Michigan Biomaterials Conference

Evaluating Forest Biomaterials with Environmental Life Cycle Assessment

Hosted by Michigan Society of American Foresters
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Sustainable Futures Institute

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Overview

- Role of MI forests in environmental protection and ecosystem services
- The importance of forests in global carbon and greenhouse emissions
- Case Study: Environmental Life cycle assessment (LCA) to understand impacts of forest products on greenhouse gas emissions.

Ecosystems - Management

Water Quality/ Quantity

Climate Mitigation

Air Quality

Biodiversity

Human Communities

Primary Production

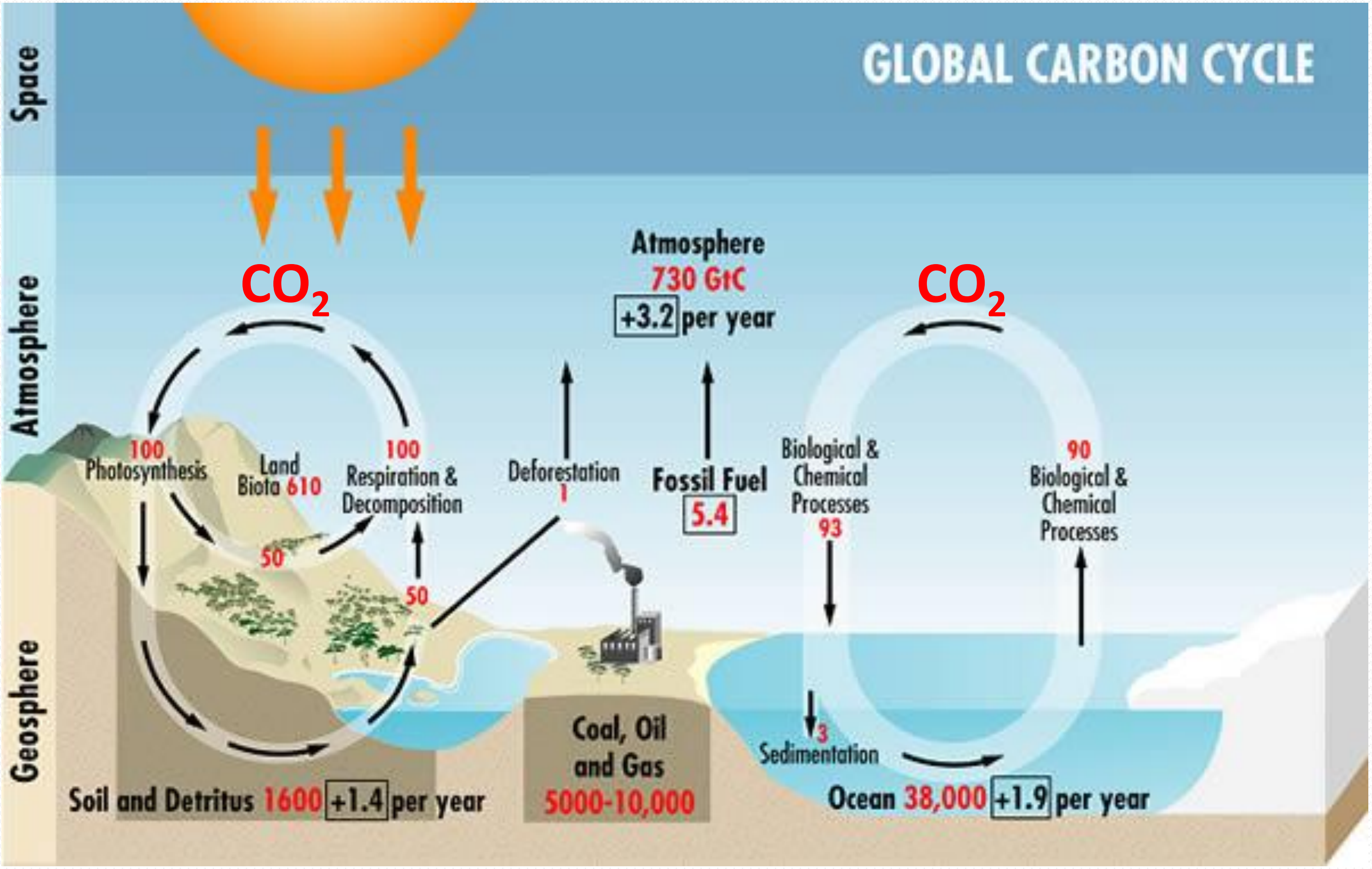
Support Processes

Soil formation, biogeochemical cycles, water purification

Image credit: Michigan Forest Products Council
Business Advocacy for the Forest Products Industry

Case Study: Climate and Forests

From http://www.bom.gov.au/info/climate/change/gallery/index.shtml



Global Forest Data

Sandra Brown   http://www.fao.org/docrep/w0312e/w0312e03.htm

TABLE 1. Estimated carbon pools and flux in forest vegetation (above- and below-ground living and dead mass, including woody debris) and soils (O horizon and mineral soil to 1 m depth) in world forests

Region/country	C pools (Pg)		C flux(Pg/yr^{-1})
	Vegetation	Soils	
BOREAL ZONE **(50° to 75° N and S)**			
Former USSR[1]	63	111	+0.30 to + 0.50
Canada	12	211	+ 0.08
Alaska	2	11	
Subtotal	**77**	**333**	**+0.48 ± 0.20**
TEMPERATE ZONE **(25° to 50° N and S)**			
United States	15	21	+0.08 to + 0.25
Europe[2]	10	18	+0.09 to +0.12
China	17	16	- 0.02
Australia	9	14	trace
Subtotal	**51**	**69**	**+0.26 ± 0.10**
TROPICAL ZONE **(0° to 25° N and S)**			
Asia	41-54	43	-0.50 to - 0.90
Africa	52	63	-0.25 to - 0.45
America	119	110	-0.50 to - 0.70
Subtotal	212	216	-1.65 ± 0.40
Total	**340**	**618**	**-0.90 ± 0.50**

world's forests contain more than **55 percent** of the carbon stored in vegetation

most vegetation biomass is in the tropical zone, but most soil C is in the boreal zone

