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Sustainable Futures Institute SFI

Understanding Sustainability of the Circular Economy Through Systems Analysis

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Overview

Comparing Linear to Circular Economy

A Systems Analysis Framework

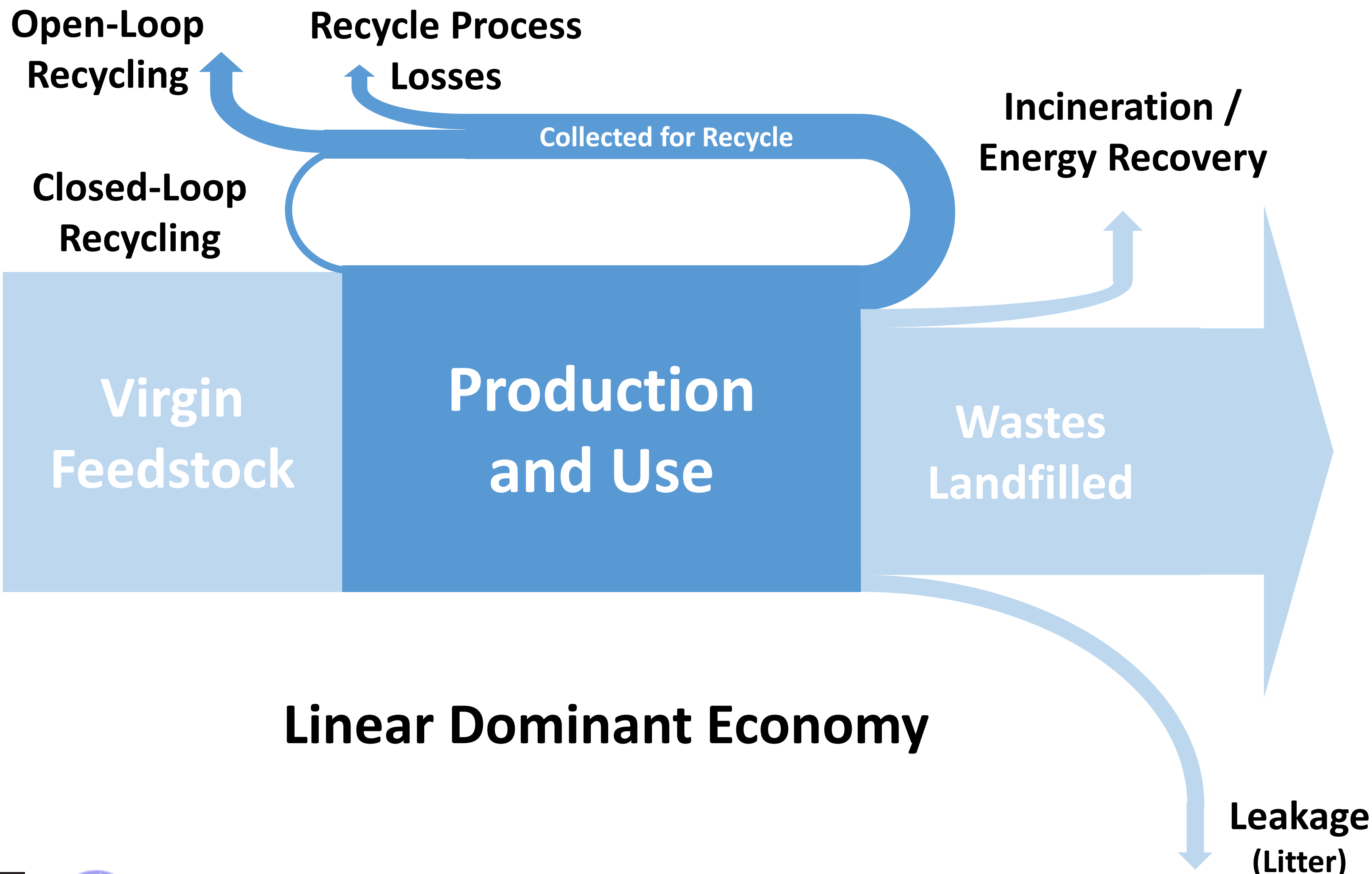
Case Studies:

Summary and Conclusions

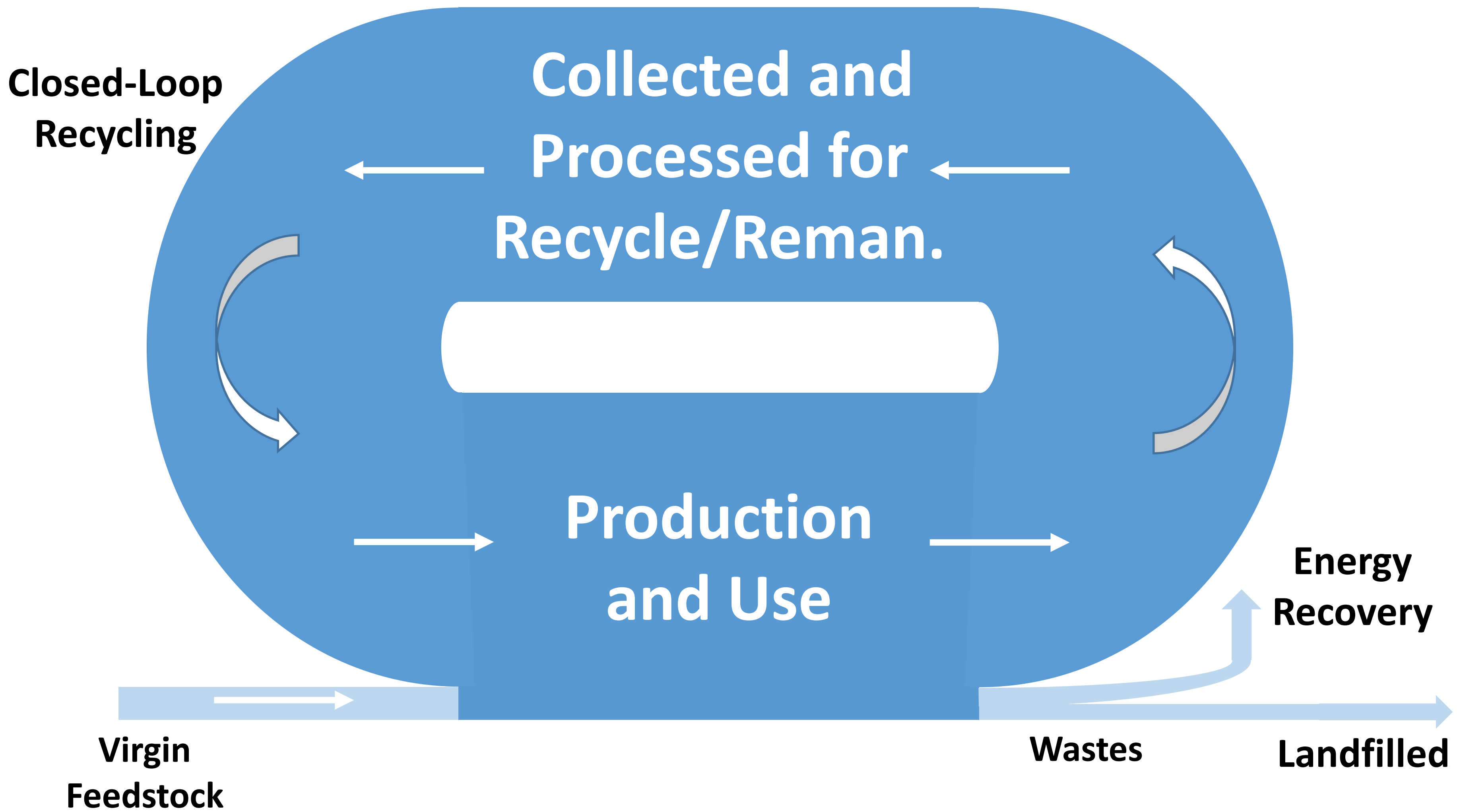
Acknowledgements

Questions

Linear Economy (Material Flow Diagram)



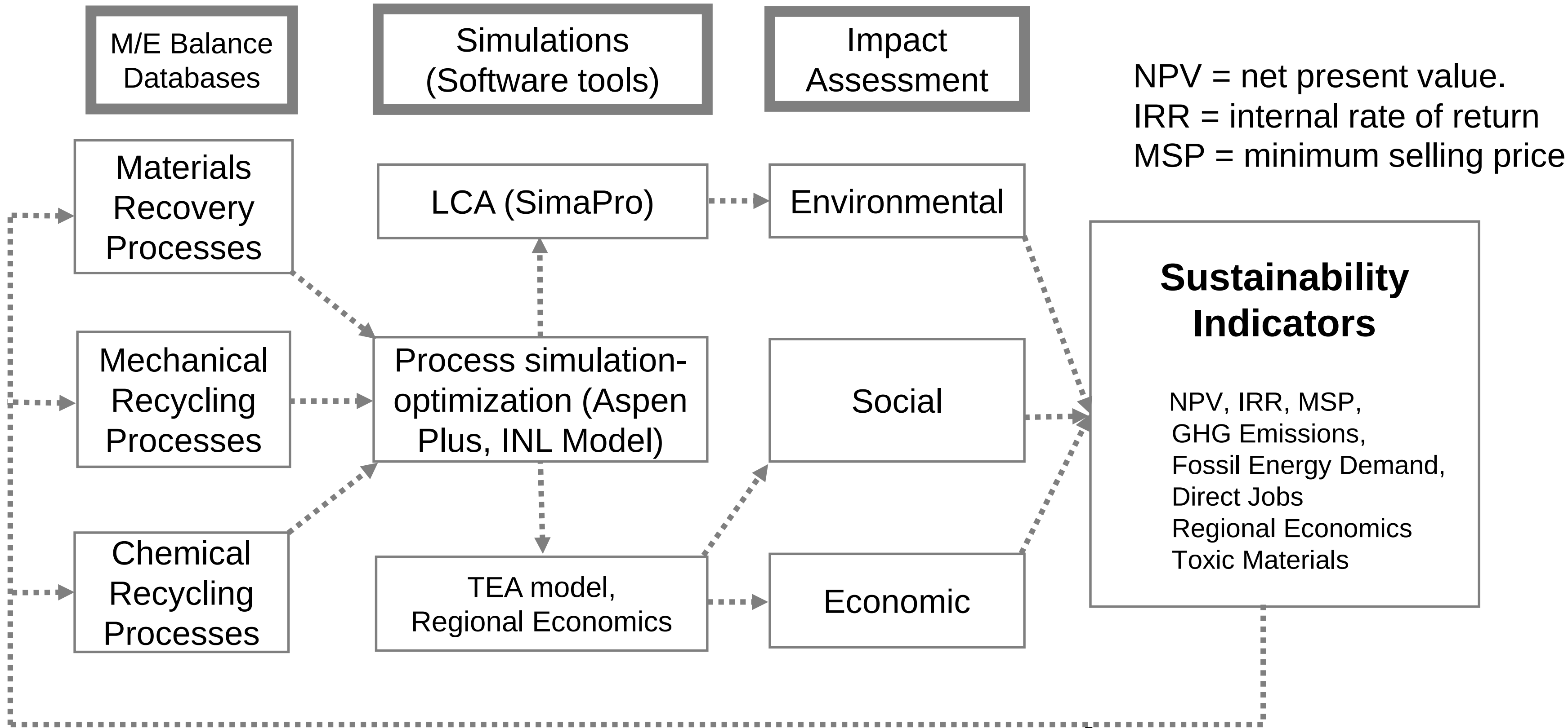
Circular Economy (Material Flow Diagram)



