Using Geographically Broad Commodity and Land-Use Modeling to Enhance Life Cycle Assessment of Greenhouse Emissions from US Biofuel Policy

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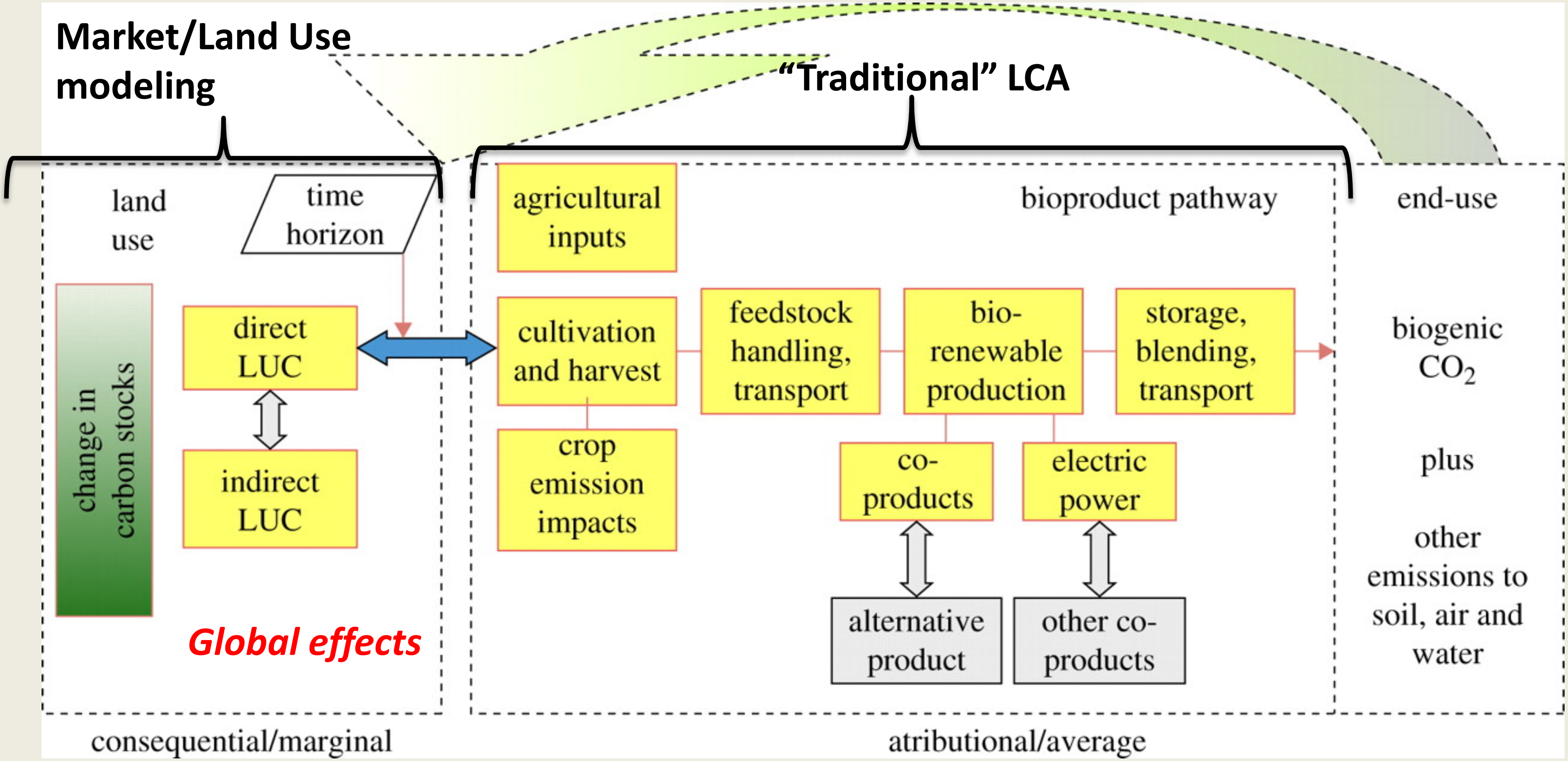
Biofuel lifecycle emissions



Hosseini and Shah. Multi-scale process and supply chain modelling: from lignocellulosic feedstock to process and products. *Interface Focus 6 April 2011 vol. 1 no. 2 255-262*

Why does commodity market/land use linkage matter?

