Co-Optimization of Fuels & Engines

ASSERT: Analysis of Sustainability, Scale, Economics, Risk and Trade

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Relevance

ASSERT guides Co-Optima towards investigation of co-optimized fuels and engines that address BETO's strategic opportunities to:

- Enhance bioenergy's value proposition through identifying bio-blendstocks that can cut fuel consumption, have low supply-chain environmental impacts, and be produced economically, generating employment in the biofuel supply chain.
- Mobilize our nation's biomass resources through examination of companion markets that can stimulate biomass production at scale for the production of bio-blendstocks that offer fuel economy benefits, viable process economics, and low environmental impacts along the supply chain.

ASSERT Goal Statement

Evaluate the bio-blendstocks and vehicle technologies under consideration within the Co-Optima program from an environmental and economic perspective while conducting research and development-guiding analyses.

As an outcome, Co-Optima teams understand environmental and economic barriers to deployment of co-optimized fuels and engines and routes to overcome them.

Quad Chart Overview – ASSERT

Timeline

- Project Start: October 1, 2015
- Project end: September 30, 2018
- Percent Complete: 42%

Barriers

- At-A: Comparable, transparent, and reproducible analyses
- At-B: Analytical tools and capabilities for system-level analysis
- Im-F: Uncertain pace of biofuel availability
- Im-H: Lack of acceptance and awareness of biofuels as a viable alternative

Budget ($K)

	Total Costs FY12 – FY15	FY16 Budget	FY17 Budget	FY18 Budget
BETO Funded	$0	$2,198	$2,224	$2,224

Partners

ANL, INL, LANL, LBNL, NREL, PNNL

1 Project Overview

ASSERT Overview

- Overarching goal of Co-Optima is to develop fuels that would impact the market place in the near term
- The ASSERT team supports Co-Optima goals by:
    - Evaluating environmental and economic drivers and the potential of bio-blendstock candidates
    - Sharing these key outputs with the teams and stakeholders
    - Guiding the Co-Optima consortium’s research and development
- ASSERT also assesses potential benefits or drawbacks of deploying co-optimized fuels and engines in the transportation sector with respect to:
    - Energy consumption
    - Harmful emissions and water consumption
    - Job creation
    - Development of markets for biomass
    - Technology readiness for scale up in the near term
    - Economic viability

2 Approach (Management)

Approach (Management)

- The ASSERT team is led by Jennifer Dunn at Argonne National Laboratory and Mary Biddy at the National Renewable Energy Laboratory
- Team members have expertise in the **crosscutting** areas of
  - Techno-economic analysis (TEA) (NREL, PNNL)
  - Life cycle analysis (ANL)
  - Refinery modeling (ANL, NREL, PNNL)
  - Job creation modeling (NREL)
  - Modeling of expansion of biofuels industry in response to demand (ANL, INL, NREL)
  - Vehicle fleet sector evolution upon introduction of new vehicle technologies (ANL, NREL)
  - Biomass market modeling (INL)
- The team holds weekly conference calls and has participants on the HPF team calls with strategic communications with other teams
- The Co-Optima Project Plan is used to organize the team's work across the individual labs' annual operating plans

Approach (Management)

Feedstock Production and Logistics

Conversion

Refinery Integration

Fuel Transportation and Distribution, Vehicle Integration

- ASSERT incorporates expertise covering the biofuel supply chain
- Examples of integration with other teams
    - High Performance Fuels: Information exchange regarding route to producing blendstock candidates and their properties. Regular participation on conference calls
    - Fuel Properties: Information exchange regarding fuel properties, especially blended fuels
    - Toolkit Team: Collaboration regarding use of economic and sustainability aspects of blendstock candidates in their overall evaluation as Thrust I candidate blendstocks
    - Advanced Engine Development Team: Seek input regarding assumptions about fuel economy gains upon deployment of Thrust I and Thrust II co-optimized fuels and engines
    - Market Transformation: Extensive collaboration and discussion around real-world aspects of fuel deployment including infrastructure considerations. Weekly team lead meetings

Team Members

FY17 ASSERT Team Members

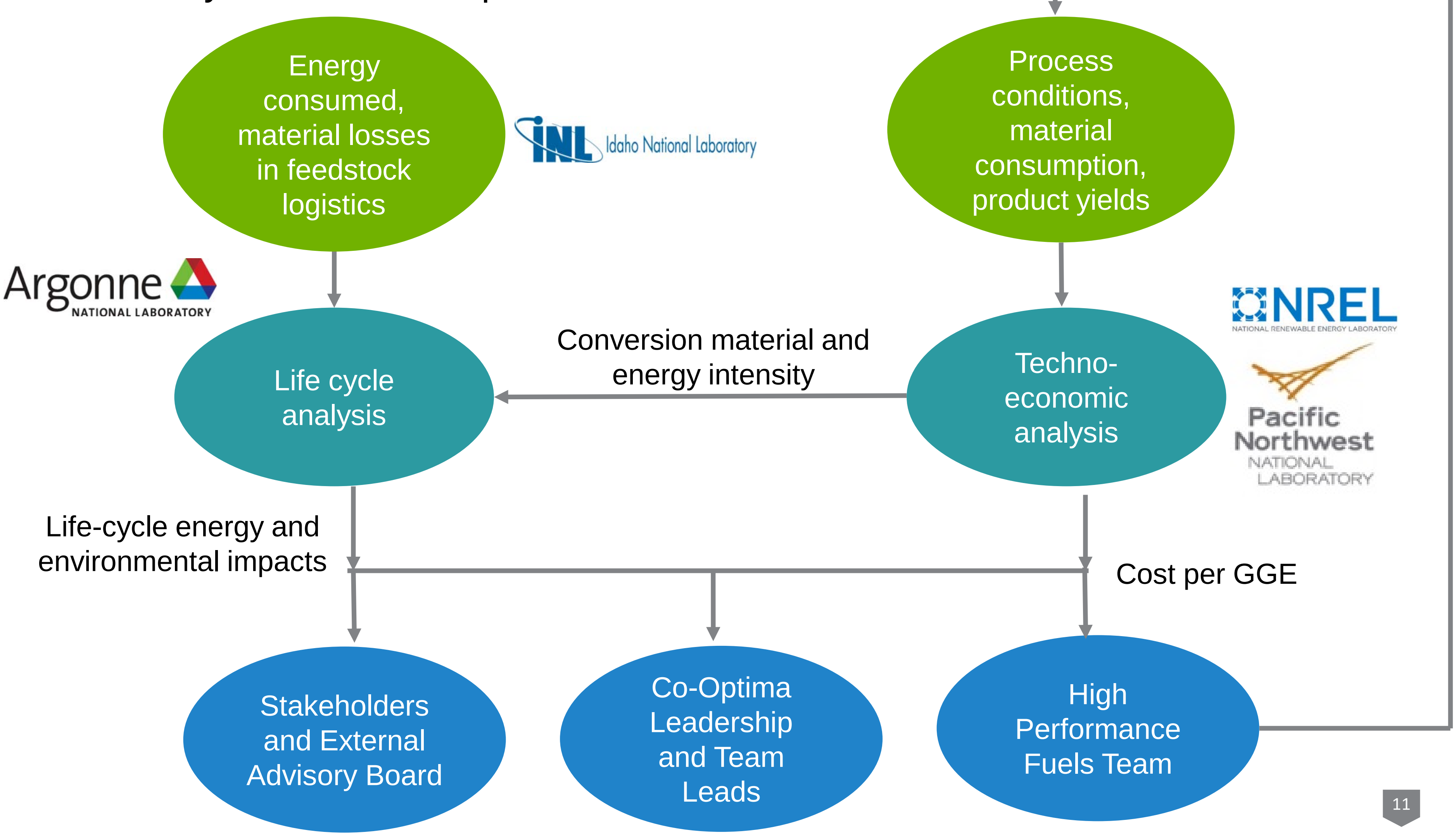
- ANL: ***Jennifer Dunn***, Hao Cai, Jeongwoo Han, Thathian Benavides
- INL: ***Patrick Lamers***, Erin Searcy
- LBL: ***Corinne Scown***
- NREL: ***Mary Biddy***, Emily Newes, Aaron Brooker, Yimin Zhang
- PNNL: ***Sue Jones***, Ken Rappe