Circular Dominant Economy

Systems Analysis Framework and Tools

Framework



Simulation Tools

Process simulation, Life Cycle Assessment (LCA), Social LCA (SLCA), TEA, Regional Economics

Research questions,
New policies,
trigger new analyses

MI Forest Biomass Supply Chain

MI Economic Development Corporation
US Department of Energy

Re-planting
Land-use change
Maintenance
→ **Feedstock Growth / Cultivation**

Fuel
Chemicals
Equipment
→ **Feedstock Harvesting**

Fuel
Chemicals
Equipment
→ **Feedstock Transport**

Heat/Power
Chemicals
Equipment
→ **Feedstock Conversion**

Fuel
Chemicals
Equipment
→ **Product Transport**

→ **Product Use**

System Boundary

Functional Unit: one green tonne of biomass delivered to factory gate

Research Methods: Surveys of loggers and haulers

MI Forest Biomass Harvesting Results

	Greenhouse gas emissions		Fossil Energy Demand	
	$\frac{kg\ CO_2 eq}{green\ tonne}$ [a]	$\frac{kg\ CO_2 eq}{dry\ tonne}$	$\frac{MJ}{green\ tonne}$	$\frac{MJ}{dry\ tonne}$
A: Full Processor / Forwarder				
30% Cut (Selective)	14.7			
70% Cut (shelterwood)	12.3			
Clearcutting	9.9			
B: Feller-buncher / Skidder / Slasher				
30% Cut (Selective)	26.3			
70% Cut (shelterwood)	19.1			
Clearcutting	13.6			
C: Chainsaws / Skidder				
30% Cut (Selective)	24.3			
70% Cut (shelterwood)	23.3			
Clearcutting	22.0			
All 30% selective cut harvesting	20.9			
All 70% shelterwood harvesting	16.3			
All Clearcut harvesting	10.3	20.6	139.6	279.2
All harvesting activity	17.8	35.7	233.1	466.1

