Biofuel Energy Metrics

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Presentation Overview

- Gathering metrics
  - Why are metrics important?
  - High variability of metrics
  - Identifying key assumptions
- Case study: Biodiesel from soybeans
  - Energy balance
    - Comparison to one corn EtOH study
  - Huge amounts of variability
- How to proceed
  - Track assumptions
  - One metric will be insufficient
    - Create a model?

Why are metrics important?

- To evaluate cost and benefits of different technologies
- Allow for comparative evaluation of potential solutions
  - Identify areas that need improvement
- Create a framework for policy decisions

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Biofuel metrics today

- No widely accepted framework for analyzing energy solutions
- Many credible different groups present radically different data
  - Each uses different assumptions
  - Different input data
  - Different system boundaries
- Ideal metrics will be transparent
  - Show effects of assumptions and values
  - Assess sensitivity to varied values on overall outcomes

Problem: Wide variety of values

Table 1—Energy input assumptions of corn-ethanol studies

Study/year	Corn yield	Nitrogen fertilizer application rate	Nitrogen fertilizer production	Corn ethanol conversion rate	Ethanol conversion process	Total[1] energy use	Coproducts[1] energy credits	Net[1] energy value
	Bu/acre	*lb/acre*	*Btu/lb*	*gal/bu*	*Btu/gal*	*Btu/gal*	*Btu/gal*	*Btu/gal*
Pimentel (1991)	110	136	37,551	2.50	73,687	131,017 (LHV)	21,500	-33,517
Pimentel (2001)	127	129	33,547	2.50	75,118	131,062 (LHV)	21,500	-33,562
Keeney and DeLuca (1992)	119	135	37,958	2.56	48,470	91,196 (LHV)	8,078	-8,438
Marland and Turhollow (1990)	119	127	31,135	2.50	50,105	73,934 (HHV)	8,127	18,154
Lorenz and Morris (1995)	120	123	27,605	2.55	53,956	81,090 (HHV)	27,579	30,589
Ho (1989)	90	NR	NR	NR	57,000	90,000 (LHV)	10,500	-4,000
Wang et al. (1999)	125	131	21,092	2.55	40,850	68,450 (LHV)	14,950	22,500
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NR: Not reported
LHV: Low heat value = 76,000 Btu per gallon of ethanol. Keeney and DeLuca used 74,680 Btu per gallon of ethanol.
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[1] The midpoint or average is used when studies report a range of values.

Shapouri et al. 2002

Case study: Biodiesel from Soybeans Energy Balance LCA

Soybean Biodiesel

- Neat numbers are available for a Net Energy Value (NEV)

Energy input for Btu/gal of Biodiesel*

Growth	Transport (to facility)	Crushing	Conversion	Transport (to market)
4,533	729	3,903	15,929	1,026

*Pradhan et al. 2009 Soon to be published
Study updates 1998 "Life Cycle Inventory of Biodiesel" study by DOE and USDA

- Lets explore how these numbers are obtained

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Growth

Feedstock Production

- Data available from USDA sources
  - Economic Research Service (ERS)
  - Agricultural Resource Management Survey (ARMS)
  - National Agricultural Statistics Service (NASS)

- Specifically:
  - Energy data from ARMS
  - State yield and fertilizer data from NASS
  - Herbicide, insecticide application data from NASS Agricultural Chemical Survey
  - Lime application rates from ERS
  - Seed application rates from ARMS