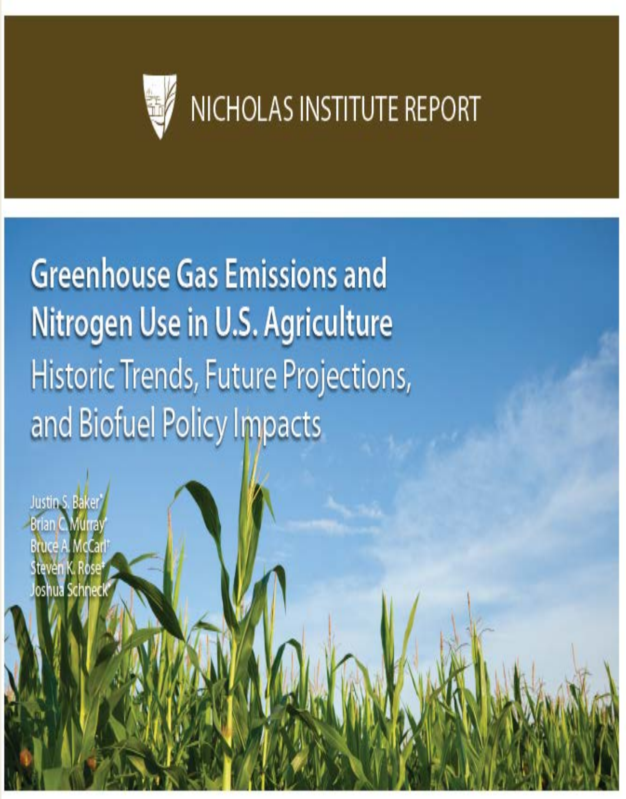
- In LCA, you want as complete a picture as possible
  - Hence the term “lifecycle”
  - But the integrated modeling is not so easy. Earlier assessments largely ignored it
- More recent studies have shown feedstock commodity-induced indirect land use change (ILUC) as an important issue
  - potential magnitudes large enough to change the sign (and presumed net benefit) of policies to expand biofuel

ILUC potential grows as geographic scale grows

Some recent studies of ILUC effects on biofuel net emissions

Study	Outlet/date	Policy	Model	Scope	Net emissions effects
Searchinger et al	*Science Express (2008)*	RFS Mandate	Global land use model with GREET	Global with indirect land use change (ILUC)	"Payback periods for carbon debt" +++: corn ++: cellulosic
Fargione et al	*Science (2008)*	NS: Increased ethanol (corn, cellulosic) and biodiesel production	Calculation based on literature review	Select global locations	++++: palm biodiesel +++: corn ethanol ++: sugarcane ethanol 0: prairie biomass ethaniol
Hertel et al	*BioScience (2010)*	NS: Increased corn ethanol production	GTAP	Global with ILUC	+
Tyner et al	*Argonne Working paper (2010)*	NS: Increased corn ethanol production	GTAP	Global with ILUC	-
*** Baker et al**	*Nicholas Institute (Duke) Report (2011)*	RFS Mandate	FASOMGHG	Domestic US with ILUC	-
Thompson et al	*Energy Policy (2011)*	Tax subsidies, tariffs and mandates (corn, cellulosic and biofuel)	FAPRI	Global with petroluem market feedbacks (and implied ILUC)	++/-
Zhang et al	*Env Research Letters (2010)*	LCFS (CA) – corn and cellulosic	CA-GREET-GHG	Global with ILUC	Corn: +/- Cellulosic: ----
*** National Academy of Sciences**	*NAS Report on GHG and the Tax Code (Ch. 5, 2013)*	Tax subsidies, tariffs and mandates (corn, cellulosic and biofuel)	FAPRI NEMS	Global with and without ILUC	+/-
*** Mosnier et al**	*Energy Policy (2013)*	RFS mandate – corn, cellulosic and biodiesel	GLOBIOM/FASOMGHG	Global with ILUC – non-CO2 gases	+/-

Study 1: Net Domestic GHG Effects



(Baker et al, Nicholas Institute, 2011)

Policy: RFS2 variations (-25% to +25% of current standard)

Model: U.S. Forest and Agricultural Sector Optimization Model with GHGs (FASOMGHG)
- Commodity markets (ag, forest, processing)
- Land Use change

Scope of GHG coverage
- United States
- Agricultural GHGs (Co2, CH4, N2O)
- Forest (CO2)
- Includes fuel use

