Comparative Life Cycle Analysis of GHG Emissions for Bio-PET Bottles

Luyi Chen, Rylie E.O. Pelton, Timothy M. Smith
NorthStar Initiative of Sustainable Enterprises | Institute on the Environment | University of Minnesota

Introduction

To provide a detailed environmental and economical profile of biorefinery systems co-producing jet-fuel (IPK, short for iso-paraffinic kerosene) and bio-chemicals, a first step has been taken to establish a separate life cycle assessment model of one promising co-product – bio-polyethylene terephthalate (bio-PET) bottles. A portion of isobutanol was deviated from the primary product system to produce paraxylene and then processed to purified terephthalic acid (PTA), one of the two precursors for PET. The other precursor, corn based ethylene glycol (EG), has been commercialized for a while. The goal of this study was to calculate and compare the life cycle Green House Gas (GHG) emissions of PET bottles produced through the traditional petrochemical pathway (crude oil refinery) and under a biorefinery context. Different biomass resources were applied to assess their environmental preference from a co-product perspective. Future studies would focus on other environmental impacts and economical values, trying to optimize the IPK refinery to a point that maximizes financial profits as well as minimizes environmental burdens.

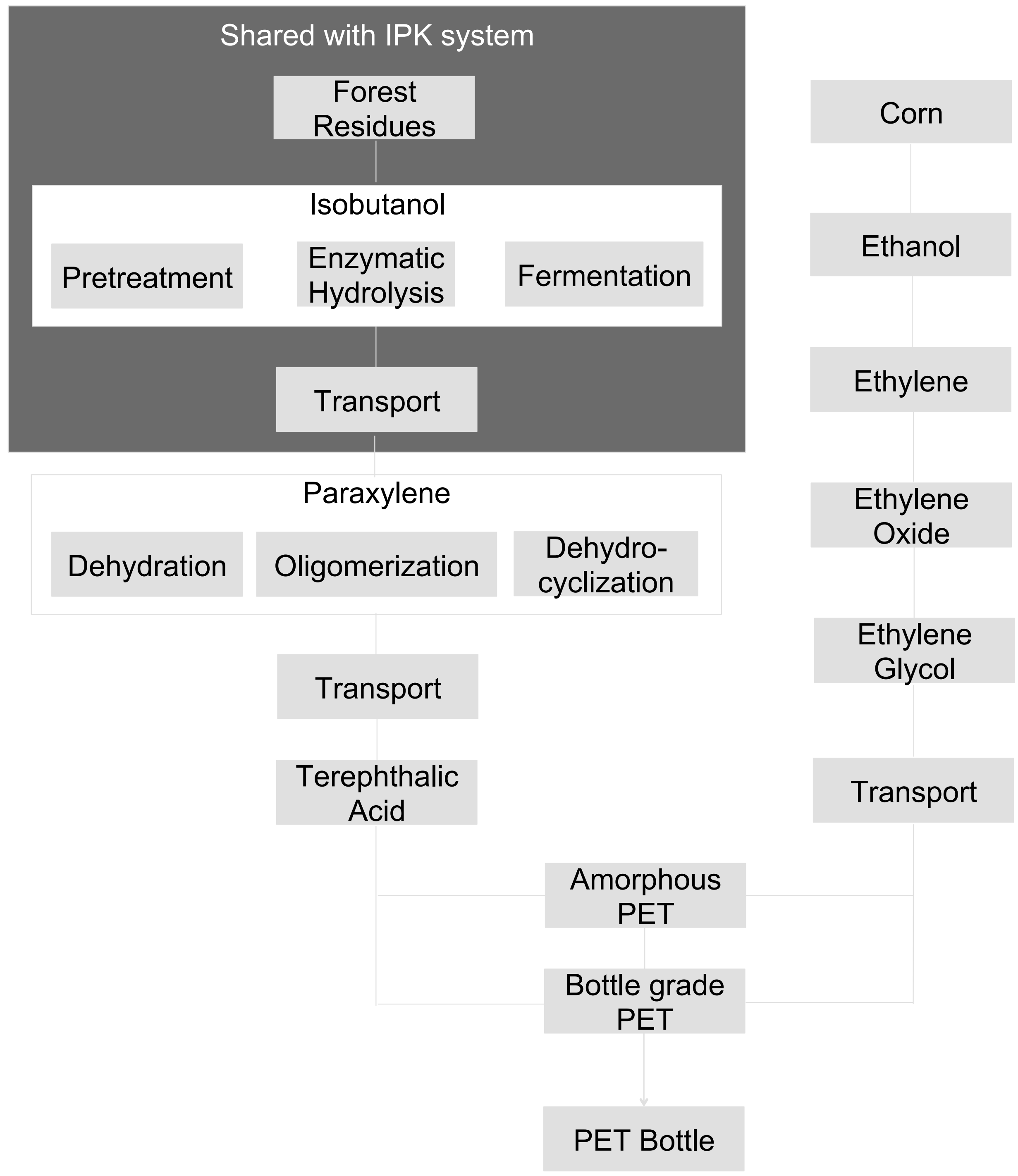
Shared with IPK system
Forest Residues
Isobutanol
Pretreatment
Enzymatic Hydrolysis
Fermentation
Transport
Paraxylene
Dehydration
Oligomerization
Dehydro-cyclization
Transport
Terephthalic Acid
Corn
Ethanol
Ethylene
Ethylene Oxide
Ethylene Glycol
Transport
Amorphous PET
Bottle grade PET
PET Bottle

