2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

3.1.2.4 - Thermal Conversion Sustainability Interface

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Technology Area Review: Analysis and Sustainability

Organization: PNNL

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Goal Statements

- Integration of BETO’s Thermochemical Conversion and Sustainability Thrusts:
  - Incorporate sustainability considerations during design and development of emerging pathways to predict and minimize environmental impact
  - Develop understanding of synergies and trade-offs between economic and environmental sustainability for bio-oils and upgrading

- Support BETO’s Goals (from the MYPP):
  - To enable the sustainable, nationwide production of advanced biofuels that are compatible with today’s transportation infrastructure
  - To understand and promote the positive economic, social, and environmental effects and reduce the potential negative impacts of bioenergy production activities
  - By 2017 and 2022, evaluate and compare the sustainability of biofuels production pathways

Quad Chart Overview

Timeline

- Project Start: Oct 2009
- Project End: Ongoing
- Percent complete: 56%

Budget

- Total through FY13: 450K
- FY 2011: 100K
- FY 2012: 125K
- FY 2013: 125K
- ARRA Funding: none
- Total Years: 5
- Average Funding: 90K/year

Barriers

- Barriers addressed
  - St-D: Implementing Indicators and Methodology for Evaluating and Improving Sustainability
  - St-F: Systems Approach to Bioenergy Sustainability
  - Tt-K: Bio-Oil Pathways Process Integration

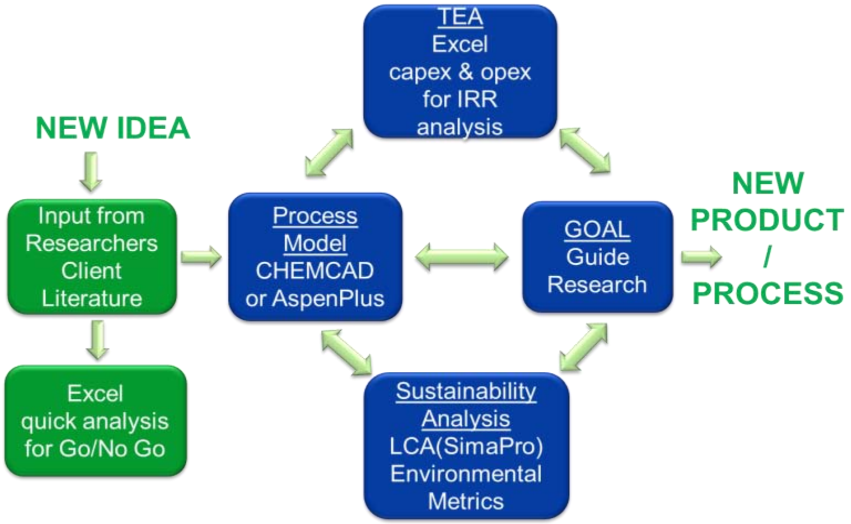
Partners & Roles

- NREL –development and measurement of sustainability metrics for conversion technologies
- ANL – integration of conversion stage data for new GREET pathways and data for water foot printing

Project Overview

- Develop biofuels that are produced in a sustainable way
- Define, quantify, and compare environmental sustainability metrics for biomass thermal conversion pathways
  - Fast pyrolysis and bio-oil upgrading
  - Catalytic pyrolysis and bio-oil upgrading
  - Others such as hydrothermal liquefaction and bio-oil upgrading

- **Overall Benefit** – Close integration of experimental work, process design, TEA, and sustainability analysis enables designs optimized for both cost and environmental performance



Approach

- Technical
  - Identify environmental sustainability metrics for thermal conversion processes (developed initial set with BETO)
  - Use process simulation model output to develop lifecycle models in SimaPro and quantify metrics
  - Identify key processes and assumptions affecting sustainability metrics through sensitivity analysis
  - In concert with TEA, determine synergies or tradeoffs between cost and sustainability metrics that exist across the continuum of crude bio-oil to partially hydrocracked hydrocarbons
- Management
  - Workplan, milestones, schedule, and quarterly-, annual-reports are described in the project management plan (PMP), managed by DOE Golden and Headquarters
  - Interface with multi-Lab/BETO sustainability activities via Office monthly team meetings, intra-Lab LCA working group, and joule milestones

Technical Accomplishments / Progress / Results

- 2011 Review:
  - Presented results from early phase of project
  - Comparison of several preliminary metrics for a broad range of thermal conversion technologies/fuels based on older models, these were not full LCAs (only direct emissions and resource use) and several processes have since been “shelved” due to economics
- 2013 Review:
  - Integrated LCA methodology into project plan
  - Re-focused on emerging liquefaction routes in BETO’s MYPP
  - Developed enhanced understanding of the critical factors affecting GHGs and other metrics for these focus pathways, which has been integrated with the TEA and overall design approach
  - Worked with BETO and other national labs to provide consistent approach, and initial set of conversion metrics for biomass conversion

Milestones/Metrics and Progress:

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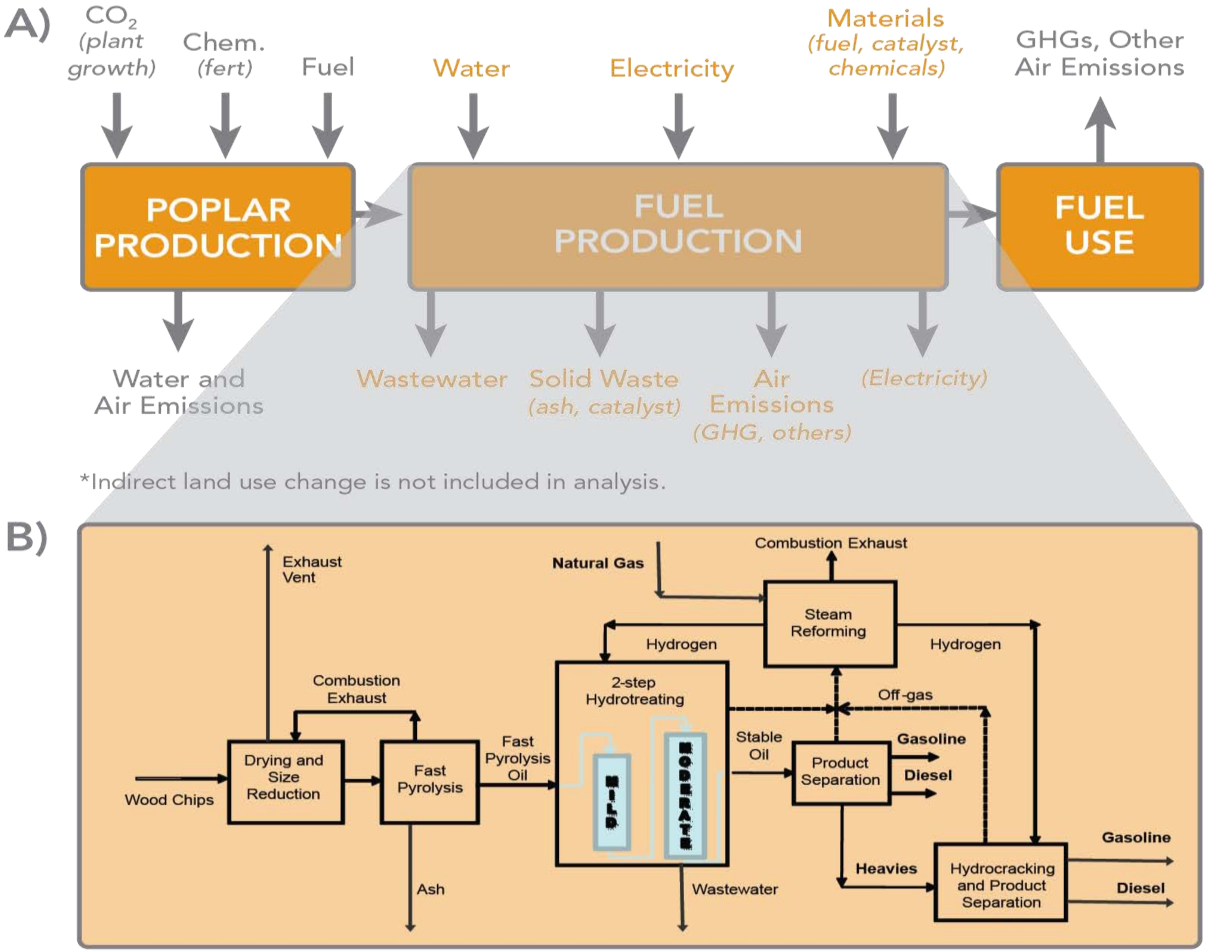
Title/Description	Due Date	Completed
Integrated lifecycle methodology into project work plan	Sep-11	✓
GHG analysis and sustainability metrics baselines for fast pyrolysis and oil upgrading 2011 SOT	Mar-12	✓
GHG analysis for no-natural gas case for fast pyrolysis and upgrading pathway	Jun-12	✓
GHG analysis for catalytic pyrolysis and upgrading (in-situ and ex-situ) And annual progress report	Sep-12	✓
Sustainability metrics analysis for 2012 state of technology fast pyrolysis and upgrading (2012 SOT report in review)	Dec-12	✓
Collection of wastewater characterization data for integration into wastewater quality metric and water footprinting analysis (with ANL)	Mar-13	✓
Sustainability metrics for fast pyrolysis and upgrading updated design case (with NREL)	Jun-13	In progress
Formal final report	Sep-13	

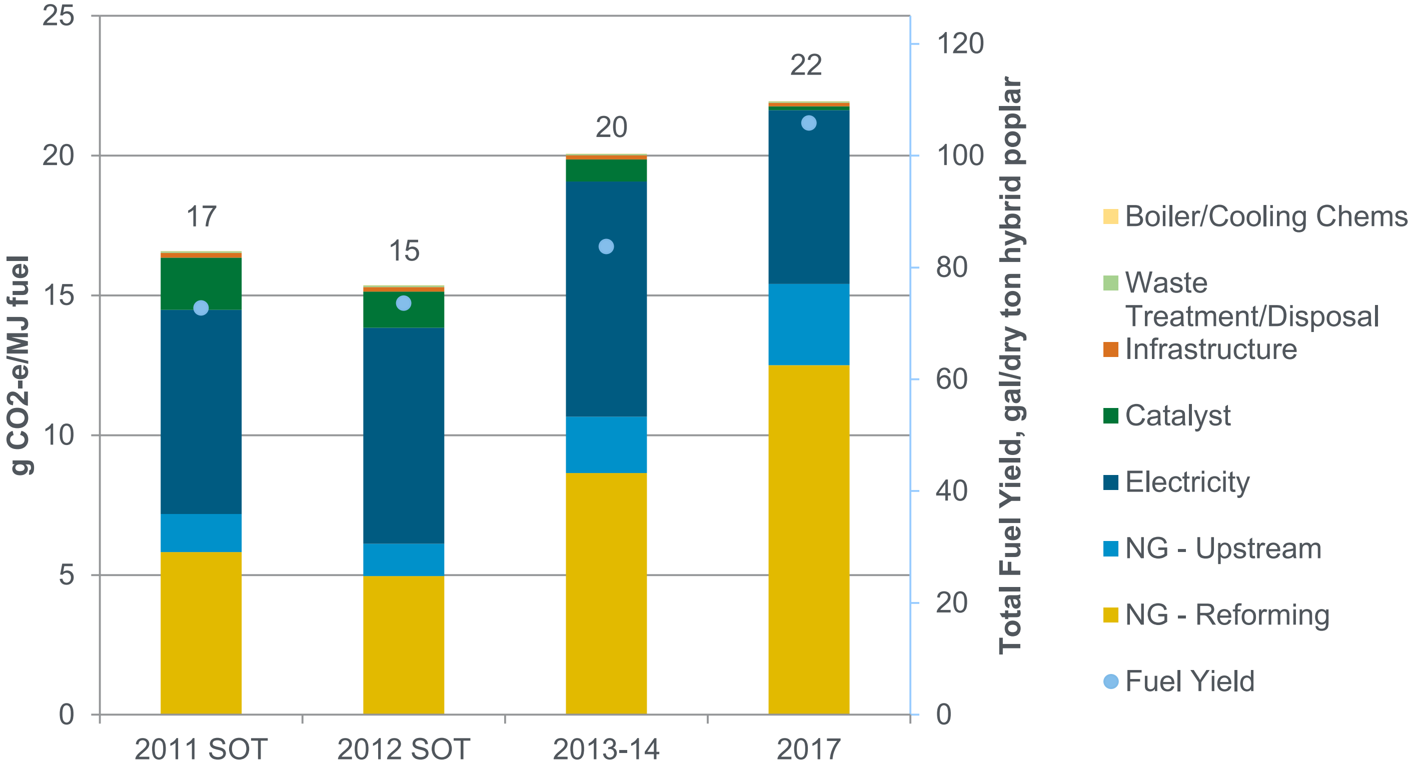
Lifecycle GHG Analysis for Fast Pyrolysis of Hybrid Poplar and Bio-Oil Upgrading



*Indirect land use change is not included in analysis.

