Pacific Northwest NATIONAL LABORATORY

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DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review

Biofuel Production in the Western U.S.

March 25, 2015

Analysis & Sustainability

Mark Wigmosta

PNNL

Goal Statement

Goal: Identify opportunities and sustainability constraints at the sub-county-level to support aquatic and terrestrial biofuel feedstocks. Three focus areas:

- Identify spatial and temporal patterns in consumptive water use and locations of water scarcity.
- Provide a detailed assessment of the potential for integration of switchgrass into the existing western U.S. crop mix to increase national biofuel production without increasing net water use or adverse environmental impacts.
- Evaluate the potential for blending feedstocks that exhibit significant seasonal variability (i.e., algae) with alternative feedstocks having superior storage and transportation properties (i.e., MSW) to stabilize supply.
- This project directly supports the following MYPP targets
  - By 2015, integrate feedstock quality criteria and blending strategies to generate more comprehensive supply scenarios, meeting biorefinery infeed specification targets at the lowest possible feedstock price.
  - By 2018, establish sub-county-level environmental impact criteria and logistics strategies.
  - By 2018, using available field data, validate case studies of feedstock production systems that reduce greenhouse gas emissions and maintain or improve water quality and soil quality compared to conventional agriculture and forestry.

Quad Chart Overview

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Timeline

- Project start date: June 2010
- Project end date: Sep 2014
- Percent complete 100%

Budget

	Total Costs FY 10 – FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date
DOE Funded	$415,254	$242,015	$179,279	$0
Project Cost Share (Comp.)*				

Barriers

- Ft-A: Biomass Availability and Cost
- St-A. Scientific Consensus on Bioenergy Sustainability
- St-C. Sustainability Data across the Supply Chain

Partners

- Washington State University
- Other Collaborators
  - USDA-ARS
  - Univ. of Arizona
  - Univ. of Nevada, Reno
  - Univ. of California, Davis
  - Univ. of Wyoming
  - Univ. of Idaho

1 - Project Overview

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- While the U.S. Billion Ton Update does not consider the use of irrigation for energy crop production, it does note (Text Box 5.1):
  - "In the western United States, most crops, including hay crops, are grown under irrigation. Irrigated energy crops will never compete economically with high-value irrigated crops, such as fruits and vegetables, but may be able to compete with lower valued crops such as hay and small grains. <u>One potential energy crop species for irrigation in the western United States is switchgrass</u>."

- This project complements ongoing Billion Ton activities by providing a systematic assessment of:
  - national water use and scarcity
  - the potential for integration of energy crops into the existing western United States crop mix <u>without increasing net water use</u>
  - the potential for blending algal feedstocks with alternative feedstocks having superior storage and transportation properties

2 – Approach (Technical)

Our resource assessment efforts have demonstrated the profound effect that relatively small scale spatial and temporal variability can have on feedstock production and resource availability. We used the following methods for our sub-county-scale analysis:

- **Water Scarcity:** Detailed spatial land use data were used to disaggregate USGS county-level annual consumptive water use data to a $1/8^{th}$ degree (~12 by 12 km) scale by water use sectors. $1/8^{th}$ degree meteorological data were then used to estimate monthly consumptive use.

- **Switchgrass Production:** A piece-wise regression was developed based on observed site growing season maximum air temperature (dominant controlling factor) and biomass yield at Western U.S. field trial sites. PRISM 4-km resolution data were used to drive the regression equations throughout the west at the farm scale on lands currently used for pasture, hay, and small grains.

- **Algae-MSW Feedstock Blending:** Data from 2,235 geo-located landfills provided point estimates of MSW volumes and characteristics. The Biomass Assessment Tool was used to estimate the timing and yield of algal biomass at ~90,000 locations. These data were used to determine the best locations for HTL oil processing plants with a specified capacity and the number and location of algal feeder farms and associated landfills to achieve that capacity.

2 – Approach (Management)

- Project Management Plans
  - SOW and impact on achieving DOE goals
  - Quarterly milestones
  - Planned spend rate
- Quarterly Progress Reports to BETO
  - Progress against PMP milestones and review of relevance to MYPP
  - Actual costs against PMP planned spend rate
  - Impact assessment and mitigation approach for any variances
  - Plans for next quarter
- Project Communications
  - Weekly status and technical discussion with PNNL staff
  - Regular conference calls with non-PNNL partners
  - Quarterly formal reporting to BETO
- Potential Challenges
  - Timely access to experimental results and data
  - Communication and feedback from industry

Water Scarcity

The understanding of water resources and its use, from a spatiotemporal perspective, is critical for shaping future water use policy and management.

