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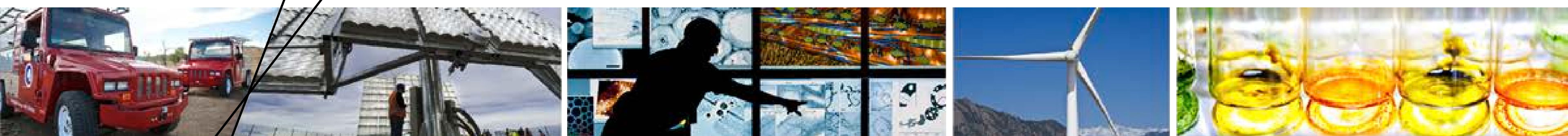
Selected Highlights of LCA Activities at NREL



LCA XIII Special Session: LCA at DOE

October 2, 2013

NREL/PR-6A20-60059

TEAM:
Alberta Carpenter
Garvin Heath
Daniel Inman
Margaret Mann
Ethan Warner
Yimin Zhang

Highlighted projects

1. Life cycle air pollutant emissions inventory for biofuels; spatially, temporally, and chemically explicit life cycle inventories
2. Materials Flows through Industry (MFI) tool for energy impacts
3. Land use change modeling methodology.

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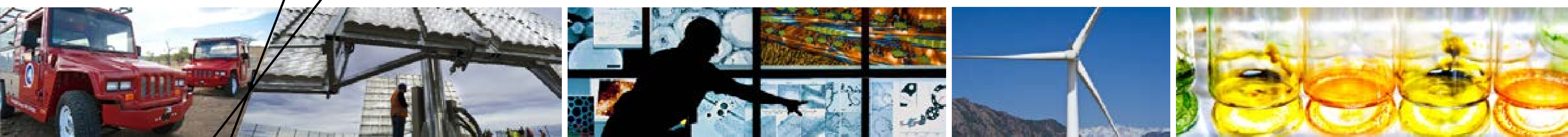
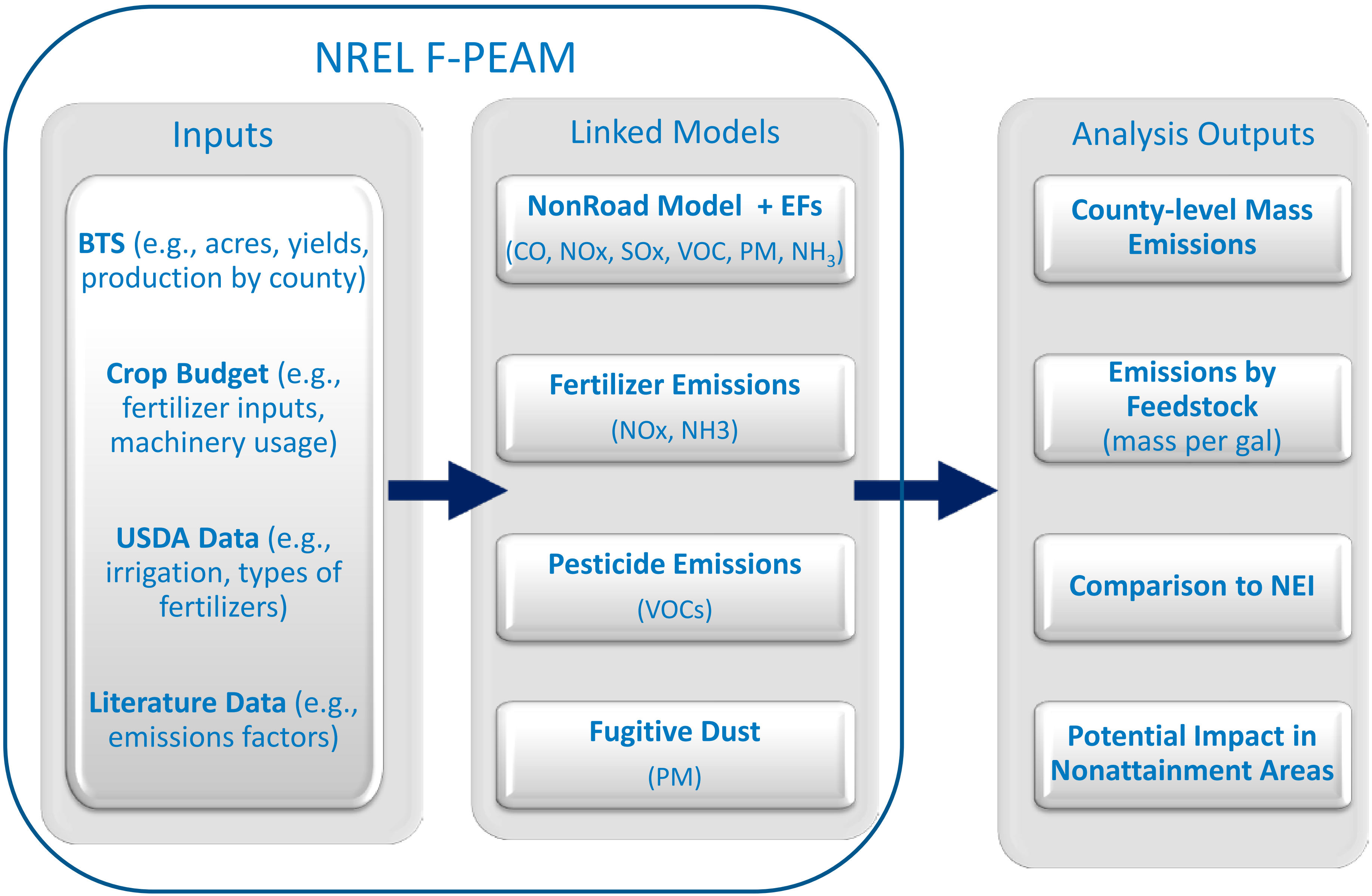


