The Forest Biorefinery- How do we capture more value?

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The BIG Picture

- Michigan's Transportation Fuel Use:
  - 5 billion gallons of gasoline per year
  - 1 billion gallons of diesel

  (our forests could supply this for 6 years, then they'd be gone)

- Michigan's Electricity Use:
  - 13.6 Gigawatts consumed

  (our forests could supply this for 6 years, then they'd be gone)

- Space and process heat
  - No good estimates available

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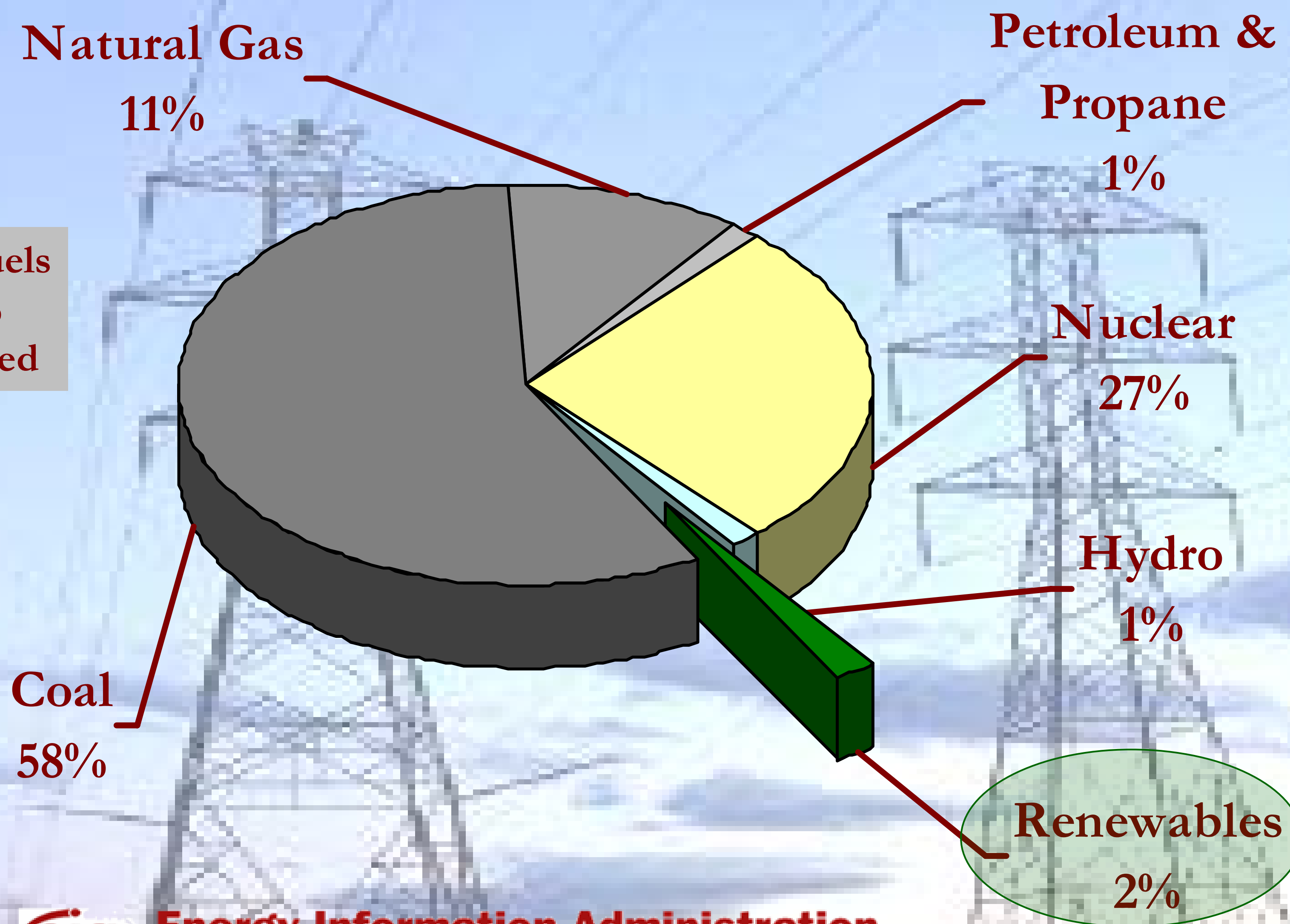
Michigan's Electric Power Generation by Energy Source in 2005



Fossil Fuels
~ 70%
Combined

FEDERAL RENEWABLE GOAL:

25% by 2025

MICHIGAN RENEWABLE GOAL:

10% by 2015
then 20% by 2025.

(Sweden is going after 100% by 2020)

