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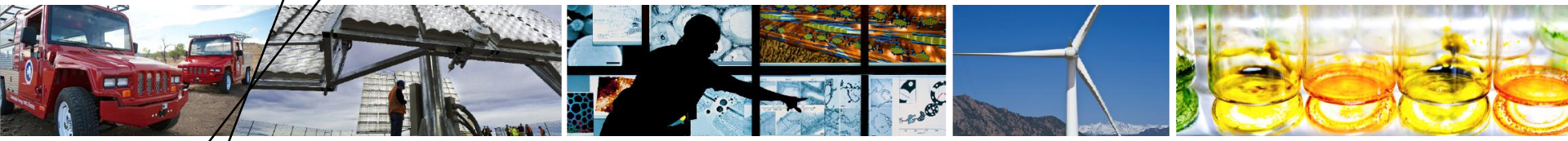
Strategic Analysis and Modeling



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National Renewable Energy Laboratory

March 24, 2015
Analysis and Sustainability Peer Review
2015 DOE Bioenergy Technologies Office (BETO) Project Peer Review

Goal Statement

- **Develop tools and perform analyses to address key questions in support of the strategic direction of the DOE Bioenergy Technologies Office**
  - Assess the current and future market drivers for the production of biomass-derived chemicals
  - Provide comparative economic analyses for jet fuel production pathways
  - Investigate the optimal biorefinery economics
  - Estimate the number of jobs that will be created in the United States with biorefinery deployment

Quad Chart Overview

Timeline

- Start Date: October 2010
- End Date: FY15-FY17

Barriers

- At-A: Lack of comparable, transparent, and reproducible data
- At-B: Limitations of analytical tools and capabilities for system level analysis
- At-C: Inaccessibility and unavailability of data

Budget

	Total Costs FY 10 –FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date
DOE Funded	$2.0M	$900k	$700k	$2.0M

Interactions/collaborations:

- National Laboratories: ANL, INL, NREL core platform analysis, NREL-Market and Policy Impact Analysis, NREL-SI, NREL-VT, ORNL, PNNL
- Industry: Celanese, ExxonMobil, Linde, Proterro, SABIC, U.S. DRIVE
- Government Agencies: CAAFI, DOE-BETO DMT, DOE-VTO, DOD, EPA
- Academia: CU, ISU, MIT

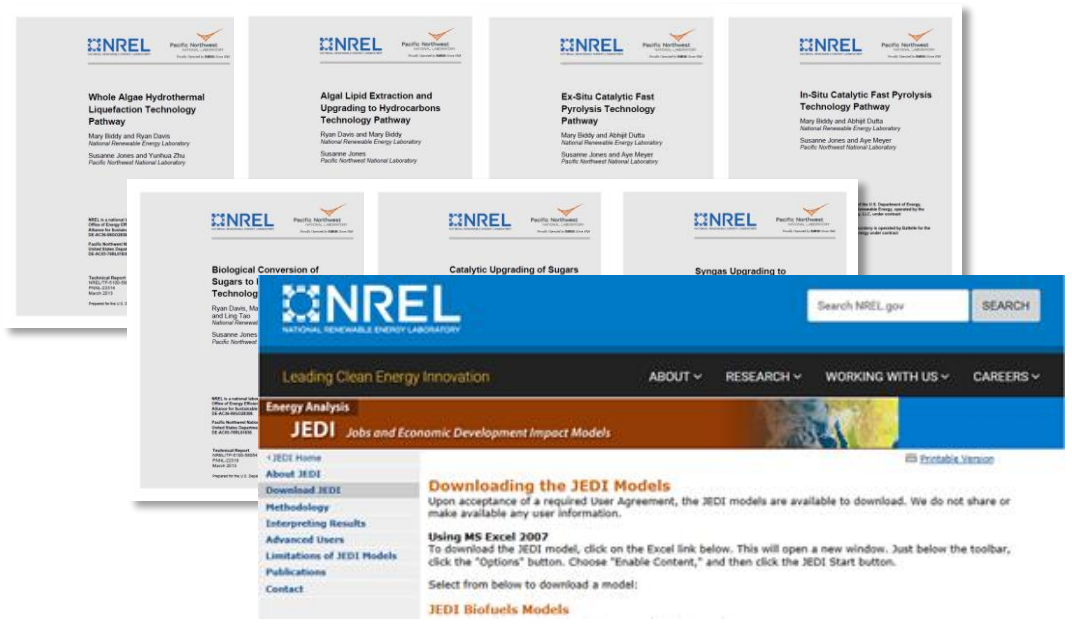
Project Overview: History

Comparative analyses of biomass conversion processes

- COP/ISU/NREL collaboration focused on TEA of biofuels (FY11)
- NREL/PNNL hydrocarbon technology pathways (FY12/13)
- Jet fuel economics and chemicals market assessment
- Provide quick turnaround analyses to support BETO and EERE

Model and tool development to support BETO and to understand the impact of expanding the biomass economy

- Estimate job growth potential for the developing bioeconomy
- Investigate the optimal biorefinery economics
- Develop economic analysis tools



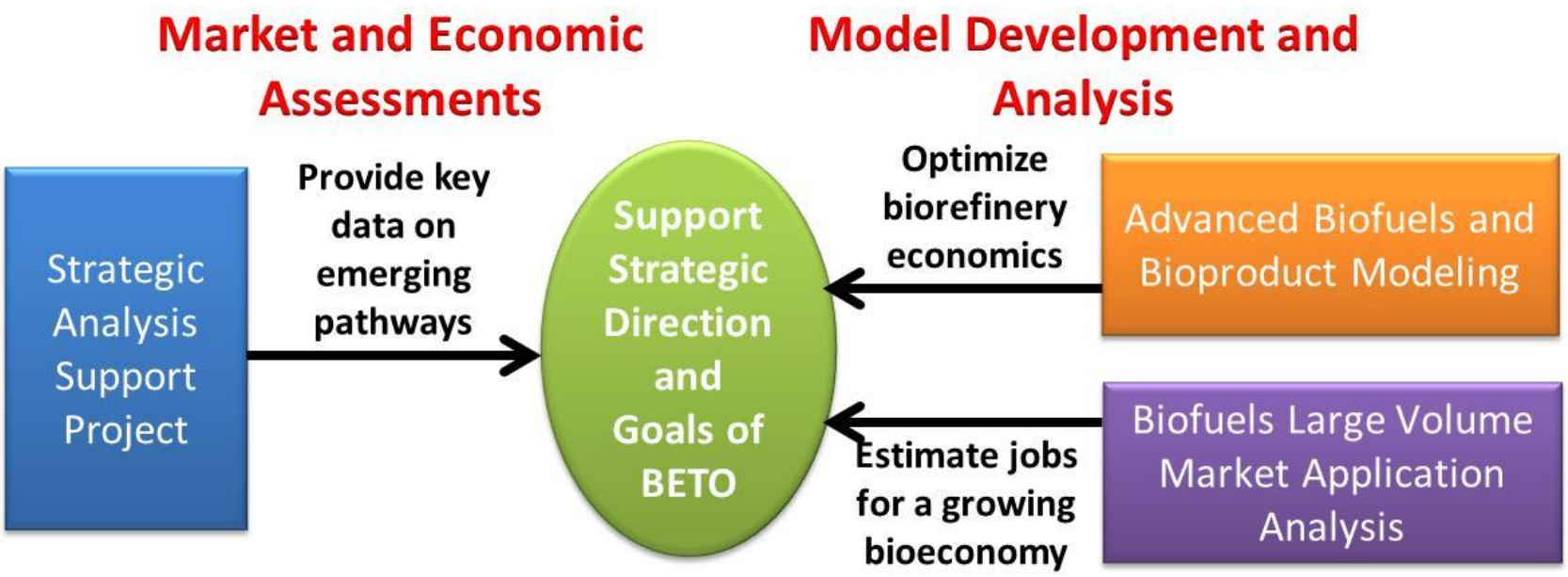
Project Overview: Objective

Develop and utilize an array of analysis tools to support the strategic direction of BETO and understand the development of a biomass economy

- **Analysis** to identify the market drivers and uncertainties in the deployment of **chemical production from biomass**
- **Integrated biorefinery optimization** to guide BETO on the development of biofuels and bioproducts
- **Techno-economic analysis** in support of the expansion of strategic programmatic technologies to **jet fuel production**
- Estimation of **job growth** and the broader impact of developing industries

Provide credible results to assist decision making in bioenergy investment through applying appropriate analyses and models

Project Technical Approach



- **Common approach for all projects:**
  - **Models are transparent and rigorous** with a consistent set of assumptions that allows for direct comparison
  - Analysis results and approaches are **vetted by stakeholders**
  - **Results and tool availability is communicated** to stakeholders through peer-reviewed publications, presentations and technical reports
- **Critical success factors:** Availability and quality of data