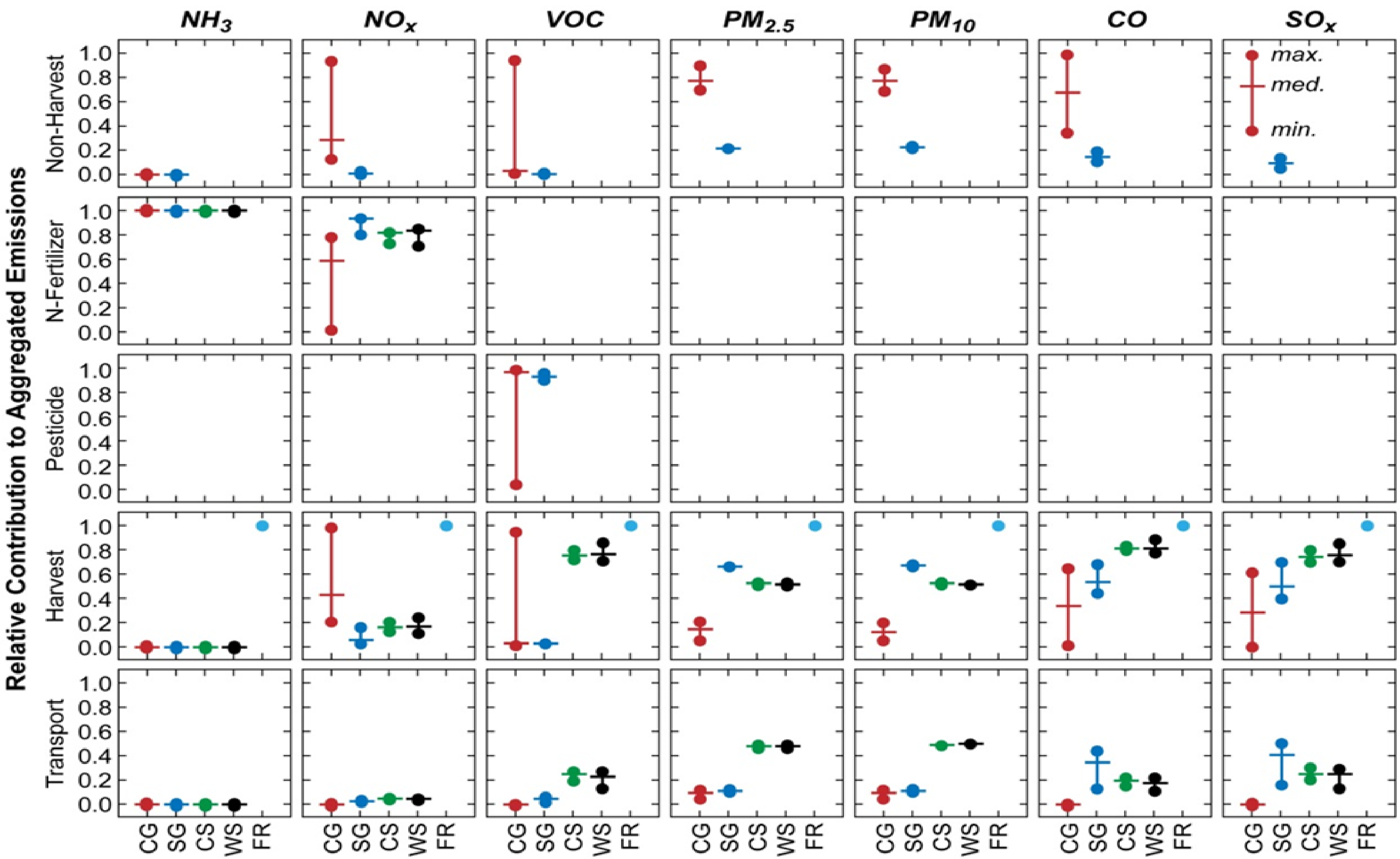
Comparative air pollutant emissions of selected biofuels feedstocks in 2022

Yimin Zhang, Garvin Heath, Alberta Carpenter, Noah Fisher

NREL Feedstock Production Emissions to Air Model (F-PEAM)

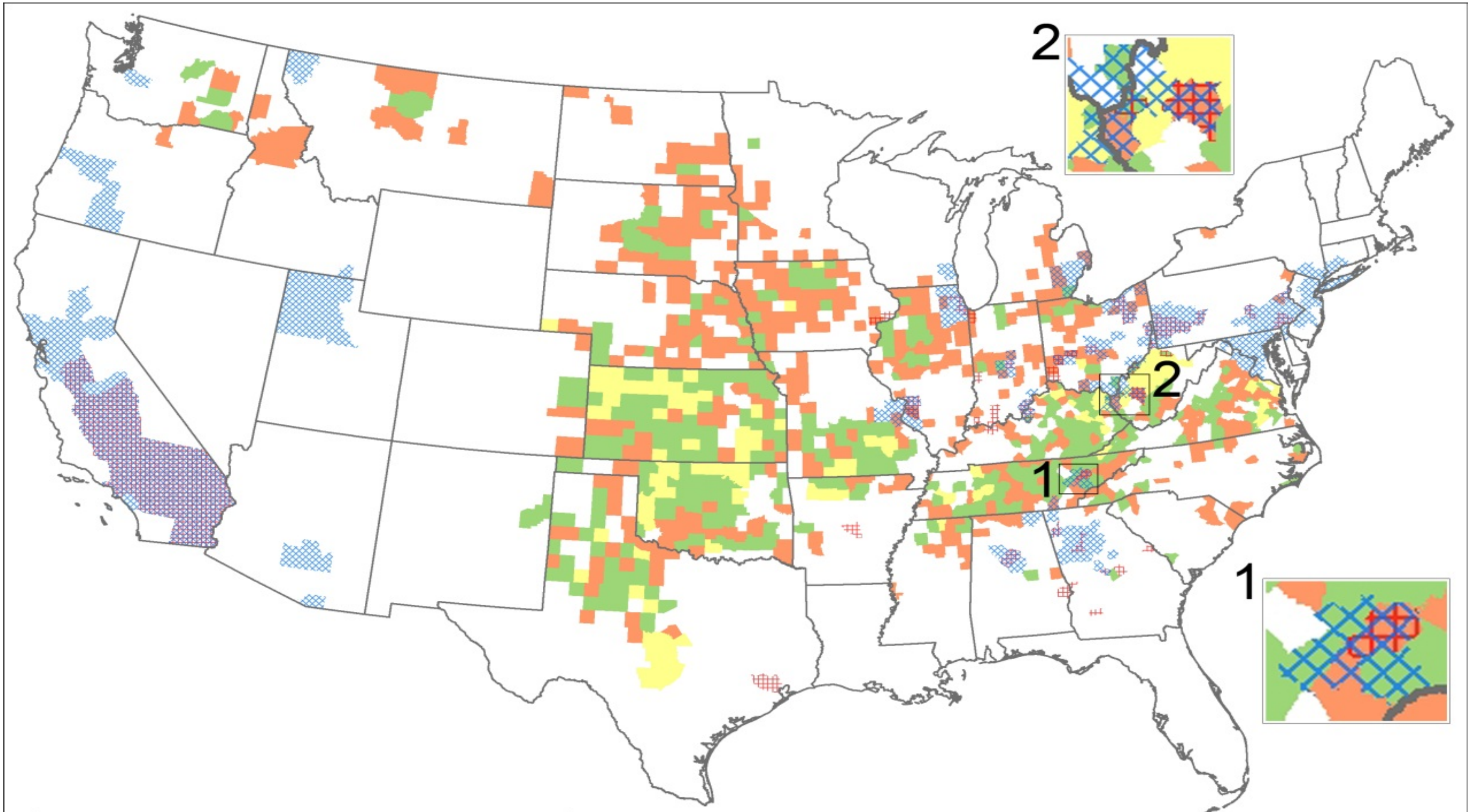


Contribution by Activity Category to County Emissions:
First Step to Target Setting