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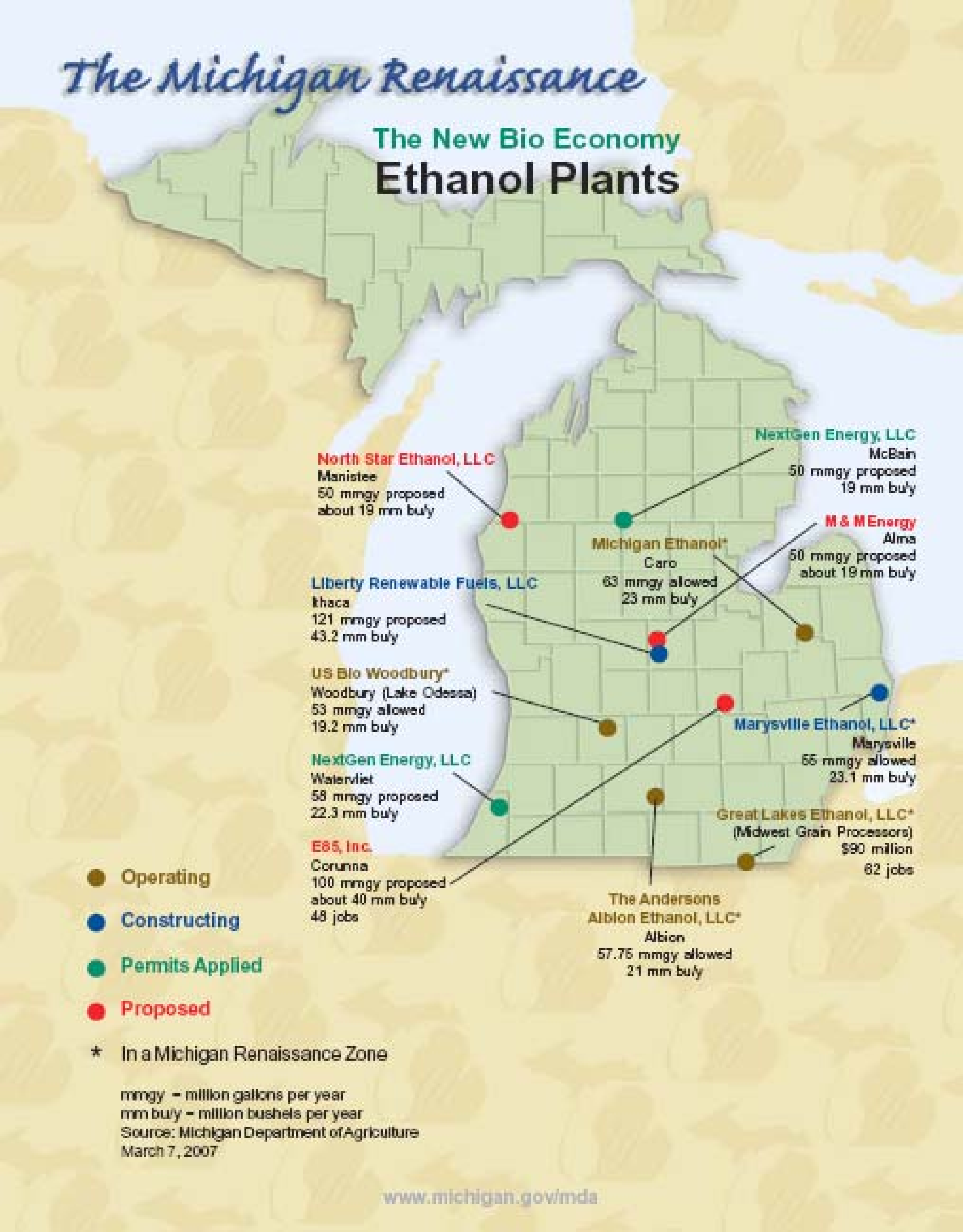

CORN ETHANOL

CURRENT PRODUCTION:

105 million gallons/year

(1.5% of gasoline consumption)

PROJECTED PRODUCTION:

536 million gallons/year

(7.5% of gasoline consumption)

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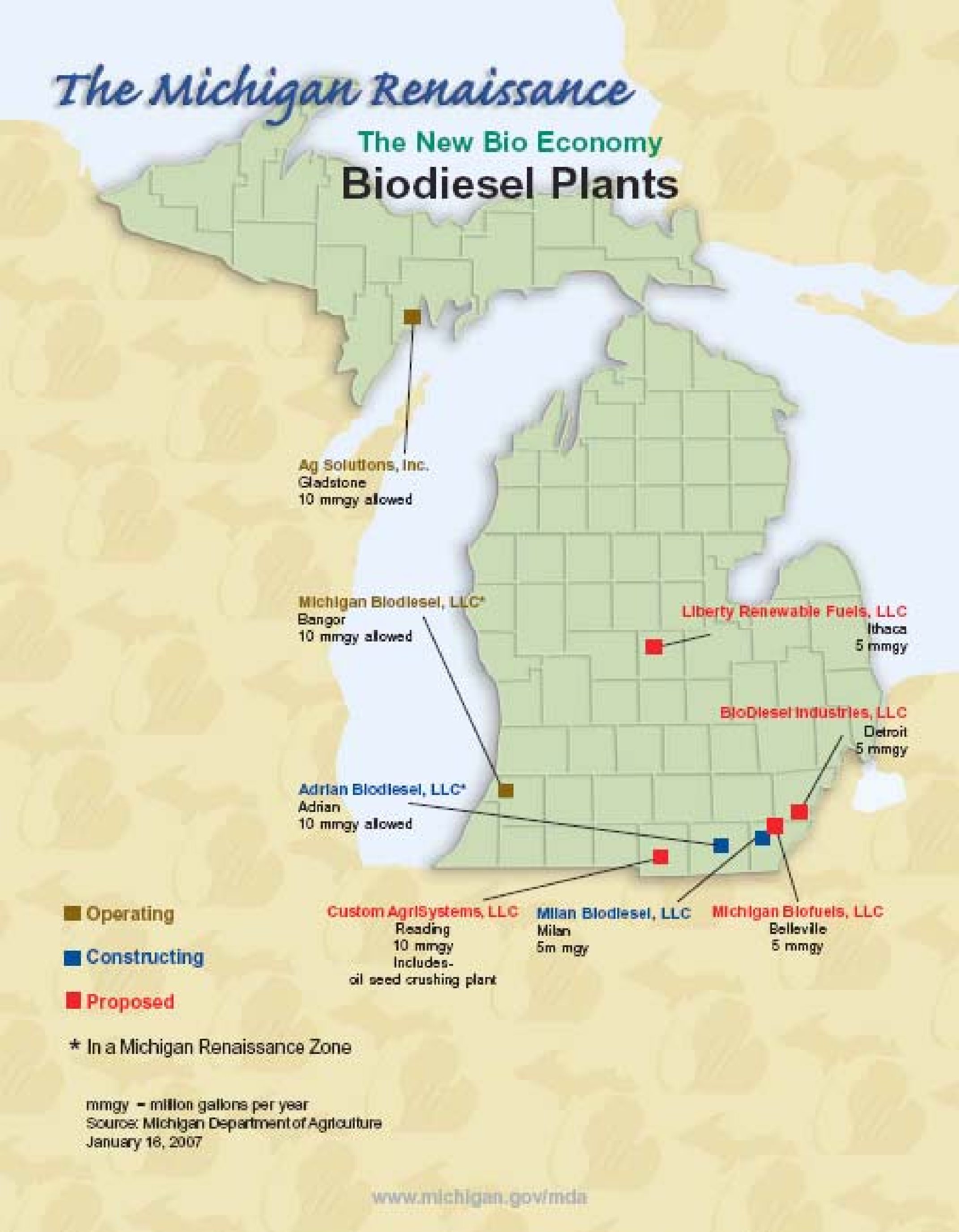