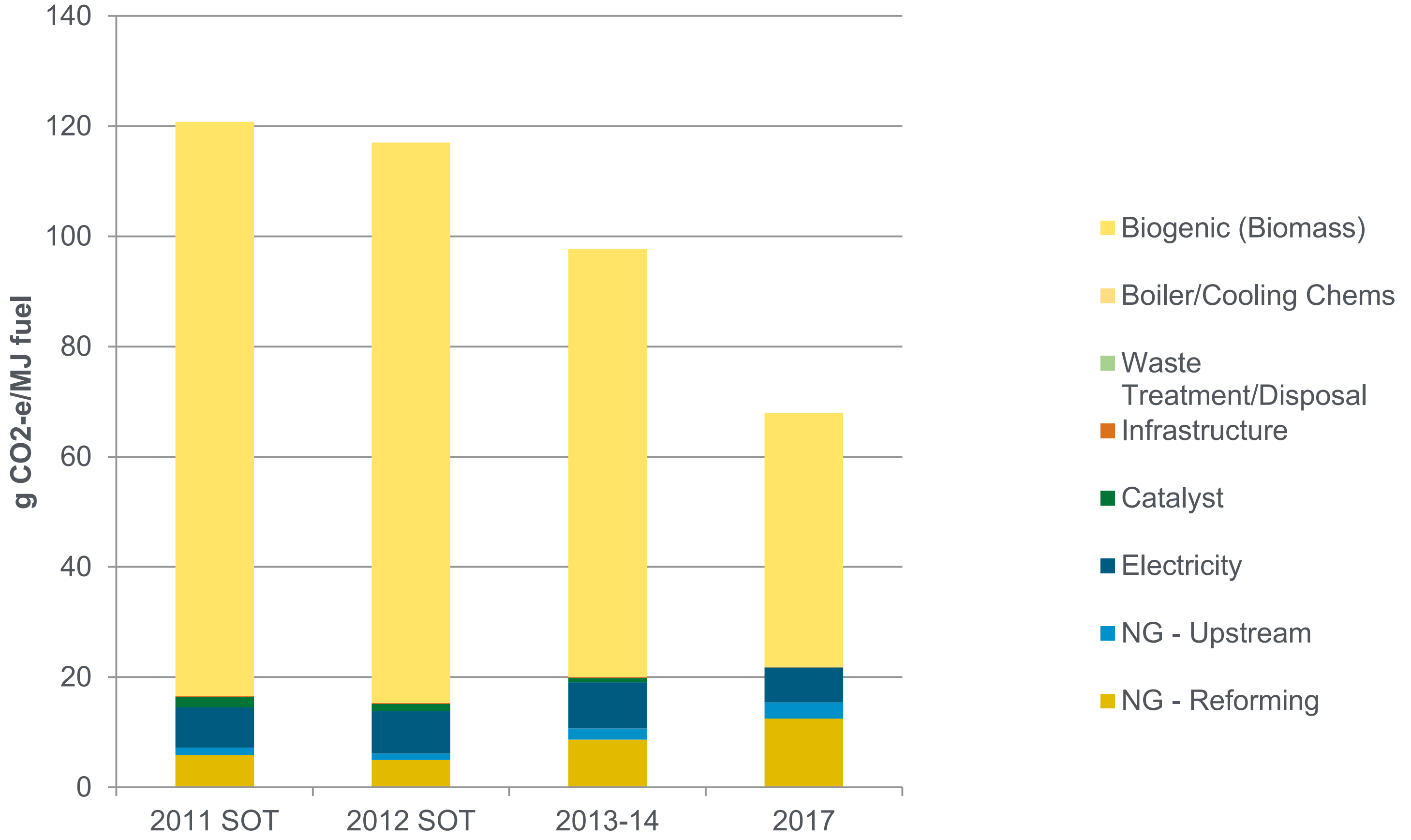
From: Snowden-Swan, LJ, JL Male, SB Jones, P Meyer. “Life Cycle Greenhouse Gas Emissions of Biofuel from Fast Pyrolysis and Bio-oil Upgrading”, Poster presentation at the ACLCA LCA XII Conference, Tacoma, WA, September 25-27, 2012.

Fossil GHGs for Fast Pyrolysis and Bio-Oil Upgrading Conversion (hybrid poplar)



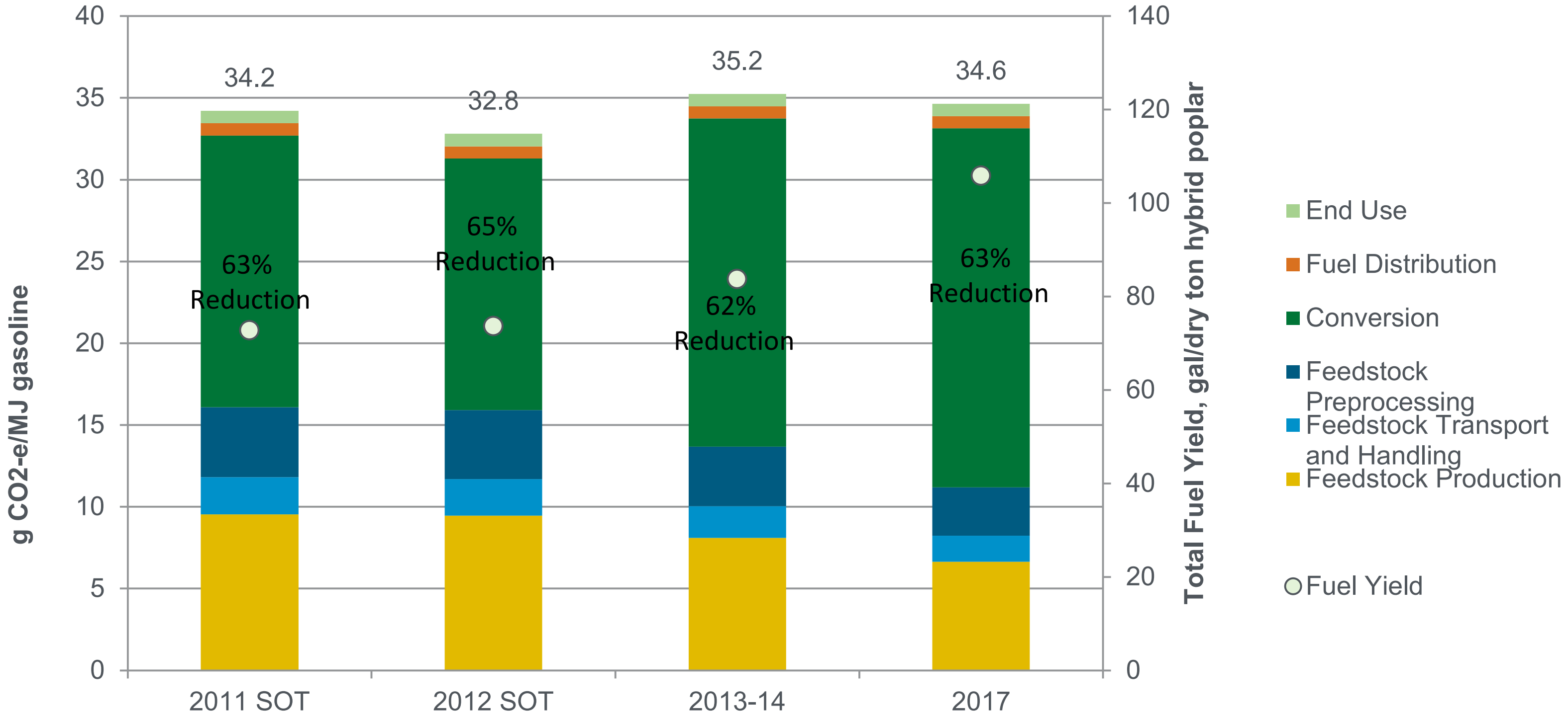
- Natural gas, electricity, and fuel yield are the primary GHG drivers for the conversion plant
- As better yields are achieved, more bio-oil is produced and less volatiles are available for reforming into H_2, increasing the need for natural gas, and increasing fossil GHG emissions for conversion

