2015 DOE Bioenergy Technologies Office (BETO) Project Peer Review

WBS 4.2.2.10: Biomass Production and Nitrogen Recovery

Date: March 23, 2015
Technology Area Review: Sustainability

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Organization: Argonne National Laboratory

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Goal Statement

In the context of developing tools for landscape design approach to satisfy different societal goals (energy security, environmental protection, low-cost commodities).

- Conduct a field study to provide performance data on one landscape design concept
- Test field methods for scale-up (remote sensing, rapid soil analysis, farmer engagement)
- Conduct watershed analysis to understand potential benefits (water quality, quantity, yields, pollinator habitat)
- Engage in stakeholder involvement to ground solutions in real world
- Develop knowledge on state of the art in demonstration methods and applications.

Project supports BETO’s sustainability platform goal of by 2022 validating landscape design approaches. By 2015, validate a case study using field data.

Outcomes:
- Field data on sustainability metrics, yields and environmental impacts of landscape-placed bioenergy crops, methods to test best practices for sustainable bioenergy production
- Connecting with existing watershed conservation efforts, builds the network to secure implementation and demonstration in the longer term, provide visibility, access, feedback from multiple stakeholders to build the basis for bioeconomy.
Quad Chart Overview

Timeline

- Project start date: 04/2010
- Project end date: 09/2015*
- Percent complete: 70%

* 1-year extension under discussion

Barriers

**Feedstocks**

Ft-B: Production — “reliable production data… And also needed to measure environmental effects”

**Sustainability**

St-E: Best Practices for Sustainable Bioenergy Production

St-G: Land Use and Innovative Landscape Design

Other: Farmer interest and adoption potential

Budget

<table>
<thead>
<tr>
<th></th>
<th>Total Costs FY 10 – FY 12</th>
<th>FY 13 Costs</th>
<th>FY 14 Costs</th>
<th>Total Planned Funding (FY 15-Project End Date)</th>
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<tbody>
<tr>
<td>DOE Funded</td>
<td>$1,050K</td>
<td>$450K</td>
<td>$540K</td>
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<tr>
<td>Project Cost Share</td>
<td>n/a</td>
<td>n/a</td>
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<td>Synergistic activities*</td>
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<td>$225K</td>
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*Landscape design workshop and Blueprints development

Partners

- Interactions/collaborations
  - University of Michigan
  - State University of New York/ ESF
  - Idaho National Laboratory

- Non-technical project management partners
  - Livingston County SWCD and NRCS
  - Conservation Technology Information Center
  - ILEPA
1 - Project Overview

- Develops Landscape Design, an alternative way to address the land use change and environmental impact concerns of bioenergy production. Designing “How to deploy bioenergy” from the ground scaling up
- Leverages strengths of bioenergy crops to address the ills of current agricultural system through holistic resource management
- Proof of concept in 2010 led to a field study (ongoing) on nitrogen recovery by bioenergy crop buffer
- Field study led to a case study in the Indian Creek watershed (ongoing) inclusive of modeling and outreach to community of farmers and other stakeholders
- Develops methods for scale up of monitoring and stakeholder acceptance in light of a potential future demonstration.
2 - Technical Approach

Analysis and Proof of concept phase (FY08-10)

Field and method testing
(FY11-15) Test at the field scale

Watershed design
(FY14-15) Develop designs for water quality, pollinators. Develop resilience implications.

Examine existing experiences
(FY14) Understand State of the Art through dedicated workshop and literature review

Watershed-landscape demonstration (Future TBD)

Metrics:
- Target: Achieve 30-90% N-NO₃ reductions at field edge based on current knowledge (Smith et al., 2013)
- Go/No-go Decision Points:
  - FY10 – propose field study if model and proof of concept provide favorable results
  - FY13 - based on precipitation, select crop to replant
  - FY15 - based on growth, propose an additional year of project

2 - Management Approach

Critical success factors:
- Identify value to farmers
- Cost-effectiveness of data collection
- Identification of a viable end use market.