Outcomes of interest
- GHG emissions
- N use

FASOMGHG Model Structure

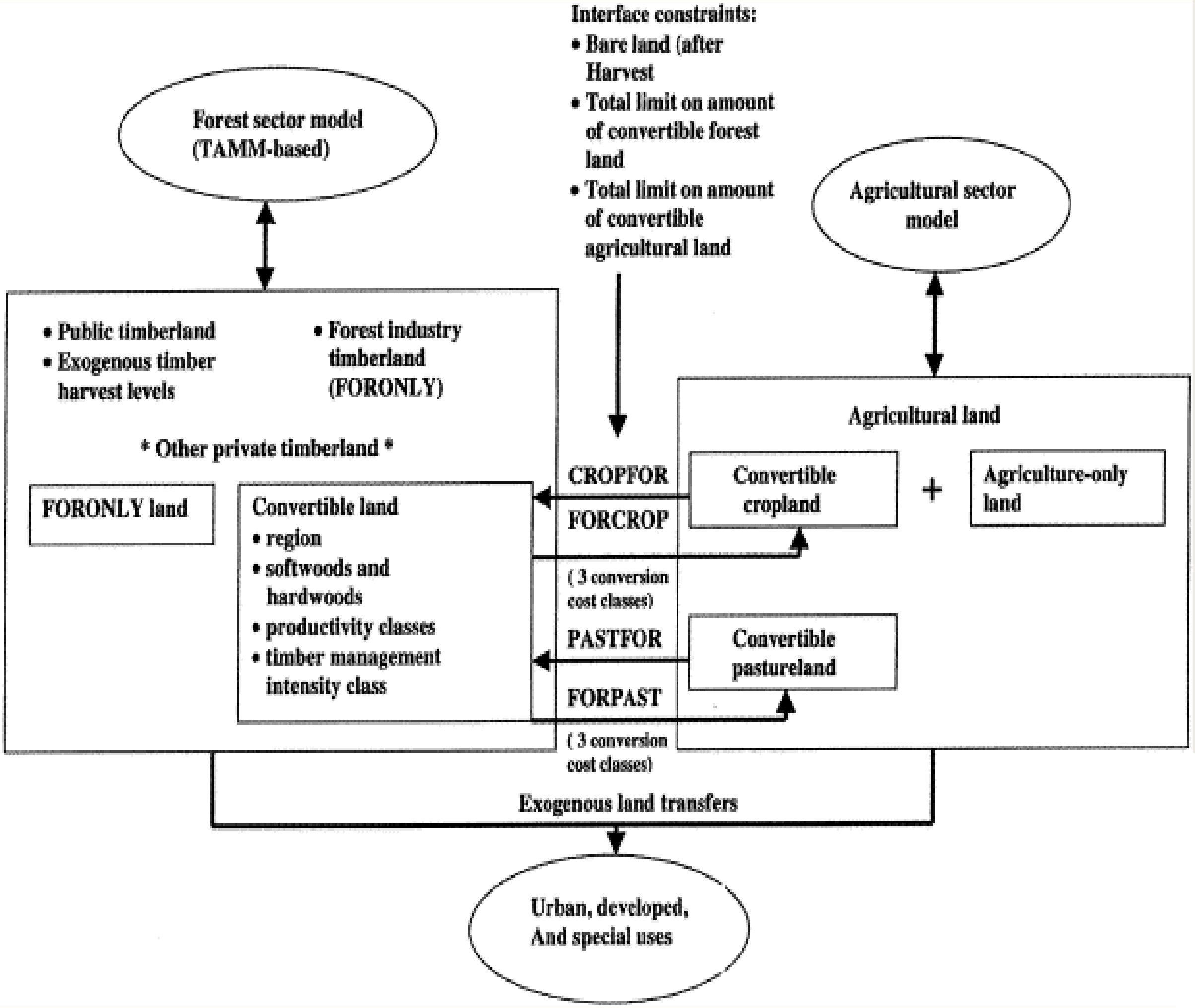


Figure 2-1. Map of the FASOMGHG Regions

Policy Scenarios

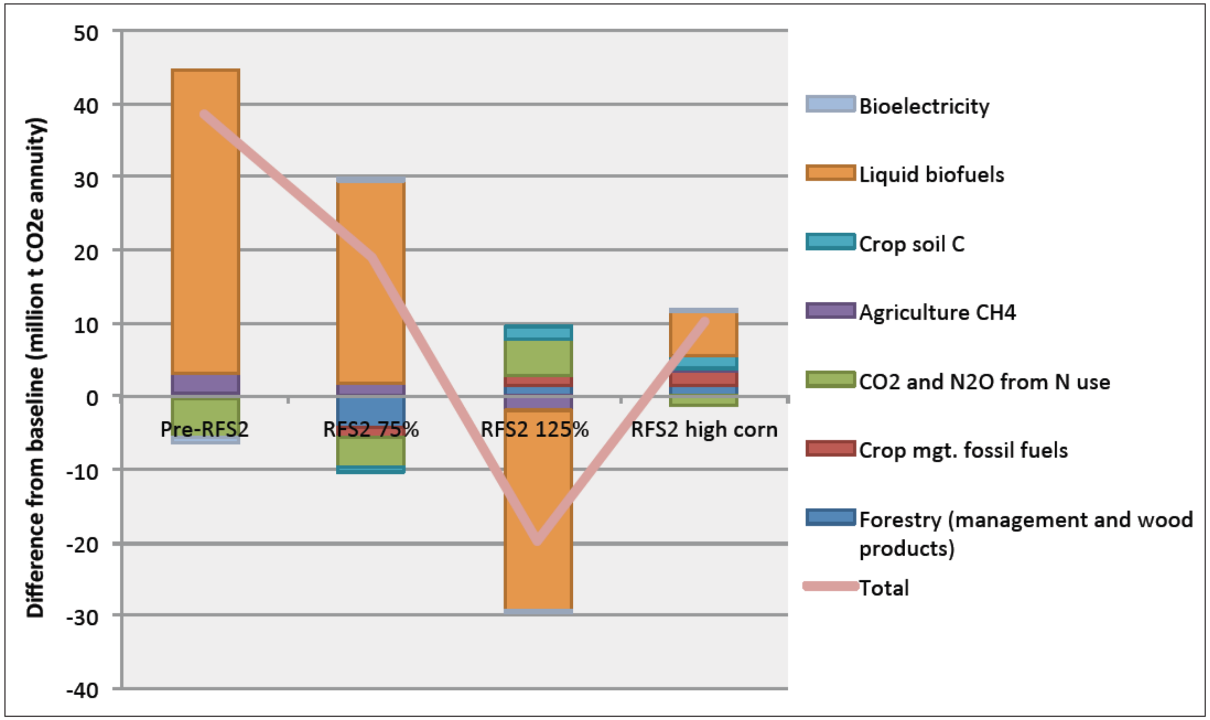
Table 12. Biofuel production mandate constraints by scenario and time period

