NREL
NATIONAL RENEWABLE ENERGY LABORATORY





NREL Waste to Energy System Simulation Model

March 7th, 2017

Waste to Energy

Daniel Inman, PhD

NREL

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Waste to Energy System Simulation Model: Goals

- Goal: to build and exercise a system dynamics (SD) model of the waste-to-energy (WTE) industry in the United States and to develop and analyze scenarios that explore the evolution of the WTE industry and how it may be deployed in a way makes a substantial contribution to the country's transportation energy.

- Project Outcomes: 1) A completed and vetted SD model of the waste-to-energy system in the United States, and 2) analyses that directly addresses specific office questions regarding the development of the WTE industry.

- Project Relevance: This project provides actionable analysis of the nascent WTE industry, e.g., identifying bottlenecks, synergies, impacts of R&D decisions, policy implications, and areas of leverage.
  - We develop and disseminate insights into potential WTE market growth and market penetration.

Quad Chart Overview

Timeline

- Project start date: 2016
- Project end date: 2018
- Percent complete: 50%

Budget

	Total Costs FY 12 – FY 14	FY 15 Costs	FY 16 Costs	Total Planned Funding (FY 17– FY18)
DOE Funded	$0	$45K	$288K	$1.25MM
Project Cost Share (Comp.)*	$0	$0	$0	$0

Barriers

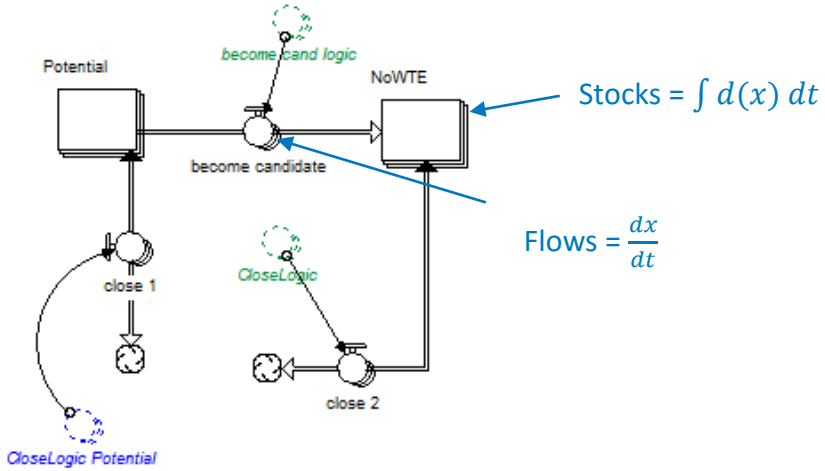
- At-A: Comparable, Transparent, and Reproducible Analyses
  - The WESyS model is transparent, reproducible, and trackable.
- At-B: Analytical Tools and Capabilities for System-Level Analysis
  - WESyS is a systems modeling tool built using established approaches and data.
- *At-C*: Data availability across the Supply Chain
  - We collect and curate data for key supply chain elements are part of our modeling process. These are made available on the KDF.

Partners

- Pacific Northwest National Laboratory
- Lexidyne LLC
- EPA

WESyS Overview

- WESyS is a national-level system dynamics model of the WTE industry in the United States.
- It tracks energy production from landfills, confined animal feeding operations (CAFOs), and publically owned treatment works (POTWs).
- The model is a system of coupled ordinary differential equations.
- Investment and buildout of the industry is tracked throughout a simulation.
- Results are a snapshot of the industry at a point in time or the development trajectory over time.



WESyS Overview

- This project began as an informal collaboration with the EPA in FY14.
- The model is built using peer-reviewed data for resource potential and process techno-economics.
- The overall objective of this project is:
  - To develop and analyze scenarios that represent multiple states of the industry and how fuel technologies may be deployed in such a way that they make a substantial contribution to the country's transportation energy (e.g. electricity, CNG, liquid fuels, etc.).

Source: Missouri Department of Conservation

Source: Wisconsin Department of Agriculture

Source: State of Massachusetts

Management Approach

- Team members and responsibilities
  - Daniel Inman, PhD – Project task lead and analyst
  - Annika Eberle, PhD – Lead analyst
  - Ling Tao, PhD – Analyst/process design liaison
  - Emily Newes, MS – Analyst/database manager
  - Dylan Hettinger – Programmer
  - Steve Peterson (Consultant) – Lead model architect
  - Dana Stright (Consultant) – Database

Management Approach

- Regularly interface with partners and subcontractors (PNNL, Lexidyne, EPA)
- Monthly team meetings
- Regularly scheduled calls with BETO
- Experiential modeling sessions with stakeholders
- Quarterly AOP milestones
- Database management best practices
- Study versioning – reproducibility
- Quantitative QA/QC on models

Researchers exploring model results in three dimensions using NREL's data cave

WESyS Approach (Technical)

- Use knowledge of system behavior and input from domain experts to build and populate models of the WTE system.
- Develop models using a flexible, transparent, and modular architecture.
- Conduct rigorous statistically based sensitivity and model validation.
- Use only vetted resource, market, and techno-economic data.

