Gasification and Techno-Economic Analysis of High-Impact Biomass Feedstocks for the Synthesis of High-Octane Gasoline

R. Gary Grim[1], Daniel P. Dupuis[1], Eric Nelson[1], Eric C. D. Tan[1], Daniel A. Ruddy[1], Sergio Hernandez[2], Tyler Westover[2], Jesse Hensley[1] and Daniel Carpenter[1]

1: National Renewable Energy Laboratory, Golden, Colorado, 2: Idaho National Laboratory, Idaho Falls, ID

Summary

Five economically advantaged biomass feedstocks identified in the US Department of Energy's 2016 Billion Ton Study were gasified and the syngas reformed at the bench scale to study the feedstock price-performance relationship. The distribution of reformed syngas compositions, heating values, and yields were similar across the different feedstocks and blends thereof, which ranged from inexpensive residual wastes to more expensive and higher quality biomass, revealing that feedstock performance was mostly insensitive to its price. Custom blended feedstocks produced syngas with characteristics resembling linear combinations of syngas from single-component feedstocks, supporting the ability to customize and predict blended properties based on single-feedstock data. A techno-economic analysis of specific feedstock costs for producing high-octane gasoline showed that miscanthus and forest residues were the most cost-effective with gas yields consistent with experimental gasification data. A field-to-wheels life-cycle assessment of greenhouse gas emissions showed that forest residues was the most environmentally benign feedstock of those studied.

Experimental Results

Raw Synthesis Gas Compositions, Heating Values, and Yields

Feedstock	H_2 (%)	CO (%)	CO_2 (%)	CH_4 (%)	C_{2+} (%)	H_2:CO	HHV ($MJ\text{-}kg^{-1}$)	Yield ($Nm^3_{gas}\text{-}kg_{feed}^{-1}$)
Clean Pine (CP)	39.0	25.8	20.1	11.0	4.0	1.51	65.9	1.12
Hybrid Poplar (HP)	39.5	22.8	22.8	11.2	3.7	1.73	66.12	1.09
Miscanthus (MI)	35.1	29.5	19.6	11.8	4.1	1.19	61.11	1.10
Forest Residues (FR)	38.8	25.6	20.9	10.8	4.0	1.52	65.32	1.15
Switchgrass (SG)	39.9	22.8	23.4	10.4	3.5	1.75	66.18	1.14
50% FR, 50% SG	39.5	23.2	22.7	10.9	3.9	1.70	66.06	1.10
60% FR, 30% CP, 10% HP	39.9	24.7	20.7	10.9	3.8	1.61	66.84	1.41

Reformed Synthesis Gas Compositions, Heating Values, and Yields

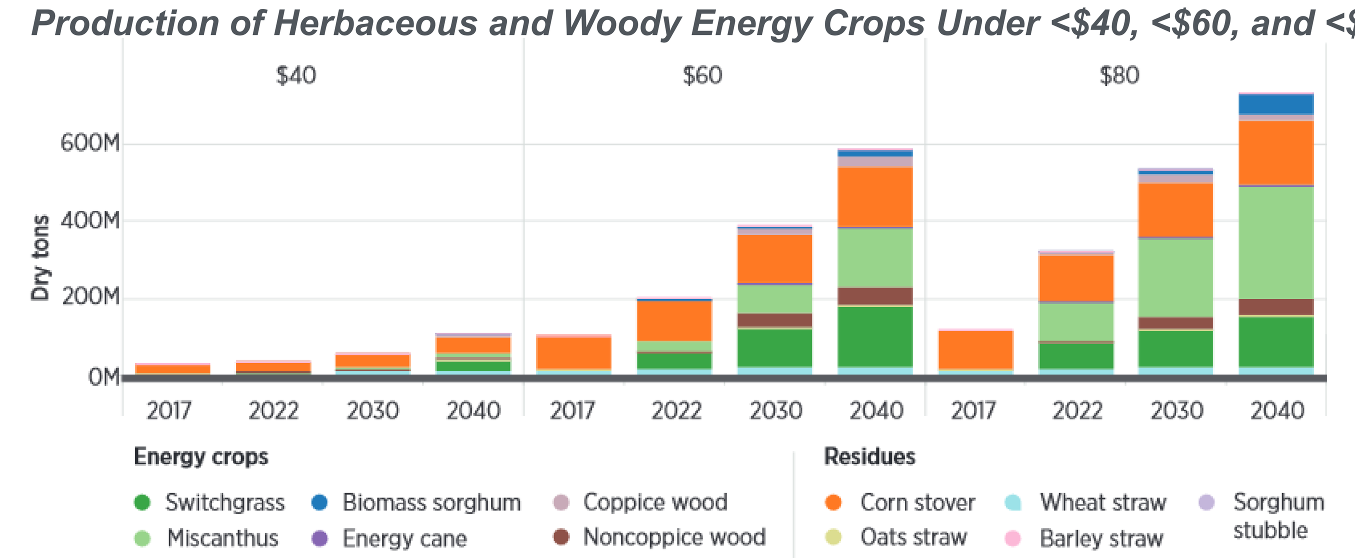
Feedstock	H_2 (%)	CO (%)	CO_2 (%)	CH_4 (%)	C_{2+} (%)	H_2:CO	HHV ($MJ\text{-}kg^{-1}$)	Yield ($Nm^3_{gas}\text{-}kg_{feed}^{-1}$)
Clean Pine (CP)	57.7	23.4	18.5	0.38	0.01	2.47	84.52	2.29
Hybrid Poplar (HP)	57.5	23.1	19.2	0.22	0.01	2.49	84.13	2.26
Miscanthus (MI)	57.8	21.6	20.4	0.24	0.01	2.68	84.33	2.23
Forest Residues (FR)	57.9	22.2	19.7	0.27	0.01	2.61	84.55	2.35
Switchgrass (SG)	56.7	20.0	22.9	0.33	0.01	2.84	82.77	2.10
50% FR, 50% SG	57.4	21.5	20.9	0.29	0.01	2.67	83.81	2.19
60% FR, 30% CP, 10% HP	57.7	22.9	19.0	0.37	0.01	2.52	84.50	2.26