	Biofuel output (billion gallons)	2010	2015	2020	2025	Constraint type
RFS2 baseline	Conventional ethanol	12.82	14.99	15.00	15.00	Exact
	Cellulosic ethanol	0.46	4.74	13.70	13.70	Exact
	Biodiesel	0.86	1.44	1.47	1.47	Exact
Pre-RFS2	Conventional ethanol	10.80	11.31	12.30	13.12	Exact
	Cellulosic ethanol	0.00	0.25	0.25	0.25	Lower-bound
	Biodiesel	0.33	0.36	0.37	0.40	Lower-bound
RFS2 75%	Conventional ethanol	9.61	11.24	11.25	11.26	Exact
	Cellulosic ethanol	0.34	3.56	10.28	10.26	Exact
	Biodiesel	0.65	1.08	1.10	1.37	Exact
RFS2 125%	Conventional ethanol	16.02	18.73	18.75	18.75	Exact
	Cellulosic ethanol	0.57	5.93	17.13	17.13	Exact
	Biodiesel	1.08	1.81	1.84	1.84	Exact
RFS2 high corn	Conventional ethanol	7.21	14.77	21.55	21.55	Exact
	Cellulosic ethanol	0.26	4.74	7.17	7.17	Exact
	Biodiesel	0.48	1.44	1.47	1.47	Exact

Note: "Exact" indicates a hard constraint.

Core GHG emissions result: RFS2 does reduce net emissions

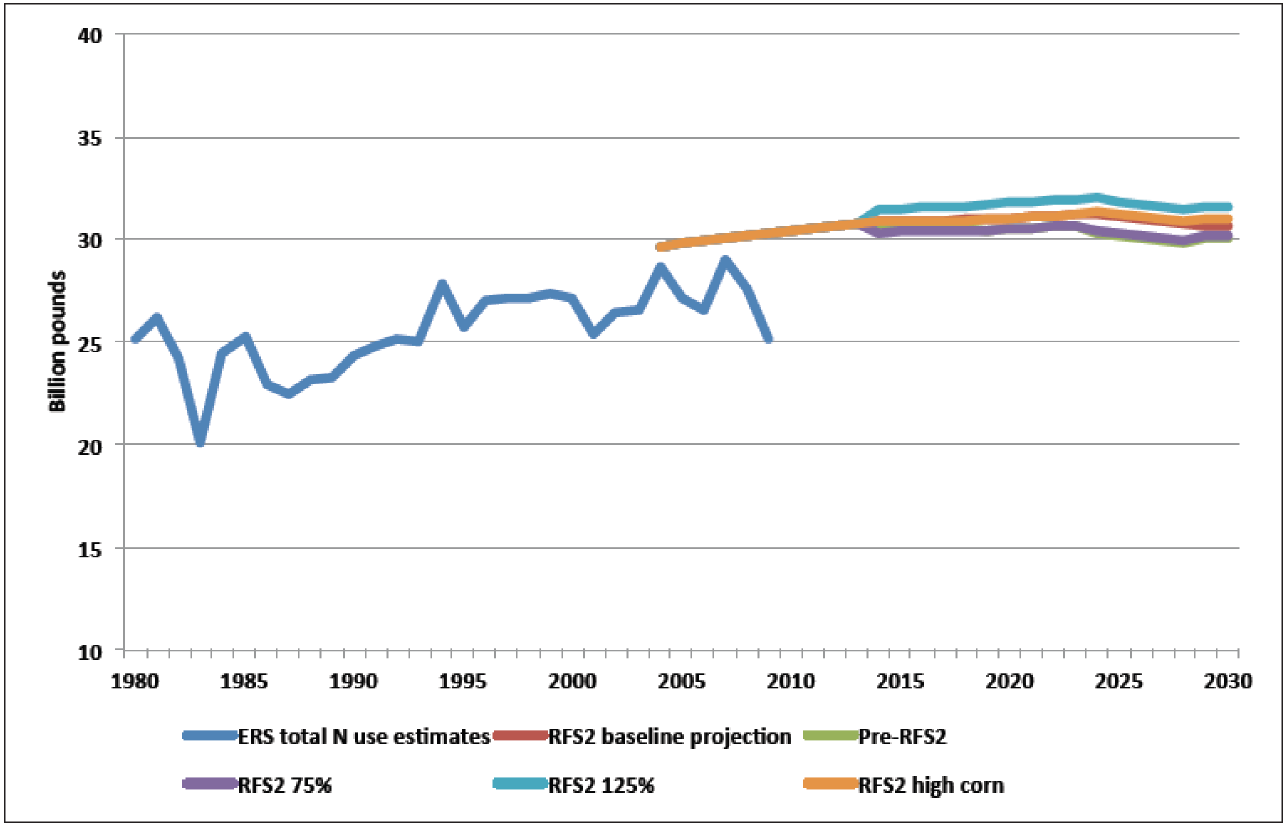
Figure 28. Annualized difference in emissions from baseline across biofuel scenarios (million t CO_2e)



Key factor – Geographic scope is US only. What if we looked globally and took in more Induced land use change?