Agricultural Inputs

Growth

State		AR	IL	IN	IA	KS	KY	LA	MD	MI	MN	MS	MO	NE	NC	ND	OH	SD	TN	VA	WI	Weighte Average
Input																						
Seed	lbs/ac	59.4	69.9	71.7	63.6	59.5	66.1	54.4	67.4	77.4	67.3	51.4	68.6	67.9	54.1	72.3	84.2	65.1	56.9	84.9	79.7	67.9
Fertilizer																						
Nitrogen	bs/ac	1.76	3.55	3.00	0.89	4.44	7.44	0.13	5.51	11.9	2.24	2.57	2.34	4.91	10.6	16.5	2.97	7.65	12.5	7.5	5.97	4.26
Phosphorus	lbs/ac	19.6	13.6	11.7	4.64	10.4	23.5	6.96	5.92	15.6	4.75	11.0	12.5	17.0	18.4	18.9	13.2	24.0	26.9	15.2	12.3	12.65
Potash	lbs/ac	22.4	40.1	47.6	15.7	2.15	36.1	9.49	14.3	58.1	5.43	17.9	31.3	3.11	37.8	1.24	58.2	5.74	42.0	38.3	35.5	25.52
Direct Energy																						
Gasoline	gal/ac	1.3	0.90	1.60	1.10	1.10	1.40	1.10	2.10	1.50	1.10	1.20	1.40	1.30	1.50	1.40	1.30	1.40	1.30	1.20	2.40	1.26
Diesel	gal/ac	9.90	2.50	2.30	3.40	2.90	2.10	6.50	2.90	4.00	4.00	4.30	4.30	12.9	2.40	3.20	2.00	2.80	2.20	1.90	5.20	4.06
LP	gal/ac	NR	0.00	NR	0.00	1.80	NR	NR	NR	NR	NR	NR	NR	4.40	NR	NR	NR	0.00	NR	NR	0.00	0.73
Electricity	kWh/ac	11.2	NR	1.30	0.00	9.10	4.50	NR	0.80	NR	NR	3.80	NR	39.4	0.60	0.80	0.00	NR	1.00	NR	NR	6.62
Natural Gas	Cf/ac	NR	0.00	NR	0.00	349	0.00	NR	0.00	0.00	0.00	0.00	0.00	586	0.00	0.00	0.00	0.00	0.00	0.00	0.00	58.41
Chemicals																						
Herbicides	lbs/ac	1.00	1.23	1.35	1.26	1.07	1.15	1.60	1.54	1.22	0.98	1.66	1.17	1.28	1.00	1.26	1.34	1.20	1.29	1.23	0.81	1.21
Insecticides	lbs/ac	0.04	0.00	0.00	0.01	0.00	0.00	0.60	0.34	0.00	0.00	0.02	0.00	0.01	0.07	0.00	0.00	0.02	0.00	0.05	0.00	0.02
Lime	lbs/ac	53.7	595	668.8	286.4	146.7	865.6	70.7	NA	323.3	181.8	120	818.5	123.9	652.9	NR	394.6	NR	828.3	769.7	379.3	357.96
Yield	Bu/ac	33.5	43.0	41.5	48.0	23.0	33.0	32.0	23.0	38.5	43.5	32.0	34.0	38.5	24.0	33.0	32.0	31.0	31.0	23.0	44.0	38.0

Source: USDA Economic Research Service; USDA National Agricultural Statistics Service, 2002; and USDA Agricultural Resouce Management Survey.

*Weighted by area harvested in each state.

NA: Not available

NR: Not reported in that State due to small sample size.