Biogenic and Fossil GHGs for Fast Pyrolysis and Upgrading Conversion (hybrid poplar)



- Total GHG emissions from conversion is dominated by biogenic CO_2
- Higher carbon-to-fuel yield results in lower total GHG emissions for conversion

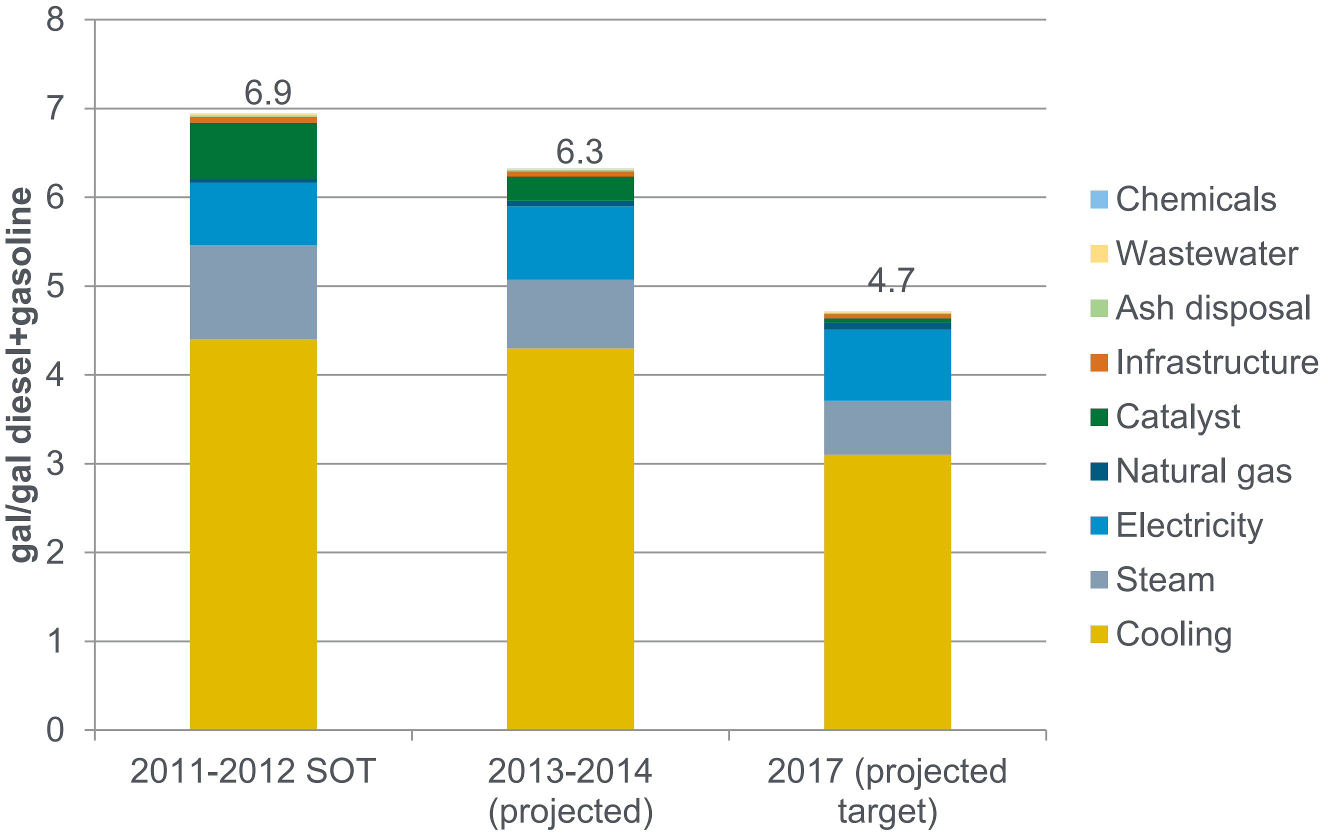
Life Cycle GHGs for Gasoline from Fast Pyrolysis and Upgrading (hybrid poplar)



*GHG reductions are relative to GREET 2005 petroleum gasoline baseline of 93.4 g CO2-e/MJ.

- Higher yields increase conversion contribution but lower feedstock contribution
- Preliminary indications are that fuel derived from fast pyrolysis of wood and bio-oil upgrading appears to be >60% GHG reduction (cellulosic biofuel), however, qualification under RFS is determined by the EPA

Water Consumption for Fast Pyrolysis and Upgrading Conversion



- Water consumption is highly dependent on the pyrolysis oil vapor quench step
- Improved yields with improvements in the technology result in lower water consumption per gallon of fuel produced
- Electricity is an important indirect consumer of water (estimated using Recipe Midpoint Method, SimaPro v. 2.2, using 0.6 gal/kWh factor for US electricity mix)

