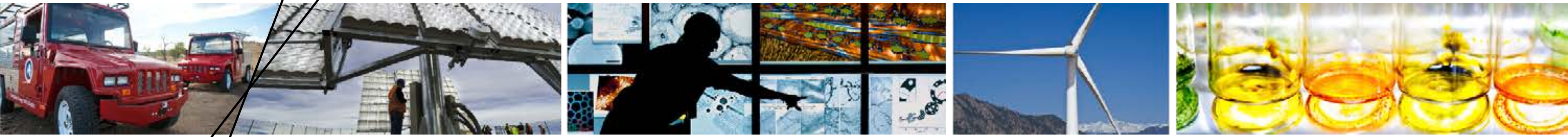
Relative Sustainability of Natural Gas Assisted High-Octane Gasoline Blendstock Production from Biomass



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Introduction/Background

- Production of cellulosic transportation liquid fuels can make a significant contribution to:
  - *Improving energy diversity (resource consumption)*
  - *Reducing GHG emissions (environmental impact)*
- It may be beneficial from economic, environmental, and societal standpoints to develop a more sustainable biofuel production process.

- Co-processing renewable biomass with fossil NG can potentially be a feasible approach to improve economic viability while still achieving an economic-environment sustainability balance.

http://www1.eere.energy.gov/biomass/pdfs/mypp_november_2012.pdf

Potential Synergistic Roles of Natural Gas

- **Increasing availability and low cost**
  - U.S. daily NG production rate has increased nearly 50% in 10 years.
  - NG price has decreased: $8.86/MMBtu (2008) – $2.88/MMBtu (Sep 17). *Source: U.S. Energy Information Administration (EIA)*
- **Providing contingency and complement biomass feedstock supply**
  - BT16 estimated combined biomass resources 0.34 (2017) to 1.5 billion tons per year (2040).
  - Sophisticated feedstock logistic supply system is critical, including pre-processing operations, moisture and ash mitigation, and storage.
  - Regional supply dependency and the inability to actively manage feedstock stability and quality, provide operational risks to the biorefinery, which translate into higher investment risk.
- **Potential of increasing yield**
  - Higher carbon conversion efficiency

Objectives/Scope

Objectives

- Determine the biomass-NG synergistic impacts and sustainability trade-offs associated with the production of high-octane gasoline blendstock via indirect liquefaction (gasification) of biomass through methanol/dimethyl intermediates.

Scope

- Focus on techno-economic analysis and sustainability assessment.
- Exclude policy considerations (such as RIN).

Biomass to High-Octane Gasoline Blendstock Conversion Pathway

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Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbons via Indirect Liquefaction

Thermochemical Research Pathway to High-Octane Gasoline Blendstock Through Methanol/Dimethyl Ether Intermediates

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Jeff Ross, Danielle Sexton, Raymond Yap, John Lukas
Harris Group Inc., Seattle, Washington

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NREL/TP-5100-62402
PNNL-23822
March 2015

Prepared for the U.S. Department of Energy Bioenergy Technologies Office

http://www.nrel.gov/docs/fy15osti/62402.pdf

Modeling and Analysis

Biofpr
Biofuels Bioproducts & Biorefining

Conceptual process design and economics for the production of high-octane gasoline blendstock via indirect liquefaction of biomass through methanol/dimethyl ether intermediates

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Lesley J. Snowden-Swan, Pacific Northwest National Laboratory, Richland, WA, USA
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Received August 5, 2015; revised September 8, 2015; accepted September 10, 2015
View online at Wiley Online Library (wileyonlinelibrary.com);
DOI: 10.1002/bbb.1611; *Biofuels, Bioprod. Bioref.* (2015)

Abstract: This work describes in detail one potential conversion process for the production of high-octane gasoline blendstock via indirect liquefaction of biomass. The processing steps of this pathway include the conversion of biomass to synthesis gas via indirect gasification, gas clean-up via reforming of tars and other hydrocarbons, catalytic conversion of syngas to methanol, methanol dehydration to dimethyl ether (DME), and the homologation of DME over a zeolite catalyst to high-octane gasoline-range hydrocarbon products. The current process configuration has similarities to conventional methanol-to-gasoline (MTG) technologies, but there are key distinctions, specifically regarding the product slate, catalysts, and reactor conditions. A techno-economic analysis is performed to investigate the production of high-octane gasoline blendstock. The design features a processing daily capacity of 2000 tonnes (2205 short tons) of dry biomass. The process yields 271 liters of liquid fuel per dry tonne of biomass (65 gal/dry ton), for an annual fuel production rate of 178 million liters (47 MM gal) at 90% on-stream time. The estimated total capital investment for an n^{th}-plant is $438 million. The resulting minimum fuel selling price (MFSP) is $0.86 per liter or $3.25 per gallon in 2011 US dollars. A rigorous sensitivity analysis captures uncertainties in costs and plant performance. Sustainability metrics for the conversion process are quantified and assessed. The potential premium value of the high-octane gasoline blendstock is examined and found to be at least as competitive as fossil-derived blendstocks.

