Model Differences and Variability
CRC E-102

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2013 CRC Life Cycle Analysis of Transportation Fuels Workshop

October 16, 2013

Introduction

- The goal of CRC Project E-102 was to better quantify sources of **uncertainty** and **variability** in selected LCA models that are being used to regulate fuels.
- Conducted an in-depth **evaluation of model inputs**, and the uncertainties around those inputs for several **specific fuel pathways**.
- Assessed the **pathway variability** and overall **model uncertainty** for the different pathways.

The Models

- **BioGrace**, used in the European Union (EU) Renewable Energy Directive (RED) program.
- The US Environmental Protection Agency (EPA) modelling framework for **RFS2**. The EPA used a series of models to determine the **direct and indirect** emissions of renewable fuels and petroleum fuels.
- The **GREET** model and the variant of the model used in California for the California LCFS program.
- **GHGenius**, used in the British Columbia LCFS program and the Alberta RFS program.

Model Summary

	BioGrace	EPA RFS2	GREET	GHGenius
Developed for Regulatory Use	Yes	Yes	No	No
IPCC GWP	2001 (2007)	1995	2007	User Choice
Type	Attributional	Consequential	Attributional	Attributional
Type	Process Chain	Partial Equilibrium	Process Chain	Process Chain
Heating Values	Lower	Lower	User Choice, LHV default	User Choice, HHV default
Geography	Europe	United States	United States	Canada/US/ Mexico/India
Co-product Allocation	Energy	Displacement	User Choice	User Choice
Data	Typical plus 40%	Expected Incremental	Average	Average
Year	Not stated, present	2022	User Choice (1990-2020)	User Choice (1995-2050)
Includes fuel combustion	No	Yes	Yes	Yes

The Pathways

- The CRC focus was on six pathways (and eight fuels). They are:
  - Petroleum - gasoline/diesel
  - Corn ethanol
  - Soy biodiesel/renewable diesel
  - Sugarcane ethanol
  - Cellulosic ethanol
  - Natural gas

Model-Pathway Matrix

	BioGrace	EPA RFS2	GREET	GHGenius
Petroleum	No	Yes	Yes	Yes
Corn Ethanol	Yes	Yes	Yes	Yes
Sugar cane Ethanol	Yes	Yes	Yes	Yes
Cellulosic Ethanol	No	Yes	Yes	Yes
Soybean Biodiesel/RD	Yes (BD only)	Yes (RD only generally)	Yes	Yes
Natural Gas	No	No	Yes	Yes

Introduction

- Each of the pathways in each of the models have been analyzed and the results for each model are presented with a **common format**.
- All results are on a **lower heating value basis**.
- The **native GWPs** are used.
  - 2007 for GREET, CA-GREET, and GHGenius, 2001 for BioGrace, and 1995 for EPA RFS2.
- GHGenius is set to **US**, to provide more comparable comparison.
- GREET and GHGenius set to **2012**.
- Most of the **drivers of the differences** in the models have been **identified**.

Gasoline

	JECv3c	RFS2	GREET		GHGenius
			2012_rev2	CA-GREET	
IPCC GWP	2001	2007	2007	2007	2007
	g CO_2eq/MJ (LHV)				
Crude Oil Extraction	5.2	3.2	2.38	11.39	7.94
Crude Oil VFF	0.0	3.6	2.42	inc	2.45
Crude Oil Transport	0.9	1.36	2.97	inc	2.04
Refining	7.0	9.24	10.80	13.72	12.18
Refined Products Distribution	1.0	1.03	0.56	0.36	1.37
Sub-total	14.2	18.55	19.12	26.27	25.99
Vehicle Use	75.2	72.43	73.61	72.91	68.96
Total	88.1	90.98	92.73	99.18	94.95

Gasoline

- The **detail** in which the crude oil extraction emissions are calculated **varies significantly**, from a single expert opinion to detailed values calculated by field.
  - In general as the level of **detail increases so do the emissions**.
- The **methane destruction rate** in associated gas flares **varies** from 5% to less than 0.1%.
- **JEC uses a marginal approach** for crude production and refining.
- Only GHGenius includes non-combustion emissions from the refinery.
- Some difference in method of allocating the refinery emissions.