FIGURE 1 – Life cycle system for wood-corn PET bottles. .

Objective

- Calculate the life cycle Green House Gas (GHG) emissions of PET bottles produced through the traditional petrochemical pathway and under a biorefinery context.
- Figure out the allocation method for primary products and co-products
- Compare GHG emissions of PET bottles under different production scenarios

Methods

- Attributional Life Cycle Assessment (LCA)
  - Conduct a “cradle to factory gate” LCA, including processes from raw material extraction, components production to product manufacturing
  - Baseline scenario and scenarios 2-3 were retrieved from GaBi 6. Scenario 1 was modeled from literature.
- Allocation of environmental impacts specified by the EPA
  - Allocate environmental impacts on mass basis for fuel co-products
  - Avoid impacts for forest biomass handling are accounted for by Ganguly et al. (Ganguly et al. 2014)
  - Replace fossil fuel with bio-energy generated by boiler within the biorefinery system

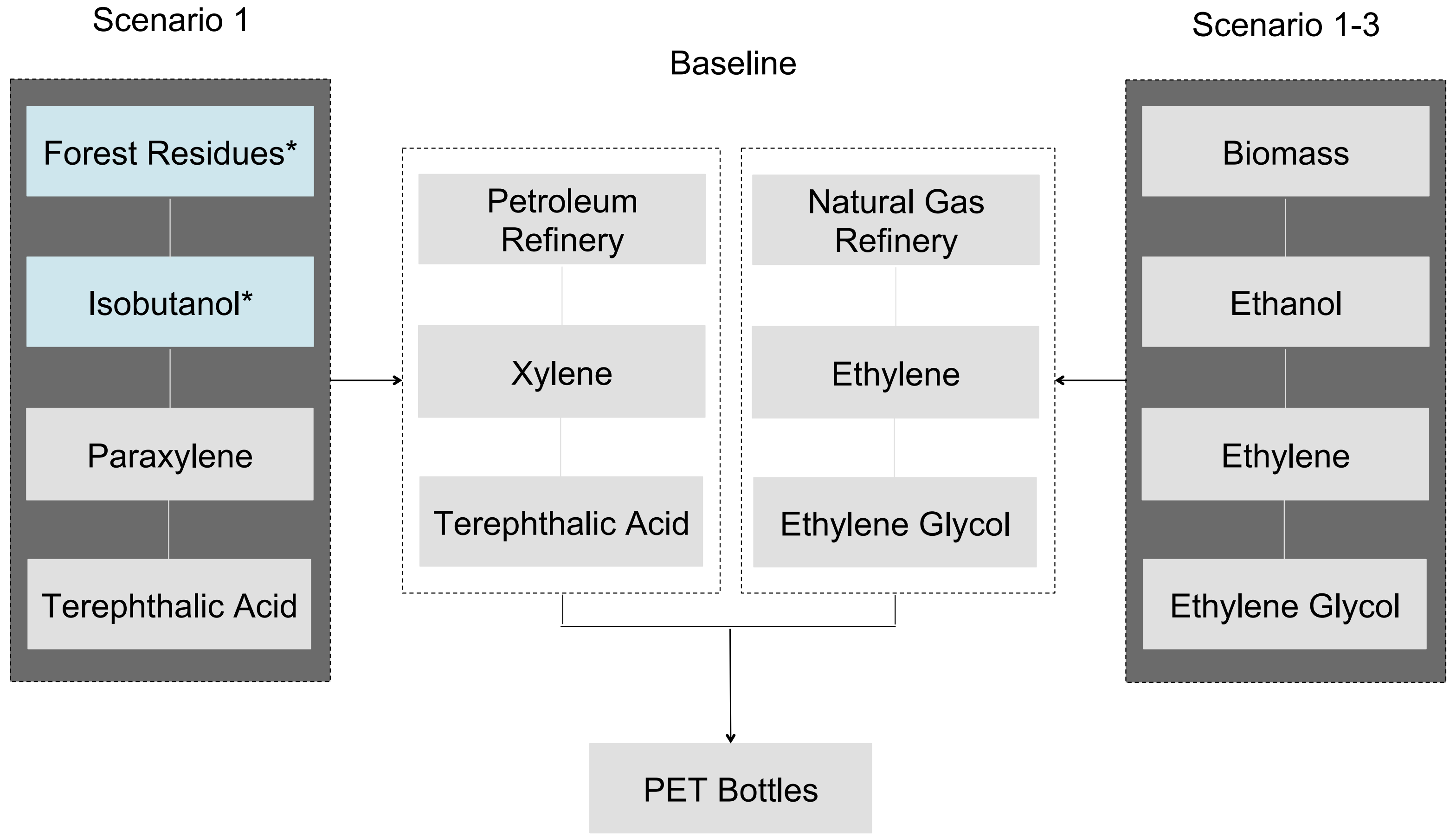
Scenario 1
Forest Residues*
Isobutanol*
Paraxylene
Terephthalic Acid
Baseline
Petroleum Refinery
Xylene
Terephthalic Acid
Natural Gas Refinery
Ethylene
Ethylene Glycol
PET Bottles
Scenario 1-3
Biomass
Ethanol
Ethylene
Ethylene Glycol

FIGURE 2 – Simplified life cycle systems for petrochemical and bio PET bottles .

* Processes marked in blue are shared with the primary product (IPK) system.

Analysis

- Baseline: PTA (crude oil) & EG (crude oil)
- Scenario 1: PTA (wood) & EG (corn grain)
- Scenario 2: PTA (crude oil) & EG (corn grain)
- Scenario 3: PTA (crude oil) & EG (wheat)

Scenario	GHG Emissions kg CO2e/kg PET	Change from Baseline	Change from Scenario 1
Baseline	4.20	0	+3%
1	4.06	-3%	0
2	3.95	-6%	-3%
3	4.11	-2%	+1%