US has more temperate zone forest C than all other countries and regions

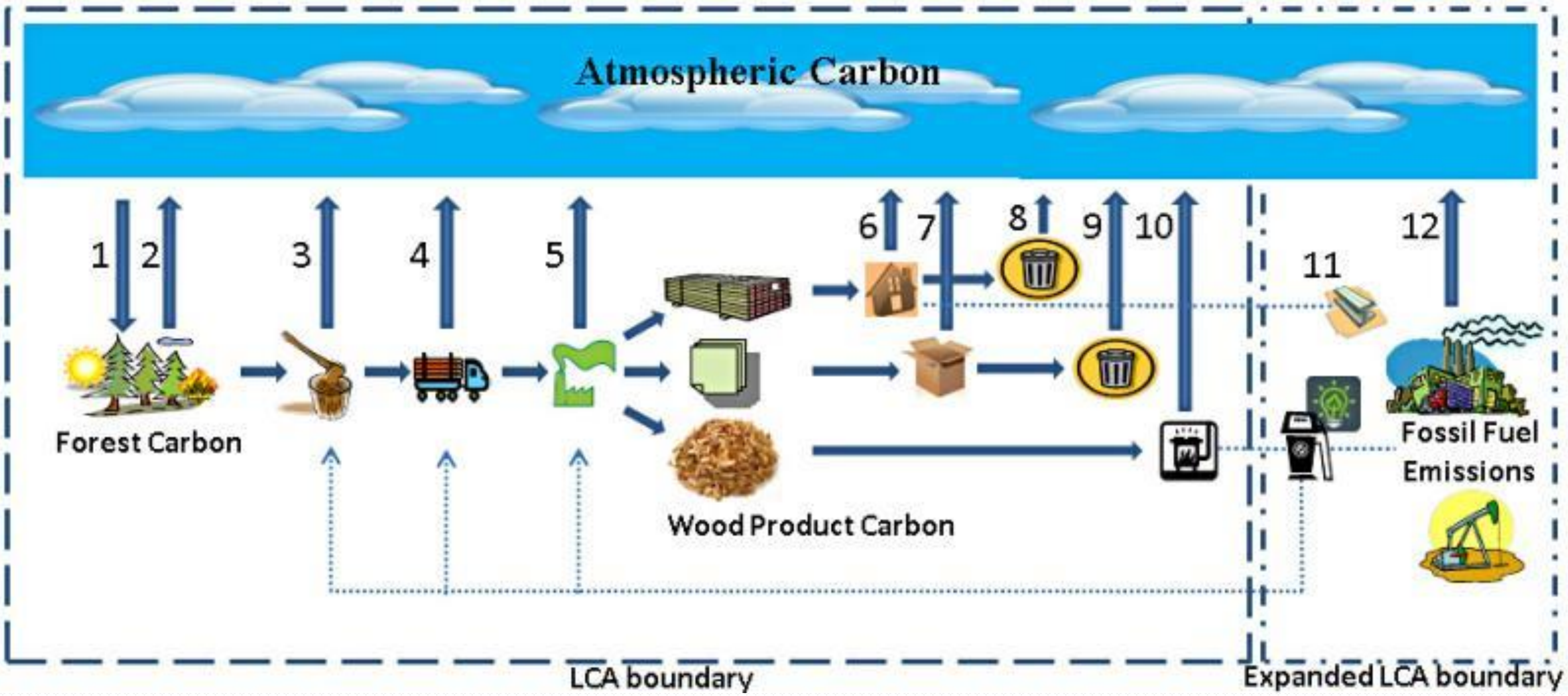
C fluxes are positive (uptake by land) in temperate and boreal zones due to re-growth after prior human disturbances (harvesting), but negative in the tropical zone (deforestation)

Summary of Forests and Climate

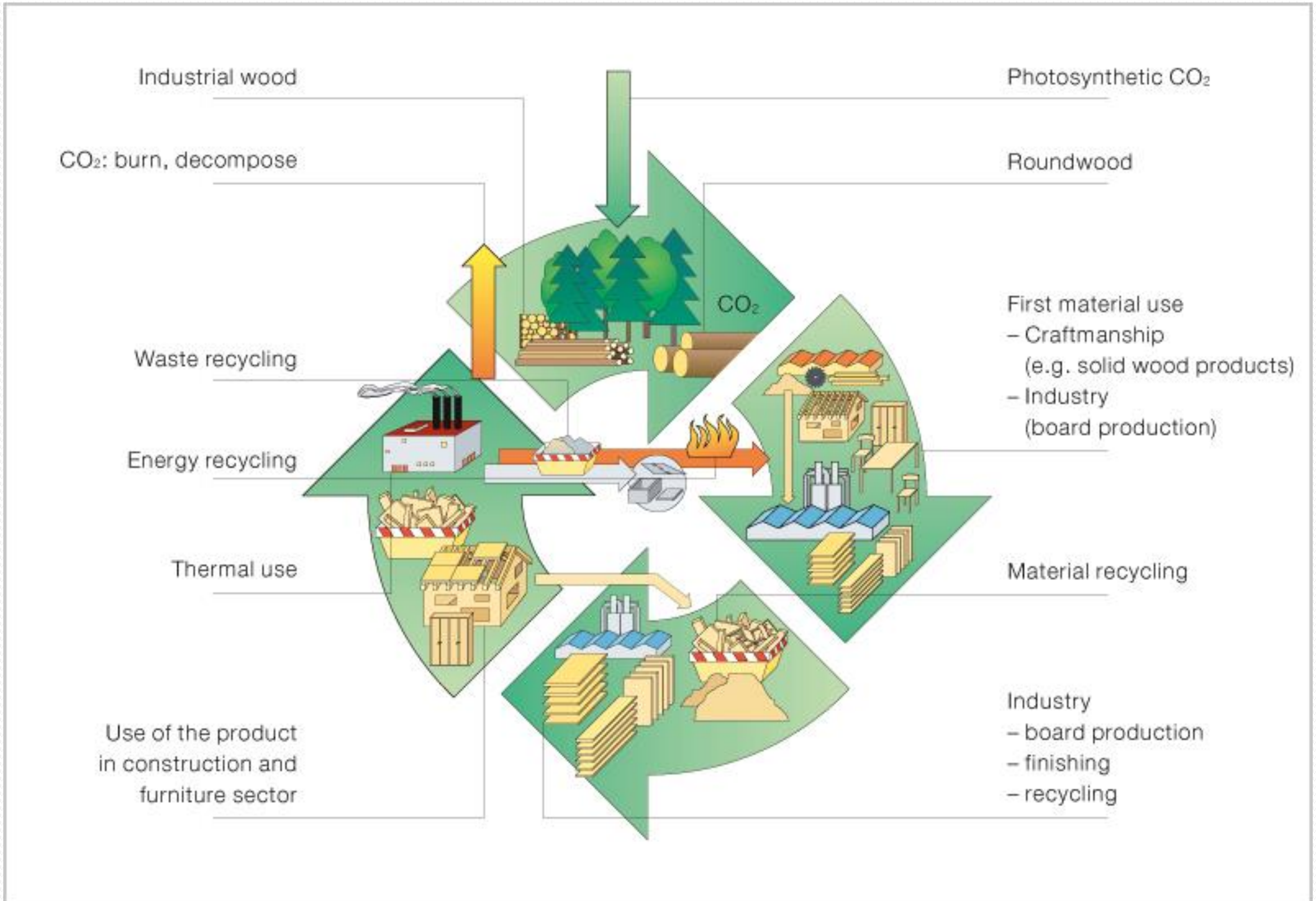
- Environmental effects of forest products must account for changes in condition of forest lands
- Environmental effects will also depend on activities tied to harvesting, processing, transporting, and storing biomass
- Increasing forest products may displace other products in the industrial sphere, with additional effects

