Case Studies on Variability in LC GHG Emissions of Biofuels

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MichiganTech

Case Studies

- Data Sources:
  - Comparison of LCA Software Platforms on Algae Renewable Diesel LCA (GREET and SimaPro)
- Accounting–Allocation:
  - Jatropha Hydro–Renewable Jet (HRJ) LCA in the Yucatan of Mexico (USA RFS and EU RED)
- System Boundary:
  - Forest C Stock Changes and Biofuel / Biopower LCA in the UP of Michigan

Data Sources: Algae Renewable Diesel

- Algal Biology, Cultivation, Harvest & Extracting, Fuel Conversion, Co-Products, Sustainability

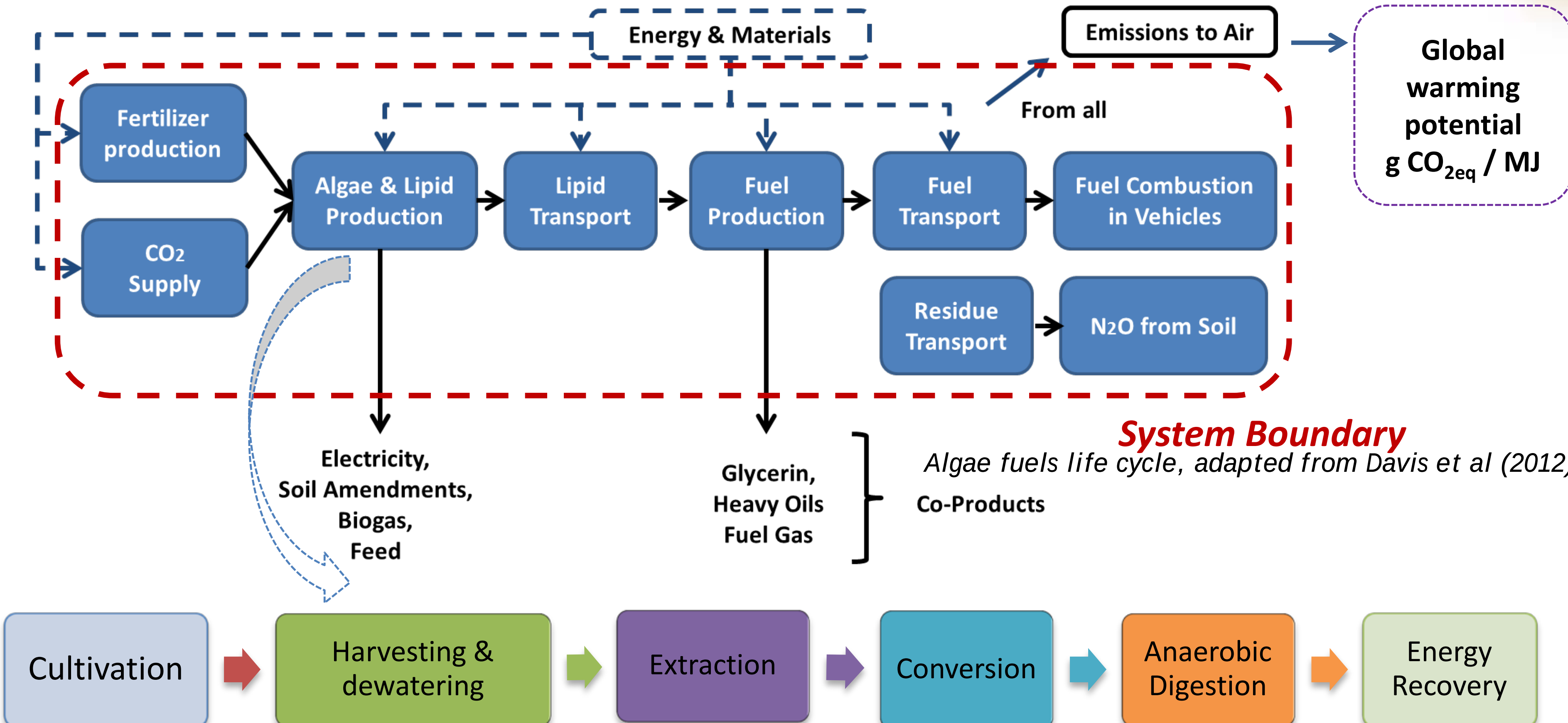
National Alliance For Advanced Biofuels and Bio-products

- **Sustainability Team** – Economic, Environmental

- **Michigan Tech**
  - Cultivation infrastructure impacts
  - Variations to baseline scenario
  - New technology (Harvesting, Extracting, Fuel Conversion)
  - Alternate co-product uses
- **Life-cycle assessment** (LCA) approach
  - GHG emissions / MJ fuel product

Life Cycle Stages of Algae Biofuel

- Translate inputs (Energy, materials,) → environmental impacts
- Baseline inputs, life cycle structure from GREET Model
- Hybrid allocation method (Energy / displacement combination)



Algae fuels life cycle, adapted from Davis et al (2012)

Comparison of SimaPro & GREET Model Life Cycle Results for Renewable Diesel

Algae renewable diesel production	GHG emissions (g CO_2 eq/ MJ)	
Item	SimaPro	GREET
CO_2 procurement	8.2	4.8
Growth/1st dewatering	60.9	33.3
Remaining Dewatering	18.2	8.7
Extraction	48.6	34.6
Transport of algal oil to conversion	1.1	0.6
Fuel conversion	9.6	9.6
Anaerobic digestion process	25.6	20.9
Biogas cleanup and transfer of CO_2 to pond	19.1	9.7
CHP credit (heat &electricity)	-116.0	-58.6
Soil application of AD residue	5.8	7.2
Fertilizer displacement	-4.7	-7.4
transport to fuel blending	0.5	0.6
Total	**77.0**	**64.1**

Diesel 90.1

Comparison of SimaPro & GREET Model Life Cycle Results

Major differences due to electricity

- ❑ GREET: Electricity sources generated on site

  LEA → Anaerobic digestion → Biogas combustion

- ❑ Different emission factors of US grid electricity

  – GREET : e-Grid database – SimaPro: ecoinvent™

	NG conversion efficiency	Transmission & distribution loss factor	Source of biomass	Electricity-generating oil
GREET	45%	6.5%	Wood/switch grass/miscanthus/ forest residue	11.74 MJ heavy fuel oil - 1Kwh
SimaPro	35%	8.5%	Wood	9. 4 MJ heavy fuel oil - 1Kwh

Comparison of SimaPro & GREET Model Life Cycle Results

The U.S. generation mix

Source	GREET		SimaPro		Difference between two databases
	Generation Mix	Emissions factor g /kwh	Generation Mix	Emissions factor g /kwh	
Oil	1.0%	1092	3.3%	935	14%
NG	23%	623	17.4%	684	-10%
Coal	46.4%	1120	49.7%	1190	-6%
Biomass	0.3%	102	1%	30.1	71%
Nuclear	20.3%	14.4	19.7%	12.8	12%
Other	9.8%	3.90	8.9%		
Total, stationary use	**100%**	**670.5**	**100%**	**751**	**-12%**

