Are Natural Fiber Composites Environmentally Superior to Glass Fiber Reinforced Composites?

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Why bio-based polymers and natural fibers?

Environmental Advantages?

- Renewable raw material base
- Biodegradable
- Reduced fossil fuel and resource consumption
- Lower Greenhouse gas emissions
- Lower overall emissions and environmental impacts

Economic advantages? (Short v/s Long run)

- Rising petroleum prices, technological progress and scale economies

Bio-based polymers

- Cellulosic plastics, PHA, PLA and others

Controversial

- Renewable base?
- Performance and cost?
- Biodegradable?
- Energy use?
- GHG emissions?
- Emissions and environmental impacts?
- Data availability and quality?

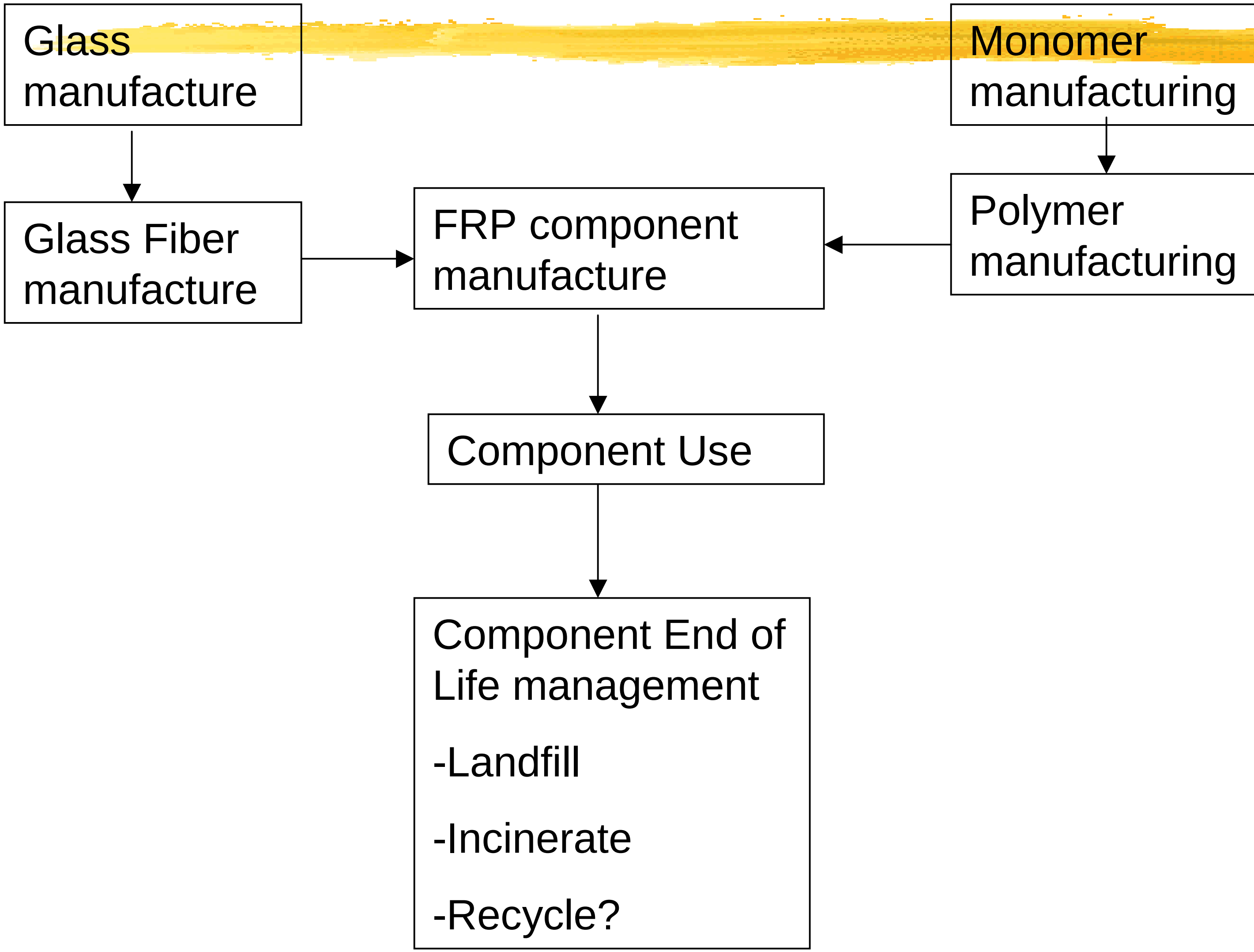
No Studies on all bio-composites?