N Use Projections

Figure 23. Comparison of historic N use to projected N use over time and by biofuel scenario



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ENERGY POLICY

Alternative U.S. biofuel mandates and global GHG emissions: The role of land use change, crop management and yield growth

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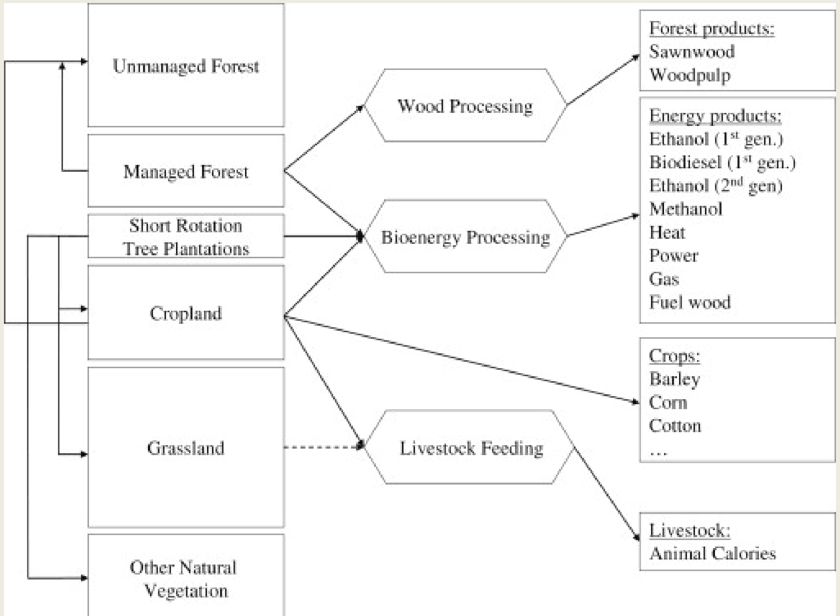
Mosnier et al, 2013

Policy: RFS2 variations (-50% to +50% of current standard, High Corn RFS2)

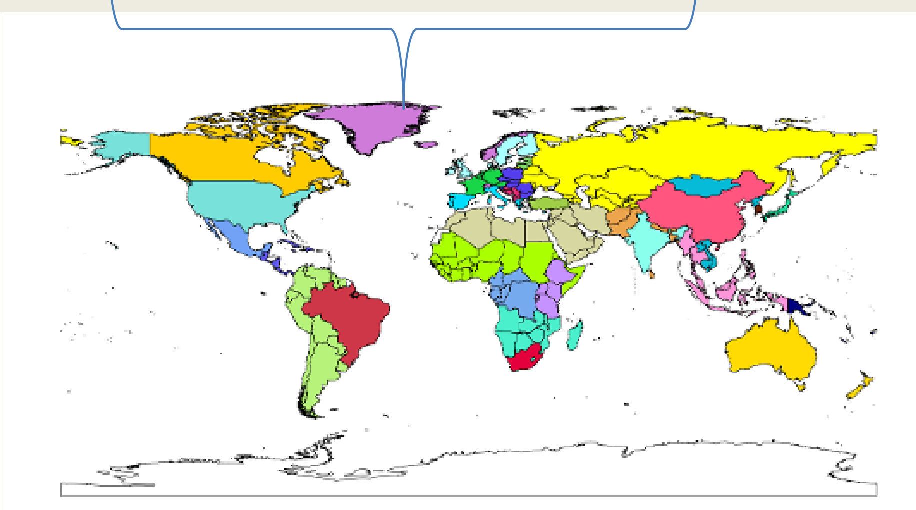
Model: Global Biosphere Management Model (GLOBIOM) with linkage to FASOMGHG
- Commodity markets and land use change

Scope of GHG coverage
- Global
- Agricultural GHGs (Co2, CH4, N2O)
- Forest (CO2)
- Includes fuel use

GLOBIOM: Sectoral and Global Integration



CO_2
CH_4
N_2O



Global markets and Resource allocation (emissions too)