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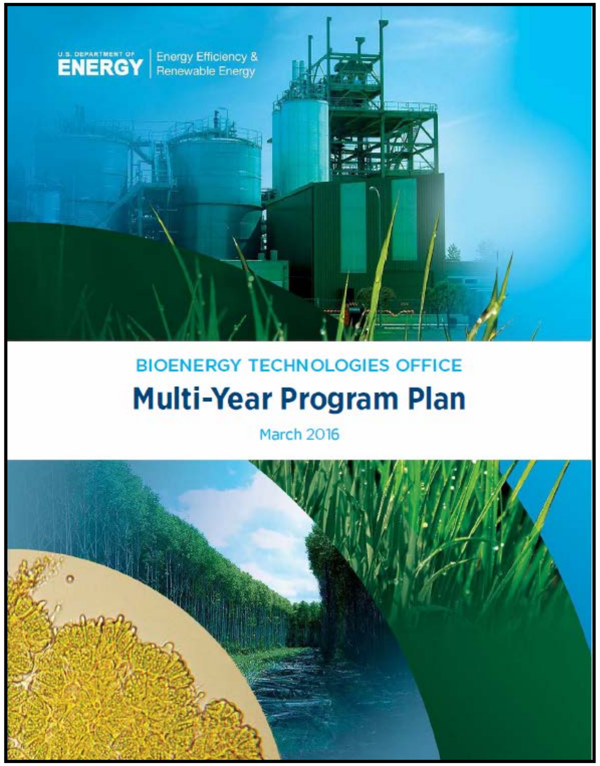
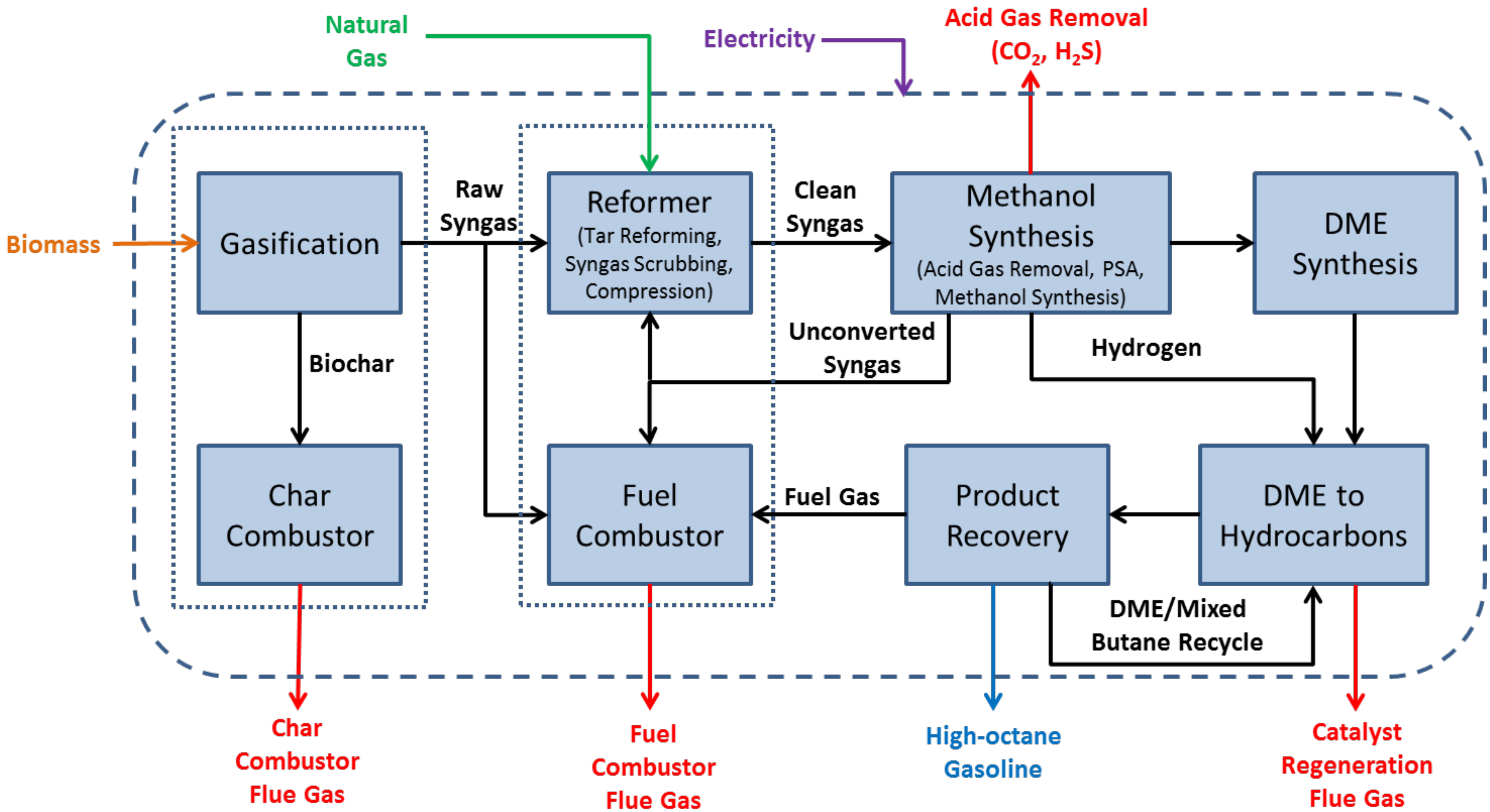
http://onlinelibrary.wiley.com/doi/10.1002/bbb.1611/abstract

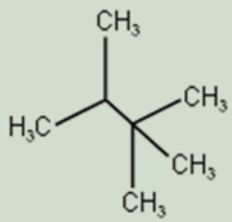


https://energy.gov/sites/prod/files/2016/07/f33/mypp_march2016.pdf

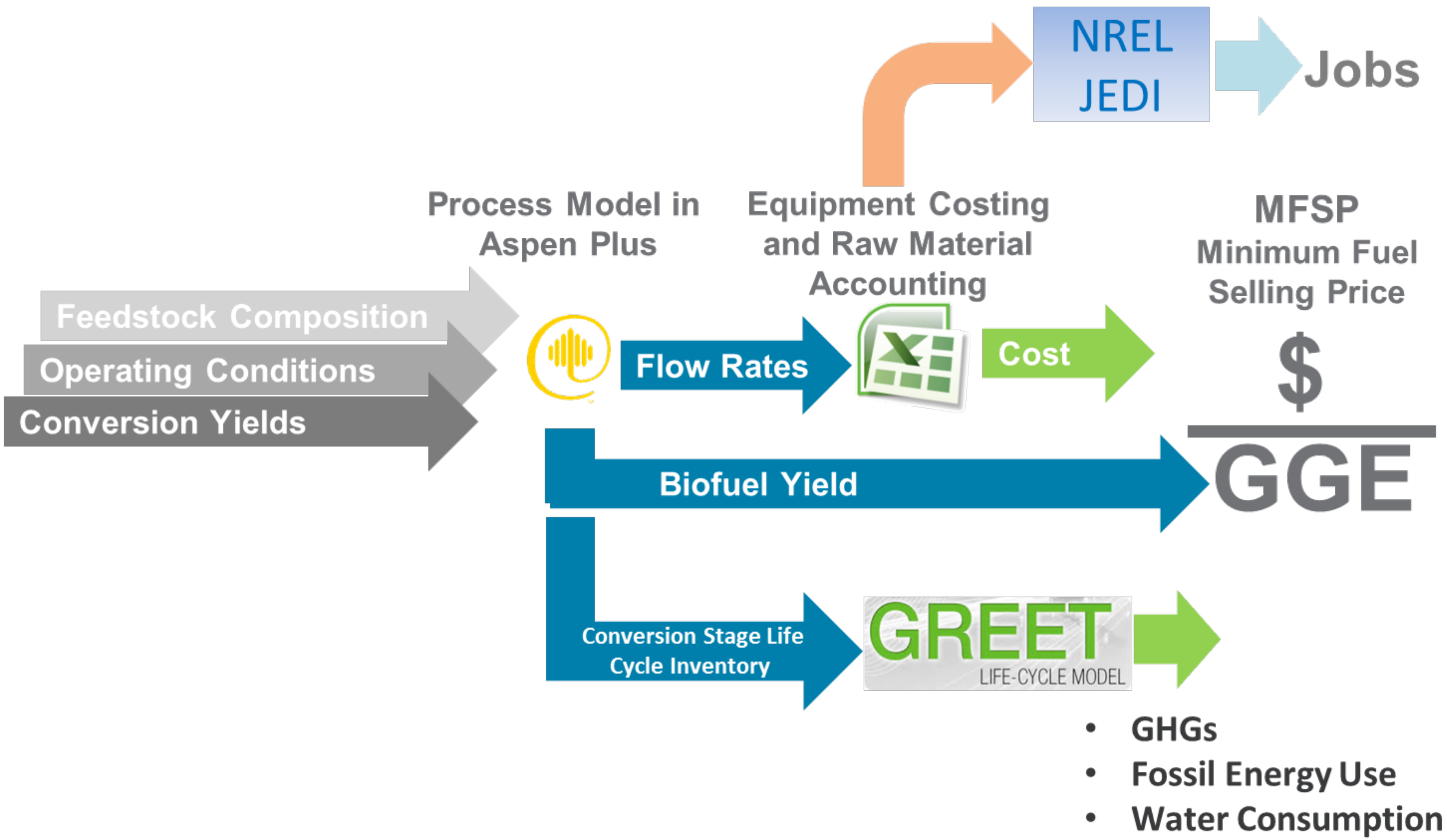
Biomass-to-High-Octane Gasoline Process Flow Diagram