Comparison of SimaPro & GREET Model Life Cycle Results

Algae RD production	$g\ CO_2\ eq/MJ$			
Item	GREET	SimaPro using Ecoinvent emission factors	SimaPro using GREET electricity emission factor	Remaining difference due to different emission factors of
CO_2 procurement	4.8	8.2	4.8	
Growth/1st dewatering	33.3	60.9	35.9	Ammonia/ Nutrients
Remaining Dewatering	8.7	18.2	9.7	Chitosan
Extraction	34.6	48.6	34.4	Hexane
Transport of algal oil to conversion	0.6	1.1	1.1	Transportation
Fuel conversion	9.7	9.6	9.3	Hydrogen, natural gas
recovery	20.9	25.6	20.8	
Biogas cleanup and transfer to pond	9.7	19.1	9.6	
CHP credit (heat &electricity)	-58.3	-116	-58.7	
Soil application of AD residue	7.4	5.8	5.8	Transportation
Fertilizer displacement	-7.4	-4.7	-4.7	Nitrogen, carbon, phosphorus
Transport to fuel blending	0.6	0.5	0.5	Transportation
Total	**64.1**	**77.0**	**68.6**	

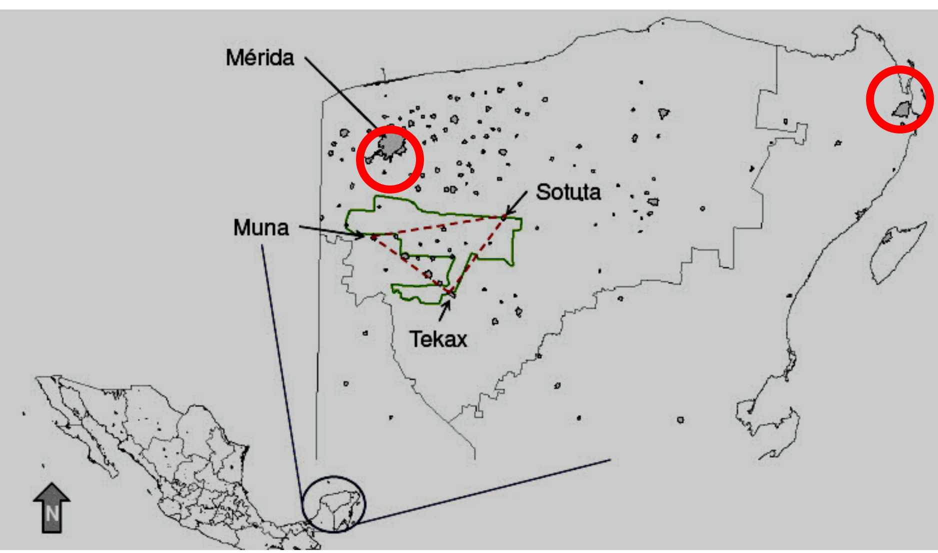
Accounting: Allocation Method

- How do we split the bill? Allocation method for co-products:
  - Energy (simple; Lower Heating Values)
  - Mass (Bias with high added-value products)
  - Market value (Subject to ‘arbitrary’ external changes; very dynamic)
  - System expansion (Displacement allocation)
- Different methods give very different results

Jatropha HRJ in the Yucatan of Mexico

- Case study: LCA of Green Jet fuel production from jatropha oil

Jatropha Cultivation Harvesting → Jatropha Biomass Transport → Jatropha Oil Extraction → Jatropha Oil Transport → Jatropha GJ Production → **Green Jet fuel**

