

# Biofuels Research at UManitoba

**David B. Levin**

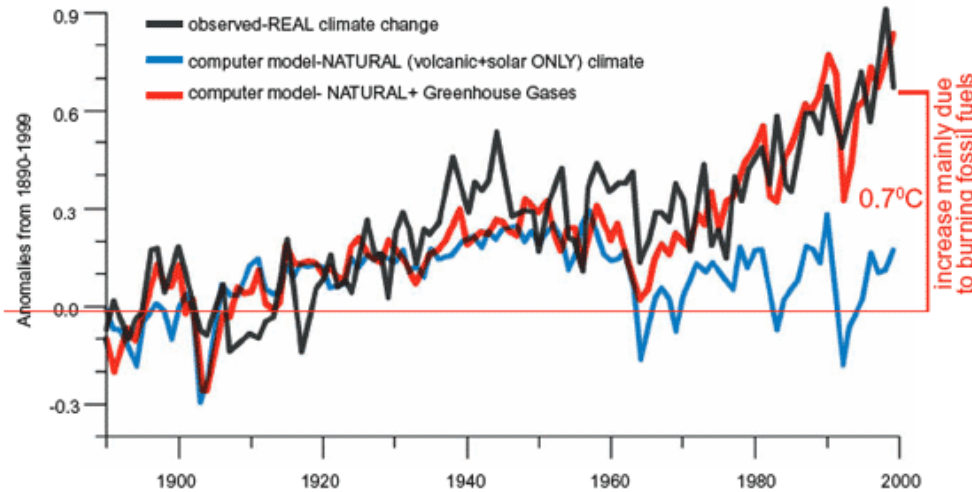
**Associate Professor**

Department of Biosystems Engineering

University of Manitoba

# Global Climate Change

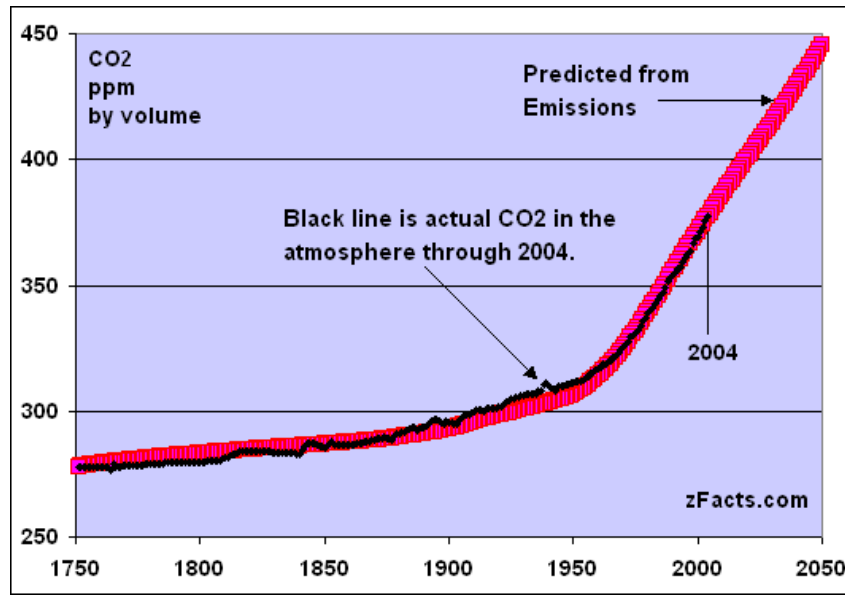
■ The greatest challenge our species will face over the next 100 years



Now



2100?



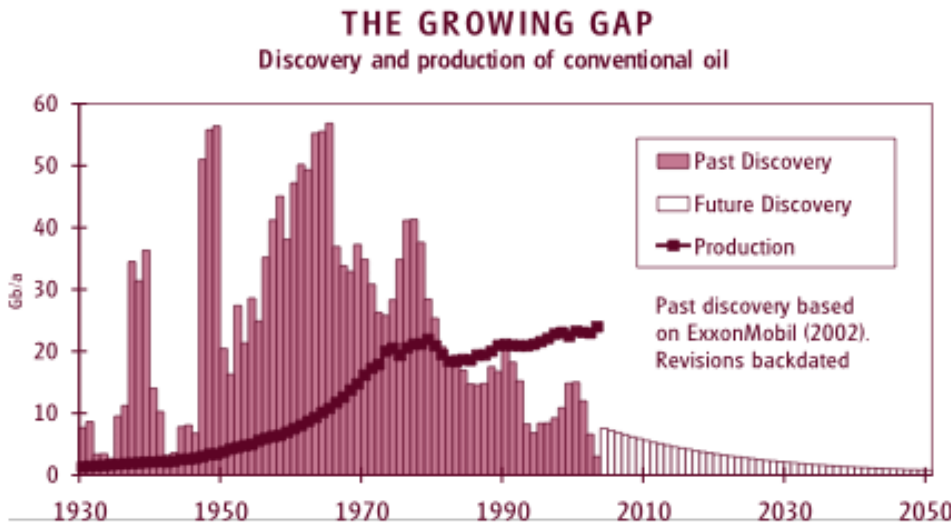
Nature of surface

- Ice
- Ocean with life
- Ocean desert
- Forests
- Scrub and desert

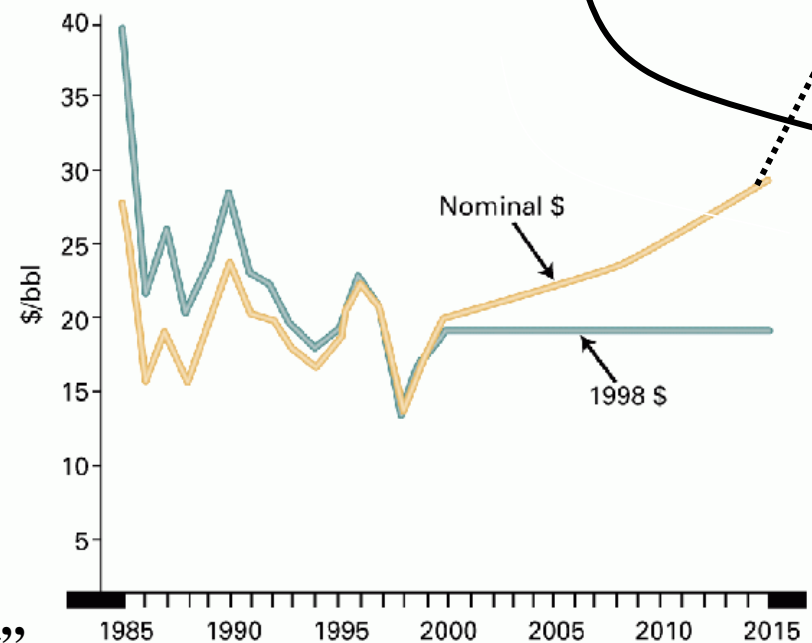
Source: James Lovelock (2006) "The Revenge of Gaia", Penguin

# Fossil Fuel Future?

- There is a growing gap between discovery of new oil reserves and production
- Alberta Oil Sands - 170 billion barrels (proven); total potential of 220 billion barrels
  - @ 2 billion barrels/year - production life span is 85 years
  - @ 10 billion barrels/year - production life span is 17 years
- Fossil fuel production costs will continue to increase
- At some point, costs of fossil fuels will exceed renewables



## REFINERS' CRUDE OIL COSTS



- Need to develop a “Sustainable Bio-economy”



# What is a Sustainable Bioeconomy?

*An economic system where a nation's 'biological capital' (forests, farmlands & aquatic resources) provide:*

- *Renewable energy, chemicals and materials;*
- *Environmental values (greenhouse gas [GHG] reductions, healthier water, air & soil)*



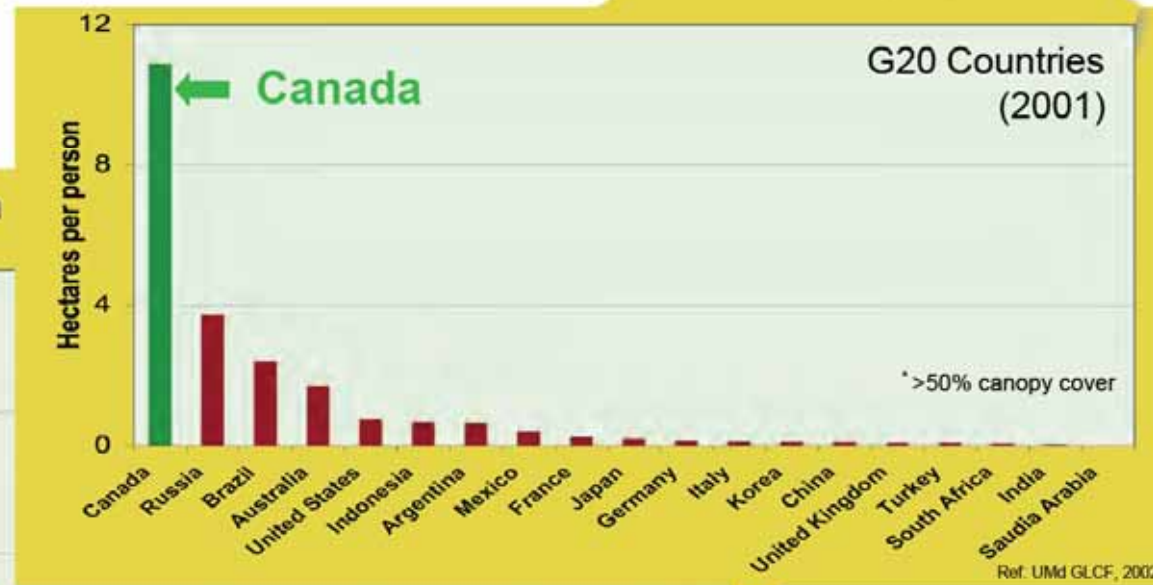
## **Canada in the World:**

- 7% land area
- 10% forests
- 68 M ha farmland
- 0.5% people

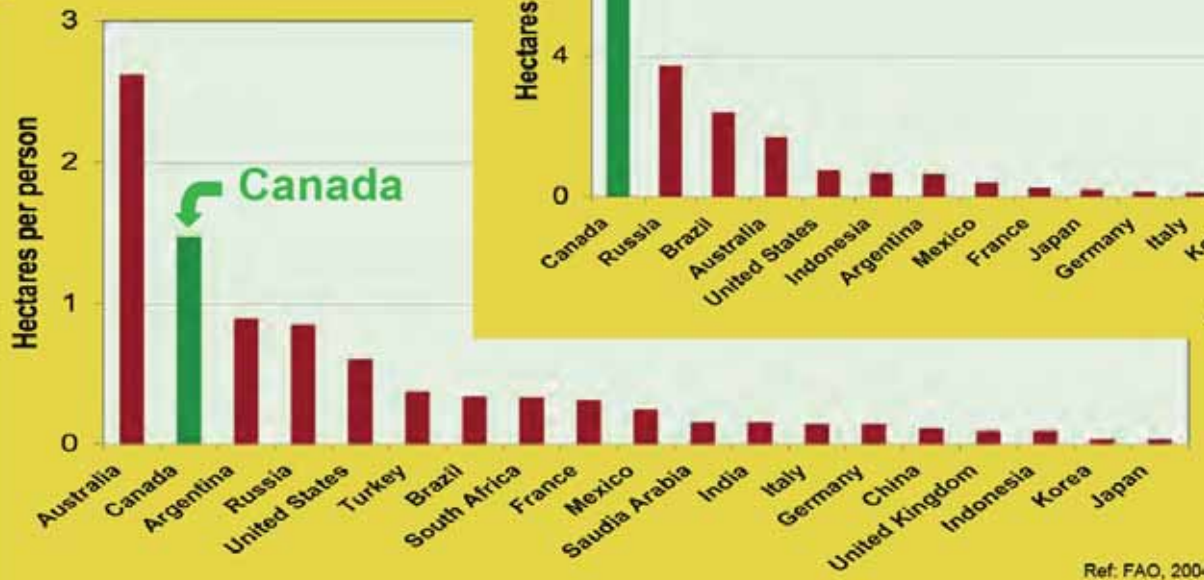
*Canada's vast biological resources provide it with a major 'Green Advantage' compared to other nations.*