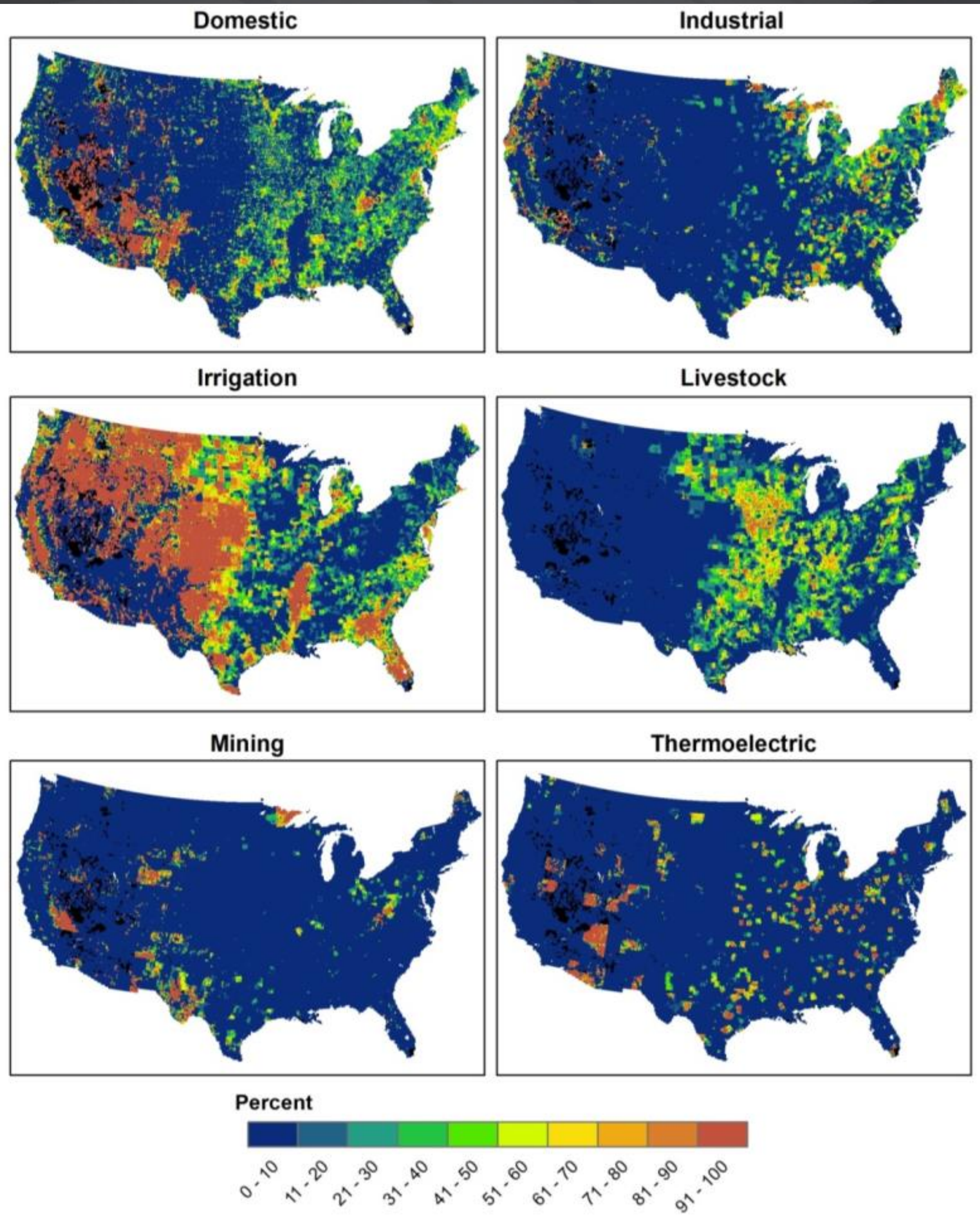
We present a systematic method for both spatial and temporal disaggregation of nationally-available annual, county-scale water use data to a consistent 1/8° spatial resolution at a monthly time-step.

- Detailed spatial land use data were used to disaggregate USGS county-level annual consumptive water use data to a 1/8° (~12 x 12 km) scale by water use sector:
  - Domestic
  - Industrial
  - Irrigation/Agriculture
  - Livestock
  - Mining
  - Thermoelectric

- 1/8° meteorological data were then used to estimate monthly consumptive use by sector.

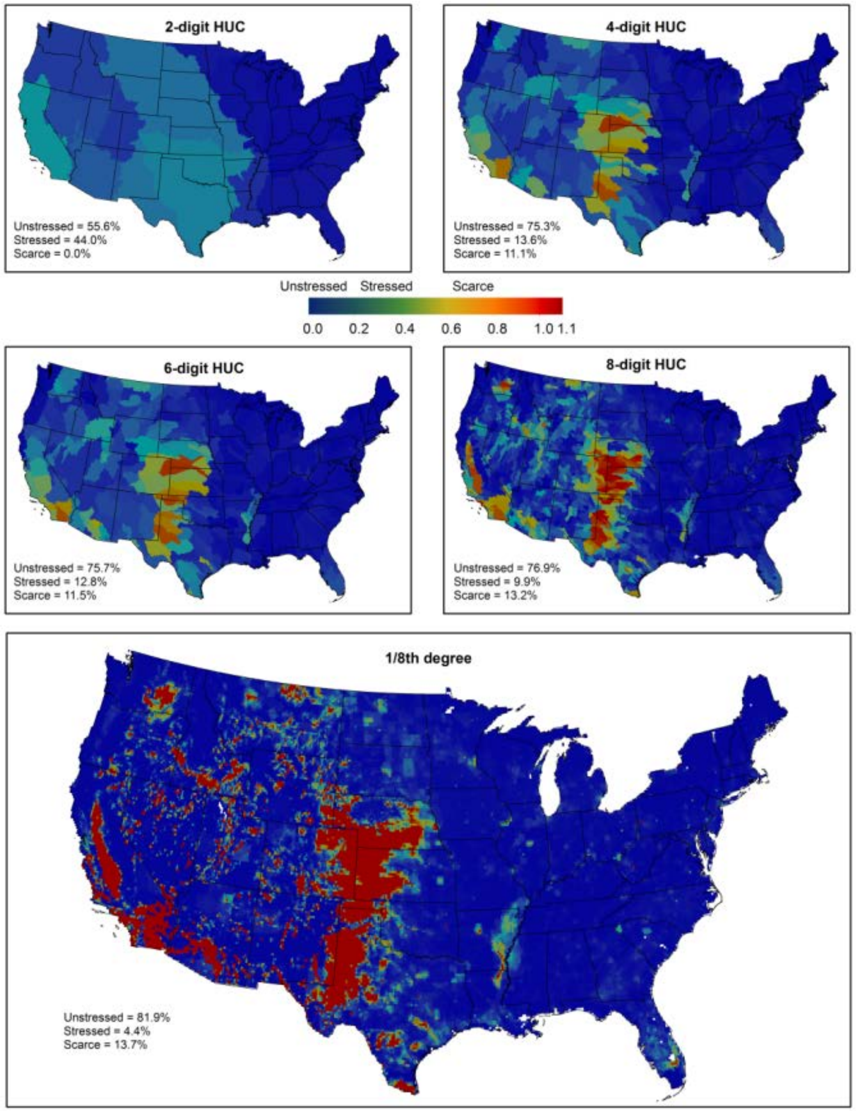
- Local estimates of average monthly runoff from 1980-2000 at the 1/8° resolution were computed using USGS 8-digit HUC runoff data (Brakehill et al., 2011).