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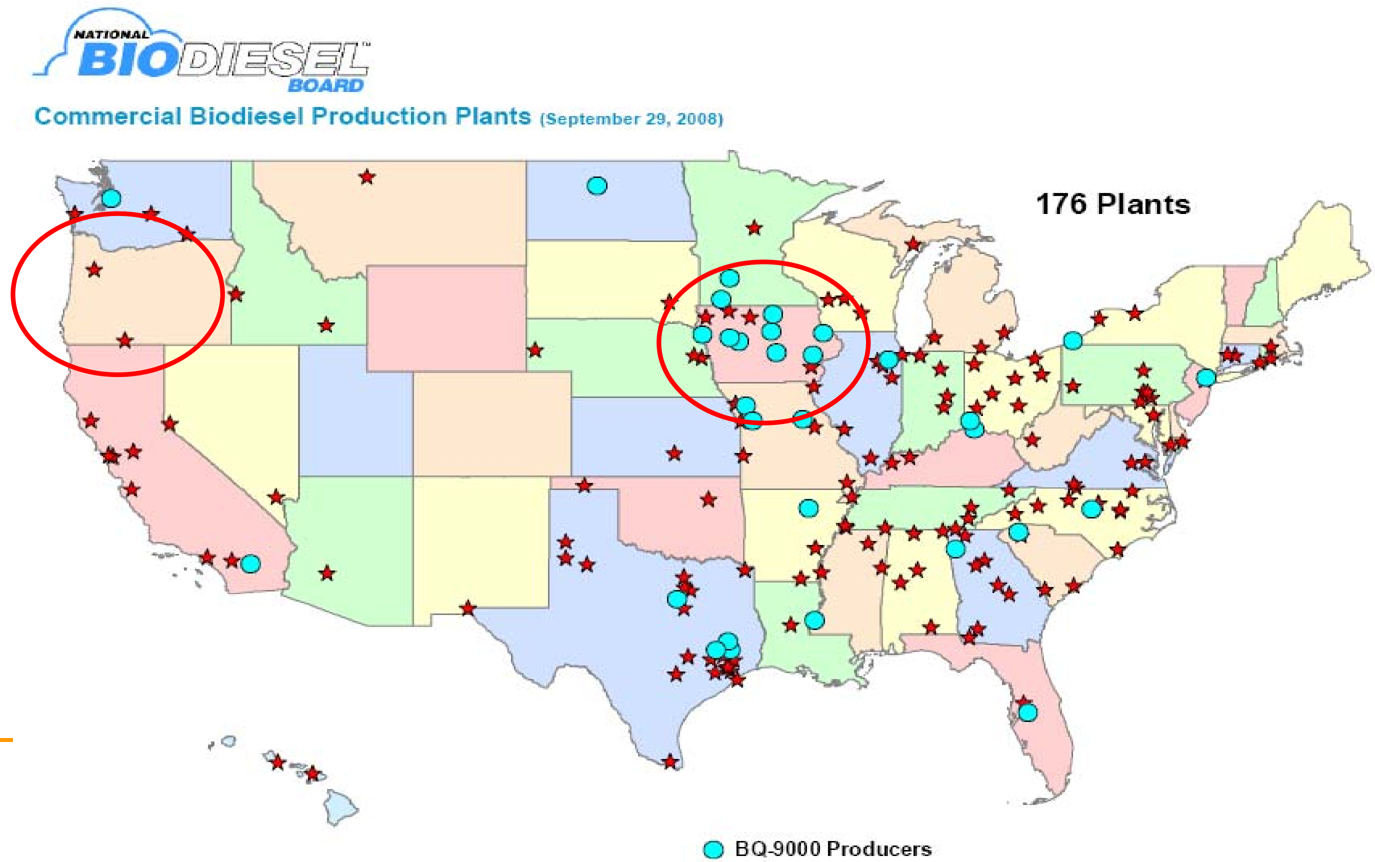
Agricultural Inputs

- Key points:
  - High Yield variation
    - From 23 Bu/Ac in VA, KS and MD up to 44 Bu/Ac in WI
  - Energy balance is significantly affected by crop productivity
  - All values converted to Btu using Lower Heating Values (LHV)
- Key assumption:
  - Energy generation comes from combination of coal, natural gas, nuclear, hydroelectric at proportion of **national average of 70%**
    - Removes energy from non-fossil/renewable sources (30%)
      - Energy usage depends on geographic area

Electrical use assumption

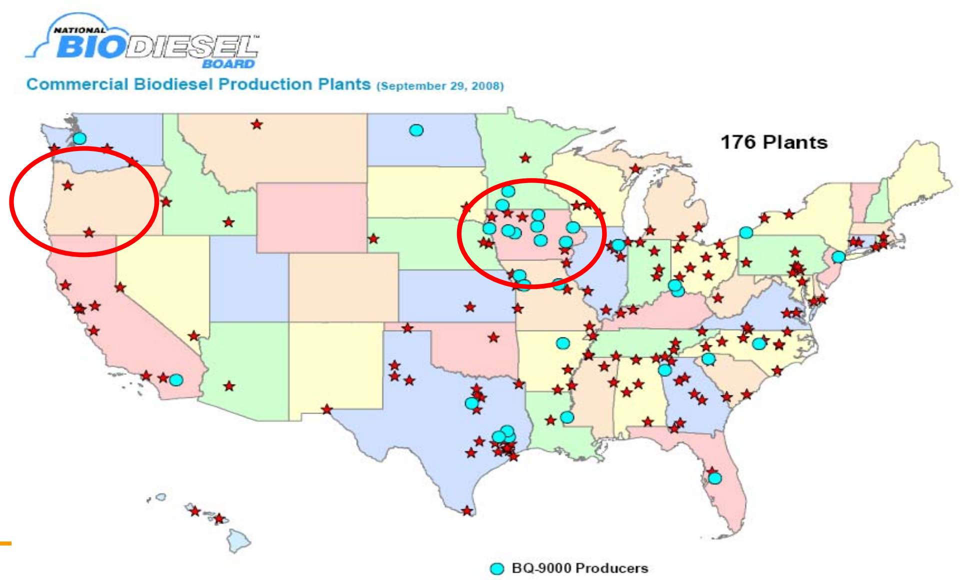
- Is the national energy proportion of **national average of 70% fair?**
  - According to Biodiesel Board there are:
    - 13 Biodiesel plants in Iowa
    - 2 in Oregon