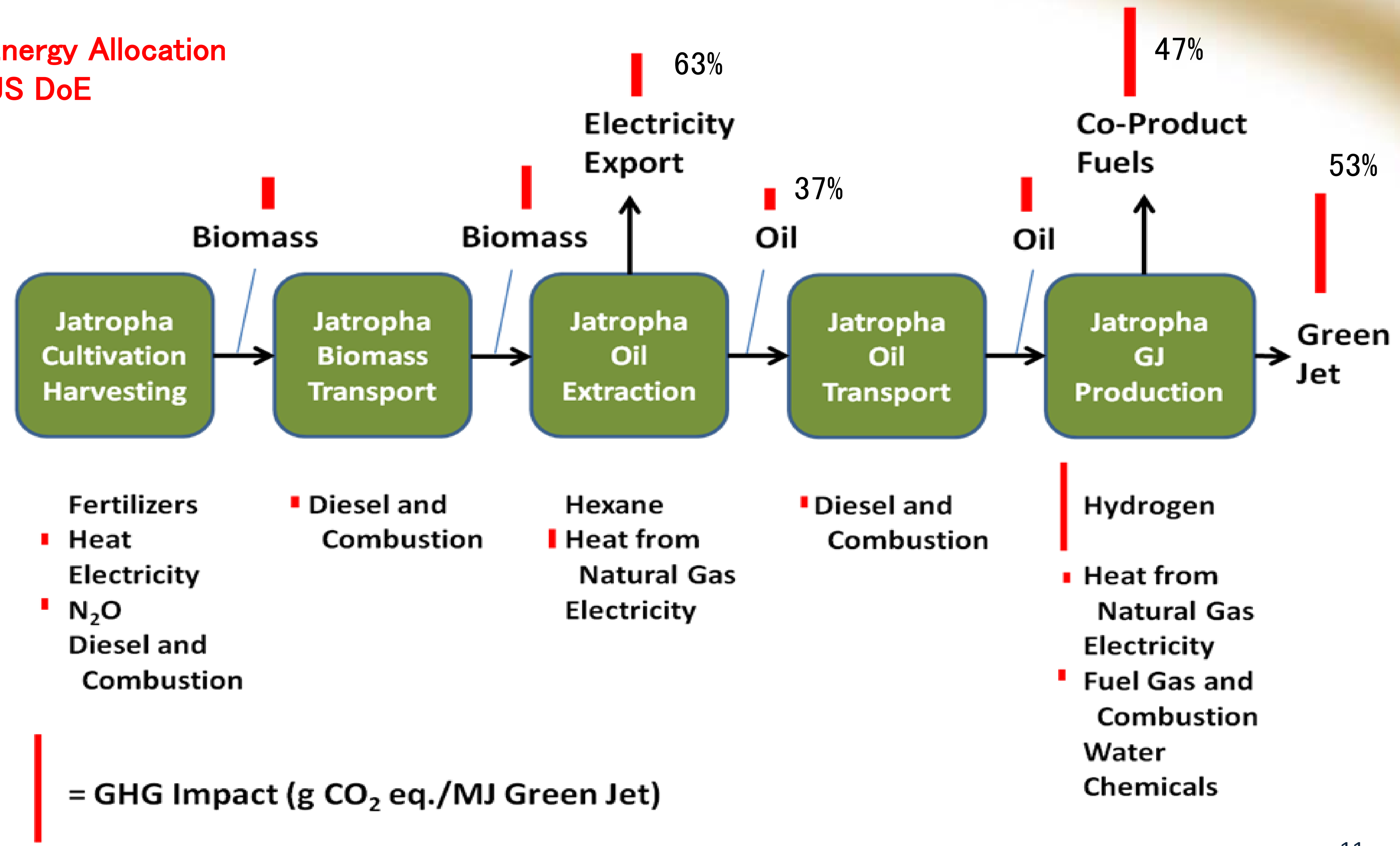


Plantation area: 55,000 ha

Production: 10 ton/ha/a wet seed

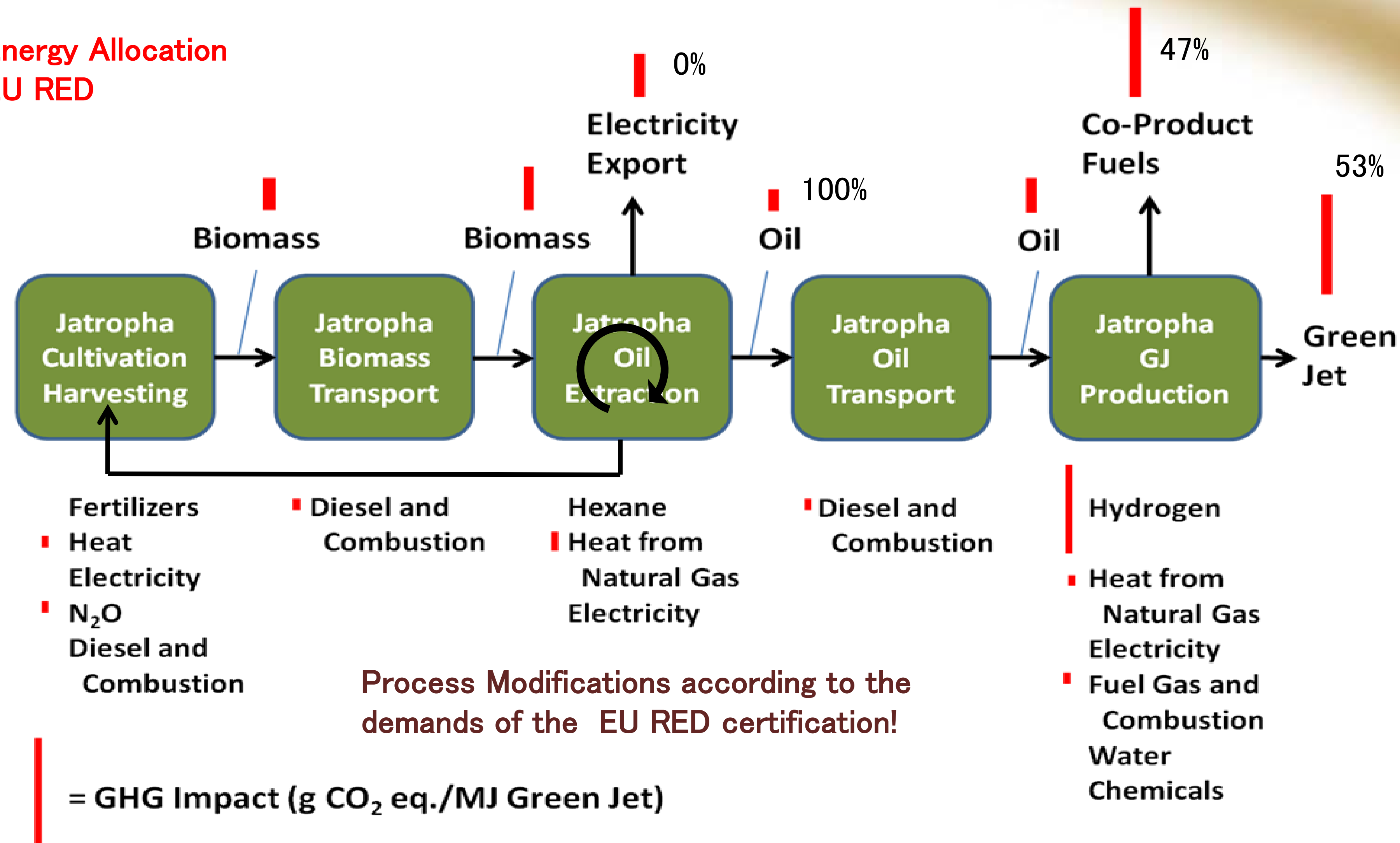
Challenges in LCA: Allocation

Energy Allocation
US DoE



Challenges in LCA: Allocation

Energy Allocation
EU RED

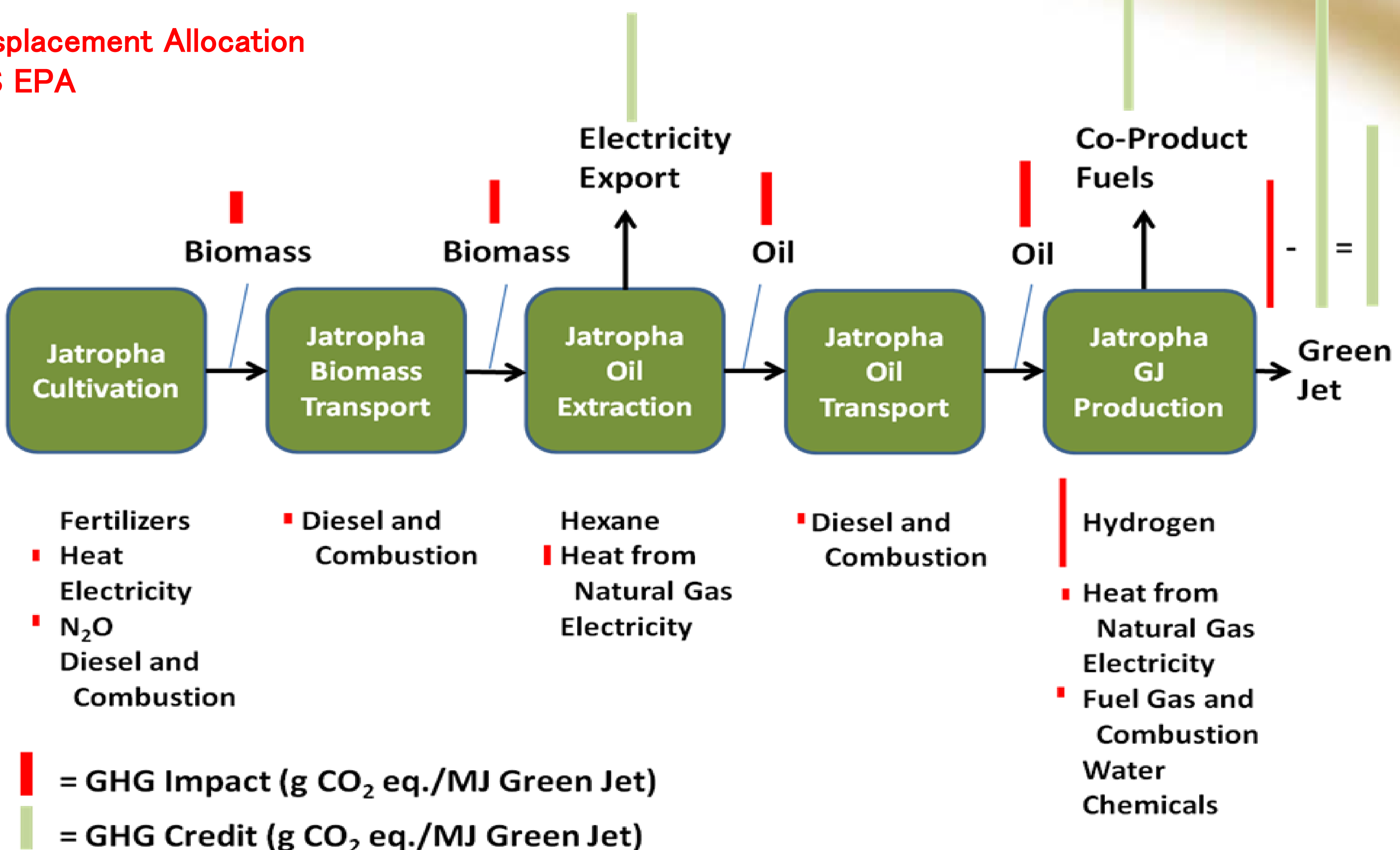


Process Modifications according to the demands of the EU RED certification!

= GHG Impact (g CO_2 eq./MJ Green Jet)

Challenges in LCA: Allocation

Displacement Allocation
US EPA



Challenges in LCA: Allocation

GHG Emissions (g CO2 eq/MJ of Green Jet) →	Fossil Jet*	US DoE	US EPA	EU RED
Jatropha Cultivation/Harvest (RMA)	6.8	1.5	7.8	1.8
Jatropha Seed, Shell Transport (RMT)	1.3	0.5	2.5	0.4
Combined Seed,Shell,Oil Transport				
Jatropha Oil Extraction		1	5.2	0.2
Jatropha Oil Transport		0.7	1.3	0.7
GJ Production from Jatropha Oil (LFP)	6	16.4	30.7	14.6
Combined Oil Extraction and GJ Production				
Co-Product Credit Extraction Stage			-61.4	
Co-Product Credit GJ Production Stage			-70	
Final Product Transport	1			
Fossil Jet Fuel Combustion	77.7			
Direct Land Use Change (dLUC)				
Total	**92.9**	**20.1**	**-83.9**	**17.7**
Savings, %		**78.4**	**190.3**	**80.9**

US DoE: Energy allocation

US EPA: Displacement allocation

EU RED: Energy allocation; no credit for electricity cogeneration