Argonne NATIONAL LABORATORY
INL Idaho National Laboratory
BERKELEY LAB Lawrence Berkeley National Laboratory
NREL NATIONAL RENEWABLE ENERGY LABORATORY
Pacific Northwest NATIONAL LABORATORY

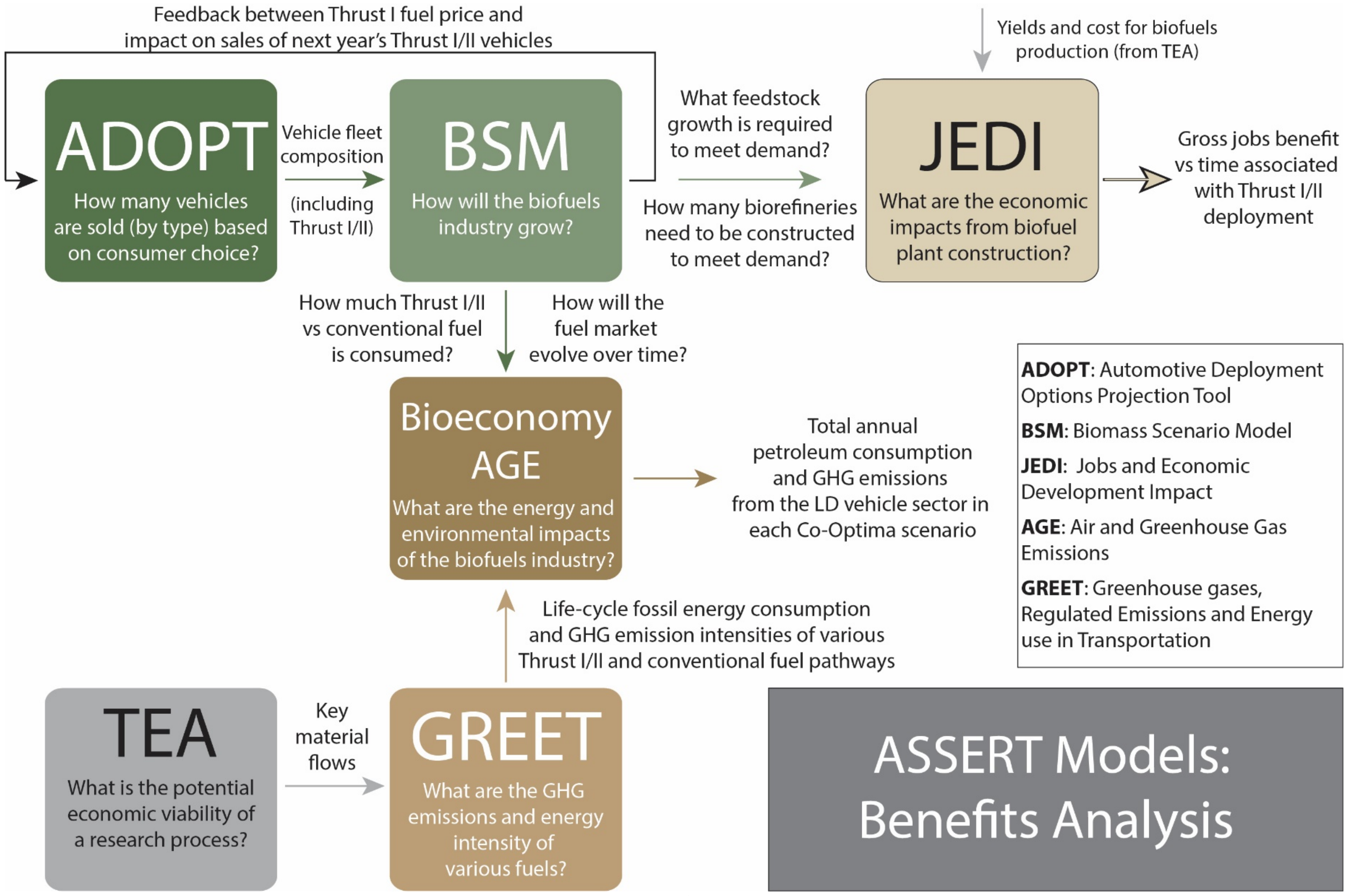
2 Approach (Technical)

Techno-economic and Life Cycle Analysis

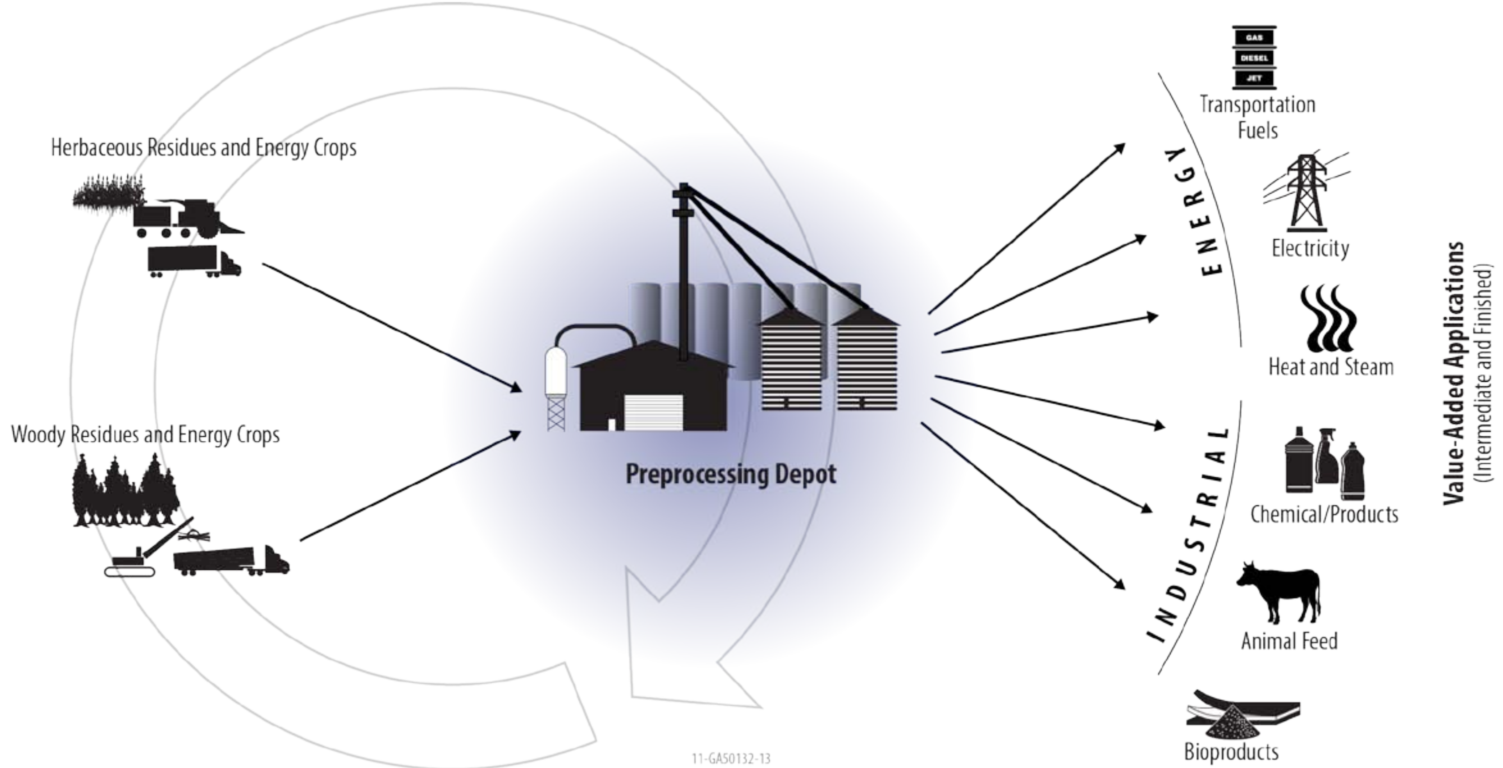
Inter-linked techno-economic and life cycle analysis inform Co-Optima research direction



