

Timeline

- Project start date: Oct. 2017
- Project end date: Sept. 2020

	FY20
DOE Funding	$500,000 (10/01/2019 – 9/30/2020) 3-year cycle: $1,300,000

Major Project Partners

- ANTARES, USDA ARS
- ANL (M. Wang, C. Negri), NREL (R. Davis), ORNL (Y. Jager, E. Parish), PNNL (M. Wigmosta)
- Des Moines Waterworks
- RFA, Growth Energy, NBB
- EPA, Water Environmental Federation, Water Research Foundation

Funding Mechanism: AOP

Project Goal

Develop science-based tools and analysis for improved understanding of the effect of feedstock and fuel production with conservation practices on regional freshwater availability and water quality, economic value, and the implication of water reuse in the bioenergy production.

End of Project Milestone

Developing water availability indices and water footprint for reclaimed water-based algae scenarios; developing water quality and economic value analysis of two Iowa watersheds.[1]

Barriers addressed

At-**B** Analytical Tools and Capabilities for System-Level Analysis

At-**C** Data Availability across the Supply Chain

At-**E** Quantification of Economic, Environmental, and Other Benefits and Costs

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Acknowledgements

BETO: Andrea Bailey, Alicia Lindauer

- ANTARES: Kevin Comer, Bill Belden
- ANL: Cristina Negri, Michael Wang
- Des Moines Waterworks
- Ecolab-Nalco
- Growth Energy
- Greeley & Hansen
- Iowa State University
- ORNL: Esther Parish, Yetta Jager
- NREL: Ryan Davis
- National Biodiesel Board
- PNNL: André Coleman, Mark Wigmosta
- Portland State University
- Renewable Fuel Association
- State of Iowa
- USDA ARS: Mark Tomer
- U.S. Army Corp. Engineers
- U.S. EPA WRAP
- Water Environmental Federation
- Water Research Foundation
- Water Reuse Association

ADDITIONAL SLIDES

DEFINITIONS

- **BMPs –** Best management practices
- **Blue water –** Fresh surface and groundwater
- **Evapotranspiration (ET) –** Loss of water from the land cover both by evaporation from the soil surface and by transpiration from the leaves of the plants growing on it
- **Effective Rain (ER) –** The part of rainfall stored in the root zone and can be used by the plants (FAO)
- **Green water –** Soil moisture from rainfall that is consumed by vegetation; the use of effective rain
- **Grey water footprint –** Volume of water required to dilute the chemicals in the wastewater to an acceptable level of concentration for the water body (*specific to the WF methodology*)
- **MRB** – Mississippi River Basin
- **Renewable Diesel Blend (RDB) –** Fuel produced from biological sugar-to-hydrocarbon process
- **SWAT –** Soil Water Analysis Tool, a hydrologic watershed model
- **WAI** – Water availability indices.
- **Water footprint (WF) –** Net water loss to evapotranspiration and evaporation; incorporation of water into products or solids by a production process or activity
- **Water withdrawal –** Water uptake from surface or groundwater
- **Water consumption or Consumptive water use –** Water evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise not available for immediate use (accounted for in WF analysis)

RESPONSES TO PREVIOUS REVIEWERS' COMMENTS (2019)

Comments

It is important to understand the freshwater demand and implications for water quality of the bioenergy sector, and the WATER model is very comprehensive. Water resource mapping of soil moisture, streamflow, etc. and evidence for water quality/quantity benefits of various management strategies could be very valuable as siting decision criteria for growing / selecting feedstocks and/or for landscape management decisions. It was not clear how the analysis takes into account existing and planned uses of the water that are not the bioenergy sector, nor if there are interactions among water demand types (i.e., if a shift to growing bioenergy crops reduces water demand from some other crop).

Responses

Thanks for the comments. This water analysis takes into consideration existing land use by agricultural sector and forestry sector — the largest water consumption players in non-bioenergy sectors. We have analyzed and will continue to examine the interactions and effects of shifting land use and shifting crop types among these sectors and bioenergy on various freshwater resources across geographic regions.

