CABBI
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Designing Payments for Multiple Ecosystem Services with Advanced Biofuels in the Mississippi River Basin

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What are the Ecosystem Benefits of Advanced Biofuels?

- Advanced biofuels can achieve multiple ecosystem services
  - Impacts depend on feedstocks used and locations

    -- Crop residue harvesting could

    - decrease soil carbon (C) stock and increase CO_2 emissions;
    - worsen nitrogen (N) losses.

    -- Perennial energy crops have the potential to

    - mitigate GHG emissions;
    - reduce N leakage.

How does the Current Biofuel Policy Affect Water Quality?

- Biofuel mandates focus on lifecycle GHG emissions reduction
  - ➢ Not consider water quality effects

    -- Corn ethanol mandate

    - increases N leaching and worsens hypoxia in the Gulf of Mexico

    -- Cellulosic ethanol mandate

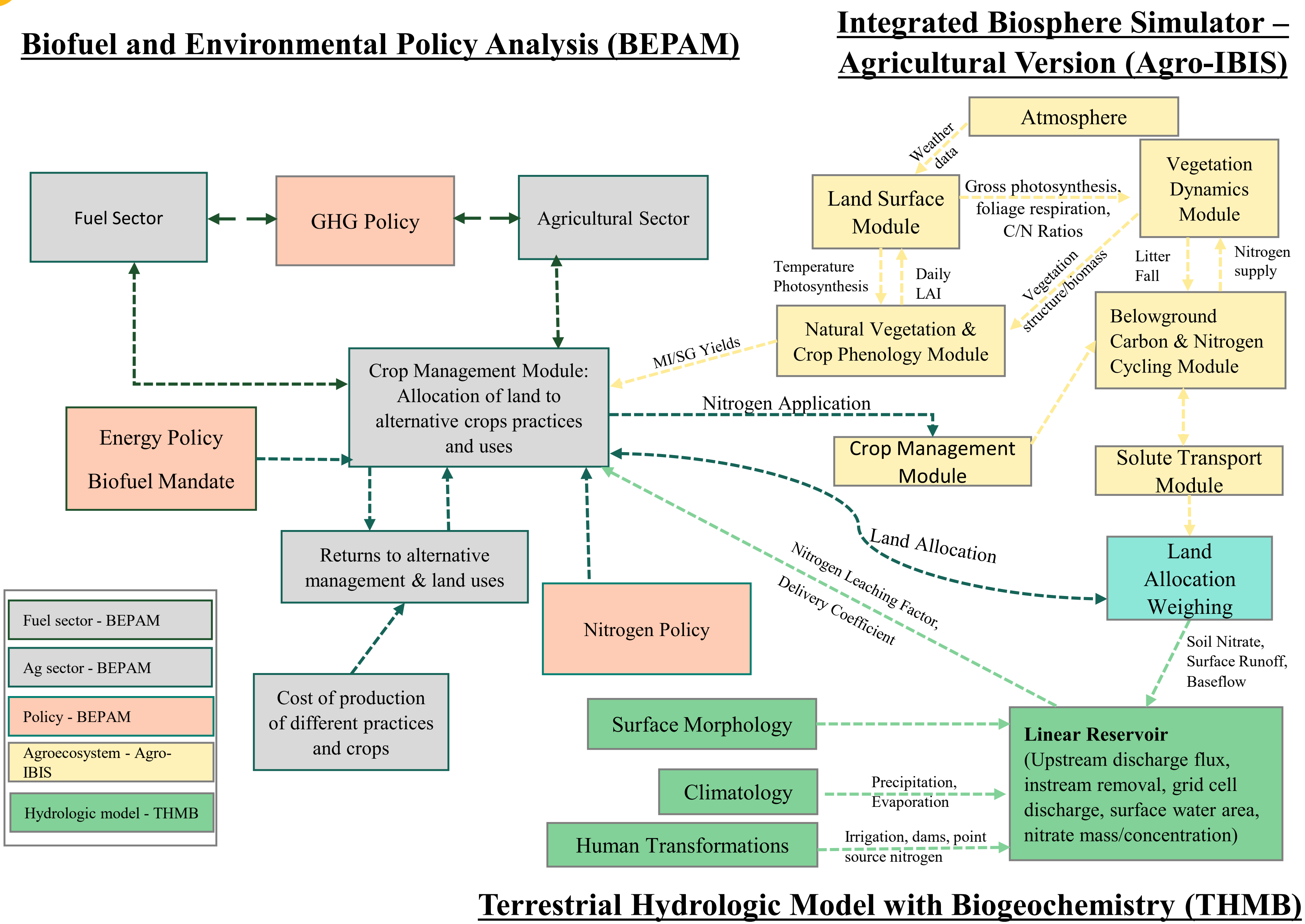
    - treats cellulosic biofuels from feedstocks that achieve GHG savings identically
    - does not create incentives for biofuels from perennial energy crops that are lower in carbon intensity and N losses while higher in costs (vs. crop residues)

