

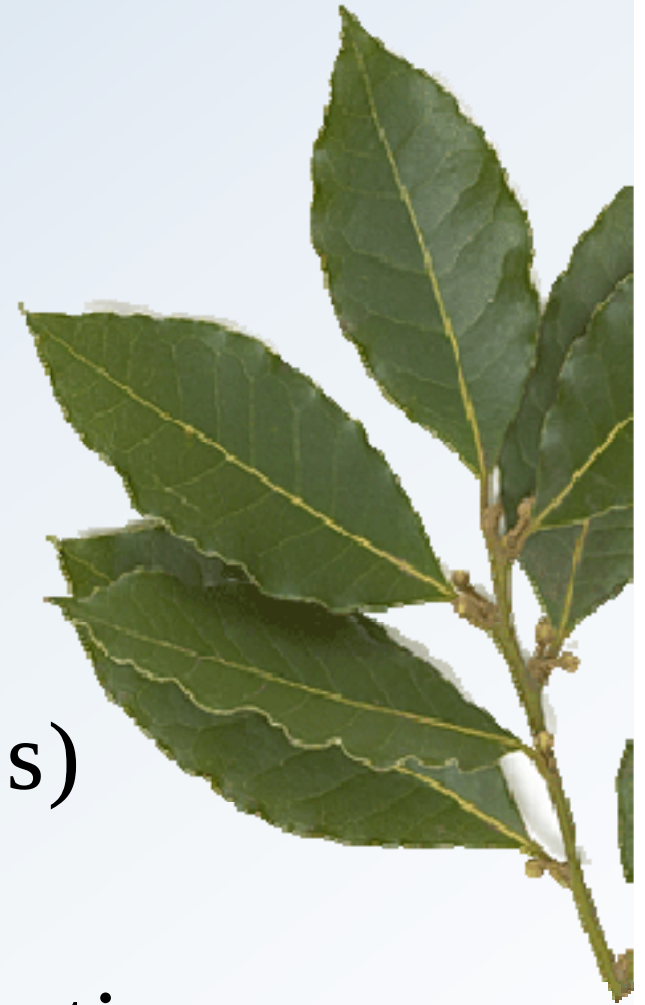
Biodegradable polymers as energy efficient replacement of polymers from fossil fuels

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Outline

- Motivation
- Types of BPs
 - Starch based
 - Poly(lactides)
 - Poly(hydroxyalkanoates)
- Life Cycle Analyses
- Conclusions/Future Direction