1/8° (~12 x 12 km) Consumptive Water Use



- Disaggregated from USGS county level annual data based on 1/8° land use / land cover
- Percent of annual consumptive use relative to the total consumptive water use for each variable included in the study

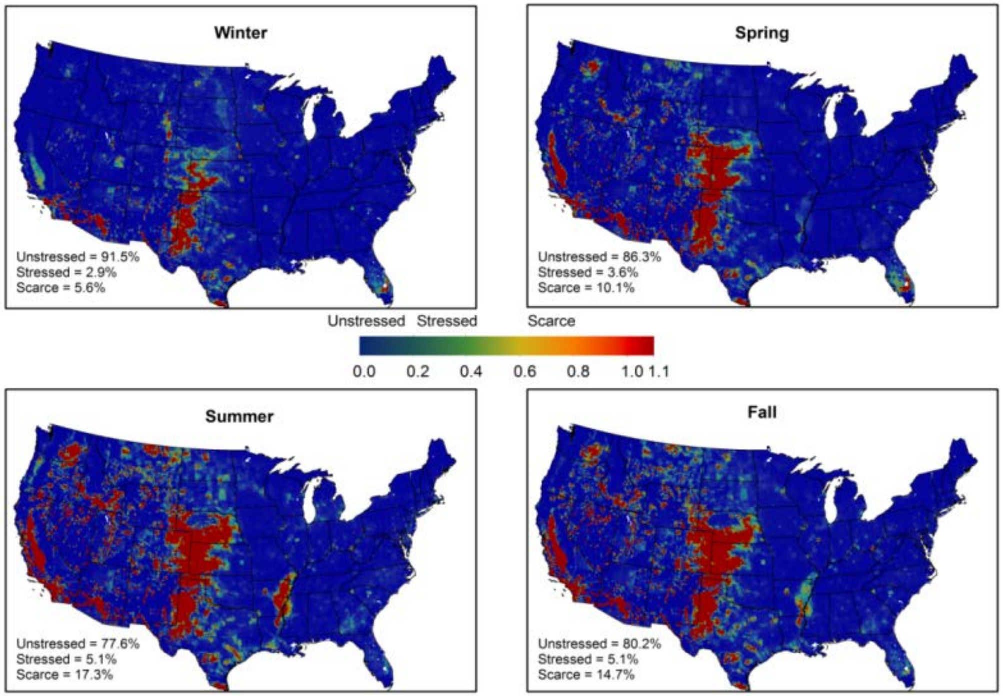
Influence of Spatial Scale on Estimates of Water Scarcity



Water Scarcity (Ws) = Consumptive Water Use / Runoff

- Unstressed: Ws < 0.2
- Stressed: 0.2 ≤ Ws < 0.4
- Scarce: Ws ≥ 0.4

Seasonal Changes in Water Scarcity



Temporal patterns of water scarcity are critical to water management.

Winter to Summer changes:

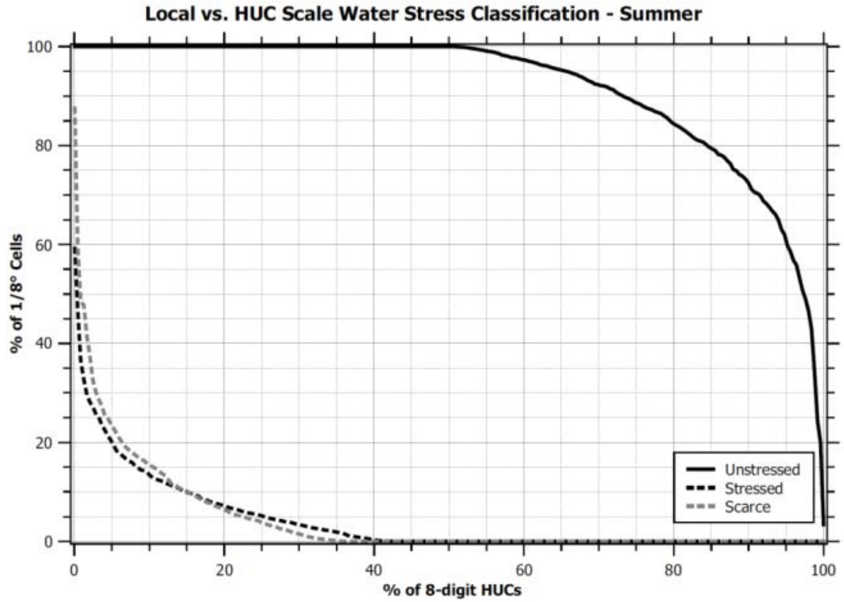
- Unstressed: 92% to 78%
- Stressed: 2.9% to 5.1%
- Scarce: 5.6% to 17.3%