* From Skone and Gerdes, 2008, Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels, DOE/NETL-2009/1346, November 26, 2008. RMA = Raw Material Acquisition,

RMA = Raw Material Acquisition; RMT = Raw Material Transport, LFP = liquid fuel production

System Boundary: Biofuels and Bioenergy from Michigan Forest

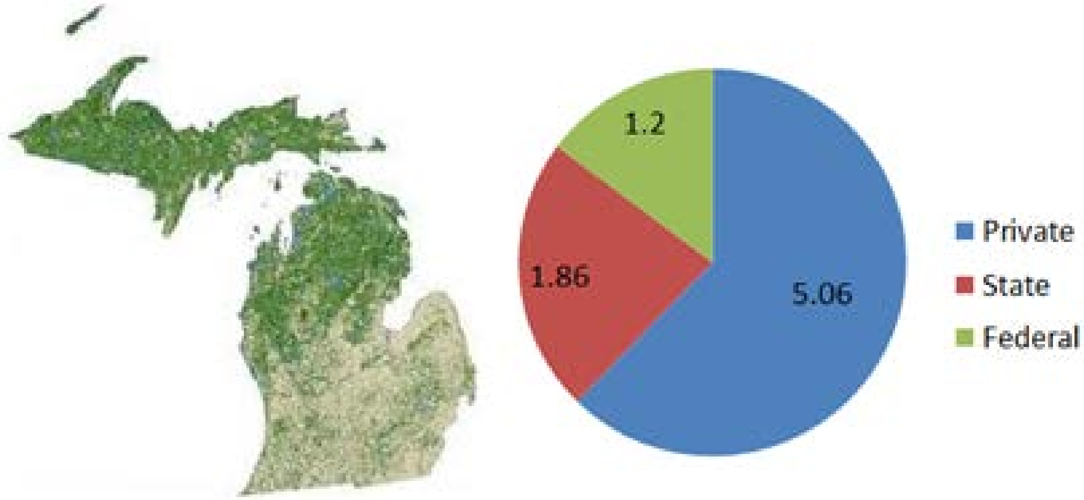


Figure 1: MI forestland and landownership (in million ha)

LCA Model

Biofuels
- cellulosic ethanol
- pyrolysis bio-oil (pyoil)

Bioenergy
- electricity from pyoil

Forest Carbon Stocks
- Business as Usual (BAU)
- Intensive Harvesting

- **Forest growth is 3x harvest removals**
- **Harvesting above current levels could provide biomass for biofuel and bioenergy**
- **However, forests globally contain 55% of terrestrial Carbon**

CBM-CFS3 model

Table: carbon pools in the CBM-CFS3 and pools recommended by IPCC GPG

CBM-CFS3 pools	IPCC GPG pools
Merchantable & bark (SW, HW)	Aboveground biomass
Other wood & bark (SW, HW)	Aboveground biomass
Foliage (SW, HW)	Aboveground biomass
Fine roots (SW, HW)	Belowground biomass
Coarse roots (SW, HW)	Belowground biomass
Snag Stems DOM (SW, HW)	Dead wood
Snag branches DOM (SW, HW)	Dead wood
Medium DOM	Dead wood
Aboveground fast DOM	Litter
Aboveground very fast DOM	Litter
Aboveground slow DOM	Litter
Belowground fast DOM	Dead wood
Belowground very fast DOM	Soil organic matter
Belowground slow DOM	Soil organic matter