Natural Gas

	JEC	RFS2	GREET		GHGenius
			2012_rev2	CA GREET	
	g CO_2/MJ				
NG Production	3.8	4.9	11.0	3.5	9.6
NG Processing	-	-	3.6	3.7	2.9
NG Transportation	7.5	-	4.4	0.97	7.5
NG Use	56.4	55.6	57.6	57.7	57.0
Lifecycle	67.7	60.5	76.6	62.4	77.0

Natural Gas

- Biggest difference is the **methane emission leakage rate** during the production stage.
- RFS2 information is from GREET 1.8c and is thus similar to CA GREET.
- New GREET and GHGenius use the same data source (with some minor exceptions). This source (EPA) now has updated emissions.
- **CARB compression** and **liquefaction** energy is quite **different**.

Corn Ethanol

	BioGrace	RFS2	GREET		GHGenius
			2012_rev2	CA-GREET	
IPCC GWP	2001	1995	2007	2007	2007
Allocation	Energy	Displacement			
	g CO_2eq/MJ (LHV)				
Feedstock Production	36.78	15.63	31.92	35.85	37.22
Feedstock Transport	0.51	2.83	2.21	2.22	1.62
Ethanol Production	86.01	30.7	33.74	38.30	38.26
Co-product (power)	-46.73	-	0.00	0.00	0.00
Co-Product (DDG)	-34.75	-	-14.16	-11.51	-18.87
Ethanol Distribution	1.54	1.18	1.52	2.70	1.61
Fuel Use	-	0.83	-	-	2.22
Total	43.4	51.21	55.22	67.56	62.06

No indirect land use change emissions included.

Corn Ethanol

- **BioGrace plant is quite different**, all steam and large co-gen.
- BioGrace use less fertilizer but more emission intensive fertilizer.
- There is a difference in **N_2O emission factors**
  - CARB, 1.0%; GREET, 1.2%; GHGenius, 1.5%.
- Farming emissions in new GREET have been updated compared to CA GREET. Same data sources, more recent data.
- Differences in **allocation** methods.
- Difference in **how many process chemicals** are included. (EPA and CA GREET, none; GREET, yeast and enzymes; GHGenius, yeast, enzymes, NaOH, Sulphuric acid, ammonia.).

Sugarcane Ethanol

	BioGrace	RFS2	GREET		GHGenius
			2012_rev2	CA-GREET	
IPCC GWP	2001	1995	2007	2007	2007
Allocation		Energy	Displacement		
	g CO_2eq/MJ (LHV)				
Feedstock Production	14.11	36.27	22.30	19.0	28.93
Feedstock Transport	0.84	1.69	2.31	2.0	2.31
Ethanol Production	0.85	2.27	2.76	2.1	5.81
Co-product (power)	0.0	-13.29	-1.63	0.0	-4.26
Ethanol Distribution	8.16	2.71	9.09	3.5	11.04
Total	23.97	31.04	34.83	26.6	43.83

No indirect land use change emissions included.

Sugarcane Ethanol

- Difference in **field emissions**.
  - BioGrace and CA GREET (for mechanical harvest).
  - **N_2O** emission rate.
    - GREET is now less than 1%, even though the reference used for the value would suggest much higher.
- BioGrace excludes methane and N_2O from bagasse combustion.
- GHGenius includes lime use at the ethanol plant and some methane emissions from vinasse distribution.
- RFS2 and CA GREET use old GREET assumption about pipelines and trains for **distribution in Brazil** rather than trucks. Also use an emission factor for a crude oil supertanker rather than a small chemical tanker.
- Type of **power displaced** varies from marginal to average, as does the quantity of power produced.