# Canada's Green Advantage

Forest area per person\*



Arable land per person



*National Opportunity and Global Responsibility*

# Magnitude of the Potential

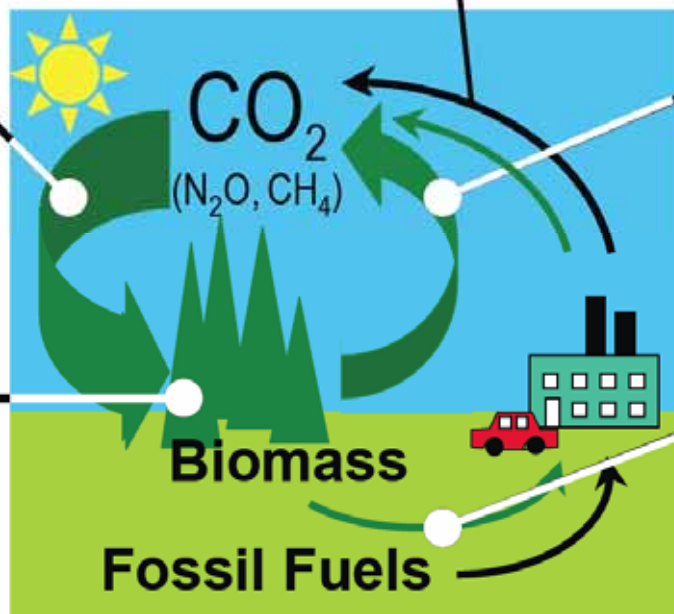
**Potential:**

100+ Mt CO<sub>2</sub>e/yr  
by 2050

**SEQUESTER**  
Atmospheric C  
& solar energy  
into biomass.

**ADAPT**  
biosphere to  
changing climate  
& atmosphere

Canada's 2004  
Emissions:  
758 Mt CO<sub>2</sub>e/yr



**Potential:**

50% reduction  
would yield  
about 40+ Mt CO<sub>2</sub>e/yr

**REDUCE** CH<sub>4</sub> &  
N<sub>2</sub>O associated  
with biosphere  
management

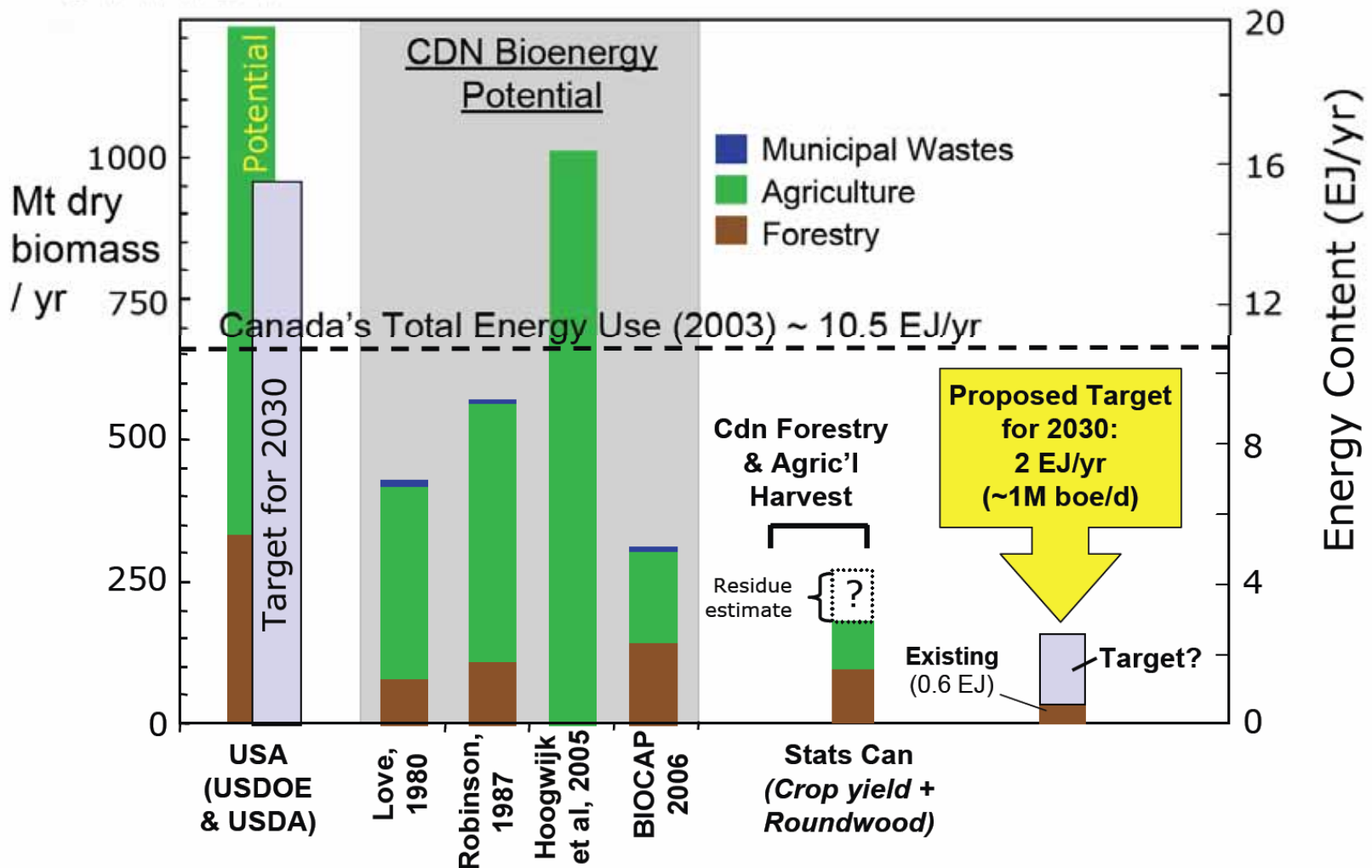
**COMPLEMENT**  
fossil energy (&  
chemicals, materials)  
with biomass