Goals

- Examine the economic and environmental impacts of
  - biofuel production in response to the biofuel mandate
  - achieving GHG emission and water quality targets in addition to a biofuel mandate

Methods

- Developed an integrated modeling framework
  - linking the Economic Model--Biofuel and Environmental Policy Analysis (BEPAM) with Ecosystem Models.
- Under multiple Policy Scenarios to estimate
  - Optimal payments and welfare costs of meeting various policy targets
  - Land use change and spatial pattern of crop production
  - Food and fuel prices


Biofuel and Environmental Policy Analysis (BEPAM)
Integrated Biosphere Simulator – Agricultural Version (Agro-IBIS)
Atmosphere
Weather data
Land Surface Module
Gross photosynthesis, foliage respiration, C/N Ratios
Vegetation Dynamics Module
Temperature Photosynthesis
Daily LAI
Vegetation structure/biomass
Litter Fall
Nitrogen supply
Natural Vegetation & Crop Phenology Module
Belowground Carbon & Nitrogen Cycling Module
Fuel Sector
GHG Policy
Agricultural Sector
MI/SG Yields
Crop Management Module: Allocation of land to alternative crops practices and uses
Nitrogen Application
Crop Management Module
Solute Transport Module
Energy Policy
Biofuel Mandate
Land Allocation
Land Allocation Weighing
Nitrogen Leaching Factor, Delivery Coefficient
Returns to alternative management & land uses
Nitrogen Policy
Soil Nitrate, Surface Runoff, Baseflow
Fuel sector - BEPAM
Ag sector - BEPAM
Policy - BEPAM
Agroecosystem - Agro-IBIS
Hydrologic model - THMB
Cost of production of different practices and crops
Surface Morphology
Linear Reservoir
(Upstream discharge flux, instream removal, grid cell discharge, surface water area, nitrate mass/concentration)
Climatology
Precipitation, Evaporation
Human Transformations
Irrigation, dams, point source nitrogen
Terrestrial Hydrologic Model with Biogeochemistry (THMB)

BEPAM Overview

- Objective Function:

  Determine the allocation of land to alternative uses to maximize the sum of producers' and consumers' surpluses (social welfare) derived from production/consumption of all primary/processed products subject to technology, climate and land availability constraints.

- Constraints
  - Agricultural Sector:

    -- Market equilibrium (demand=supply)

    - Row crops: domestic demand + livestock feed + processed commodity + export
    - Biomass
    - Livestock

    -- Land availability (crop land & marginal land): row crops + grazing land

    -- Historical land constraint

    -- Productivity of the commodities and input requirements
  - Fuel Sector:

    -- Market equilibrium (demand=supply)

    - Crude oil, gasoline, diesel, and biofuel, imports and exports of fossil fuels, vehicle miles traveled

    -- Constraints of ethanol blending rate for gasoline vehicles

    -- Biofuel mandate constraints

Policy Scenarios

- Combine one biofuel mandate scenario below over 2016-2030:
  - Corn Ethanol Only:
    -- 15 billion gallons of corn ethanol only
  - Corn + Cellulosic Ethanol:
    -- 15 billion gallons of corn ethanol + 16 billion gallons of cellulosic ethanol

- With environmental targets over 2020-2030 individually and jointly:
  - N Policy:
    -- 5%, 10%, 15%, or 20% reduction target of N leaching to the Gulf of Mexico
  - GHG Policy:
    -- 5%, 10%, 15%, or 20% reduction target of GHG emissions