Challenges:
- Farmer acceptance and feedback will be critical to adoption of the approach: project builds the R&D and farmer connections in parallel by creating opportunities for feedback through meetings, workshops and farmer engagement study, discussion of local markets for produced biomass.
- Maintaining research-grade conditions at the field scale and attaining robust statistical design was the immediate challenge which required blending of different approaches. Challenge was addressed previously and continuously re-evaluated with addition of monitoring points/methods.
- Scaling up to watershed research will require significant effort to ensure participation and the cost-effective collection of sufficiently detailed data for planning. Project is testing precision agriculture approaches to develop rapid planning methodologies.

<table>
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<tr>
<th>Milestones</th>
<th>FY08-FY10</th>
<th>FY11-FY13</th>
<th>FY14</th>
<th>FY15</th>
<th>FY16</th>
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<tbody>
<tr>
<td>Complete resource assessment and proof of concept</td>
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<tr>
<td>Identify field site, NEPA, install monitoring system &amp; baseline</td>
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<tr>
<td>Plant bioenergy crop (willow)</td>
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<td>............X</td>
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<td>Monitor sustainability indicators</td>
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<td>............X</td>
<td>* X</td>
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<td>............X</td>
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<td>Design alternative watershed land use</td>
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<td>............X</td>
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<td>Develop model for farmer involvement &amp; conduct workshop</td>
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<td>Organize Landscape Design workshop series and report</td>
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<td>Watershed scale demonstration plan drafted</td>
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<td>Blueprints summary completed</td>
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* Go/No-go decision point
3 - Technical Accomplishments/ Progress/Results

Field trial: Progress from willow re-planting - May 14, 2013 through growth to Winter 2015

Willow growth in literature vs field plots at Fairbury. Comparison for same time from planting

Note: no fertilizer in Willow plots, control refers to productive soil conditions
Field monitoring infrastructure

- Buried Nitrate collectors
- Soil-water sample collectors
- Water table monitoring
- Static GHG chambers

Profile soil moisture monitoring [10, 30, 60, 100, 120 cm depth]

Crop growth monitoring

Total soil moisture in top 150cm soil layer
- ANL-2 Corn 2
- ANL-3 Corn 1
- ANL-4 Willow 1
- ANL-5 Willow 2
Spatial-Temporal variation of NO₃-N Concentrations (mg L⁻¹) at 1.2 - 1.5m depth
NO$_3$-N leachate analysis

- Prior to willow planting
- Willow establishment
- 1st year after willow coppicing

- 28.4% difference in corn & willow plots
- 25.3% difference in corn & willow plots
Greenhouse Gas Flux monitoring

- Collected greenhouse gas flux samples and developed streamlined procedure
- Added deeper soil gas sampling probes to monitor N2O evolution at 4 feet bgs – next to static gas flux chambers to determine extent of denitrification at depth
- Analyzed some 700 samples in 2014: CO₂, N₂O, CH₄.
- Modeled field biogeochemistry using DNDC
2014 GHG emissions

- **N₂O (mg of N m⁻² hr⁻¹)**
  - Rain [mm]
  - corn
  - Willow
  - Control corn
  - Control willow

- **CO₂ (mg of C m⁻² hr⁻¹)**
  - Rain [mm]
  - corn
  - Willow
  - Control corn
  - Control willow

- **CH₄ (mg of C m⁻² hr⁻¹)**
  - Rain [mm]
  - corn
  - Willow
  - Control corn
  - Control willow

- **Average N₂O and CO₂**
  - N₂O [mg of N m⁻² hr⁻¹]
  - CO₂ [mg of C m⁻² hr⁻¹]

- **Date Range**
  - 4/1/2014 to 11/27/2014

- **Legend**
  - Control corn [CC]
  - Control willow [CW]
  - Lowland corn [LL]
  - Uphill Corn [UH]
  - Willow [W]
Testing methods for scale-up:

a- Estimating yield using remotely sensed imagery

Testing methods for scale-up:

a- Estimating yield using remotely sensed imagery
Testing methods for scale-up:
b-Delineating underproductive land - from field to watershed
Testing methods for scale-up:
c- Rapid soil mapping at the Fairbury site

Crop Yield (Ground Truth)

Legend
Soil OI (%)

VERIS® soil mapping and image provided by Farm Map Solutions, LLC.
Watershed scale design and assessment

Bioenergy crops on
1. Low crop productivity index areas (2.7% of WS)
2. Areas with at least 2 marginalities or susceptible to nitrate leaching (22.2% of WS)