Project Management Approach

- **Annual Operating Plans prepared prior to each fiscal year outline the project budget and milestones**
  - Develop **annual operating plans** coordinated with BETO with **clearly defined metrics for milestones** and deliverables
  - **Quarterly reports** summarize the approach, results, and next steps
  - Progress updates reviewed with BETO team in **quarterly meetings**
  - Share updates to platform PIs in **monthly A&S coordination calls**
  - Develop **detailed** and clear **documentation** for all models and analyses to **allow for transferability of projects**

- **Critical success factors**
  - On-time and on-budget delivery of results
    - ✓ Track progress through quarterly reports/updates
  - Clearly define objectives and milestones of the project

Strategic Analysis Support

Strategic Analysis Support: Market Analysis *Approach* (WBS 4.1.1.30)

- Market analysis report for the production of bio-derived chemicals based on public information
  - Initially identified 27 biomass-derived products
  - Downselected to **10 products** for inclusion in the report based on market potential
  - Summarized **near-term potential opportunities** for growth in biomass-derived products; identified **challenges to scale-up** and the current market champions
  - Report reviewed by over 15 experts from academia, national laboratories, and industry

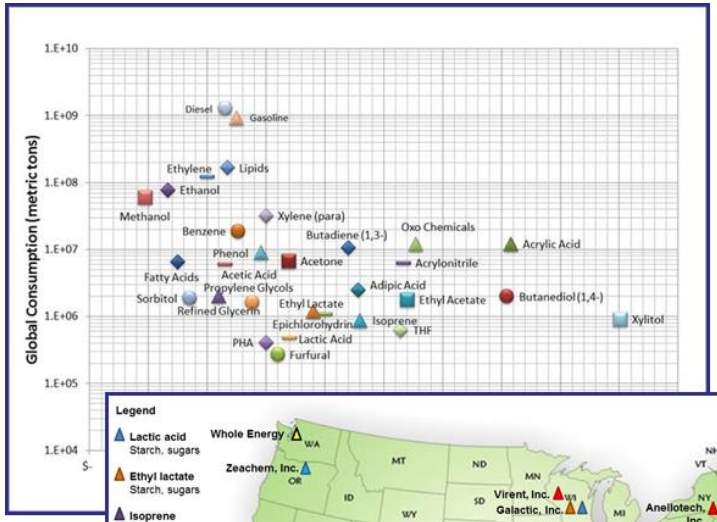
Criteria used to evaluate the market potential of biomass-derived products

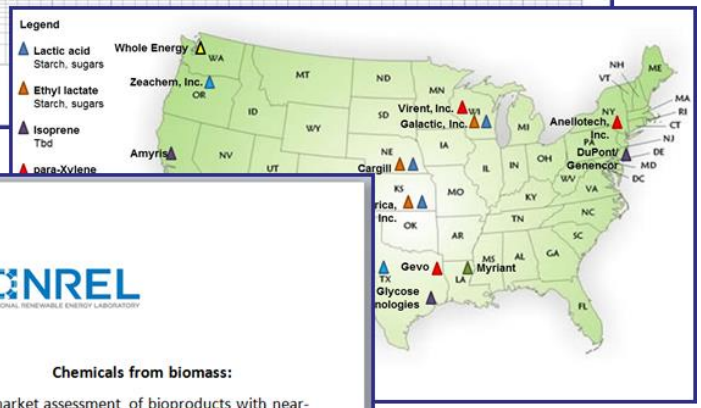
High Volume/Value	Market maturity	High growth (domestic)
High growth (global)	Feedstock flexibility	Platform chemical
DOE interest/funding	Integrated with conversion pathways	Avoids competition with natural gas
Market pull	End user specifications	Bioprocess advantage
Current scale	Favorable Life Cycle	Near-term deployment (High TRL)

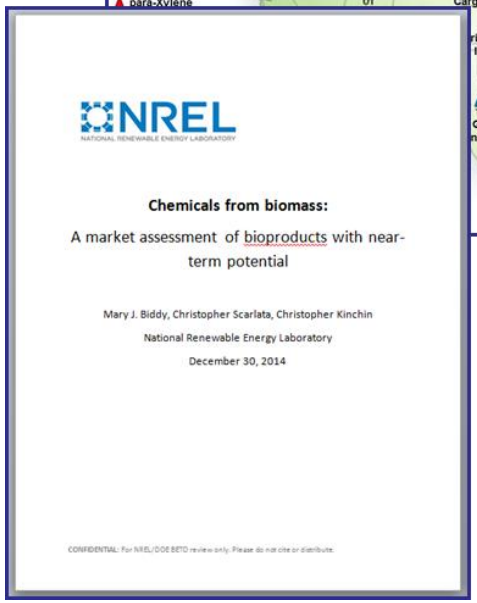
Strategic Analysis Support: Market Analysis *Progress* (WBS 4.1.1.30)

Prepared market analysis report for the production of bio-derived chemicals

- Focus of the report is on products that will have near-term market impact
- Understand the key drivers and challenges to move biomass-derived chemicals to market
  - Low-cost natural gas has allowed for opportunities for C3/C4 products
  - Push by large companies to utilize renewable materials
  - Growth in the functional replacements market
- Assess ways in which chemicals production can be leveraged to accelerate the growth of biofuels
- Planned publication in FY16



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Chemicals from biomass:

A market assessment of bioproducts with near-term potential

Mary J. Biddy, Christopher Scarlata, Christopher Kinchin

National Renewable Energy Laboratory

December 30, 2014

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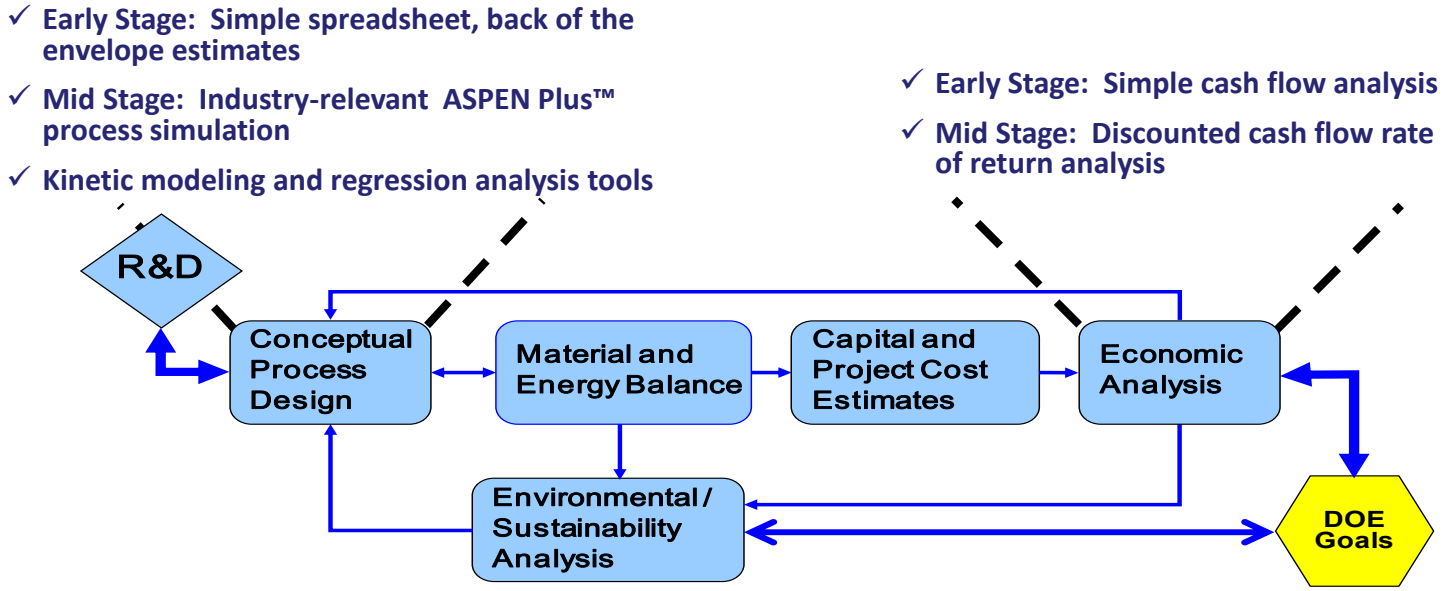
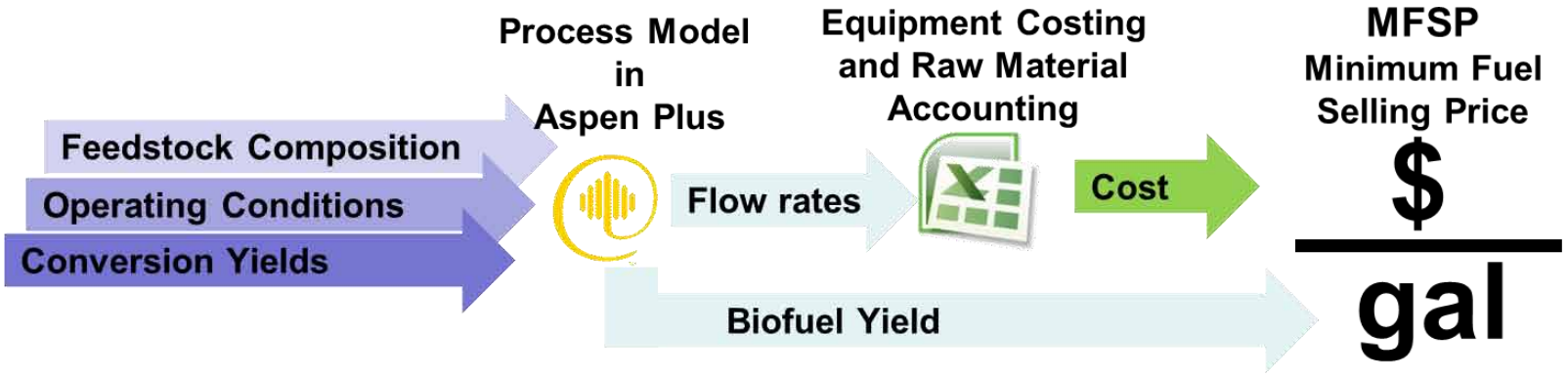
Strategic Analysis Support: Market Analysis *Approach* (WBS 4.1.1.30)