Electrical Use Assumption

- Iowa has **81%** of energy from fossil fuel sources
- Oregon has **30%** of energy from fossil fuel sources
  - According to 2007 DOE EIA report

- **70% assumption distorts values**
  - **Carries over throughout life cycle (not just in growth)**



Growth Data

- Energy used for:
  - Planting
  - Land preparation
  - Plowing
  - Fertilizer and pesticide application
  - Irrigation
  - Harvesting
  - Drying

  Are included in total farm fuels and efficiency estimates

Inputs*	20 States Weighted Average	
	Btu/bu	Btu/gal
Seeds	3,491	2,343
Fertilizer:		
Nitrogen	2,483	1,667
Phosphorus	1,314	882
Potassium	1,723	1,157
Direct Energy:		
Diesel	16,280	10,928
Gasoline	4,782	3,210
LP gas	1,817	1,220
Electricity**	1,288	865
Natural Gas	1,607	1,079
Ag. Chemical Application:		
Herbicide	4,371	2,934
Insecticide	55	37
Lime	506	340
Total Fossil Energy for Agriculture	39,717	26,662

*Inputs are adjusted by energy efficiency factors.

**Assumes 70 percent of electricity generated from fossil sources.

Transport (to facility)

Transport (to facility)

- Energy for transporting estimated using GREET model (Argonne National Laboratory
  - This is a widely used model for predicting transportation energy use
  - Assumes **50 miles** of trucking soybeans from a distribution center to a crusher/biodiesel plant
  - Assumes that crusher and conversion facility are combined
    - Many times not the case
  - Comes to 6,393 Btu/Bushel

Crushing

Crushing

- Key Assumptions
  - Average 70% energy costs again
  - Uses a modern design of plant – not a real plant
    - Uses a model from USDA ARS of a joint soybean crushing and biodiesel plant
      - Produces 9.8 million gallons of biodiesel
      - 151,515 tons of soybean meal
      - 9,000 tons of soybean hulls
      - 4,380 tons of crude glycerin
    - According to study: "actual industry data for soybean crushing and biodiesel production was unavailable"

Crushing energy used

Inputs	Equivalent* Energy (Btu/gal)	Source
Soybean crushing:		
Electricity**	5,933	ARS
NG/Steam	15,460	ARS
Hexane	1,567	Huo et al.
Total fossil energy for crushing	22,960	

* Inputs are adjusted by energy efficiency factors.

**Assumes 70 percent of electricity generated from fossil sources, which is adjusted for generation and line losses.

Conversion

Conversion

- Key assumptions
  - Only examines one process:
    - React oil with methanol and sodium hydroxide
    - Centrifuge
    - Wash with water acid solution
    - Dry
- This may be valid as it appears that most plants use this process as well

Conversion energy use

Inputs	Equivalent* Energy (Btu/gal)	Source
Biodiesel conversion:		
Electricity	951	ARS
NG/Steam	6,286	ARS
Methanol	10,626	Huo et al.
Sodium Methoxide	1,396	Huo et al.
Sodium Hydroxide	26	Huo et al.
Hydrochloric Acid	42	Huo et al.
Total fossil energy for conversion	19,327	

* Inputs are adjusted by energy efficiency factors.

**Assumes 70 percent of electricity generated from fossil sources, which is adjusted for generation and line losses.

Transport (to market)

Transport (to market)

- GREET model
  - Assumes distances for truck, barge and rail
    - 32 miles truck
    - 42 miles barge
    - 232 miles rail
    - 30 miles by truck for distribution

    - Predicts 1,026 Btu per gallon of biodiesel transported

Energy Use Allocation

- Distorts final results...
  - Removes >50% of energy from LCA inventory
  - Key assumption – is it valid?