Although the feedstocks ranged from relatively inexpensive waste products such as forest residues ($70.55/tonne) to more expensive and higher quality biomass such as clean loblolly pine ($95.90/tonne), the distribution of reformed syngas compositions, heating values, and yields were similar, indicating that for these feedstocks, price and performance are not strongly correlated. Of the five unblended feedstocks tested, those with the highest and lowest reformed syngas yield and HHV were forest residues and switchgrass, respectively.

Background

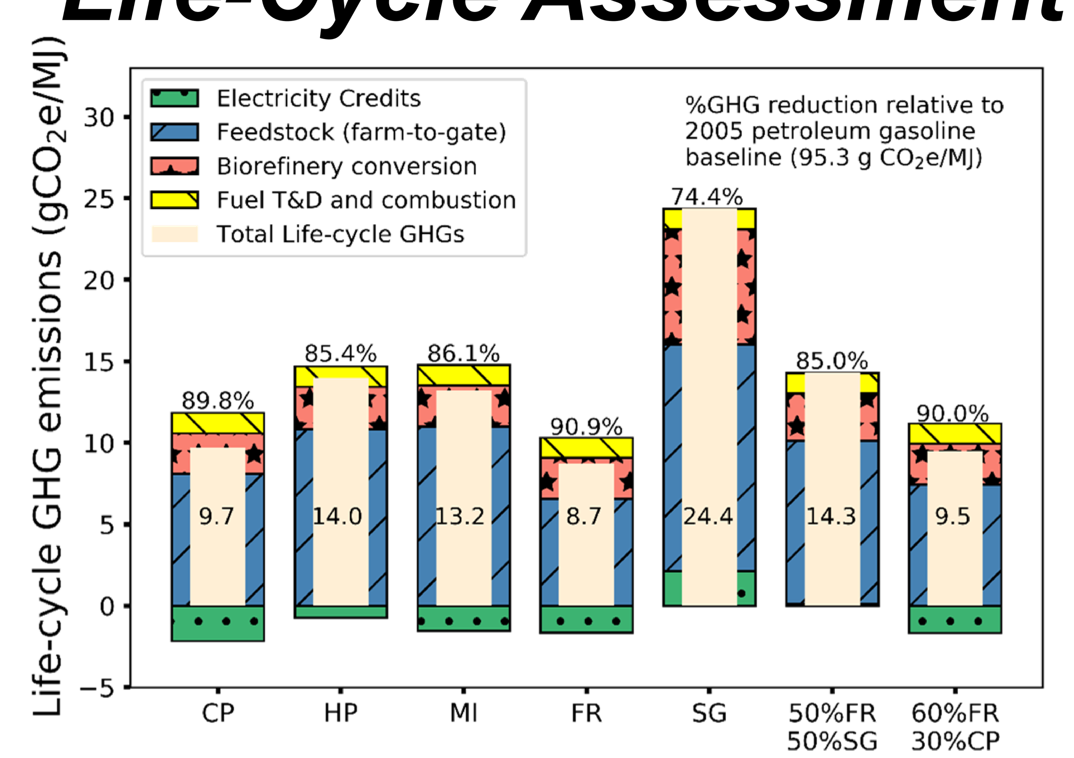
The US Department of Energy has defined a "high-impact feedstock" as a "feedstock that is domestically available and has the agronomically and ecologically sustainable ultimate availability potential of at least 50 million dry metric tons of cellulosic biomass per year". Within the draw radius of a biorefinery, there will likely be a mixture of feedstocks available, and it is likely that more than one feedstock will be needed in order to meet the demand. Practical implementation of feedstock flexibility requires an understanding of blending behavior, physical and chemical properties, and identification of key process cost drivers.