BIODIESEL

CURRENT PRODUCTION:

20 million gallons/year

(2% of petrodiesel consumption)

PROJECTED PRODUCTION:

60 million gallons/year

(6% of petrodiesel consumption)

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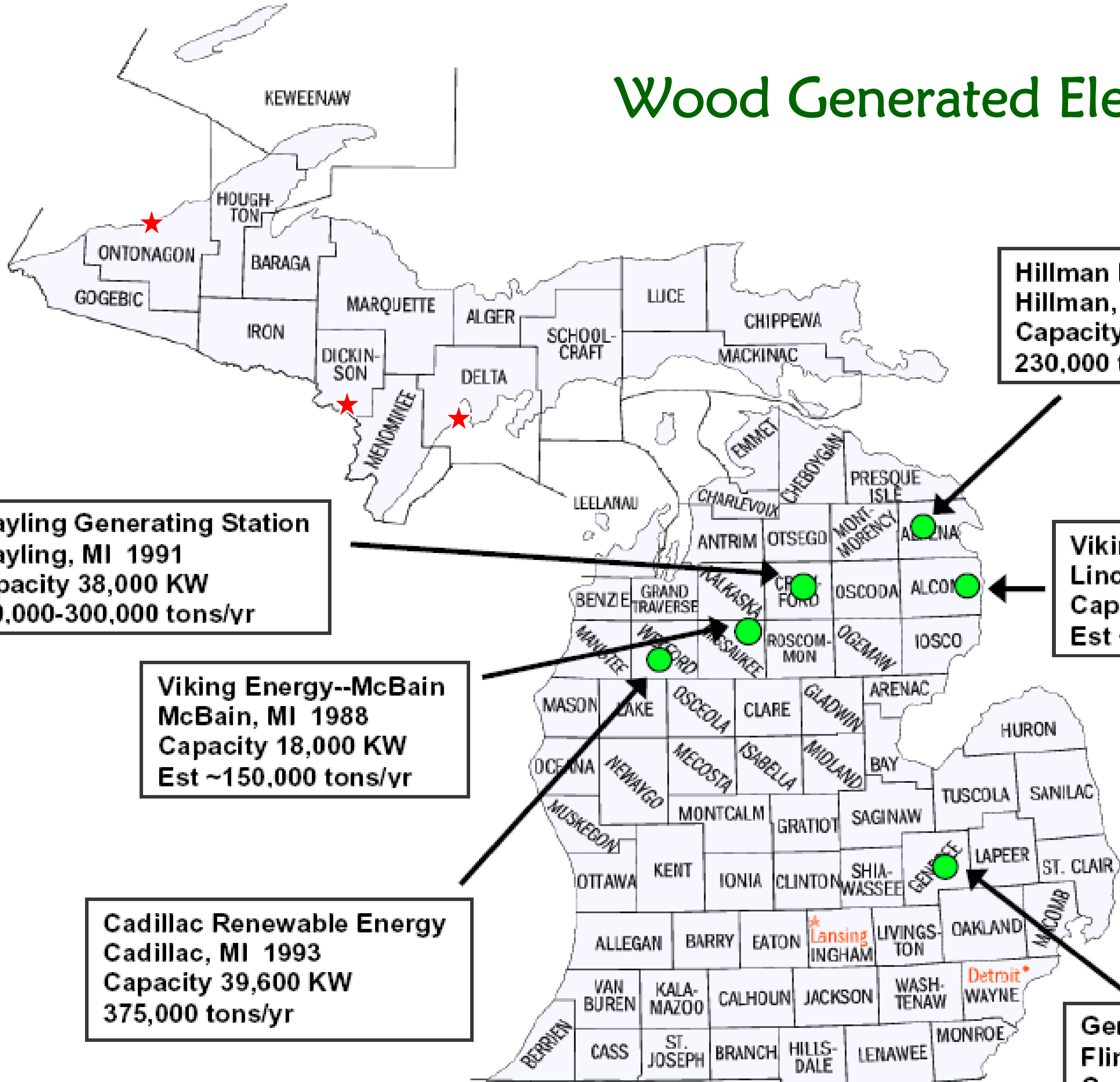
Wood Generated Electricity



Hillman Power Co.
Hillman, MI 1987
Capacity 20,000 KW
230,000 tons/yr

Grayling Generating Station
Grayling, MI 1991
Capacity 38,000 KW
250,000-300,000 tons/yr