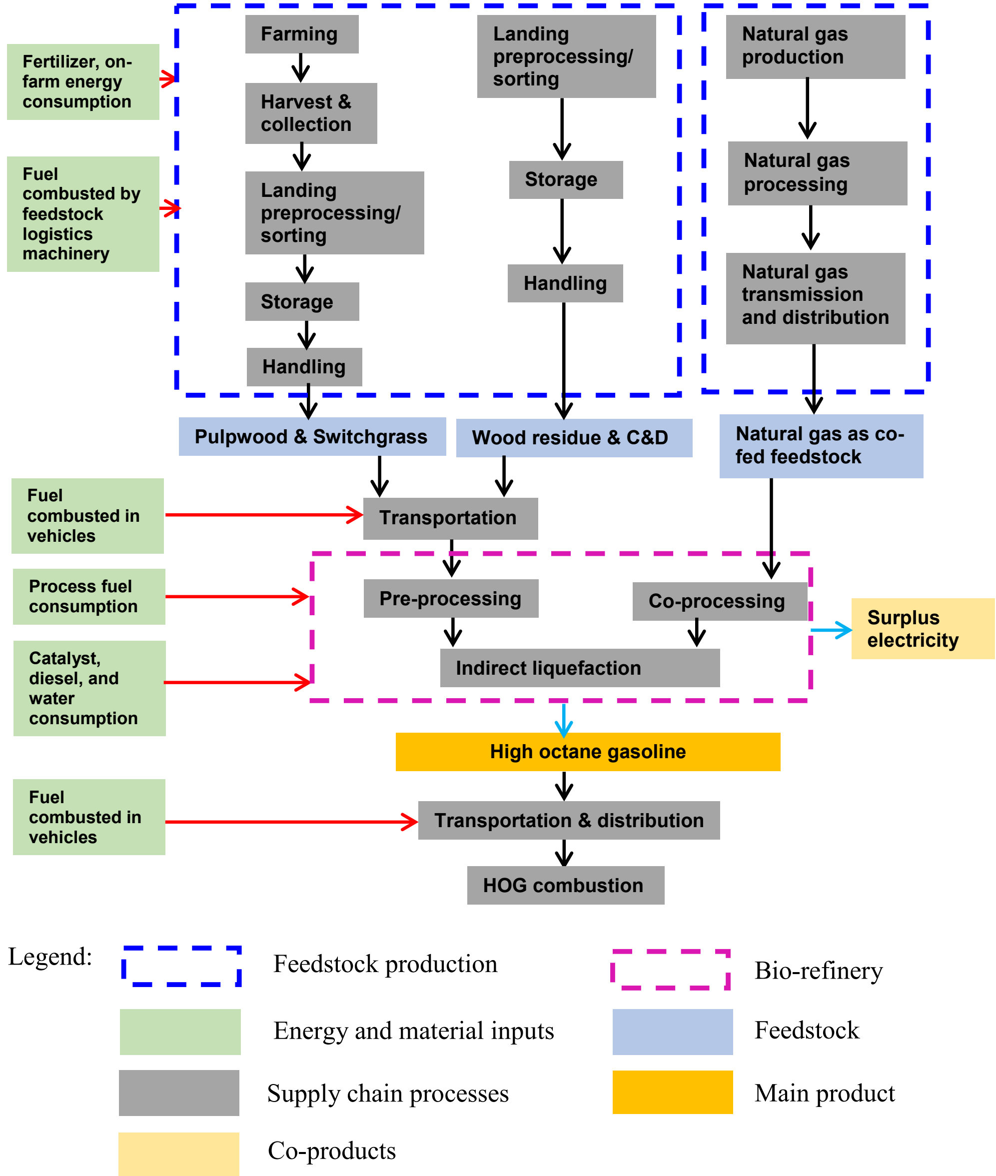
High-Octane Gasoline Pathway vs. MTG

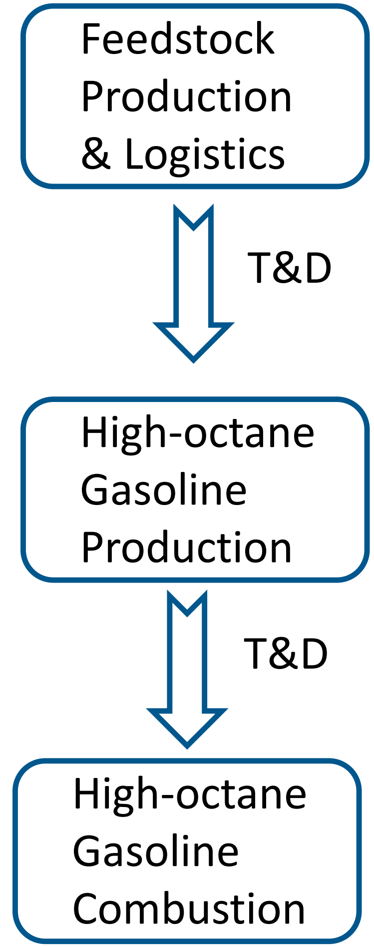
Process Attribute	High-Octane Gasoline Pathway Target	Methanol to Gasoline (MTG) Pathway	Impact on Techno-Economic Analysis
Molecular structures favored in synthesis reactions Example Compound Specific Gravity	Branched paraffins  Triptane 0.70	Aromatics  Toluene 0.87	High octane product rich in branched paraffins, similar to a refinery alkylate. H-saturation decreases density, increasing product volume.
Hydrocarbon synthesis catalyst	Beta-Zeolite (12-membered rings)	ZSM-5 (10-membered rings)	Different pore sizes and structures result in different compound selectivities.
Octane number of gasoline-range product	RON: 95+ MON: 90+	RON: 92 MON: 83	Octane number increases value of product as a finished fuel blendstock.
Selectivity of C_5+product	C_5+ product only (~65 Gal / Ton)	~ 85% C_5+ (~55 Gal / Ton)	High selectivity to primary (premium quality) product maximizes overall product value.
Severity of synthesis operating conditions	350 – 450 Deg. F 130 PSIA	650 – 950 Deg. F 315 PSIA	The lower severity operating conditions result in lower capital and operating costs relative to MTG.
Coke formation	Coke formation is minimized by hydrogen addition and selectivity to branched paraffins rather than aromatics.	High propensity for coke formation due to aromatic coke pre-cursors.	Minimizing coke formation helps to maximize product yield / carbon efficiency and maximizes catalyst regeneration and replacement cycles.