Production of Herbaceous and Woody Energy Crops Under <$40, <$60, and <$80



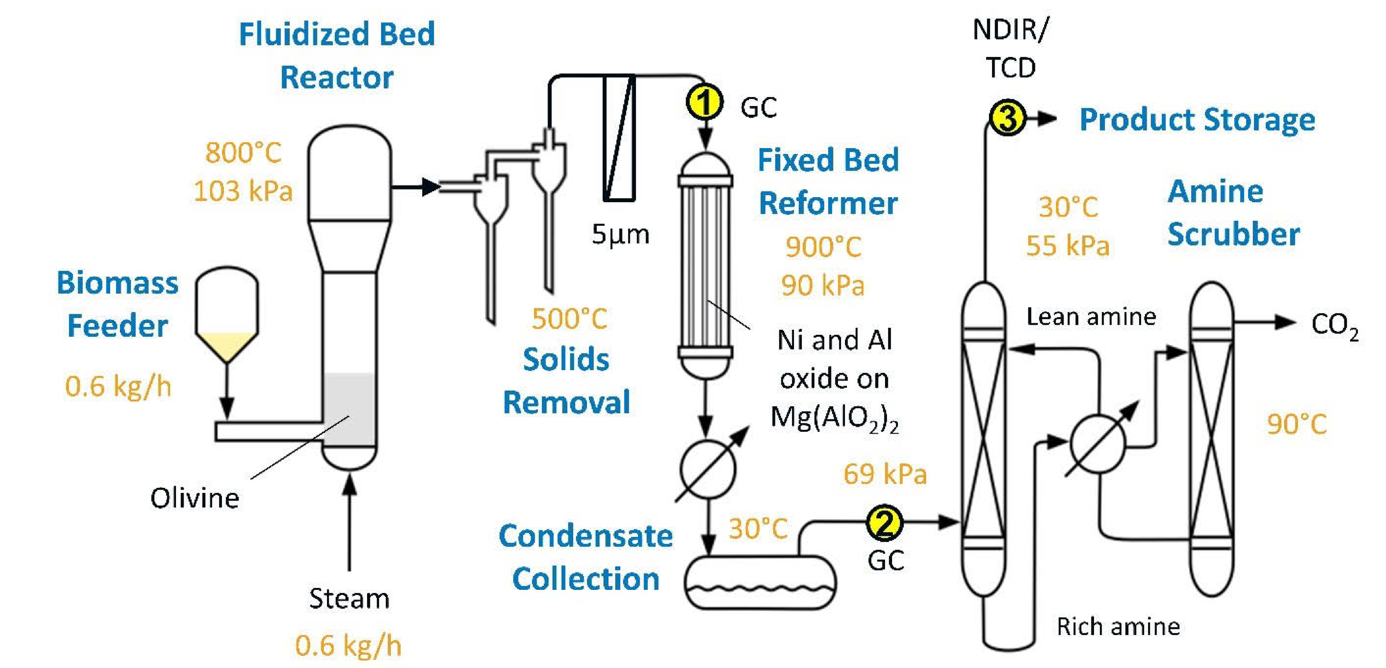
Miscanthus ($68.30/tonne)	*Switchgrass ($68.30/tonne)*	*Forest Residues ($70.55/tonne)*	*Pine + Poplar ($95.90/tonne)*
			
293M Dry Tons (2040)	*137M Dry Tons (2040)*	*53M Dry Tons (2040)*	*43M Dry Tons (2040)*