Viking Energy--Lincoln
Lincoln, MI 1989
Capacity 18,000 KW
Est ~150,000 tons/yr

Viking Energy--McBain
McBain, MI 1988
Capacity 18,000 KW
Est ~150,000 tons/yr

Cadillac Renewable Energy
Cadillac, MI 1993
Capacity 39,600 KW
375,000 tons/yr

Genesee Power Station
Flint, MI 1996
Capacity 39,500 KW
300,000 tons/yr

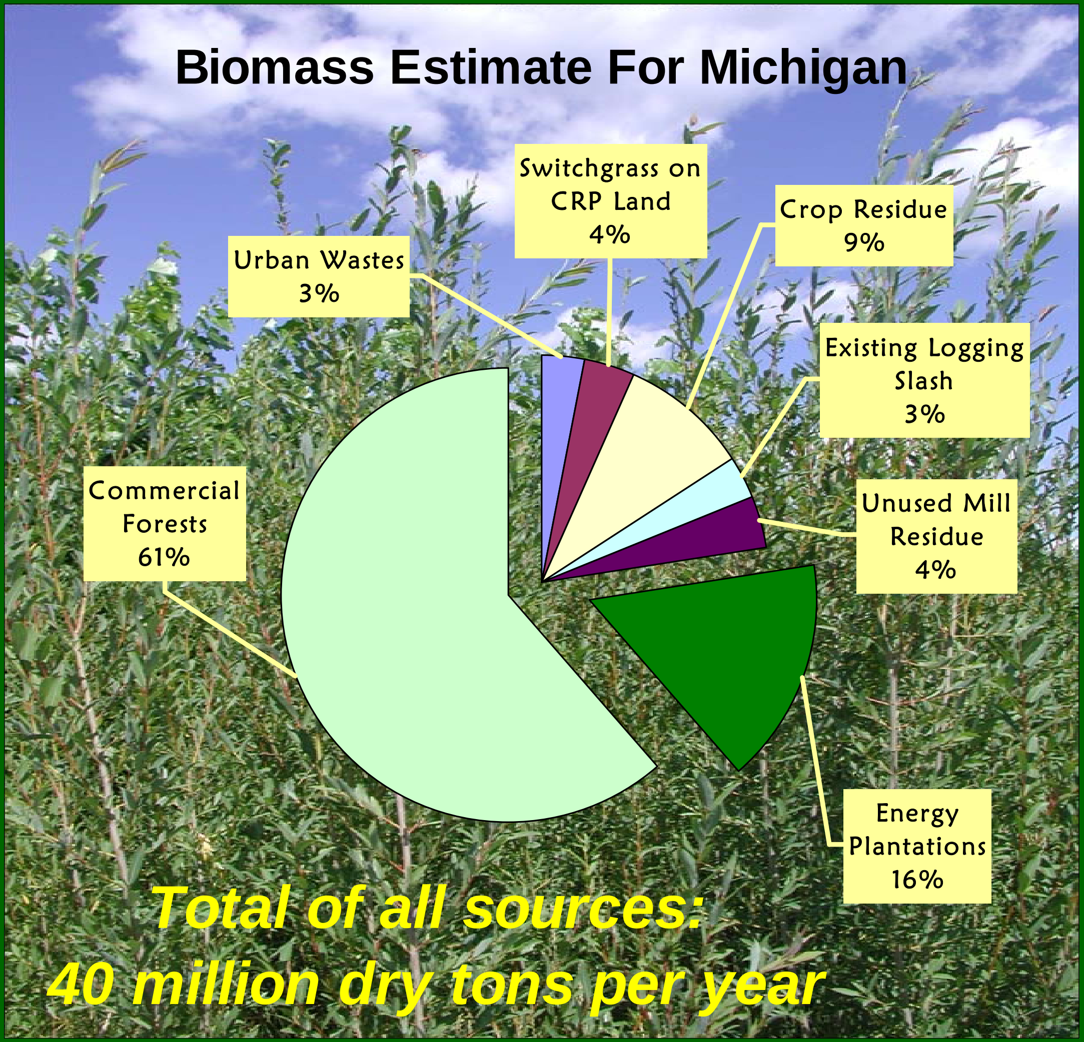
Source: REPiS, online at http://www.nrel.gov/analysis/repis/.

Wood Electric Production

Wood Electric Generator	Capacity
Utilities (sold to grid)	173 MW/yr
Mills (used on site)	195 MW/yr*
TOTAL	**368 MW/yr****

* 75% @ the big papermills –
Escanaba, Quinnesec, & Ontanogan

** 2-3% of today's total electricity production



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Six US Cellulosic Ethanol Plants Selected

- DOE announcement February 28th, 2007
- Total DOE funding $385 million over 4 years
- Total investment in 6 plants of >$1.2 billion
- 6 biorefineries producing more than 130 million gallons per year
- Objective to make cellulosic ethanol competitive with gasoline by 2012
- Reduce US gasoline consumption by 20% in 2017 by producing 35 billion gallons of ethanol

Information on Six US Projects

Company	Technology	Feed Type	Feed Rate (T/D)	Ethanol Rate (G/Y)	Ethanol – Feed Ratio (G/T)
Abengoa (Colwich-KA)	Syngas + fermentation	Corn stover, straw	700	11.4	54
Alico/JGC Co (LaBelle-FL)	Syngas fermentation	Wood, agro waste	770	7 (1st) 14 (2nd)	30 (1st) 60 (2nd)
Blue-Fire (S-California)	Sugar fermentation	Agro, wood waste	700	19	90
Broin/Dupont/ NREL/Novozymes (Iowa)	Sugar fermentation	Corn stover	842	31	124
Iogen/Shell (Shelley-ID)	Sugar fermentation	Agro waste	700	18	86
Range Fuels/ Koshla (GA)	Syngas catalytic	Wood waste	1200	10 (1st) 40 (2nd)	28 (1st) 120 (2nd)

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http://www.energy.gov/news/4827.htm

Conclusions

- We have good biomass resources
- We have a long way to go to replace petroleum
- How do we get there from here in a way that is both good for society and also sustainable good business?
- Replacement of fossil fuels in high margin applications counts toward the goal.

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Pulp Industry Challenge

- Due to global competition, wood pulp prices decrease by about 1% per year.
- Wood/biomass cost is correlated with energy cost, so feed stock price is increasing
- Profitability is "squeezed" from both sides

➔ **Traditional forest products industry desperately needs more revenue from higher value-added products besides wood, pulp and paper products**

How to Increase Revenue?

- Maximize pulp production
- Make ethanol, chemicals and polymers from hemicellulose
- Make transportation fuel from black liquor
- Use bark and biomass as fuel for pulp mill

→Forest Biorefinery which produces pulp besides chemicals, fuels and polymers

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Approach for Hemicelluloses

Hemicelluloses: - have low fuel value (half of lignin)
- are valuable in pulp
- degrade during pulping
- undegraded sugars needed for biofuels and chemicals

→ **Extract hemicelluloses before pulping**

How to Obtain Undegraded Hemicelluloses?