- Provide strategic and comparative economic analyses for biofuels and bioproducts conversion technologies
- Develop economic evaluations at varying levels of detail
- Provide quick turnaround of analysis
- Identify R&D data needs for emerging pathways
- Supply key process data for expansion of GREET LCA pathways

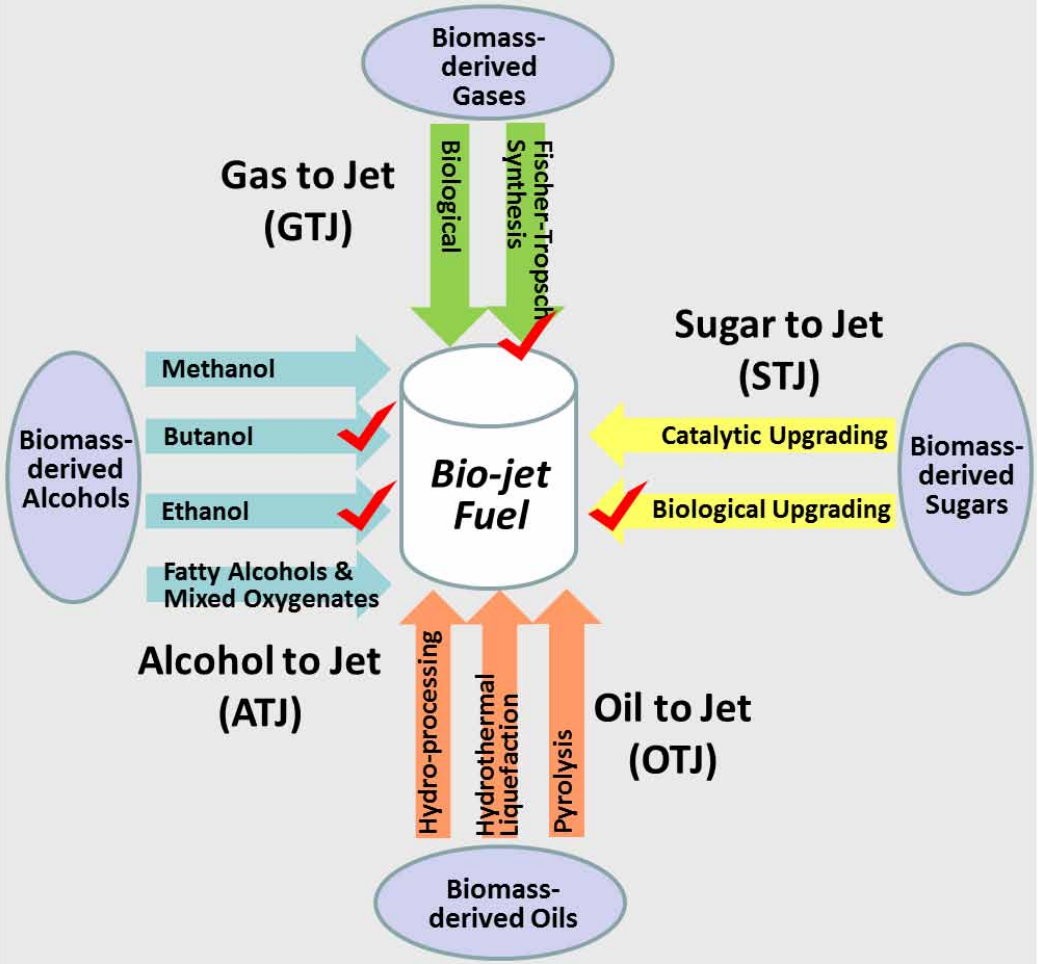


Strategic Analysis Support: TEA *Approach* (WBS 4.1.1.30)



- Modeling is rigorous and detailed with **transparent assumptions**
- Discounted cash-flow rate of return calculation to estimate MFSP
- Baseline assumes n^{th}-plant equipment costs
- Perform **pioneer plant** evaluations to understand the near-term cost of jet fuel production pathways
- Quantify the underlying uncertainties through **sensitivity analysis**
- Prioritize TEAs based on programmatic requests and data availability

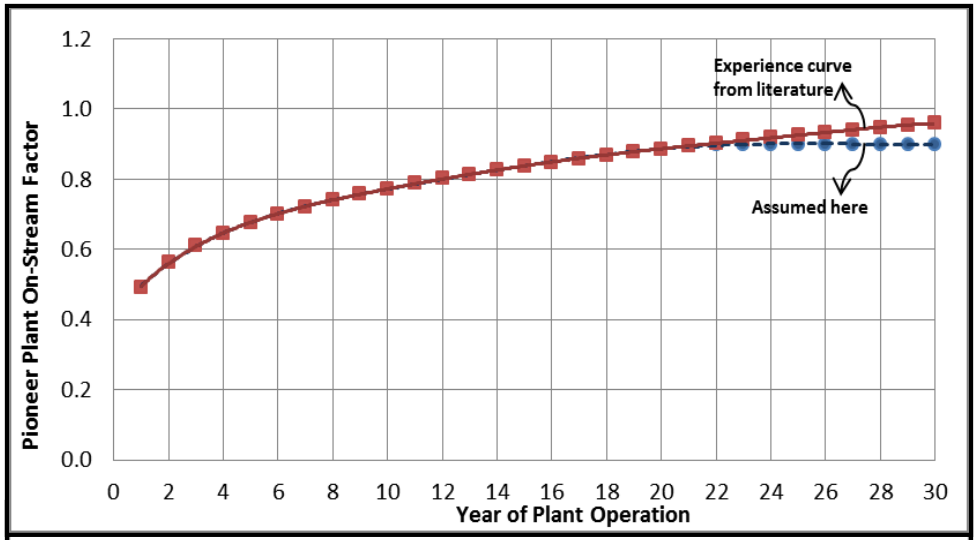
Strategic Analysis Support: TEA *Progress* (WBS 4.1.1.30)

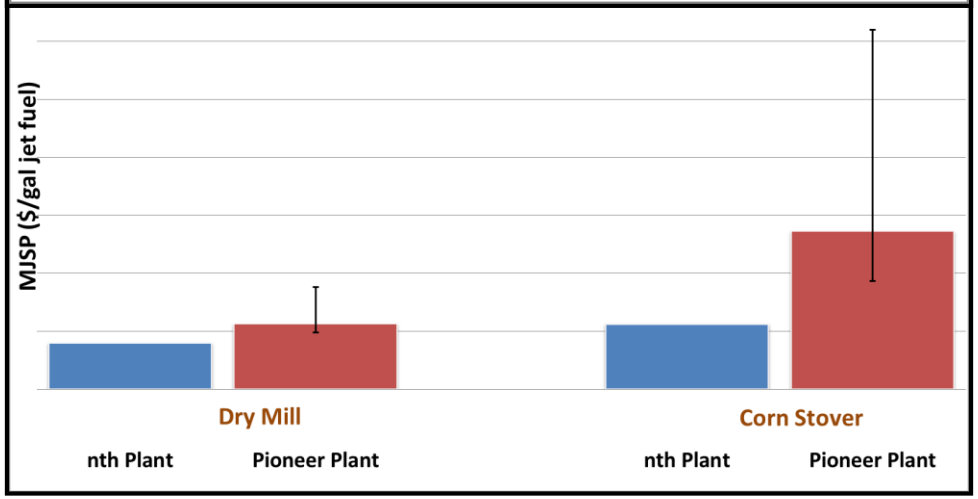


- **Established a library of TEA models for biomass-derived jet blendstocks**
  - 14 pathways developed
  - Identify key cost drivers
  - Develop pioneer plant estimates
  - Perform sensitivity analyses to quantify uncertainty impacts
- TEA provides data for conversion pathways in GREET
- Collaborations with CAAFI, DOD, EPA, and MIT
- Published 4 papers and 4 additional drafts