Challenges

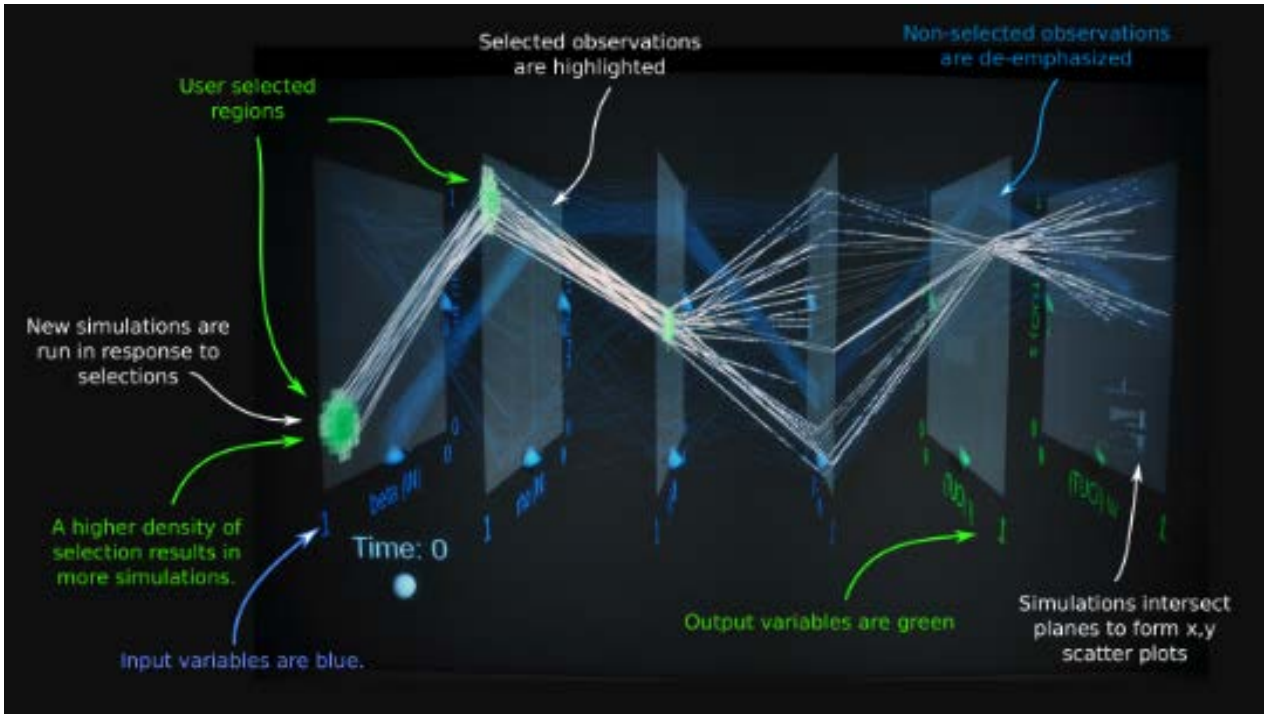
- Consistent and verified data
- Anticipating analyses that are relevant to the industry.

Success factors

- Provide analyses that enable the WTE industry to develop more rapidly and more robustly.
- Become a resource for other agencies (USDA, EPA) and stakeholder groups.
- Publish results that promote fruitful conversations within and among agencies and stakeholder groups.

Accomplishments

- Developed a Renewable Identification Number (RIN) market model that will be included in WESyS.
- Built an SD model of the WTE industry in the United States.
- Posted model outputs, results, and scenarios to ORNL's BioEnergy Knowledge Discovery Framework (KDF).
- Conducted three immersive and interactive modeling sessions with stakeholders