Benefits Analysis and Models



Biomass Companion Market Model Development



Key research questions regarding production of biomass feedstock at scale:

- How can companion markets, for example, animal feed, stimulate an advanced feedstock system that will benefit biorefineries and move the domestic biomass supply from potential to available?
- Will the presence of companion markets raise biomass prices above those viable for biorefineries? Will these markets limit biomass supply to biorefineries?

3 Technical Accomplishments

Evaluation of 20 Thrust I Blendstock Candidates

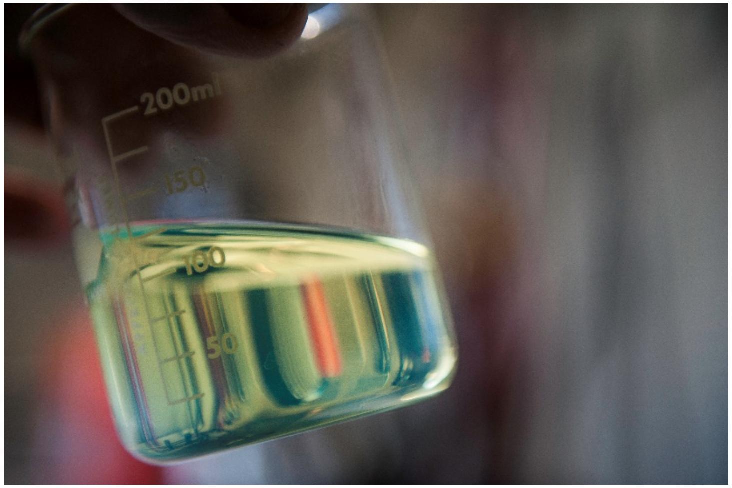
Sample metrics and binning definitions from each category. Overall, 17 metrics were applied.

Metric	Favorable	Neutral	Unfavorable	Approach
Technology Readiness: Conversion State of technology (SOT) technology readiness level	Demo scale	Bench scale	Partly literature based	Is conversion process 1) notional, 2) literature based, 3) bench-scale data, 4) demo or larger
Economic Viability: Cost reduction needed to go from SOT to target case	<2	2< <4	> 4	Based on ratio of Min Fuel Selling Price of SOT case to target case.
Environmental Sustainability: Carbon efficiency; fossil and renewable input carbon	>40%	30%-40%	<30%	Based on known conversion methods and input from HPF team & lit, how would the candidate be made? Use high-level TEA mass balance to estimate

Candidates were evaluated with 14 additional metrics.

Evaluation of 20 Thrust I Blendstock Candidates

- Twenty candidates selected in consultation with HPF team, leadership
- Evaluation of two cases for each blendstock
  - State of technology (SOT) case illustrating current yields, efficiencies, and other parameters
  - Target case illustrating mature potential technology performance
- Leveraging of existing TEA models in addition to generation of new models where necessary
- Incorporation of process model material and energy flows into GREET for each of the compounds with generation of life cycle analysis results
- QA of results and communication by technical report



Evaluation of 20 Thrust I Blendstock Candidates

17 ASSERT Metrics

20 Thrust I blendstock candidates

	Economic Viability							Technology Readiness					Environmental Sustainability				
	SOT-fuel	SOT-vehicle	Conversion TRL	Feedstock quality	# viable routes	Feedstock sensitivity	Process robustness	Target cost	Cost reduction	Coproducts	Blendstock competition	Feedstock cost	Carbon efficiency	Yield	Life cycle GHG	Life cycle FE consumption	Life cycle water
Ethanol	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Green	Green	Green	Green	Yellow	Red	Green	Green	Yellow
Methanol	Green	Yellow	Green	Green	Red	Yellow	Yellow	Green	Green	Green	Green	Green	Yellow	Green	Green	Green	Yellow
1-Butanol	Yellow	Gray	Yellow	Green	Yellow	Yellow	Yellow	Green	Green	Red	Yellow	Green	Red	Red	Yellow	Green	Yellow
2-methyl butanol	Red	Gray	Red	Green	Yellow	Yellow	Yellow	Red	Red	Green	Green	Green	Red	Yellow	Red	Green	Yellow
2-Butanol	Red	Gray	Red	Green	Yellow	Yellow	Yellow	Yellow	Red	Green	Green	Green	Red	Yellow	Yellow	Green	Yellow
iso-Butanol	Green	Gray	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Green	Green	Green	Red	Yellow	Yellow	Green	Yellow
Guerbet alcohols	Green	Gray	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Green	Green	Yellow	Green	Yellow	Yellow	Green	Green	Yellow
Furan mixture	Red	Gray	Red	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Green	Green	Yellow	Green	Yellow	Green	Yellow
Methyl acetate	Green	Gray	Red	Green	Yellow	Yellow	Yellow	Green	Green	Green	Yellow	Green	Green	Green	Green	Green	Yellow
Ethyl acetate	Yellow	Gray	Red	Green	Yellow	Yellow	Yellow	Red	Green	Green	Yellow	Green	Red	Red	Green	Green	Yellow
Butyl acetate	Red	Gray	Red	Green	Yellow	Yellow	Yellow	Red	Green	Green	Yellow	Green	Red	Red	Red	Green	Yellow
Anaerobic mixed esters	Red	Gray	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Green	Green	Green	Green	Yellow	Yellow	Green	Green	Yellow
2-pentanone	Red	Gray	Red	Green	Yellow	Yellow	Yellow	Red	Green	Green	Yellow	Green	Red	Yellow	Green	Green	Yellow
2-butanone	Yellow	Gray	Red	Green	Yellow	Yellow	Yellow	Red	Green	Green	Yellow	Green	Yellow	Yellow	Yellow	Green	Yellow
2,2,3-trimethylbutane	Green	Green	Yellow	Green	Red	Green	Green	Green	Green	Red	Yellow	Green	Red	Red	Green	Green	Yellow
iso-octene	Yellow	Yellow	Red	Green	Yellow	Yellow	Yellow	Red	Green	Green	Green	Green	Red	Red	Green	Green	Yellow
Ethanol to Hydrocarbons	Yellow	Yellow	Red	Green	Yellow	Yellow	Yellow	Yellow	Green	Green	Yellow	Green	Yellow	Green	Green	Green	Yellow
Sugar condensation	Red	Gray	Red	Green	Red	Red	Red	Green	Yellow	Yellow	Green	Green	Red	Red	Yellow	Green	Yellow
Catalytic fast pyrolysis	Green	Yellow	Red	Green	Green	Yellow	Yellow	Green	Green	Green	Green	Green	Yellow	Green	Green	Green	Green
Catalytic sugar conversion	Yellow	Green	Red	Yellow	Green	Yellow	Yellow	Yellow	Green	Green	Green	Green	Yellow	Green	Red	Green	Yellow
Methanol to gasoline	Green	Green	Red	Green	Green	Yellow	Yellow	Green	Green	Green	Yellow	Green	Red	Yellow	Green	Green	Yellow