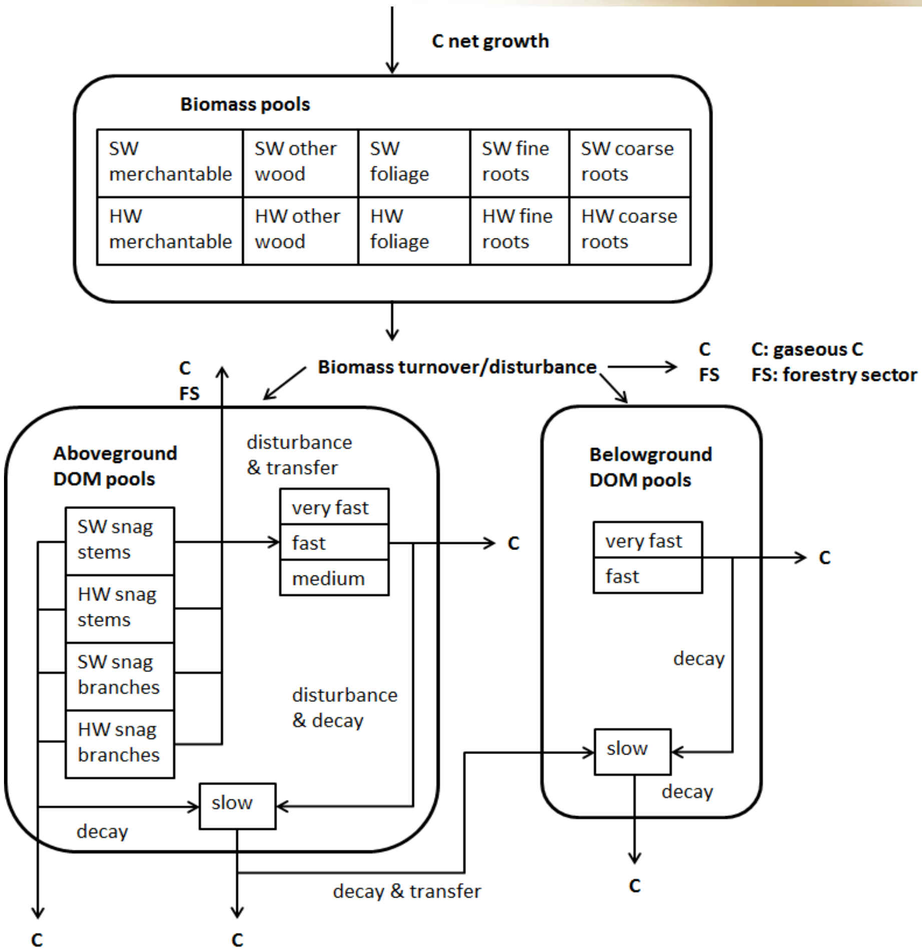
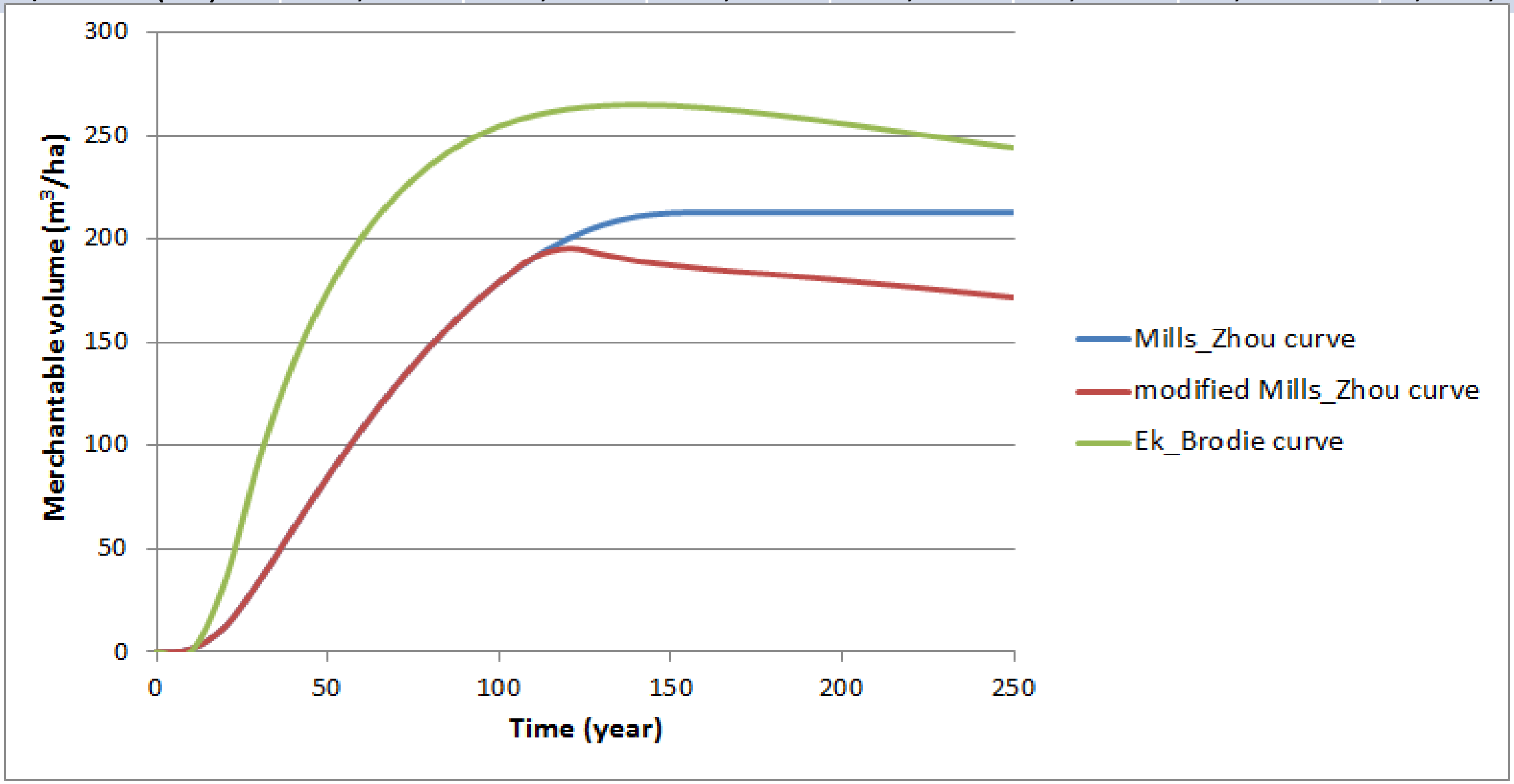


Figure: C flow between biomass and DOM pools in the CBM-CFS3 (adapted from Kurz et al, 2009)