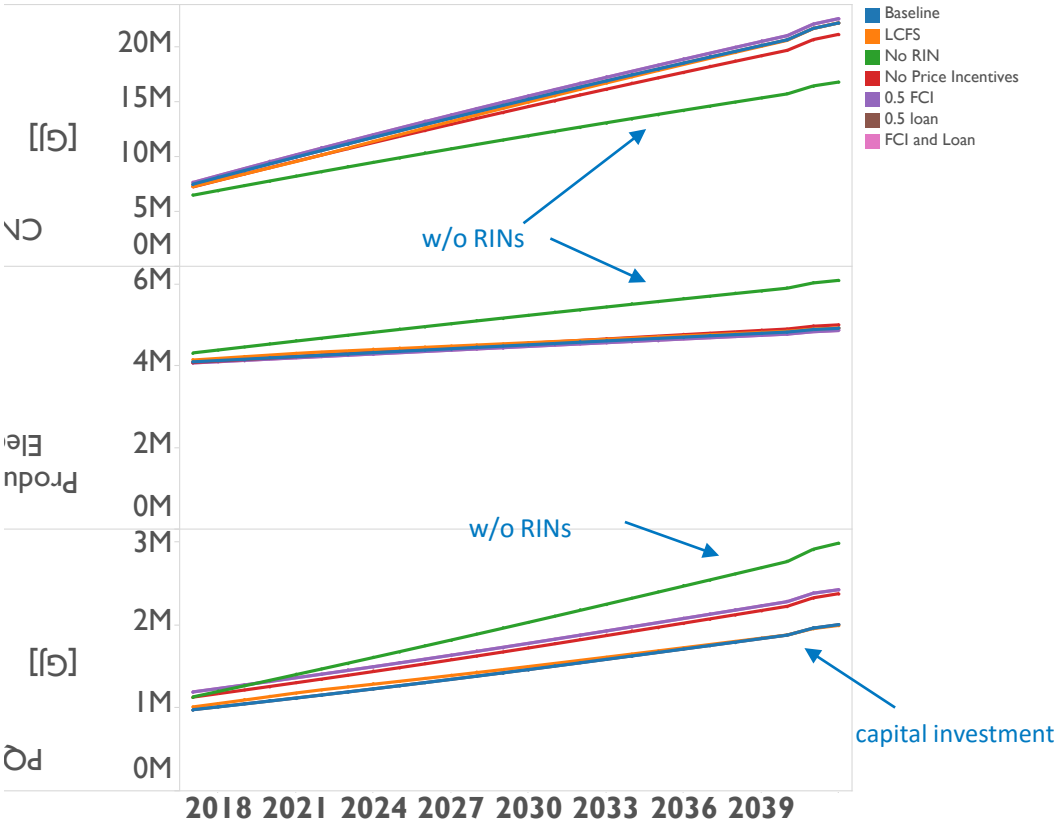


Example of a parallel planes implementation of the WESyS model in NREL's data cave. In this format, users can run the model in real time.

Example Application - Biogas from CAFOs

- We performed both a scenario analysis and a sensitivity study using the WESyS model.
- This study was focused on biogas production from landfills and CAFOs.
- Scenarios included combinations of RINs, incentives, and capital/operational requirements.
- The sensitivity analysis involved simultaneously varying all model parameters over their range. This resulted in > 50,000 runs.
- The objective of this study was to identify market and technological barriers to energy production from waste materials, provide insights on the role of policy for this market, and identify data/modeling gaps in the existing modeling and data structure.

Preliminary Results: Biogas from CAFOs



- Compressed natural gas (CNG) from dairy production has the greatest market potential.
- Overall CNG potential is ~350 MM GJ annually (~ $3x10^6$ GGE)
- Scenario Analysis:
  - RIN accrual has a strong impact on the total energy produced and the technology choices.
- Sensitivity Analysis
  - The time between making an investment and having installed capital is the highest leverage variable.
  - Avoided disposal costs and operating expenses are also high leverage.