Commodity Trade/Land Use Effects

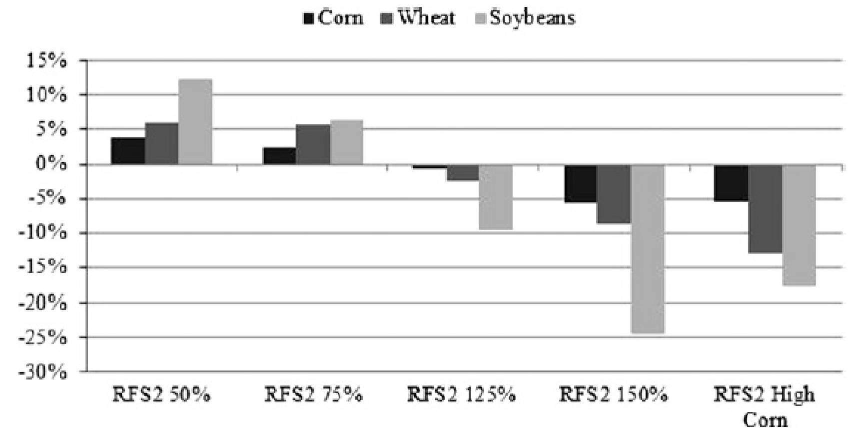


Fig. 1. U.S. net exports in five biofuel policy scenarios relative to the RFS2 baseline in 2020.

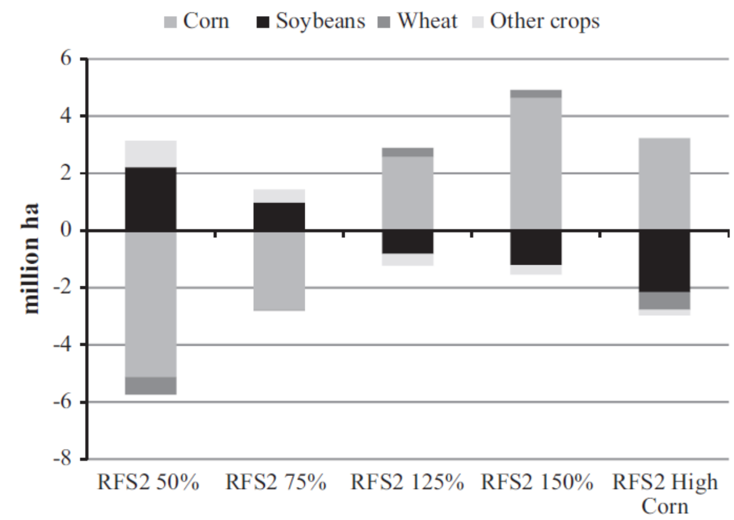


Fig. A3. Absolute area change by crop relative to the RFS2 baseline in 2020 in the United States.

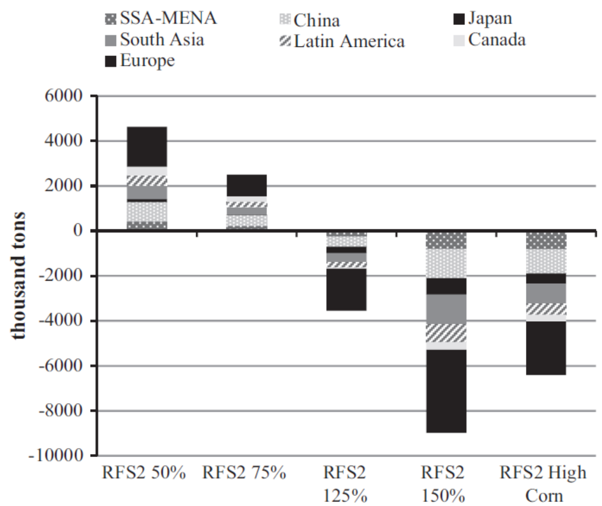


Fig. A2. Absolute differences in soybean U.S. exports by destination relative to the RFS2 baseline in 2020.

Table 2
Annualized GHG emissions by source for different U.S. biofuel targets (in million ton CO_2 equivalent).

Baseline

Source of GHG emissions	RFS2 50%	RFS2 75%	RFS2 100%	RFS2 125%	RFS2 150%	RFS2 High Corn
U.S.						
Afforestation	−23	−23	−23	−24	−24	−23
Deforestation	33	34	34	33	34	33
Other LUC	3	4	5	5	7	6
Total LUC	**14**	**14**	**16**	**15**	**17**	**16**
Crop	302	315	328	345	358	338
Livestock	225	225	226	226	226	226
Total agriculture	**527**	**540**	**554**	**571**	**584**	**564**
Fossil fuel displacement	**−59**	**−88**	**−120**	**−153**	**−185**	**−119**
Total	**482**	**467**	**450**	**434**	**416**	**461**
Rest of the world						
Afforestation	−21	−21	−20	−19	−20	−20
Deforestation	920	931	935	943	957	942
Other LUC	223	225	230	236	243	233
Total LUC	**1122**	**1135**	**1145**	**1160**	**1180**	**1156**
Crop	3477	3484	3496	3510	3520	3501
Livestock	2697	2698	2694	2695	2694	2695
Total Agriculture	**6174**	**6182**	**6190**	**6205**	**6214**	**6196**
Fossil Fuel Displacement	**−162**	**−165**	**−167**	**−169**	**−171**	**−167**
Total	**7134**	**7151**	**7169**	**7196**	**7223**	**7185**
World						
Afforestation	−44	−44	−44	−42	−43	−44
Deforestation	953	964	969	976	991	976
Other LUC	226	229	235	242	250	239
Total LUC	**1136**	**1149**	**1161**	**1176**	**1197**	**1172**
Crop	3780	3799	3824	3855	3879	3840
Livestock	2923	2923	2920	2921	2920	2921
Total agriculture	**6703**	**6722**	**6744**	**6776**	**6799**	**6761**
Fossil fuel displacement	**−221**	**−253**	**−286**	**−322**	**−356**	**−286**
Total	**7617**	**7618**	**7619**	**7629**	**7639**	**7646**