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Energy Coproduct values

- Soybean meal and crude glycerin are excluded from energy inventory because they are coproducts
- Many methods for allocating coproduct values
  - Energy content
    - Problem: Measured in calories – not a good estimate for energy in a fuel context
  - Market values
    - Problem: Determined by market factors unrelated to energy content
- This study uses the mass based allocation method: allocates coproducts by their relative weights

Allocation method

- Therefore, allocating based on weight

$$\text{Energy input allocation for biodiesel} = E_1 f_1 + E_2 f_2 + E_3$$

E1 = Energy input for agriculture

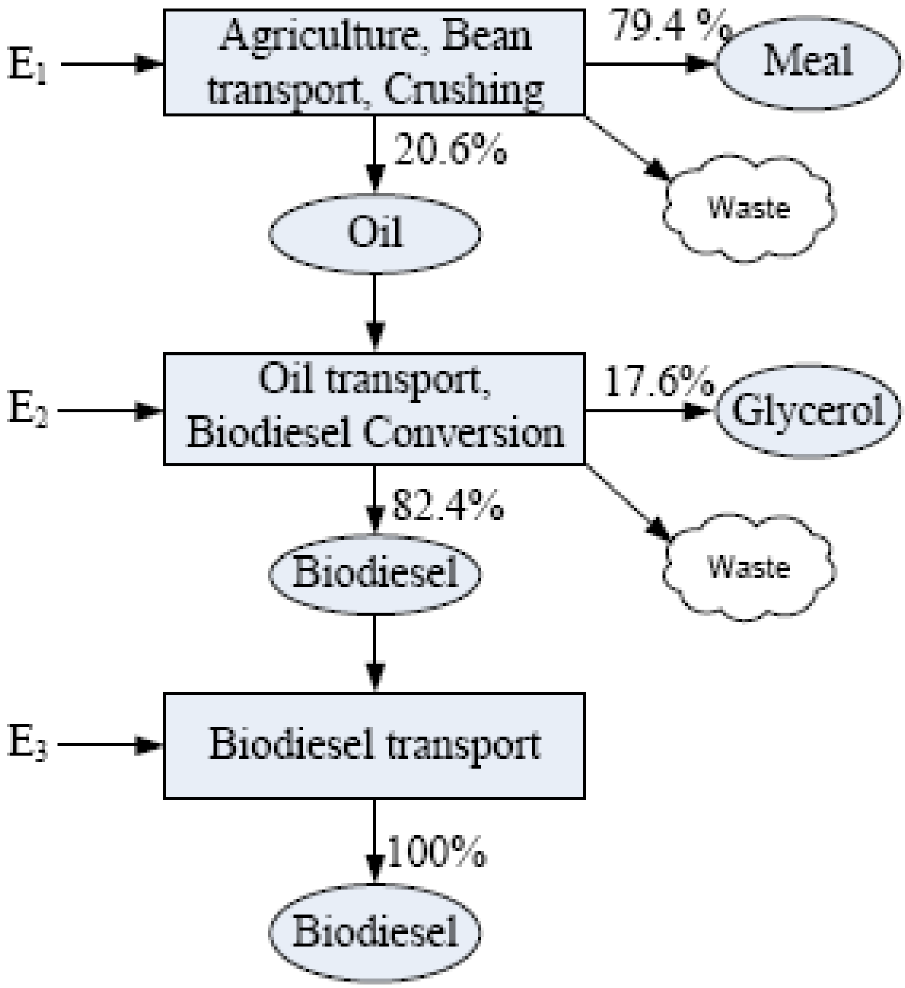
f1= mass fraction of soybean oil used to produce biodiesel

E2 = Energy required for conversion and transport of soybean oil

f2 = Mass fraction of processed oil used to produce biodiesel

E3 = Energy input for biodiesel transport

Mass based allocation



Effects of mass-based allocation

LCA Inventory	Fossil Energy Use (BTU/gal of BD)	
	Total	Biodiesel fraction[1]
Agriculture	26,662	4,533
Soybean transport	4,291	729
Soybean crushing	22,960	3,903
Biodiesel conversion	19,331	15,929
Biodiesel transport	1,026	1,026
Total Energy Input for biodiesel adjusted for coproducts		26,120
BD Total Energy Output		117,093
Net Energy Value		90,973

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Important Points

- This study is used by biodiesel trade organizations
- All data is variable – one metric is insufficient
- Lots of data is available from government sources
  - USDA
    - National Agriculture Statistics Survey (NASS)
    - Agricultural Resource Management Survey (ARMS)
    - Economic Research Service (ERS)

- How accurately can we compare this study to another type of fuel?