Projected impact on
1. Commodity yields
2. Water yield
3. Nitrate leaching
4. Sediment transport

Baseline data
Input data
1. Digital elevation model (DEM)
2. Soils data
3. Current land use and land cover
4. Climatic data
5. Farm management and operations

Soil and Water Assessment Tool (SWAT)

Soil based FLP
Bioenergy crops on
1. Corn yield ≤ 3.1 Mg ha⁻¹ (1.6% of WS)
2. Corn yield ≤ 4.7 Mg ha⁻¹ (6.3% of WS)
3. Corn yield ≤ 6.3 Mg ha⁻¹ (14.4% of WS)

RS based FLP
Bioenergy crops on
1. Corn yield ≤ 3.1 Mg ha⁻¹ (1.6% of WS)
2. Corn yield ≤ 4.7 Mg ha⁻¹ (6.3% of WS)
3. Corn yield ≤ 6.3 Mg ha⁻¹ (14.4% of WS)

FLP = future landscape patterns
RS = remote sensing
Watershed analysis of underproductive and vulnerable land (marginal)
Testing methods for scale-up: Donor watershed method - when long term watershed data are not available

- Similarity between slope and LULC in the Vermilion River at Pontiac, IL vs Indian Creek Watersheds
  - Land cover distribution: 31% corn-soybean, 29% soybean-corn, and 8% continuous corn rotations
  - Topography: about 67% has a 0 – 1% slope
  - Tile drainage coverage: 87%

- The high correlation ($R^2 = 0.87$) gage for extending Indian Creek daily streamflow of the Line of organic correlation confirms Vermilion River as an appropriate index or donor
Biomass logistic system analysis - precursor to economic analysis in collaboration with INL

**Economics**
- **Production**
  - Cost estimates developed by others are acceptable at this field site but not generalizable (slope, remote location, irregular field)
  - Consider impact on corn production costs (time)
- **Logistics**
  - Depend on spatial configuration, transport from field.
- **Farmer profit:**
  - from crop
  - from ecosystem services

Need: to determine how biomass harvesting and transport from A is different than the same from B

What we learned from a preliminary run
- Used our land marginality data and FLP as basis
- Hypothesized current grain elevators as locations for depots
- Hypothesis was that distributed collection would have impact on cost ratios
- Useful to determine what to focus on:
  - Need to focus on transport from field
  - Need sensitivity analysis.
- Work ongoing 2015 Q2.
Designs - future landscape pattern and simulation results leached nitrate and sediment
Results from watershed design assessment

**NO$_3$-N reduction (%)**

- Energy crops on CPI areas
- Switchgrass
- Willow
- Big bluestem
- Energy crops on marginal areas

**Sediment reduction (%)**

- Energy crops on CPI areas
- Switchgrass
- Willow
- Big bluestem
- Energy crops on marginal areas

**Water yield reduction (%)**

- Energy crops on CPI areas
- Switchgrass
- Willow
- Big bluestem
- Energy crops on marginal areas

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**Soil data based analysis**

- Remote sensing based analysis

**Low corn yield thresholds**

1. Case 1: 3.1 Mg ha$^{-1}$ (50 bu/ac)
2. Case 2: 4.7 Mg ha$^{-1}$ (75 bu/ac)
3. Case 3: 6.3 Mg ha$^{-1}$ (100 bu/ac)
Modeling pollinator habitat - Indian Creek, current crops vs switchgrass for water quality design. John Graham, U. of Michigan

Pollinator nesting index, InVEST model

Pollinator diversity, Bennet Index

Pollinator abundance, Bennet Index
Stakeholder engagement in the watershed and regionally

- March 8, 2013 - workshop in Fairbury on bioenergy crops, 45 people attending, experts presented agronomics and uses of major bioenergy crops
- Presented at the CTIC National conservation tour in July 2013
- Held several planning meetings with local County NRCS/Soil Water Conservation District technical staff and consultants - spring 2014
- Conducted Farmer workshop in August 2014
- Other regionally relevant venues are important to build interest.