Gasification/catalysis Fermentation Hydrolysis/catalysis Pyrolysis

Preliminary results, publication pending

Evaluation of 20 Thrust I Blendstock Candidates

Key conclusions

- All candidates received a favorable rating for fossil energy consumption and feedstock cost
- The early development stage of many candidates resulted in an unfavorable rating for conversion SOT readiness
- More information being sought to understand potential bendability of several candidates
- Candidates that were at or near commercialization received generally favorable ratings
- No one candidate fared unfavorably overall
- Analysis will be expanded to include five additional candidates prior to publication

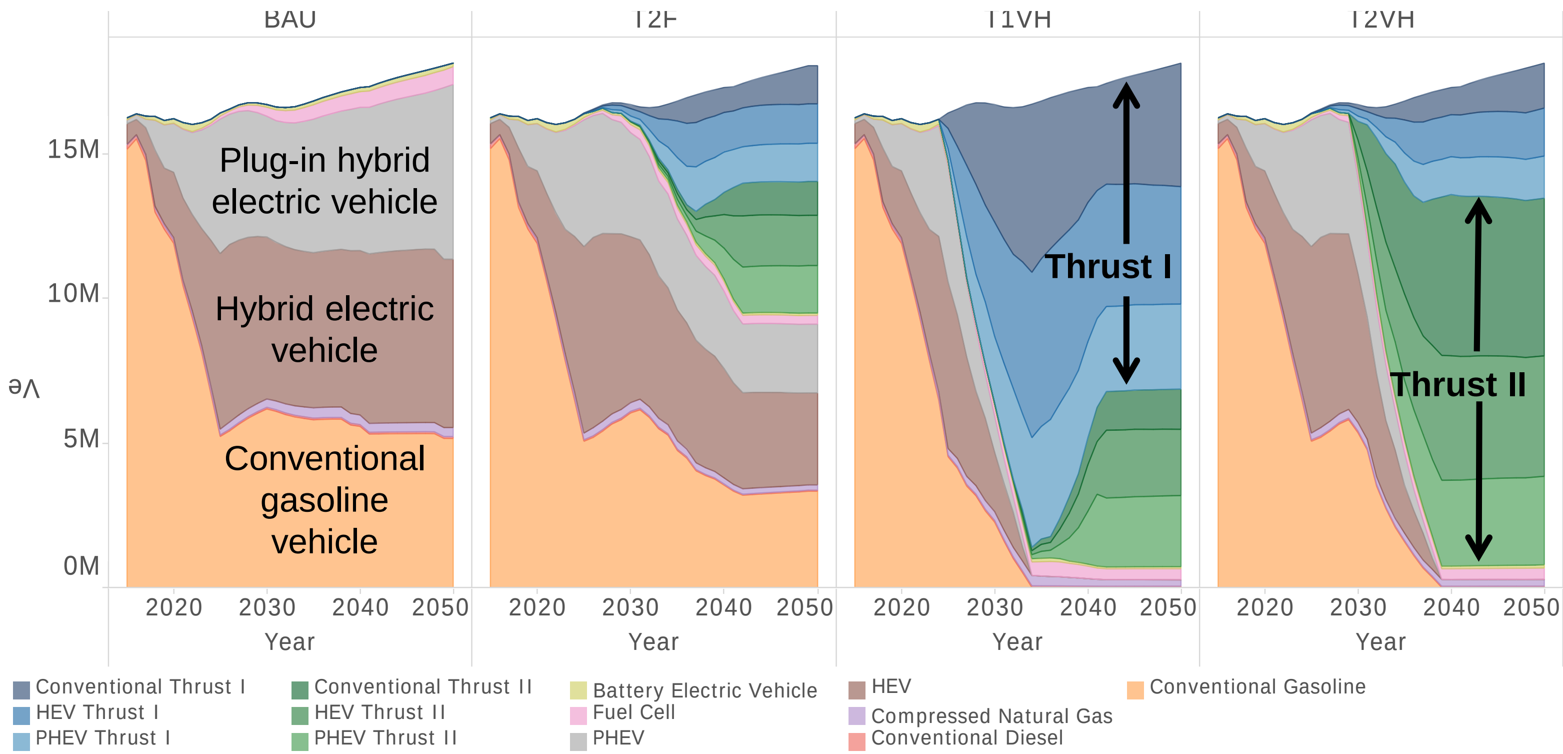
Co-Optima Benefits Analysis

- Establish methodology for Co-Optima program to evaluate potential transportation sector effects through application of several BETO-funded models
- The goal of this analysis was to evaluate the energy and environmental benefits of the Co-Optima program through assessing the influence of introduction of Thrust I and II fuels and vehicles on the vehicle fleet and biofuel production
- Evaluate changes in the light-duty transportation sector fossil fuel consumption, greenhouse gas emissions under several scenarios with Thrust I and II fuel and vehicle introduction against a business-as-usual scenario based on Energy Information Administration projections
- Estimate potential job creation effects of the new fuel and vehicle technologies
- Results presented in ranges and as estimates given uncertainty about identity of Thrust I and II fuels and their influence on fuel economy and will be updated as Co-Optima progresses

Scenario	Abbreviation	Description
Thrust II Fuel Penetration	T2F	No turnover specified.
Thrust II Vehicle High Penetration	T2VH	Fleet turns over to Thrust II vehicles within 10 years after Thrust II vehicle introduction. Thrust I vehicles are not replaced by Thrust II turnover.
Thrust I Vehicle High Penetration	T1VH	Fleet turns over to Thrust I vehicles within 10 years after Thrust I vehicle introduction. Thrust II vehicles are not replaced by Thrust I turnover.

Co-Optima Benefits Analysis

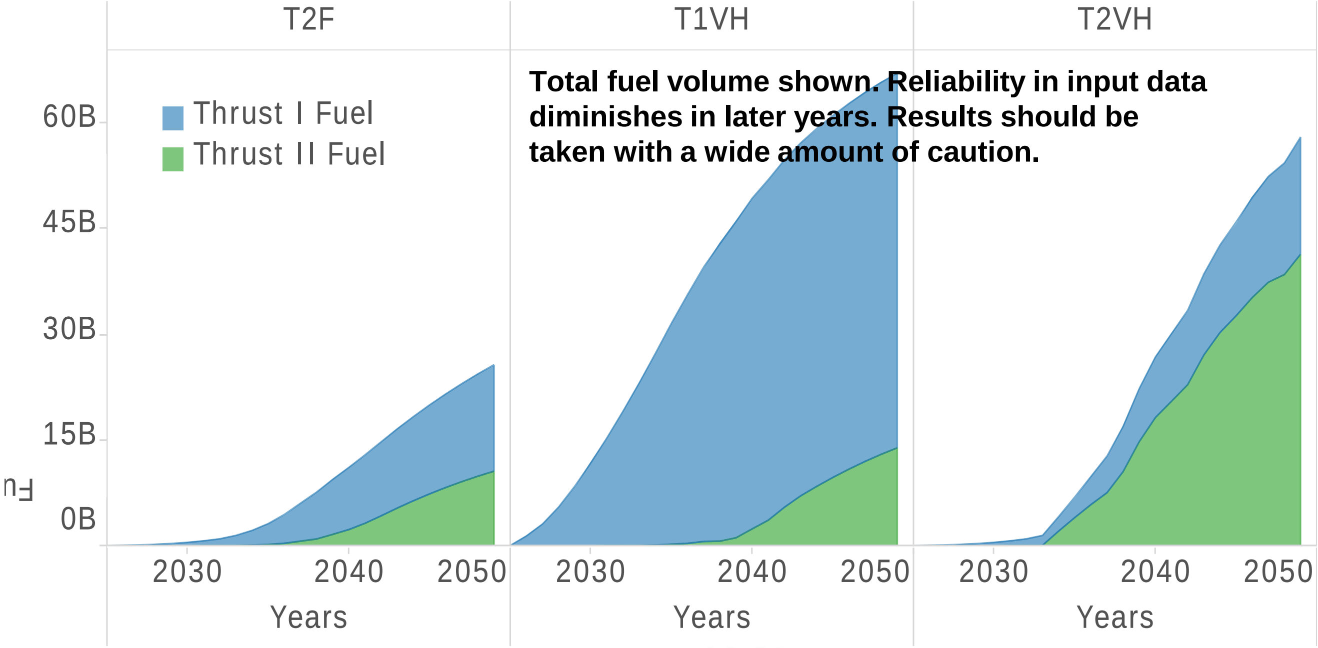
- Market demand alone in the T2F scenario could expand Co-Optima vehicles to half of new sales
- Thrust I and Thrust II vehicles, including hybrid electric and plug-in hybrid vehicles, dominate in T1VH and T2VH scenarios, respectively