Sustainability Metrics for Fast Pyrolysis and Upgrading Conversion

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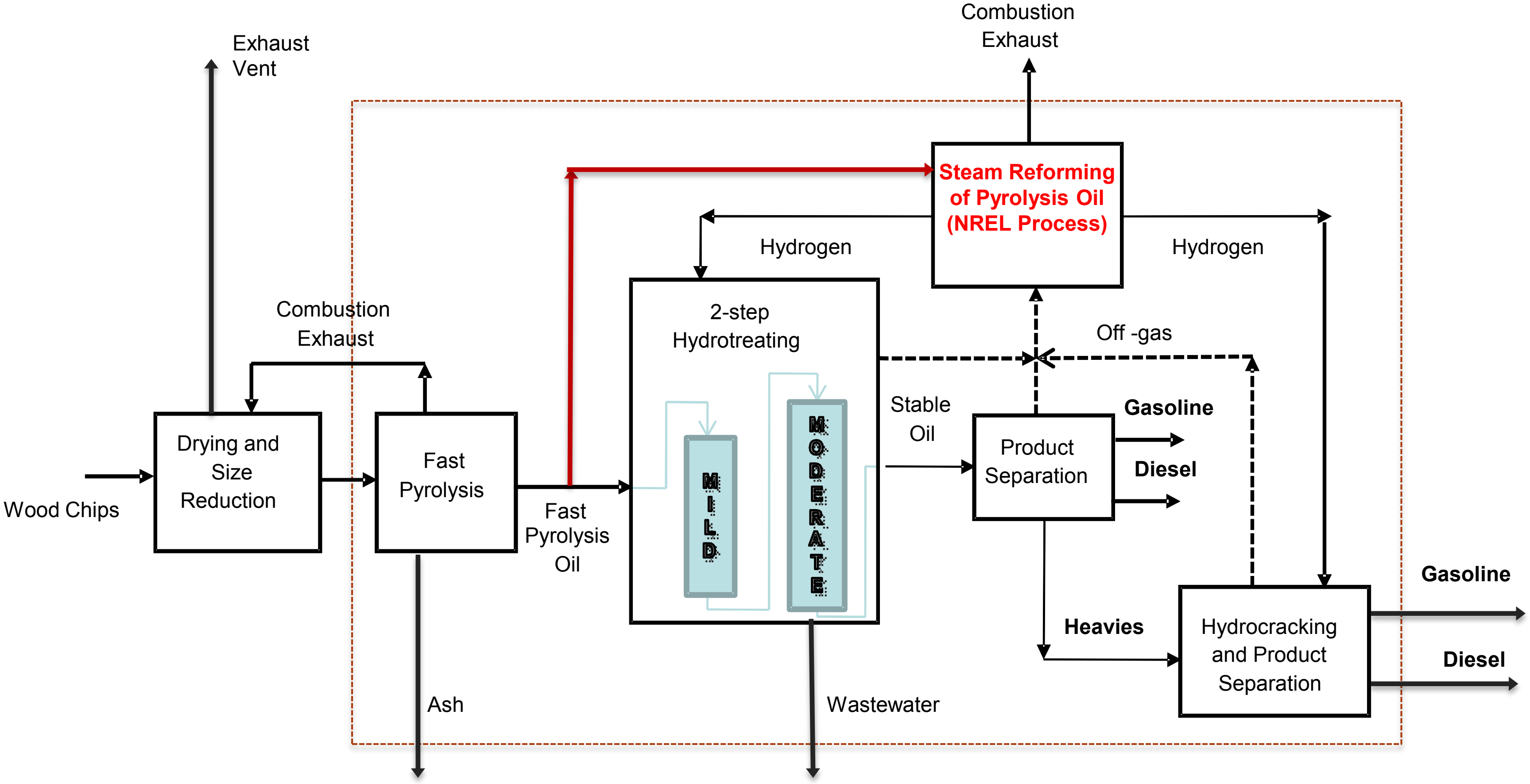
Sustainability Metric	2011 SOT	2012 SOT	2013-14 Projected	2017 Projected
GHGs (g CO2-e/MJ fuel) – (fossil emission; biogenic emissions)	17; 104	15; 102	20; 78	22; 46
Fossil Energy Consumption (MJ fossil energy/MJ fuel)[1]	0.25	0.23	0.32	0.38
Total Fuel Yield (gal/dry ton wood)	73	74	84	106
Carbon-to-Fuel Efficiency (% of biomass carbon in liquid fuel product)	42[2]	41[2]	49	62
Water Consumption (m3/day; gal/gal fuel)[3]	3330; 5.5	3160; 5.1	3510; 5.0	3270; 3.7
Wastewater Generation (m3/day; gal/gal fuel)[3,4]	1320; 2.2	1310; 2.1	1370; 2.0	1340; 1.5

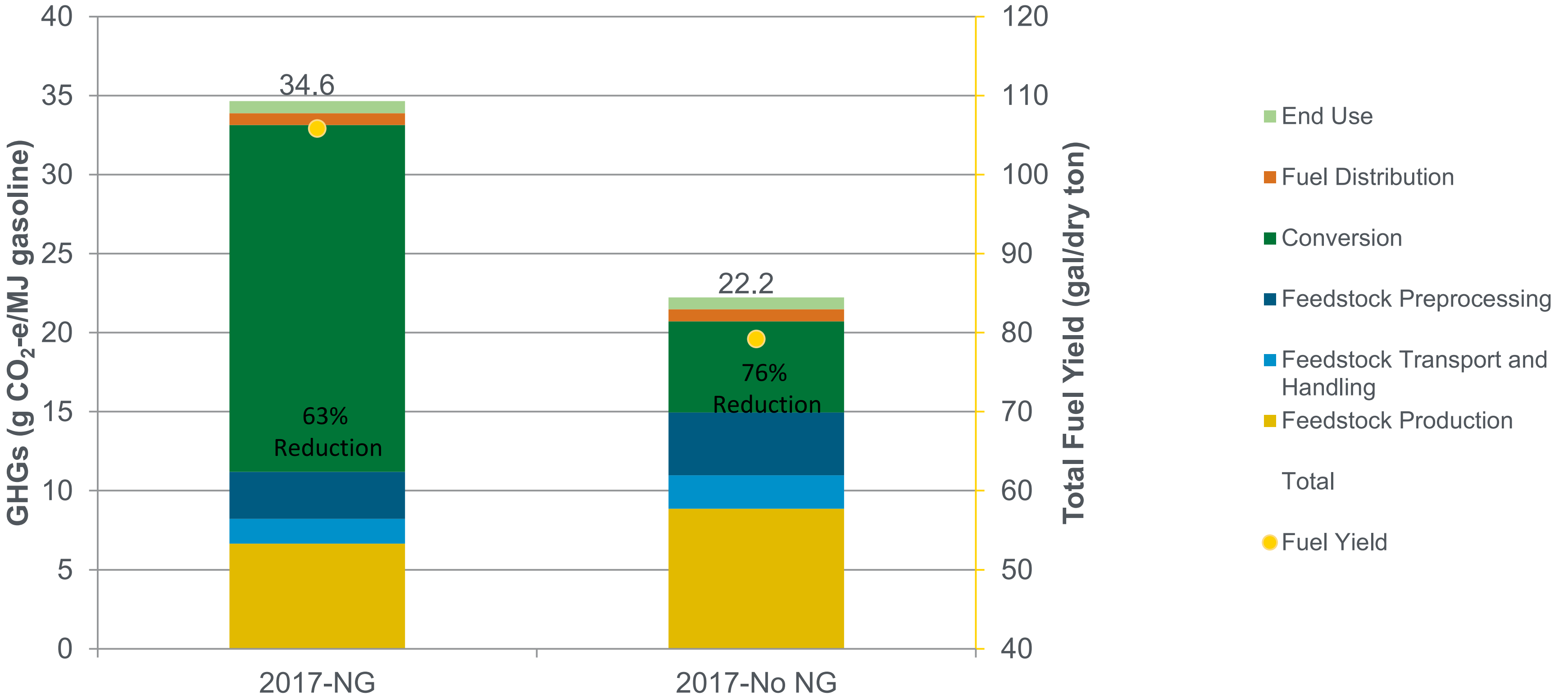
- Preliminary set of baseline conversion metrics established for the pathways currently in the MYPP (with NREL)
- Sustainability metrics for the first time are integrated into the annual State of Technology Report (2012 Report in review)
- In FY13 the fast pyrolysis design case is being redeveloped and metrics will be updated (w/ NREL)

No- Natural Gas Case for Fast Pyrolysis and Upgrading to Reduce GHGs



- What if renewable hydrogen could be produced on-site from off-gas and a portion of the pyrolysis oil? What would the GHGs look like then?
- Result is lower fuel yields, but natural gas is not needed, lowering GHGs

Preliminary No-Natural Gas Case of Pyrolysis and Upgrading (hybrid poplar)



*GHG reductions are relative to GREET 2005 petroleum gasoline baseline of 93.4 g CO2-e/MJ.