Life Cycle Assessment Method

- The boundary of the analysis is the “cradle-to-grave” product system including; forest carbon, product chain, and displaced product systems (cement, steel, fossil fuels)

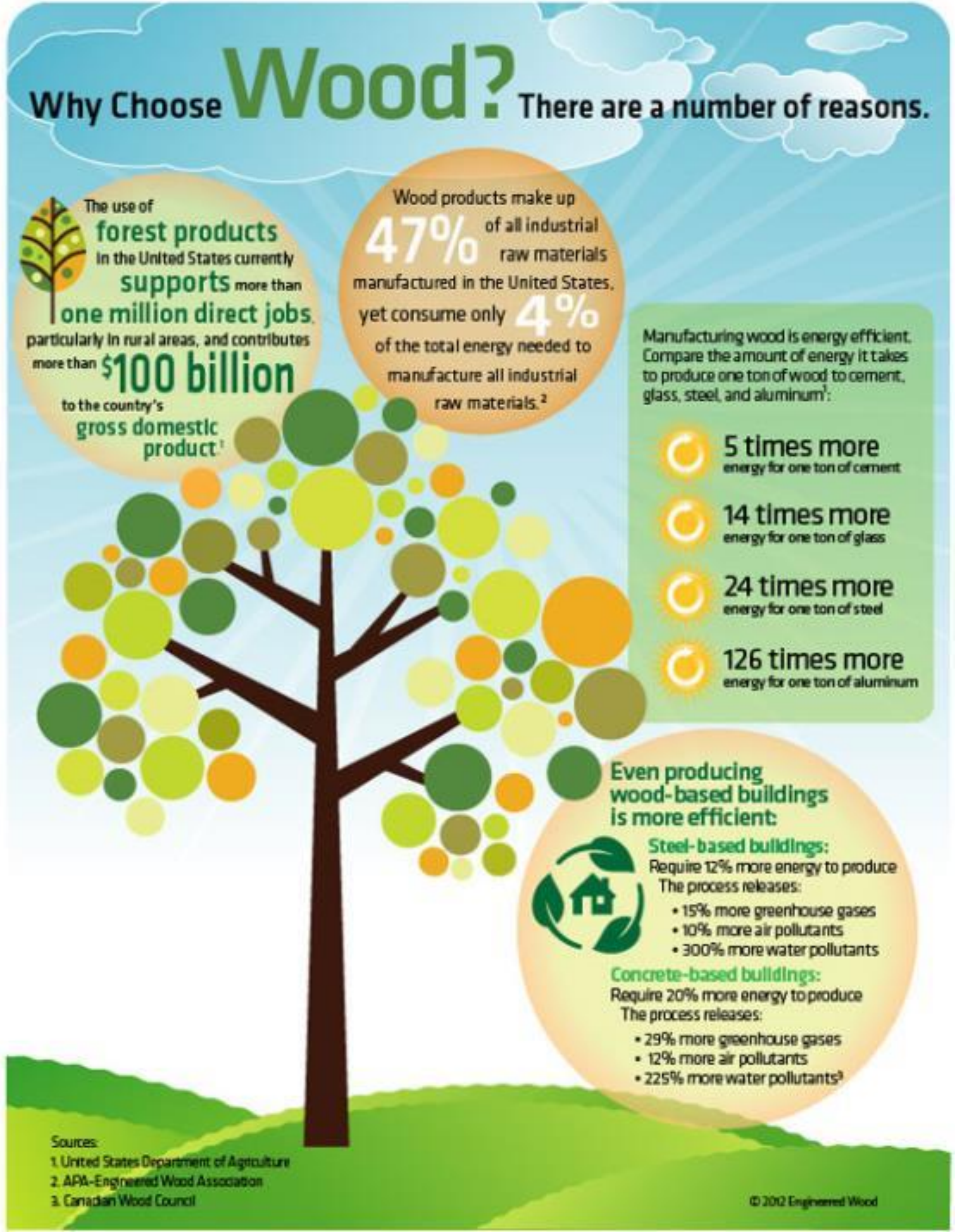


Forest Product System



Life Cycle Assessment Uses

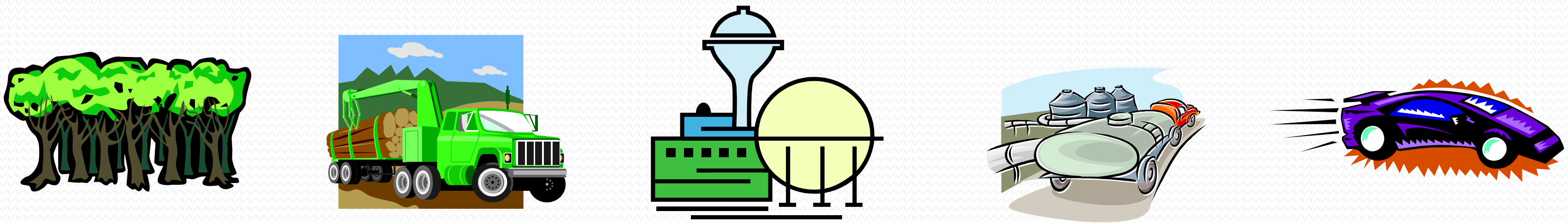
- Understand a product system's effect on the environment
- Minimize environmental impacts
- LCA can be use to support product declarations on environmental benefits compared to other products



Case Study: Biofuels from MI Forests

Dr. Jiqing Fan, Postdoc, SFI (MTU), Dr. Robert Froese, SFRES (MTU)

- A generic forest-based biofuels pathway



Biomass Production | Transportation | Feedstock Conversion | Fuel Distribution | End Use

Biomass Production: Model changes in C stocks on MI aspen forests over time from more intensive harvesting compared to business as usual (BAU)

Conversion: Model cellulosic ethanol and pyrolysis bio-oil

C Accounting: Model GHG emissions for use of fossil fuels along the pathway as well as emissions of biogenic CO_2 from changes in forest C stocks

Carbon Budget Model for the Canadian Forest Sector (CBM-CFS3)

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

Forest C dynamics simulation

- The CBM-CFS model estimates the aboveground biomass from the merchantable timber volume based on yield-to-biomass equations developed by Boudewyn 2007
- The CBM-CFS then estimates aboveground C increments (0.5 kg C/kg biomass)
- Once the aboveground C increment is estimated, belowground biomass and C increment are calculated using equations from Li 2003
- The model estimates biomass turnover to represent biomass mortality using annual turnover rate. Then the model uses litterfall transfer rates to assign C to different DOM pools.
- Decomposition is modeled by a temperature-dependent decay rate that determines the amount of organic matter that decomposes in a DOM pool every year.
- The CBM-CFS3 uses a simulation initialization procedure that links biomass, DOM dynamics and historic disturbance regimes at the beginning of a model run.