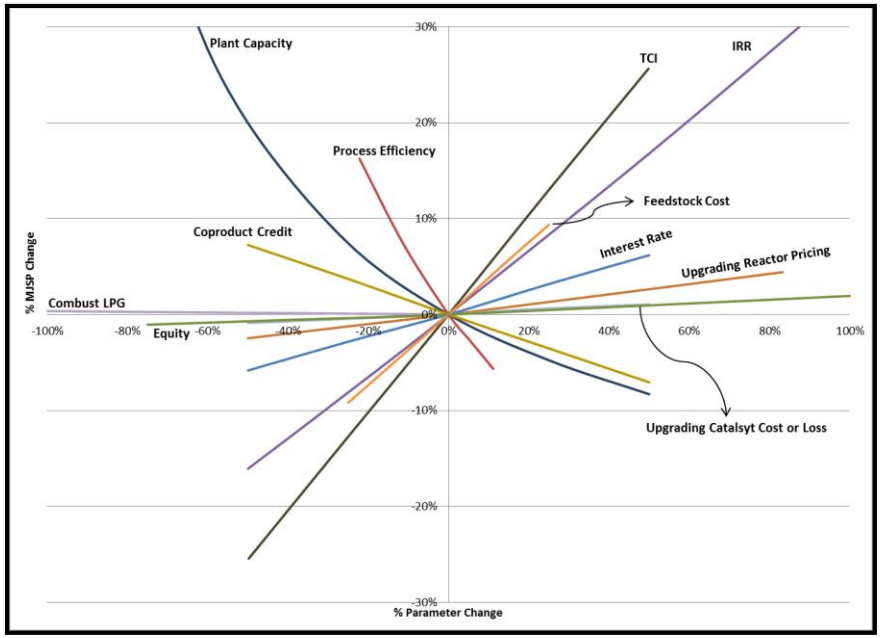
Strategic Analysis Support: TEA *Results* (WBS 4.1.1.30)

Catalytic Upgrading of Ethanol to Jet Fuel





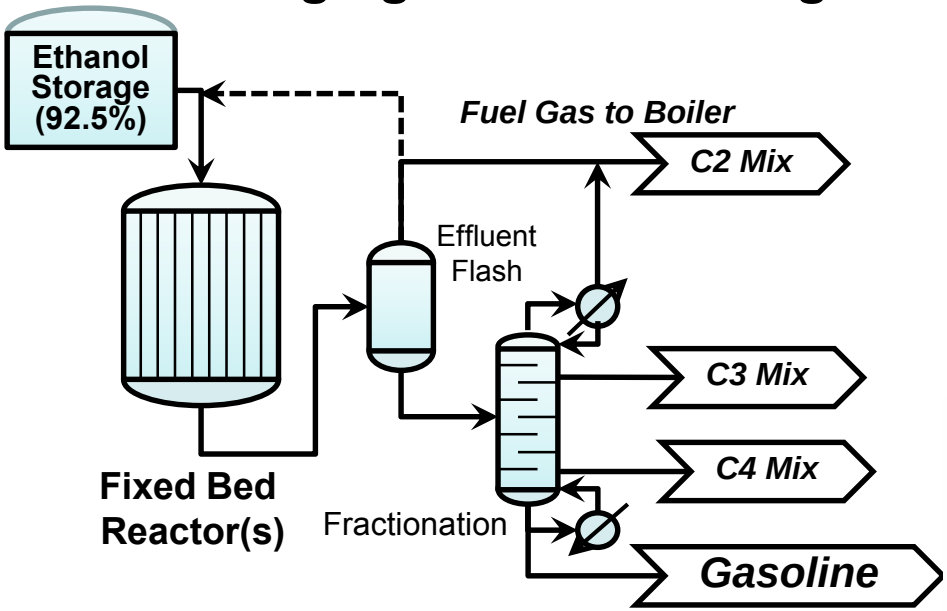
- Pioneer plant estimates consider both performance and design impacts
- Pioneer costs provided as a range of values
- Single point sensitivity analysis used to quantify impacts of assumptions and uncertainties



Merrow EW, Phillips KE, Myers C: Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants. In Book Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants. City: The Rand Corporation; 1981.

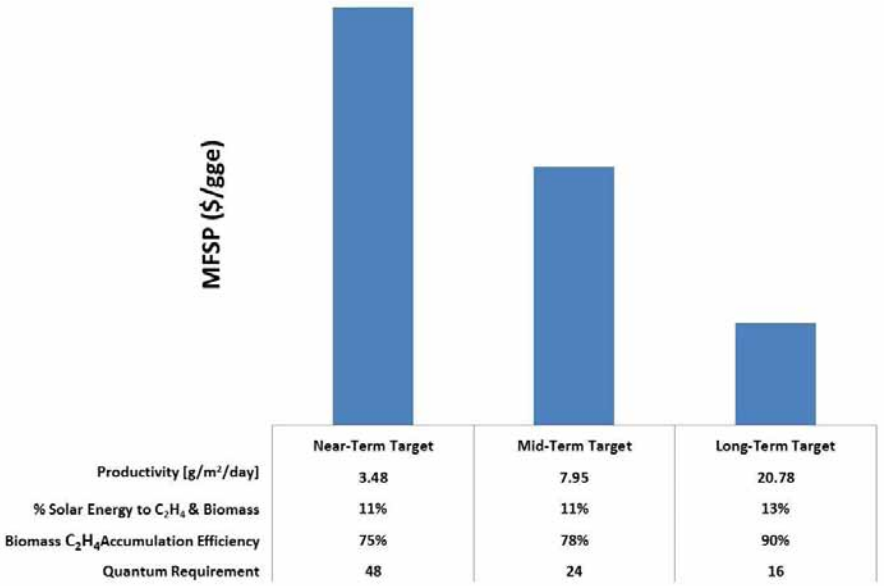
Strategic Analysis Support: TEA *Progress / Results* (WBS 4.1.1.30)

TEA of emerging / new technologies



Cyanobacteria Photosynthesis to Ethylene

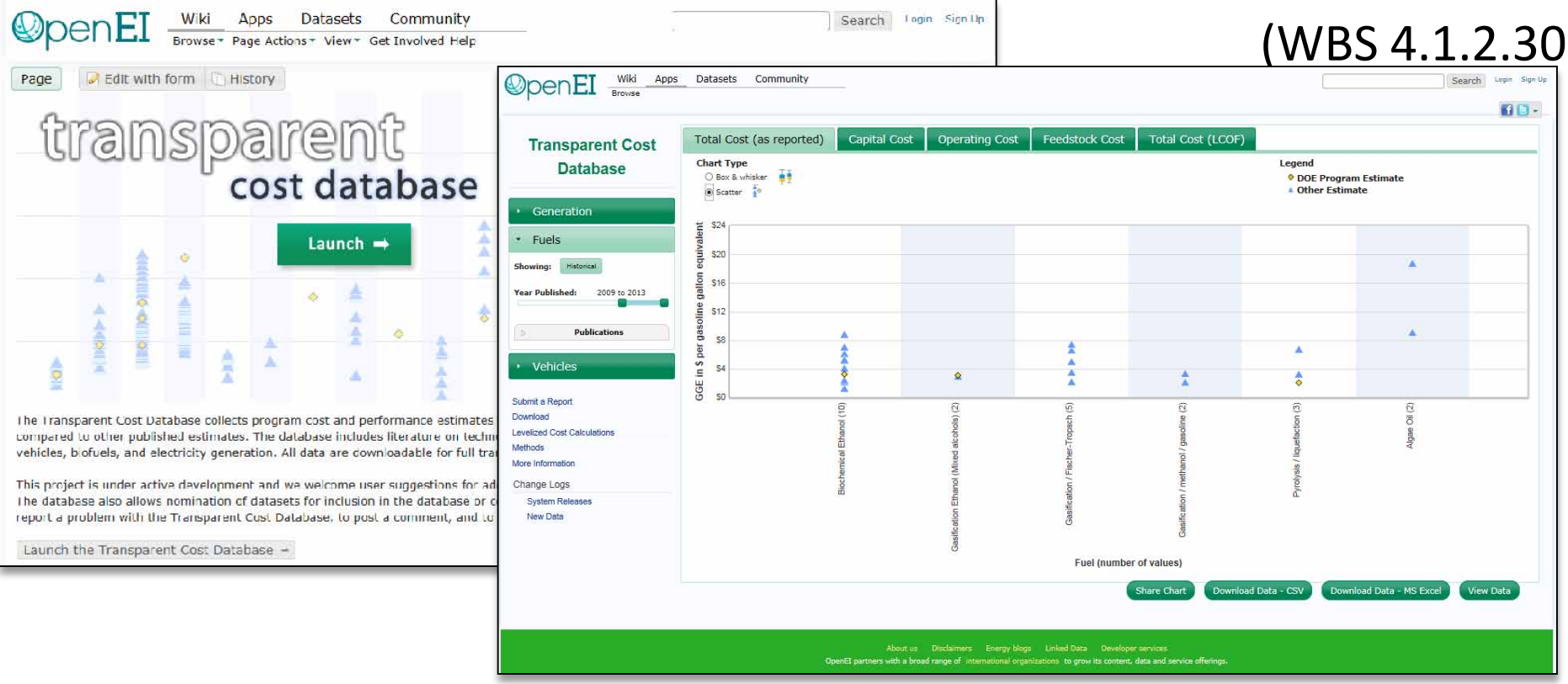
- Established TEA baseline
- Performed sensitivity analysis to quantify uncertainties
- Manuscript in preparation