Best ***t***

Mid-input, high productivity

High input, high productivity

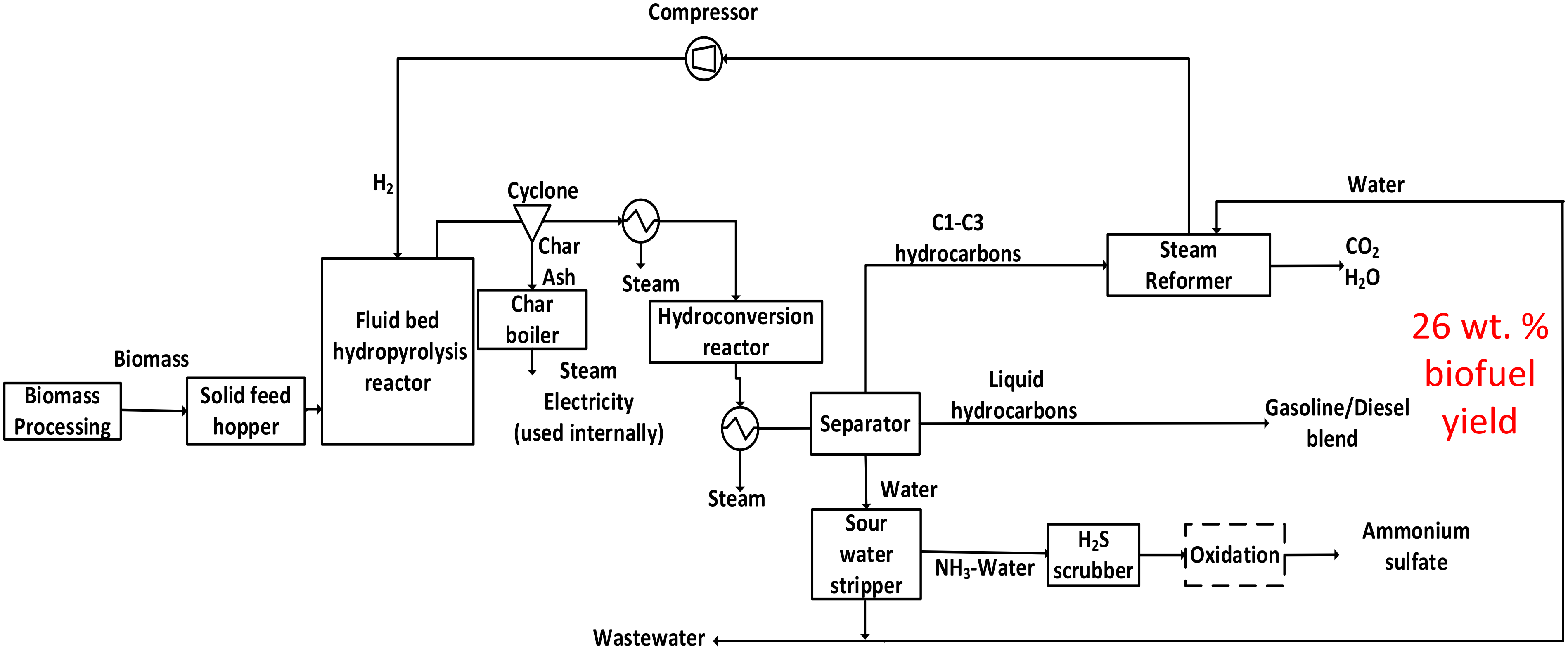
Low input, low productivity

Aggregated harvesting/forwarding

a – 'tonne' refers to metric tonne

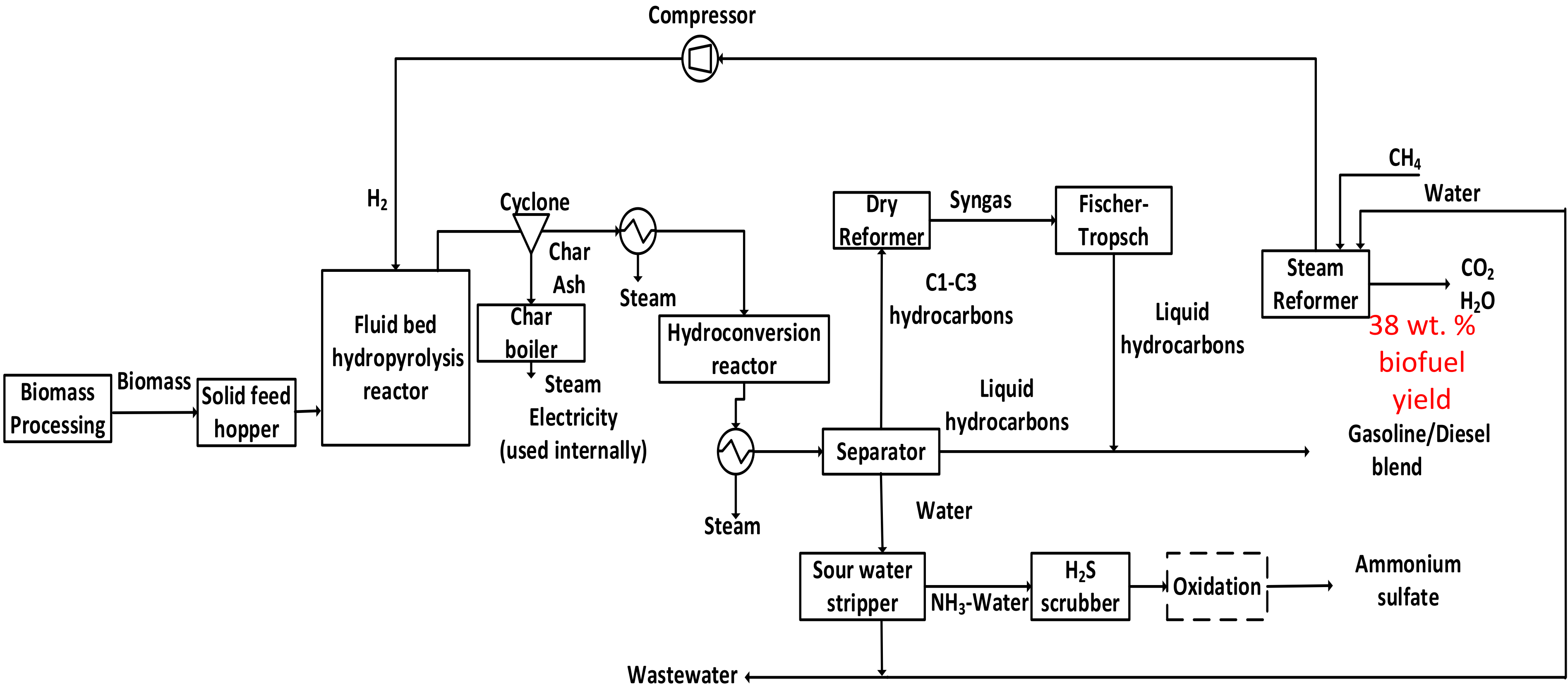