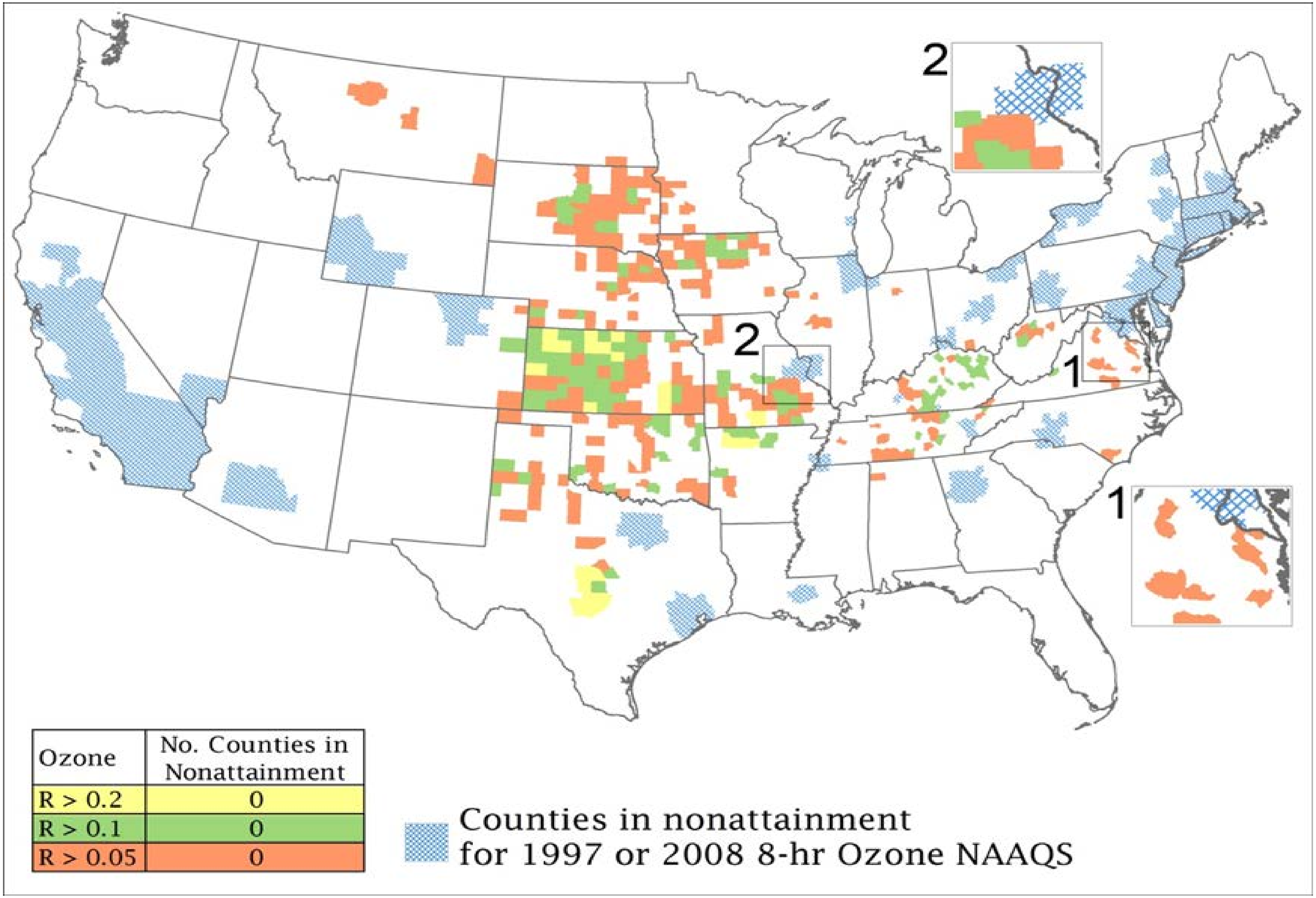
Blanks represent no emissions of that pollutant for that feedstock.

Counties with Cellulosic Feedstock O_3 Precursor Emissions Exceeding 3 NEI Thresholds, Alongside Current O_3 Nonattainment Areas



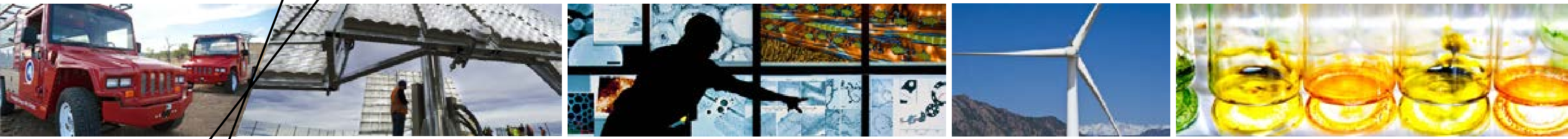
$PM_{2.5}$	Number of Counties	
	1997/2006	2012
R > 0.2	3	0
R > 0.1	13	4
R > 0.05	34	12

Counties with Cellulosic Feedstock O_3 Precursor Emissions Exceeding 3 NEI Thresholds, Alongside Current O_3 Nonattainment Areas



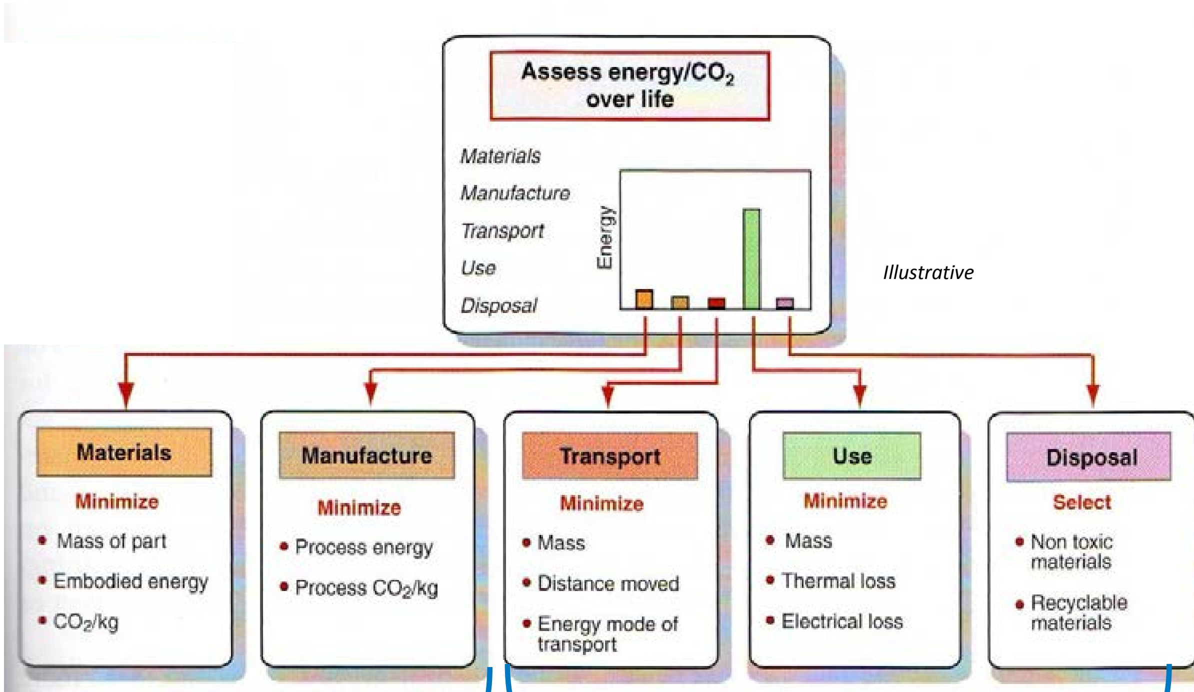
Source: NREL

Materials Flows through Industry (MFI) tool for energy impacts



Alberta Carpenter, Margaret Mann

DOE AMO Life Cycle Approach



Illustrative

Reference: "Materials & the Environment," Michael F. Ashby

Advanced Manufacturing

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Target Technologies

- Manufacturing energy/emissions reductions
- Increased manufacturing efficiency (lower energy, faster throughput, etc.)
- New and improved processes/product.

leads to

- Use and re-use energy/emissions reductions (e.g., light-weighting)
- Increased value added
- Improved quality
- Etc.

What are the opportunities for manufacturing impacts across the life cycle?