MI aspen harvesting

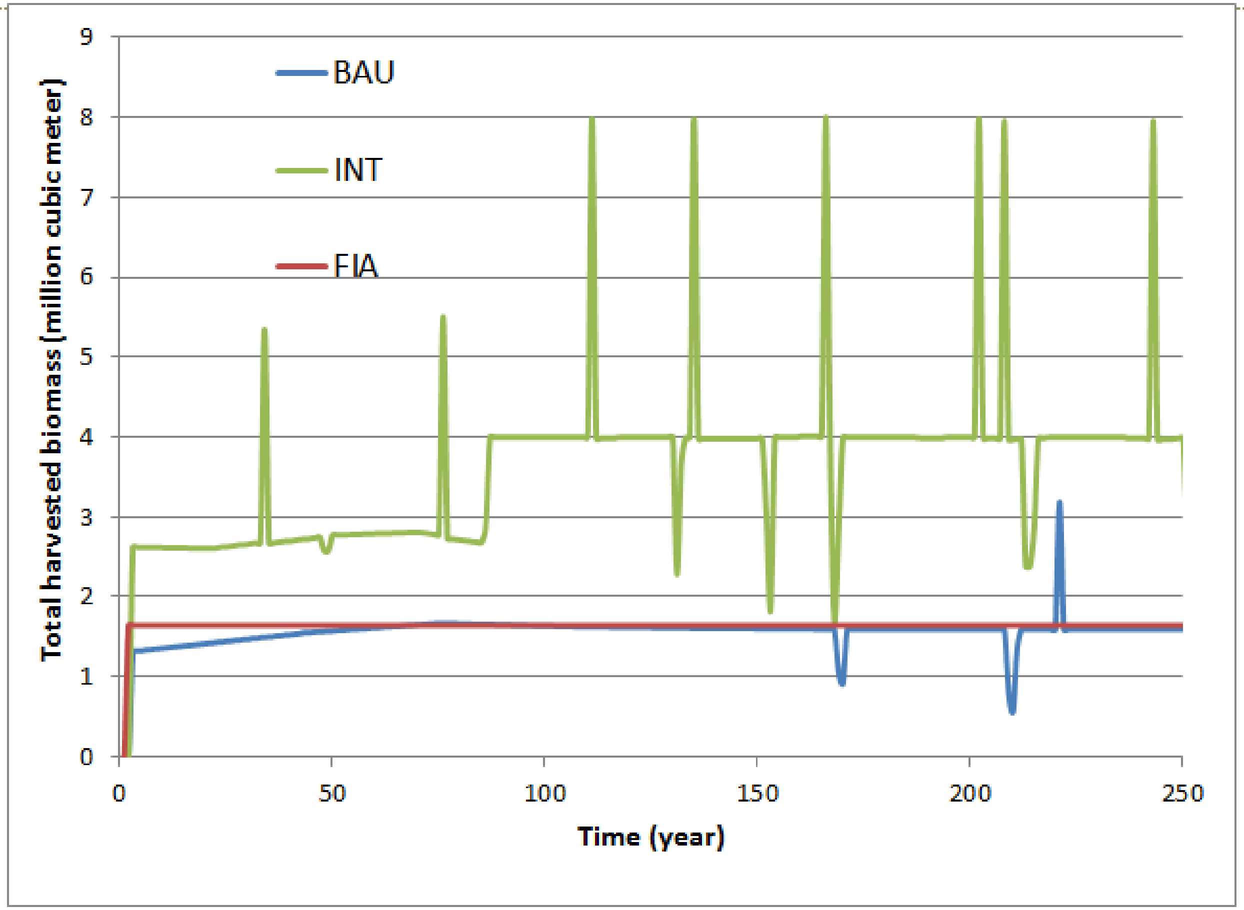
Table: Current age distribution (in ha) of aspen in Michigan (USDA 2013)

Age (yr)	0-19	20-39	40-59	60-79	80-99	100-119	Total
Aspen/birch (ha)	225,000	311,000	385,000	278,000	87,000	13,000	1,299,000



Assumed growth curves of aspen in Michigan

Harvested biomass: Business as usual (BAU) and intensive (INT) harvesting



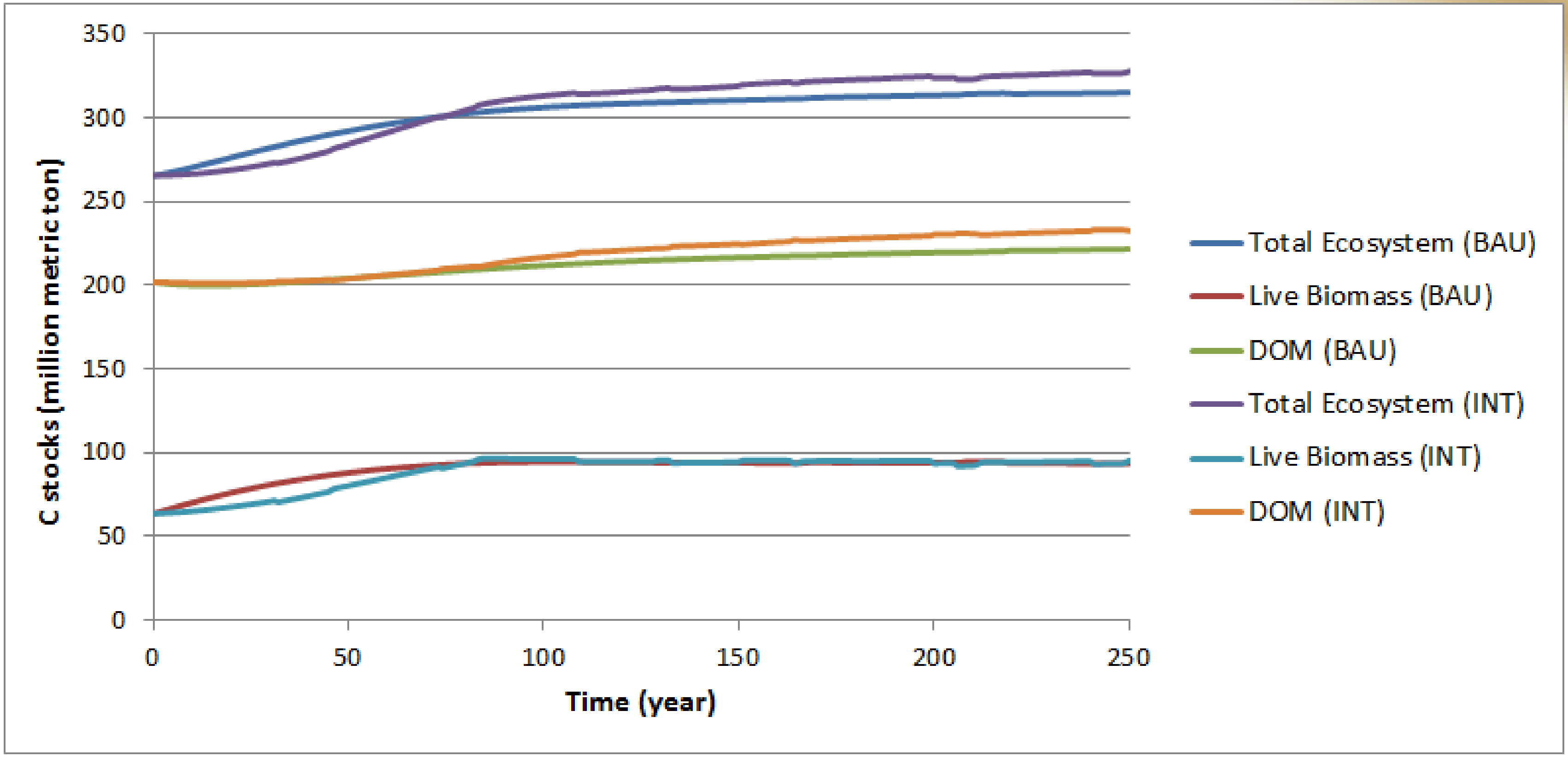
Total biomass harvested in the BAU and INT scenarios over 250 years