*What is the magnitude of the  
bioenergy opportunity in Canada?*

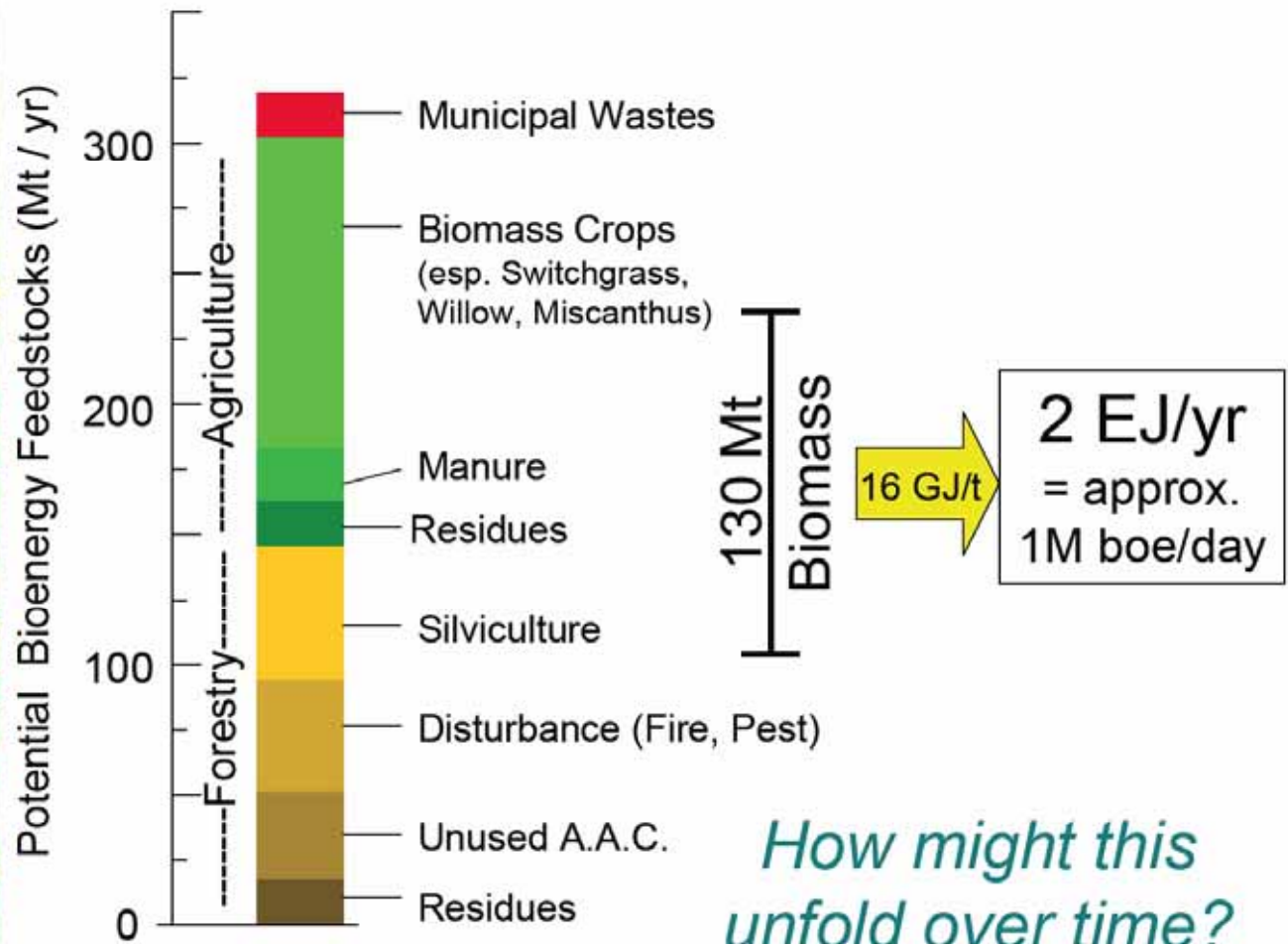


# A USA - Canada Comparison

## - Bioenergy Potential vs. Targets -

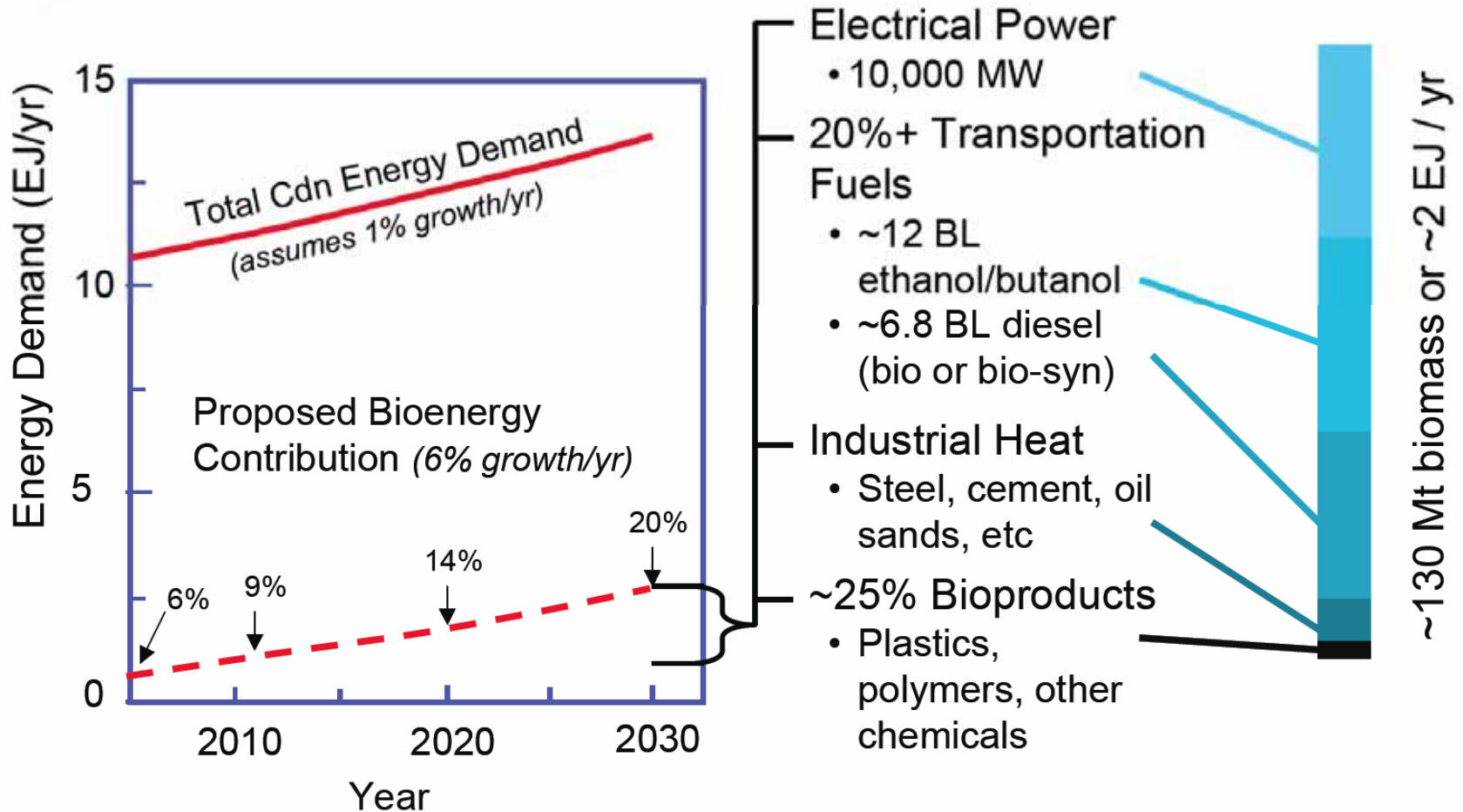


# How Could a 2 EJ/yr Target be Met?

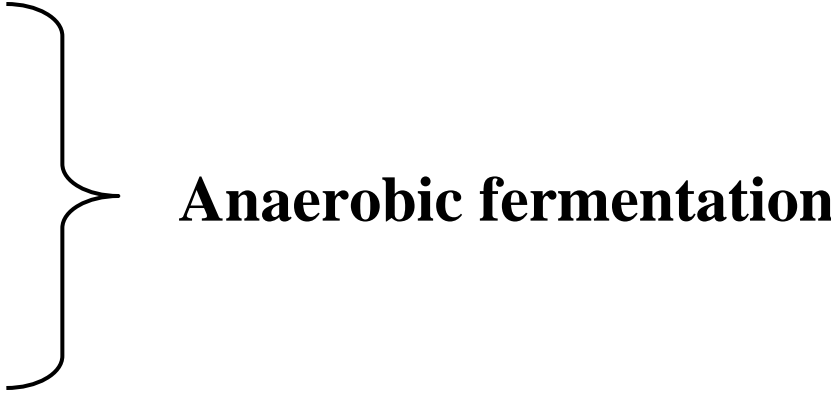


From BIOCAP, 2006

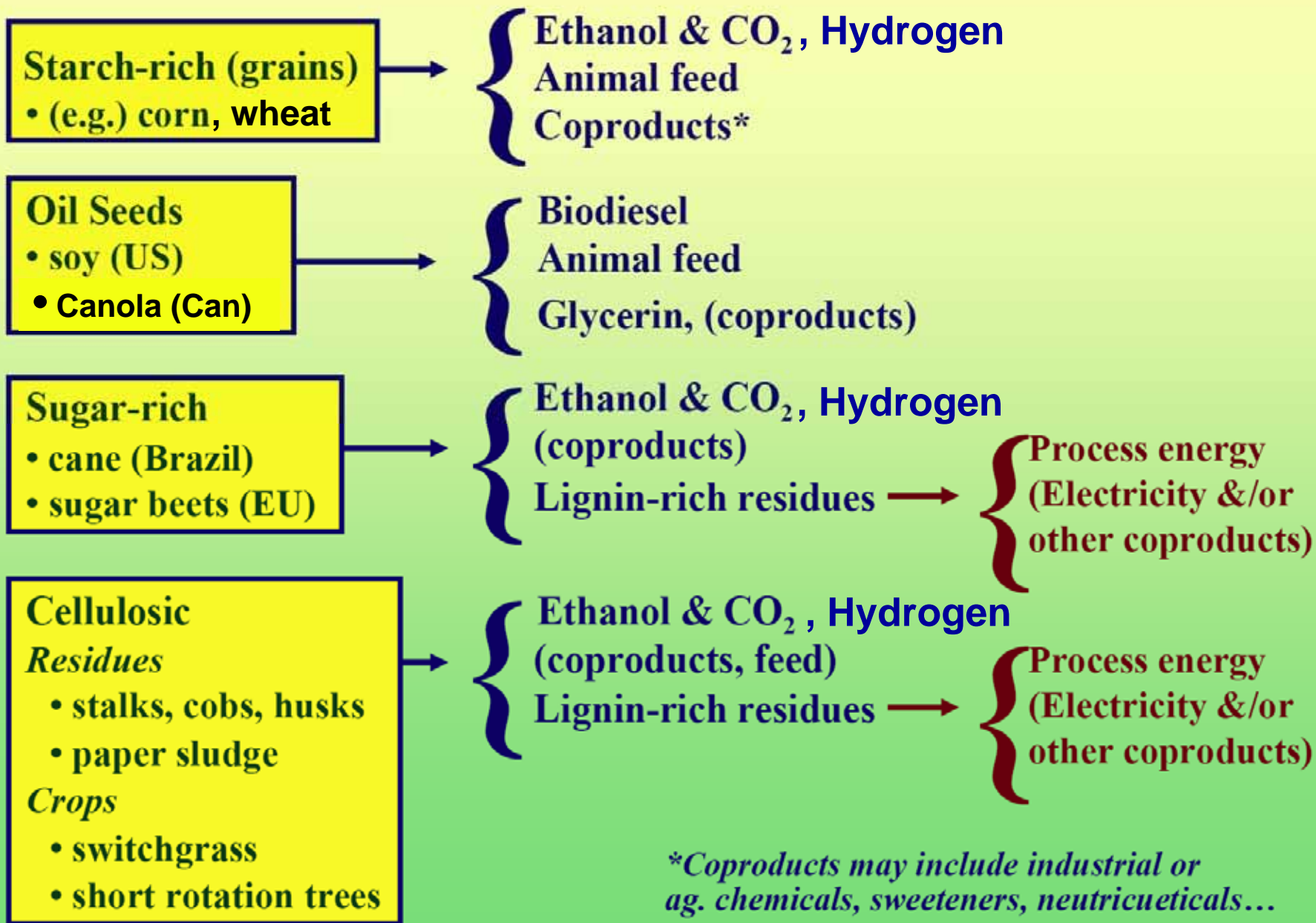
# Vision for a Bioenergy Future



# Key Challenge

- **Develop cost effective “biofuels” that are competitive with fossil fuels**
  - **What kinds of biofuels can be made from biomass?**
    - **Biodiesel**
      - ✓ **Trans-esterification of lipids from either plant oils or animal fat**
    - **Ethanol**
    - **Methane**
    - **Hydrogen**
- Anaerobic fermentation**
- 

# Biofuel Feedstock & Product Options



# Biomass Feedstocks, Especially Cellulosic, are Cost Competitive with Oil & Gas

<u>Energy Carrier</u>	<u>Price</u>		<u>Cost/Difficulty of Subsequent Conversion</u>
	<u>Common</u>	<u>\$/GJ</u>	
<i>Fossil</i>			
Petroleum	\$ 60/bbl	\$8.8	Low
Gasoline	\$1.67/gal <sup>a</sup>	\$ 17.0	-
Natural gas	\$7.50/scf	\$ 6.0	Low
Coal	\$20/ton	\$ 0.25	Moderate to high; Higher w/ CO <sub>2</sub> capture
<i>Electricity</i>	\$0.04/kWh	\$11.1	Very low for many applications; High for storage as H <sub>2</sub> , batteries
<i>Biomass</i>			
Soy oil	\$0.23/lb	\$13.8	Very low
Corn kernels	\$2.25/bu	\$6.5	Low
Cellulosic crops <sup>b</sup>	\$40/tonne	\$2.4	High now; Moderate/low in the future
Cellulosic residues	≤ crops, some < 0		

<sup>a</sup>Wholesale

<sup>b</sup> e.g. switchgrass, short rotation poplar

**\*Bioethanol from grain: \$15.8/GJ\***



# BIOFUELS IN CONTEXT

- Energy imports will be approximately \$2.5 Billion in 2005

Gasoline, Natural Gas,  
Diesel



\$2.5 Billion





# BIODIESEL – Our Next Biofuel

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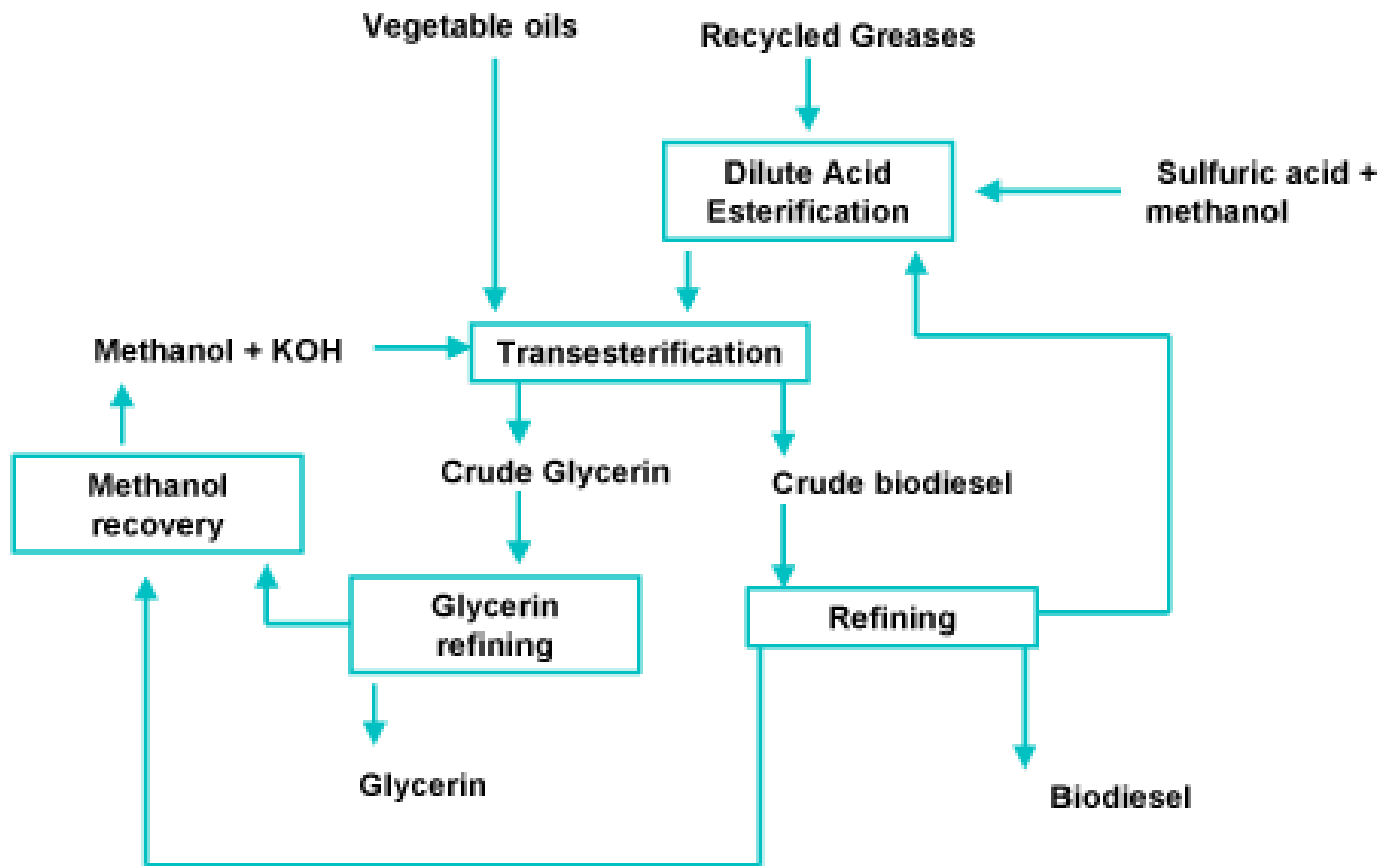
- Renewable fuel made from oil seed crops, animal fats and waste cooking grease
- Biodiesel is recyclable and fully biodegradable
- Rudolph Diesel's first engine used biodiesel
- May be blended at various levels from B1 to B100
- Improves lubricity - good alternative for low-sulfur diesel
- Various co-products include glycerol, protein meals, etc.