Materials Flow through Industry (MFI) Tool

Function: A tool enables scenarios of changes in energy efficiency of processes, changes in materials use, changes in carbon intensity of materials:

- Process comparisons
- Material substitution
- Sector energy efficiency potential
- Grid mix evaluation
- Track energy & GHG emissions at the per unit (mass) product level

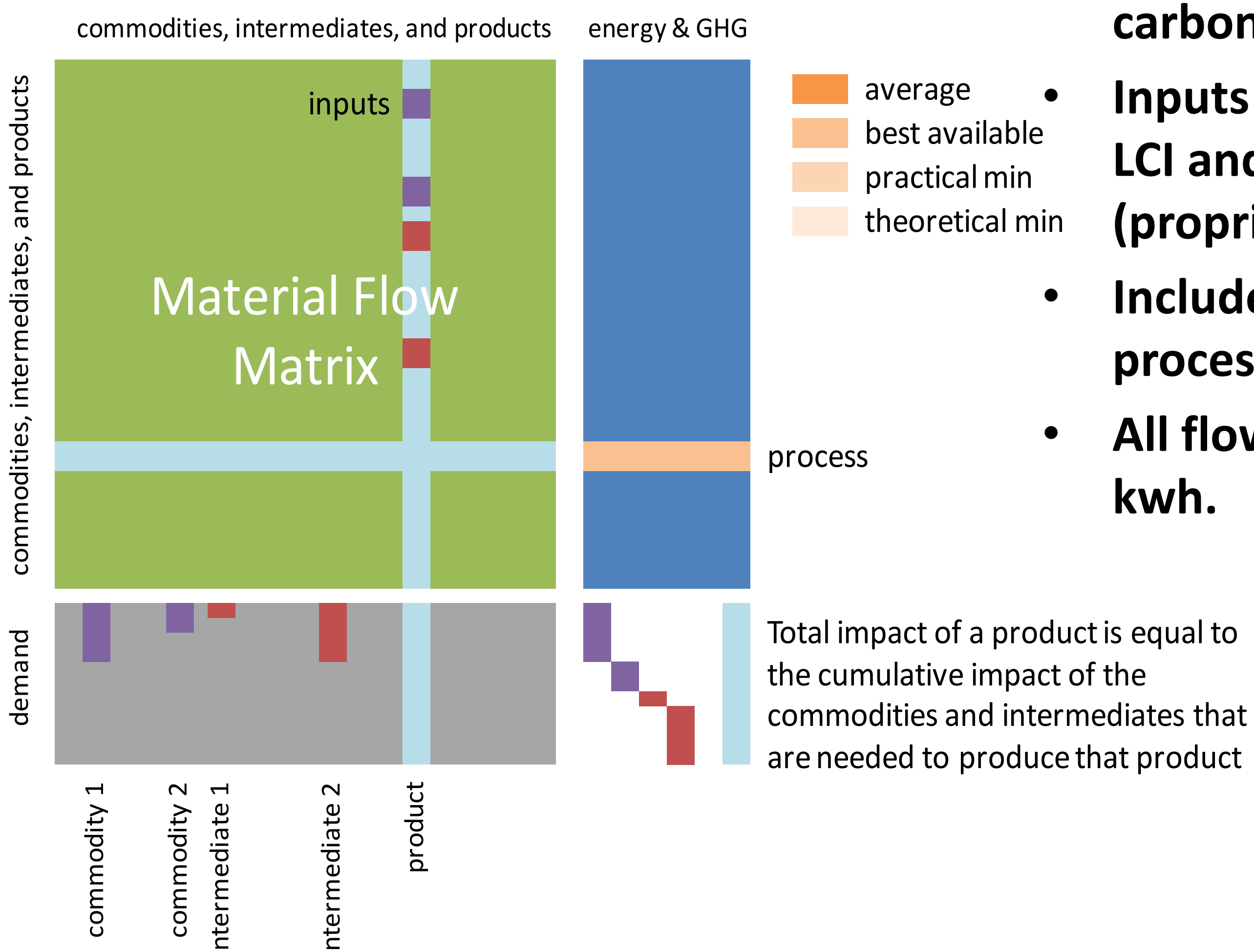
Data Driven:

- Use pre-existing lifecycle (LC) data readily adopted for parts of the sector (USLCI, ecoinvent).
- Market data and recipes for over 500 products and 1200 processes
- Recipes (mass & energy balance) of the manufacturing step: raw materials; fuel inputs; product & co-product outputs; GHG emissions (SRI).

Output:

- Overall material & energy balance – material flows of through supply chain.
- Energy & GHG emissions tracked at the per unit product level and at market use level.
- Tabular and graphical representation of “base case” and “scenario” (e.g. after material substitution).

MFI Tool Structure



- **IO process based matrix model**
- **Tracks energy and fuel derived carbon emissions**
- **Inputs and outputs are based on LCI and process economics data (proprietary)**
- **Includes 500+ products, 1200+ processes**
- **All flows accounted for in kg or kwh.**

Source: Seungwook Ma, PhD, DOE

Tool Inputs

1	**User Input Page**		
2			
3			
4	**Step 1:**	Select category:	NONFERROUS
5			
6			
7	**Step 2:**	Reculate:	Recalculate
8			
9			
10	**Step 3:**	Select material:	ALUMINUM, SMELT
11			
12			
13	**Step 4:**	Recalculate:	Recalculate
14			
15			
16	**Step 5:**	Demand (KG):	1,000
17			
18			
19	**Step 6:**	Steps in the supply chain:	
20			
21		**Scenario A**	5
22		**Scenario B**	5
23		**Scenario C**	5

Source: NREL

Tool Inputs

Number of Substitutes: 0

Substitute	Replacement Factor (lb per 1 lb of ALUMINUM, SMELT) Low	High	Functionality

User Input Page

Step 1:	Select ca	
Step 2:	Reculate	
Step 3:	Select material:	ALUMINUM, SMELT
Step 4:	Recalculate:	Recalculate
Step 5:	Demand (KG):	1,000
Step 6:	Steps in the supply chain:	
	Scenario A	5
	Scenario B	5
	Scenario C	5

Tool Inputs

Choose Baseline, Equal Weighting or Input Own Values

Product: ALUMINUM, SMELT Process	Baseline Weighting	Equal Weighting	Choose Baseline Input Own New Weighting Scenario A	Choose Baseline Input Own New Weighting Scenario B	Choose Baseline Input Own New Weighting Scenario C
CARBOTHERMIC	0%	17%	100%	100%	100%
CLAY CARBOCHLORINATION	0%	17%	0%	0%	0%
HH WETTED CATHODE	0%	17%	0%	0%	0%
H-H/INERT ANODE	0%	17%	0%	0%	0%
MODERN HALL HEROULT PROCESS	100%	17%	0%	0%	0%
SMELTING OF REFINED ALUMINA TO METALLIC ALUMINUM	0%	17%	0%	0%	0%
			0%	0%	0%
			0%	0%	0%
			0%	0%	0%
			0%	0%	0%
			0%	0%	0%
			0%	0%	0%
			0%	0%	0%
			0%	0%	0%
			0%	0%	0%

12			
13	**Step 4:**	Recalculate:	Recalculate
14			
15			
16	**Step 5:**	Demand (KG):	1,000
17			
18			
19	**Step 6:**	Steps in the supply chain:	
20			
21		**Scenario A**	5
22		**Scenario B**	5
23		**Scenario C**	5

Source: NREL

Tool Inputs

Choose Baseline, Equal Weighting or Input Own Values

Product: ALUMINUM, SMELT Process	Baseline Weighting	Equal Weighting	Choose Baseline Input Own New Weighting Scenario A	Choose Baseline Input Own New Weighting Scenario B	Choose Baseline Input Own New Weighting Scenario C
CARBOTHERMIC	0%	17%	100%	100%	100%
CLAY CARBOCHLORINATION	0%	17%	0%	0%	0%
HI					0%
H-ion					0%
M					0%
SM					0%
					0%
					0%
					0%
					0%
					0%
					0%
					0%
					0%
					0%

Choose Baseline or Own Values

Product: ALUMINUM, SMELT Process	Baseline Implimentation	Choose Baseline Input Own New Implimentation Scenario A	Choose Baseline Input Own New Implimentation Scenario B	Input Own Input Own New Implimentation Scenario C
CARBOTHERMIC	0%	100%	100%	100%
CLAY CARBOCHLORINATION	0%	0%	0%	0%
HH WETTED CATHODE	0%	0%	0%	0%
H-H/INERT ANODE	0%	0%	0%	0%
MODERN HALL HEROULT PROCESS	0%	0%	0%	0%
SMELTING OF REFINED ALUMINA TO METALLIC ALUMINUM	0%	0%	0%	0%
		0%	0%	0%
		0%	0%	0%
		0%	0%	0%
		0%	0%	0%
		0%	0%	0%
		0%	0%	0%
		0%	0%	0%
		0%	0%	0%
		0%	0%	0%