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Compare metrics

VS

One Corn EtOH study

- Shapouri et al. 2002
  - Tried to reconcile differing values:

Table 1—Energy input assumptions of corn-ethanol studies

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Growth

- Used USDA survey data to determine energy inputs
  - Used a 3 year average of yields to account for variation in growing seasons
  - Used a nine-state weighted average
    - Yield ranges from 79-130 bushels/acre in 1991
    - Ranges from 94-133 bushels/acre in 1996
- Used total energy – did not remove non-fossil sources, e.g. hydroelectric

Transport (to facility)

- Transporting corn to EtOH plants
  - Used GREET model
    - 40 miles by truck from collectors to terminals
    - 350 miles by barge from terminal to EtOH plants
    - 400 miles by rail from terminal to EtOH plants
- Compared with 50 miles by truck only for soybean study

Conversion

- Surveyed EtOH plants to determine conversion rate
  - Not based on a theoretical plant
    - Combined processing faclity
  - Distinguish between two types of plant

Table 6—Energy use and net energy value per gallon without coproduct energy credits, 1996

	Milling process		
Production phase	Dry	Wet	Weighted average
	Btu per gal		
Corn production	21,803	21,430	21,598
Corn transport	2,284	2,246	2,263
Ethanol conversion	48,772	54,239	51,779
Ethanol distribution	1,588	1,588	1,588
Total energy used	74,447	79,503	77,228
Net energy value	9,513	4,457	6,732
Energy ratio	1.11	1.04	1.08

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Distribution

- GREET Model used:
  - 80 miles by truck from plant to terminal
  - 520 miles by barge from terminal to destribution center
  - 800 miles by rail from terminal to distribution center
  - 25 miles by truck from distribution center to refueling station

Distribution

- Comparison

Transportation miles by:	Corn EtOH	Soybean Biodiesel
Truck	80	32
Barge	520	42
Rail	800	232
Truck (distrib)	25	30

- Is this valid?
  - Could we have a standard distance?
    - Would facilitate comparison between fuels

Energy Allocation

- Corn coproducts:
  - Distiller’s dried grains
  - Corn oil
  - Corn gluten meal
  - Corn gluten feed
- Replacement value method
  - Energy credits are assumed to be equal to the energy required to produce a substitute for the coproduct
    - Eg. Soybean meal replaces distillers grain, corn gluten meal and corn gluten feed

Energy allocation

- This method leads to 19% of energy used to produce ethanol is allocated to coproducts

	Energy allocation: Ethanol	Energy allocation: Coproduct	Energy use	Coproduct credit	Energy use with coproduct credit	NEV with coproducts	Energy ratio
	Percent		---------- *Btu/gal* ----------				
Replacement value:							
Wet mill	81	19	79,503	14,804	64,699	19,262	1.30
Dry mill	82	18	74,447	13,115	61,332	22,629	1.37
Weighted average	81	19	77,228	14,372	62,856	21,105	1.34

- Compared to the ~65% allocated for soybean biodiesel

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Conclusion

- There is wide variability within reported metrics because:
  - High variability in data:
    - Yields, energy allocation, transportation distances
- Work to coordinate and harmonize researchers
  - Develop lifecycle assessment methodologies
  - Keep data and assumptions transparent

Goal: Develop a transparent, credible and comprehensive energy analysis framework