Cellulosic Ethanol

	RFS2	GREET		GHGenius
		2012_rev2	CA-GREET	
IPCC GWP	1995	2007	2007	2007
Feedstock	Stover	Stover	Wood	Stover
	g CO_2eq/MJ (LHV)			
Feedstock Production	0.34	10.32	4.44	10.52
Feedstock Transport	1.11	1.05	2.10	2.48
Ethanol Production	2.66	8.19	2.56	33.14
Co-Product (Power)	-33.60	-17.11	-10.2	-15.84
Ethanol Distribution and storage	1.18	1.52	2.70	2.25
Total	-28.32	3.97	1.60	32.55

No indirect land use change emissions included.

Cellulosic Ethanol

- Very large difference in the results.
- **EPA RFS2** has a **soil carbon credit** for the initial year but no other year.
  - They also have a **very large power credit** due to very aggressive rates of improvement in the technology.
  - They don't consider any **process chemicals**.
- GREET includes yeast and enzymes but no other chemicals.
- GHGenius includes most chemicals. Latest NREL design used 0.5 kg chemicals for every kg of ethanol produced.

Soybean Biodiesel

	BioGrace	RFS2	GREET		GHGenius
			2012_rev2	CA-GREET	
IPCC GWP	2001	1995	2007	2007	2007
Allocation	Energy	Displacement	Energy	Mass/energy	Displacement
	$g\ CO_2eq/MJ$ (LHV)				
Feedstock Production	56.21	-16.78	8.39	5.42	61.65
Feedstock Transport	35.95	2.52	1.19	0.50	2.20
Oilseed Crushing	17.24	-	22.74	20.53	19.21
Biodiesel Production	12.50	17.83	7.48	5.47	14.80
Co-products meal	-72.89	-	-13.55	-15.33	-46.53
Co-products glycerine	-0.58	-5.35	-4.45	-0.27	-17.69
Biodiesel Distribution	1.26	0.76	0.71	0.75	1.15
Total	49.69	-1.03	22.50	17.06	34.80

No indirect land use change emissions included.