- Extraction of hemis as polymers before pulping
- Extract with water and chemicals which are compatible with the kraft process
- Minimize the amount of additional water introduced in the pulping process
- Hardwood and softwood need different approaches because their hemicelluloses are chemically different

Pulp Production Benefits of Hemicellulose Extraction

- Decreased alkali consumption
- Reduced organic + inorganic load to recovery
- Increased delignification rate
- Increased pulp production rate

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Value of Cellulose Pulp Fibers

- Maximum theoretical yield of ethanol from cellulose pulp on weight basis is ~ 50%
- Ethanol price must be at least > $1000/MT ($3.00/gallon) for economical conversion of cellulose ($500/MT) into ethanol
- Cellulose has high crystallinity, is durable and has unique structural properties

➔**Pulp is more valuable than *fuel* ethanol. Keep pulp as product in paper or structural products**

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Fuel Costs in Forest Biorefinery

Fuel	Heating Value (GJ/MT)	Fuel Cost (US$/Dry MT)	Energy Cost (US$/GJ)
Oil	43.5	555 (US$65/barrel)	12.8
Biomass (20% moisture)	15	55	3.7
Black Liquor (20% moisture)	12.6	75 x 3/4 = 56 (org/inorg = 3/1)	4.4
Lignin	26.9	75	2.8
Carbohydrates	13.6	75	5.5

- Obtain energy from biomass and/or black liquor!
- Do not use oil!
- Minimize use of carbohydrates for energy purposes

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Hemicellulose Conversion Strategy

- Produce oxygen containing products to increase yield, shorten conversion path and competitiveness relative to petroleum-based
- Produce alcohols, carboxylic acids, lactones, and esters
- Novel catalysts and engineered organisms are required for high yield and selectivity
- Bio and catalytic conversions must work for both C5 and C6 sugars

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Development Challenges

- Maintain yield an quality of pulp
- Selective and economic pre-extraction of hemicellulose polymers
- High yield conversion of extract into ethanol, chemicals and polymers.
- Economic purification processes
- Use of precipitated lignin for non-energy uses
- Demonstrate pressurized kraft black liquor gasification at the mill scale

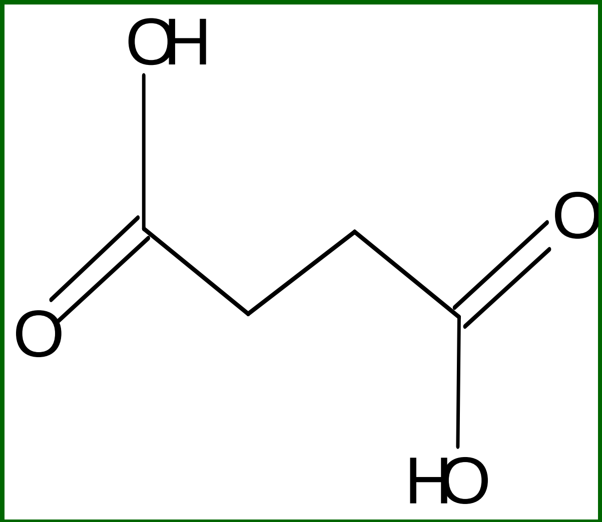
A successful biorefinery is a combination of the following elements:

- Physical processes
- Thermal processes
- Chemical processes
- ***Biochemical processes- White biotechnology***

Impact of white biotechnology in biorefining

- Micro-organisms are proficient in the production of chemicals with broad functionality
- Fermentation processes can take advantage of dilute streams as feedstocks
- Some fermentation processes can use carbon dioxide as a feedstock
- Many fermentation processes can utilize a wide range of substrates
- Fermentation products are usually higher margin offering better overall biorefinery economics

Development of a new biobased molecule- Succinic Acid (bärnstensyra)



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The participants for succinic acid development & commercialization - an international consortium

- US Department of Energy (USDOE), USA
- Toyota Tsusho Company (TTC), Japan
- Japan Asia Investment Corporation (JAIC), Japan
- Diversified Natural Products, Inc. (DNP), USA
- Agro Industrie Recherches et Développments (ARD), France
- Luleå University of Technology (LTU), Sweden
- Alfredshem Group (Processum AB/ SEKAB/ Etek AB) , Sweden
- Showa High Polymer (SHP), Japan
- PlasEx AB (PEAB), Sweden
- Michigan State University (MSU), USA
- Solander Group(Smurfit Kappa/ KIRAM AB/ ETC), Sweden

The biorefinery using the C4 bio-based platform

Chemistry that does not use oil, is recyclable, and biodegradable

C1 — C1 platform dominated by the methane business. A basic building block for petrochemicals.

C2 — C2 platform dominated by acetic acid and ethanol producers.

C3 — C3 platform dominated by lactic acid for use in biodegradable polymers and other compounds. Cargill, Purac and Galactic are the major competitors in this market.