US: Raising RFS2 lowers emissions
Greater reliance on corn raises emissions

Globally: Raising RFS2 raises emissions
as does reliance on corn

Sensitivity to Projected Yield Assumptions

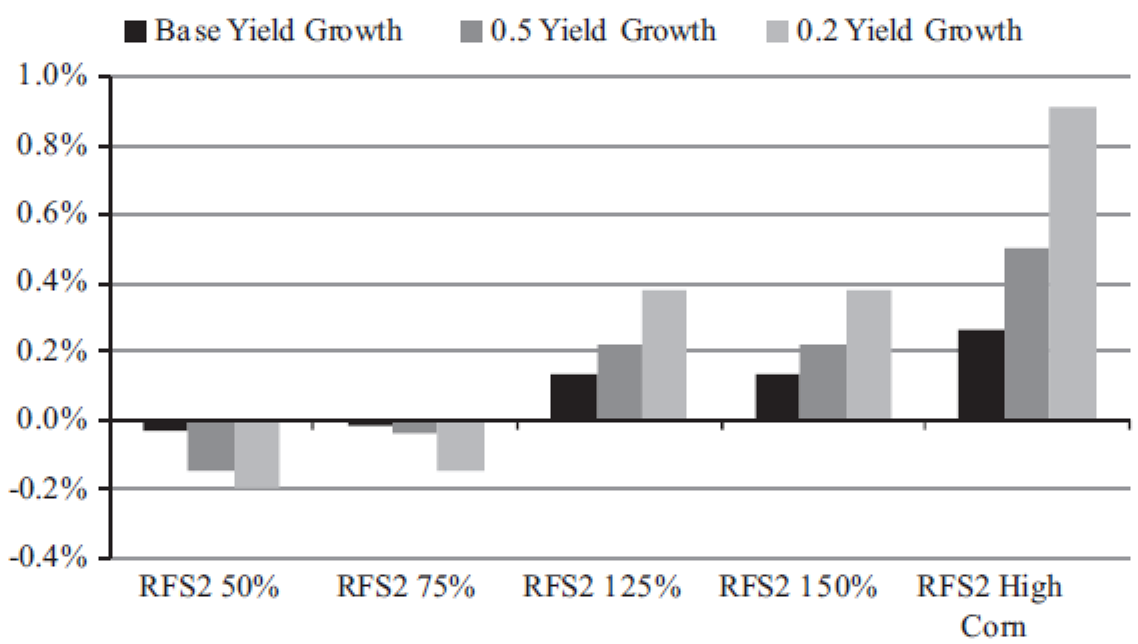
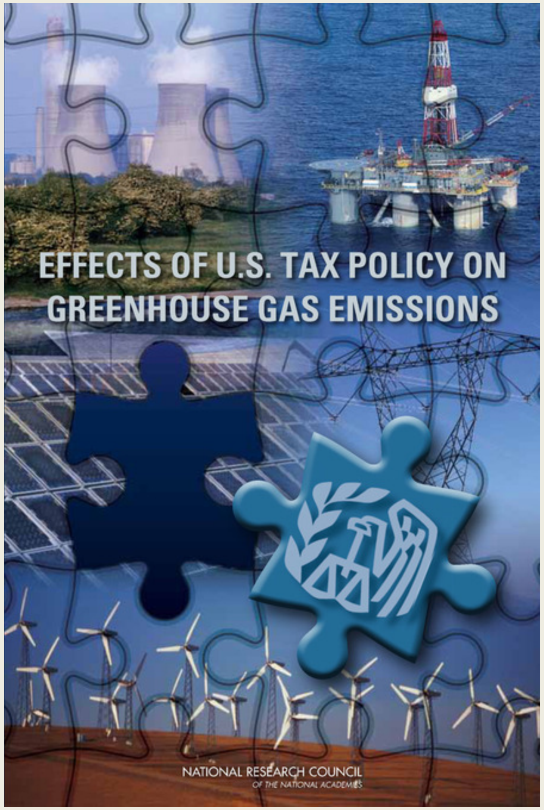


Fig. 2. Sensitivity of global annualized GHG emissions to varying assumptions about exogenous productivity growth relative to RFS2 baseline. *Note:* GHG emissions are computed as an average annuity over the 2010–2030 period with a 4% discount rate.