Process diagram of the IH^2® process

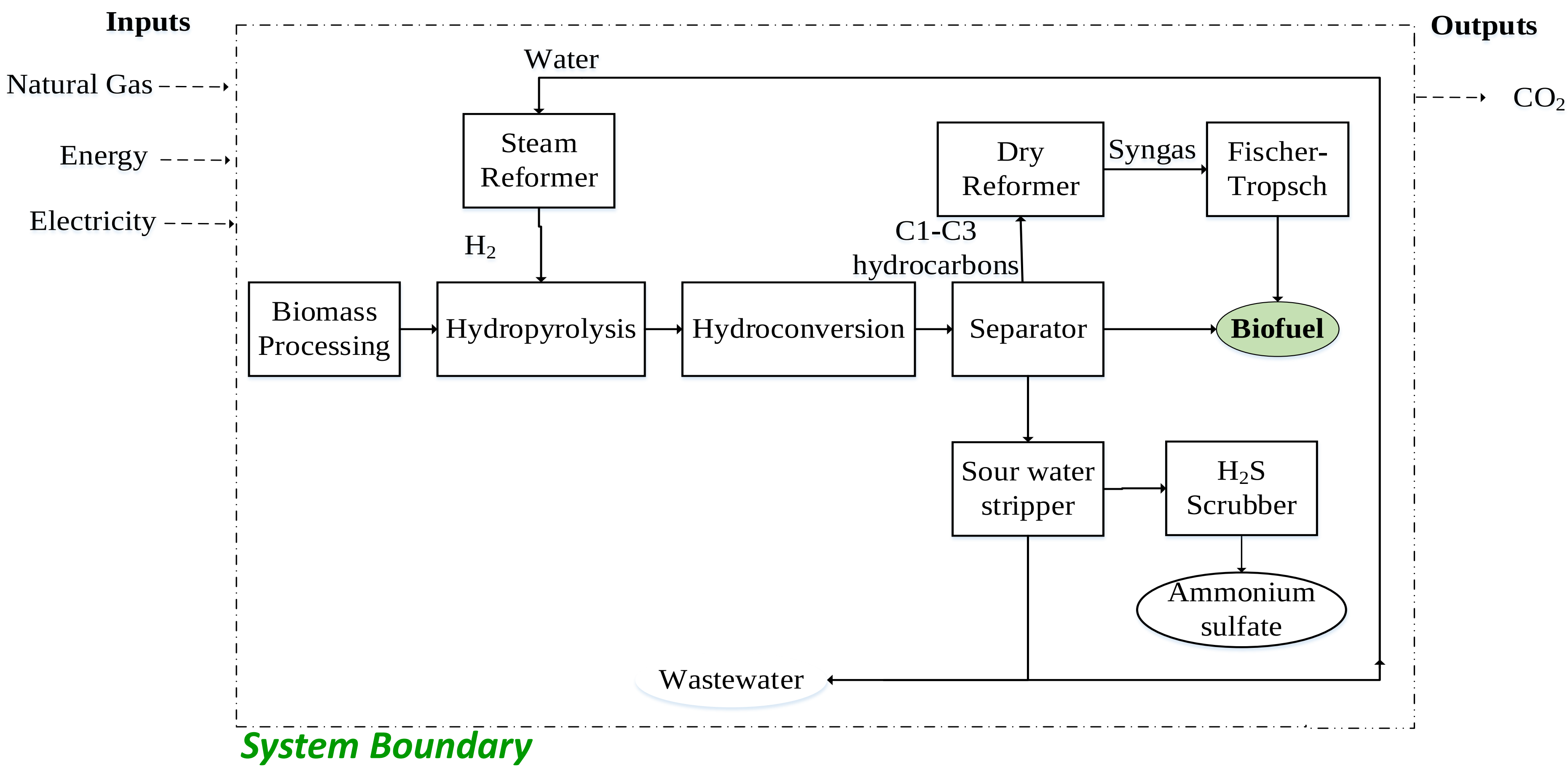
Case 1



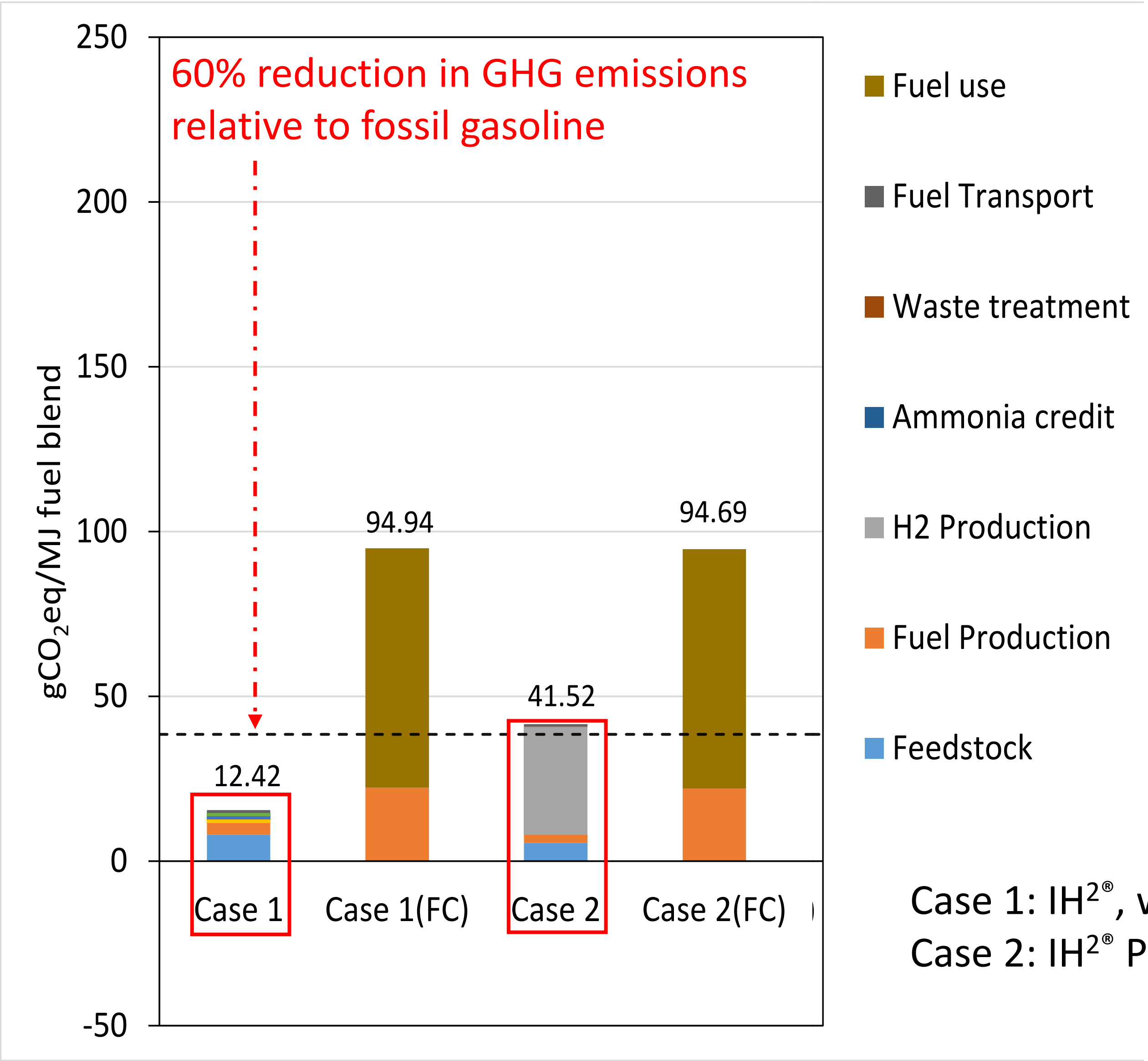
Process diagram of the IH^2® **Plus** process

Case 2




Inputs
Natural Gas
Energy
Electricity
Outputs
CO2
Water
Steam Reformer
H2
Dry Reformer
Syngas
Fischer-Tropsch
C1-C3 hydrocarbons
Biomass Processing
Hydropyrolysis
Hydroconversion
Separator
Biofuel
Sour water stripper
H2S Scrubber
Ammonium sulfate
Wastewater
System Boundary