C4 — **C4 bio-based platform based on succinic acid**

C5 — C5 platform reverts back to sugar compounds such as xylose

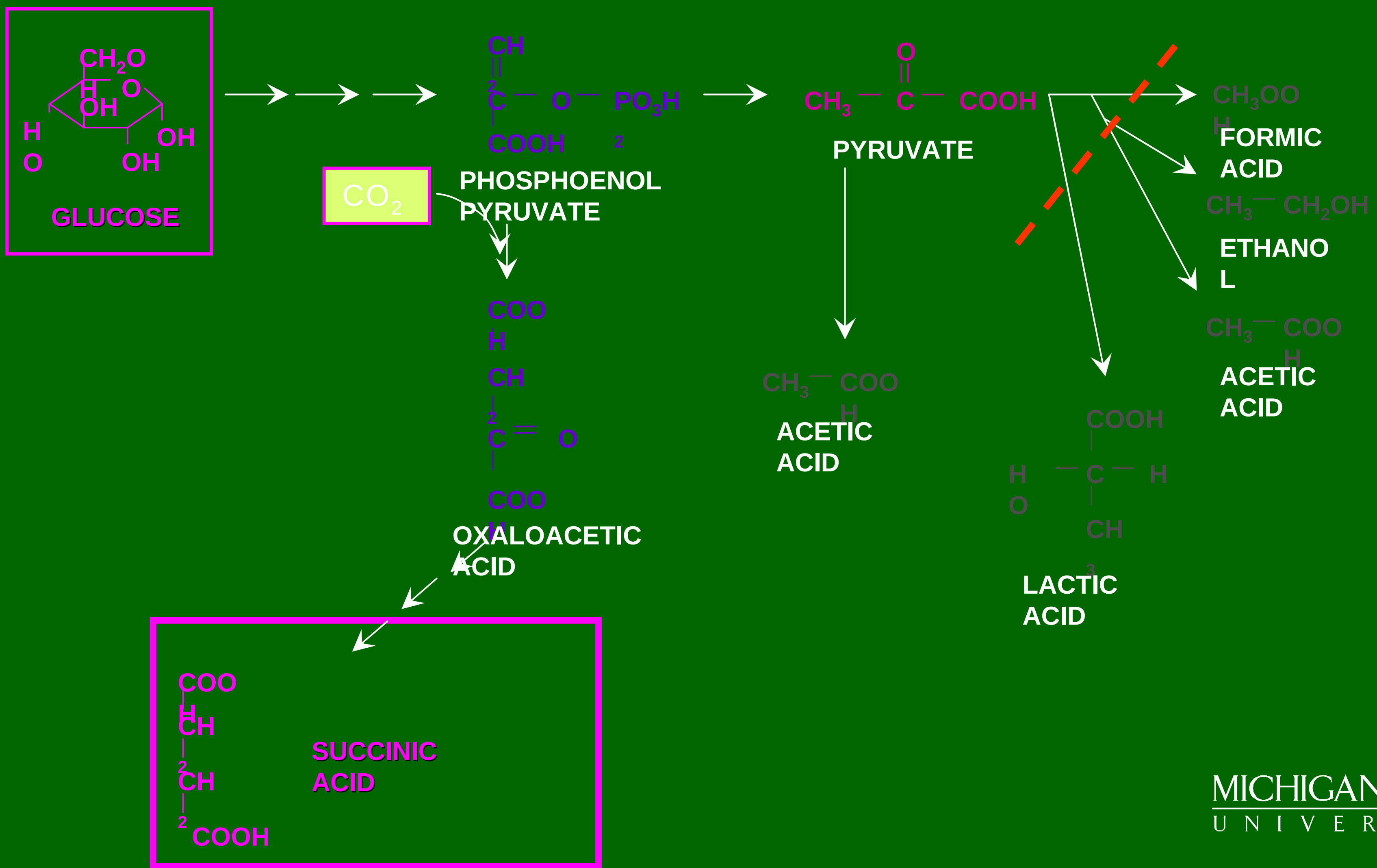
Technology Highlights

- Patent portfolio of over 25 issued and pending patents .
- Proprietary organisms that can ferment a wide range of sugars including xylose, arabinose, mannose, glucose, and fructose.
- Novel two-stage fermentation ***that requires carbon dioxide*** to be fed in the anaerobic stage.
- Downstream process technology for separations and derivatives.
- New applications technology.
- Minimal environmental impact.

Coupling to forest biorefinery

- Sugars- hemicellulose
- Carbon dioxide- numerous sources
- Energy

Metabolic pathways



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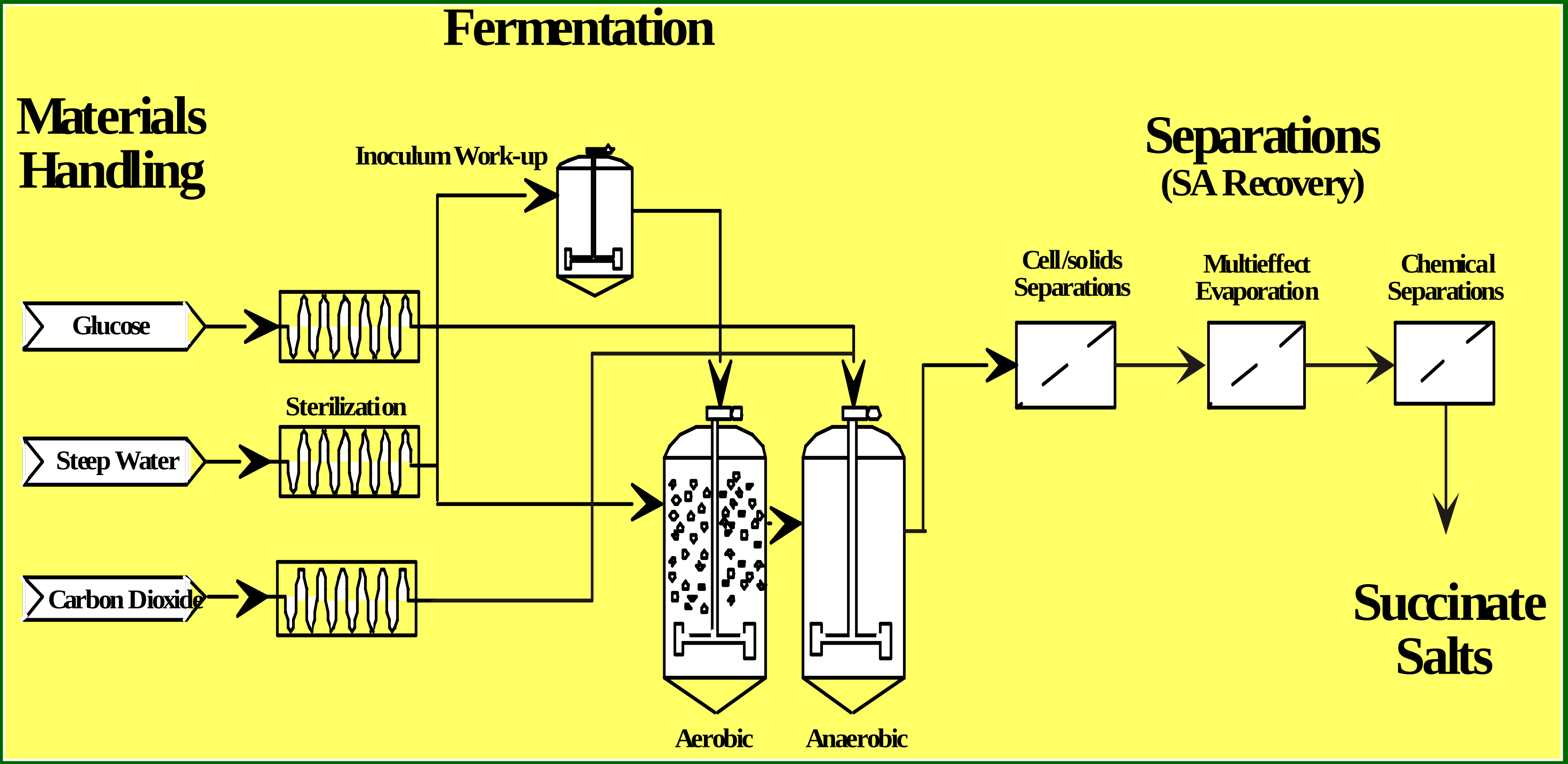
E Coli Fermentation