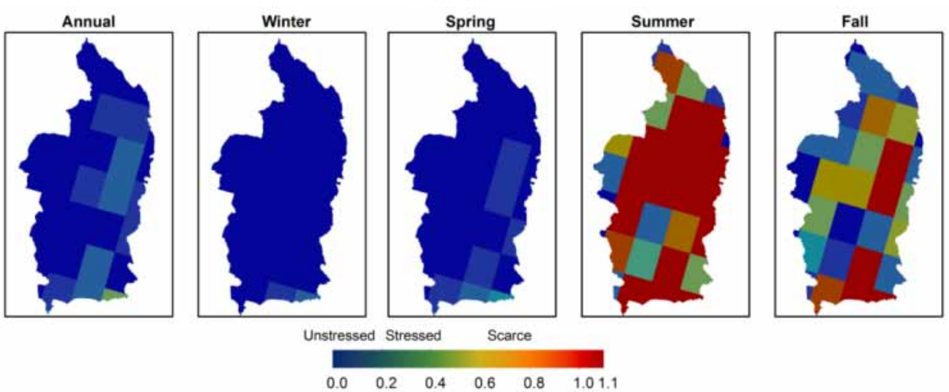
Water demand in scarce areas likely met through inter-basin transfer or mining of ground water

- western irrigation
- Ogallala Aquifer

Moore BC, AM Coleman, MS Wigmosta, RL Skaggs, and ER Venteris. A high spatiotemporal assessment of consumptive water use and water scarcity in the conterminous United States. Water Resources Management, *in review*.

Water Scarcity Classification at 8-Digit HUC for Annual Scale and Summer Season





Annual

- In 10% of these HUCs ~15% of the basin is classified as stressed or scarce
- In 5% of these HUCs ~25% of the basin is classified as stressed or scarce

Summer

- In 10% of these HUCs 27% of the basin is classified as stressed or scarce
- In 5% of these HUCs over 43% of the basin is classified as stressed or scarce

There are significant water stressed and scarce areas within 8-digit HUCs classified as unstressed at the annual scale.

Integration of Switchgrass into the Existing Western U.S. Crop Mix

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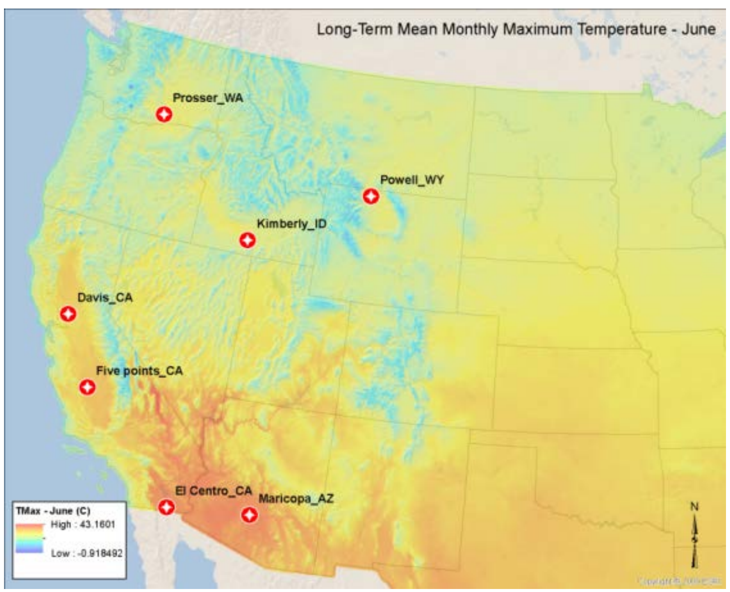
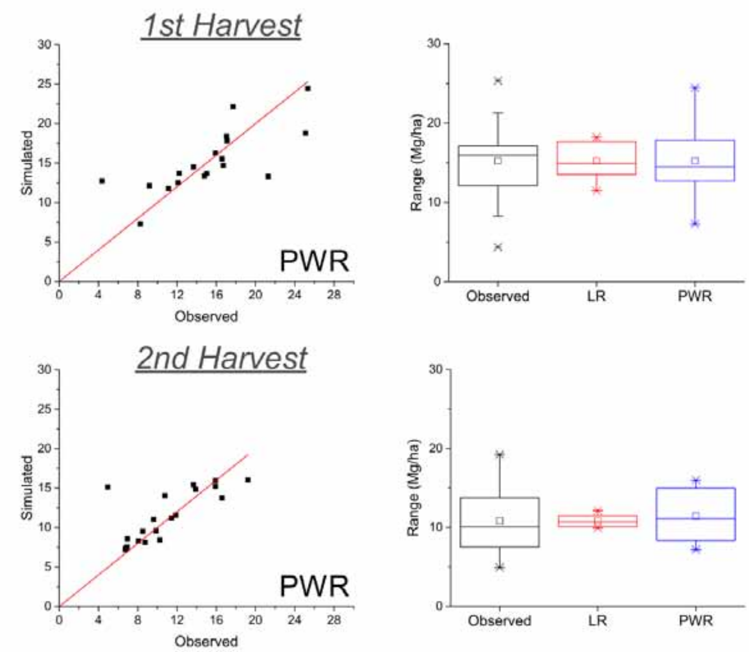
- Three switchgrass types (Alamo, Blackwell, Kanlow) were evaluated under a twice per year harvest system.
- A piece-wise regression was developed based on observed site growing season maximum air temperature (dominant controlling factor) and biomass yield at Western U.S. field trial sites from 2006-2010.
- PRISM 4-km monthly maximum air temperature from 2006-2010 was used to drive the regression equations to estimate production potential on existing irrigated pasture, hay, and small grains throughout the 11 western states.