Approach / Methodology



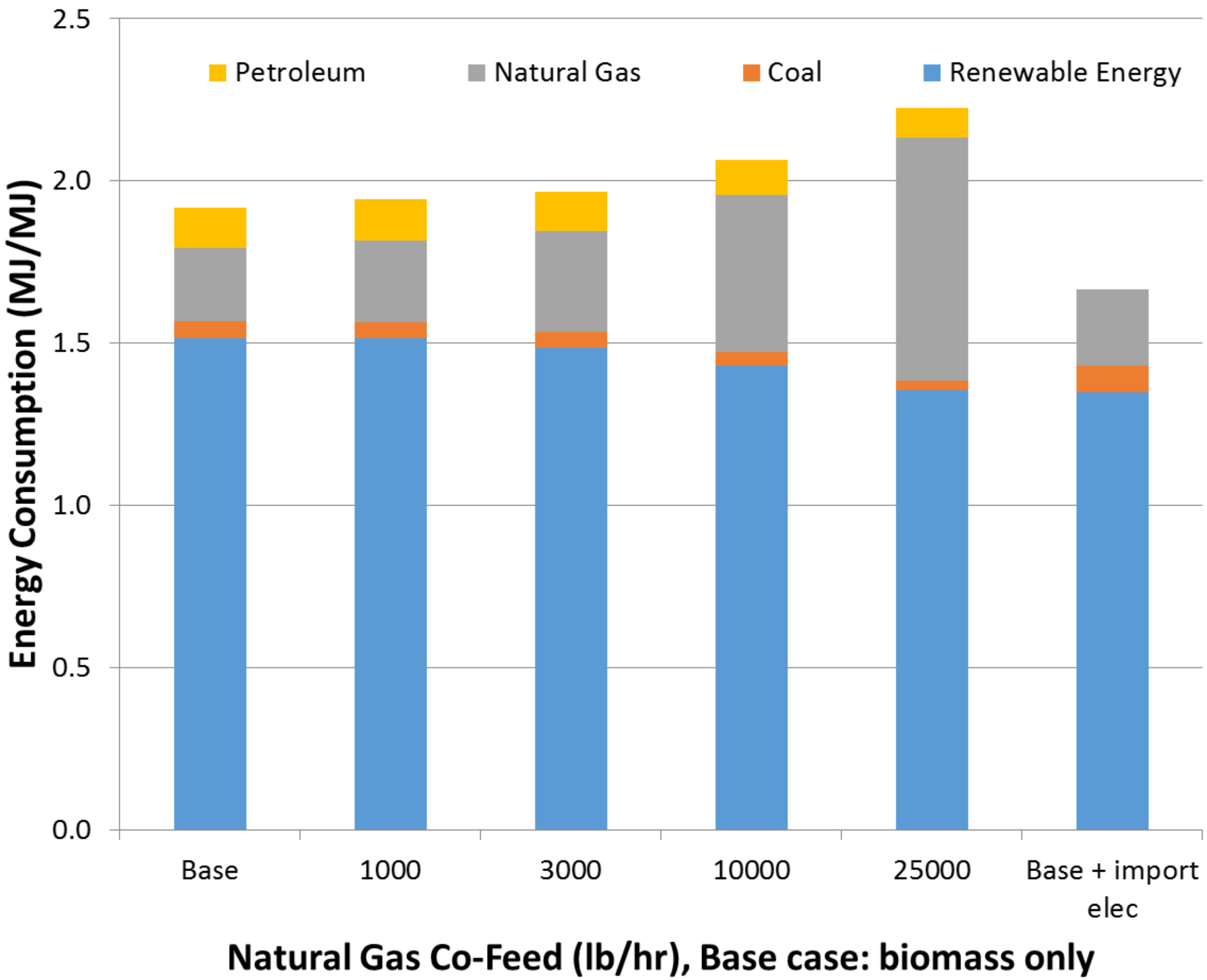
LCA System Boundary





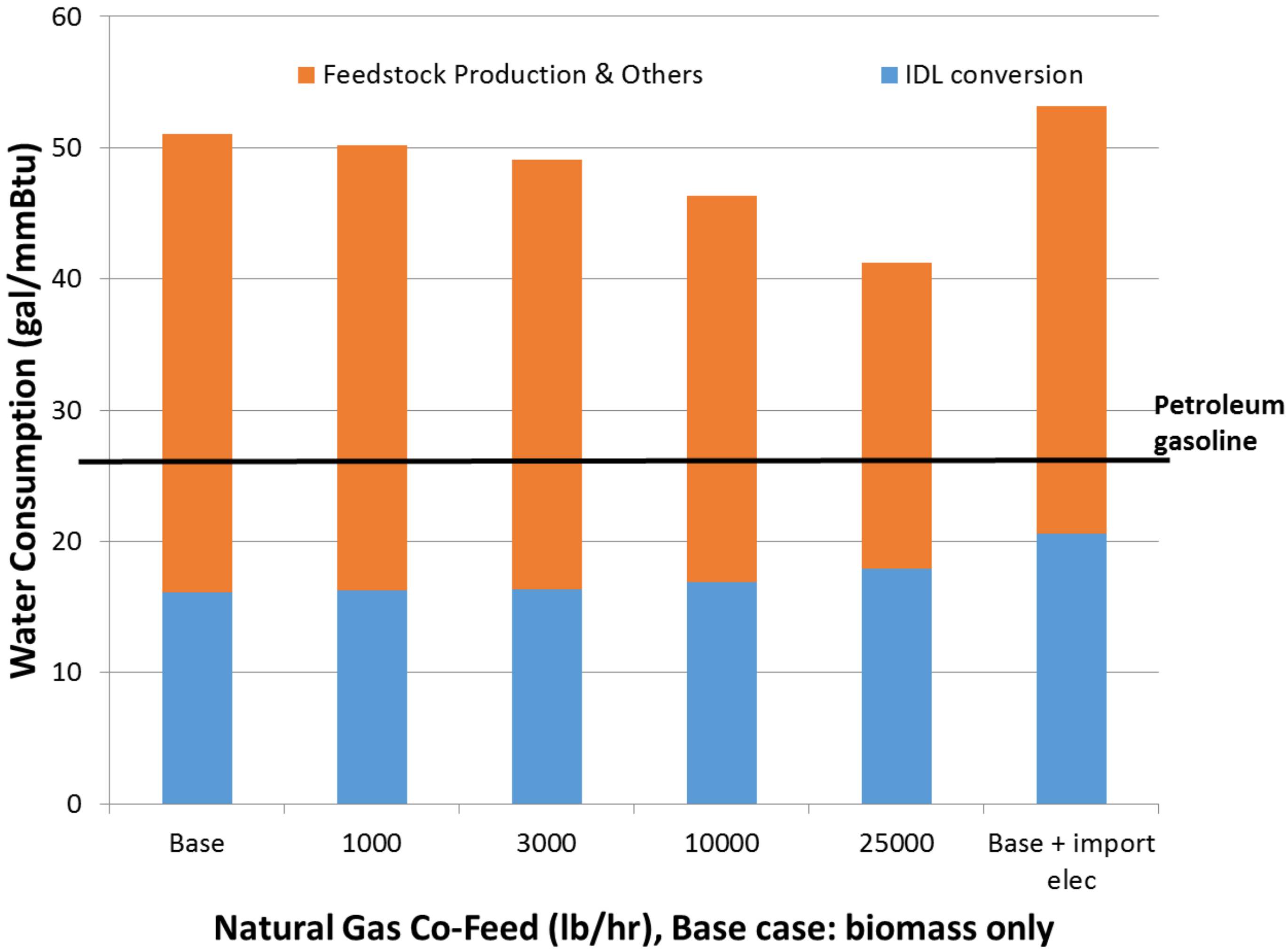
Life Cycle Energy Consumption

Modeled impact of increased NG input on energy consumption.