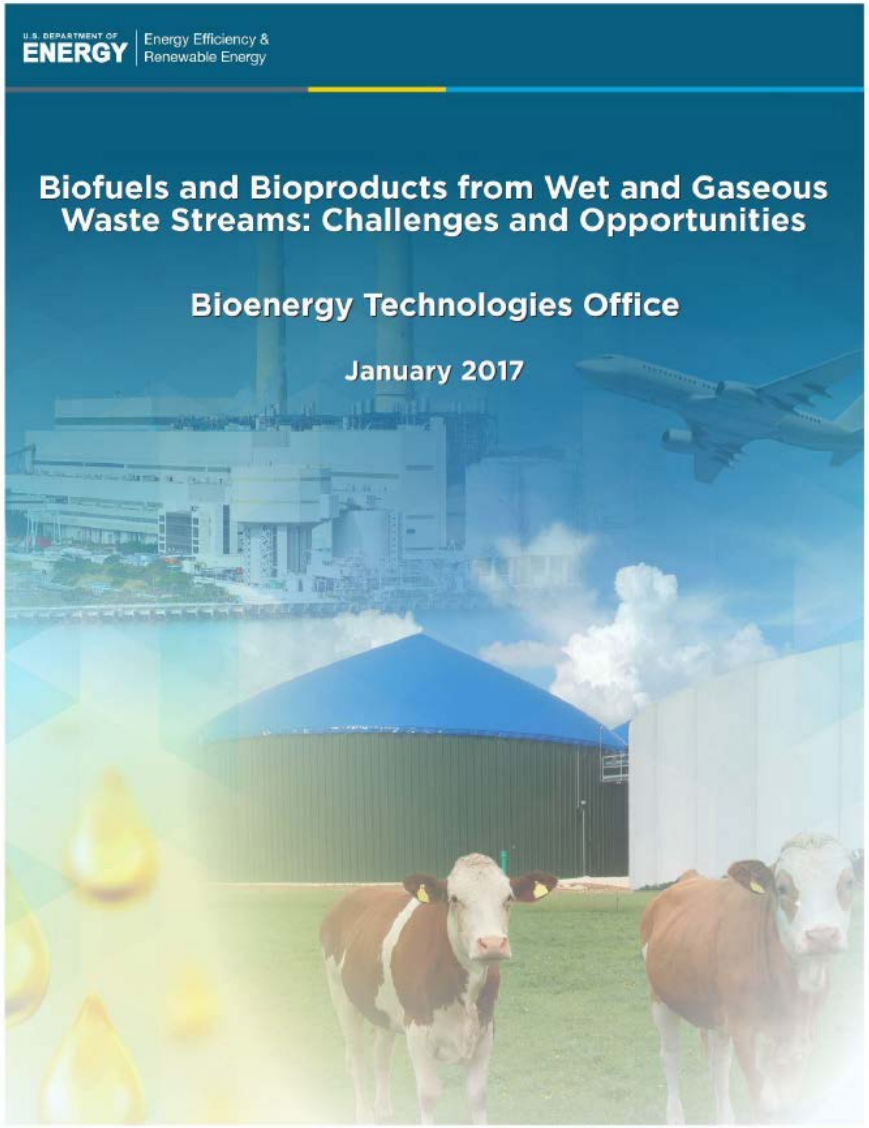
- CNG = compressed natural gas
- PQNG = pipeline quality natural gas

Study Findings

- Opportunities:
  - RINs are important for investor decision making
  - Collection and conversion of biogas from landfills and CAFOs to energy has the potential to contribute as much as 400 MM GJ annually (~ $3x10^6$ gallons of gasoline equivalent).
  - The largest energy potential is from dairy operations (~ 200 MM GJ annually).
- Challenges:
  - Minimizing the time between project approval and project start has a positive impact on industry development.
  - Manure disposal costs (tipping fees) have a high impact on industry development.
  - Operating costs have a significant impact on industry growth.

Project Relevance

- Provides insights into the investment decisions
- Results from this project were used in the BETO WTE challenges and opportunities document, published in January 2017.
- Supports tactical and strategic planning
  - Identifies opportunities and barriers to industry development
- Informs the industry on the complex dynamics and feedbacks influencing the growth
- Developed a transparent and accessible tool to understand the evolution of the WTE industry



Future Work: FY17 & 18

- Link the WESyS model to the Biomass Scenario Model (BSM)
- Assess the D3 RIN market in the context of biogas-derived energy products
- Perform variance-based sensitivity analysis to identify:
  - The techno-economic parameters that are most influential for maximizing biofuel production from WTE.
  - The range of techno-economic assessment parameters that lead to successful market penetration for one WTE biofuel pathway.
- Immersive modeling sessions with stakeholders
- Publish analysis results in the peer-reviewed literature
- Formalized model review workshop

Project Summary

- **Overview:** WESyS dynamically evaluates potential waste-to-energy feedstocks, technologies, and end uses using a scenario-based approach. Results from this project enable the development of insights into potential industry growth and market penetration, particularly with respect to policies, incentives, technological advances (R&D, industrial learning), related and/or competing energy markets, demand for petroleum-based fuels, and competing uses of feedstock.
- **Approach:** WESyS uses a system dynamics modeling framework. The model is built from vetted and/or published resource, market, and techno-economic data. A flexible, modular, and transparent architecture is used.
- **Accomplishments:** Conducted three interactive model exploration sessions with BETO, completed initial analysis of the energy potential from landfills and CAFOs, updated data sources, and developed a model of the RIN market.
- **Relevance:** Understanding potential industrial trajectories is critical for maximizing the impact that the WTE industry may have on the nation's energy supply.
- **Future Work:** Major model expansion—linking to BSM, high-impact analysis of the D3 RIN market, and a large sensitivity study.

www.nrel.gov

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.