Production of Alamo, Kanlow & Blackwell Switchgrass on Existing Irrigated Pasture, Hay, and Small Grains

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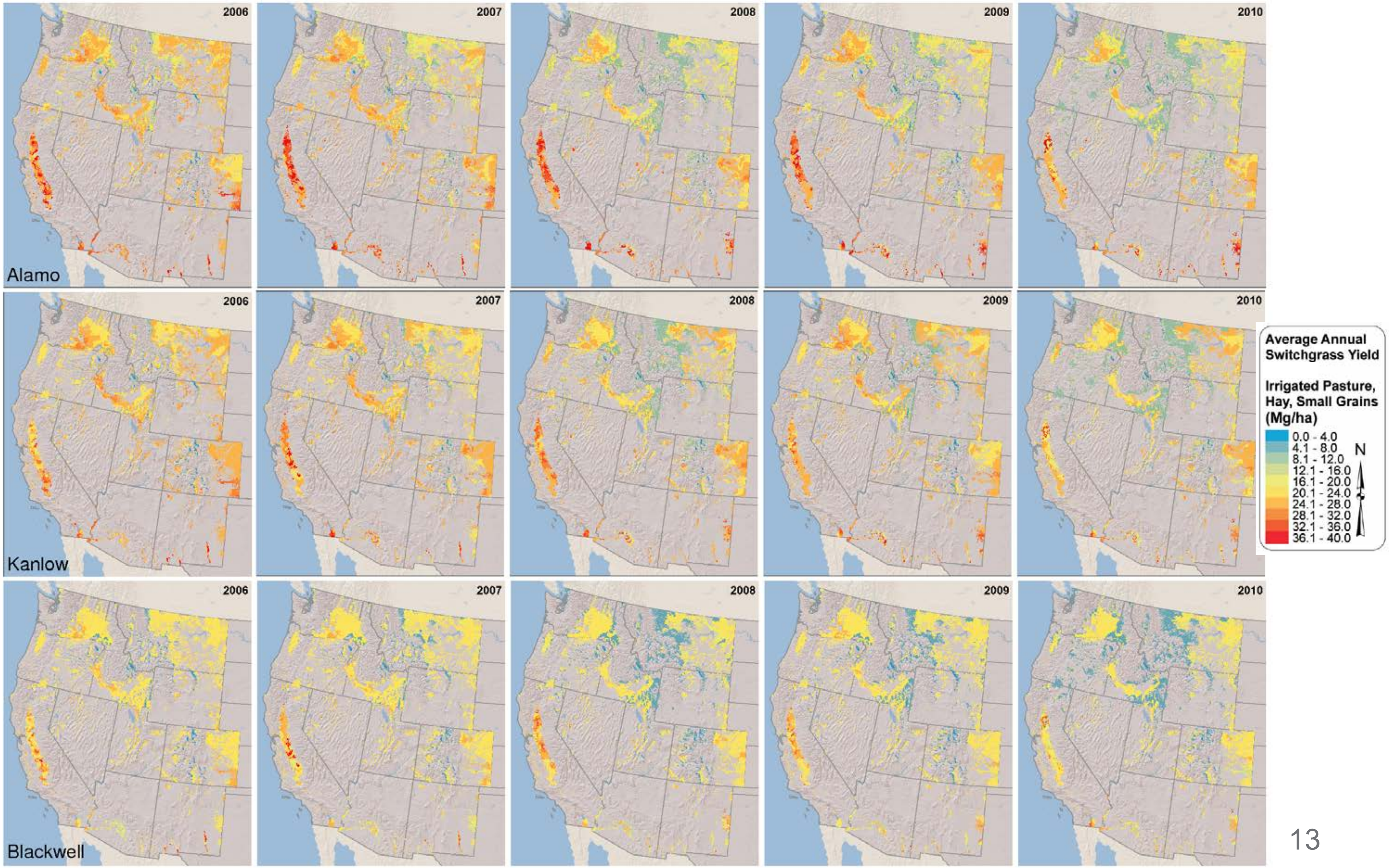
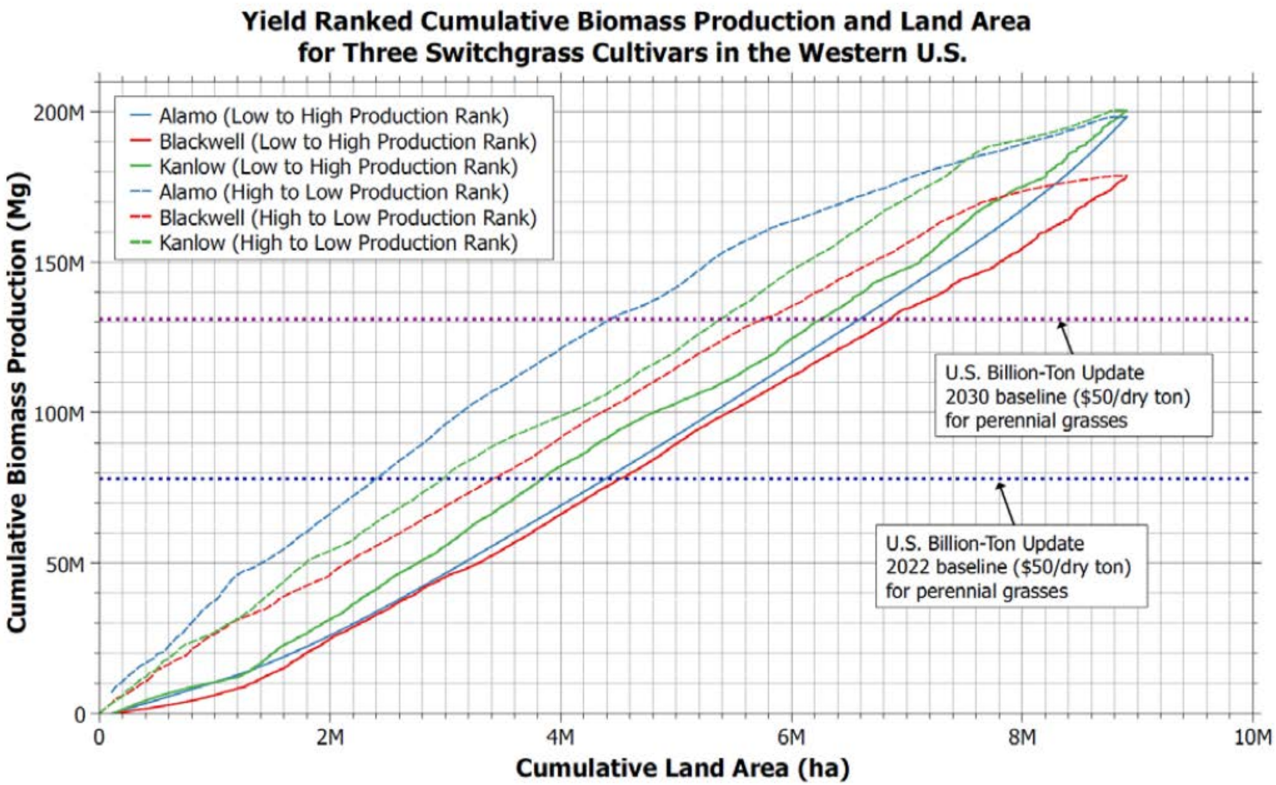