Two-Stage Process



Ethanol from biomass fermentations

- Massive efforts are underway on a global level to produce fuel ethanol
- Little attention is being paid to value added derivatives that can leverage the capital investments for ethanol plants that is currently being made
- A chemical business that is parallel to fuel ethanol will offer diversification and stable margins.

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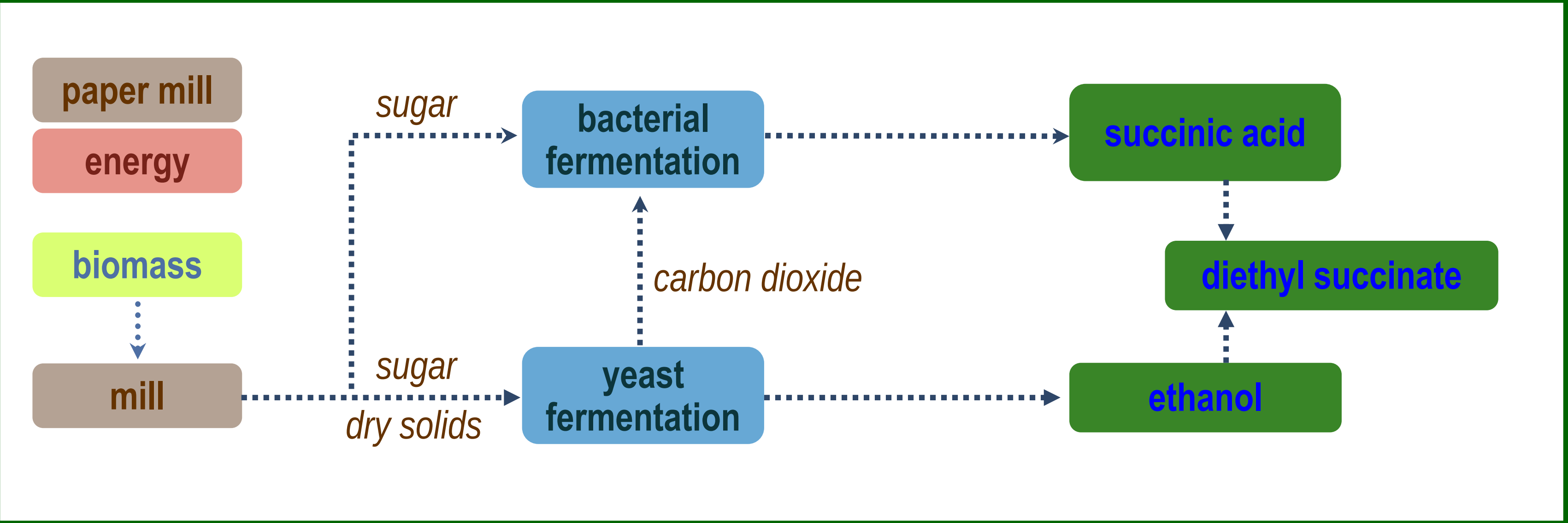
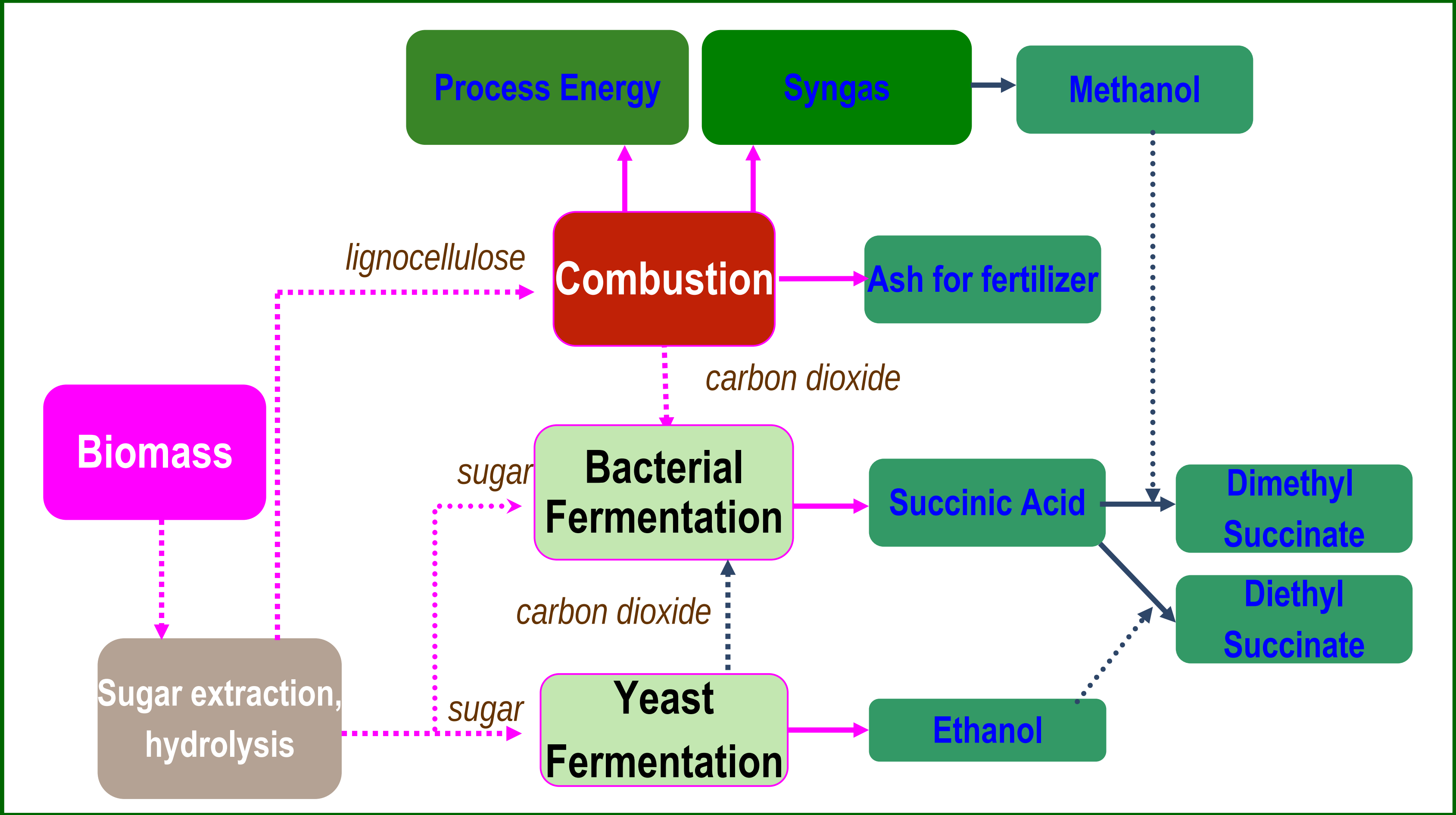
The succinic acid biorefinery concept coupled to ethanol production