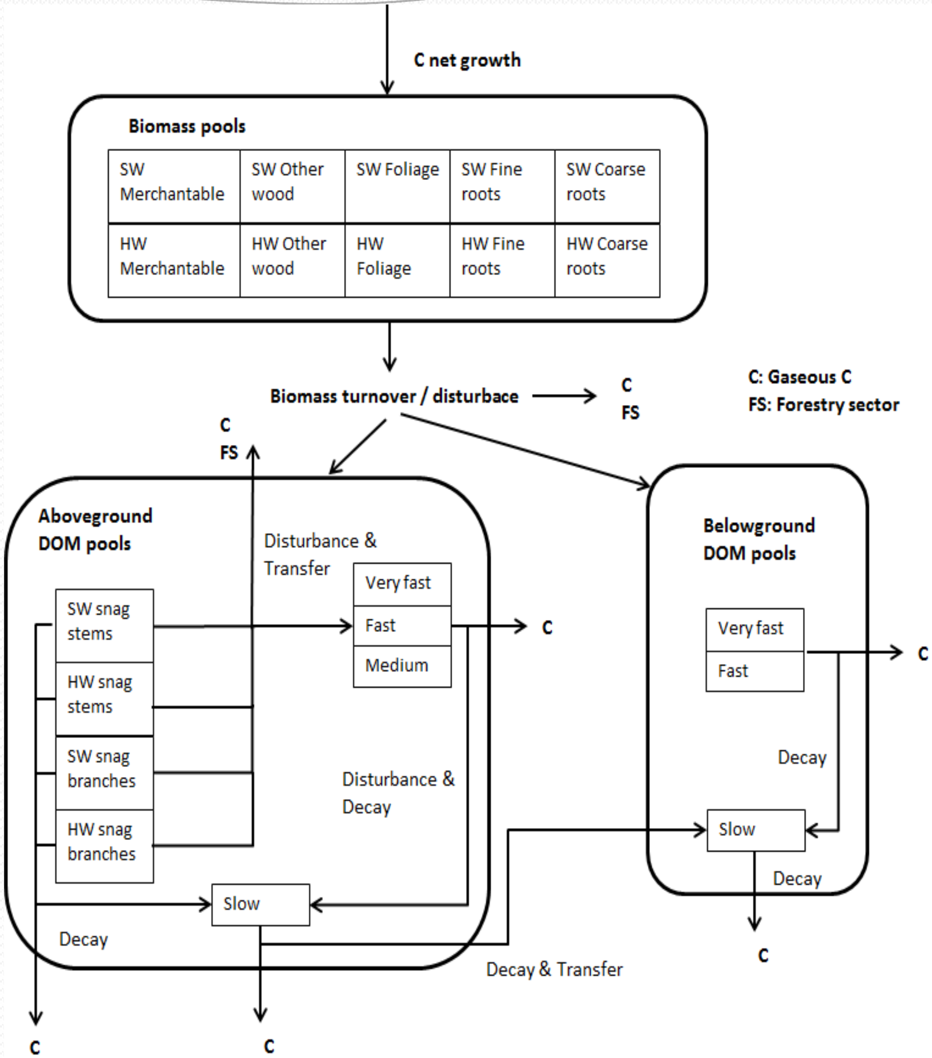


Figure: C flow between biomass and DOM pools in the CBM-CFS3 Adapted from Kurz 2009

Aspen harvesting

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

age	0-19	20-39	40-59	60-79	80-99	100-119	Total
Aspen/birch group	225,000	311,000	385,000	278,000	87,000	13,000	1,299,000

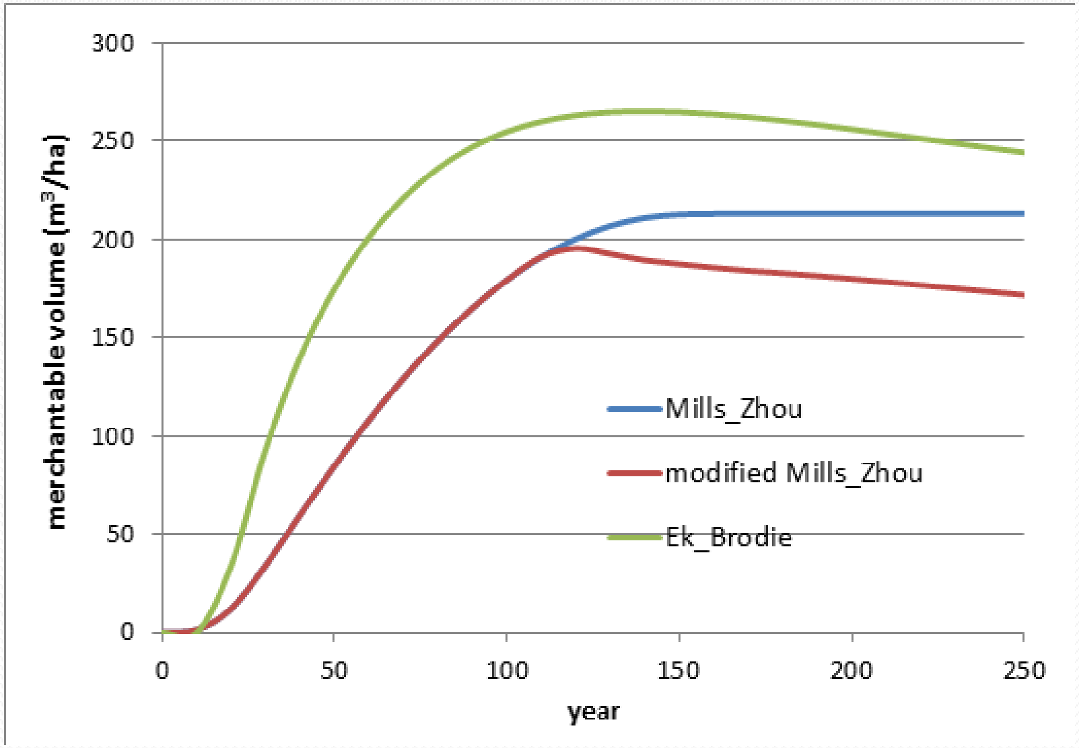


Figure: Growth curves of aspen in Michigan

- Growth curves are the fundamental data for forest C modeling
- The red curve represents "business as usual" (BAU) aspen growth and harvesting for existing uses (pulp and paper,..)
- The green curve is an improved growth curve for aspen representing active best practice management