PUBLICATIONS (*SINCE 2019 REVIEW*)

- **Miae Ha., May Wu**, M. Tomer, P. Gassman, T. Isenhart, J. Arnold, M. White, E. Parish, K. Comer, and W. Belden. 2020. "Biomass Production with Conservation Practices for Two Iowa Watersheds," *JAWRA*. Published. Doi.org/10.1111/1752-1688.12880.
- **May Wu.** 2019. "Energy and Water Sustainability in the U.S. Biofuel Industry"., Argonne National Laboratory, ANL/ESD-19/5.
- **May Wu, Sarah McBride, and Miae Ha**. Implications of Reclaimed Municipal Water Resource Geospatial and Temporal Availability for the Production of Algal Biofuel in the United States, under review with *Journal of Algal Research*.
- Uisung Lee, Hoyoung Kwon, **May Wu**, Michael Wang. Retrospective Analysis of U.S. Corn Ethanol Industry for 2005–2019: Implication for Greenhouse Gas Emission Reductions, under review with *Environmental Research Letters*.
- R. Dodder, Y. Yuan, S. Evett, **M. Wu**, J.E. Compton. *Chapter 11, Water Use and Availability*, in EPA's Third Triennial Report to Congress, second order draft, under review.
- J. Compton, B. Niblick, J. Carleton, R. Haerer, S. Miller, M. Pennino, R. Sabo, **M. Wu**, Y. Yuan, X. Zhang. *Chapter 10: Water Quality*, in EPA's *Third Triennial Report to Congress*, second order draft under review.
- **Miae Ha and May Wu**. Economic and ecosystem benefits of multi-purpose buffer with biomass production in an agricultural-urban watershed, under review.

PRESENTATIONS (*SINCE 2019 REVIEW*)

- **May Wu** co-chaired the organization committee for 2020 AIChE Bioenergy Sustainability Conference (Virtual), show casing BETO sustainability program with keynote speaker **Alicia Lindauer** and highlighting ANTARES Landscape Design project, Oct. 13-15, 2020.
- **May Wu.** *Implications of Regional Produced Water Use in crude Production Water Footprint*. Ground Water Protection Council (GWPC) Annual Forum Virtual, Water Reuse Session. Sept. 28-30, 2020.
- **May Wu, Miae Ha, Sarah McBride**. *Reclaimed Water Resource Availability for Algal Biomass in the U.S.* 14th Algae Biomass Summit Virtual, Sustainability and Resource Availability Session. Aug. 12 - Sept. 30, 2020.
- **May Wu**. *Energy-Water Nexus of the U.S. Biofuel Industry – 2017 Ethanol plants Survey*. BIofuels Environmental, Health & Safety Forum, Virtual 2020 Few Ethanol Workshop & Expo. Virtual, Sept. 15-17, 2020.
- **May Wu**. *Energy and Water Sustainability of Biorefineries* . AWMA ACE 2020, Virtual Conference, Live Stream Session: Zero Waste Innovation, Plans, & Program. June 30-July 1, 2020.
- **May Wu and Miae Ha.** *Water quality modeling and analysis,* Landscape Design project meeting, December 17–18, 2019, Des Moines, IA.
- **May Wu and Miae Ha.** *Assessing Reuse of Reclaimed Water for Energy Production in the United States,* 2019 Annual Water Resources Conference, November 3–6, 2019, Salt Lake City, UT.
- **Miae Ha and May Wu**. *Biomass production with conservation practices,* 2019 Annual Water Resources Conference, November 3–6, 2019, Salt Lake City, UT.
- **Miae Ha and May Wu**. *Impacts on water quality of integrating landscape design with conservation practices for biomass production*, 2019 AIChE Bioenergy Sustainability Conference, October 21–22, 2019, Nashville, TN.
- **May Wu. I**nvited panel speaker, *Water Footprint—Application in LCA and Water Management*, American Center for Life Cycle Analysis (ACLCA) webinar, August 28, 2019.
- **Miae Ha**, *Implication for biomass production with landscape design to water quality in two Iowa watersheds,* Landscape Design Project meeting, August 15, 2019.
- **May Wu.** Invited speaker, *Water Sustainability*, Great Lakes Ecosystem, Graduate Program and Partnerships, Chicago Zoological Society, July 24, 2019.