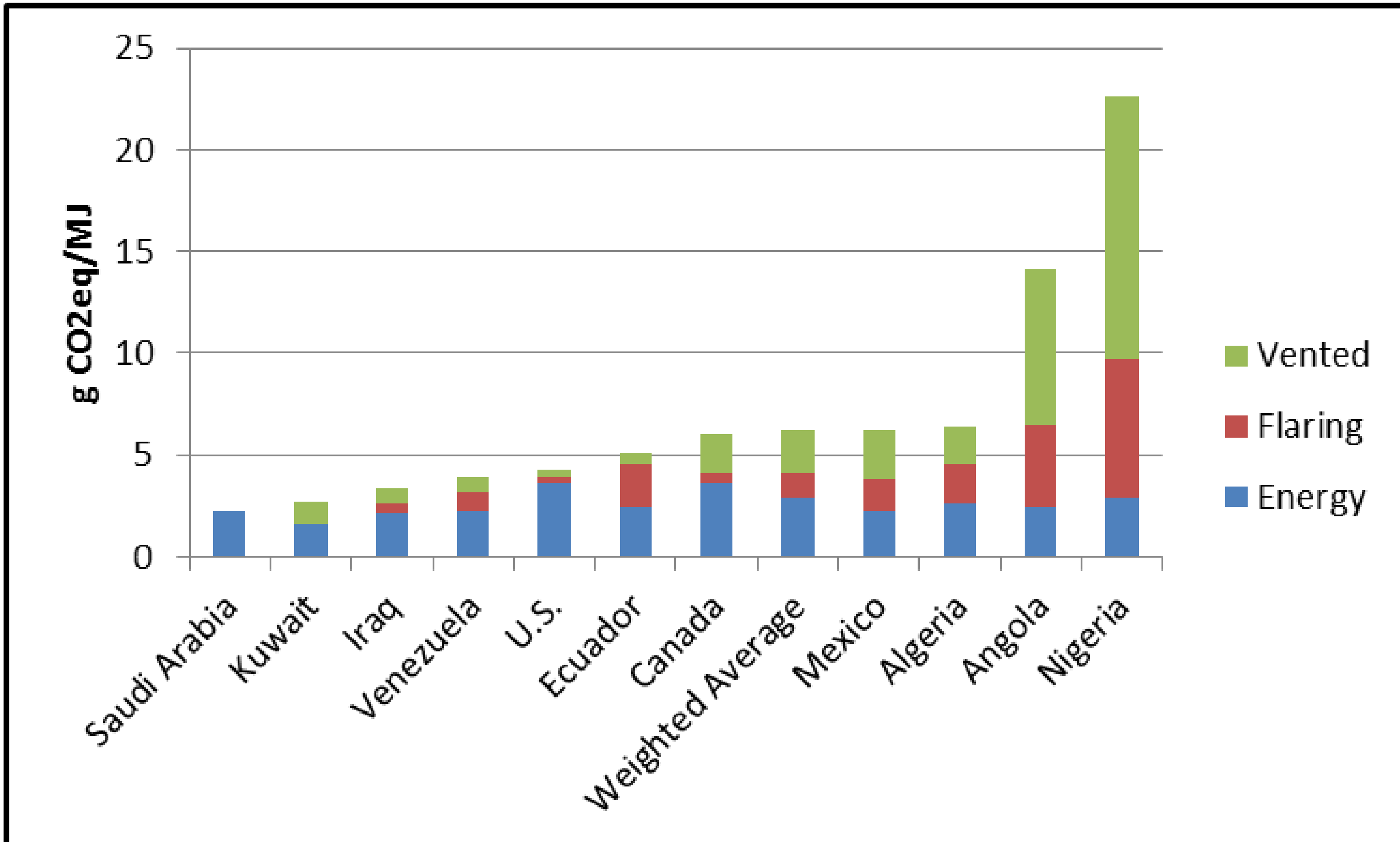
Soybean Biodiesel

- BioGrace **ships soybeans** from Brazil to Europe for processing. Leading to very high transportation emissions.
- GREET has very low **N_2O emissions**.
- RFS2 emissions are quite different. Not all of the inputs are transparent. The meal effectively accrues all of the emissions for growing and crushing soybeans.