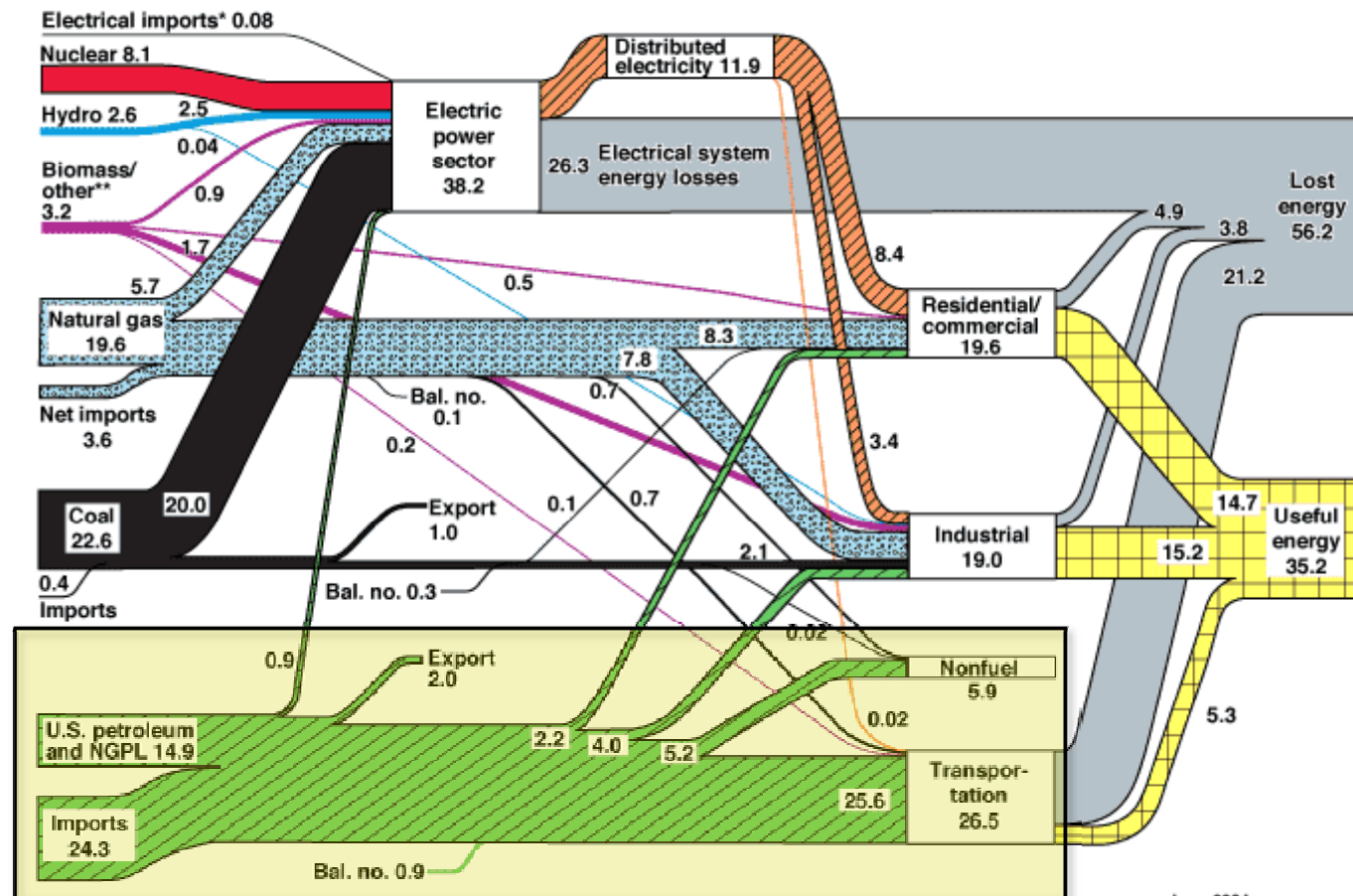
Motivation

- Plastics/polymer production exceeds 450 billion pounds per year!
 - That's **3 billion Kevins** of material by weight.
- The feedstock/fossil fuel energy used in the production of plastic is ~10% of total oil consumption
- Changing to a renewable feedstock could save 270 million tons of oil annually



Perspective

U.S. Energy Flow Trends – 2002 Net Primary Resource Consumption ~97 Quads



Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002*.

*Net fossil-fuel electrical imports.

**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

June 2004
Lawrence Livermore
National Laboratory
<http://eed.llnl.gov/flow>

Solution?

- Use renewable feedstock from nature

➔ Biodegradable polymers!

• Advantages

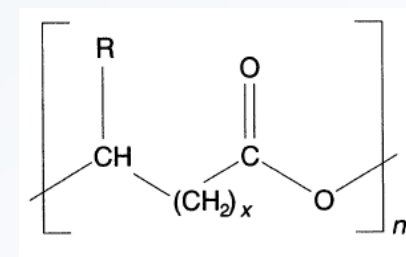
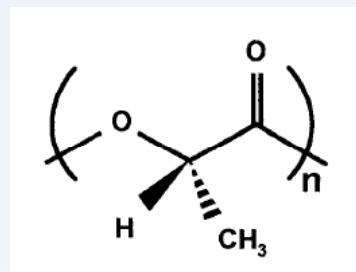
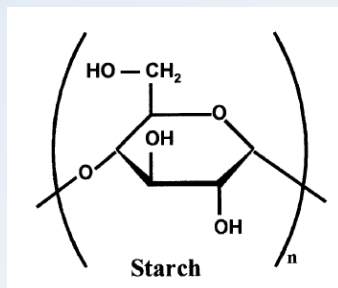
- Eliminate fossil fuels as feedstocks
 - Saves millions of barrels of oil for use in other applications
- More environmentally friendly?
 - Plastic accounts for 12% of solid municipal waste

• Disadvantages

- Not as well developed
- Current output is 0.1% of petroleum based polymer

Types of BPs

Starch	Polyester	
	PLA	PHA
●Made from corn	●Made from corn	●Made from corn
●Chains are amylose and amylopectin	●Chains are lactic acid	●Chains are hydroxy alkanoates
●Naturally available-made by grinding components of corn	●Made by fermentation of glucose	●Made by fermentation of glucose or directly in bacterial or plant cells



Life Cycle Analysis

PRODUCTION AND ENERGY DEMANDS

Plant-derived plastics require more energy to produce—and thus result in higher emissions of greenhouse gases associated with burning fossil fuels—than do many of their petrochemical counterparts.