Cumulative Switchgrass Production and Land Area in the Western U.S.



Required existing land in existing pasture, hay, and small grains to meet BT 2022 $50/dry target:

- Poorest performing lands first, the target can be met using about 45-50% of the available land
- Highest yielding lands first, the target can be met with 31-37% of the available land

Mishra, AK, AM Coleman, S Fransen, MS Wigmosta, HP Collins, A Islam, A Gray, M Ottman, DH Putnam, G Shewmaker. Bioenergy production potential of three switchgrass cultivars in the western United States. *Geophysical Research Letters*, in review.

Algae – MSW Feedstock Blending

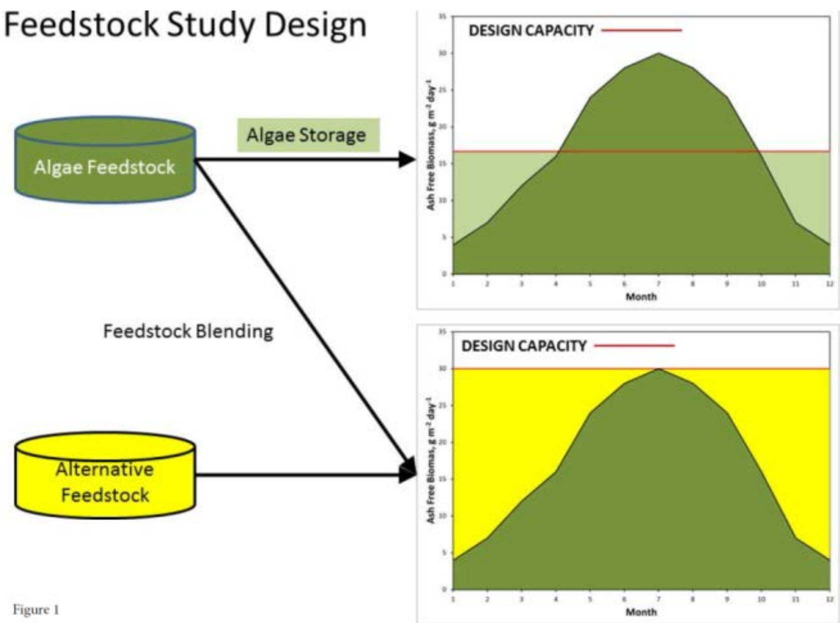


Figure 1

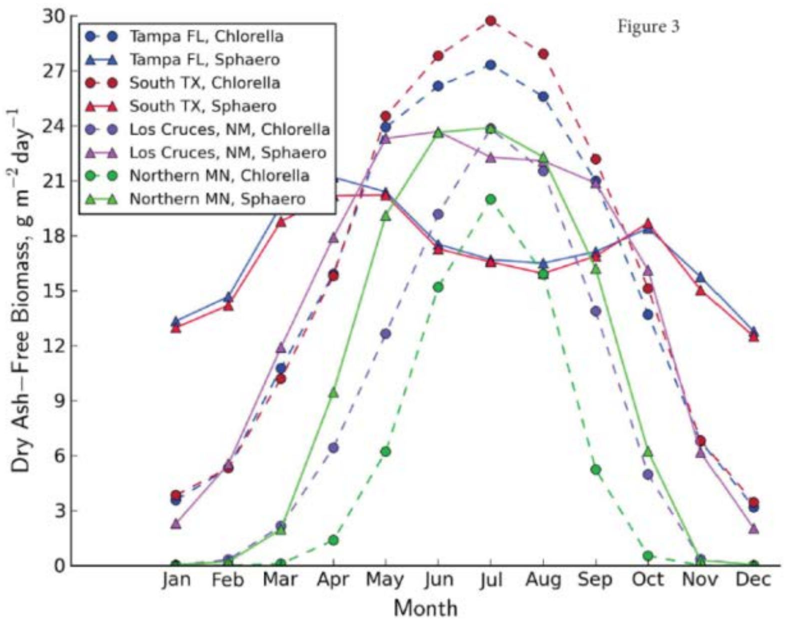


Figure 3

- Variability in regional, seasonal, and short-term algal production introduce considerable inefficiency and uncertainty to algal biofuel enterprise design and operations.

- Blending w/ alternative feedstocks having superior storage and transportation properties (MSW, Biosolids, animal manure, etc.) offers potential for stabilizing feedstock throughput.