Results

Table 1: Effects of biofuel mandates over 2016-2030

Scenario	No Policy	Corn Ethanol Only	Corn + Cellulosic Ethanol
	($ billion)	Absolute change relative to No Policy	
Fuel Sector	7305.9	-163.0	-255.1
Agricultural Sector	3000.1	53.8	81.5
Government Revenue	854.2	-4.3	0.0
Total Welfare	**11160.2**	**-113.5**	**-173.6**
	(billion MT)	% change relative to No Policy	
Cumulative Fuel Sector Emissions	29.6	-4.1%	-7.6%
Cumulative Ag Sector Emissions	0.5	24.0%	24.4%
Cumulative Total GHG Emissions	**30.1**	**-3.6%**	**-7.0%**
	(M MT)	% change relative to No Policy	
N Leaching in 2030	**0.6**	**16.9%**	**20.0%**

Note: **No Policy** assumes corn ethanol production is at the 2007 level of 6.5 billion gallons

under Biofuel Mandate Scenarios:

- Social welfare decreases;
- GHG emissions decrease while N leaching increases.

Table 2: Optimal payments and welfare costs over 2016-2030

Scenario	Corn Ethanol Only (Baseline)	N or GHG Reduction under Corn Ethanol Only			Corn + Cellulosic Ethanol	N or GHG Reduction under Corn + Cellulosic Ethanol		
		20%NR	**20%GHGR**	**20%NR + 20%GHGR**		**20%NR**	**20%GHGR**	**20%NR + 20%GHGR**
N tax ($/kg)		**17.7**		**9.6**		**16.2**		**5.9**
C tax ($/tCO2e)			**116.1**	**115.3**			**67.3**	**66.3**
	($ billion)	**Absolute change relative to baseline**						
Fuel Sector	7142.9	-6.8	-796.7	-796.2	-92.1	-102.3	-493.7	-491.8
Agricultural Sector	3054.0	13.4	-7.0	-3.9	27.7	33.2	232.8	236.3
Government Revenue	849.9	-0.4	-52.6	-52.5	4.3	3.7	-22.2	-22.0
Total Welfare	**11046.7**	**6.2**	**-856.3**	**-852.7**	**-60.0**	**-65.5**	**-283.1**	**-277.5**

Note: **NR** denotes **N** leaching **R**eduction **and** **GHGR** denote **GHG** emission **R**eduction

- Imposing both a N tax and a C tax is more cost effective, particularly under corn + cellulosic ethanol scenario.
- Welfare tends to increase (or decrease slightly) in the agricultural sector while decrease greatly in the fuel sector.

Table 3: Cropland allocation and crop prices in 2030

	Corn Ethanol Only (Baseline)	N or GHG Reduction under Corn Ethanol Only			Corn + Cellulosic Ethanol	N or GHG Reduction under Corn + Cellulosic Ethanol		
		20%NR	20%GHGR	20%NR + 20%GHGR		20%NR	20%GHGR	20%NR + 20%GHGR
Cropland by Crop	(M Ha)	**% change relative to baseline**						
Total	114.0	-3.4%	-3.8%	-4.5%	2.1%	-0.6%	1.8%	0.2%
Corn	32.6	-4.4%	-8.0%	-9.3%	-1.0%	-5.5%	-9.5%	-10.6%
Soybeans	33.3	-1.4%	4.8%	4.1%	-1.8%	-3.1%	0.7%	-0.1%
Wheat	18.0	-6.0%	-8.4%	-9.0%	-4.7%	-9.1%	-9.0%	-12.6%
					Absolute value			
Miscanthus					5.0	5.5	8.4	8.2
Switchgrass					0.8	0.7	0.7	0.7
Crop Price	($/MT)	**% change relative to baseline**						
Corn	138.3	15.9%	-0.5%	7.1%	2.2%	16.7%	1.8%	6.9%
Soybeans	273.6	3.2%	-10.6%	-9.0%	5.2%	7.9%	0.0%	2.1%
Wheat	169.8	6.8%	15.4%	17.1%	6.1%	13.7%	15.4%	20.4%
Cropland by Rotation	(M Ha)	**% change relative to baseline**						
Corn-Soybean	47.8	-0.1%	0.0%	-2.5%	-4.1%	0.3%	-2.2%	-3.4%
CT	21.3	-1.8%	-99.2%	-99.3%	-1.8%	-7.3%	-98.8%	-99.2%
NT	26.5	1.2%	80.1%	75.6%	-5.9%	6.4%	75.8%	74.0%
Continuous Corn	8.6	-16.4%	-30.3%	-28.6%	7.6%	-21.7%	-29.8%	-30.8%
CT	0.2	8.5%	-99.4%	-99.4%	130.2%	12.7%	-58.2%	-58.2%
NT	8.4	-17.0%	-28.9%	-27.2%	5.0%	-22.4%	-29.2%	-30.3%

Note: **NR**: **N** leaching **R**eduction **and** **GHGR** denote **GHG** emission **R**eduction;
CT: **C**onventional **T**illage. **NT**: **N**o **T**illage.