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

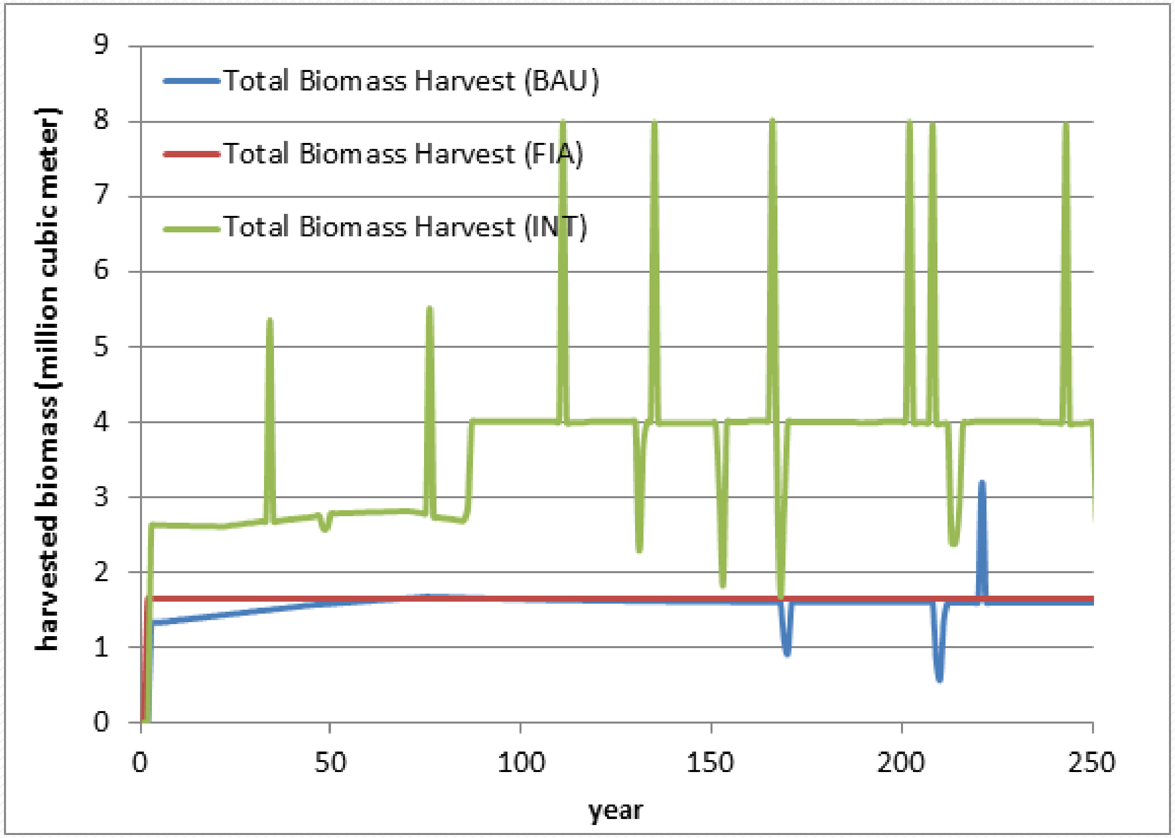


Figure: Total biomass harvested in the BAU and INT scenarios over 250 years

- In the BAU scenario, 7200 ha of aspen is assumed to be harvested every year to match FIA data, while INT scenario doubles the areas to 14400 ha.
- The extra biomass harvested in the INT scenario additional to the BAU scenario (205 million metric ton) is used for biofuel and bioenergy production.