In the BAU scenario, 7200 ha of aspen is assumed to be harvested every year

INT doubles the harvest to 14400 ha

The extra biomass (205 million metric tons over 250 yr) is used for biofuel and bioenergy production.

Forest C stocks



Ecosystem C stored in the BAU and INT scenarios

CO_2 emissions due to dLUC

$$CO_2\,(t) = \frac{C^{BAU}_{storage(t)} - C^{INT}_{storage(t)}}{\sum_1^t biofuel} * \frac{44\ g\ CO_2}{12\ g\ C}$$

Assuming all C transferred to atmosphere as CO_2

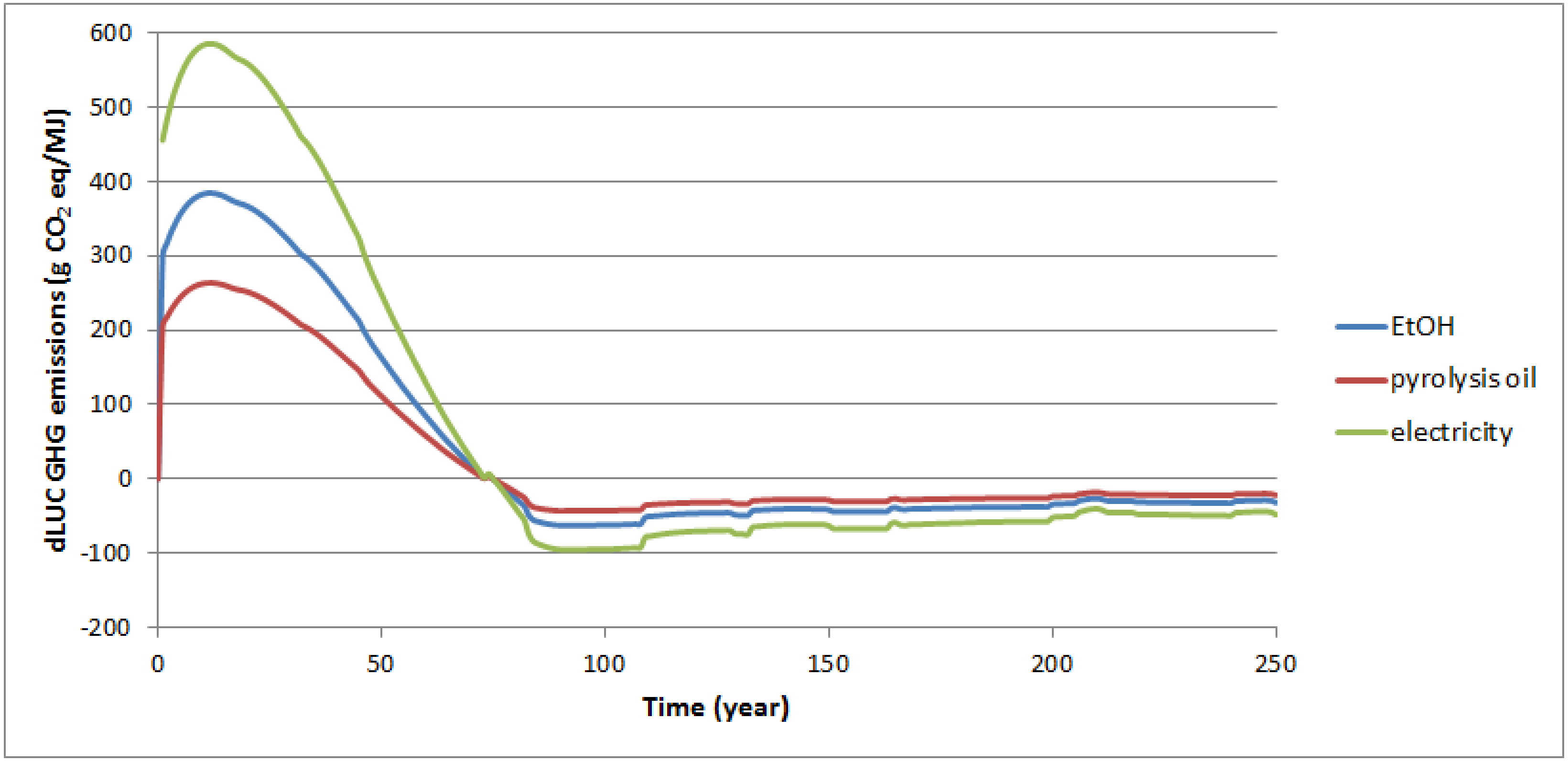
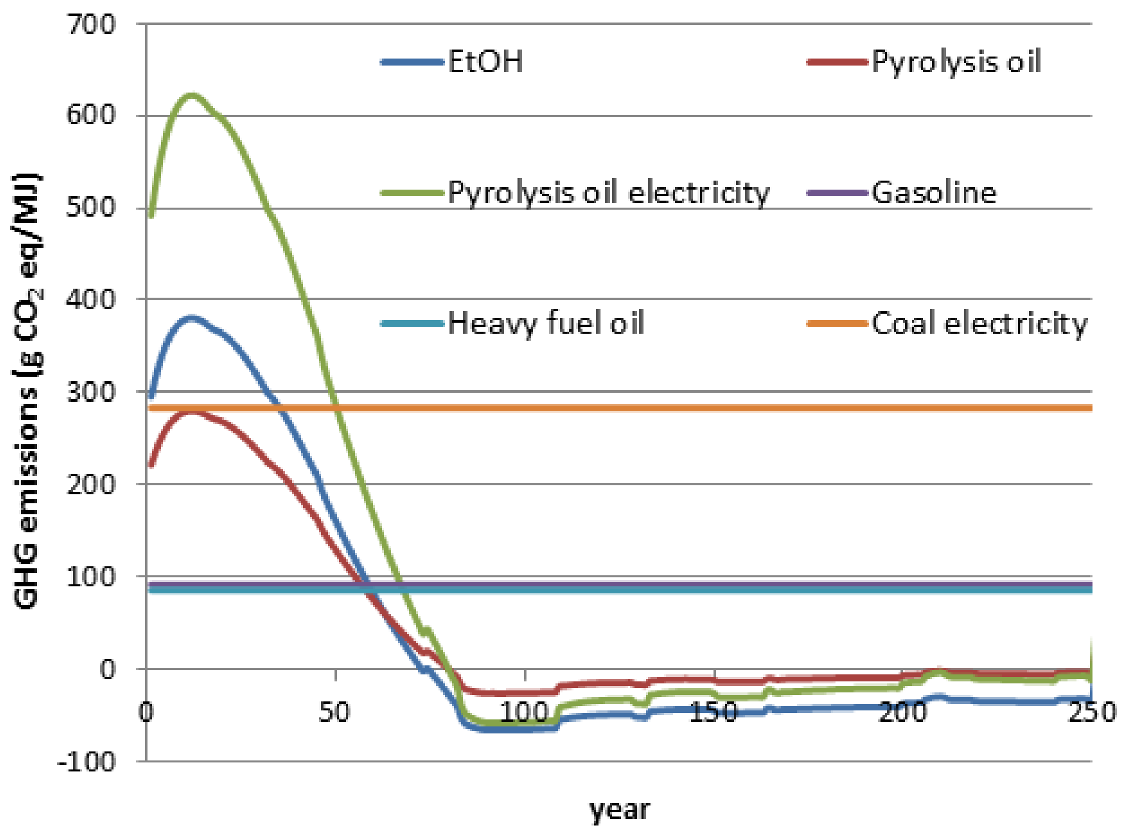