PLANT-BASED PLASTICS

Corn stover grown, harvested and delivered to factory

Plastic extracted from stover using solvents

Solvents distilled and separated from plastic

FOSSIL-FUEL REQUIREMENTS
(in megajoules per kilogram of plastic)

ENERGY

RAW MATERIALS

Are BPs really more energy efficient?

grown, harvested and delivered to factory

to yield sugar

fermented into lactic acid

molecules converted to plastic

PLA

56

FOSSIL FUEL-BASED PLASTICS

PE

29

81

PET

37

76

NYLON

93

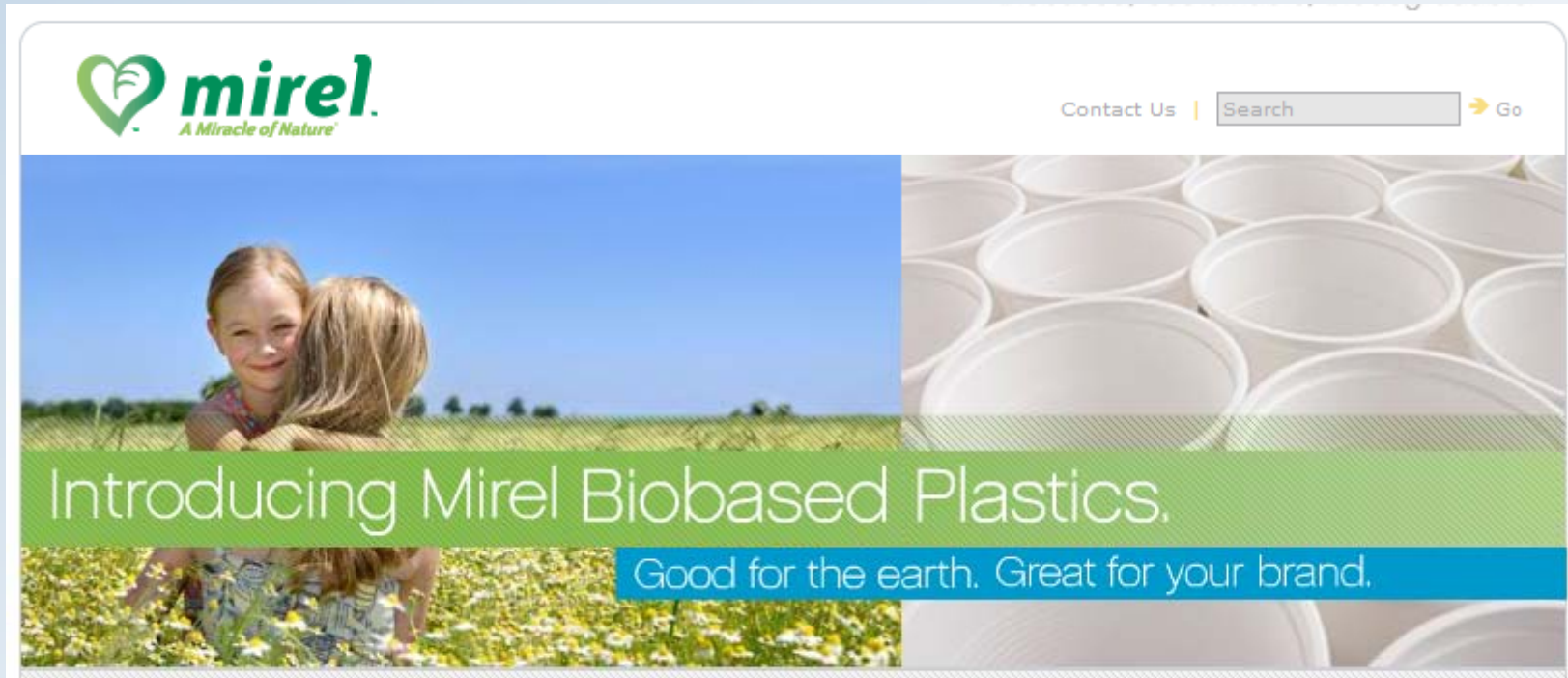
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Life Cycle Analysis