- About 25% of the pyrolysis oil is needed to provide 100% renewable hydrogen at the biorefinery
- Are there other renewable H_2 options for the biorefinery?

Preliminary Cost and GHG Trade-offs for Fast Pyrolysis and Upgrading

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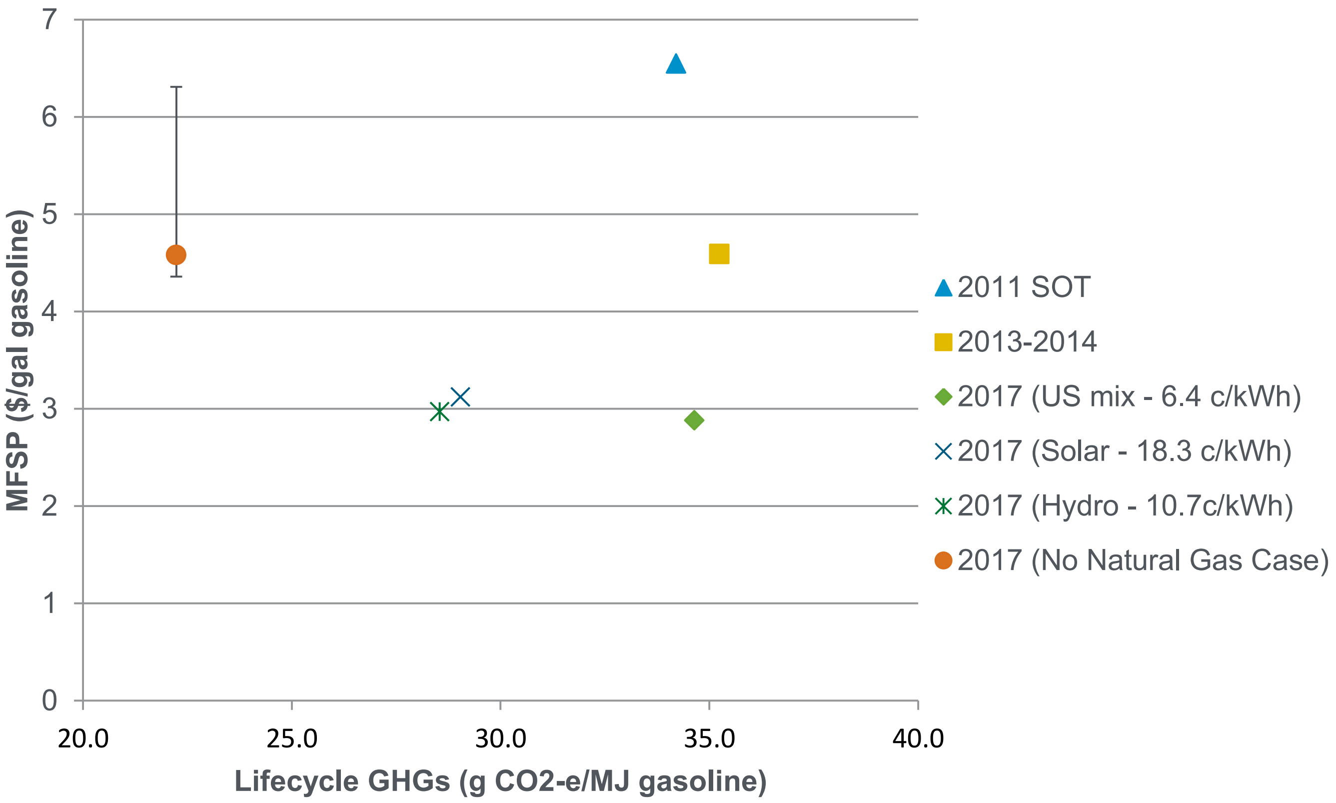
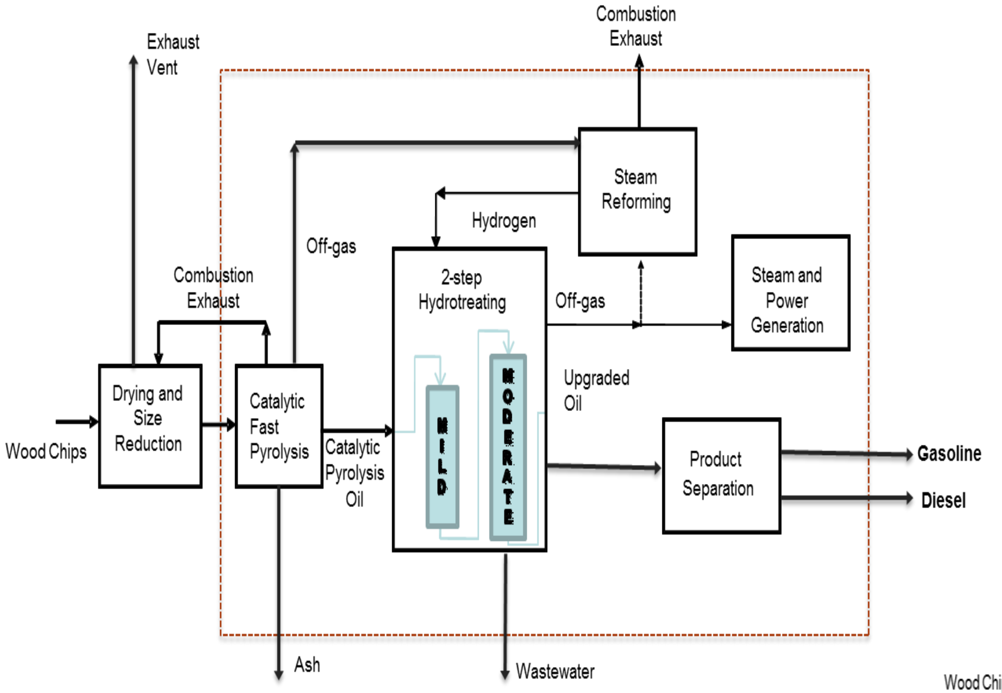