Results – GHG emissions for IH²® vs IH²® **Plus**



Case 1: IH²®, wood residue

Case 2: IH²® Plus, woody residue

Pyrolysis-Based Hydrocarbon Biofuel Pathway

Logging Residue

Fast Pyrolysis 500-550 °C

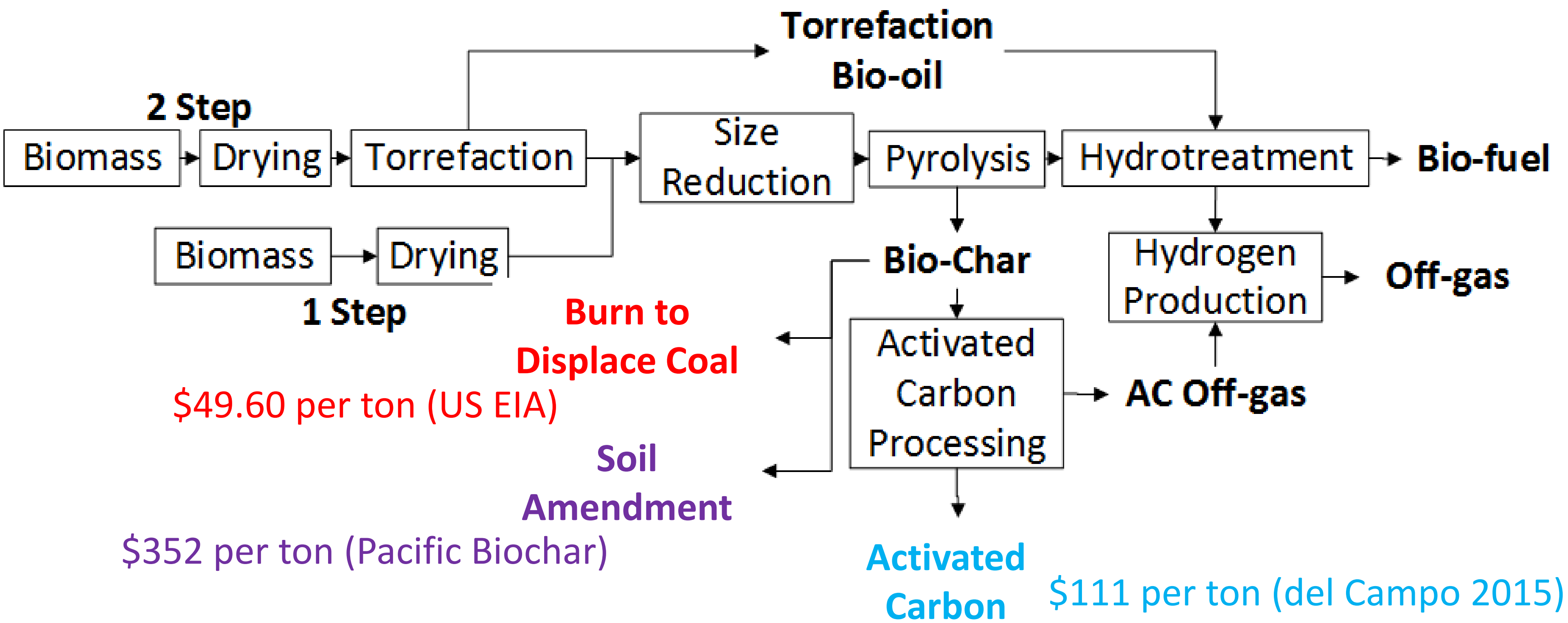
Co-product Biochar

Bio-oil

Catalytic Upgrading

Hydrocarbon Biofuel

Process Flowsheet with Three Co-Product Options

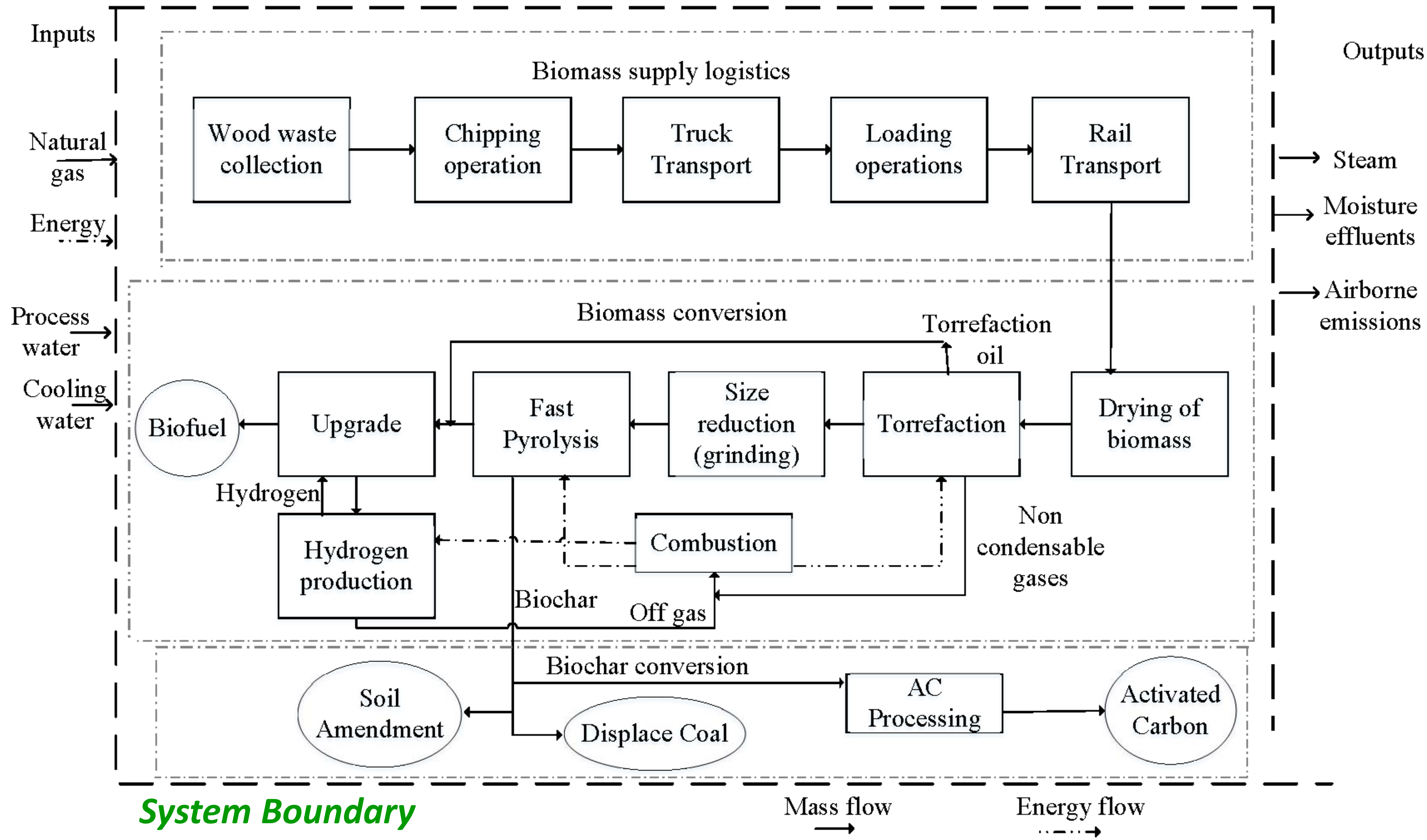


- Modeled in Aspen Plus
- Design basis of 1,000 metric tons/day of dry feed to the pyrolysis unit