Algae – MSW Feedstock Blending

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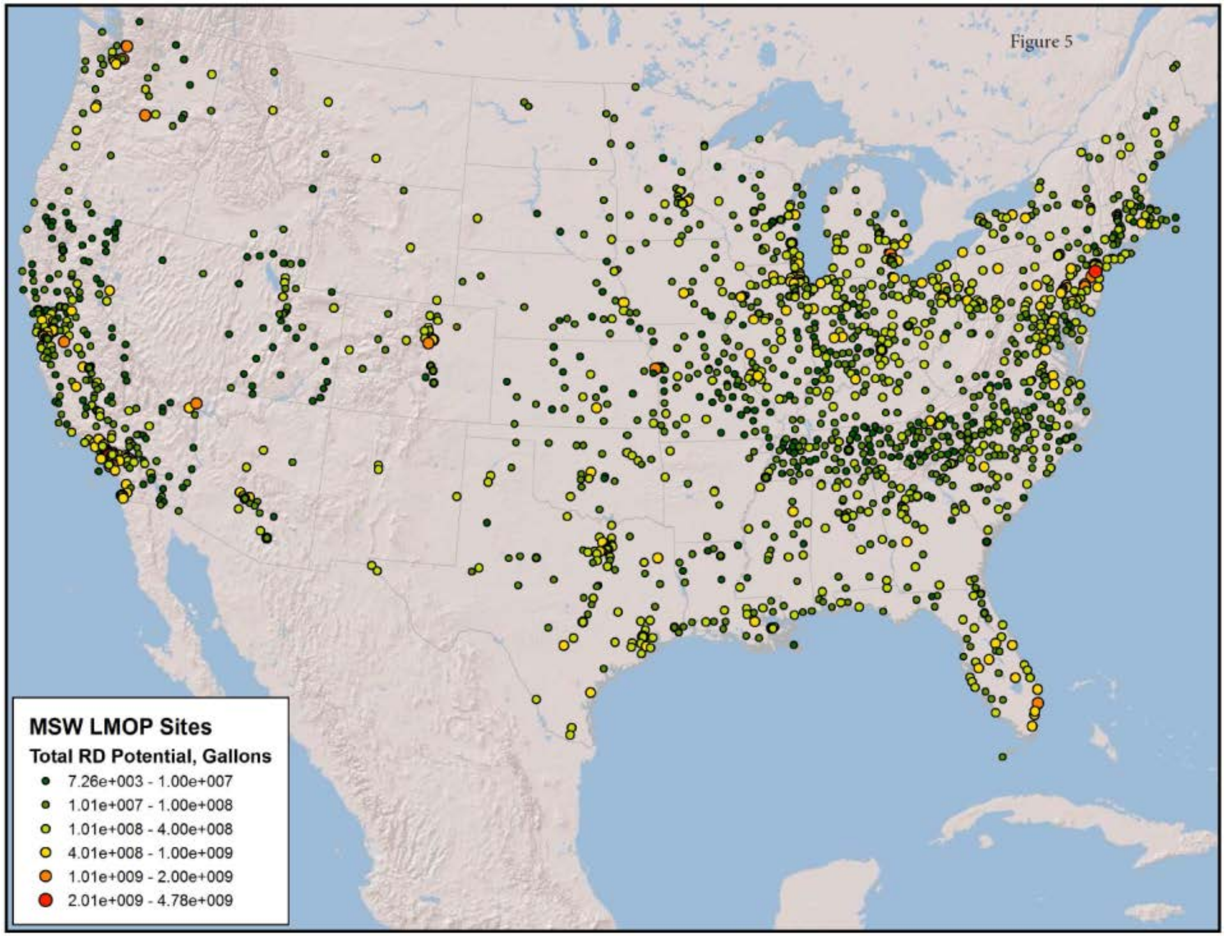
First Step: Broadly Assess Potential for Blending of Individual Feedstocks with Algae

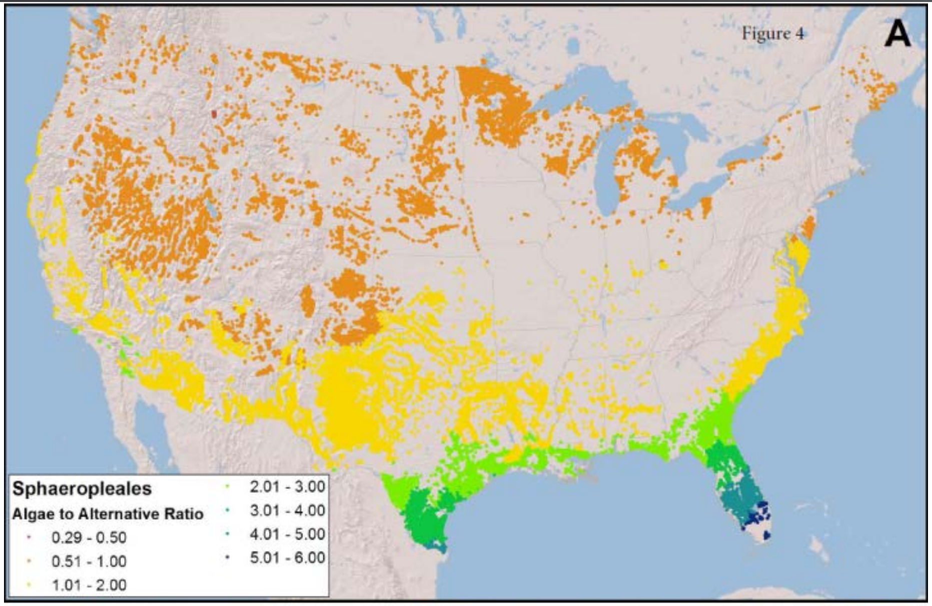
Municipal Solid Waste (MSW)