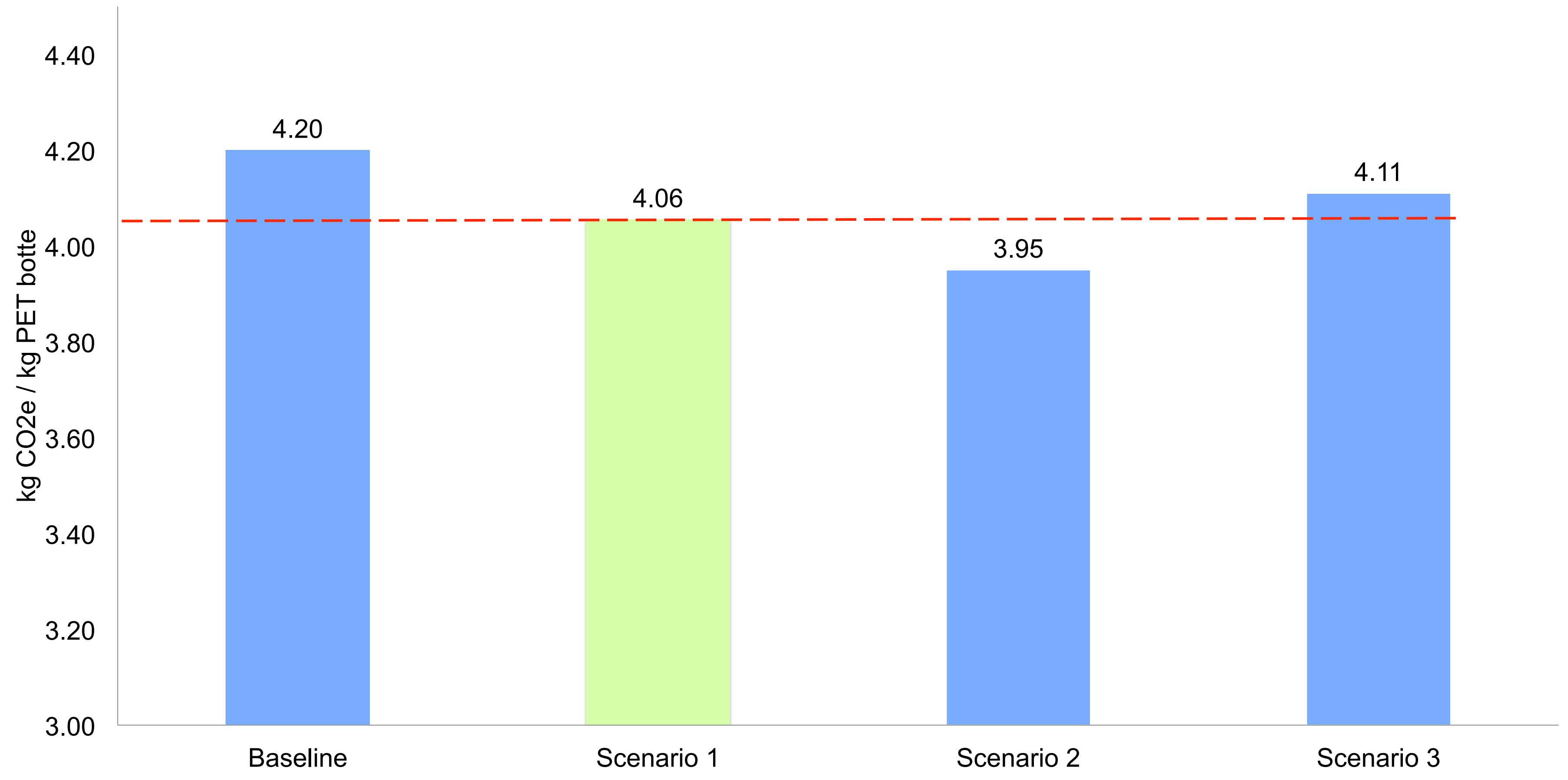

FIGURE 3 – Comparison of GHG emissions of different PET bottle production scenarios