12			
13			
14			
15			
16			
17			
18			
19	**Step 6:**	Steps in the supply chain:	
20			
21		**Scenario A**	5
22		**Scenario B**	5
23		**Scenario C**	5

Source: NREL

Tool Inputs

Choose Baseline, Equal Weighting or Input Own Values

Product: ALUMINUM, SMELT Process	Baseline Weighting	Equal Weighting	Choose Baseline Input Own New Weighting Scenario A	Choose Baseline Input Own New Weighting Scenario B	Choose Baseline Input Own New Weighting Scenario C
CARBOTHERMIC	0%	17%	100%	100%	100%
CLAY CARBOCHLORINATION	0%	17%	0%	0%	0%

Choose Baseline or Own Values

Product: ALUMINUM, SMELT Process	Baseline Implimentation	Choose Baseline Input Own New Implimentation Scenario A	Choose Baseline Input Own New Implimentation Scenario B	Input Own Input Own New Implimentation Scenario C
CARBOTHERMIC	0%	100%	100%	100%
CLAY CARBOCHLORINATION	0%	0%	0%	0%
HH WETTED CATHODE	0%	0%	0%	0%
H-H/INERT ANODE	0%	0%	0%	0%
MODERN HALL HEROULT PROCESS	0%	0%	0%	0%
SMELTING OF REFINED ALUMINA TO METALLIC ALUMINUM	0%	0%	0%	0%

Choose Baseline or Own Values

Product: ALUMINUM, SMELT Process	Baseline Implimentation	Choose Baseline Input Own Grid Mix Scenario A	Choose Baseline Input Own Grid Mix Scenario B	Choose Baseline Input Own Grid Mix Scenario C
ELECTRICITY GRID, FRCC	0%	0%	0%	0%
ELECTRICITY GRID, MRO	0%	0%	0%	0%
ELECTRICITY GRID, NATIONAL	100%	100%	100%	100%
ELECTRICITY GRID, NPCC	0%	0%	0%	0%
ELECTRICITY GRID, RFC	0%	0%	0%	0%
ELECTRICITY GRID, SERC	0%	0%	0%	0%
ELECTRICITY GRID, SPP	0%	0%	0%	0%
ELECTRICITY GRID, TRE	0%	0%	0%	0%
ELECTRICITY GRID, WECC	0%	0%	0%	0%

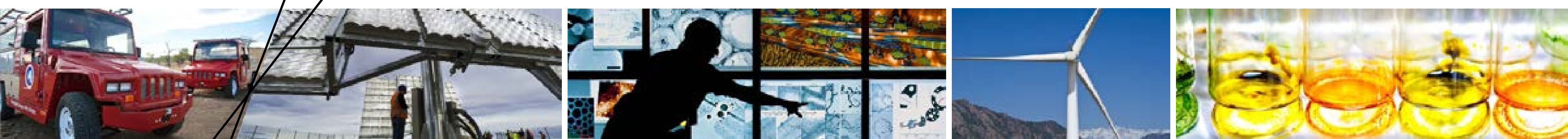
Source: NREL

Tool Outputs

Scenario A: Results per 1000 KG of ALUMINUM, SMELT for 5 Steps

	SORTED BY DIRECT	Electricity	Coal (GJ)	Natural Gas	Diesel (GJ)	Kerosene	Fuel Oil and	Crude Oil	Primary Energy	Steam (GJ)	Mass (KG)	Carbon Dioxide	Carbon Dioxide
	TOTAL	**3.08E+03**	**9.01E+00**	**9.77E+03**	**-4.60E+04**	**-2.32E+04**	**9.58E+03**	**2.20E+05**	**1.70E+05**	**0.00E+00**	**3.62E+05**	**1.28E-02**	**2.19E-04**
1	REFINERY GAS	1.53E+03	0.00E+00	1.07E+03	-2.76E+04	-1.47E+04	-1.01E+03	1.35E+05	9.29E+04	0.00E+00	2.04E+02	7.14E-03	1.24E-07
2	COKE	3.67E+02	0.00E+00	2.56E+02	-6.60E+03	-3.52E+03	-2.43E+02	3.23E+04	2.22E+04	0.00E+00	4.14E+04	1.71E-03	2.51E-05
3	KEROSENE	1.63E+02	0.00E+00	6.10E+02	-3.10E+03	0.00E+00	8.51E+02	1.19E+04	1.02E+04	0.00E+00	3.13E+04	7.66E-04	1.90E-05
4	GASOLINE	1.42E+02	0.00E+00	3.80E+01	-3.68E+02	-1.96E+02	8.08E+03	1.80E+03	9.35E+03	0.00E+00	1.45E+05	7.01E-04	8.81E-05
5	PETROLEUM, COPRODUCT	1.46E+02	0.00E+00	1.02E+02	-2.63E+03	-1.40E+03	-9.67E+01	1.29E+04	8.85E+03	0.00E+00	1.43E+04	6.80E-04	8.66E-06
6	BITUMEN	1.46E+02	0.00E+00	1.02E+02	-2.68E+03	-1.40E+03	-9.67E+01	1.29E+04	8.80E+03	0.00E+00	1.02E+04	6.77E-04	6.16E-06
7	LIQUID PETROLEUM GAS	1.45E+02	0.00E+00	1.01E+02	-2.61E+03	-1.39E+03	-9.60E+01	1.28E+04	8.78E+03	0.00E+00	6.90E+03	6.75E-04	4.19E-06
8	DIESEL	1.92E+02	0.00E+00	6.74E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.74E+03	0.00E+00	8.77E+04	3.39E-04	5.32E-05
9	FUEL GAS	2.02E+02	0.00E+00	7.13E+02	-5.83E+02	-4.94E+02	1.17E+03	0.00E+00	8.01E+02	0.00E+00	4.90E+03	4.82E-05	2.97E-06
10	BUTYLENES	2.44E+01	0.00E+00	2.96E+00	0.00E+00	0.00E+00	7.69E+02	0.00E+00	7.72E+02	0.00E+00	4.03E+03	5.76E-05	2.45E-06
11	BAUXITE	7.51E+00	0.00E+00	6.40E-02	2.54E+02	0.00E+00	4.84E+01	0.00E+00	3.03E+02	0.00E+00	5.29E+03	2.12E-05	3.21E-06
12	NAPHTHA	9.35E-01	0.00E+00	1.07E+01	-3.84E+01	-1.08E+02	1.91E+02	0.00E+00	5.52E+01	0.00E+00	1.33E+03	4.65E-06	8.06E-07
13	ALUMINA	8.74E-01	4.65E+00	9.09E+00	5.97E-02	0.00E+00	8.26E+00	0.00E+00	2.21E+01	0.00E+00	1.93E+03	1.50E-06	1.17E-06
14	PROPYLENE	4.50E+00	0.00E+00	8.54E+00	0.00E+00	0.00E+00	8.29E+00	0.00E+00	1.68E+01	0.00E+00	2.76E+03	1.05E-06	1.68E-06
15	SODIUM HYDROXIDE	9.06E-02	3.96E+00	2.45E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.99E+00	0.00E+00	1.73E+02	3.57E-07	1.05E-07
16	C4 FRACTION	9.03E-03	0.00E+00	3.75E-01	0.00E+00	0.00E+00	2.73E+00	0.00E+00	3.11E+00	0.00E+00	7.74E+00	2.23E-07	4.70E-09
17	NATURAL GAS, LIQUIDS, 86% E	4.64E-03	0.00E+00	2.90E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E+00	0.00E+00	6.47E+01	1.46E-07	3.92E-08
18	GAS OIL, VACUUM	7.94E-03	0.00E+00	6.40E-02	-7.78E-01	0.00E+00	2.42E+00	0.00E+00	1.70E+00	0.00E+00	2.55E+02	1.30E-07	1.55E-07
19	ISOBUTANE	1.39E-01	0.00E+00	1.33E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.33E+00	0.00E+00	2.17E+03	6.71E-08	1.32E-06
20	ANODE	2.09E-01	2.82E-02	9.66E-01	4.73E-02	0.00E+00	2.14E-01	0.00E+00	1.26E+00	0.00E+00	4.50E+02	7.04E-08	2.73E-07
21	METHANOL	0.00E+00	8.42E-02	7.23E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.07E-01	0.00E+00	2.34E+01	4.39E-08	1.42E-08
22	XYLENES, MIXED	9.77E-02	0.00E+00	5.84E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.84E-01	0.00E+00	6.51E+02	2.94E-08	3.95E-07
23	CALCIUM OXIDE	1.43E-02	2.75E-01	5.01E-02	2.12E-03	0.00E+00	0.00E+00	0.00E+00	3.28E-01	0.00E+00	5.87E+01	2.74E-08	3.56E-08
24	COAL	5.26E-02	0.00E+00	7.15E-02	5.13E-02	0.00E+00	0.00E+00	0.00E+00	1.23E-01	0.00E+00	2.92E+02	7.15E-09	1.77E-07
25	LIMESTONE	2.15E-03	1.38E-04	8.06E-04	3.16E-03	0.00E+00	0.00E+00	0.00E+00	4.10E-03	0.00E+00	1.41E+02	2.72E-10	8.57E-08
26	IRON, PIG	0.00E+00	2.67E-03	2.32E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.69E-03	0.00E+00	1.93E-01	2.41E-10	1.17E-10
27	FERRONICKEL, 25% Ni	2.41E-04	3.43E-04	2.55E-04	1.64E-05	0.00E+00	3.22E-05	0.00E+00	6.47E-04	0.00E+00	8.58E-03	4.72E-11	5.21E-12
28	LIME	1.75E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-04	0.00E+00	1.14E-04	0.00E+00	7.63E+01	8.54E-12	4.63E-08
29	N-METHYL-2-PYRROLIDONE	3.84E-06	0.00E+00	5.03E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.03E-05	0.00E+00	6.06E-02	2.53E-12	3.67E-11
30	FERROCHROMIUM, HIGH-CARB	3.78E-05	3.07E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.07E-05	0.00E+00	3.16E-03	2.75E-12	1.91E-12
31	STEEL, ALLOYED	3.13E-05	9.90E-08	1.48E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E-05	0.00E+00	3.96E-01	7.55E-13	2.40E-10
32	IRON, SCRAP	9.76E-07	0.00E+00	0.00E+00	2.71E-06	0.00E+00	0.00E+00	0.00E+00	2.71E-06	0.00E+00	2.71E-02	1.88E-13	1.64E-11
33	FERROMANGANESE, HIGH-CO/	1.11E-05	1.34E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.34E-06	0.00E+00	2.98E-03	1.20E-13	1.81E-12
34	DOLOMITE	6.90E-08	0.00E+00	0.00E+00	1.06E-08	0.00E+00	5.51E-08	0.00E+00	6.57E-08	0.00E+00	5.90E-04	4.85E-15	3.58E-13
35		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