ORNL Ethanol to Gasoline Approach

- Established TEA baseline using ORNL research data, analysis assumptions consistent with all other pathway TEA
- Included analysis of both grain (corn) and cellulosic (corn stover) feedstocks

(WBS 4.1.2.30)

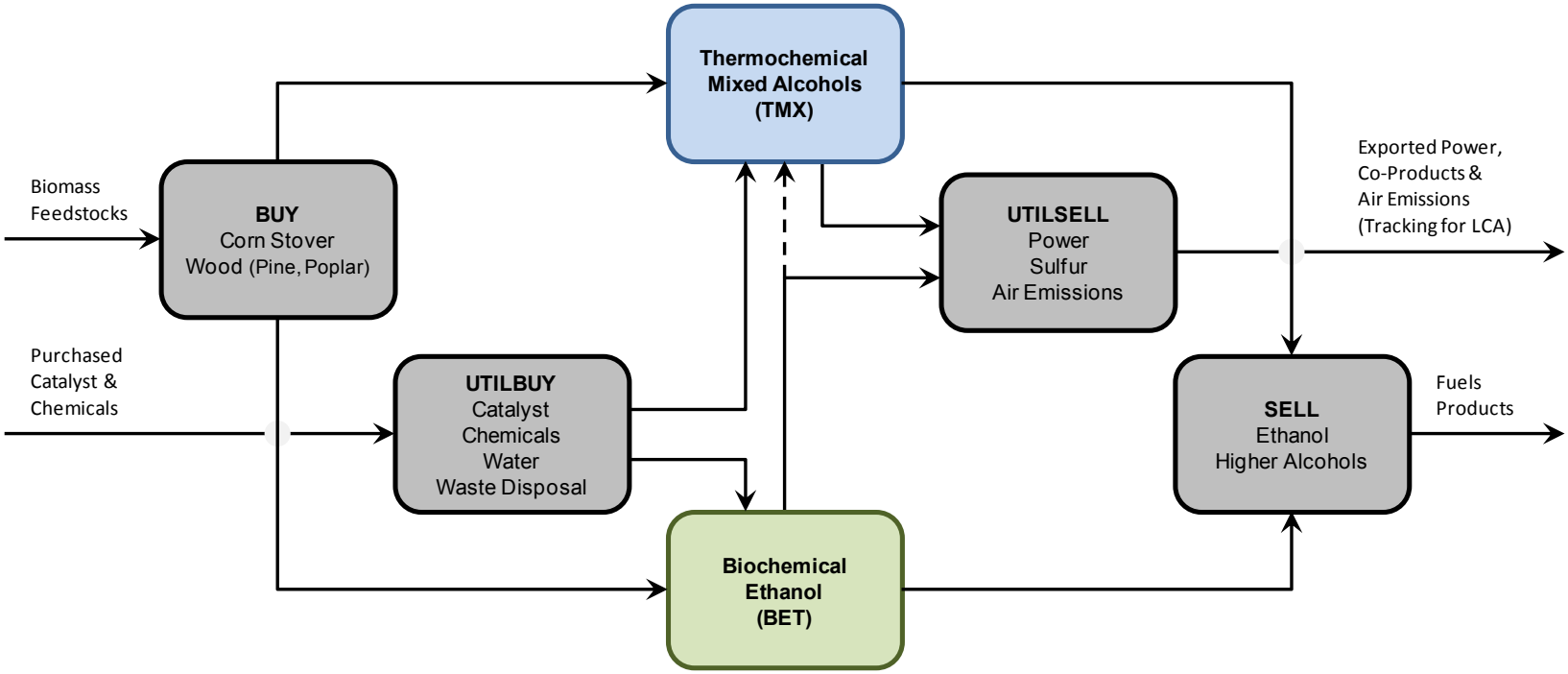


- **Support the Office of Energy Efficiency and Renewable Energy's (EERE) Transparent Cost Database web application:**
  - Collecting cost and performance estimates for EERE technologies in a public forum where they can be viewed and compared to other published estimates
  - Documented and published the methodology for producing levelized cost of energy (LCOE) for a variety of advanced biofuels (FY13)
  - Contributed **50 additional data points** to incorporate into the database

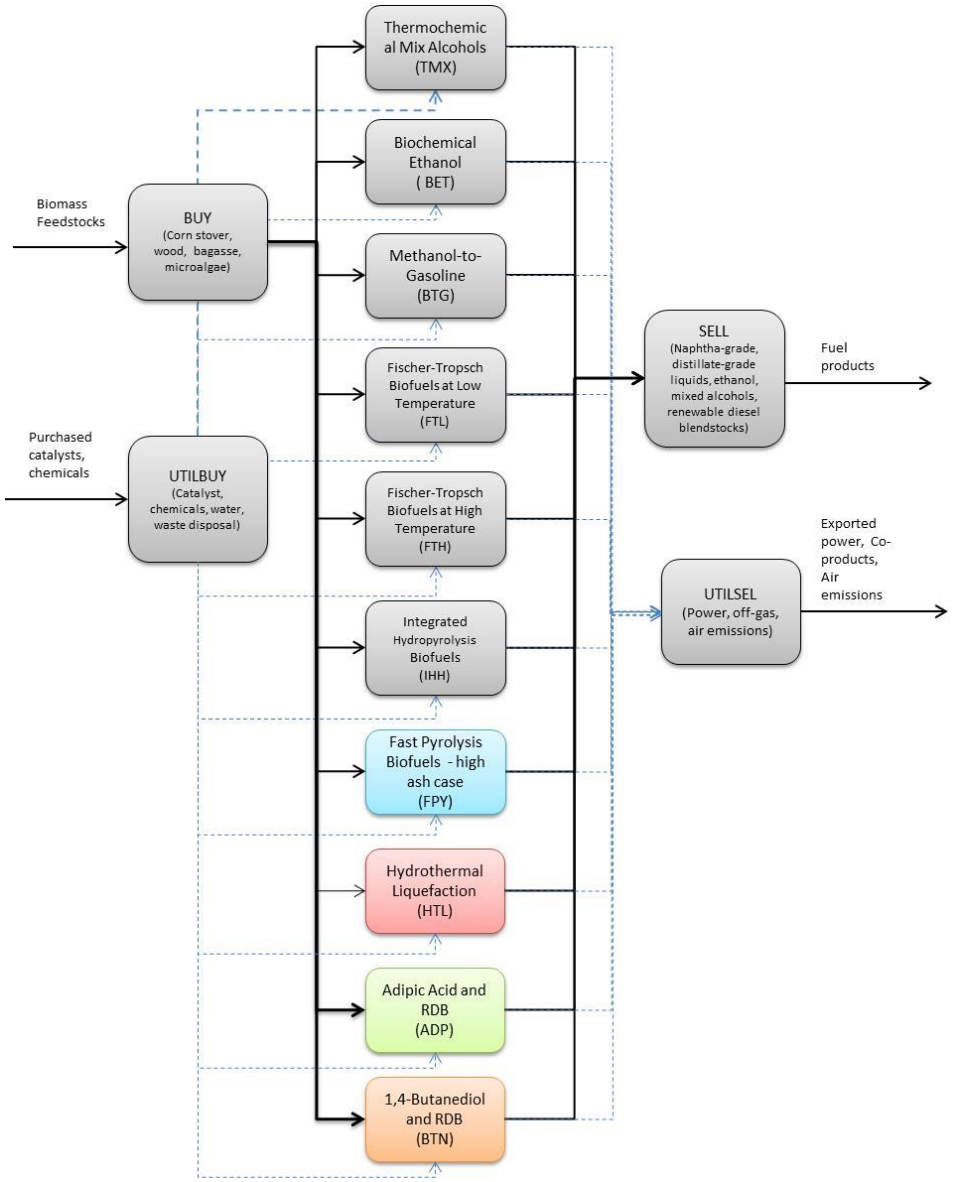
Advanced Biofuels and Bioproducts Modeling