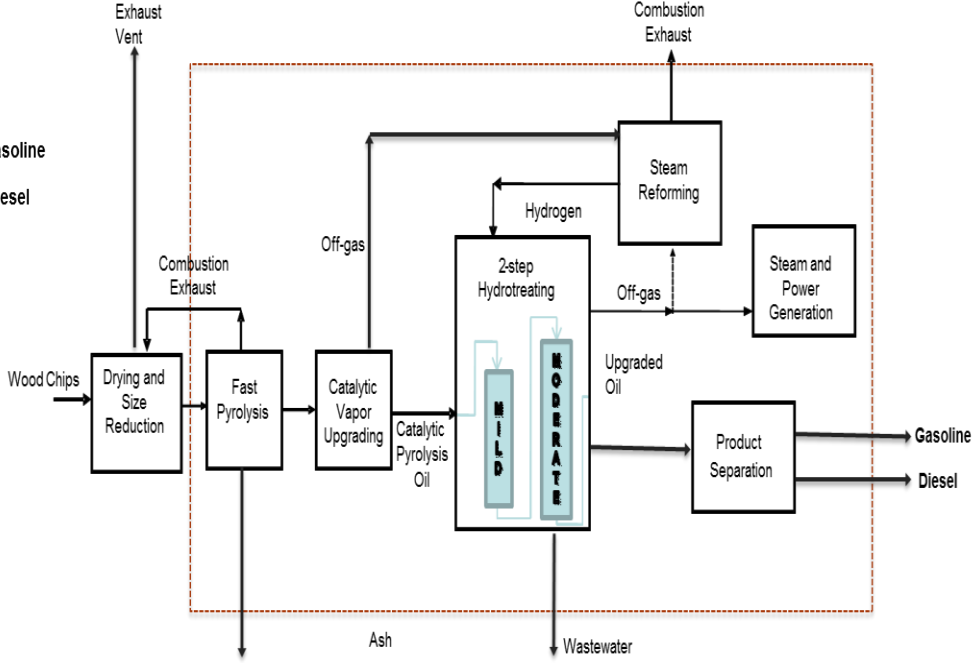
- No NG case is preliminary and uses pyrolysis oil to provide H_2 (Czernik et al, 2007). Cost range estimated relative to conventional SMR plant capital and catalyst cost (low: 5 x SMR plant and 10 x catalyst; mid: 5 x SMR and 50 x catalyst; high: 10 x SMR and 100 x catalyst).
- Price for renewable energy based on LCOE*1.2 for new sources in 2017 (tax credits not included).

Catalytic Fast Pyrolysis and Bio-oil Upgrading Pathways



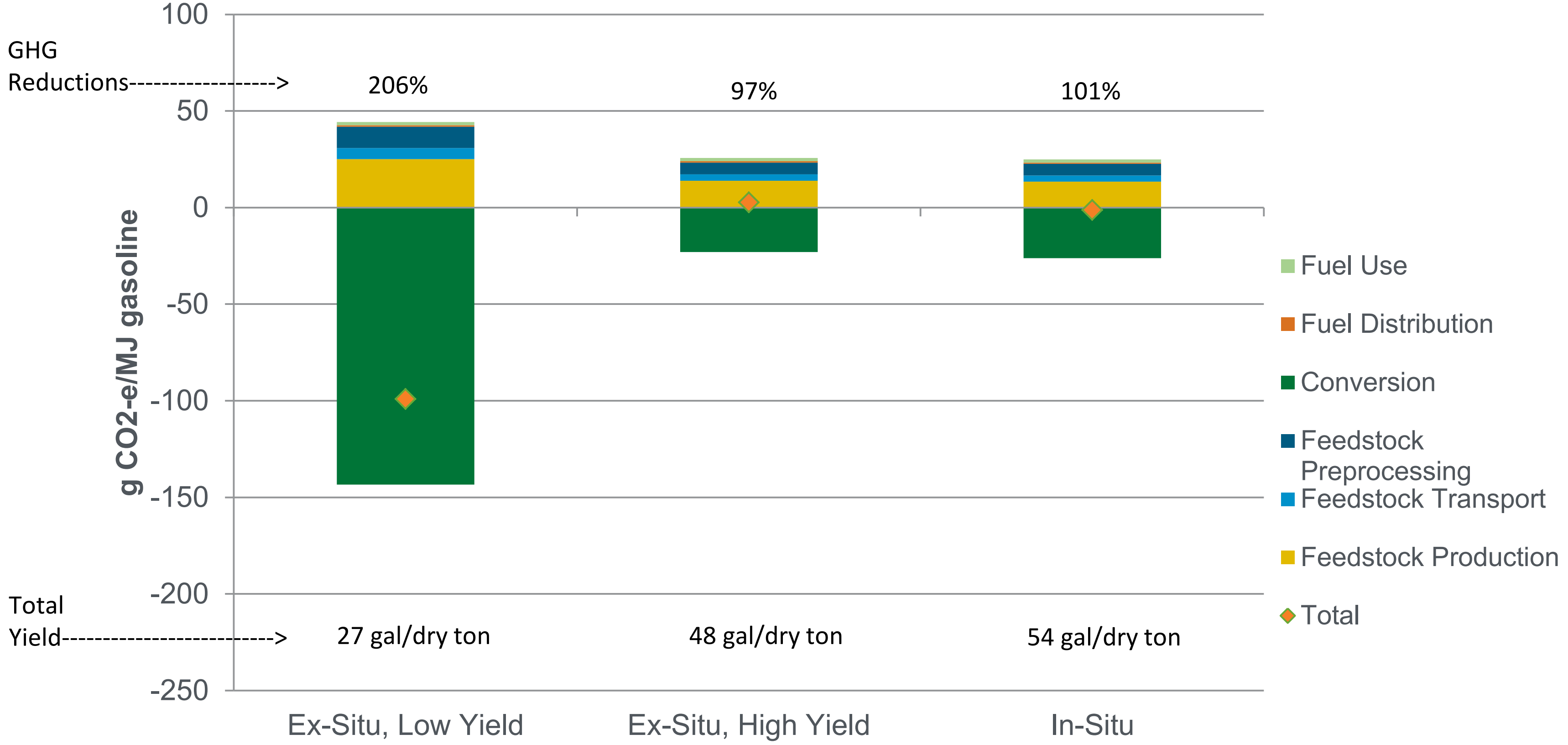
"*In-situ*"

"*Ex-situ*"



- Based on Models for 2012 Down-Select Process and Technology Pathway Memos (Biddy, Dutta, Jones and Meyer, 2012)

Preliminary GHG Analysis for Catalytic Pyrolysis and Upgrading (hybrid poplar)



*GHG reductions are relative to GREET 2005 petroleum gasoline baseline of 93.4 g CO2-e/MJ.