- **Results are still in preliminary stages**
- **Looking to identify which product inputs have largest energy and carbon demands.**



Land use change model

Ethan Warner, Daniel Inman, Yimin Zhang

Background

Land use change (LUC) may cause large GHG emissions

U.S. corn/soybean farmers sell land to developers, land is now developed

U.S. soybean exports go down and world soybean prices rise

Additional land in Brazil (for instance) is put into soy production

Soy farmers everywhere use more inputs to increase yields

Unobservable variables!

Indirect LUC emissions

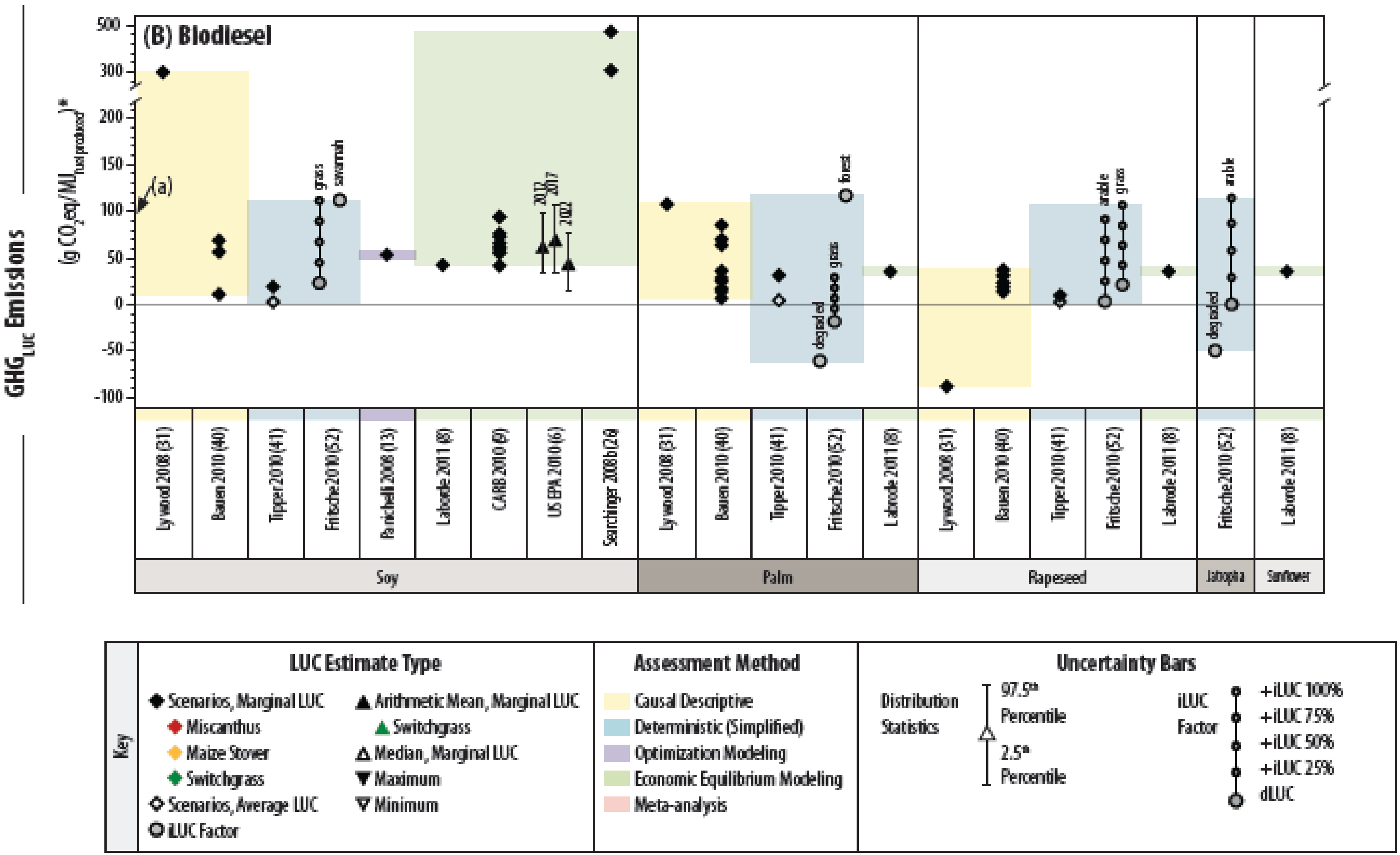
Indirect process emissions

Potentially large global land carbon debt!