Advanced Biofuels and Bioproducts Modeling: BIOREFINE *Approach* (WBS 4.1.3.30)

- **Model 1: BIOREFINE**
  - **Simulate biofuels pathways within complex biorefinery configurations**
    - **Utilize linear programming (LP) models**
  - Solver applies matrix-solving techniques to maximize profit
  - Profit = SELL + UTILSELL – BUY – UTILBUY



Advanced Biofuels and Bioproducts Modeling: BIOREFINE *Accomplishments* (WBS 4.1.3.30)



- Incorporated **10 new pathways** into the BIOREFINE model
- Validated that BIOREFINE economics are consistent with the design report data within 2%
- Demonstrated the capability of the tool to optimize feedstock allocations to biorefinery conversion processes given a slate of woody and herbaceous feedstocks

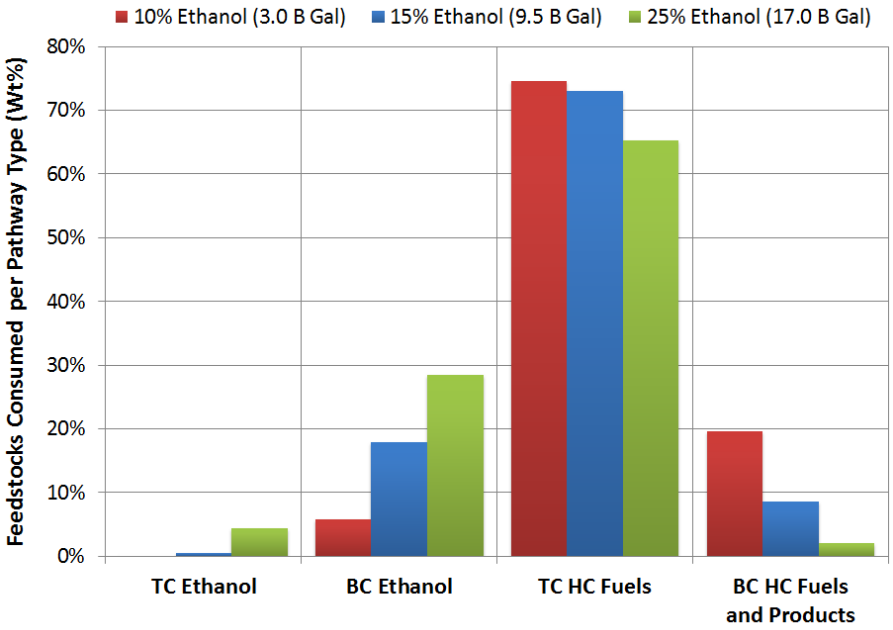
Advanced Biofuels and Bioproducts Modeling: BIOREFINE *Accomplishments* (WBS 4.1.3.30)

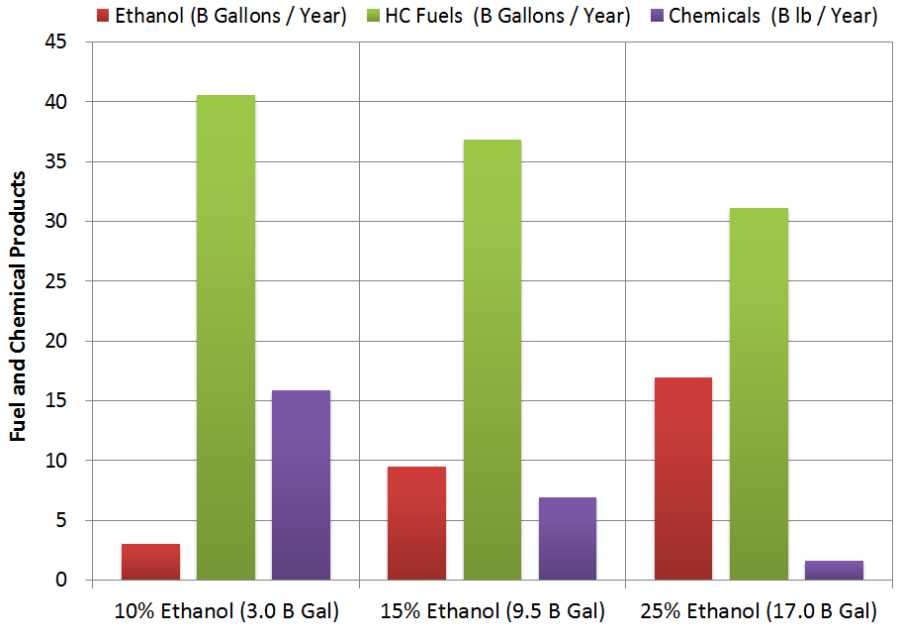
Demonstrated capability of BIOREFINE to optimize feedstock allocations

FEEDSTOCK	FS Quantity (MMTons / yr)
Herbaceous Biomass	395
Woody Biomass	240
Total Feedstocks	635

FUEL PRODUCT (ethanol in gasoline)	Cellulosic Ethanol (BGal / yr)
10 vol%	3.0
15 vol%	9.5
25 vol%	17.0

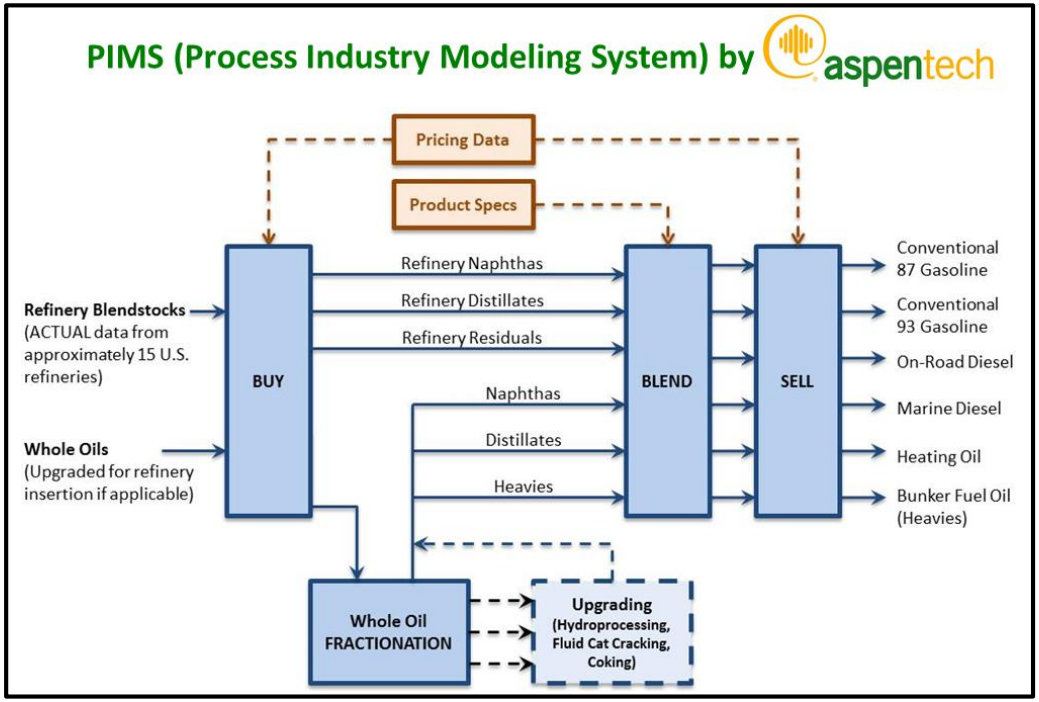
Note: Once the required ethanol production is achieved, LP will produce HC fuels and co-products.