- Electricity and fuel yield are the primary GHG drivers for the conversion plant
- Higher GHG reductions than fast pyrolysis because of lower oil yields (more off-gas for H_2 and electricity) and lower hydrogen consumption (sensitivity analysis needed for H_2 consumption assumption – highly uncertain)
- Higher yields mean less off gas to raise steam and generate power (GHG credits)

Observations

- As better carbon-to-fuel yields are achieved, fossil GHGs increase due to need for external H_2 and electricity
- Low yielding conversion processes may co-produce large power export, which results in a large GHG credit when performing LCA
- The trade-off between carbon-to-fuel yields (and lower cost) and fossil GHGs is a critical balancing point for fuels made via hydrocarbon-based intermediates that require deoxygenation
- Water consumption is dominated by cooling water makeup for the pyrolysis vapor quench. Steam for reforming and indirect water inputs from grid electricity use are also significant
- **Integrated LCA/TEA provides flexibility to look at sensitivities and adjust design to meet both economic and environmental goals**

Relevance

- **Sustainability analysis of MYPP conversion pathways directly supports BETO goals and technical barriers**

  Goals:
  - By 2012, identify metrics and set targets for climate, water, and land use for agricultural residues, energy crops, and forest resources pathways
  - By 2017, evaluate and compare the sustainability of biofuels produced from agricultural residues, energy crops, forest resources and algae
  - By 2022, evaluate and compare the sustainability of biofuel production pathways

  Barriers:
  - St-D: Implementing Indicators and Methodology for Evaluating and Improving Sustainability
  - St-F: Systems Approach to Bioenergy Sustainability
  - Tt-K: Bio-Oil Pathways Process Integration
- This project contributes to strategies for improving environmental sustainability of biorefineries and informs overall supply chain characterization (GREET model)

Critical Success Factors

- Integration of sustainability metrics into overall pathway development and analysis advances the environmental performance of developing biofuel production technologies
- Identifying interactions and trade-offs between environmental and cost goals helps inform decisions on current and future pathway development
- Isolating key process parameters for meaningful sensitivity analyses is challenging due to the complexity of process models (e.g., pyrolysis chemistry, oil composition, recycle, and heat integration), interdependence of variables (integrated refinery), and limited data – need for close integration with experimentalists and TEA experts
- Maintaining consistent and appropriate assumptions across multi-Lab collaborative efforts
  - Joint project milestones with ANL and NREL
  - Intra-Lab LCA group: NETL, NREL, ANL, LNL, PNNL
  - Monthly Analysis and Sustainability telephone conference calls

Future Work

ML, DL or Go/No Go	Description	FY13 Q3	FY13 Q4	FY14 Q1	FY14 Q2	FY14 Q3	FY14 Q4
A.ML.11	Sustainability metrics for updated design case for fast pyrolysis/upgrading	🟩					
A.ML.12	Sustainability metrics for gaseous intermediates to hydrocarbons pathway		🟩				
A.DL.4	Annual Progress Summary			🟩			
A.ML.14	Sensitivity analysis (integrated TEA/LCA) for updated design case for fast pyrolysis/upgrading				🟩		
A.ML.15	GHG analysis for bio-oil upgrading catalysts					🟩	
A.ML.16	Sustainability metrics for catalytic pyrolysis and upgrading design case						🟩

Overall:

- Develop understanding of the total process economic trade-offs across the continuum of crude bio-oil to partially hydrocracked hydrocarbons
- Continued collaboration with ANL and NREL on water foot-printing data and sustainability metrics for MYPP and emerging pathways
- Develop understanding of the impact of novel upgrading catalysts on GHGs and other metrics

Summary

Approach: Identify key process parameters and assumptions affecting sustainability metrics for conversion to enable designs optimized for cost and environmental performance

Technical Accomplishments:

1) Established environmental metrics for biofuel conversion pathways in the MYPP and pathways currently emerging (NREL/PNNL)

2) Enhanced understanding of the critical factors affecting sustainability GHGs for bio-oils and upgrading pathways - balance of yield, external hydrogen, and electricity needs

Relevance: Supports BETO goals to identify metrics and set targets for MYPP pathways, and develop sustainable technologies

Critical Success Factors/Challenges: Efficient, meaningful sensitivity analysis with highly integrated, complex models

Future Work: Metrics and sensitivity analysis for new design cases for the MYPP; determine GHG impact of oil upgrading catalysts

Tech Transfer: Consider results in future design efforts, and continue to work with ANL to integrate data into GREET and water footprint modeling

Additional Slides

Acknowledgements

- BETO: Paul Grabowski, Melissa Klembara, Liz Moore, Kristen Johnson, Alicia Lindauer

- PNNL: Sue Jones, Aye Meyer, Jonathan Male, Corinne Valkenburg, John Lee, Kurt Spies, Alan Zacher, Dan Howe

- NREL: David Hsu, Danny Inman, Eric Tan

- ANL: Michael Wang, Jennifer Dunn, May Wu

Responses to Previous Reviewers’ Comments

- **Provide definition behind the metrics and why they were chosen:** Since 2011 Review, a joint effort was made between the BETO and DOE National Laboratories, in direct support of the BETO’s 4th Quarter joule milestone, to develop an initial set of metrics, baselines and targets for biomass conversion technology. This is a subset of overall metrics for biofuel supply chains as described and rationalized in ORNL’s McBride *et al* (2011) and Efroymson *et al* (2012)

- **Sustainability metrics need to include fossil energy metric, and water consumption per gallon of fuel for proper comparison to other technologies:** Set of metrics resulting from the work and incorporated into SOT Report includes these metrics

Publications and Presentations

- Report currently in review: Fast Pyrolysis and Upgrading 2012 State of Technology and Projections to 2017
- Snowden-Swan LJ, and JL Male. December 2012. Summary of Fast Pyrolysis and Upgrading GHG Analyses . PNNL-22175, Pacific Northwest National Laboratory, Richland, WA.
- Snowden-Swan LJ, SB Jones, JL Male and P Meyer. Life Cycle Greenhouse Gas Emissions of Biofuel from Fast Pyrolysis and Bio-Oil Upgrading. Poster presentation at the ACLCA LCA XII Conference, Tacoma, WA, September 25-27, 2012.
- Butner RS and LJ Snowden-Swan. LCA/Sustainability Activities at Pacific Northwest National Laboratory, presented at the ACLCA LCA XII Conference, Tacoma, WA, September 25-27, 2012.
- Contributed to data in GREET release, GREET1_2012.
- L.J. Snowden-Swan, "Sustainability Assessment for Biomass Thermochemical Conversion Technologies", presented at the Puget Sound Chapter of the AIChE, Pacific Northwest Sustainability Conference, April 29-May 1, 2011.

Assumptions for Steam Reforming of Pyrolysis Oil

	Czernik *et al* (2007)	**Model (Gibbs Free Energy Reactor)**
% of bio-oil C converted to gas	95%	97% (3% to carbon residue)
Reformer Product Gas Composition (dry)	**Vol %**	**Mol%**
H_2	70	66
CO	10	10
CO_2	20	24
CH_4	(0.02)	(0.3)
Steam:Carbon (mol)	5.8	6.0
% of Stoichiometric H_2 Potential	70-80%	86%*
Stoichiometric H_2 potential of bio-oil, g/g	13.8	16.0

*Including H_2 potential of process off-gas.