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# BIODIESEL

# Basic Technology





# MANITOBA ADVANTAGES

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**Manitoba has many advantages for producing biodiesel:**



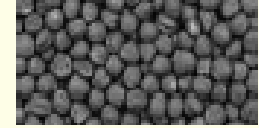
- feedstock availability
- affordable land and labour costs
- strong livestock industry
- low energy costs
- large transportation sector
- prime location for export



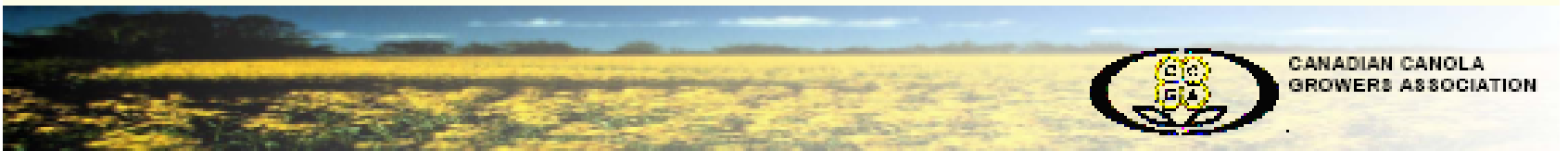
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# BIODIESEL

# Canola Biodiesel



- **Excellent cold flow properties** - Lowest saturated fat content of any available feedstock (7%). Remember the Canadian climate.
- **Good oxidative stability**
- Can produce biodiesel which meets both **ASTM D 6751** and European **EN 14214** quality specifications
- Feedstock has “**proven itself**” in the **EU!** In 2004 EU produced and consumed 1.65 Billion liters of biodiesel mainly from rapeseed/canola feedstock.



# Biodiesel Benefits

- Environmental benefits – biodegradable, nontoxic, lower exhaust emissions
- Renewable – very favorable energy balance, 3.2 to 1 - Life Cycle Assessment
- Improved lubricity – ultra low sulfur diesel fuel improved lubricity with B2
- New market for oils and fats



CANADIAN CANOLA  
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# BIODIESEL – The Opportunity

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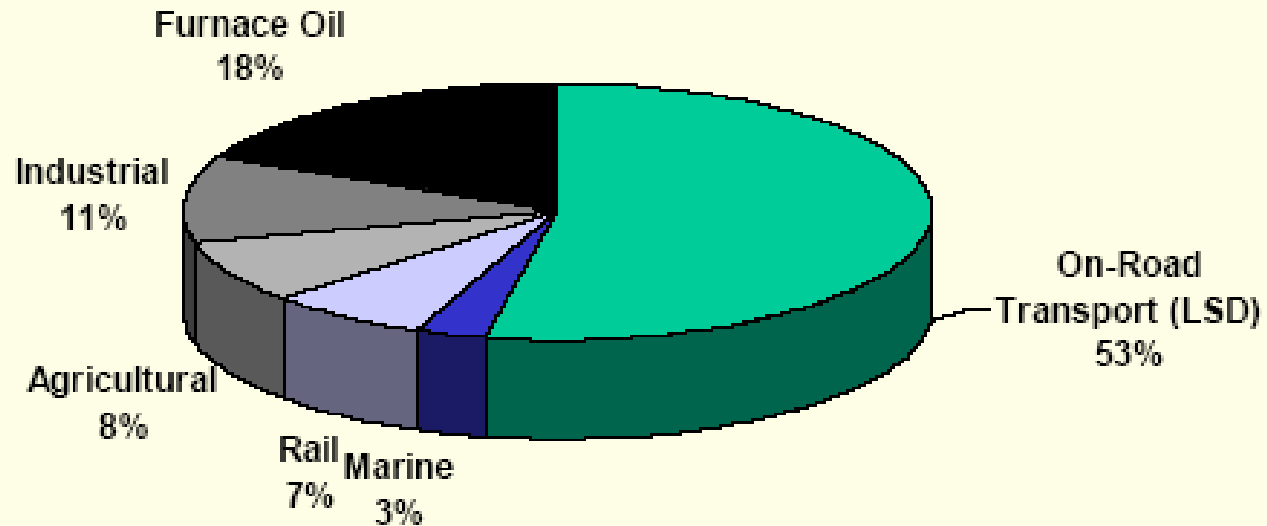
- Over 850 million litres of diesel annually
  - 300 million litres agricultural use
    - ➔ Potential for high blend usage
- Strong energy balance – 3.2 to 1
- GHG reductions – from 63% to 92%
- Huge potential for rural Manitoba
  - SRM's and deadstock



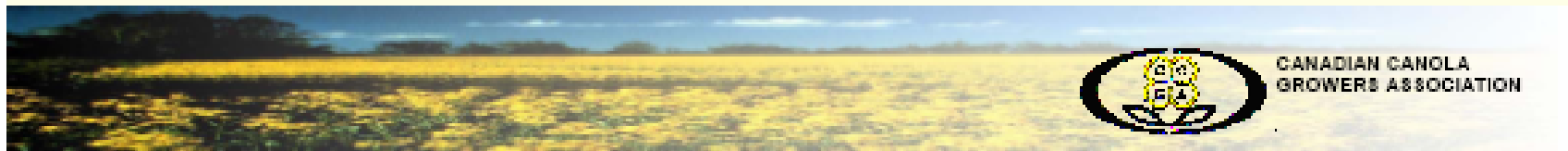
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# BIODIESEL

# Canadian Diesel Fuel Demand by End Use, 2003 28.9 Billion Litres



Source: - Statistics Canada Catalogue no. 57-003-XIB



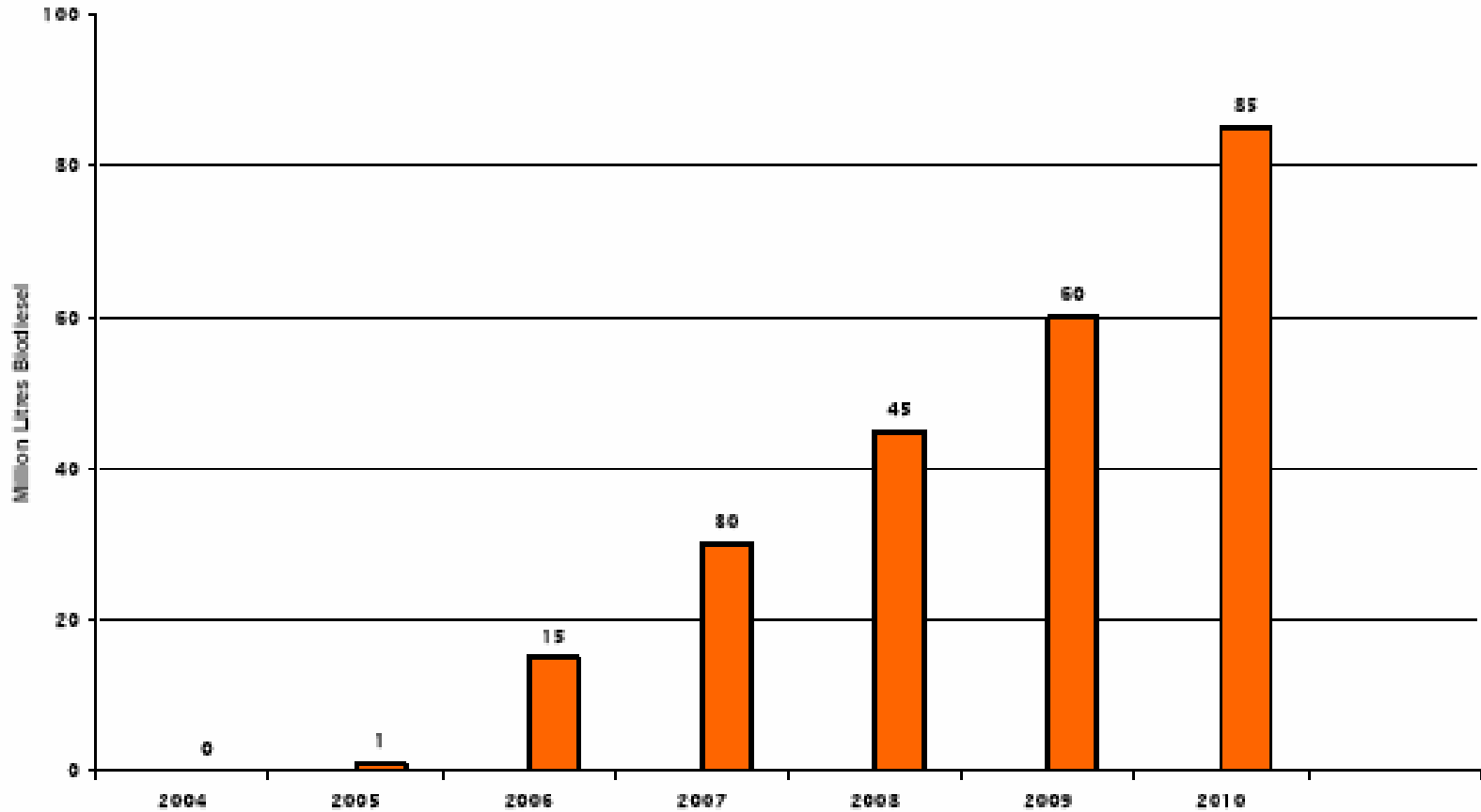
# Potential Biodiesel Production from Canadian Feedstock Sources 2007 to 2010

<b>Source</b>	<b>Biodiesel Production</b>
Tallow	160 million litres
Yellow Grease	80 million litres
Canola	220 million litres
Soybeans	40 million litres
<b>TOTAL FORECAST</b>	<b>500 million litres</b>



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# MANITOBA BIODIESEL PROJECTIONS\*



\*estimated based on higher cost of diesel fuel and Federal participation

# What can Biodiesel mean to Canola in Canada

- B2 Blend– 680,000 tonnes of Canola Seed
- B5 Blend– 2,600,000 tonnes of Canola Seed



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# Biomass as a Source of Ethanol

## ■ Why Ethanol?

### ➤ Compared with gasoline, combustion of ethanol:

- ✓ Is more efficient and burns more cleanly
- ✓ Has high octane rating
- ✓ Has low temperature yield
- ✓ Is compatible with current technologies
  - ❖ E10 or E85 blends with gasoline
- ✓ Produces less ozone precursors
- ✓ Emits less CO (30%↓), CO<sub>2</sub> (10%↓)  
SO<sub>x</sub> and No<sub>x</sub> (7% ↓)
- ✓ Has lower volatility and photo-reactivity
- ✓ Renewable
- ✓ Stimulate local rural economies

Good engine performance

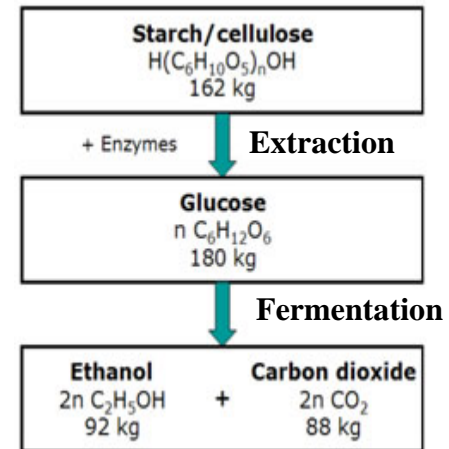
Reduced air pollution

# Biomass as a Source of Biofuels

## Ethanol yields on from feedstocks

<u>Feedstock</u>	<u>Ethanol Yield (litres/dry tonne)</u>	
Sugar cane	> 900	→ sugar-based
Corn	750	} starch-based
Wheat	365	
Corn stover	345	} cellulose-based
Delignified wood fibers	333	
Wheat straw	330	
Switchgrass	310	
Hay	305	
MSW	166	

logen Corporation: 300 (pre-commercial cellulosic production)