Advanced Biofuels and Bioproducts Modeling: Blending Model *Approach* (WBS 4.1.3.30)

- **Model 2: Blending Model**
  - Investigate blending of biomass-derived products into the petroleum fuel pool
  - Incorporate **actual process data** from 15 US refineries
    - Varying complexity of refineries that span all 5 US PADDs
    - Data includes overall and unit capacity and blend stream qualities
    - Bio-derived data from public sources and collaborative partners
  - Estimate 1) the **value of a bio-blendstock** to a refiner/fuel blender and 2) **blending limits**
  - Pursue analyses for all hydrocarbon pathways under development by BETO core platform R&D
  - Tools and results are continuously vetted by key stakeholders



Advanced Biofuels and Bioproducts Modeling: Blending Model *Accomplishments* (WBS 4.1.3.30)

Blend Property	Specification Type	On-Road Diesel	GTI IH^2	Amyris Farnesane
90 Vol % Distilled Temp (Deg F)	Minimum	540.0		
90 Vol % Distilled Temp (Deg F)	Maximum	640.0	645.0	471.2
EP Vol % Distilled Temp (Deg F)	Maximum	690.0	700.0	500.0
Aromatics (Vol %)	Maximum	31.7	83.0	0
Sulfur (Wt ppm)	Maximum	11.0	30.0	0
Specific gravity	Maximum	0.880	0.940	0.770
Flash Point (Deg F)	Minimum	125.0	312.0	228.2
Carbon Residue (Wt %)	Maximum	0.35	0.25	0.01
Cetane blend index	Minimum	40.0	27.0	70.8

Refinery Product	Wholesale Price for Analysis ($ / Gallon)
Regular CBOB 87 Octane	$3.07
Premium RBOB 93 Octane	$3.56
On-Road Diesel	$3.03
Marine/Locomotive Diesel	$3.01

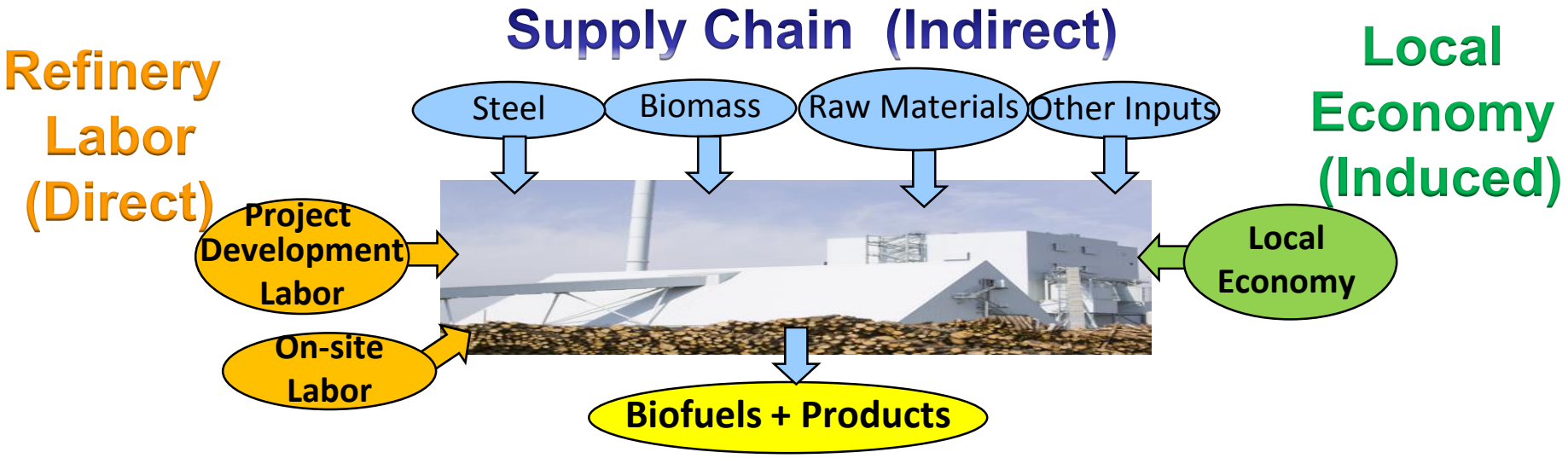
- Demonstrated the capabilities of the blending model using **3 biomass-derived blendstocks**
- Blending values ranged between **$2.20 - $4.00 /gge** depending on the refining configuration and biomass blendstock properties
- Blending values ranged between **10 - 60 vol%** of a gallon of fuel
- Identified limiting factors for blending biomass-derived hydrocarbons into the fuel pool:
  - Oxygen content
  - Quality of the intermediate
  - Challenges of a single blending component meeting all fuel specs

Price calcs. based on EIA Data (Oct 8, 2012) and Platts Oilgram Price Report (July 12, 2011)
Properties from: Marker, Terry et al. Long Term Processing Using Integrated Hydropyrolysis Plus Hydroconversion (IH2) for the Production of Gasoline and Diesel from Biomass. and Renninger, Neil et al. . U.S. Patent No. 7,399,323. 15 Jul. 2008.

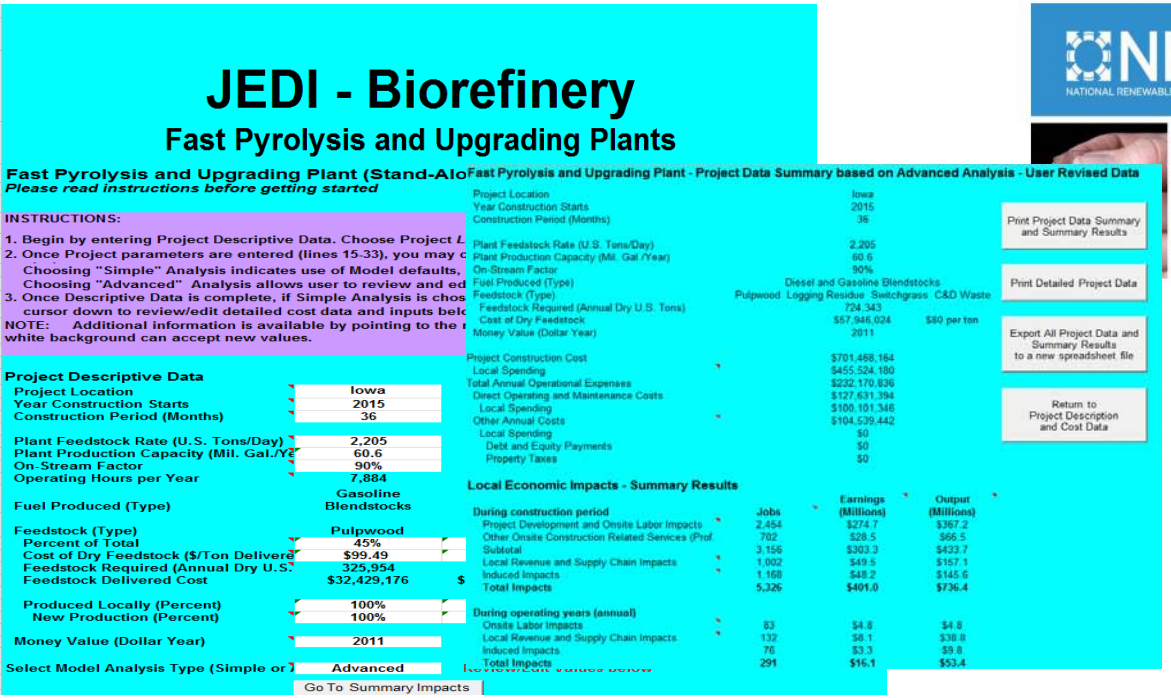
Biofuels Large Volume Market Application Analysis

Biofuels Large Volume Market Application Analysis: JEDI *Approach* (WBS 4.1.2.30)

- **Development of a suite of Jobs and Economic Development Impact (JEDI) models**
  - Publically available tools found at http://www.nrel.gov/analysis/jedi/
- **The model represents the entire economy as a system of linkages between subsectors of the economy**
  - The linkages are represented by multipliers (derived from IMPLAN, 2014) that determine the impact of construction and operation of a new project on employment, earnings, and output in other sectors
  - Uses input-output analysis to capture the impacts throughout the supply chain



Biofuels Large Volume Market Application Analysis: JEDI *Approach* (WBS 4.1.2.30)



Jobs and Economic Development Impact (JEDI) User Reference Guide: Fast Pyrolysis Biorefinery Model

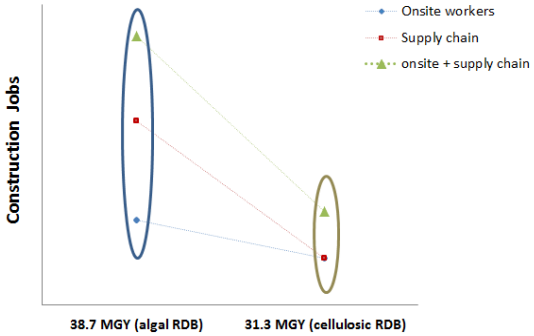
Yimin Zhang
National Renewable Energy Laboratory