Life-Cycle Assessment



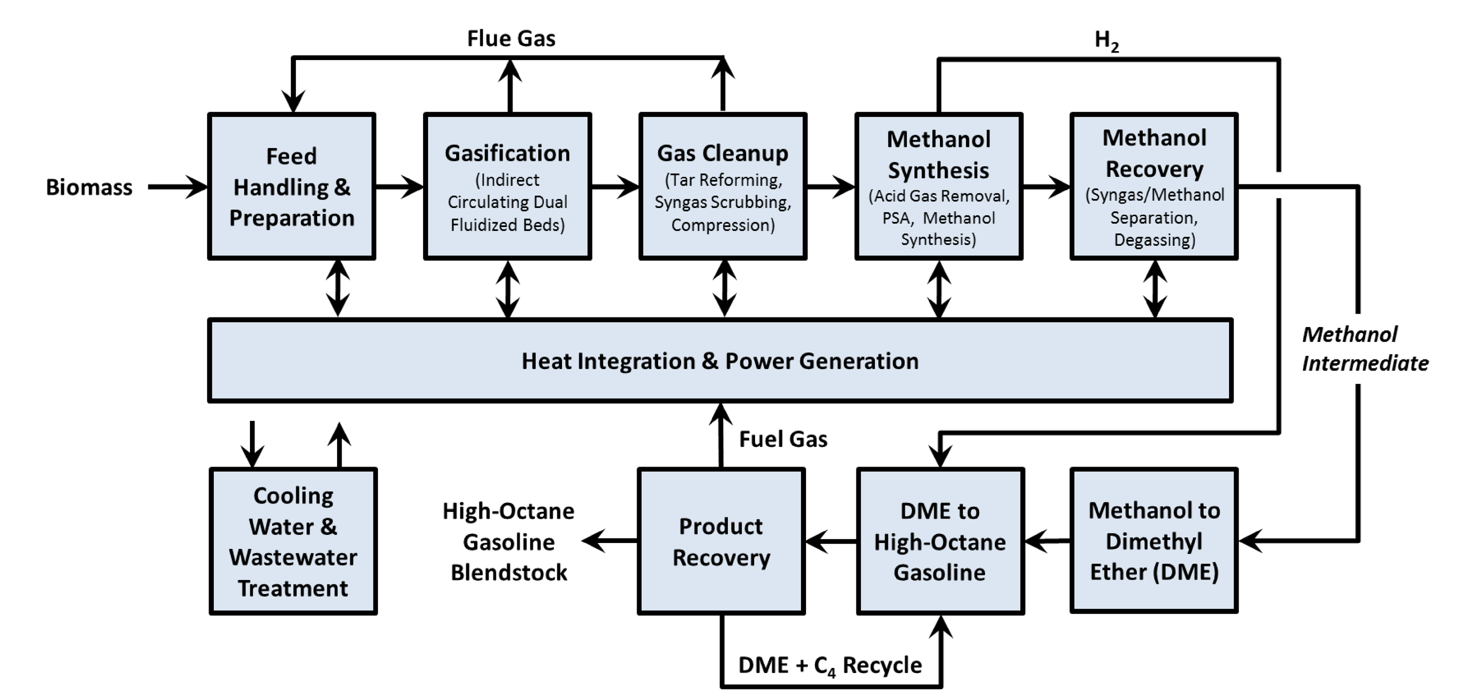
The life-cycle stage that contributes the most is the feedstock production and logistics (farm-to-gate). GHGs for the combined fuel transportation, distribution, and combustion for all cases are identical at 1.25 g CO_{2e}/MJ, excluding CO_2 from fuel combustion as it is biogenic CO_2 (from fuel originated from biomass). Forest residues exhibits the lowest overall life-cycle GHGs, at 8.7 g CO_{2e}/MJ. On the other hand, switchgrass has the highest FTW GHG emissions (24.4 g CO_{2e}/MJ), primarily because it has the lowest yield and highest farm-to-gate GHGs (13.9 g CO_{2e}/MJ).

Gasification System



- 4" ID fluidized bed gasifier
- Three analytical sampling locations (2 GC, 1 NDIR/TCD)
- Integrated fixed bed reformer and amine scrubbing system for syngas clean up

Techno-Economic Analysis



Economic Parameter	CP	HP	MI	SG	FR	50% FR 50% SG	60% FR 30% CP 10% HP
Cost Contributions $/GGE							
Specific Feedstock Cost	1.45	1.52	1.05	1.17	1.08	1.12	1.23
Ash Removal	0.01	0.01	0.02	0.10	0.05	0.07	0.03
Other Operating Costs & Credits	0.56	0.60	0.58	0.67	0.57	0.62	0.57
Capital Charges & Taxes	1.60	1.63	1.61	1.69	1.60	1.64	1.60
Fuel Production, MM GGE/yr	43.5	41.4	42.7	38.2	43.1	40.7	43.1
Product Yield, GGE/dry tonne	66.2	63.0	65.0	58.2	65.6	61.9	65.7

Miscanthus (MI) and forest residues (FR) have the lowest specific feedstock cost contributions to the production of HOG at $1.05/GGE and $1.08/GGE respectively, while hybrid poplar (HP) has the highest cost at $1.52/GGE. Specific feedstock costs vary by up to $0.42 (~12% of total HOG production cost), while each of the other contributions vary by less than $0.11 (~3% of total HOG production cost). The comparatively high variation in specific feedstock cost indicates that when selecting a feedstock, total delivered cost is the most important economic consideration for HOG production since feedstock selection has minimal impact on downstream economics.

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