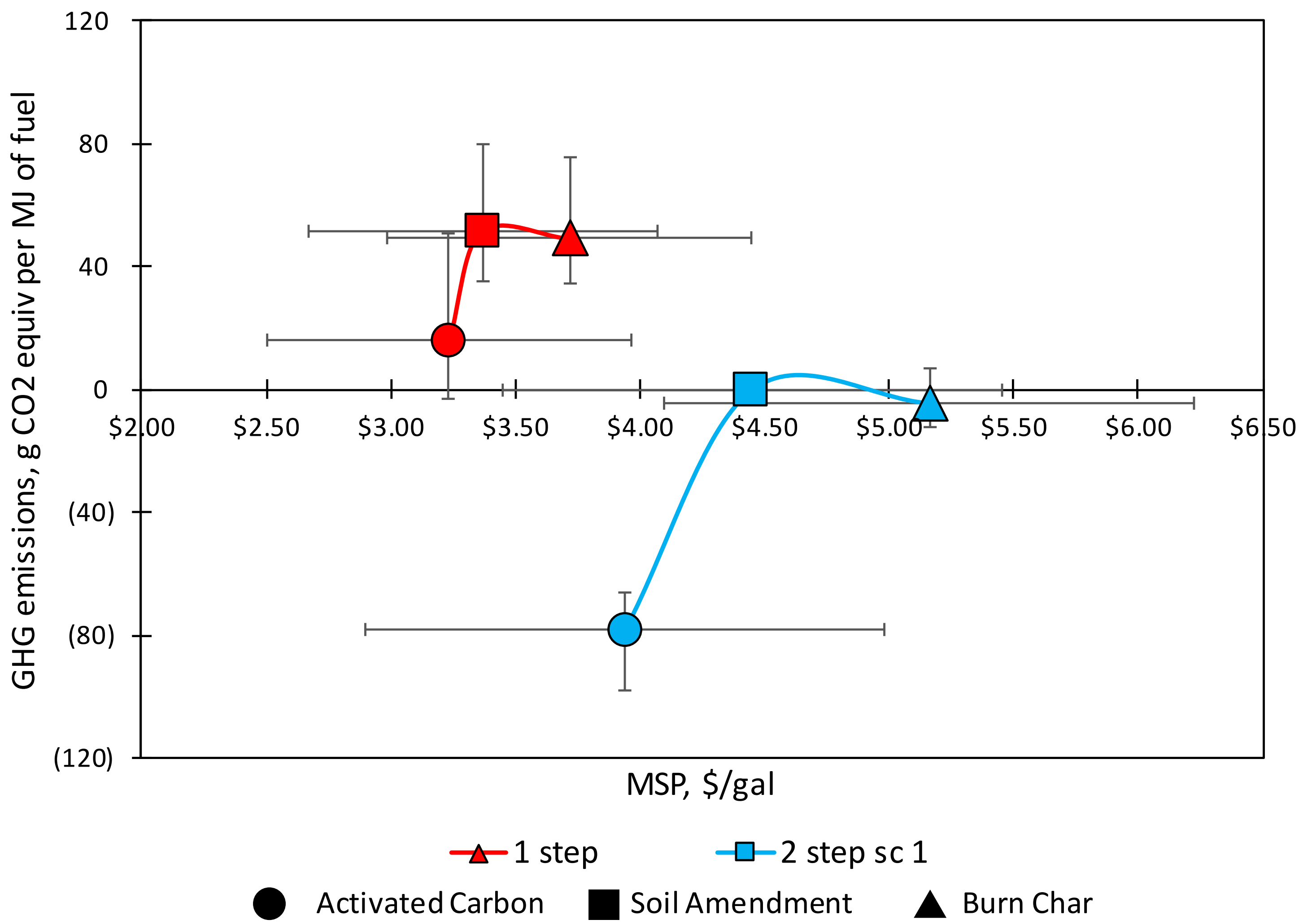
Techno-Economic Inputs to a Discounted Cash Flow Analysis

Parameters	Values	Parameters	Values
Poplar Feedstock Price (dry basis)	\$60 per dry metric ton	**Operating Days Per Year**	350 days
Project Economic Life	20 years	**Natural Gas Price**	\$5.04 per GJ
Internal Rate of Return	10%	**Electricity Price**	5.77 cents/kW-hr
Working Capital	5% of total capital investment	**Process Cooling Water Price**	\$0.16 per GJ energy removed
Depreciation Method	7-Year MACRS	**Refrigerant Price**	\$20 per GJ energy removed
Base Year	2016		

LCA System Boundary



Economic and Environmental Results



Trade-off plot showing the effect of different co-products for all heat integration scenarios with displacement allocation

Summary and Conclusions

- A systems analysis framework is useful for evaluating sustainability of a circular forest bioeconomy
- A systems analysis framework
  - Based on a set of predictive models
  - Driven by research questions and policy/process alternatives
  - Inclusive of several sustainability indicators
- Forest-based biofuels achieve large GHG savings compared to fossil fuels, but
- Minimum selling prices are higher than fossil fuels for current market conditions.

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  - Bethany Klemetsrud
  - Wen Zhou

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Thank you for your attention!

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