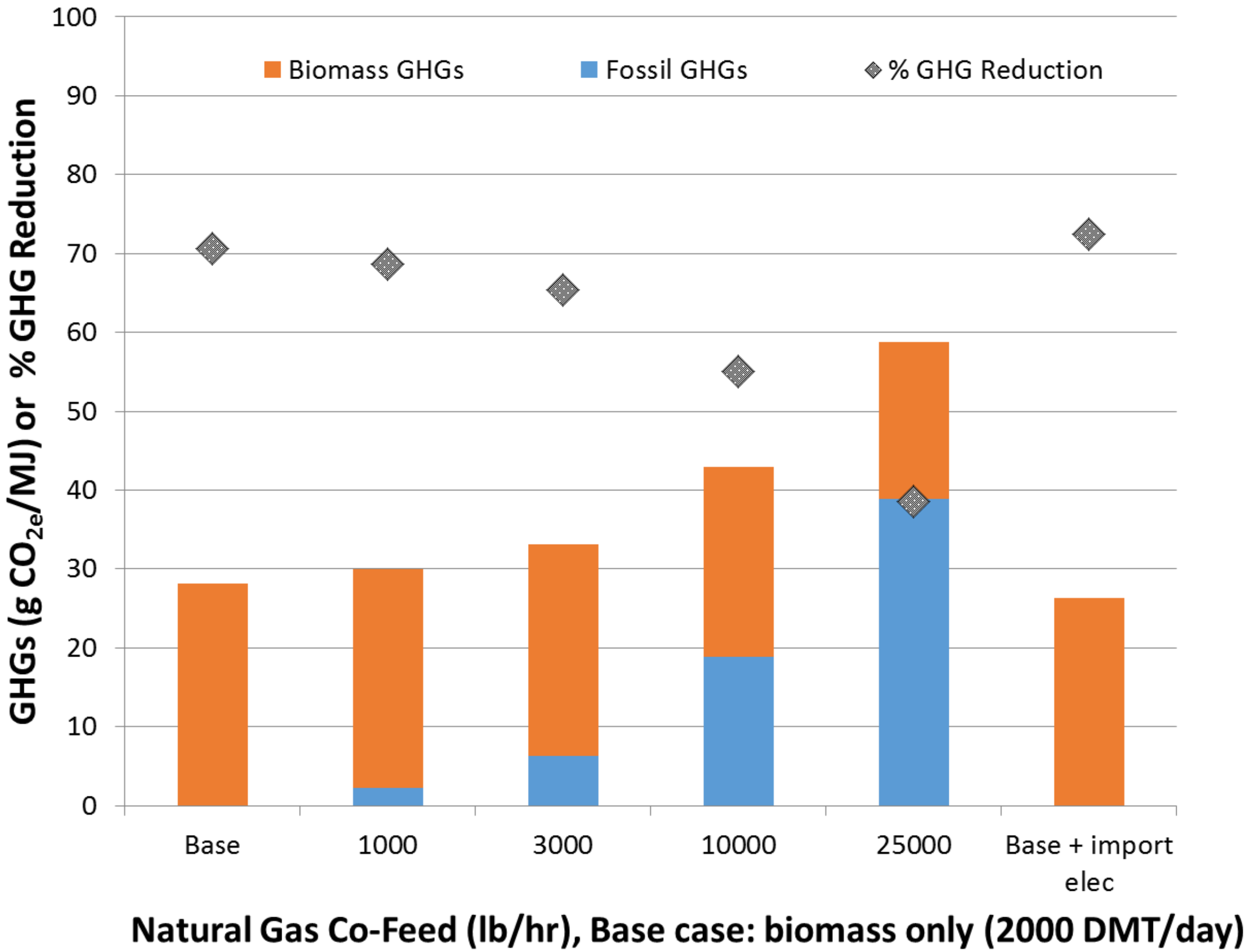
Life Cycle Water Consumption

Modeled impact of increased NG input on water consumption.



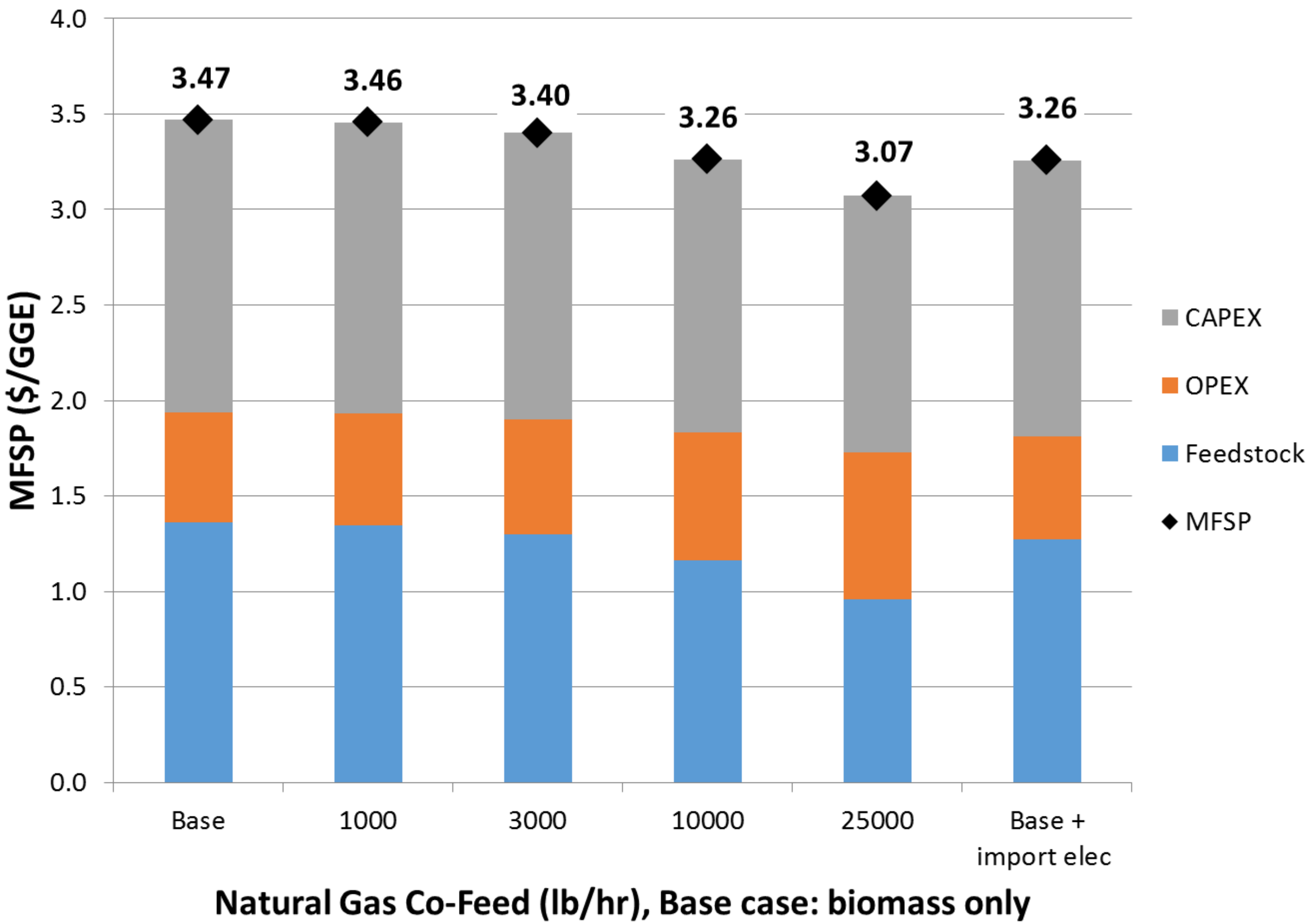
Life Cycle GHGs

Modeled impact of increased NG input on GHGs.