Forest C Stocks in Aspen

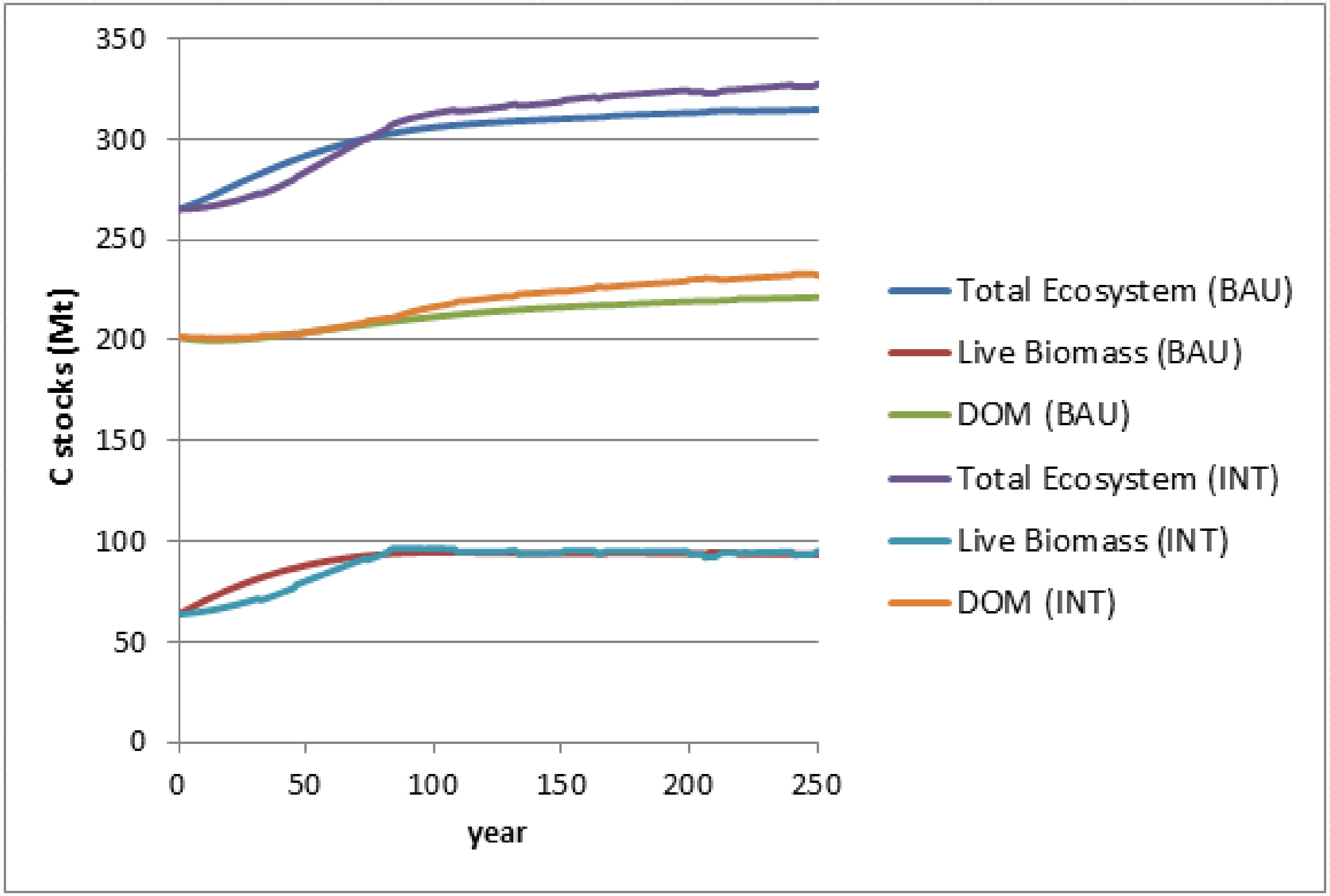
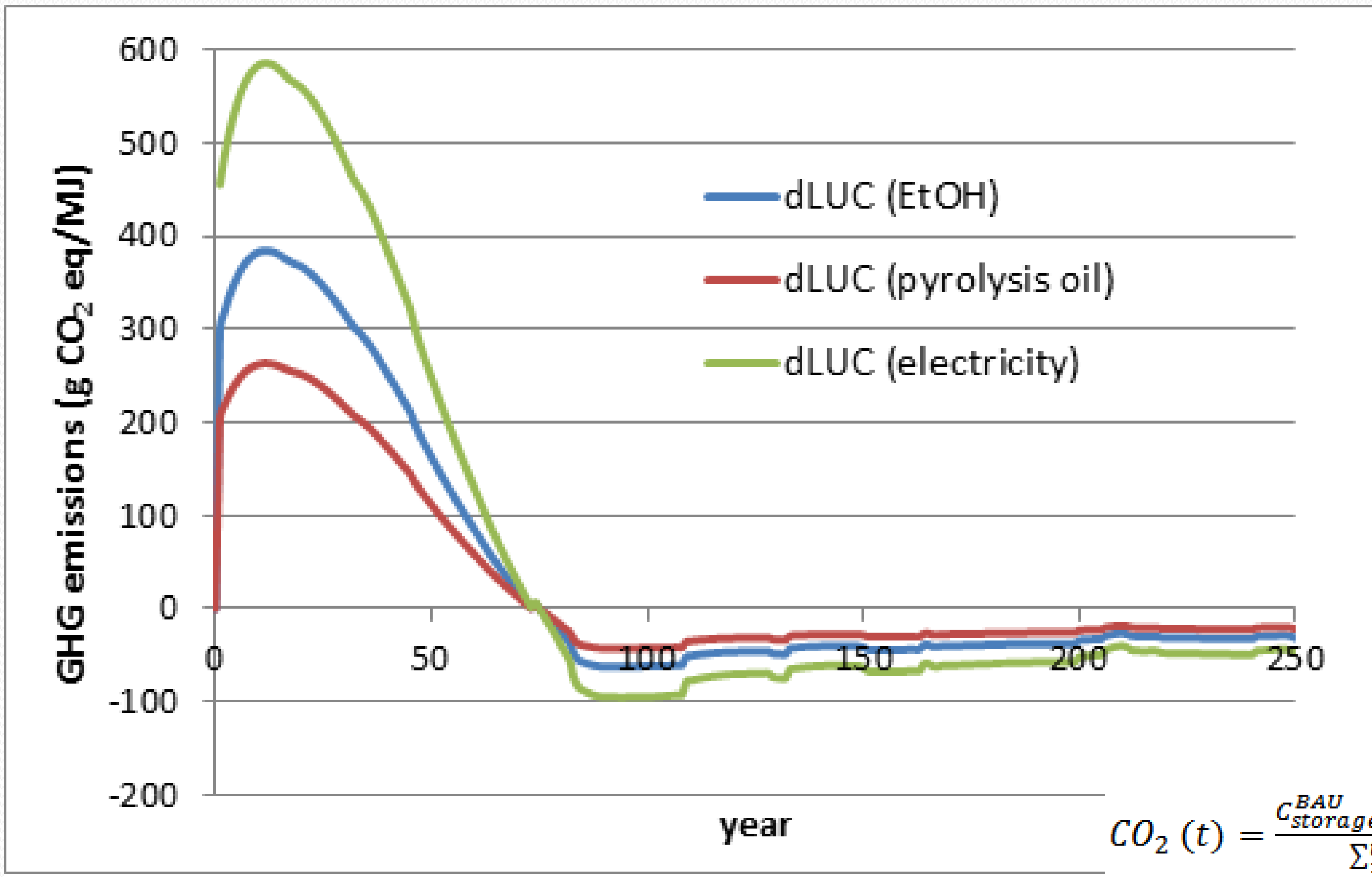


Figure 7: Ecosystem C stored in the BAU and INT scenarios

Direct land use change (dLUC) CO_2 emissions of biofuels and bioenergy



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

Figure: dLUC of biofuel and bioenergy over 250 years

Life cycle GHG emissions of biofuels and bioenergy

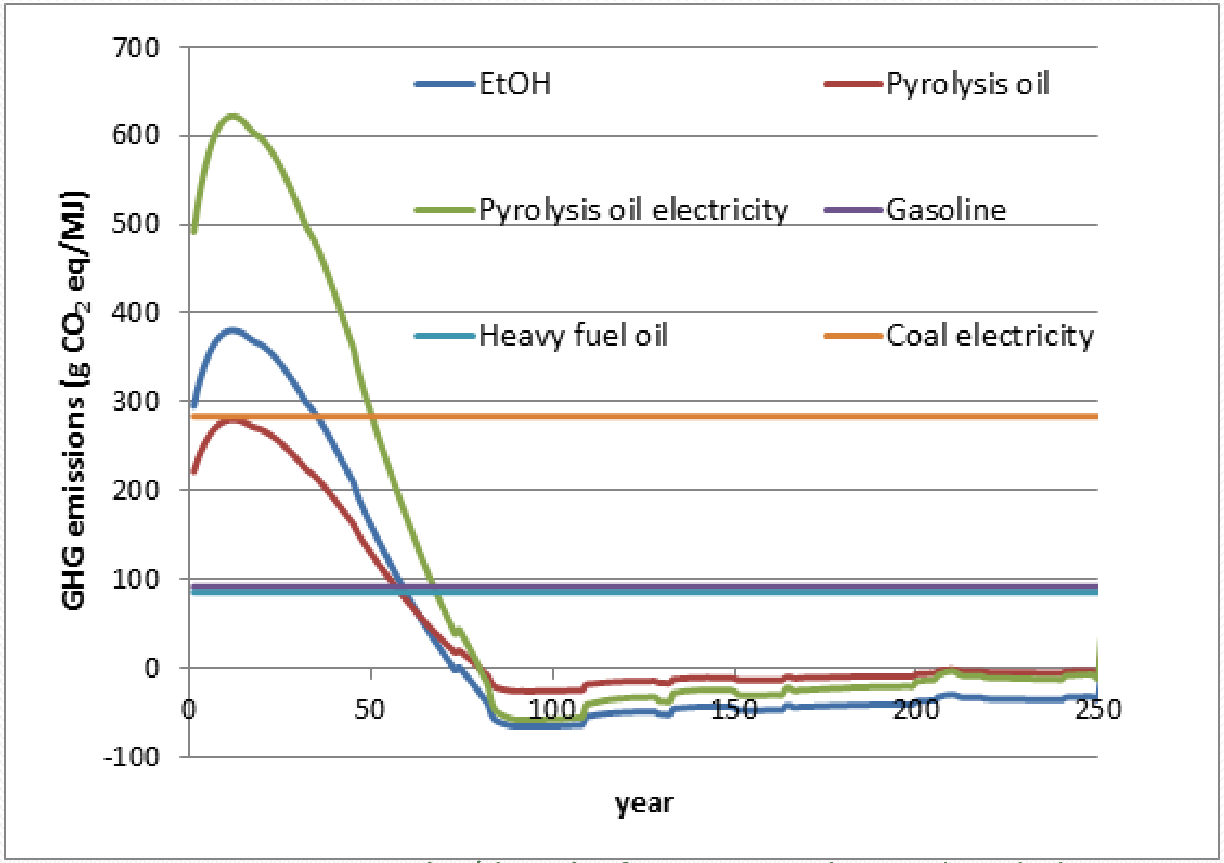


Figure: GHG emissions (w/dLUC) of EtOH, pyrolysis oil and electricity over 250 years, comparing to their petroleum counterparts