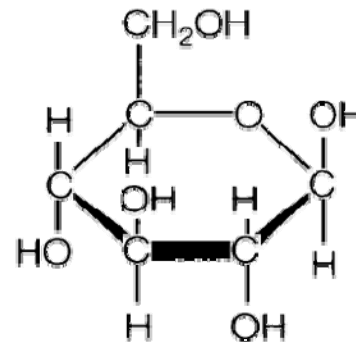


## Conversion efficiencies from wheat and cellulosic biomass are very low

# Sugars vs Starch vs Cellulose ?

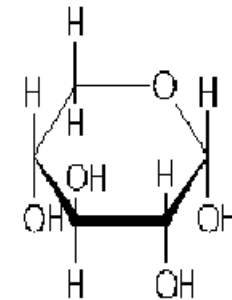
## ■ Simple Sugars

6-carbon sugars



**Glucose**

5-carbon sugars

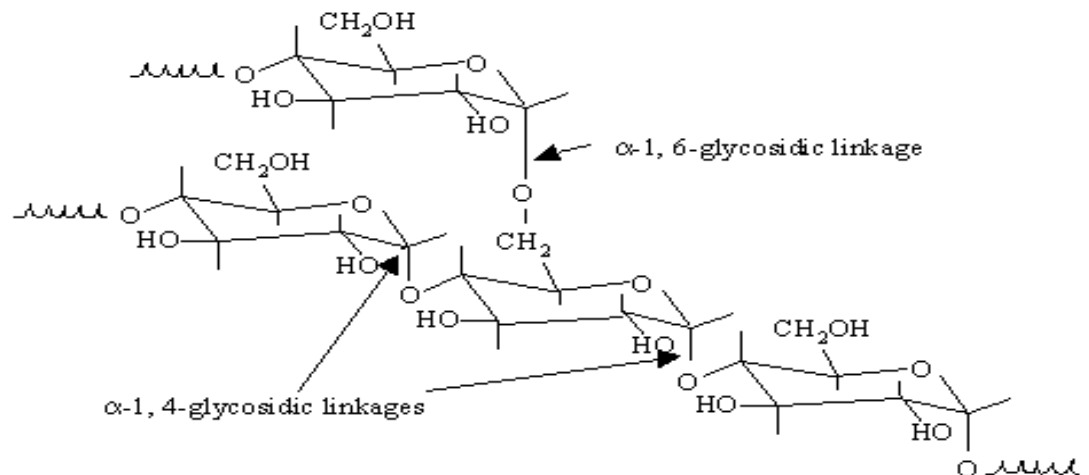


**Xylose**

## ■ Starch

➤ Amorphous polymers of glucose

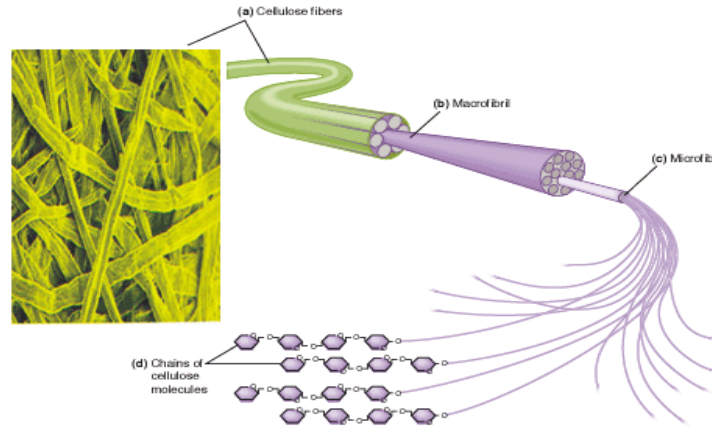
$\alpha$ -1,4 linkages within chains  
 $\alpha$ -1,6 linkages between chains



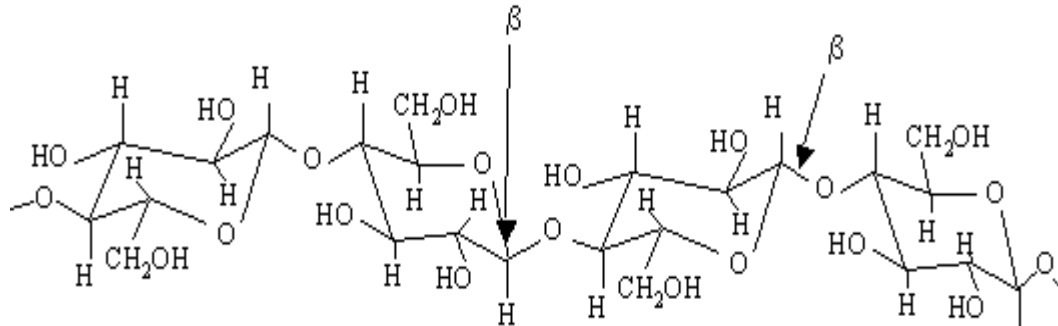
# Sugars vs Starch vs Cellulose ?

## ■ Cellulose

- Primary structural component of plant biomass



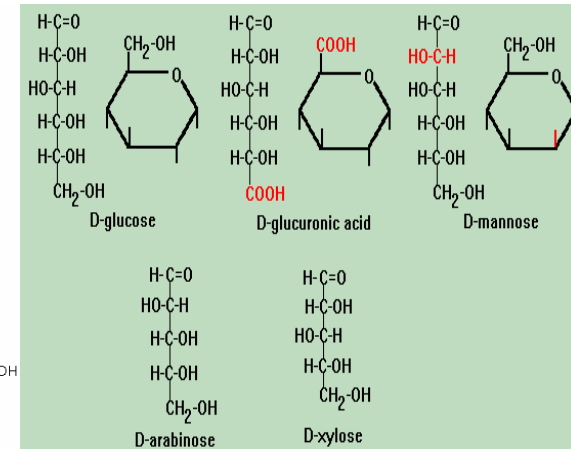
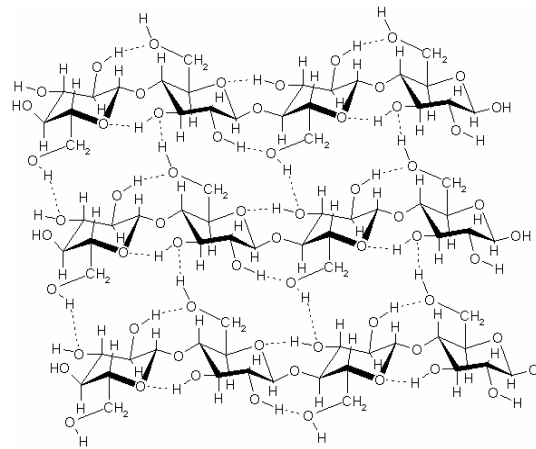
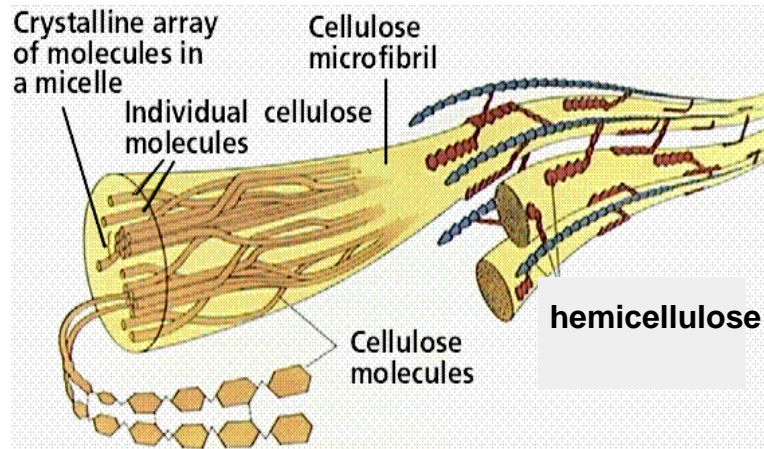
- Highly ordered polymers of glucose with  $\beta$ -1,4 linkages



# Sugars vs Starch vs Cellulose ?

## ■ Plant fibers also contain hemicellulose

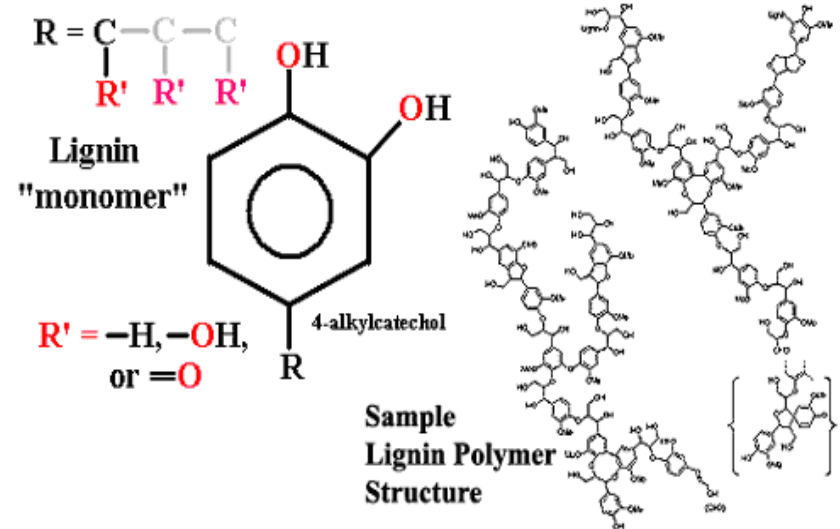
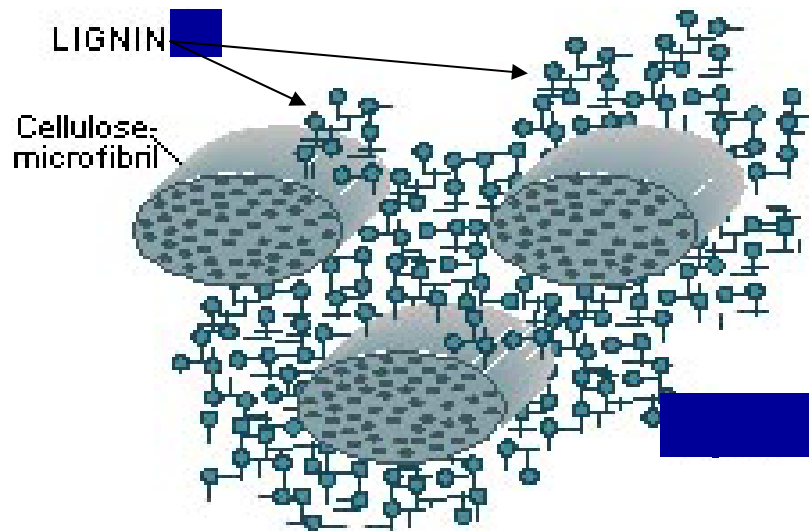
- Amorphous polymer consisting of short, highly branched, chains containing
  - ✓ 5-carbon sugars: D-xylose, L-arabinose
  - ✓ 6-carbon sugars: D-glucose, D-galactose, D-mannose
  - ✓ Sugars are highly substituted with acetic acid