Natural Fiber Composites

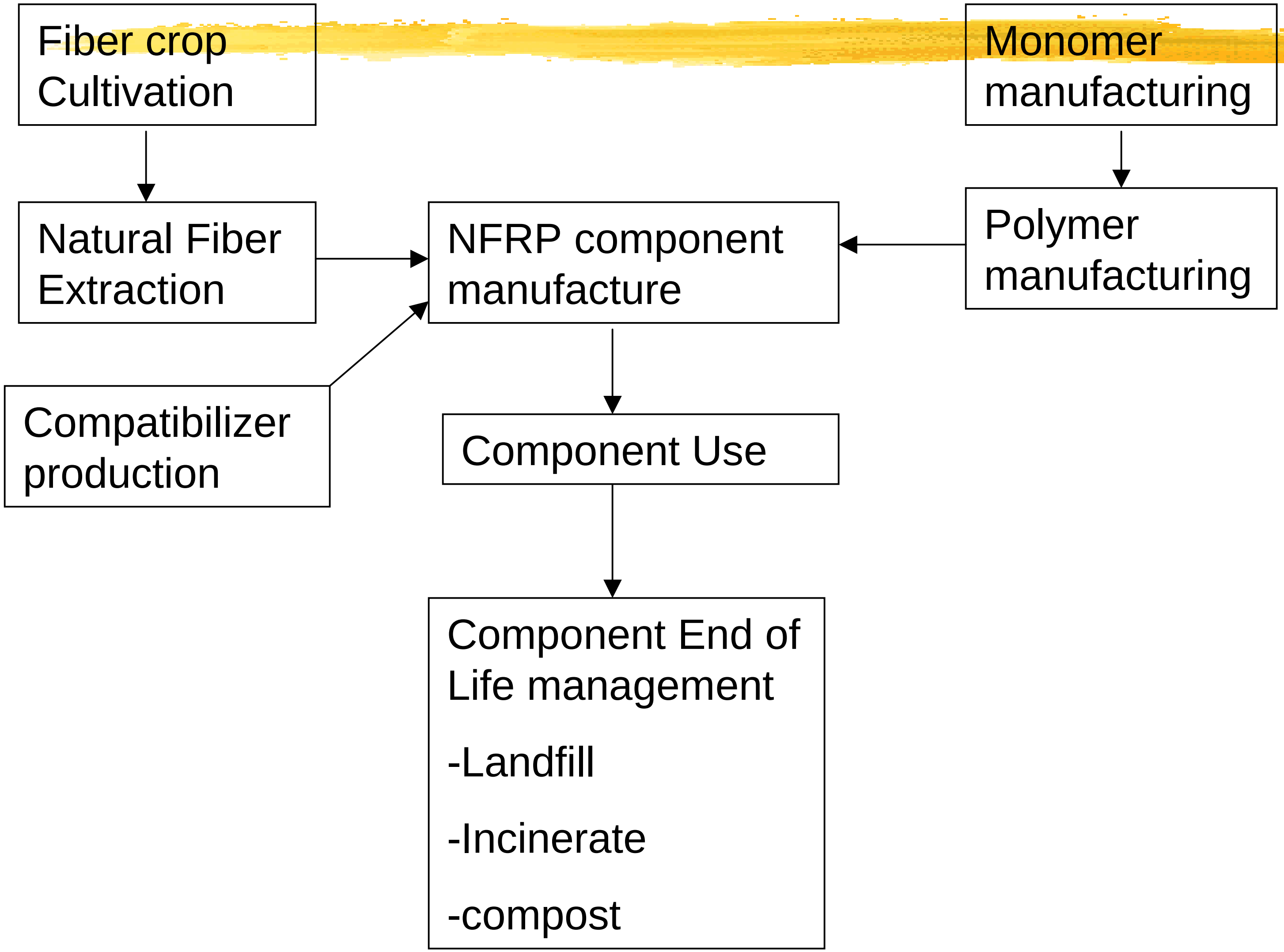
Natural fibers as reinforcing material

- Economic
  - Glass fiber (~US $ 2/kg)
  - Natural fibers (~ $0.44-$0.55/kg)
- Weight reduction
  - Glass fiber 2.5-2.8 g/cm^3
  - Natural fibers 1.2-1.5 g/cm^3
- Performance?
- Environmentally superior?

Life Cycle of GFRP



Life Cycle of NFRP



Empirical Studies

- Wotzel et al (1999)
  - Hemp-Epoxy v/s ABS auto side panel (Audi A3)
- Corbiere-Nicollier et al (2001)
  - China reed-PP v/s Glass-PP transport pallet (Swiss Federal Institute of Technology)
- Schmidt and Meyer (1998)
  - Hemp-EPDM-PP v/s GF-EPDM-PP auto insulation component (Ford car)
- Diener and Siehler (1999)
  - GF-PP v/s Flax-PP auto floor panel (Mercedes A car)

Issues

- Comparative basis (material and application)
- Performance equivalence
- Life cycle stages modeled/boundaries
- Data source/approximation/details
- End of life management and credits for recycled material/energy
- Environmental impacts considered and aggregation

Materials compared

- Wotzel et al (1999): auto side panel
  - Hemp(66%v)-Epoxy(36%v) v/s
  - ABS (100%)
- Corbiere-Nicollier et al (2001):transport pallet
  - China reed (52.8%w)-PP(47.2%w) v/s
  - Glass (41.8%w) – PP(58.2%w)
- Schmidt and Meyer (1998) auto insulation component
  - Hemp (30%w) –EPDM(6.4%w) - PP(63.6%w) v/s
  - GF – EPDM – PP (??)
- Diener and Siehler (1999) :Auto under floor panel
  - GF-PP v/s Flax-PP (??)