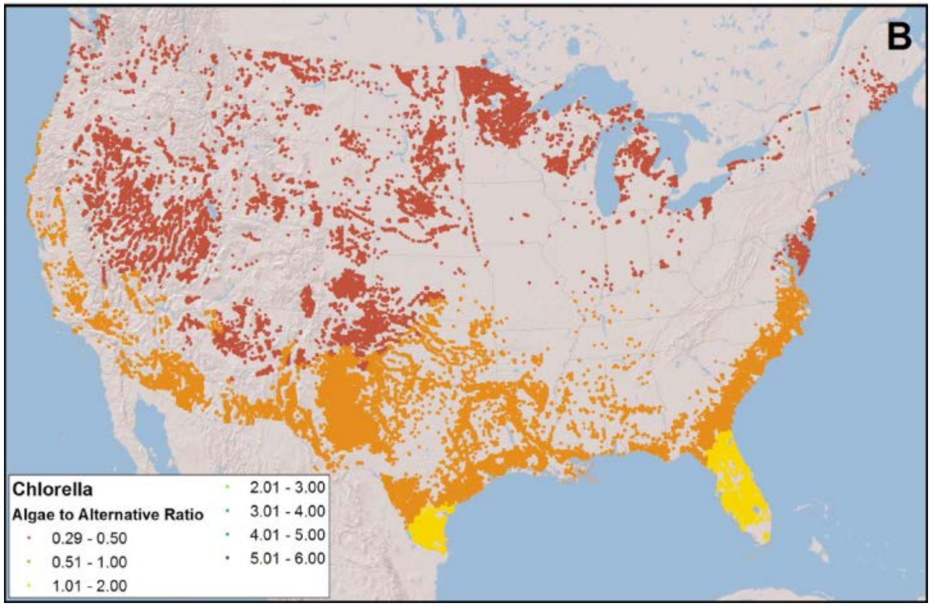
- Two sources: legacy and collections
- Multiple components w/ high carbon content e.g., paper, wood, yard and food waste
- Challenge: sorting and pre-processing
- Analysis: EPA Landfill Methane Outreach Program (LMOP)
- 2,235 landfills were generally geo-located



Algae – MSW Feedstock Blending

- Specify processing design capacity at maximum monthly mean algal production
- Satisfy algal biomass shortfall via MSW
- Sphaeropleales with blending
  - 15.2 BGY RD
  - Land requirement reduced by 34%
  - Slight decrease in water use
- Chlorella with blending
  - 16.9 BGY
  - Land requirements reduced by 50%
  - Water consumption reduced by 62%
- Reduction in nutrients requirements





4 – Relevance

- This project directly supports DOE environmental sustainability objectives around water quantity, soil quality, land use, and productivity described in the Biomass Program Multi-Year Program Plan by providing a systematic, sub-county-level assessment of:
  - National consumptive water use and locations of water scarcity
  - The potential for integration of energy crops into the existing western United States crop mix without increasing net water use
  - The potential for blending algal feedstocks w/ alternative feedstocks having superior storage and transportation properties

- This project directly supports the following MYPP targets
  - By 2015, integrate feedstock quality criteria and blending strategies to generate more comprehensive supply scenarios, meeting biorefinery infeed specification targets at the lowest possible feedstock price.
  - By 2017, establish available resource volumes for non-woody municipal solid waste and algal feedstocks at $80/dry ton delivered cost.
  - By 2018, using available field data, validate case studies of feedstock production systems that reduce greenhouse gas emissions and maintain or improve water quality and soil quality compared to conventional agriculture and forestry systems.
  - By 2018, establish sub-county-level environmental impact criteria and logistics strategies.

Summary

The goal of this project was to identify opportunities and sustainability constraints at the sub-county-level to produce specific biofuel feedstocks. Efforts were focused on three specific areas:

1) Identify spatial and temporal patterns of consumptive water use and water scarcity
The spatiotemporal scale of the analysis is critical in defining water scarcity. During the winter, at the local scale (~12- x 12-km) 91.5% of the land in the contiguous U.S. is unstressed, 2.9% stressed and 5.6% water scarce. In the summer these percentages are 77.6%, 5.1%, and 17.3%, respectively.

2) Assess the potential for integration of switchgrass into the existing western U.S. crop mix to increase national biofuel production without increasing net water use. We evaluated the introduction of Alamo, Blackwell, and Kanlow switchgrass on currently irrigated pasture, hay, and small grains. Approximately 31-37% of the highest yielding lands would be required to meet the Billion Ton 2022 $50/dry total production target of 78.2 Tg/yr.

3) Evaluate the potential for blending feedstocks that exhibit significant seasonal variability (i.e., algae) with alternative feedstocks having superior storage and transportation properties (i.e., Municipal Soil Waste) to stabilize feedstock throughput. Depending on the algae strain, feedstock blending reduced the amount of land required for a given production target by 34-50% and the amount of water by up to 60%. There was also a significant reduction in required nutrients.

Additional Slides

Publications, Patents, Presentations, Awards, and Commercialization

- Langholtz M, AM Coleman, L Eaton, MS Wigmosta, CM Hellwinckel , and CC Brandt. Potential Land Competition Between Open-Pond Microalgae Production and Terrestrial Dedicated Feedstock Supply Systems in the U.S. *Renewable Energy*, in review.

- Moore BC, AM Coleman, MS Wigmosta, RL Skaggs, and ER Venteris. A high spatiotemporal assessment of consumptive water use and water scarcity in the conterminous United States. *Water Resources Management*, in review.

- Mishra, AK, AM Coleman, S Fransen, MS Wigmosta, HP Collins, A Islam, A Gray, M Ottman, DH Putnam, G Shewmaker. Bioenergy production potential of three switchgrass cultivars in the western United States. *Geophysical Research Letters*, in review.