BAU: business as usual; HEV: hybrid electric vehicle; PHEV: plug-in hybrid electric vehicle

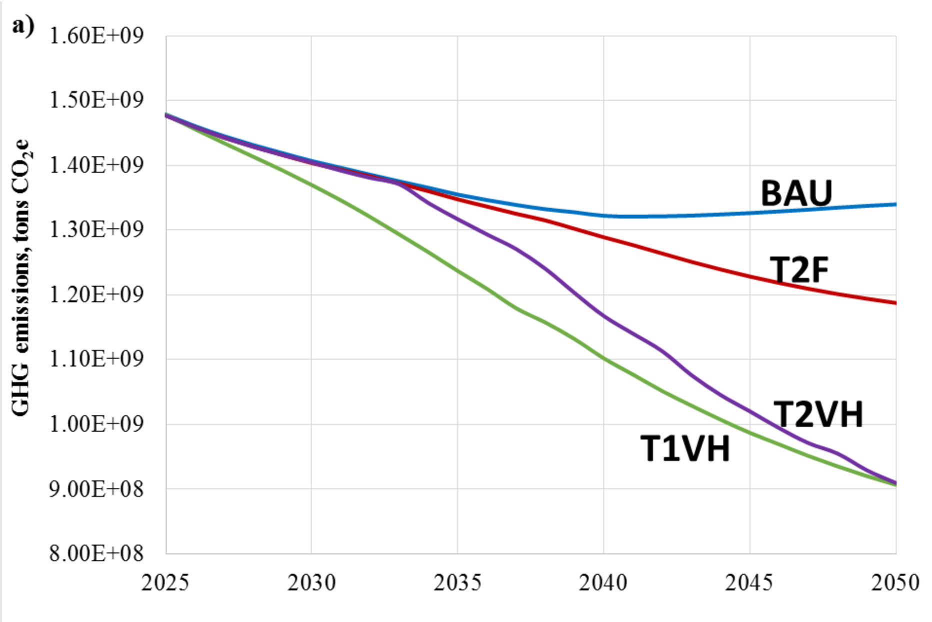
Co-Optima Benefits Analysis

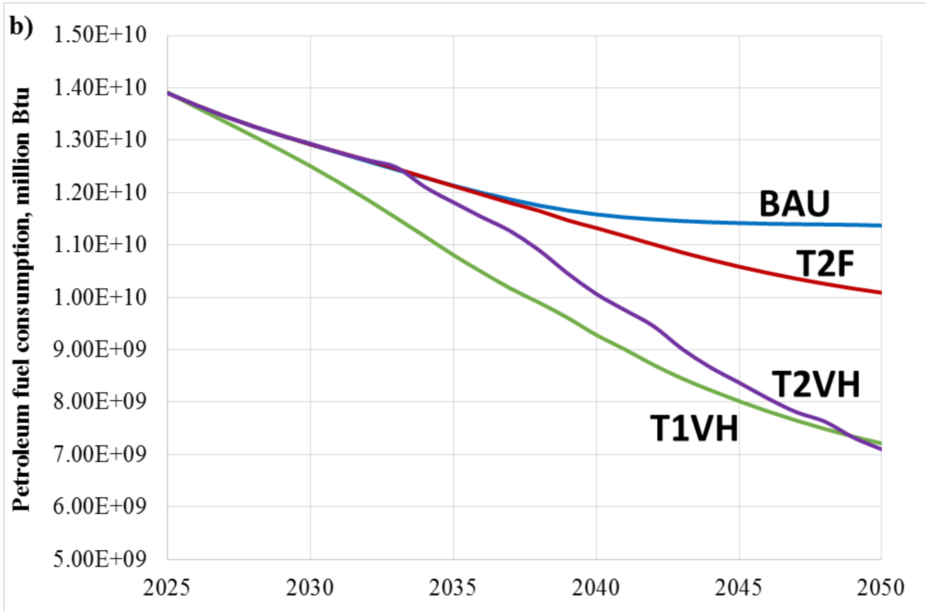
- E25 adopted as Thrust I fuel to leverage past analyses
- 50:50 blend of E10 and a bio-derived hydrocarbon produced thermochemically selected as model Thrust II fuel
- Pace of biorefinery growth in the bookend T1VH and T2VH scenarios very aggressive and considered to be an upper bound
- Even in high-demand scenarios, ethanol production drops because of increased fuel economy.
- In bookend cases, high demand for biofuel stresses feedstock supply system and raises feedstock costs.



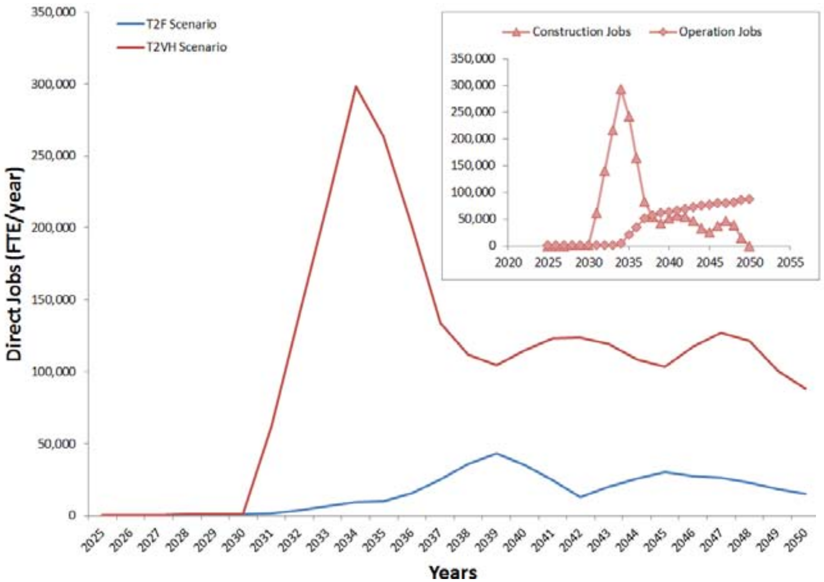
Co-Optima Benefits Analysis

- Greenhouse gas emissions calculations assume Thrust II bio-blendstock is 60% less GHG intensive than gasoline
- GHG emissions reductions range between 3% and 14%