ILUC emissions effects are far more pronounced under more pessimistic yield assumptions



(NAS, 2013)

Policy: US Biofuel Tax Subsidies with and without RFS)

Models: FAPRI and NEMS
- Ag Commodity markets
- Biofuel markets
- Petroleum markets

Scope of GHG coverage
- Global (FAPRI) United States (NEMS)
- Agricultural GHGs (Co2, CH4, N2O)
- Fuel use
- ILUC (by varying assumptions)

Outcomes of interest
- GHG emissions
- US Treasury revenues

TABLE 5-2 Removal of Biofuel Provisions – Key Modeling Results

Key Variable (annual average, 2014-2021)	Remove VEETC			Remove all Provisions	
		Change Relative to Reference Scenario		Change Relative to Reference Scenario	
CO_2-e Emissions (MMT)		-4.8		-5.4	
Federal Expenditures ($ billion)		-7.2		-12.6	
Tons CO_2-e per $ of Revenue (calculated)		0.0007		0.0004	
	Baseline (with RFS2)	**Change Relative to Reference Scenario**	**%**	**Change Relative to Reference Scenario**	**%**
FUEL USE (billion gallons, gasoline equivalent)					
Gasoline Use					
World	360.10	+0.44	+0.1%	+0.64	+0.2%
U.S.	120.91	+1.29	+1.1%	+1.30	+1.1%
Ethanol Use					
World	27.75	-1.15	-4.1%	-2.35	-8.5%
U.S.	15.27	-1.60	-10.5%	-1.72	-11.3%
Conventional	11.90	-1.74	-14.6%	-1.75	-14.7%
Cellulosic	2.33	0.69	+29.5%	-1.58	-67.9%
Other Advanced	1.04	-0.55	-52.7%	+1.61	+154.4%
Diesel Use					
World	445.14	+0.25	+0.1%	+0.42	+0.1%
U.S.	73.20	-0.08	-0.1%	-0.11	-0.2%
Biodiesel Use					

World	9.43	0.00	—	-0.01	-0.1%
U.S.	1.31	0.00	—	0.00	—
U.S. FUEL PRICES (wholesale $ per gallon unless otherwise indicated)					
Petroleum Refiner's Cost ($/barrel)	123.47	+0.63	+0.5%	+0.91	+0.7%
Gasoline	3.52	+0.06	+1.7%	+0.07	+2.0%
Ethanol					
Conventional	2.82	-0.30	-10.5%	-0.26	-9.1%
Cellulosic	4.12	+0.21	+5.0%	-0.63	-15.3%
Other Advanced	3.27	-0.24	-7.4%	-0.07	-2.2%
Diesel	2.90	+0.02	+0.7%	+0.03	+1.0%
Biodiesel	5.51	-0.09	-1.6%	-0.11	-2.0%
CROP AREA (MM ac)					
World					
Corn	439.9	-4.27	-1.0%	-3.26	-0.7%
Soybean	278.9	+1.27	+0.5%	+1.09	+0.4%
U.S.					
Corn	93.8	-3.32	-3.5%	-2.47	-2.6%
Soybean	73.4	+1.15	+1.6%	+1.05	+1.4%
U.S CROP PRICES ($/bushel)					
Corn	5.42	-0.34	-6.3%	-0.30	-5.5%
Soybeans	11.98	-0.23	-2.0%	-0.27	-2.2%

Sensitivity to inclusion of RFS2 and to scope of ILUC coverage

TABLE 5-5 Sensitivity of GHG Impacts from Variations in Biofuel GHG Emission Coefficients: *Removing all Provisions* Scenario (All quantities are changes from baseline, million t CO_2-e, 2014-2021 annual average.)

	EISA	EPA w/ILUC	EPA w/o ILUC	High Biofuel Emissions	Low Biofuel Emissions
With RFS2	-5.4	-2.2	+3.5	-14.9	+6.7
No RFS2	-7.0	-5.6	+2.4	-14.1	+3.7

- ***RFS2 mandate limits response to removing the subsidy***
- ***Inclusion of ILUC can change the sign of the net emissions effect***

Take Home Messages

- **ILUC from biofuel policy is too important to ignore**
  - Best way to address it is through explicit connection of biofuel policy/demand – commodity markets – and land use - GHGs Broad geography gives more complete estimate, but perhaps greater room for specification error
- **Modeling estimates suggest…**

  If not a consensus, certain patterns are emerging …
  - Biofuel policy – even with high dependence on corn ethanol, can be net GHG reducer if looking just within US
  - If we look globally, the net effects tend toward net GHG neutrality/ increases from increased biofuel use, but effects are small
  - Global net emissions effects tend to be small - less than 20% of one US coal plant (NAS study)
- ***Ex post* empirical analysis should emerge to help "true up" perspectives set by *ex ante* modeling**
- **Policy implications**
  - RFS and tax subsidies are duplicative and with one in place, the other is marginally less effective
  - Aggressive biofuels policy should probably be matched with aggressive policies to raise/maintain agricultural productivity – globally
  - Need more advances in cellulosic technology
  - Underscores that biofuel policy best viewed through multiple lens – GHG, energy security, local economic development

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