Direct process emissions: Change in CO_2 flux on land

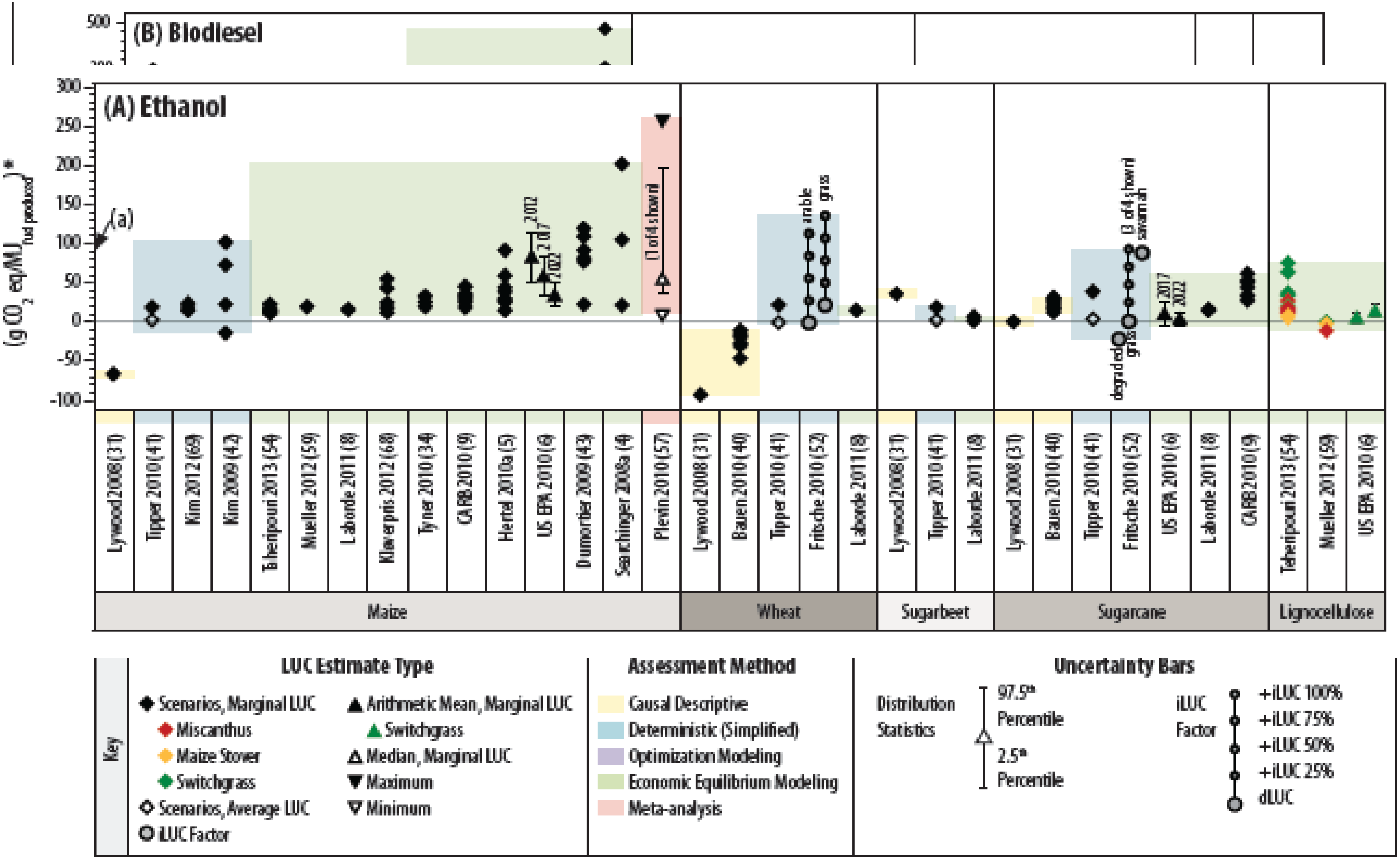
Source: Searchinger T, Heimlich R, Houghton R A, Dong F, Elobeid A, Fabiosa J, Tokgoz S, Hayes D and Yu T H 2008 Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change Science 319 1238–40

Literature Review



Source: Warner, Zhang, Inman and Heath. 2013. Challenges in the estimation of greenhouse gas emissions from biofuel-induced global land-use change. Biofuels, Bioproducts and Biorefining. DOI: 10.1002/bbb.1434

Literature Review



Source: Warner, Zhang, Inman and Heath. 2013. Challenges in the estimation of greenhouse gas emissions from biofuel-induced global land-use change. Biofuels, Bioproducts and Biorefining. DOI: 10.1002/bbb.1434

Goal Statement

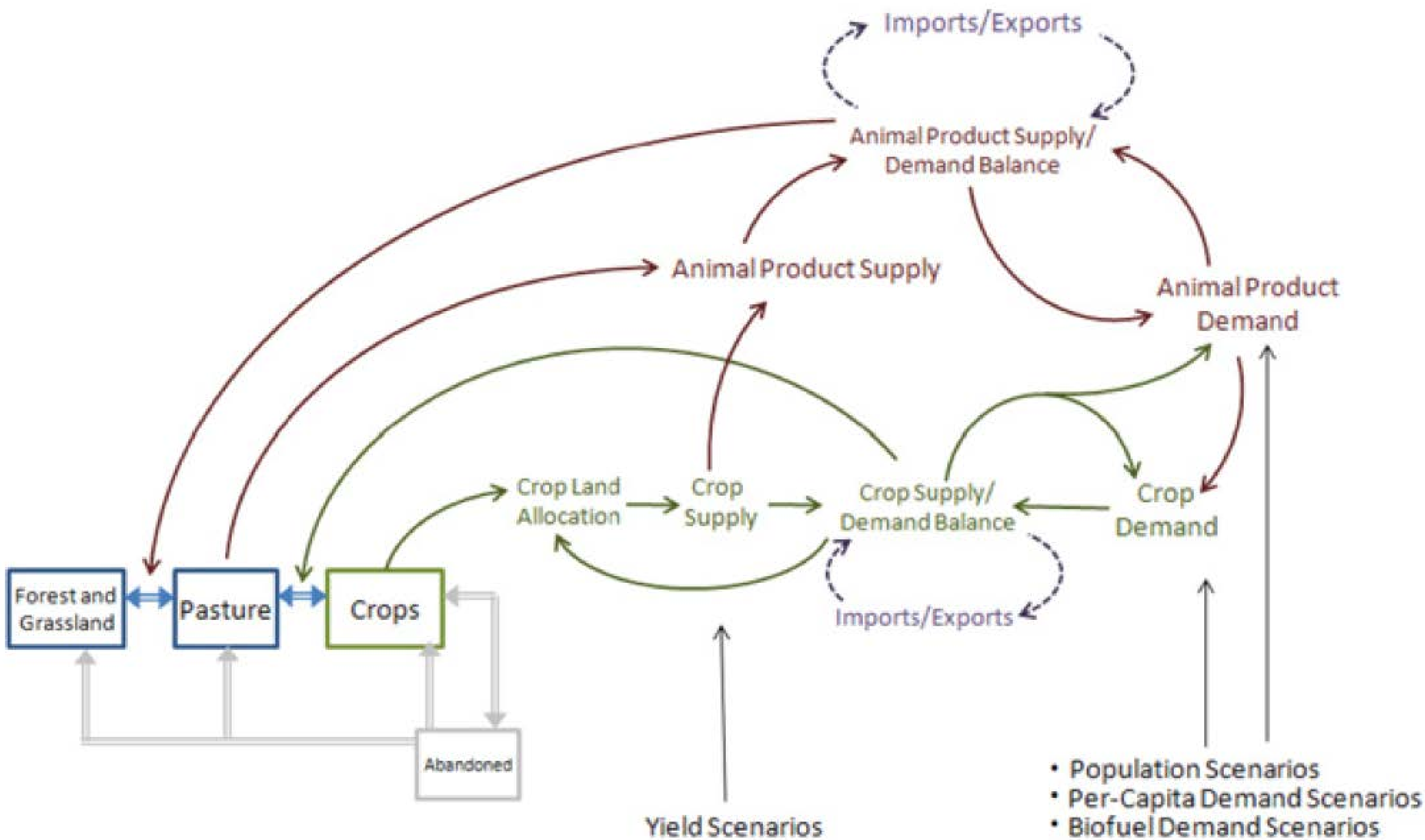
1. To create and utilize systems dynamics to model the key drivers of land use change, including biomass conversion and biofuels production

2. To create a transparent and relatively simple model for test assumptions about land use change and to facilitate discussion about the topic area.