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)

$\Delta FC(t)$: change in forest carbon at any time (t) due to biomass harvest for bioenergy, calculated by $C_{ecosystem}^{INT} - C_{ecosystem}^{BAU}$.
GHG: net savings of GHG emissions for biofuels and bioenergy

Emissions from fossil fuels displaced are substracted from the biofuel system emissions from the previous slide.

A GHG emissions "debt" is overcome between 50 and 100 years in the future.

In the short term, MI forest-based biofuels from INT harvesting emits more than fossil fuels

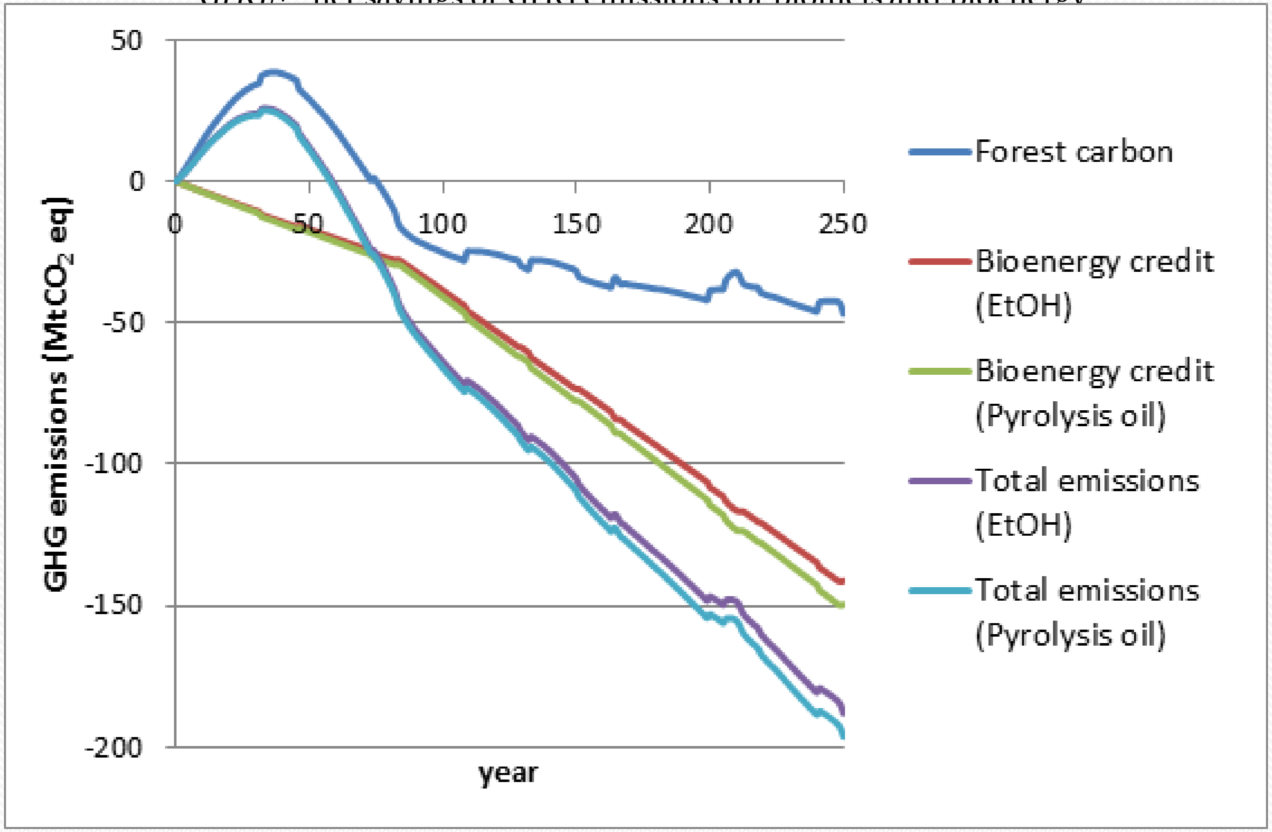


Figure: Total GHG emissions of forest-based biofuels system

Summary on Forest-Based Biofuels

- Biofuels produced from forest resources that are harvesting more intensively than the normal harvest level will incur direct land use change emissions of CO_2
- The dLUC emissions will cause a C debt early in the production cycle that range over many 10s of years.
- Improved management of forest for such intensive harvests can moderate or eliminate the dLUC emissions
- Forest plantations on abandoned agricultural may offer benefits for biofuels production by eliminating the C “debt”