Drivers of Differences

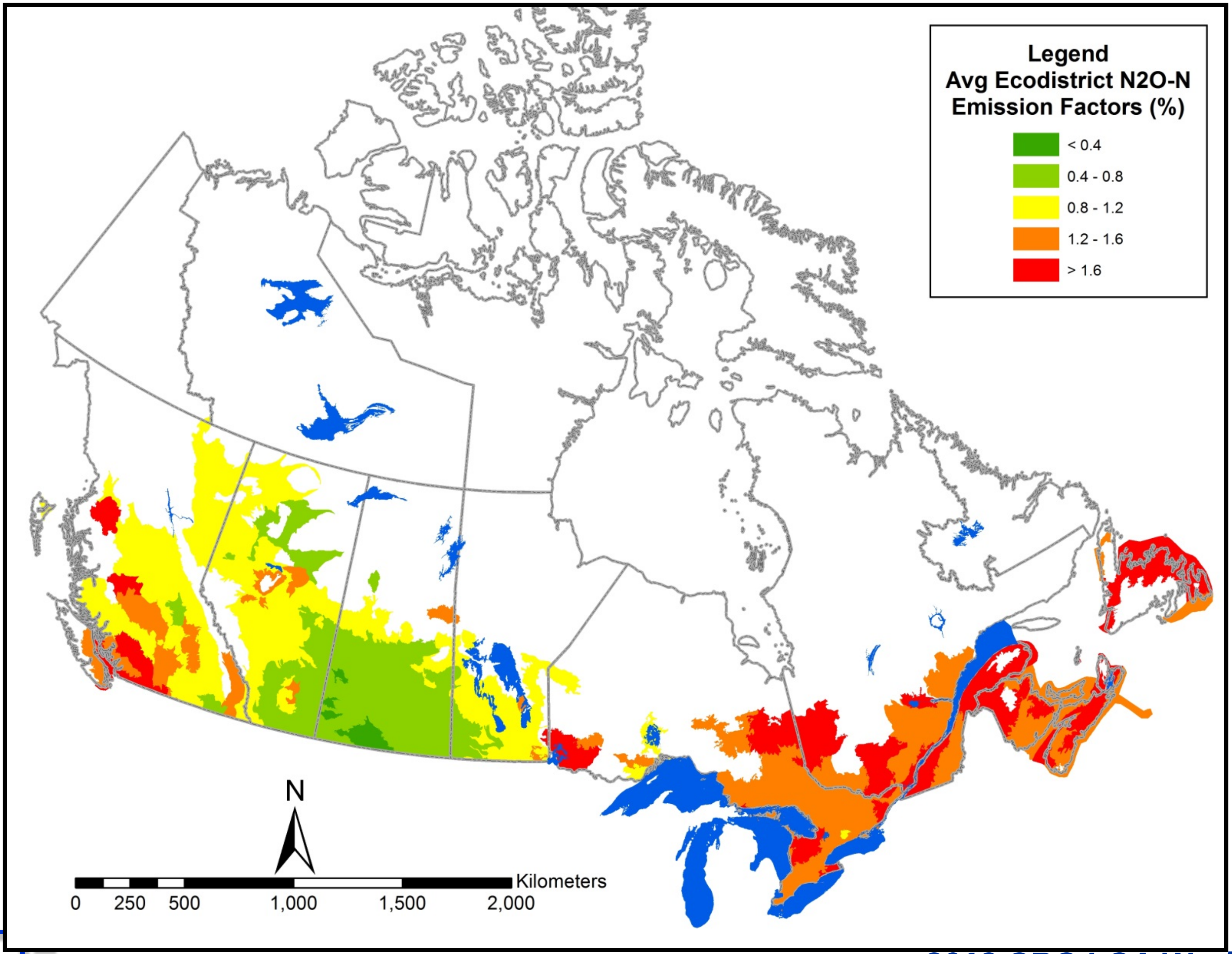
- Spatial variation
- Temporal variation
- System boundary variation
- Assumptions used to fill in data gaps
- Allocation approaches
- Some process differences
- Some errors and omissions