NREL's Modeling Strategy & Approach

- **System dynamics framework**
  - Stocks/flows
  - Feedback within and across stages in supply chain.
- **Modular, "regional" model architecture**
  - "Region" can reflect world, nation, geographical region, level of development, etc.
  - Enables rapid extension of model from 1 → 2 → n regions.
- **Reliance on demographic scenarios and FAO/GTAP data to drive dynamics around population, yield, food demand**
- **Calibrate model against FAO datasets for land use and disposition**
- **Avoidance of explicit market mechanism.**

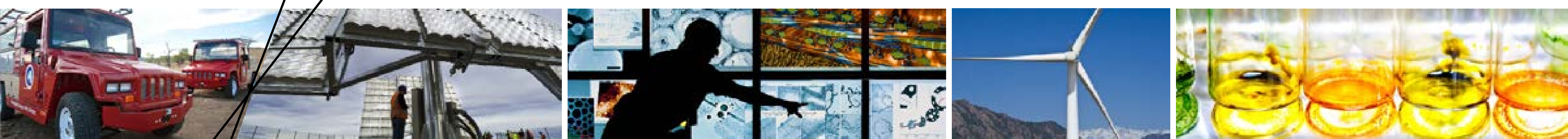
Our Model Captures Important System Interactions



Source: Warner et al. 2013, Environ. Res. Lett. 8 015003

Conclusions

- **BioLUC modeling effort is focused on improving our understanding of how bioenergy and LUC interact**
- **Once complete, the model will be released publically along with processed datasets**
  - To be hosted on GitHub with links; also on Bioenergy KDF
- **We expect the model to facilitate much discussion among stakeholders and provide an accessible medium for groups to test different assumptions and datasets**
- **Having a transparent and relatively simple model (i.e., runs quickly, isn't very large, etc.) will add value to the community as a whole**
- **It is our hope that model release will stimulate an "open-source" level of interest and external development.**



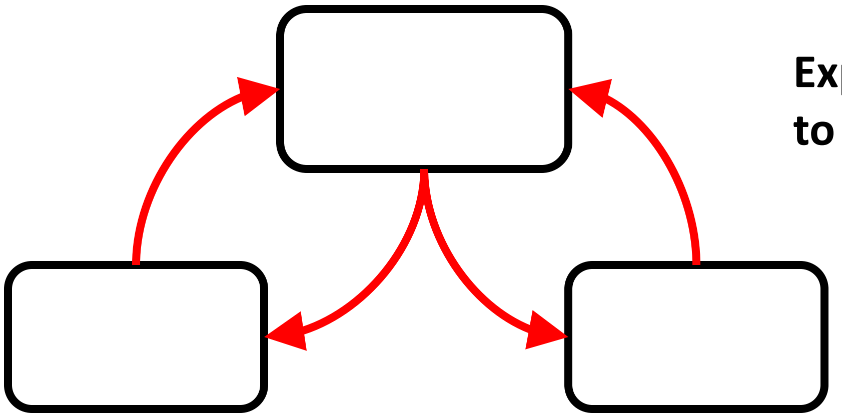
Questions?

LUC paper citation:

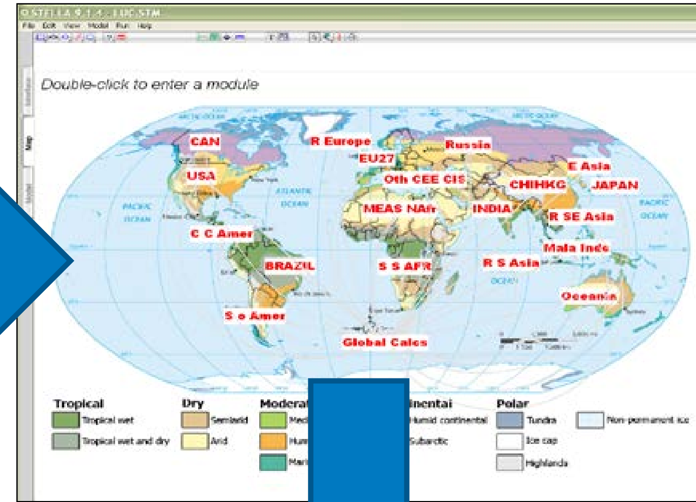
Warner, Inman, Kunstman, Bush, Vimmerstedt, Peterson, Macknick and Zhang. 2013. Modeling biofuel expansion effects on land use change dynamics. ERL, Vol. 8, No. 1

Supplemental Slides

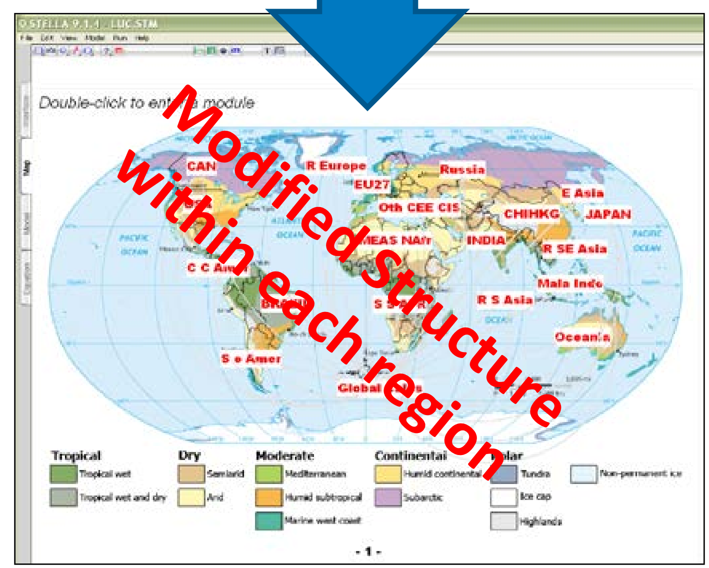
BioLUC Model Progression



Expansion from 2 to 19 regions.



Modifications to land stocks and flows based on feedback from the ORNL workshop.



Two-Region Insights

- **Results suggest that even in a future with high food and biofuel demands there is enough "available" land to meet both food and fuel needs.**
- **Most of the land is supplied by "pasture"**
- **Demand for land-intensive meat is difficult to supply under the high biofuel scenarios**

	Base case system input per kg of product								
Animal Class	Forage	Pasture	Maize	Wheat	Rice	NEC	Oil Crop	Sugar	Total kg
Cow Goat Sheep	6.1	4.9	2.6	0.1	0.0	0.0	1.1	0.0	14.8
Dairy	4.5	0.0	1.2	0.0	0.0	2.0	0.0	0.0	7.7
Pig	0.0	0.0	1.2	1.4	0.0	0.3	0.7	0.0	3.6
Poultry	0.0	0.0	1.4	0.3	0.0	0.0	0.6	0.0	2.4