LCA of Forest Products for Homes

PNW Forest C Pools for Different Harvest Rotations

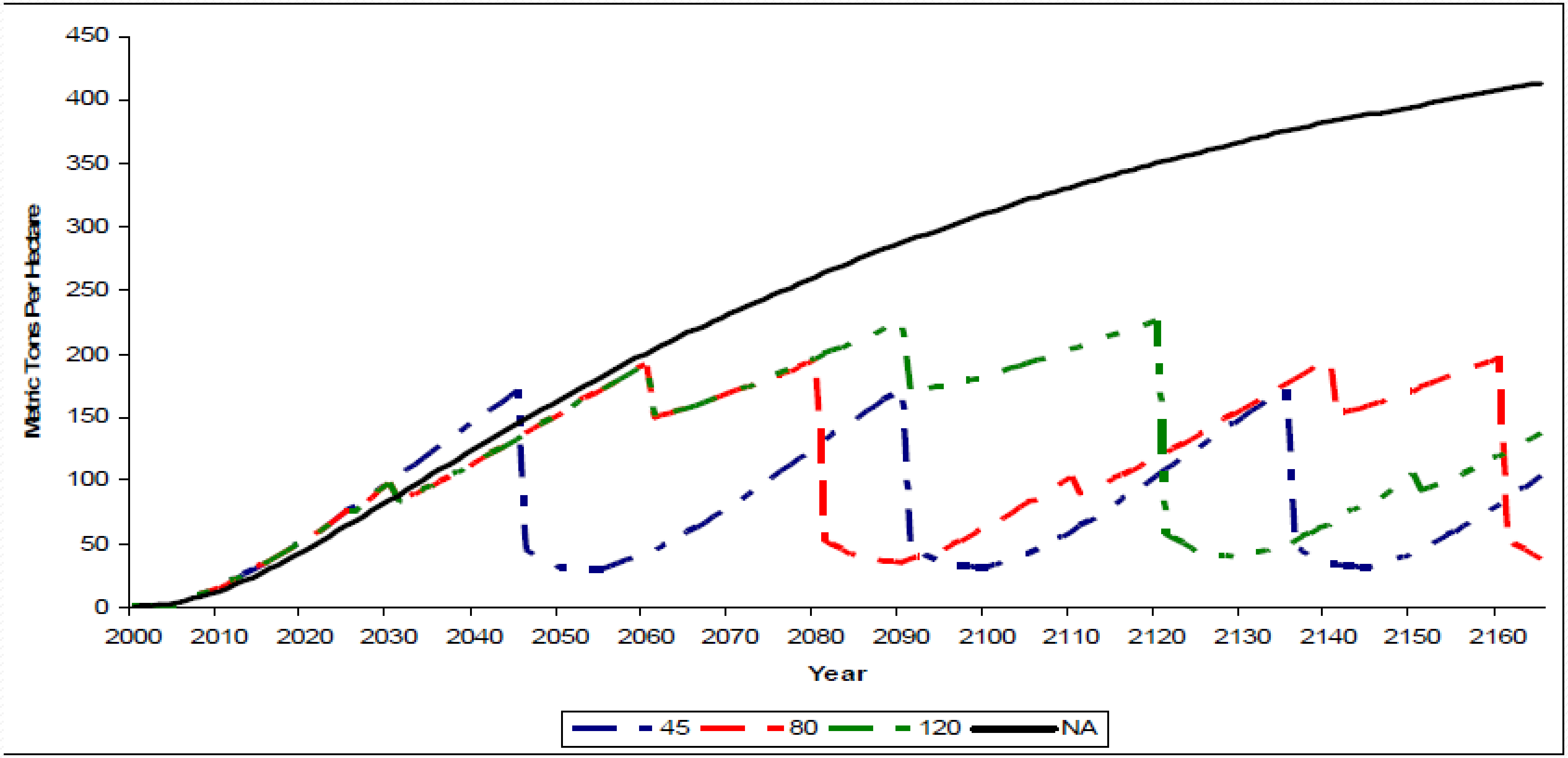


Figure 1. Carbon in forest pools for different rotations

CORRIM (2004)

LCA of Forest Products for Homes

Short- and Long-Lived C Pools, Displaced energy, Concrete Sub.

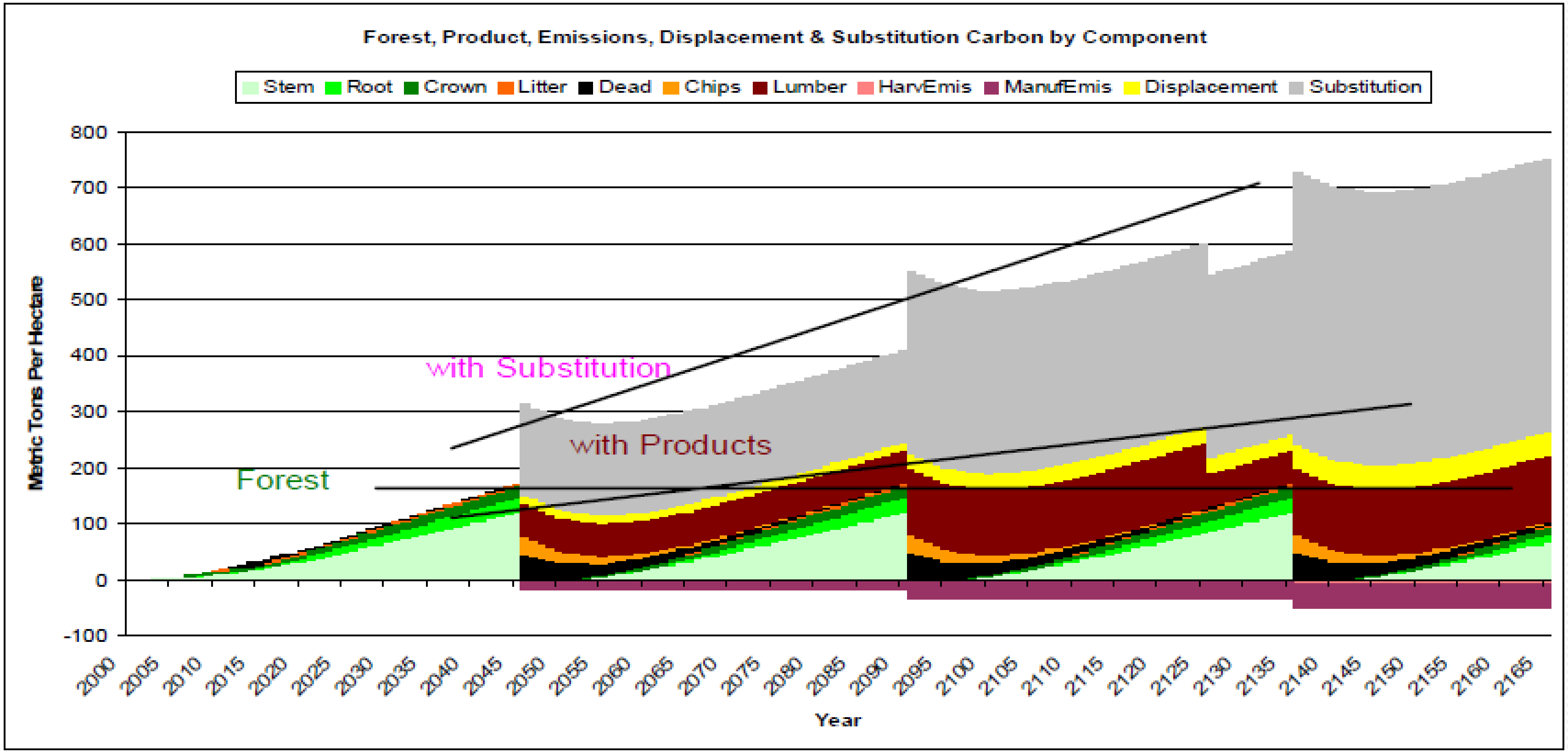


Figure 3. Carbon in the forest and product pools with concrete substitution for the 45 year rotation

CORRIM (2004)

Conclusions

- Producing products from forest resources can have long-term benefits to the environment (C storage in products, avoided emissions from fossil fuels,..)
- Environmental life cycle assessment (LCA) is a comprehensive method to understand impacts across a product's life cycle
- LCA of forest products must include these key features;
  - Modeling of forest management with respect to C storage and other environmental effects (biodiversity, water quality, …)
  - Modeling of the activities and process for cultivation, harvest, transport, and manufacturing processes
  - End of life processes such as recycle and disposal
  - Substitution of equivalent products in the market