	Source	CO ₂ (kg/kg)	Fossil Energy (MJ/kg)
PHA/PHB	PHA: Gerngross (1999) ¹¹	2.4	50.4
	PHA: Kurdikar (2001) ⁵	2.0	--
	PHA: Akiyama (2003) ⁴	0.26-0.45	50-59
	PHB: Nonato (2001) ¹²	--	113.7
	PHB: Harding (2007) ¹³	2.6	44.7
PLA	Bohlman (2001) ¹⁴	-.0005	56.7
	Vink (2003) ⁸	1.8	54
	Vink (2007) ¹⁵	0.27	27.2
Starch	Motor Bi-	1.28	52.4

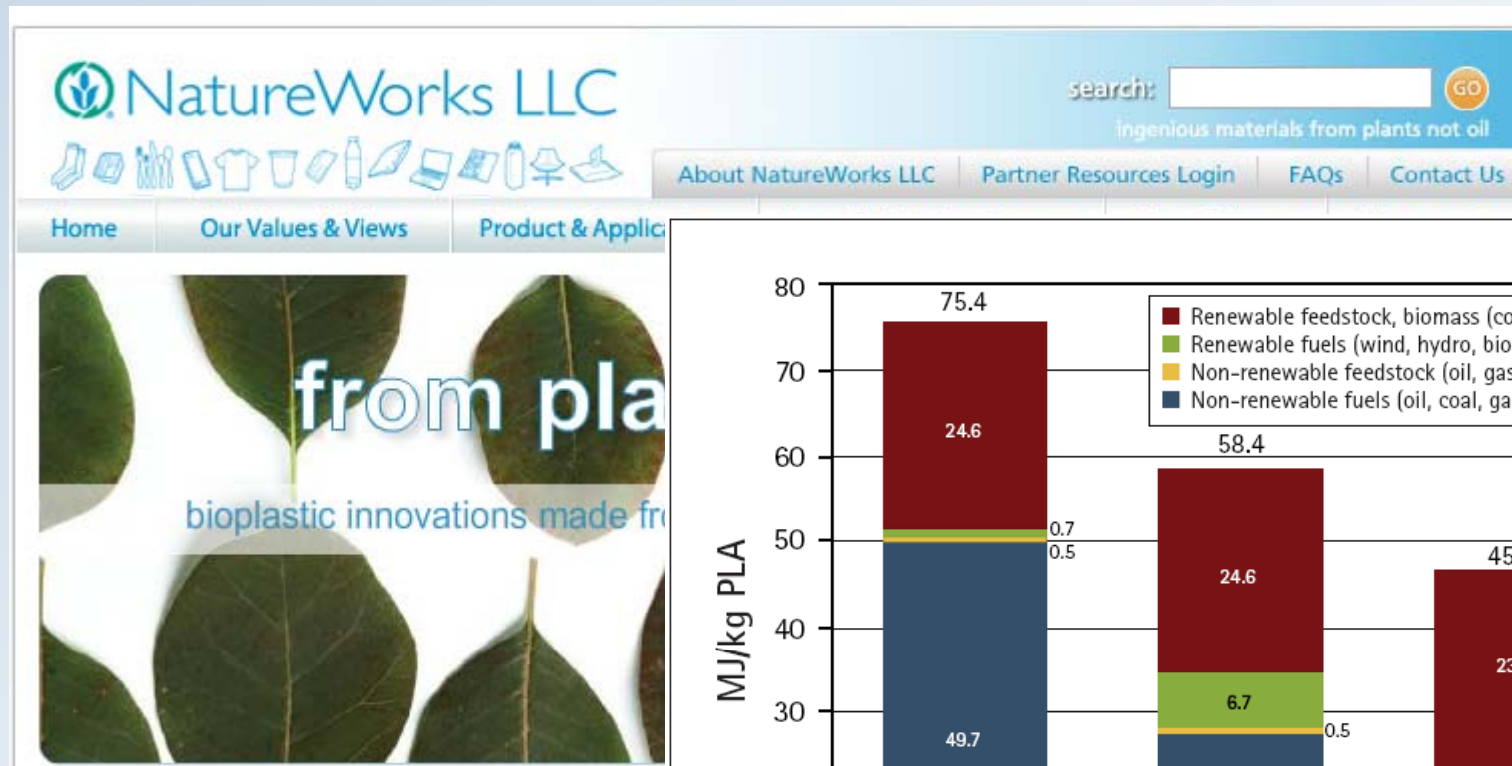
New technology and optimization is making BPs more energy efficient