# Sugars vs Starch vs Cellulose ?

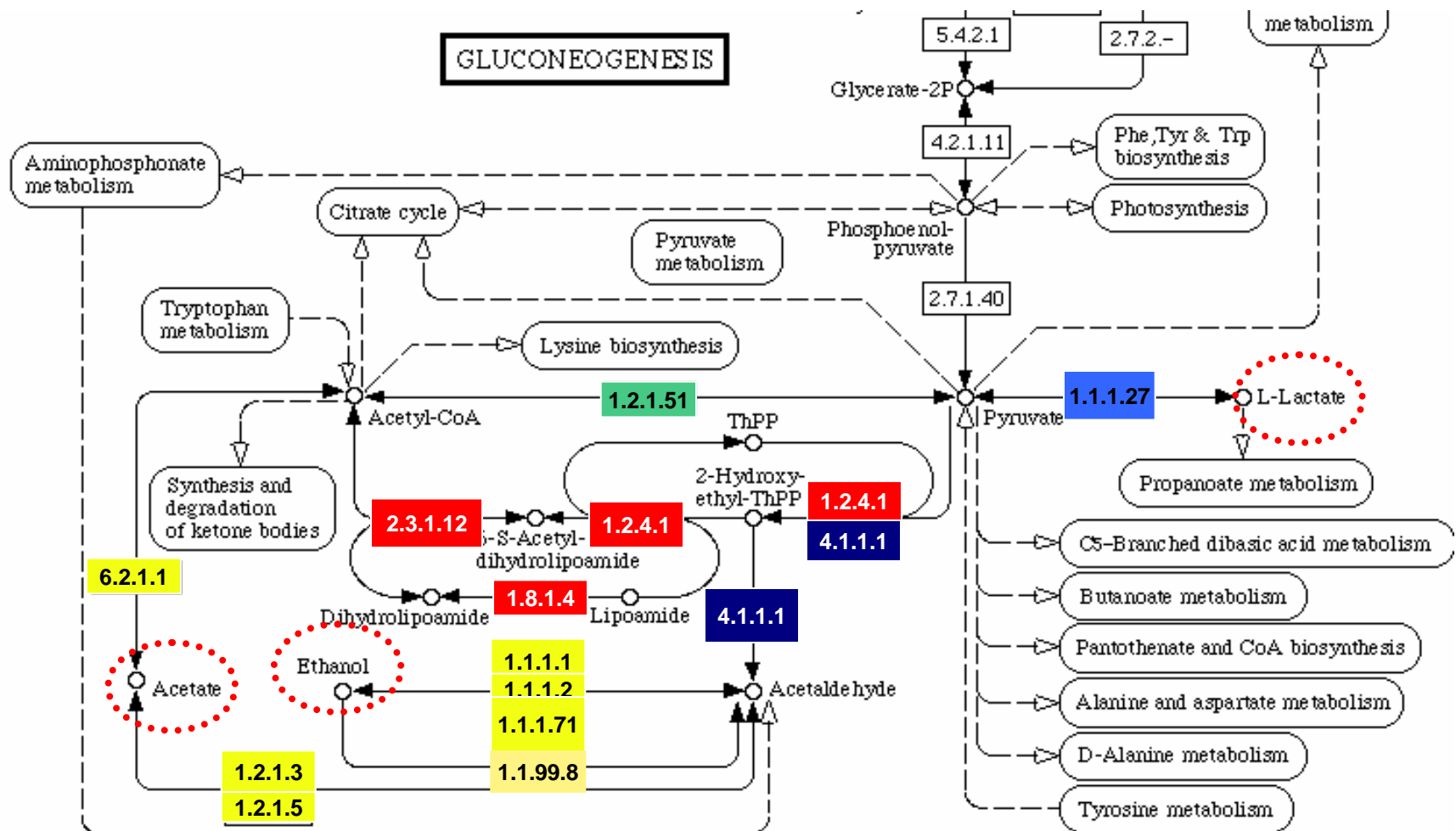
## ■ Plant fibers also contain lignin

- Biopolymer that provides structural integrity to plants
- Rich in phenolic components



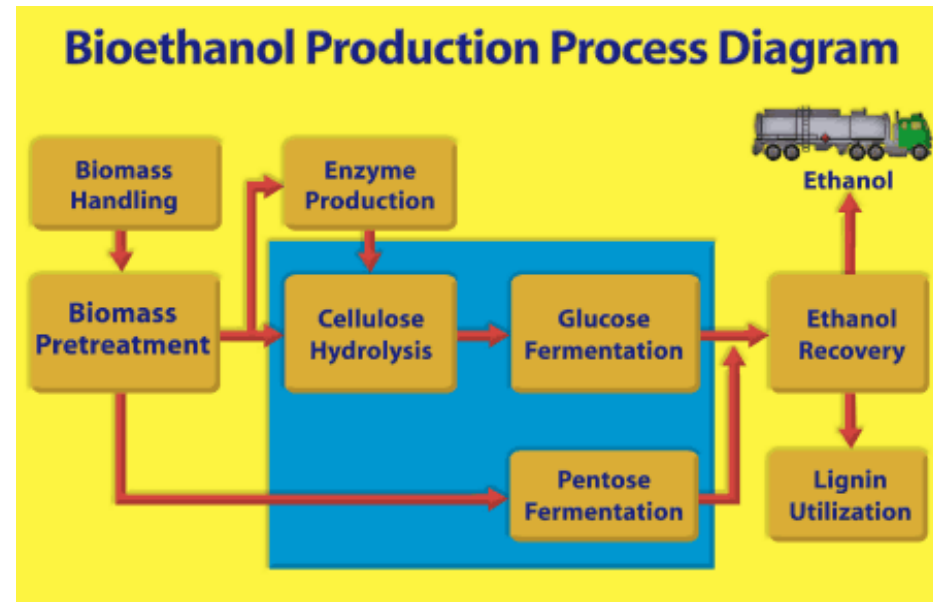
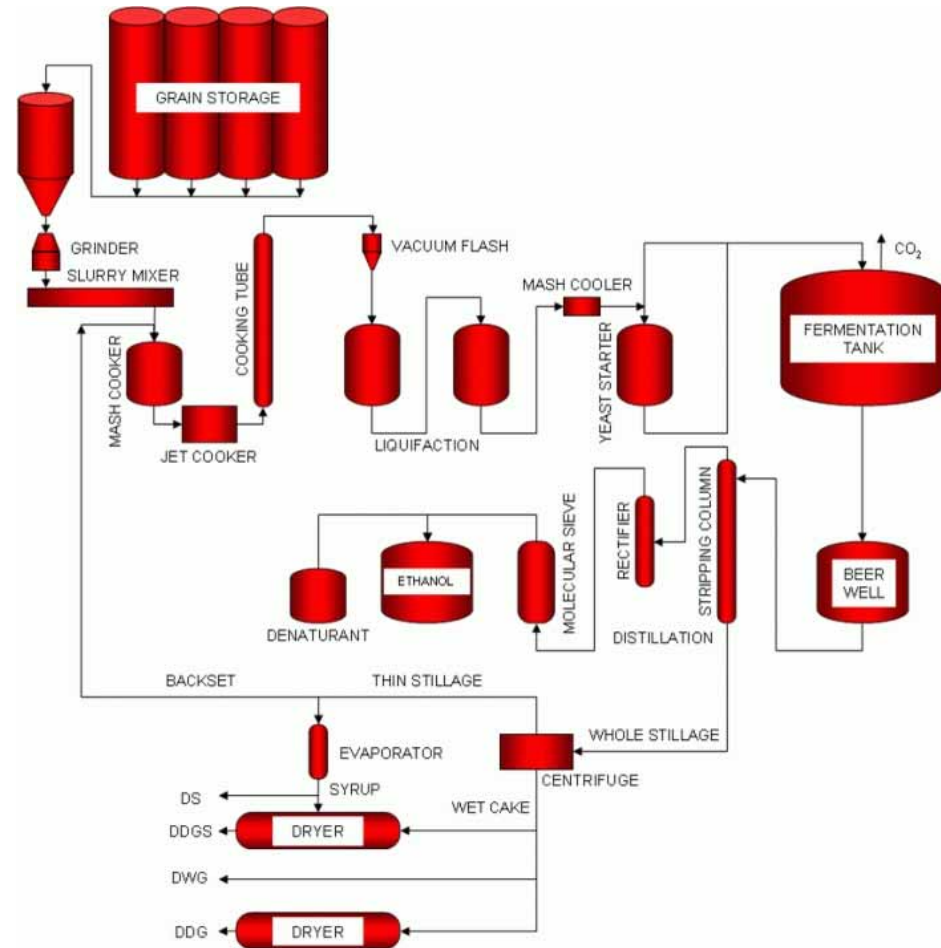
# Ethanol Synthesis by Fermentation

- Primary source of ethanol is *Sacharromyces cerevisiae* – Brewers' Yeast
- Many other organisms make ethanol
- Several metabolic pathways to ethanol; Not all organisms use all pathways
- Synthesis of other end-product compete with biofuels synthesis



# Biomass as a Source of Biofuels

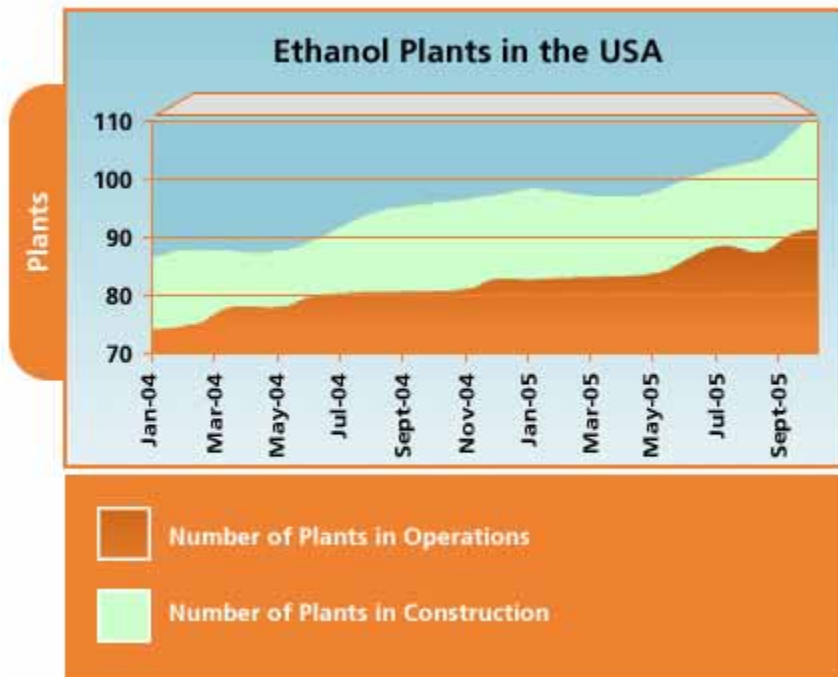
## Ethanol production from grain vs cellulosic feedstocks



# Biomass as a Source of Biofuels

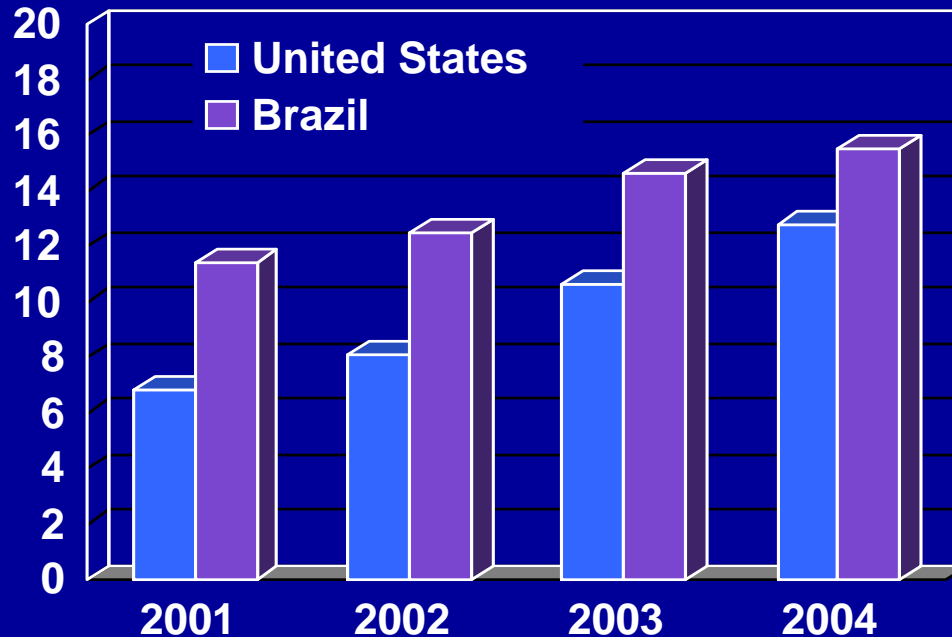
## ■ Ethanol production in the US and Canada