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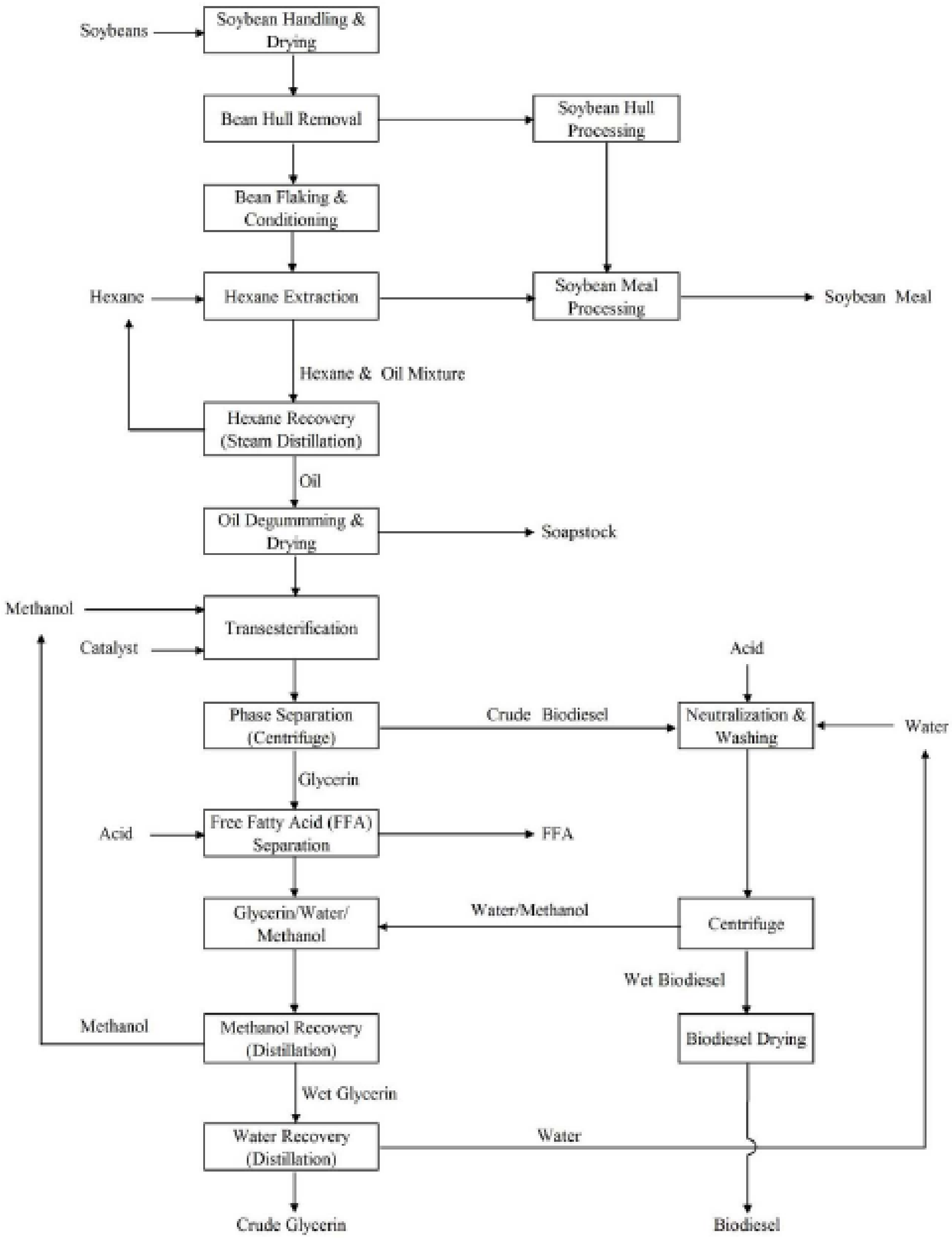
Thank you!

- Darlene Schuster
- John Carberry
- Dana Dang
- Institute for Sustainability
- Founders Societies Technologies for Carbon Management



Biodiesel Production Process

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Energy Coefficients used to convert inputs into British thermal units (Btu)

Inputs	Energy Value	Sources
Fuel Inputs	**Low heating value**	
Diesel (Btu/gal)	128,450	Huo et al. (2008)
Gasoline (Btu/gal)	116,090	Huo et al. (2008)
LP Gas (Btu/gal)	84,950	Huo et al. (2008)
Natural Gas (Btu/cft)	983	Huo et al. (2008)
Electricity (Btu/kWh)	3,412	Huo et al. (2008)
Material Inputs		
Nitrogen (Btu/lb)	22,147	Hill et al. (2006)
Phosphorus (Btu/lb)	3,946	Hill et al. (2006)
Potassium (Btu/lb)	2,565	Hill et al. (2006)
Lime (Btu/lb)	53.72	Graboski (2002)
Seeds (Btu/lb)	1,954	Sheehan et al. (1998)
Herbicide (Btu/lb)	137,263	Hill et al. (2006)
Insecticide (Btu/lb)	139,845	Hill et al. (2006)
Methanol (Btu/lb)	9,768*	Elert (2008)

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Life cycle energy efficiency factors for fossil fuels and electricity

Inputs	Life Cycle Efficiency percent
Diesel	84.3
Gasoline	80.5
LP Gas	89.8
Natural Gas	94.0
Electricity	31.7
Methanol	67.8

Source: Huo et al., 2008