Spatial Variation

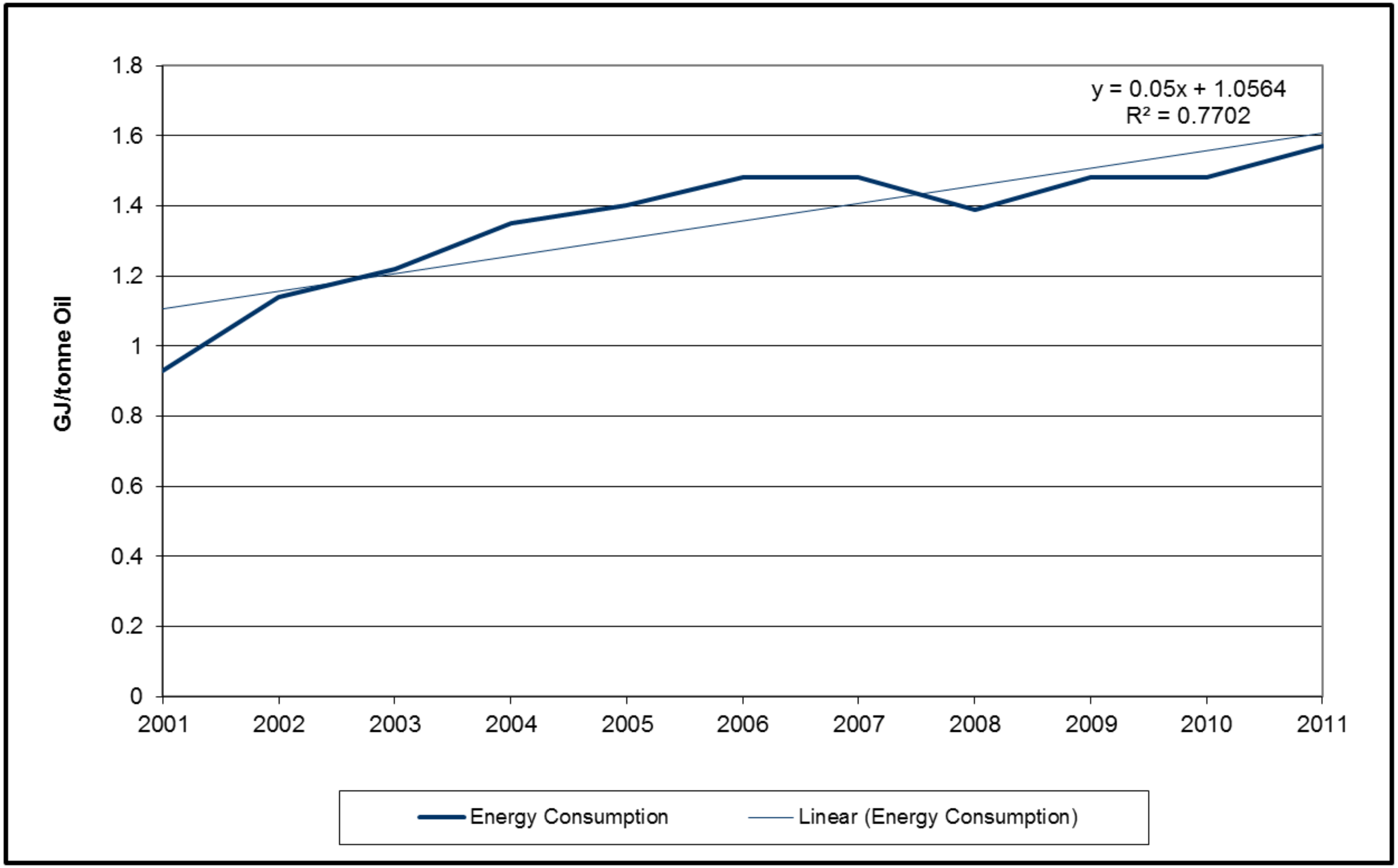


NETL Crude Oil Production

Spatial Variation – N_2O Emissions



Temporal Variation

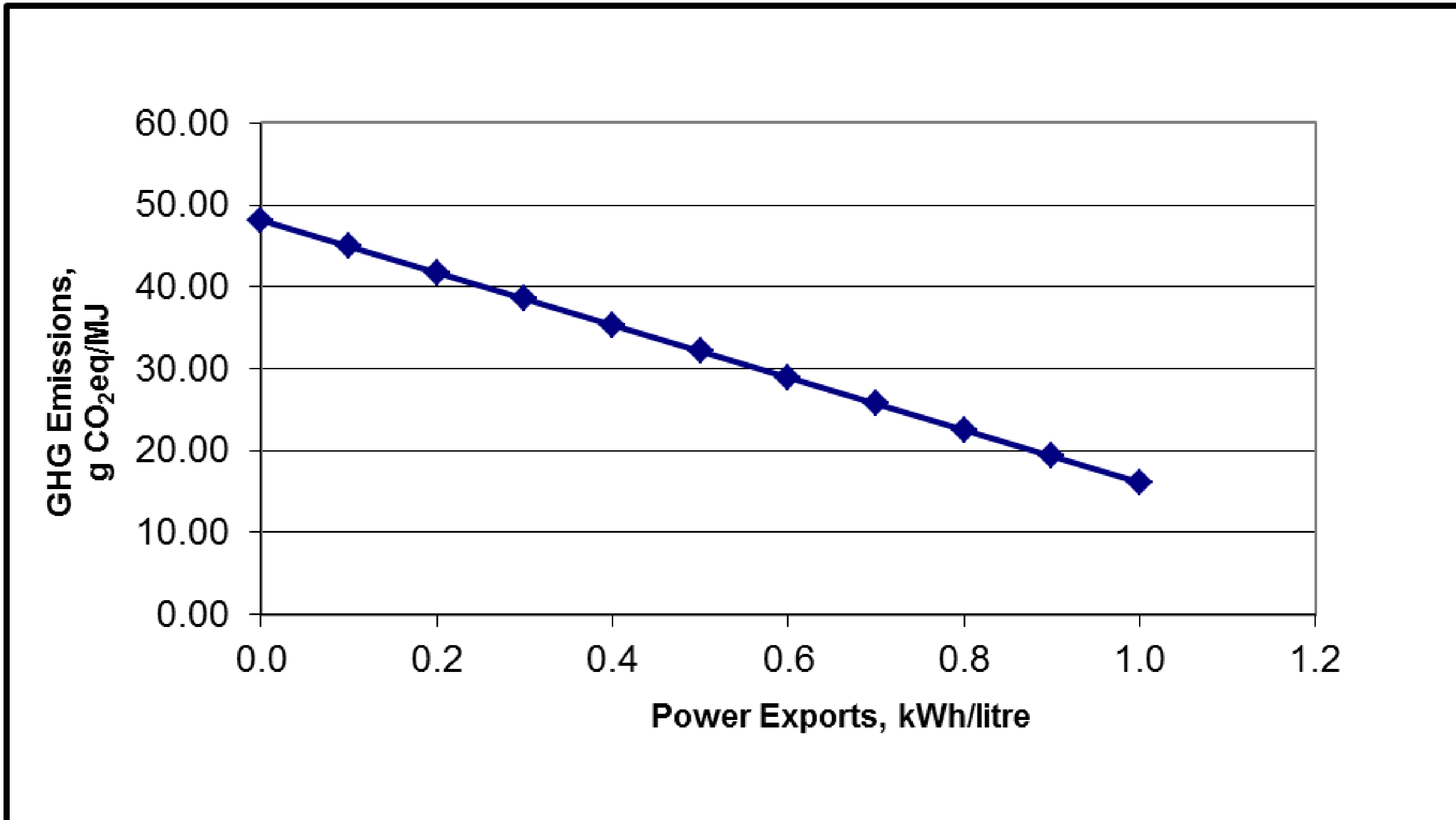


OGP Crude Oil Production Energy

System Boundary

- Cellulosic Ethanol Example
  - Process chemicals included or not?
  - Cut off approaches used in one pathway are not necessarily appropriate for another pathway.