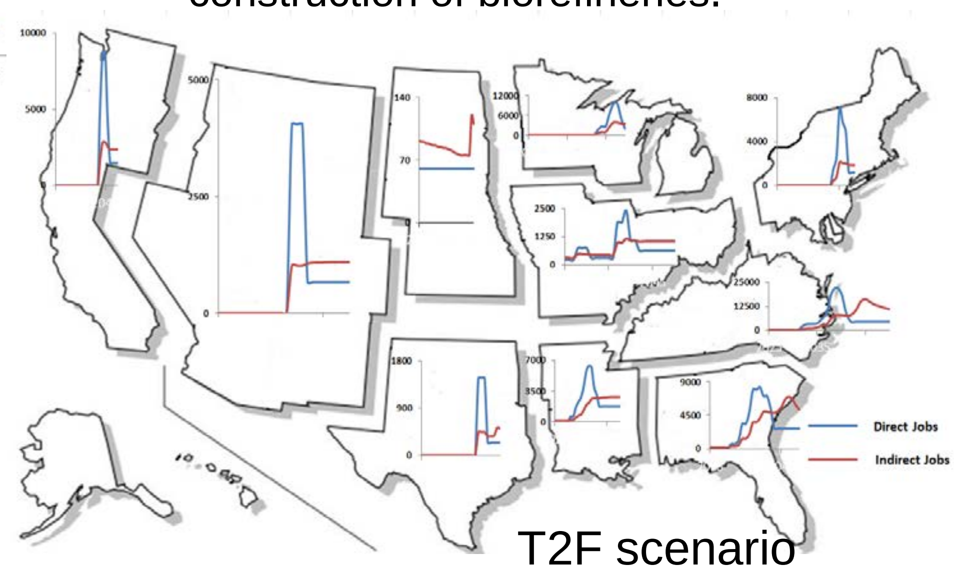


Co-Optima Benefits Analysis



- Estimate *gross* jobs associated with feedstock production, biorefinery construction and operation.
- Between 600 and 1,000 direct jobs could be supported at biorefineries between 2025 and 2030
- Peak direct jobs for T2VH scenario reach about 300,000, mostly for construction of biorefineries.

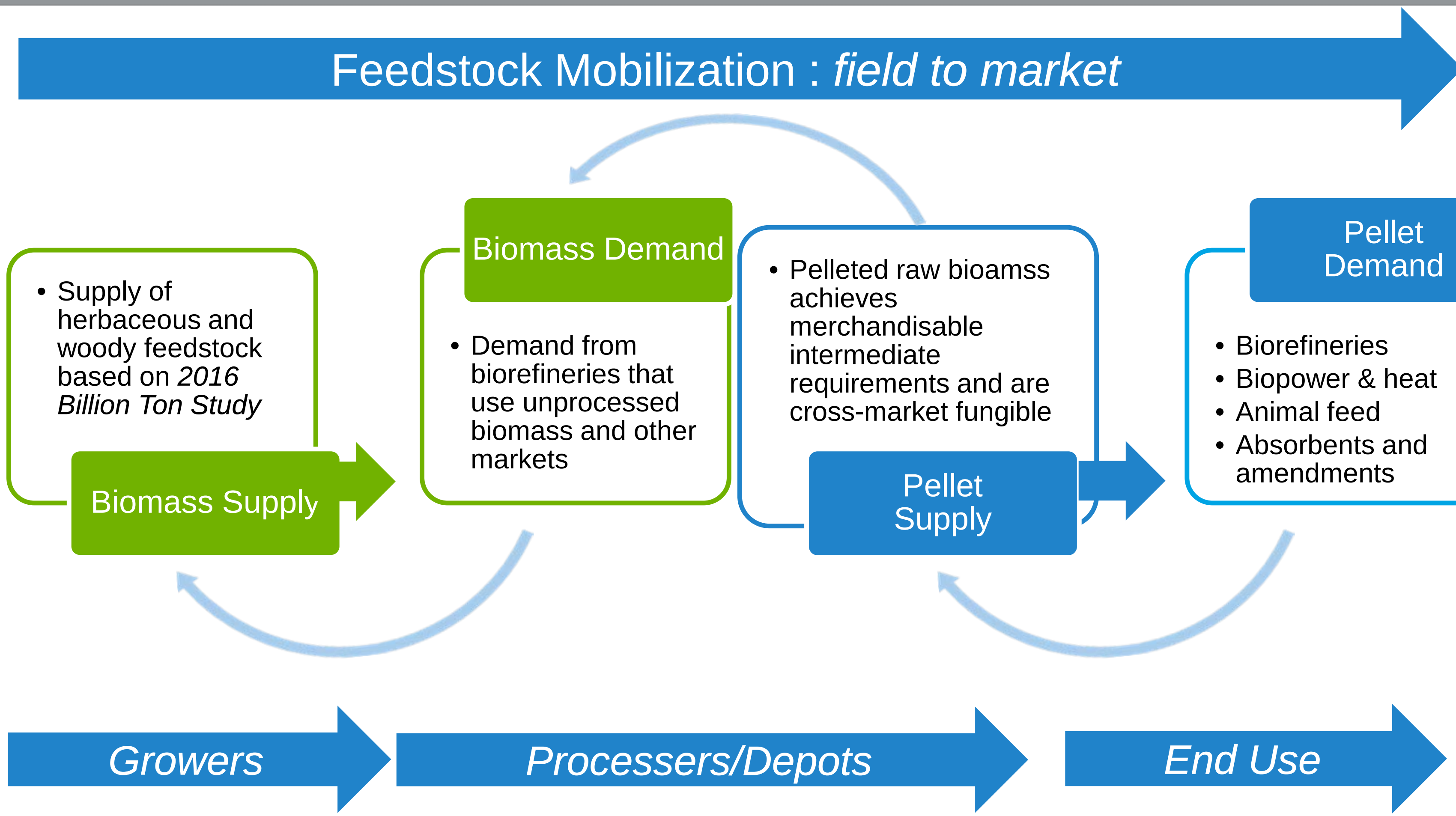
- JEDI accounts for regional variation in job creation considering regional feedstock cost and availability
- Non-coastal, Western states see most direct jobs in the T2F scenario.



T2F scenario

Direct jobs are on-site at the biorefinery. Indirect jobs are supply-chain related. Induced jobs stem from increased spending by biorefinery or supply-chain workers.

Companion Market Model

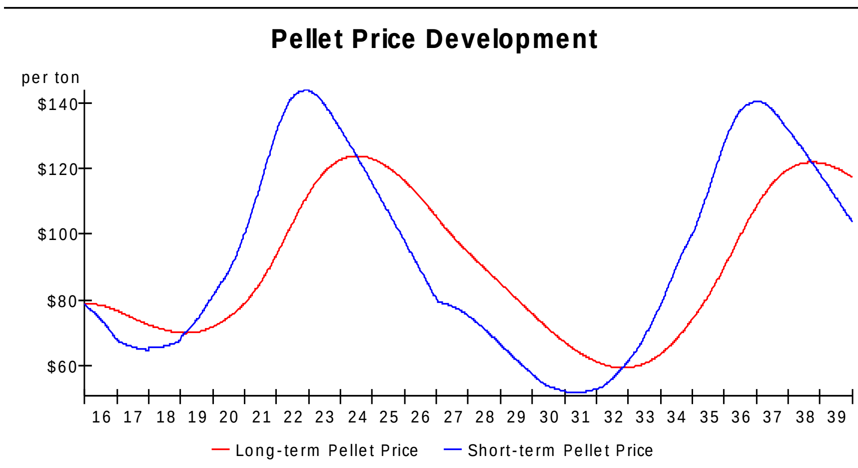


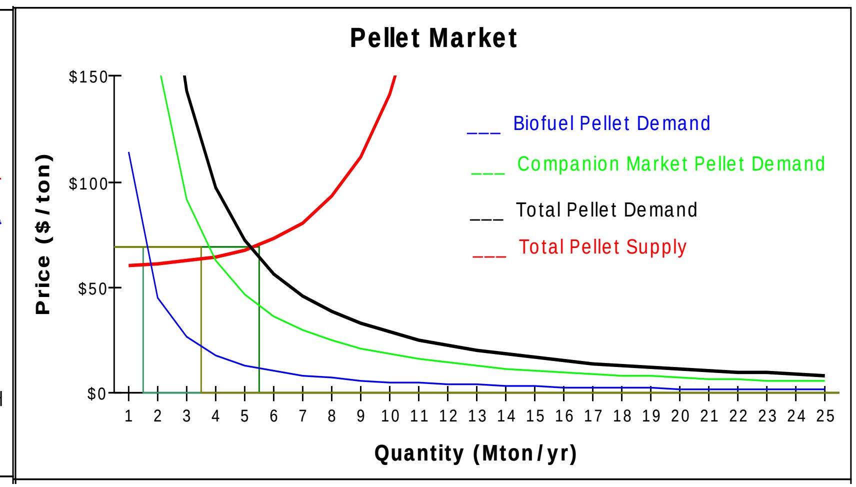
- Understand the role of companion markets (e.g., animal feed) in stimulating an advanced feedstock system that will benefit biorefineries and move the domestic biomass supply from potential to available.
- Determine whether the presence of companion markets raises biomass prices above those viable for biorefineries and limit biomass supply to biorefineries.