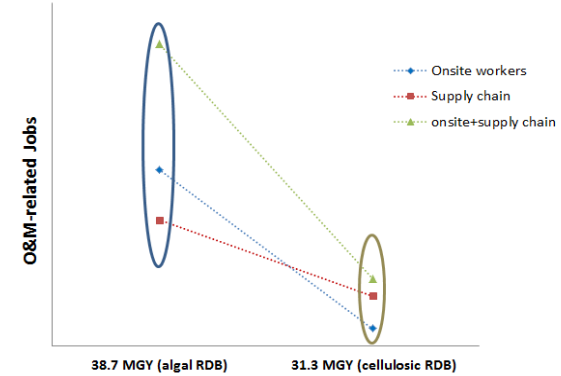
Marshall Goldberg
MRG and Associates

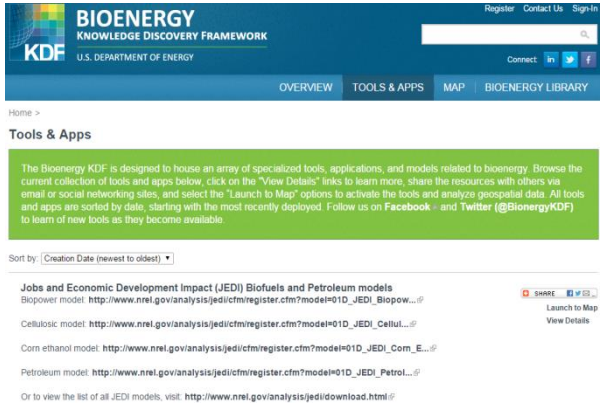
- Publicly available Excel-based, user friendly models
- Each JEDI model has a user guide that summarizes input requirements, interpretation of results and limitations of the tool
- Recently developed JEDI tools are based on hydrocarbon design reports and the latest design of biomass logistics systems
- Models are reviewed and vetted by PIs (INL, NREL, PNNL) prior to release

Biofuels Large Volume Market Application Analysis: JEDI *Accomplishments* (WBS 4.1.2.30)

- **Developed JEDI models for three advanced biofuel pathways**
  - Biological conversion of cellulosic sugars to hydrocarbons (renewable diesel blendstock)
  - Renewable diesel and gasoline via fast pyrolysis (final model to be published in Spring FY15)
  - Renewable diesel blendstock (RDB) from algal lipids upgrading
- **Developed preliminary scenario analysis** to understand comparative job impacts to **support FY15 paper and tool vetting efforts**
- **Expanded tool distribution** to key stakeholder and users by linking models to KDF







Relevance

Project directly contributes to BETO goals per 11/2014 MYPP:

- Provide analyses that "help the Office focus its technology development priorities and identify key drivers and hurdles for industry growth"
  - **Chemicals market report** focused on understanding **potential commercial success**, market **uncertainties**, and financial backing
- Provide an analytical basis for BETO planning and assessment of progress
  - **Strategic TEA** models identify **key cost drivers** for jet fuel and new emerging technologies, as well as develop pioneer plant costs for near-term deployment
- Apply these models to conduct systems-level analyses, which support decision-making at different levels (*e.g.*, policy, industry, and bioenergy projects)
  - **BIOREFINE LP tools** reduce the barriers for process integration and allow optimization of a biorefinery for a range products and available feedstocks
  - The **biofuels blending model** estimates the **value of a bio-blendstocks** to a petroleum refiner
- Develop models and methodologies to advance the understanding of the impacts and socio-economic benefits in the US due to the growth of the bioeconomy
  - **JEDI tools** help to understand bioenergy's **impact on creating green jobs in the US**

Relevance

Impacts to the biomass and bioenergy community:

- Engage and communicate results of analyses to stakeholders
  - **JEDI models** (biofuels, biopower and petroleum fuels) **are widely used** and are publically available (via the NREL website and the KDF) with **over 860 downloads** in the last 2 years
  - **Strategic TEA** on jet fuel pathways are utilized to **expand** the conversion processes in **GREET** and **support collaborative relationships** with CAAFI, DOD, EPA, and MIT
  - Strategic Support efforts have maintained external collaborations with **DOE VTO, US DRIVE and US CAR** teams to provide cost numbers and key biofuel production metrics
  - Have published 4 peer-reviewed papers and technical publications with 6 more drafts in preparation for peer reviewed journals; Have given over 10 presentations

Future Work

- **Develop tools and analyses in support of pathways to biomass-derived hydrocarbon fuels and chemicals**
  - Perform analysis to quantify the impact of by-product cost assumptions on economic viability (in support of the FY16 A&S platform milestone)
  - Expand jet fuel pathway portfolio and provide data to GREET
  - Expand JEDI to include advanced biomass logistics systems
  - Continue to vet models and results with key stakeholders
  - Support researchers by performing initial feasibility assessments and modeling for novel conversion concepts
- **Planned peer reviewed journal articles and public milestone reports by the end of FY15 / early FY16:**
  - Publish chemicals market analysis report
  - Paper on jobs analysis to identify key factors that drive jobs associated with the entire supply chain of selected biofuel pathways; Conference presentation
  - Journal article on BIOREFINE model methodologies and capabilities
  - White paper on the impact of by-product cost assumptions

Summary

- **Develop tools and perform analyses to address key questions in support of the strategic direction of the DOE Bioenergy Technologies Office**
- **Develop models and methodologies that directly contribute to BETO goals and the biomass conversion community**
- **Key deliverables include**
  - Preparation of market analysis report for the production of bio-derived chemicals
  - Development and demonstration of biofuels blending model
  - Support development of additional jet fuel conversion TEAs
  - Vetting, expansion, and publication of JEDI models for hydrocarbon fuels
- **Future work will develop tools and analyses in support of pathways to biomass-derived hydrocarbon fuels and chemicals**
- **Provide credible results to assist decision making in bioenergy investment through applying appropriate analyses and models**
  - Document sources of data, understand uncertainties, and quantify impact of uncertainties

Acknowledgements

- **Thank you to…**
  - Bioenergy Technologies Office:
    - Alicia Lindauer, Kristen Johnson, Zia Haq (Strategic Analysis and Sustainability Platform)
    - Kevin Craig, Jay Fitzgerald, Nichole Fitzgerald, Prasad Gupte, Bryna Guriel, Liz Moore (Conversion)
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    - Adam Bratis, Ryan Davis, Abhijit Dutta, Daniel Inman, Chris Kinchin, Jennifer Markham, Anelia Milbrandt, Asad Sahir, Christopher Scarlata, Michael Talmadge, Eric Tan, Ling Tao, Yimin Zhang, Yanan Zhang, Helena Chum, Mark Davis, Rick Elander, Tom Foust, Philip Pienkos, and NREL technology platform researchers
  - PNNL collaborators:
    - Sue Jones, Aye Meyer, Corinne Valkenburg, Yunhua Zhu
  - National Laboratory Partners (PNNL, INL, ORNL)
  - Industrial and Academic Partners

Additional Slides

Responses to reviewer feedback

- Sustainability aspects beyond economics are less emphasized in the project suite, with job creation the sole societal indicator.
  - We have established a collaboration with ANL to utilize results from the TEA efforts to expand the GREET portfolio. This collaboration helps support a number of the sustainability assessment projects at ANL.
- This project area needs to establish a clear methodology that balances analysis that are driven by bottom-up considerations of the technology and research capabilities versus market- and strategy-driven goals established from a top-down perspective.
  - The methodology utilized for the on-going Strategic TEA efforts has focused on a bottom-up approach to evaluate the current state of the technology for each conversion technology. This approach is supported by using the highest quality research data and cost numbers available.
  - The TEA team works closely with the R&D groups to understand the potential of each technology and to develop out-year R&D targets based on input and advisement from the researchers on what is possible in the given time frame.
  - The impact of any uncertainties or assumptions in the studies is quantified through sensitivity analyses.

Abbreviations and Acronyms

- A&S: Analysis and Sustainability
- ANL: Argonne National Laboratory
- AOP: Annual operating plan
- BETO: Bioenergy Technologies Office
- CAAFI: Commercial Aviation Alternative Fuels Initiative
- COP: ConocoPhillips
- CU: University of Colorado
- DOD: Department of Defense
- EPA: US Environmental Protection Agency
- GGE: Gasoline gallon equivalent
- JEDI: Jobs and Economic Development Impact
- INL: Idaho National Laboratory
- ISU: Iowa State University
- LCA: Life-cycle analysis
- MFSP: Minimum fuel selling price
- MYPP: Multi-year program plan
- NREL: National Renewable Energy Laboratory
- ORNL: Oakridge National Laboratory
- PNNL: Pacific Northwest National Laboratory
- VTO: Vehicles Technology Office

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