Data Assumptions

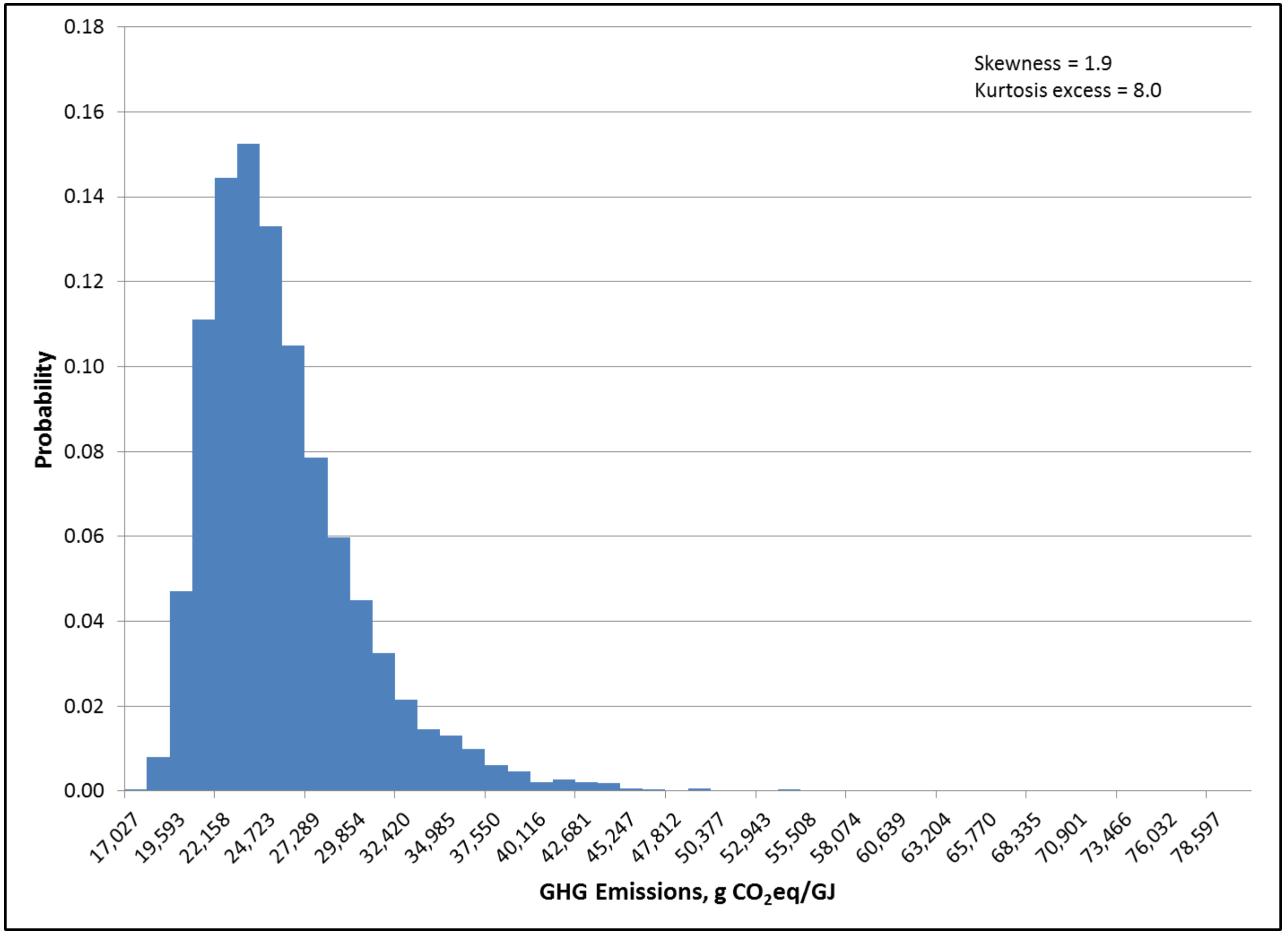


Sugar Cane Ethanol

Allocation

Overall	Process Level Allocation/ Displacement			
Meal	Displacement	Energy	Market	Mass
Glycerine	Displacement	Energy	Energy	Energy
	g CO_2eq/MJ (LHV)			
Feedstock Production	20.76	8.07	8.79	4.00
Feedstock Transport	2.96	1.15	1.25	0.57
Oilseed Crushing	22.74	22.74	22.74	22.74
Biodiesel Production	7.48	7.48	7.48	7.48
Co-Product meal	-22.41	-13.49	-12.73	-17.79
Co-Product glycerine	-34.75	-0.71	-0.71	-0.71
Biodiesel Distribution and storage	0.71	0.71	0.71	0.71
Total	-2.51	25.93	27.52	16.98

Gasoline Uncertainty



Excludes vehicle use stage

Summary

- There is **significant variability** between the models studied.
- The **drivers of the variability are real**, with a couple of exceptions they are not model “errors”.
- In some cases, the modellers have chosen **different approaches**,
  - **Average vs. marginal**
  - **Allocation**
- There are **real spatial variation** issues.
- There are **real temporal issues**.
- Data quality issues,
  - **Primary vs. secondary data**
  - **Data assumptions**.

Thank You