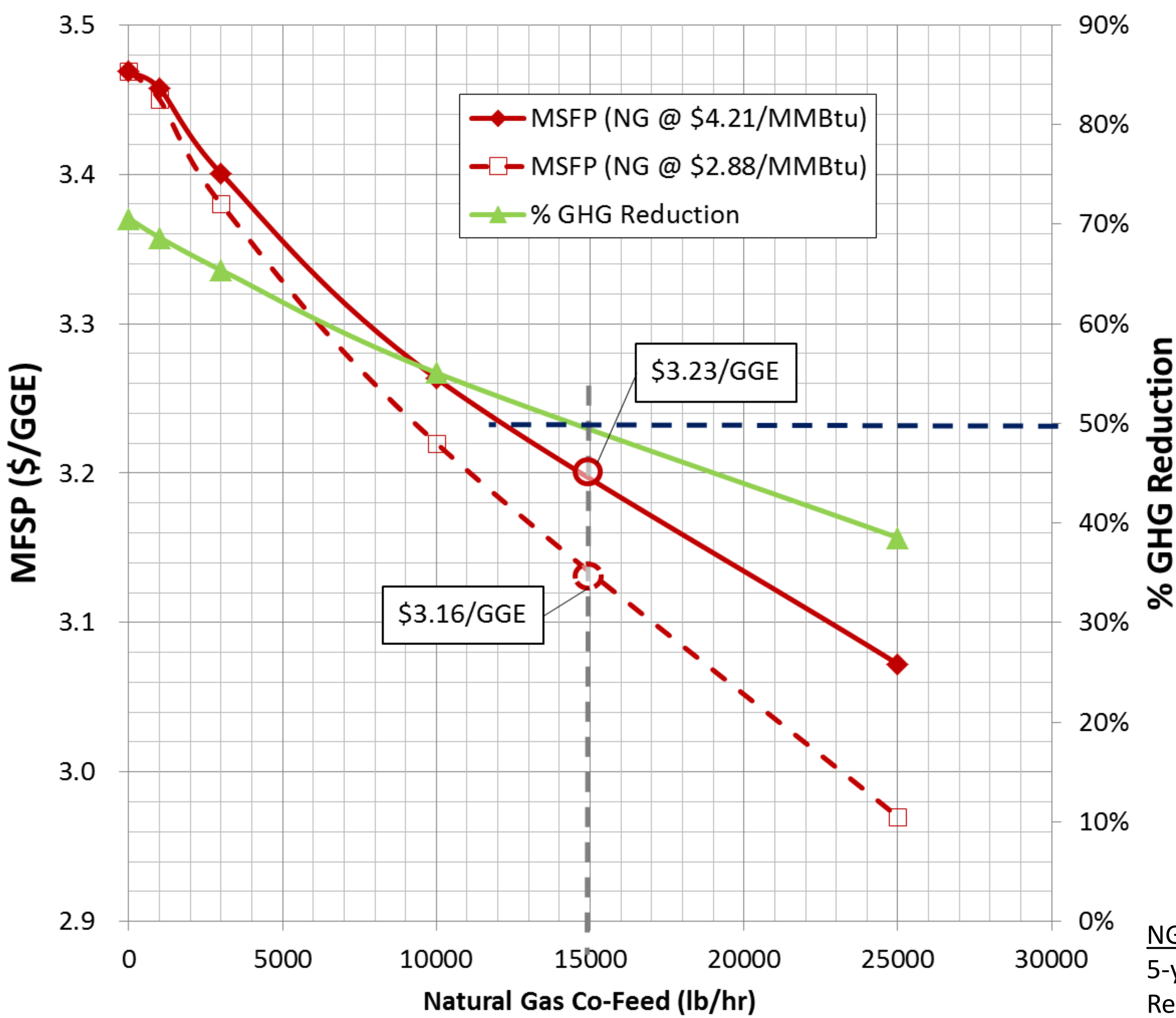


Minimum Fuel Selling Price (MFSP)

Increasing NG input leads to lower MFSP (primarily due to higher yield).



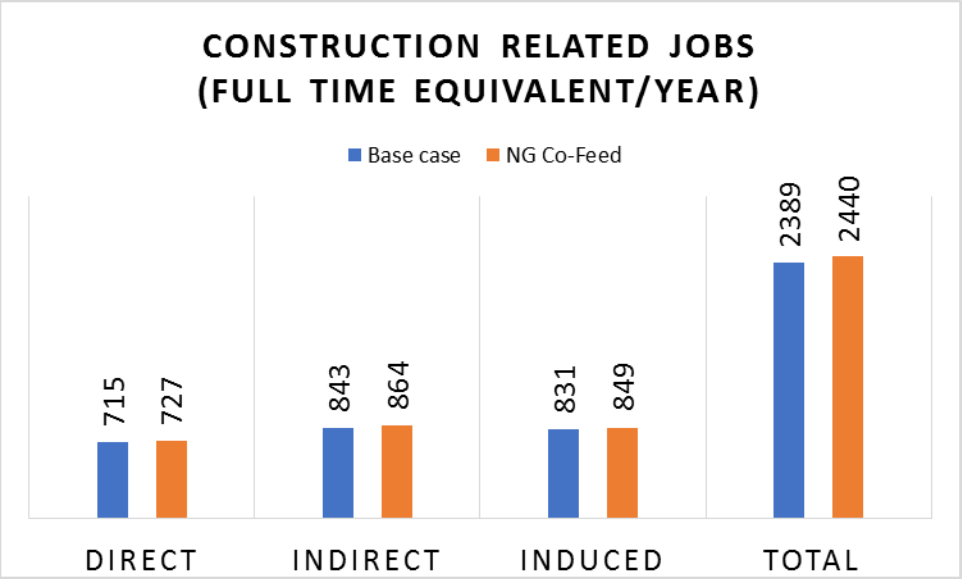
MFSPs and GHGs As A Function of NG Supplement