Figure: dLUC of biofuel and bioenergy over 250 years

Life cycle GHG emissions of biofuels and bioenergy



GHG emissions (w/dLUC) of EtOH, pyrolysis oil and electricity over 250 years, comparing to their petroleum counterparts

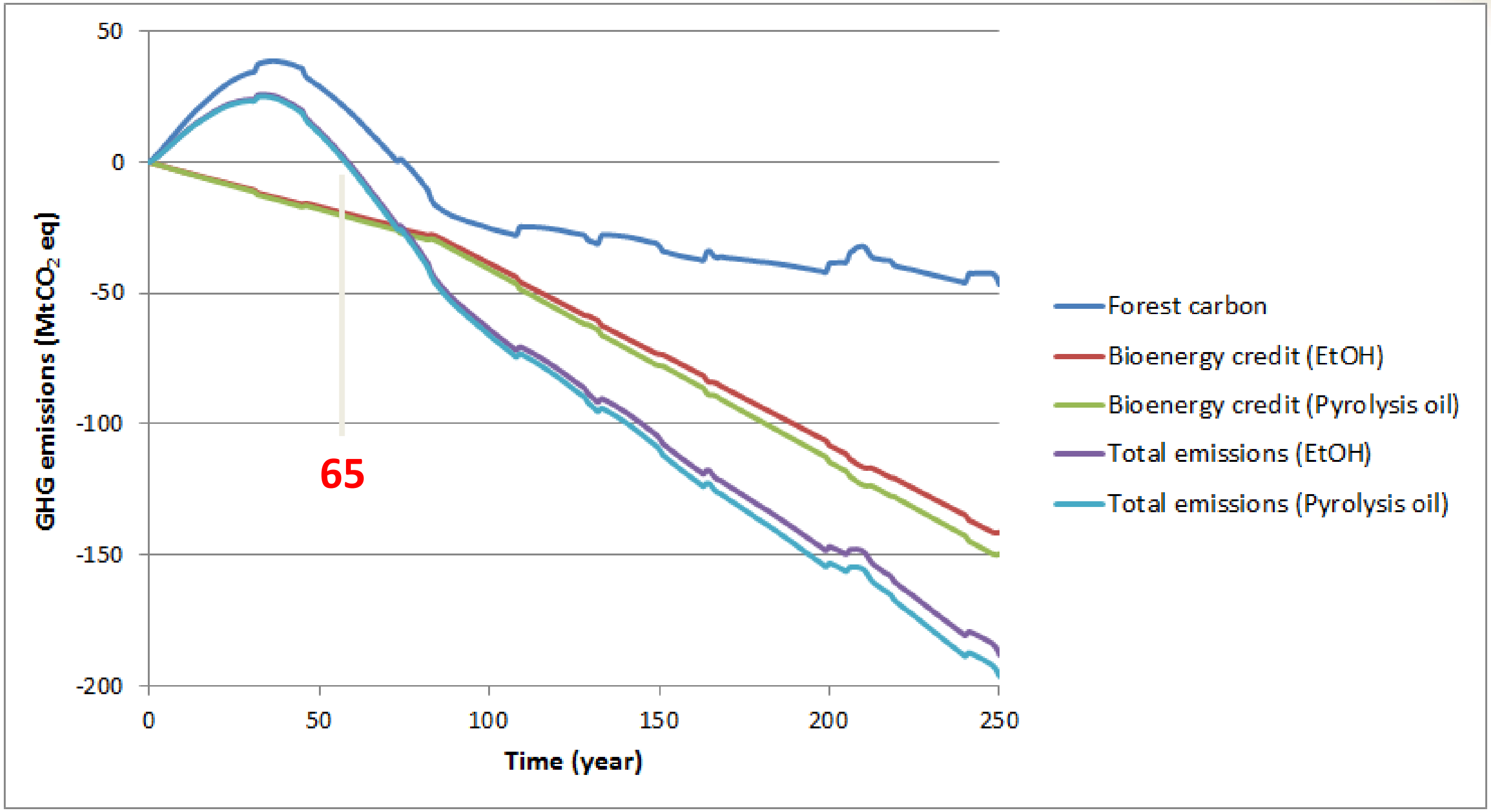
GHG emissions w/o LUC:

- **EtOH: -3.74 g CO_2 eq/MJ (GREET 2012)**
- **Pyrolysis oil: 16.35 g CO_2 eq/MJ (Fan, 2012)**
- **Pyrolysis electricity: 130.8 g CO_2 eq/kWh (Fan, 2012)**

Bioenergy system total emissions

$$GHG_{tot(t)} = \Delta FC(t) + GHG_{bio(t)}$$

(Mckechnie, 2011)



Total GHG emissions of forest-based biofuels system

Closing Remarks

- Data Sources: Inventory databases each have advantages and limitations, but detecting and eliminating errors remains a high priority.
- Accounting: Different regulatory environments will force biofuel LCA practitioneers to meet evolving methodology constraints
- System Boundary: The path to biofuel sustainability will involve ever broader system scope and boundaries in biofuel LCA.