Table 4: Cropland allocation in Mississippi Atchafalaya River Basin (MARB), 2030

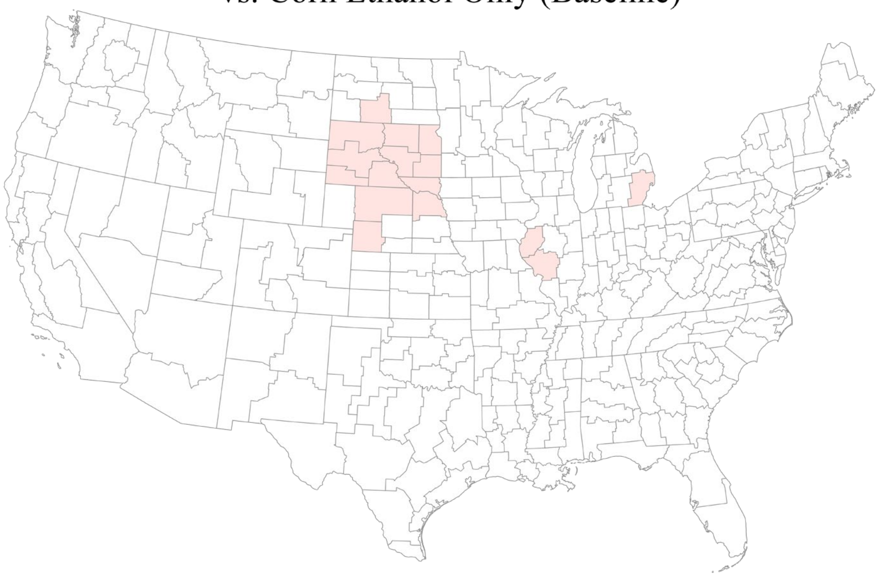
	Corn Ethanol Only (Baseline)	N or GHG Reduction under Corn Ethanol Only			Corn + Cellulosic Ethanol	N or GHG Reduction under Corn + Cellulosic Ethanol		
		20%NR	20%GHGR	20%NR + 20%GHGR		20%NR	20%GHGR	20%NR + 20%GHGR
Rotation	**(M Ha)**	**% change relative to baseline**						
Continuous Corn	5.6	-29.9%	-35.5%	-38.9%	12.8%	-32.9%	-36.7%	-40.5%
Corn-Soybean	41.1	-2.6%	0.0%	-3.6%	-4.5%	-2.1%	-2.3%	-4.2%
Continuous Soybean	5.9	10.7%	29.7%	35.3%	9.4%	2.5%	17.0%	21.2%
Continuous Wheat	11.8	-10.9%	-11.2%	-12.6%	-6.4%	-13.6%	-11.0%	-16.3%
Energy Crops					**Absolute value**			
Miscanthus					3.5	4.1	6.0	5.8
Switchgrass					0.3	0.3	0.3	0.4

Note: **NR** denotes **N** leaching **R**eduction **and GHGR** denote **GHG** emission **R**eduction

- Land under continuous corn decrease the most while land under corn+soybean rotation the least.
- Land under energy crops increases.

Figure 1: CRDs with Cropland under Continuous Corn Decreases While under Cron+Soybean Increases in 2030