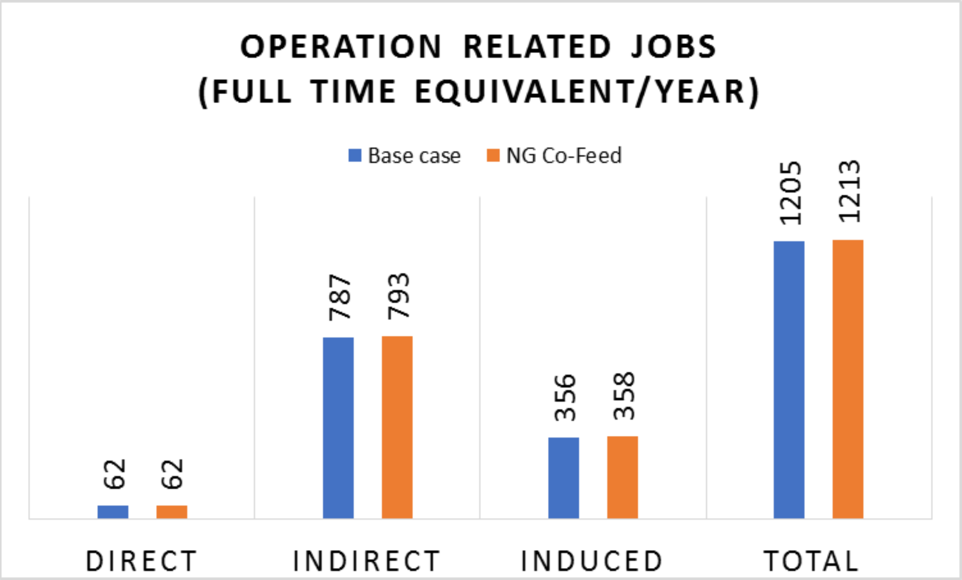


NG Prices
5-year average: $4.21/MMBtu
Recent (8/9/2017): $2.88/MMBtu

Economic Impact Analysis

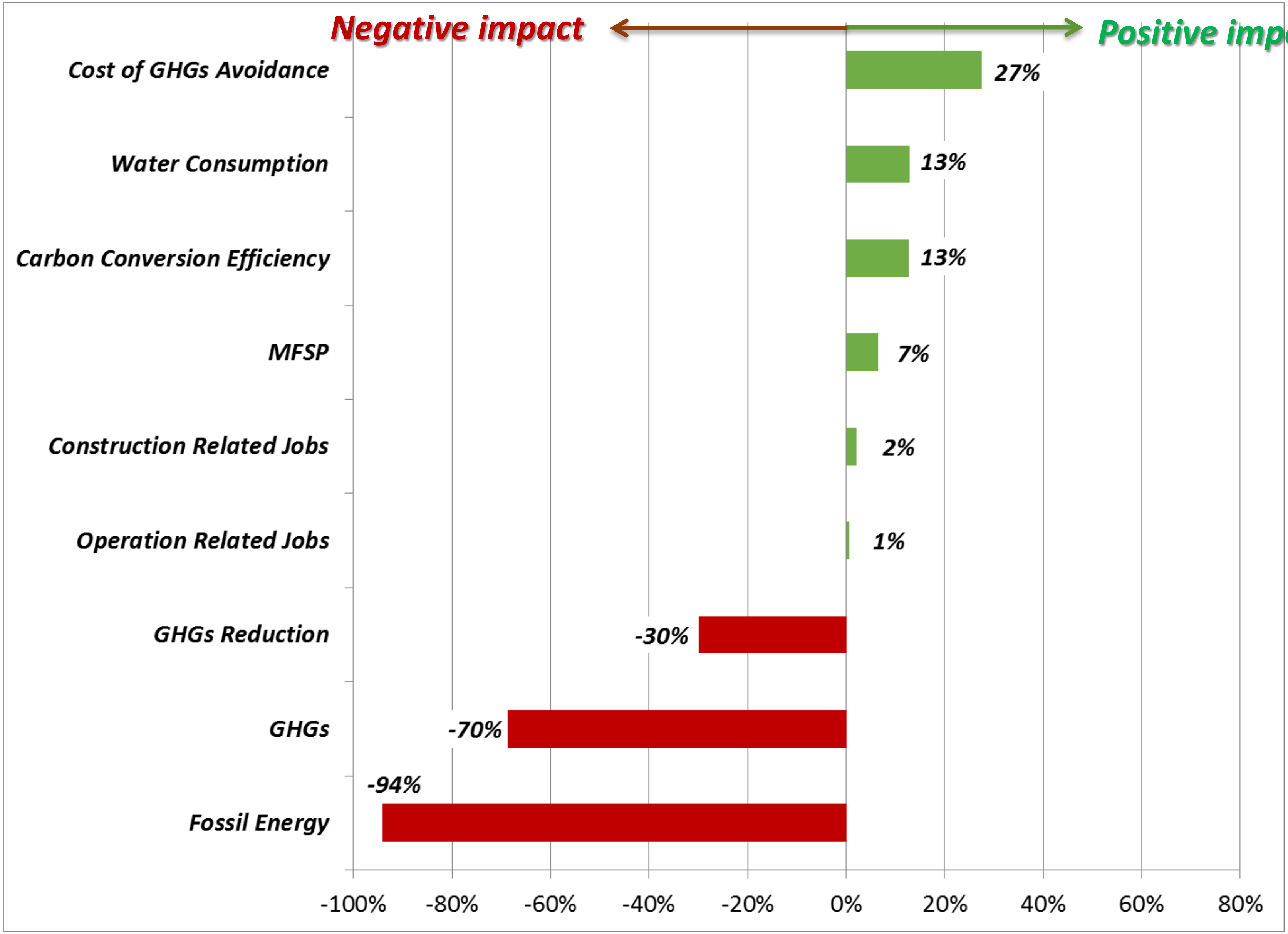
Jobs and Economic Development Impact (JEDI) model



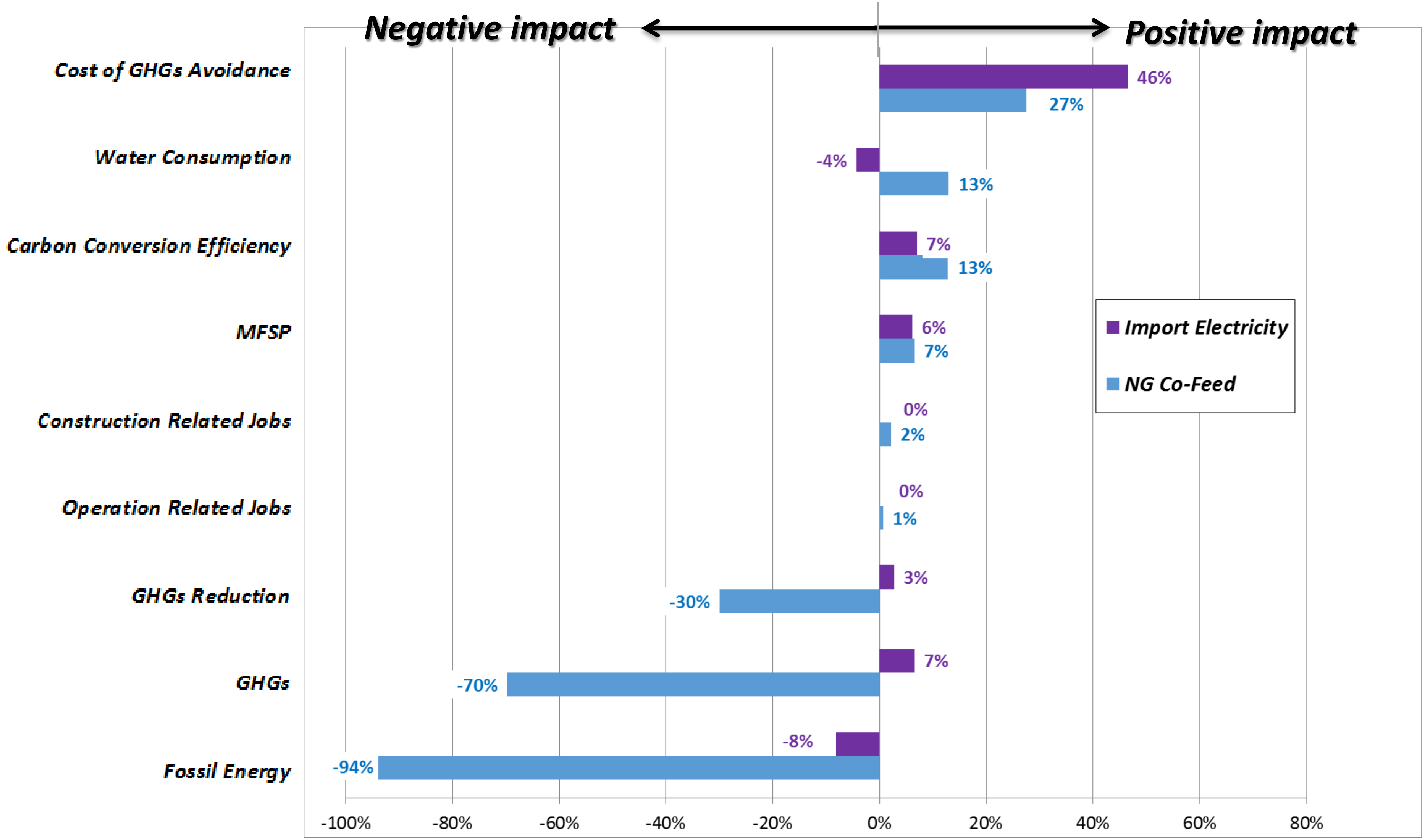


- The construction of a new biorefinery yields about 2389 to 2440 jobs/year (combining direct, indirect and induced jobs), during the three year construction period.
- The number of construction related jobs depends primarily on capital investment and expenditure categories (e.g., equipment manufacturing, engineering design, finance).
- Ongoing operating of the biorefinery is not labor intensive, and requires only about 62 on-site jobs.
- Most jobs associated with biorefinery operation are supply-chain related indirect jobs such as workers in the forestry and transportation sectors, which harvest, collect and ship feedstocks to the biorefinery.
- All operation-related jobs are permanent jobs, which are different from the temporary jobs supported by biorefinery construction.

Relative Impacts and Trade-off of Max NG Co-Feed (i.e., at 50% GHGs Reduction) on Sustainability Metrics



Relative Impacts and Trade-off of Max NG Co-Feed and Import Electricity (Biomass Only) on Sustainability Metrics



Summary

- Co-feeding NG improves MFSP, cost of GHGs avoidance, life cycle water consumption, and the overall carbon conversion efficiency. It can potentially create slightly more jobs.