Mirel by Metabolix



- Claim to reduce fossil fuel use by **95%** and **200%** reduction in CO2 emission
- Employs bacterial fermentation for PHA production

NatureWorks PLA



- Fossil fuel use reduced
- reduction in CO2 emissions
- Employs bacterial fermentation

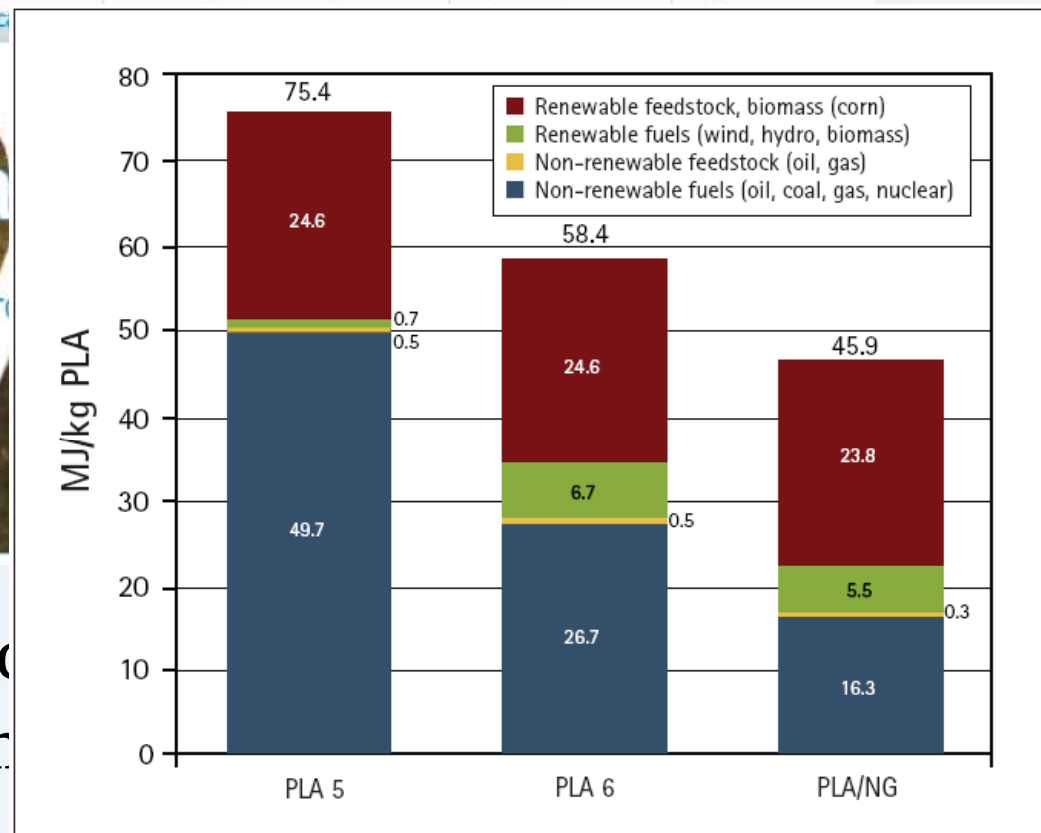


Figure 6. Cradle-to-polymer-factory-gate gross energy use for the various PLA production systems

How much land is necessary?

- NatureWorks reports 1.65 m² land requirement for producing 1 kg of PLA
- Total cropland in US: 1.8 trillion m²
- Could meet entire polymers production worldwide with **18% of current cropland**
- Could meet North American consumption with **4.8%**



Issues

Very complex topic- many points to consider

- Effect on food cost/production
- Recycling compatibility with current polymers
- CO₂ emission from biodegradation
- Landfill space requirements for polymers
- Concern with GMO's
- Mechanical properties of BPs
- Production capability in coming years
- Cost of technology

Future Directions

- Using non-edible portions of plant to grow polymer at same time as another crop
- Cellulose-based fermentation
- Specialty facilities for biodegradation of polymer/recovery of fuel produced
- Cost-competitiveness with oil as prices increase



Conclusions

- Polymeric materials are used in a substantial amount of consumer goods, and have properties not available in other materials
- With depletion of oil reserves, plastics production will become more expensive and difficult
- A lot of controversy behind BPs but a lot of potential demonstrated within the past 2-3 years
- Sequestration versus landfilling

Promising Technology!

Questions?