- Corn in the US and eastern Canada
- Wheat in the Canadian Prairies



# Bio-Ethanol

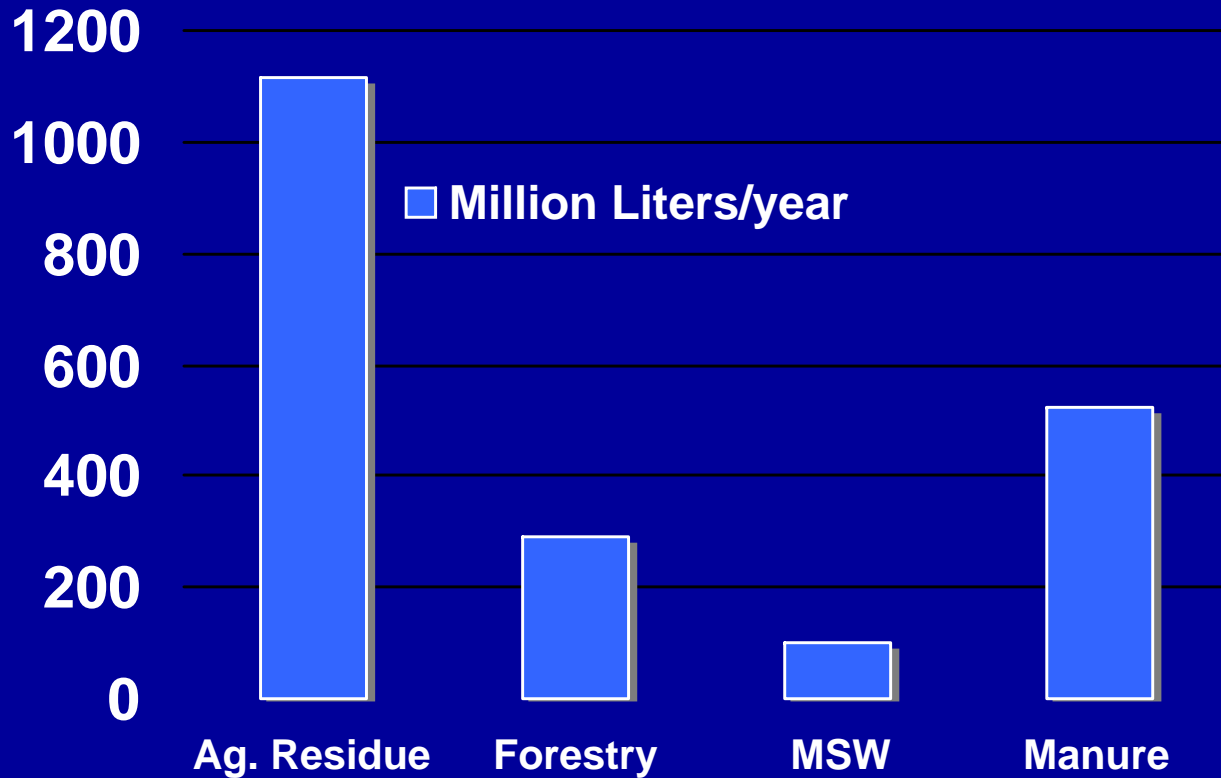
## Ethanol output, billion liters



Source: US Renewable Fuels Association, Brazilian Ministry of Agriculture

- \* Europe Bio-ethanol production capacity: ~ 400 million liters/year (Primarily Spain, France , and Sweden)
- \* China's annual production is around 3 billion liters (most of it not for fuel use)
- \* Canada existing capacity: ~238 million liters/year (two new plants coming on line for 260 million liters/year)
- \* US target for 2030 is 37 billion litres/year

# Manitoba Bio-ethanol Capacity



- Manitoba Gasoline use: ~1.40 billion L/yr
- Potential ethanol production w/ cellulosics: 2.03 billion L/yr
- Potential ethanol production w/o cellulosics: 1.50 billion L/yr



## *What would it mean for Canada?*

- \$7.8B/yr (2005\$) invested directly in farms and forestry operations;
- \$30B+/yr (2005\$) stimulus to the national economy;
- 100,000 jobs across Canada;
- Greenhouse gas emission reductions of 70 Mt CO<sub>2</sub>e/yr (*corrected for LCAs*);
- Cleaner air and water;
- Solutions for municipal & animal waste;
- Improved energy security;
- More fossil resources available to export.



# Key Challenges for Biofuels

## ■ Food vs Fuel?

### ➤ Should we use food crop for biofuel production?

- ✓ Lower grade crops (# 2, #3) used for bioethanol

## ■ Dedicated bioenergy crops vs crop residues as feedstocks?

### ➤ Food vs cellulosic waste for bioethanol production?

- ✓ High starch content wheat as dedicated biofuel crop
- ✓ Cellulosic bioethanol production (ag residues, straw..)

## ■ Efficiency of ethanol production and energy balance?

### ➤ Increase yield of glucose from starch and cellulose

### ➤ Increase rates and yields of ethanol synthesis during fermentation

### ➤ Increase yields of ethanol by improved bioprocessing

### ➤ Reduce fossil fuel inputs

Improve energy balance

## ■ Value of co-products

### ➤ Biodiesel - glycerol

### ➤ Bioethanol - dried distillers grains (DDG)

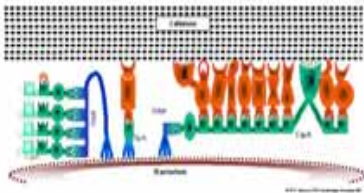
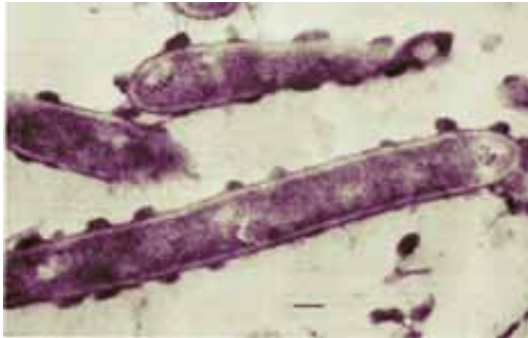
### ➤ Reduce fossil fuel inputs to improve energy balance

## ■ Sustainable cropping systems?

- ✓ Effect of continuous canola - winter wheat rotations on soil fertility?

# My Research

- **Hydrogen production from cellulosic biomass**
  - **Why H<sub>2</sub>?**
    - ✓ Burns cleanly- no emissions other than water
    - ✓ Compatible with conventional internal combustion engines
  - **H<sub>2</sub> production by *Clostridium thermocellum***
    - ✓ Gram positive
    - ✓ Degrades cellulose at high rate
    - ✓ Produces acetate or ethanol depending on growth conditions
    - ✓ Produces H<sub>2</sub> and CO<sub>2</sub> gas as by-products of metabolism



Paper



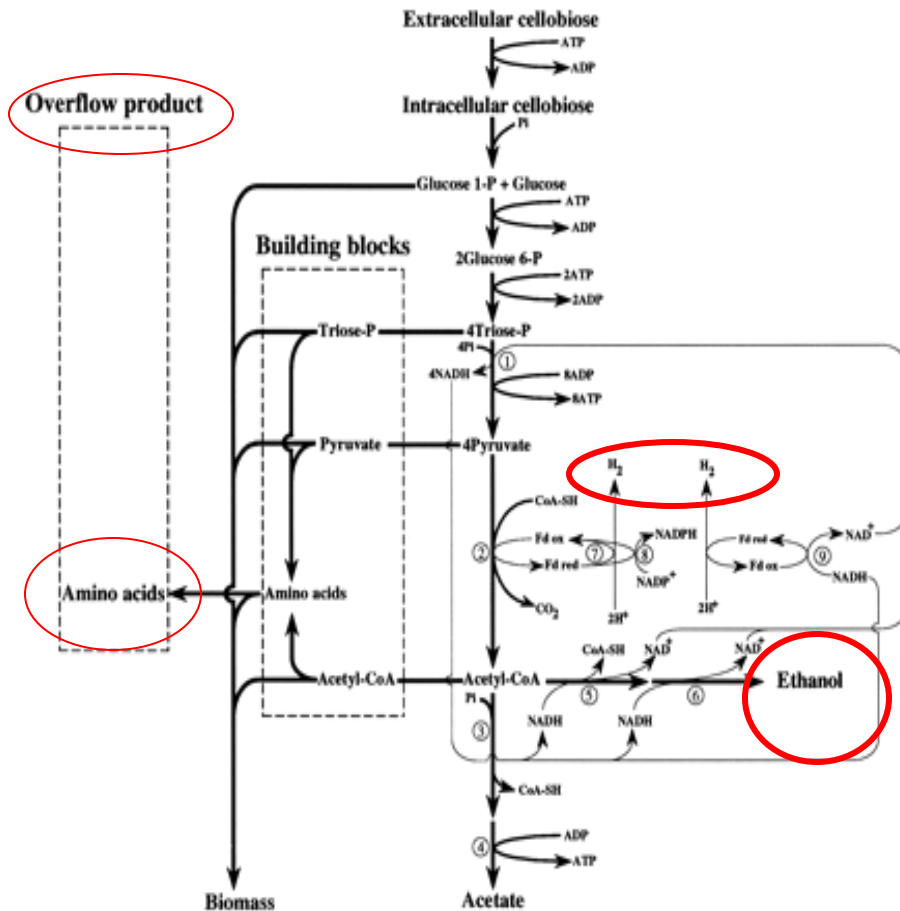
Wood fibers



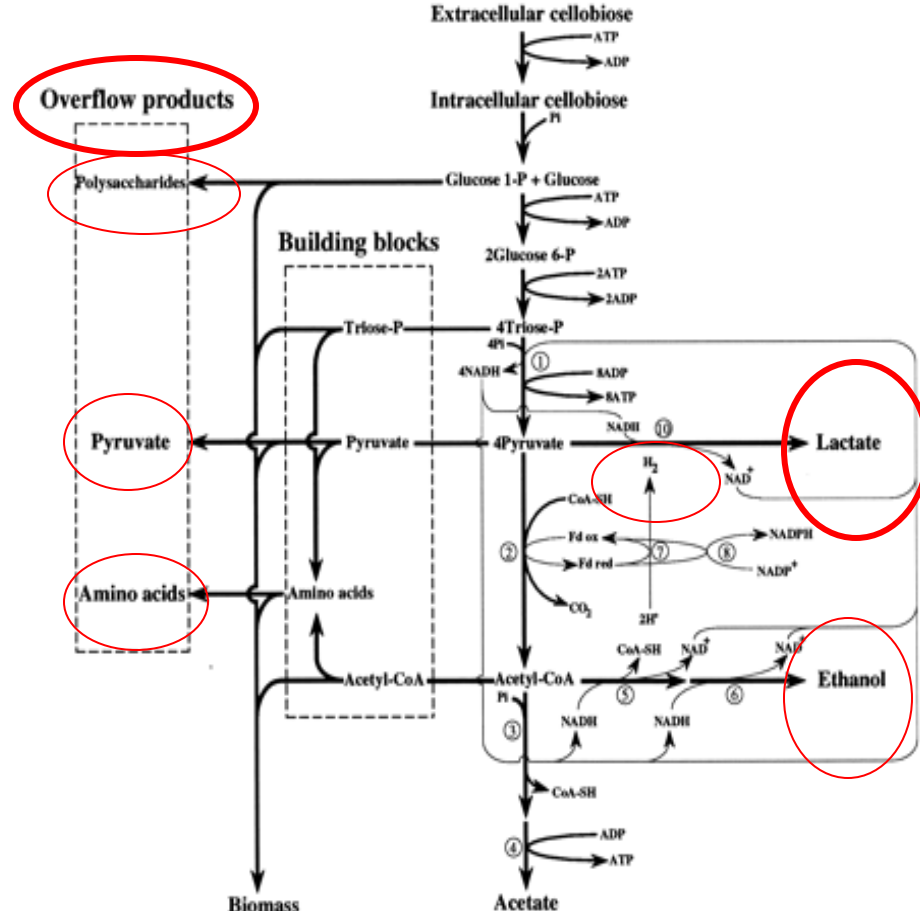
# My Research

- 1<sup>st</sup> key to increasing biofuels synthesis is to understand “metabolic fluxes”
- What end-products are made and when?