Companion Market Model

Key conclusions

- Pellet fungibility across multiple markets allows processing capacity expansion
- In the scenarios examined to this point, biomass and pellet markets grew with relatively stable prices over the long term (out to 2040)
- Steady companion market growth prompts feedstock mobilization
- The existence of animal feed markets in the scenarios did not limit long-term biorefinery feedstock supply or elevate long-term supply prices

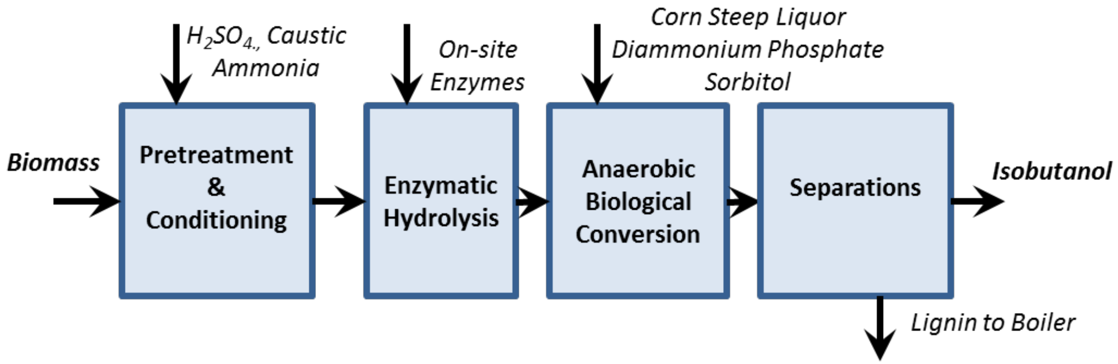




Large-Scale Deployment of High-Octane Fuels

- Framed analysis with objective of identifying supply chain barriers to large-scale deployment of Thrust I fuels with RONs surpassing 98.
- Considerations include feedstock type, availability, and cost, economic viability challenges of conversion process, influence of fuel on refinery blends and economics, infrastructure type and costs, compatibility with vehicles, and possible fuel economy gain range
- Selected isobutanol and aromatic-rich hydrocarbon blendstocks as preliminary candidates for full analysis. Vetting decisions and assumptions with External Advisory Board (EAB).
- Analysis output will include vehicle market, biofuel production, and job creation impacts in addition to GHG emissions and fossil energy consumption changes as compared to business as usual.
- Feedback sought from EAB regarding choice of blendstocks for analysis.

Large-Scale Deployment of High-Octane Fuels



Motivations for choosing isobutanol as a representative near-term oxygenated blendstock

Isobutanol has desirable fuel properties: [1,2]

- Higher octane rating of 105 (RON)
- Lower volatility than ethanol
- Not corrosive to steel and can be transported by pipeline

Approved by EPA for blending [1,2]

- The Environmental Protection Agency (EPA) allows up to 12.5% butanol under subsim waiver and 16% under an old octamix waiver

Potential for near-term deployment: [3,4]

- Both Gevo and Butamax are working on developing isobutanol technology.
- Gevo is working to produce isobutanol in Luverene, MN with aims to produce up to 1 million gallons of isobutanol in the near-term
- Comparatively, Butamax has an isobutanol demonstration plant in the United Kingdom

1. Ryan, C., et al., GEVO White Paper: Transportation Fuels. Englewood, CO: GEVO, 2011. http://www.gevo.com/wp-content/uploads/2011/05/GEVO-wp-iso-ftf.pdf. 2. Lane, J. "Renewable Isobutanol: It's Time for a Truce". In Biofuels Digest, 2015. http://www.biofuelsdigest.com/bdigest/2015/05/18/renewable-isobutanol-its-time-for-a-truce/ 3. Fletcher, K. 2016. Gevo Q1 results provide update on isobutanol equipment upgrades. Biomass Magazine, May 13, 2016. 4. Shaffer, D. 2015. Ending years of litigation, Gevo and Butamax to work on creating markets for new biofuel. Star Tribune.

Large-Scale Deployment of High-Octane Fuels

Potential Conversion Routes

Biomass

- Catalytic Fast Pyrolysis
- Indirect Liquefaction to MTG
- Catalytic Upgrading of Sugars

Aromatic-rich Hydrocarbon Blend

Motivations for choosing aromatic-rich hydrocarbon as a representative near-term blendstock

Desirable fuel properties:

- Higher octane ratings greater than 98 RON
- Can be incorporated into today's infrastructure

Multiple pathways for production that align with BETO hydrocarbon R&D pathways

- Catalytic fast pyrolysis, indirect liquefaction, catalytic upgrading of sugars

Potential for near-term deployment:

- A number of companies are pursuing these pathways for production of aromatic-rich hydrocarbon blendstocks, including Virent and Anellotech

Key questions to address with analysis include

- Impact that additional aromatics will have on market given blending constraints

4 Relevance

Relevance to MYPP Goals and Barriers

MYPP Goal or Barrier	ASSERT approach to addressing
Goals	
Ensure high-quality, consistent, reproducible, peer-reviewed analyses.	Working with the other Co-Optima teams to incorporate up-to-date and defensible data, ASSERT will produce high-quality analyses that will be peer-reviewed and available to stakeholders. Vetting approach and analysis outcomes with stakeholders via interaction with EAB.
Barriers	
At-A. Comparable, Transparent, and Reproducible Analyses	Integrating standardized datasets, assumptions into full supply chain analyses to inform Co-Optima research direction.
At-B. Analytical Tools and Capabilities for System-Level Analysis	Employing, refining, expanding, and linking BETO analysis platform models to carry out full supply chain analyses of co-optimized fuels and engines, offering utility to Co-Optima stakeholders through insights into deployment barriers.
Im-F. Uncertain Pace of Biofuel Availability	Employing suite of models that consider the integrated supply chain to identify barriers and investigate the market and policy drivers to enhance biofuel availability in scenarios relevant to the Co-Optima project.
Im-H. Lack of Acceptance and Awareness of Biofuels as a Viable Alternative	ASSERT's impartial and reliable analyses regarding the economic and environmental benefits and impacts of expanded bioblendstock production and use in co-optimized engines can inform industry and consumers and pave the way towards improved acceptance and awareness of biofuels.

Relevance to BETO Strategic Plan

BETO Strategic Goal: Develop and demonstrate innovative and integrated value chains for biofuels, bioproducts, and biopower that can respond with agility to market factors while providing economic, environmental and societal benefits.

ASSERT Relevance: Quantification of the influence of co-optimized fuels and engines on energy consumption, harmful emissions, and employment.

BETO Strategy: Conduct analysis to inform research and development and programmatic priorities.
Underlying substrategy: Provide analysis on the environmental and social sustainability of bioenergy.

ASSERT Relevance: Techno-economic, life cycle analyses, and benefits analysis inform research and development priorities for Co-Optima and can be leveraged for the broader BETO research portfolio.