Performance

- Wotzel:Auto side panel
  - Do not discuss performance.
- Cobiere:Pallet
  - Satisfying service requirement(1000km/yr for 5 years)
  - Theoretical mixture % to achieve equivalent stiffness
- Schmidt: Auto Insulation
  - Intensive technical checks found hemp fibers are able to replace glass fibers in the specific application
- Diener: Auto Under floor panel
  - Successfully passed all tests

LC stages and Data

- Wotzel: Auto side panel
  - LC stages up to component mfg considered
  - Hemp: cultivation, fiber extraction modeled
  - ABS, Epoxy : from APME ecoprofiles
- Schmidt: auto insulation
  - Full LC with 50% landfill,50% incineration
  - PP,EPDM,GF, fuels from APME/IDEA
  - Hemp data a: approximation from available data on flax, maize cultivation (educated guesses)
  - No compatibilizer
- Corbiere(pallet)
  - Full LC stages including compatibilizer considered and modeled

Conclusions from studies

- All studies provide a LCI of components with some degree of impact aggregation
- Natural fiber composites have environmental benefits over comparable designs with conventional materials
  - CED savings of 88.9MJ/component
  - Eco-indicator impacts less by 8-17%
  - CML indicator points for human toxicity less by 57%, aquatic toxicity by 39%, GHG by 46%
- Little intermediate details
- HOW GENERALIZABLE ARE THESE RESULTS?

Drivers of environmental superiority of NFRP

- Natural fiber production v/s glass fiber production emissions
- Higher fiber % (substitution of base polymer and GF with lower emission NF)
- Weight reduction (Higher fuel efficiency during use phase)
- Energy credits due to EOL fiber burning
- GWP credits for carbon sequestration
- Higher N_2O & eutrophication due to cultivation

Fiber emissions

China Reed fiber(/kg)		Glass Fiber (/kg)	
Energy	3.4MJ	Energy	48.3MJ
CO_2	0.64kg	CO_2	2.04kg
SO_x	1.2g	SO_x	8.8g
NO_x	0.95g	NO_x	2.9g
PM	0.2g	PM	1.03g
BOD	0.265 mg	BOD	1.75 mg
COD	3.23 g	COD	0.02g

Source: Corbiere 1999

NF to PP substitution

China Reed fiber(/kg)		PP (/kg)	
Energy	3.4MJ	Energy	101.1MJ
CO_2	0.64kg	CO_2	3.11kg
SO_x	1.2g	SO_x	22.2g
NO_x	0.95g	NO_x	2.9g
PM	0.2g	PM	4.37g
BOD	0.265 mg	BOD	38.37 mg
COD	3.23 g	COD	1.14g

Source: Corbiere 1999

Weight Reduction

Component	Study	NFRP component	Base component
Auto side panel	Wotzel et al	820 g (hemp-epoxy)	1125g (ABS)
Auto insulation	Schmidt	2.6 kg (hemp-PP)	3.5kg (GF-PP)
Transport Pallet	Corbiere	11.77kg (CR-PP)	15kg (GF-PP)

Use-phase fuel reduction

- Fuel reduction coefficients*
  - Gasoline vehicles
    - 0.34-0.48L/100kg/100km
    - Or 6.8-9.6 L/kg/200,000km-vehicle life time
    - Ford Model 5.6 L/10000km
  - Diesel vehicles
    - 0.29-0.33 L/100kg/100km
    - Or 5.8-6.6L//kg/200000km
- Component transportation fuel use savings in non-auto applications

** Source: Eberle and Franz,1998 (SAE-TLC)p139)*

Effects of Fuel Savings

- 1 kg weight savings due to NF substitution implies avoided environmental effects of the production and burning of ~7 L of gasoline.

  Energy ~273 MJ (NF = 3.4 MJ)

  CO_2 emissions ~ 17.76kg (NF=0.64kg)

  SO_x emissions ~ 5.78g (NF=1.2g)

  NO_x emissions ~163g (NF=0.95g)

- For auto applications the use phase weight reduction-fuel savings effects totally dominate other effects and life cycle stages

Other Benefits

- Carbon sequestration in hemp ~ 0.79kg CO_2/kg fiber
- Energy recovery from fiber burning ~10 MJ/kg
- RENEWABLE/LOCAL Material base

CONCLUSIONS

- Substitution of glass fibers with natural fibers is environmentally beneficial.
- In automotive applications, environmental benefits due to weight reduction-fuel use effects during the use phase of the auto dominate the environmental effects of all other stages
- When combined with cheaper prices, the future of NFRP in auto/transport applications is bright
- Technologies for achieving equivalent/superior component performance should be the focus of research

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