*C. cellulolyticum*: Low Carbon flow



*C. cellulolyticum*: High carbon flow

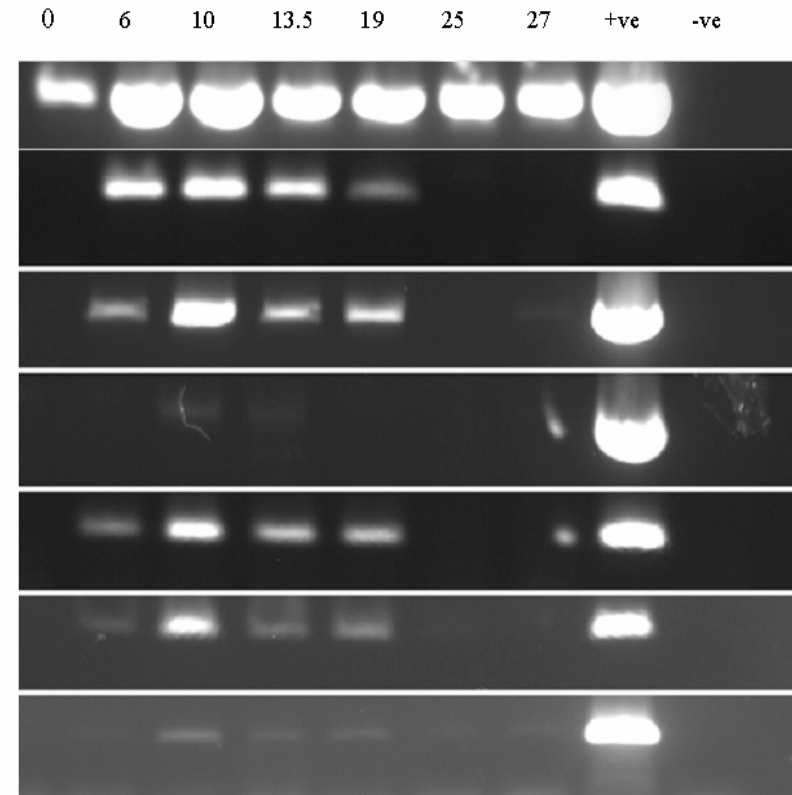
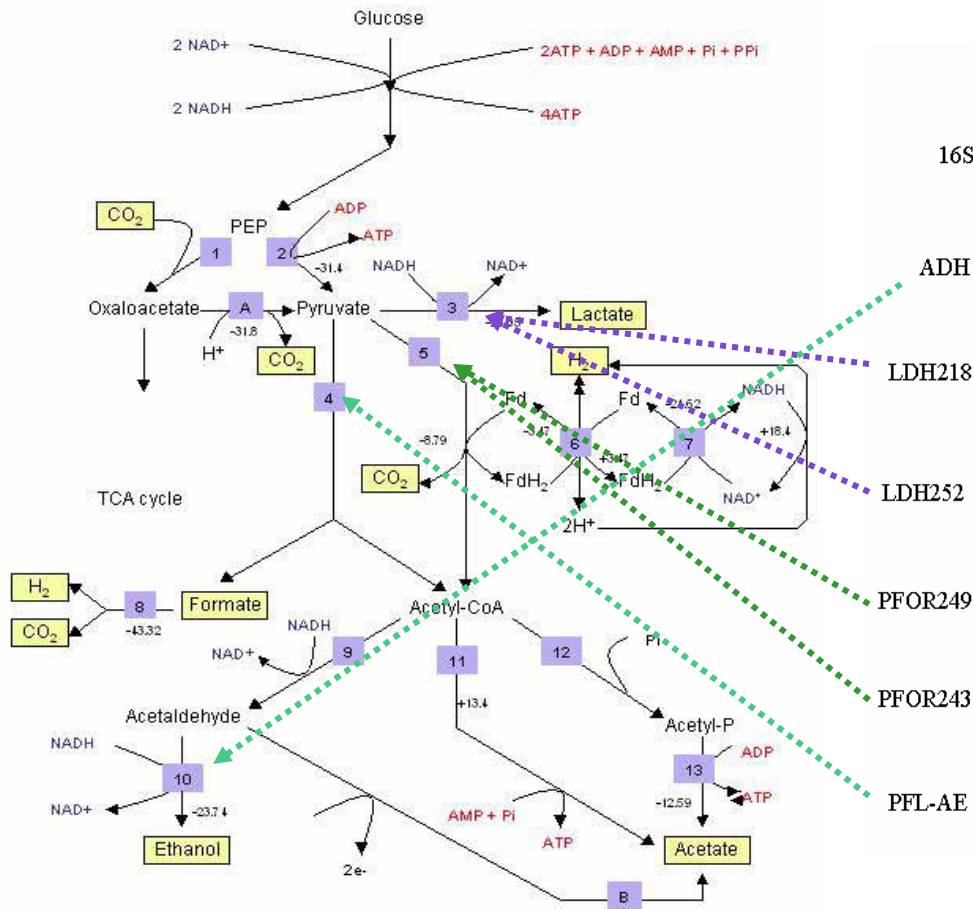


# My Research

■ 2<sup>nd</sup> key to increasing biofuels synthesis is to understand how metabolic fluxes are regulated

➤ What genes encode the enzymes that carry out synthesis? When are these expressed?

- ✓ Transcription of key metabolic pathway genes in *C. thermocellum* by RT-PCR reveals changes in gene expression at different phases of growth



# NSERC-Husky Energy Biofuels Research Program

2007 - 2012

## Ethanol Feedstock Breeding

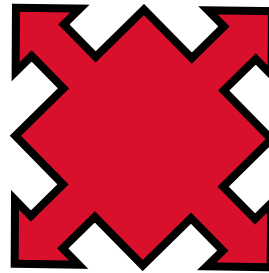
*Brule-Babel*

Novel high starch content,  
FHB resistant varieties of winter wheat

## Dried Distillers Grains

*Wittenberg*

Increase value of DDG as  
livestock feed supplement



## Ethanol Feedstock Physiology

*Razem*

Factors that influence seed size &  
starch content/storage

## Bioengineering for Biofuels

*Levin*

Increase conversion efficiencies & yields:  
Starch to sugars to ethanol  
during fermentation

# Future Research

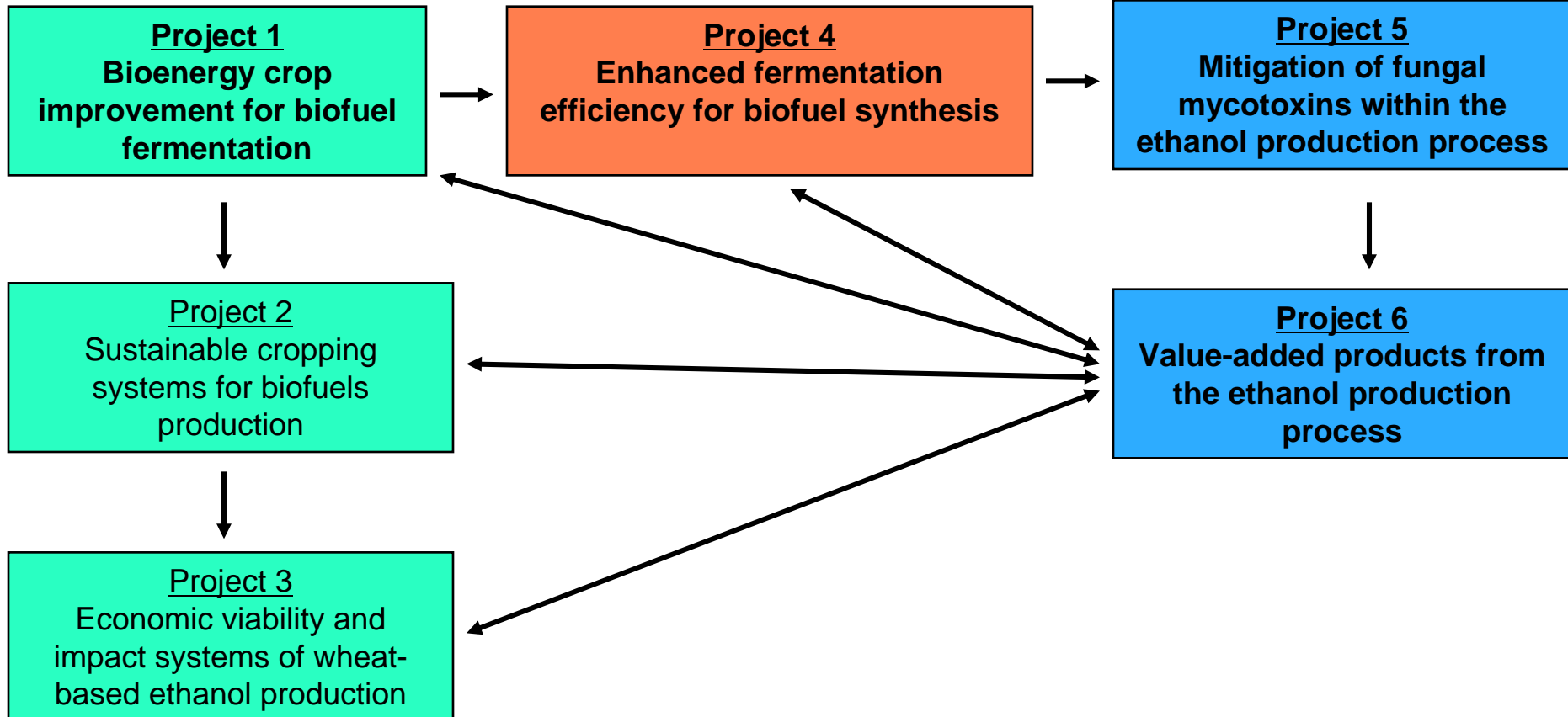
## Advanced Bioethanol and Co-products Network

ABIP Research Priority Areas

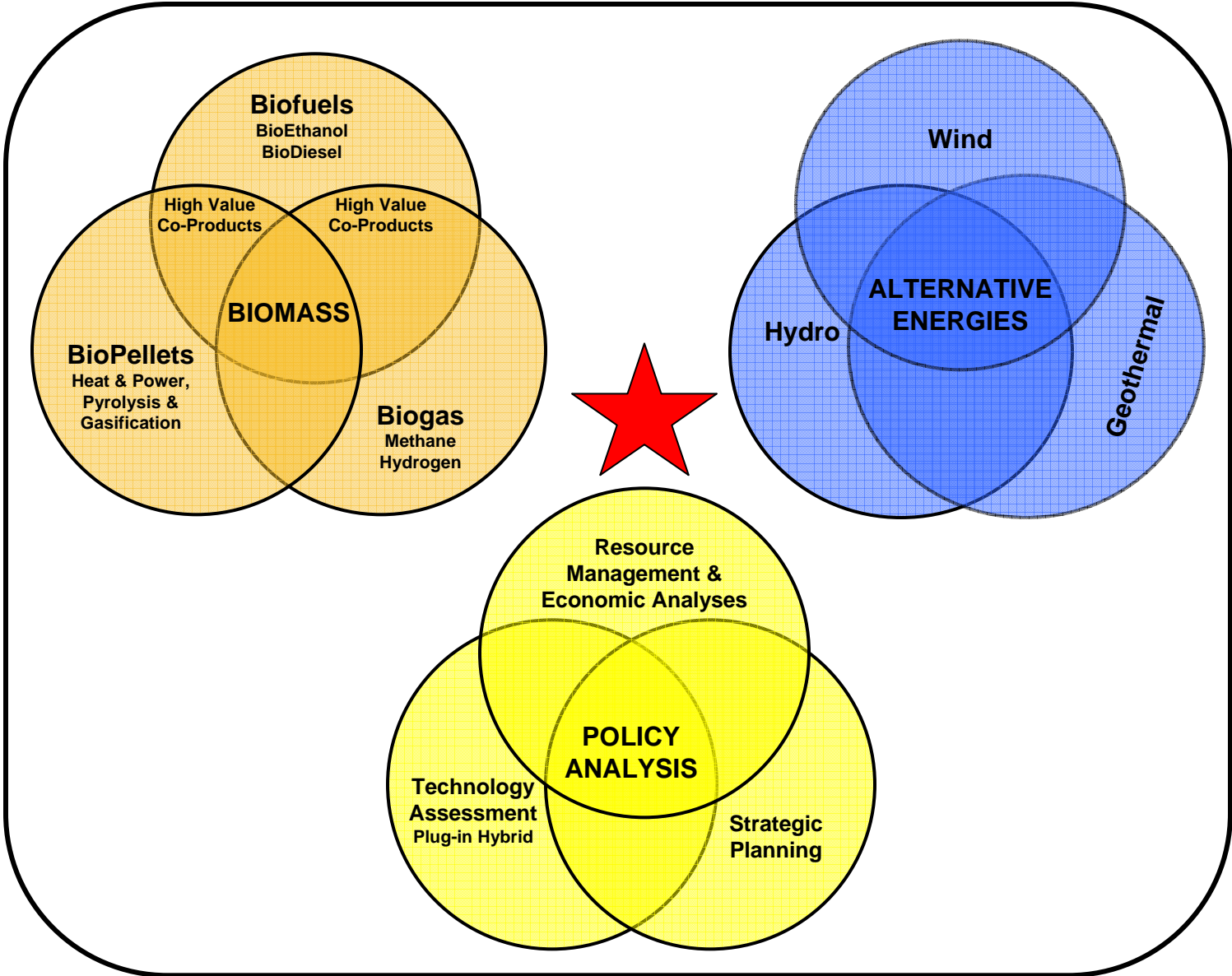
### 1) Bioenergy Crops

### 2) Conversion Technologies

### 3) Bioproduct Diversification



# BIOENERGY & BIOPRODUCTS RESEARCH CENTRE



**Thank You!**