Assumptions

Processing	Flows	Assumptions/Notes	Sources
Scenario: 100% bio-based PET Bottle - PTA (wood) & EG (corn grain)			
Forest Establishment	Fertilizer and seedlings	Input assumptions for three levels of management intensity in the PNW. (weighted average)	Calculated from Puettman et al. 2012
	Energy	Fuel consumption for PNW forest resource management processes (regeneration)	Calculated from Puettman et al. 2012
	Yield	Unit process inputs/outputs for sawing for the production of 1 m3 of rough green lumber (includes log yard activities), PNW.	Calculated from Puettman et al. 2012; Ganguly et al. 2014
Forest Logistics	Accepts, Moisture Content, Emissions	TSI-101-A; 1400,000 short tons per year. 55% Moisture content.	Calculated from Spink 2013
		Avoid impacts from slash pile burning are included.	Calculated from Ganguly et al. 2014
Pretreatment	Physical flows	TSI-102-A	Calculated from Spink 2013; ASPEN model 2014
	Energy	HP steam 0.1218 kg/hr; electricity 0.003474 kWh	Calculated from ASPEN model 2014
Enzymatic Hydrolysis	Physical flows	TSI-103-A	Calculated from Spink 2013; ASPEN model 2014
	Enzyme production	7.9 MJ steam/kg cellulase enzyme; 17 MJ electricity/kg cellulase enzyme	Dunn et al. 2012; Maclean and Spatari 2009
	Energy	MP steam 0.2266 kg/hr; electricity 0.007284 kWh	Calculated from ASPEN model 2014
Fermentation & Distillation	Emissions	Ethanol fermented from sugar cane	Ecoinvent v2.2 2010
	Yield (29.9%)	From fermenter feeds (solid) to isobutanol	Calculated from Spink 2013
Transport of IBA	Starting Point	Oregon	Spink 2013; Leu et al. 2013
	Destination	Silsbee, Texas, where the Gevo’s biorefinery plant is located	Gevo Inc. 2013
	Distance	2305 miles = 3710 km	Google Maps 2014
Biochemical conversion from IBA to PX	Yield (39.8%)	Example 16 The yield of xylenes from the reactor relative to C8 alkenes in the feed is 42% With a selectivity to p-xylene of 90%.	Peters et al. 2011
	Energy	Steam, hydrogen and natural gas are allocated by mass (IPK 84%, butane/isooctane 16%)	Demriel 2012; Calculated from Spink 2013
Transport of PX	Starting Point	Silsbee, Texas	Gevo Inc. 2013
	Destination	Coca-Cola Bottling Co. CONSOLIDATED (Charlotte, NC; Mobile, AL; Nashville, TN; Roanoke, WV)	Coca-Cola Bottling Co. Consolidated 2010
	Distance	1271 km (average distance for four destinations)	Calculated from Google Maps 2014
Paraxylene oxidation	Ethylene Glycol	Purchased from other suppliers. Produced from US corn grain.	ICIS Chemical Business 2012 Ecoinvent v2.2 2010; Tabone et al. 2010
	Energy and other physical flows	Purified terephthalic acid, at plant	Ecoinvent v2.2 2010

Table 1– Part of assumptions for Scenario 1 (Deviating 16% of isobutanol to produce bio-PET bottle)