Relevance to BETO Strategic Plan

BETO Substrategy: Better understand the benefits of bioenergy to rural communities.

ASSERT Relevance: Carry out regional analysis of job creation, including in rural communities.

BETO Substrategy: Improve knowledge of biofuels emissions compared with conventional fuel emissions

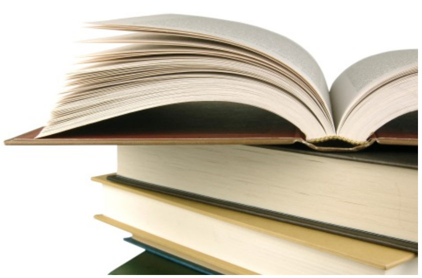
ASSERT Relevance: Assessment of the influence of improved fuel economy from co-optimized fuels and engines in the transportation sector and through interactions with the Fuel Properties and Advanced Engine Teams to include air pollutant emissions (e.g., particulate matter) when information allows.

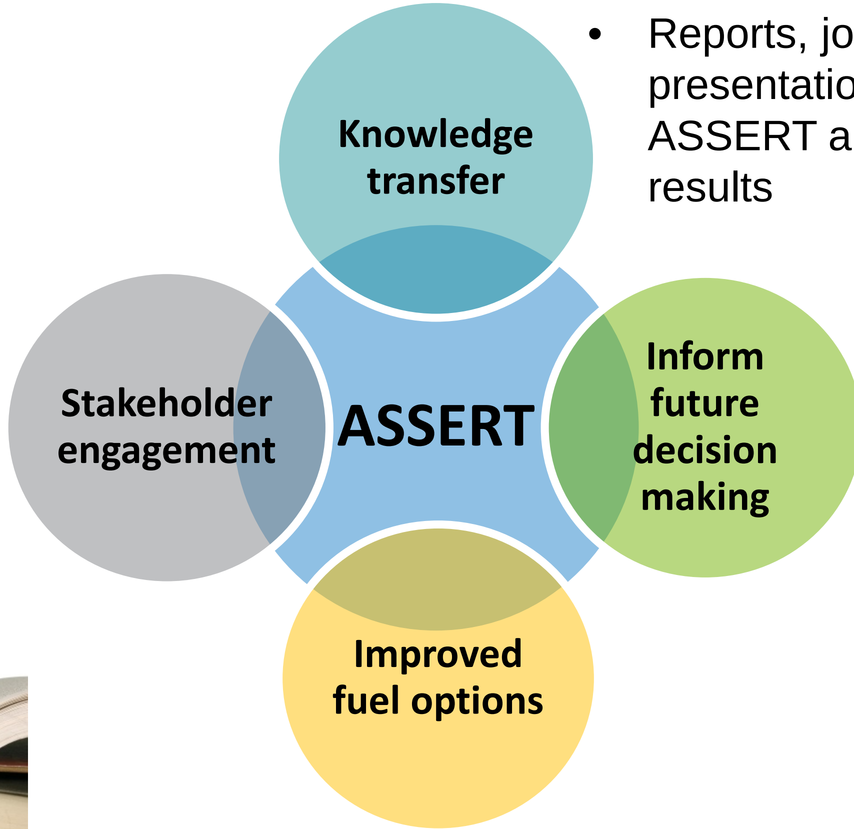
Relevance to other BETO projects

- Close link to BETO's Analysis and Sustainability platform through use of models developed under that platform including JEDI, GREET, blending model, and BSM.
- Ongoing work with conversion platform to share analysis results and key lessons learned when considering a wide range of fuel products.
- Further, analysis methodology to assess benefits of Co-Optima can be applied in other projects as can improvements, refinements, and expansions of the ASSERT suite of models.
- Insights ASSERT gains into barriers to large-scale deployment of co-optimized fuels and engines can inform BETO research and development priorities and directions overall.

Relevance to Bioenergy Industry

- Deep dive presentations on stakeholder calls
- Work with EAB to provide guidance on the direction of ASSERT analyses and feedback on results





- Reports, journal articles, presentations documenting ASSERT analyses and results

- Provide insights into potential influence of bio-blendstocks on jobs
- Disseminate information on scalability, economic viability, and environmental sustainability of bio-blendstocks that may be of interest to industry
- Outline key economic and sustainability drivers and barriers for moving fuels to market

Investigate a range of fleet options
- Light duty
- Medium duty
- Heavy duty

Relevance: Impact on Commercial Viability of Biofuels

Change the value proposition

- Quantify and identify value to the transportation sector, the environment, and society
- Identify win–win opportunities for different stakeholders through analysis

Identify red flags in the path towards commercialization for various bio-blendstock candidates so that mitigation strategies can be developed.

Contribute to overall understanding of what constitutes a promising bio-blendstock beyond its physical properties.

5 Future Work

Future Work

- Overall, ASSERT will aim to inform the cost-effective and low environmental impact production of bio-blendstocks of interest to Co-Optima teams based on properties and market viability

- Specific near-term future work will include:
    - Support decision point with analysis of up to five additional blendstock candidates
    - Highlight barriers, potential mitigation, and potential jobs, energy, and environmental benefits of high-octane Thrust I fuel rollout to inform stakeholders regarding potential routes to market adoption and to potential benefits of this adoption
    - Detailed TEA and LCA of select bioblendstock candidates to inform R&D direction of HPF Team, identify cost and environmental barriers
    - Feedstock market evaluation to enable production of large volumes of Thrust I and II fuels
    - Assess net jobs associated with producing co-optimized fuels and engines across the supply chain to inform estimates of societal benefits of Co-Optima
    - Utilize blending model to characterize petroleum refiners' valorization and estimate potential blending volumes based on fuel properties

Future Work

Future work in out years will include:

- Focus on Thrust II bioblendstocks with consideration of TEA, LCA, and benefits analysis
- Detailed incorporation of criteria air pollutant emissions along the supply chain
- Evaluation of costs and sustainability of after treatment devices for Thrust II
- Enhanced consideration of infrastructure costs and environmental impacts in analysis
- Development of case study business cases for several bioblendstocks to inform risk and consumer acceptance implications of their deployment (incorporated to support stakeholder feedback)

Credit: National Renewable Energy Laboratory

Summary

- The objective of the ASSERT Team is to evaluate the blendstock and vehicle technologies under consideration within the Co-Optima program from environmental and economic perspectives while conducting research and development-guiding analyses.
- The ASSERT Team brings together expert analysts across multiple disciplines and the full biofuel supply chain.
- ASSERT analyses contribute to the decision point and to overall development of Co-Optima research and development strategy.
- To date, ASSERT has evaluated 20 Thrust I blendstocks against technology readiness, economic viability, and environmental sustainability metrics and evaluated the benefits of large-scale deployment of co-optimized fuels and engines through development and refinement of a suite of models. Additionally, the team has investigated the role of companion markets for biomass in increasing biomass availability.
- ASSERT will plan future analyses to continue to guide Co-Optima strategy and to inform BETO and its stakeholders regarding economic, environmental, and societal advantages and drawbacks of co-optimized fuels and engines.

Additional Slides

Publications and Presentations

Pending publications:

- Dunn, J.B., M. Biddy, S. Jones, H, Cai, and P. Benavides, “Economic, Environmental, and Technology Readiness Assessment of 25 Bio-blendstocks with the Potential to Raise Fuel Economy.” In preparation for submission to *ACS Sustainable Chemistry and Engineering*.
- Cai, H., E. Newes, A. Brooker, J. Han, S. Peterson, S. Jones, Dunn, J.B., M. Biddy. “Evaluation of High-octane Bio-blendstocks to Increase Fuel Economy, Reduce Transportation Petroleum Consumption and Greenhouse Gas Emissions, and Create Employment.” In preparation for submission to *Energy and Environmental Science*.
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