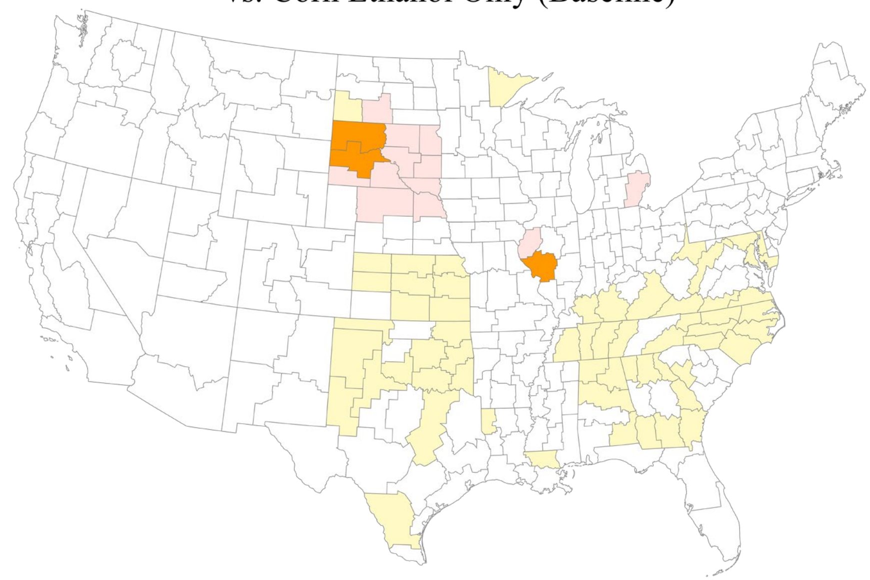
20% NR + 20% GHGR with Corn Ethanol Only vs. Corn Ethanol Only (Baseline)



Others   Δ COCO Land < 0 & Δ COSB Land > 0

Figure 2: CRDs with Cropland under Continuous Corn Decreases While under Cron+Soybean or Energy Crops Increases in 2030

20% NR + 20% GHGR with Corn+Cellulosic Ethanol vs. Corn Ethanol Only (Baseline)



- Others
- Δ COCO Land < 0 & Δ COSB Land > 0 & Δ EnergyCrop on Cropland = 0
- Δ COCO Land < 0 & Δ COSB Land = 0 & Δ EnergyCrop on Cropland > 0
- Δ COCO Land < 0 & Δ COSB Land > 0 & Δ EnergyCrop on Cropland > 0

- land under continuous corn decreasing while land under corn+soybean rotation or energy crops increasing would occur in the MARB, particularly under corn+cellulosic ethanol scenario.

Note: CRD: Crop Reporting District
MARB: Mississippi Atchafalaya River Basin

Table 5: Effects of N and GHG policy on fuel sector in 2030

Scenario	Corn Ethanol Only (Baseline)	N or GHG Reduction under Corn Ethanol Only			Corn + Cellulosic Ethanol	N or GHG Reduction under Corn + Cellulosic Ethanol		
		20%NR	20%GHGR	20%NR + 20%GHGR		20%NR	20%GHGR	20%NR + 20%GHGR
Fuel Consumption	(billion liters)	**% change relative to baseline**						
Gasoline	373.7	-0.3%	-20.5%	-20.6%	-13.1%	-13.4%	-23.2%	-23.2%
Diesel	199.5	-0.3%	-14.9%	-14.8%	-1.3%	-1.5%	-9.4%	-9.4%
Corn Ethanol	53.5	-1.0%	-22.8%	-23.1%	-0.2%	-1.6%	-24.8%	-24.9%
					Absolute value			
Cellulosic Ethanol					60.6	60.6	60.6	60.6
Corn Stover Ethanol					15.4	13.2	0.7	0.7
Miscanthus Ethanol					41.6	44.5	57.6	57.5
Consumer Fuel Price	($/liter)	**% change relative to baseline**						
Gasoline	0.7	0.9%	52.0%	52.1%	5.4%	6.3%	33.9%	33.9%
Diesel	0.6	1.1%	67.0%	66.9%	5.7%	6.8%	42.6%	42.3%
Corn Ethanol	0.7	6.0%	0.3%	3.2%	0.6%	6.2%	0.6%	2.4%
					Absolute value			
Cellulosic Ethanol					1.0	0.9	2.5	2.4

Note: **NR** denotes **N** leaching **R**eduction **and GHGR** denote **GHG** emission **R**eduction

- Fuel consumption decreases and Prices increase.

Conclusions

- Imposing payments for both C emissions and N reduction is more cost effective than payment for one environmental service alone

  -- particularly with cellulosic biofuels generating multiple co-benefits

- The addition of environmental performance goals to a biofuel mandate creates incentives to convert land

  -- from N and C intensive continuous corn to corn-soybean rotation;

  -- from row crops to energy crops in the Mississippi River Basin rather than producing energy crops only on low-cost marginal land.

- The results suggest trade-offs among economic effects and environmental benefits

Thank you very much!