Conclusions

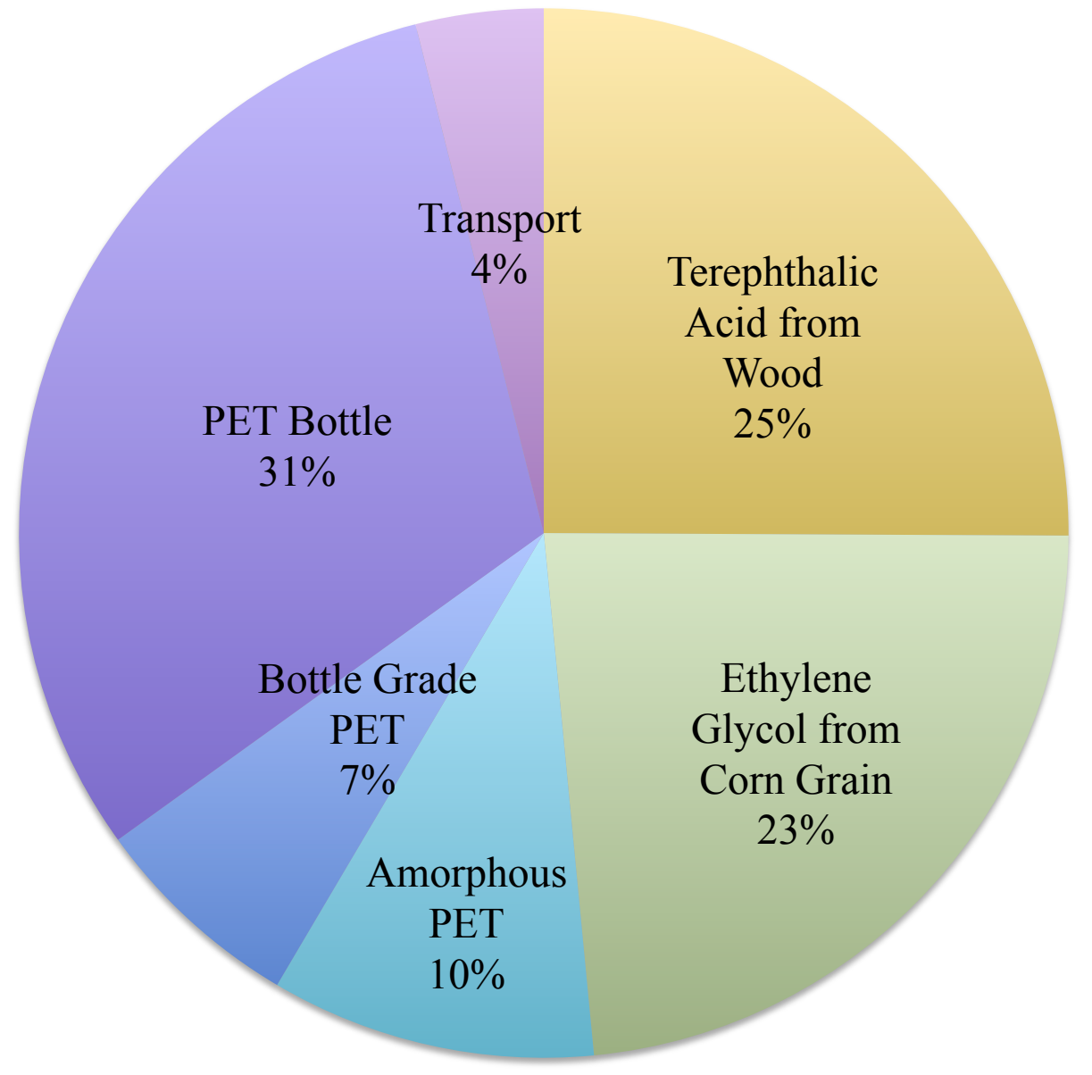

FIGURE 4 –GHG emissions break down of Scenario 1 (co-produced PET from IPK refinery)

Replacing traditional PET bottles with woody-biomass based bio-PET bottle creates a 3% carbon credit. It also has lower GHG emissions comparing to wheat based PET bottles. However, looking at a single precursor only, generating purified terephthalic acid (PTA) from woody biomass results in a 3% emission debt comparing to petrochemical PTA processing (Scenario 1 and Scenario 3). The process of Injection blow molding (forming PET bottles from bottle grade PET sheets) are most responsible for impacts. Future work will focus on modifying the model and evaluate economical profile of co-producing PET bottle and IPK.

NARA
Northwest Advanced Renewables Alliance

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