- Co-feeding NG increases life cycle GHGs and consumes more fossil energy.

- The import electricity case exhibits positive impact on all indicators (except life cycle water and fossil consumption) evaluated in this study.

- In comparison with the NG co-feed case, the import electricity case has similar impact on MFSP but significantly better impact on life cycle GHGs and fossil energy usage.

Acknowledgements

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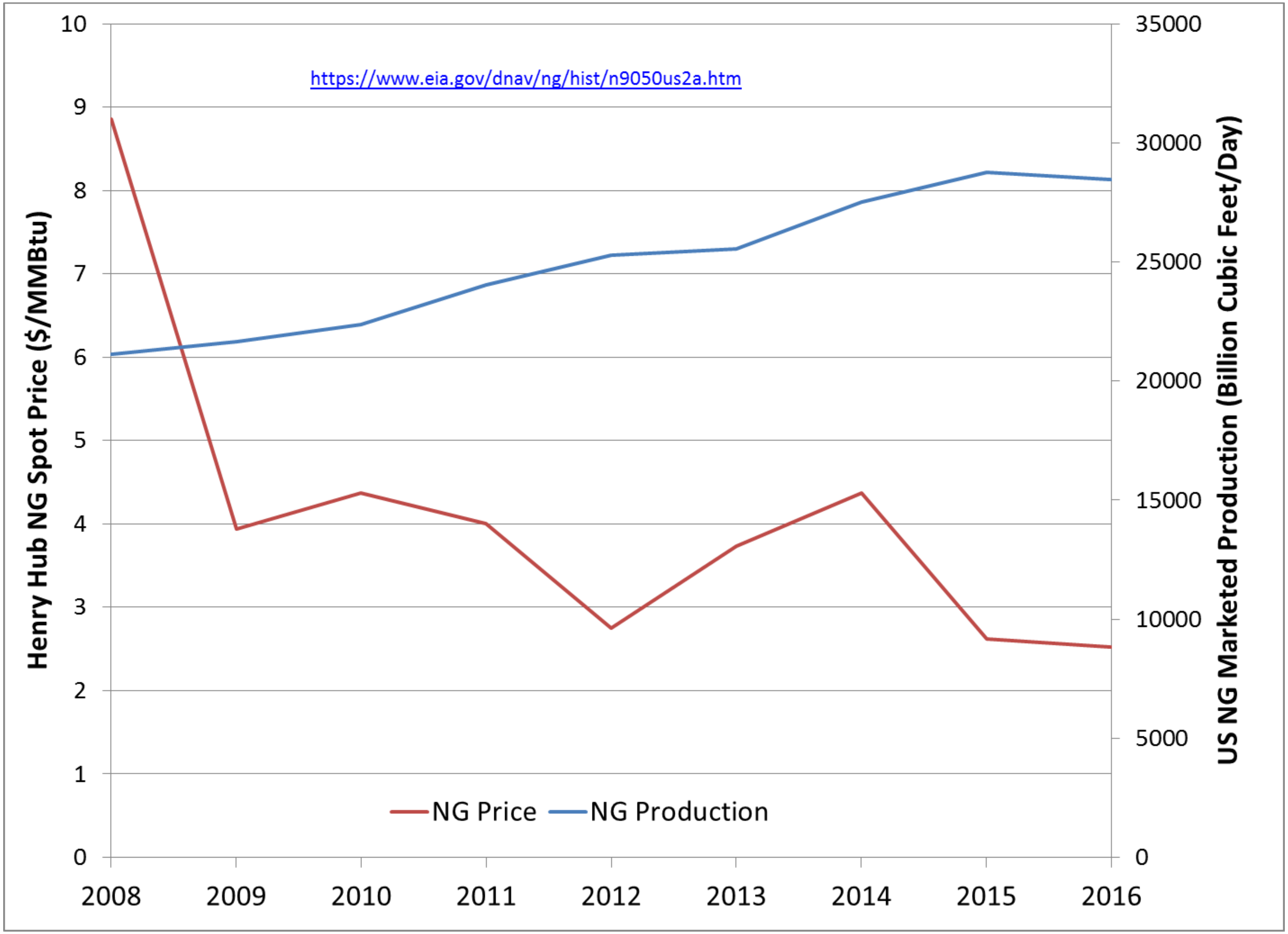
The U.S. NG Production and Price Trends



n^{th}-Plant TEA Assumptions

Description of Economic Parameter	Analysis Value / Basis
Delivered Feedstock Cost	$84.45/ US Dry Ton
Internal Rate of Return (IRR)	10.0 %
Plant Financing by Equity / Debt	40% / 60% of Total Capital Investment
Plant Life	30 Years
Income Tax Rate	35.0 %
Interest Rate for Debt Financing	8.0 % Annually
Term for Debt Financing	30 Years
Working Capital Cost	5.0% of Fixed Capital Investment
Depreciation Schedule	Total Plant: 7-Year MACRS
Construction Period (Spending Schedule)	3 Years (8% Y1, 60% Y2, 32% Y3)
Start-Up Time	6 Months
Revenue and Costs During Start-Up	Revenue = 50% of Normal Operation Variable Costs = 75% of Normal Operation Fixed Costs = 100% of Normal Operation
On-Stream Percentage After Start-Up	90% (7,884 Operating Hours per Year)

Relative Sustainability Impact Summary

Sustainability Indicators	lb/hr	Base	Max NG	Relative Impact	Imported Electricity	Relative Impact
MFSP	$/GGE	3.47	3.24	7%	3.26	6%
GHGs	g CO2e/MJ	28.11	47.73	-70%	26.26	7%
GHGs Reduction	%	70.57	49.45	-30%	72.50	3%
Fossil Energy	MJ/MJ	0.40	0.79	-94%	0.44	-8%
Water Consumption	gal/MMBtu	51.01	44.40	13%	53.18	-4%
Carbon Conversion Efficiency	%	31.16	35.14	13%	33.36	7%
Construction Related Jobs	FTE	2389	2440	2%	2389	NA
Operation Related Jobs	FTE	1205	1213	1%	1205	NA
Cost of GHGs Avoidance	$/kg CO2e	0.06	0.04	27%	0.03	46%

Feed Input and Product Output Summary

		Base	Max NG	Import Electricity
Biomass Feed	LHV, MMBtu/hr	1467	1467	1467
NG to Reformer	LHV, MMBtu/hr	0.00	321	0.00
Total	LHV, MMBtu/hr	1467	1788	1467
HOG	GGE/hr	5689	7061	6092
HOG/Total Feed	GGE/MMBtu	3.88	3.95	4.15
Capacity	MMGGE/yr	44.9	55.7	48.0
Capacity Change	%		24%	7%

Economic Impact Analysis
Jobs and Economic Development Impact (JEDI) model

- **Onsite (or direct) effect** – immediate effect created by an expenditure.

  For example, during the construction of a biorefinery, the direct effect on jobs results from hiring contractors and workers to install process equipment and construct other parts of the plant. Similarly, during the operation, the direct effect on jobs refers to workers directly hired to operate the facility.

- **Revenue and supply chain (or indirect) effect** – occurs when contractors, vendors, or manufacturers receive payment from the biorefinery to provide goods and services required for the construction or operation of the facility and, in turn, also purchase goods and services from their suppliers.

  For instance, the supply chain effect includes farmers who produce the biomass feedstock, bankers who finance the project and farming operations, and equipment manufacturers who make process or farming equipment, among others.

- **Induced effect** – measures the impacts resulting from the changes in household spending of workers directly and indirectly employed by the construction companies, manufacturers, and service industries, as well as the biorefinery itself and farmers who produce and supply feedstocks to the biorefinery, among others.