Key points

- Initial polling showed that using sub-productive or “nuisance” land for bioenergy perennials is attractive to farmers
- Suggestions or ideas included opportunities to streamline farm operations
- Flexible-use crops that can double as forage may be attractive while markets build
- Interest in farm energy self-sufficiency
- Interest in climate-related change management needs, adaptation
- Periodic workshops may be beneficial and cost effective
Seeking Farmer and stakeholder input - method testing - (collaboration with U. of Michigan)

- Farmer workshop August 4-5, 2014 sought input from farmers based on 4 scenarios for 2030
- Visualizations of landscapes as boundary object to gather discussion and consensus
- Developed framework for Agent Based Modeling of farmer decisions
4 - Relevance

Barriers addressed

**Ft-B:** answers sustainability and productivity questions related to bioenergy feedstock production

**St-E:** developing and testing Best practices for Sustainable bioenergy production

**St-G:** Develops science-based, multi-stakeholder strategies for Innovative bioenergy Landscape Design.

Project is relevant to:

- **DOE and BETO:** through WBS element “Sustainable System Design” provides field data and designs for sustainable bioenergy landscapes. Addresses a critical “how” question at the base of sustainability analysis and land use change.

- Contributes to fulfilling BETO goal of, by 2022, validating landscape design approaches.

- **Conversion industry:** tests ways to intensify biomass supply and prepares community for investments in bioenergy.

- **Rural communities:** Considers needs and barriers within farming community and gives them an opportunity to be part of the design process and options to diversify their production.

- Through developing partnerships, the project provides a substantial opportunity to link suppliers and end users of biomass for integrated deployment at the landscape scale.

- **Society:** provides concepts and data to develop alternative land management systems to deliver food, feed, energy and ecosystem services.
5 - Future Work

- Continue field monitoring and harvest willows either in December of 2015 or 2016
- Analysis of landscape-based biomass logistics in the watershed (with INL)
- Develop economic framework and analysis
- Quantify watershed scale GHG emissions and SOC under different Future Land Patterns (FLP)
- Build the framework for assessing the resilience of designs to climate disruption and assess which designs could provide the most benefits in a locally scaled climate change scenario.
Summary

Overview and approach
Project develops Landscape Design tools to address LUC and environmental concerns. Leverages strengths of bioenergy crops, and conducts field testing to watershed scale-up provides data to:
• Understand productivity, environmental performance and economics of landscape-placed bioenergy cropping recovering nutrients lost from farming
• Test methodologies for land targeting, crop deployment and monitoring
• Develop approach for stakeholder involvement and provide visibility
• Develop watershed designs for water quality and pollinator habitat
• Develop a plan for an on-the-ground watershed demonstration.

Relevance
• Relevant to BETO’s WBS element “Sustainable system design”
• Supports conversion industry by advancing integrated approaches to strengthen rural bioeconomies and environment
• Provides field data and tools for designing best practices and validating case studies
• Proposes designs for bioenergy systems with minimized LUC and environmental impacts
• Addresses Barriers in sustainability and sustainable feedstock supply including farmers concerns.

Accomplishments
• Successfully established field site, collecting yield and environmental data that are beginning to show buffer impacts
• Tested promising approach from precision ag and remote sensing to baseline and monitor at larger scale
• Hosted several farmer meetings, used on site visit, visualizations and geospatial information to elicit comments and ideas for farmer-vetted designs
• Established a solid connection with farming community and early adopters
• Identified vulnerable or underproductive land in the watershed for bioenergy, modeled potential environmental services and productivity
• Developed a broad partnership to carry out demonstration in the watershed.

Future Work
• Continue field monitoring and harvest willows
• Complete analysis of landscape-based biomass logistics in the watershed (with INL)
• Develop economic framework and analysis
• Quantify watershed scale GHG emissions and SOC under different Future Land Patterns
• Build the framework for assessing the resilience of designs to climate disruption.
Additional Slides
Responses to Previous Reviewers’ Comments

- Logistics and economics were not considered
  - Response:
    - Lack of data prevented us from carrying out this analysis in the past.
    - We have now completed a watershed scale analysis and a design to work from
    - Began work with INL on logistics, 2015 Quarter 2
    - Asked farmers relevant questions on feasible approaches
    - Ecosystem services role needs also to be included in the economic analysis

- Uncertainty on how the findings/approach can be scaled up
  - Response: We have used our field site and watershed case to test methods for efficient scale-up in modeling, data acquisition, area selection.
Select Publications, Patents, Presentations, Awards, and Commercialization