Succinic acid/ ethanol biorefinery concept coupled to gasification technology



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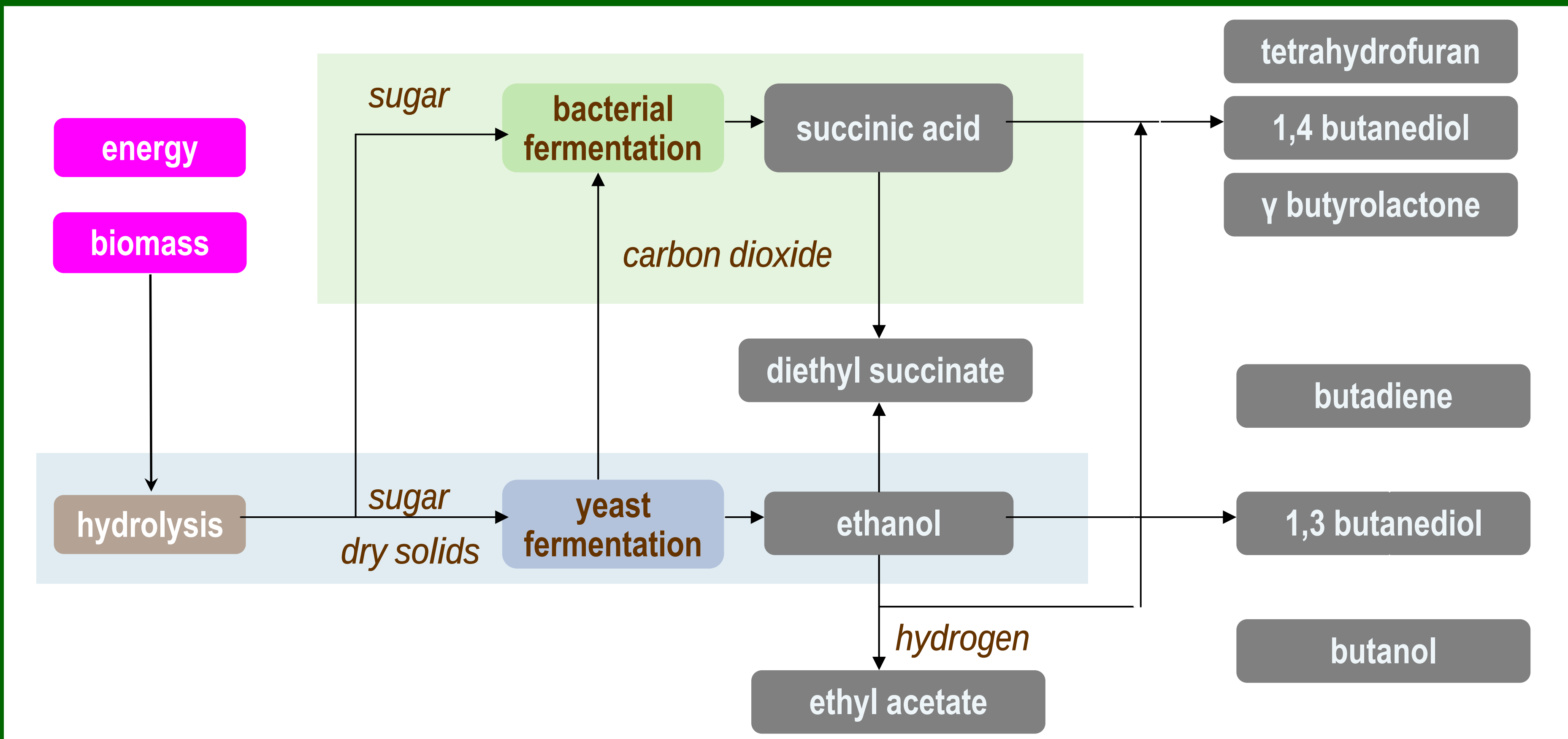
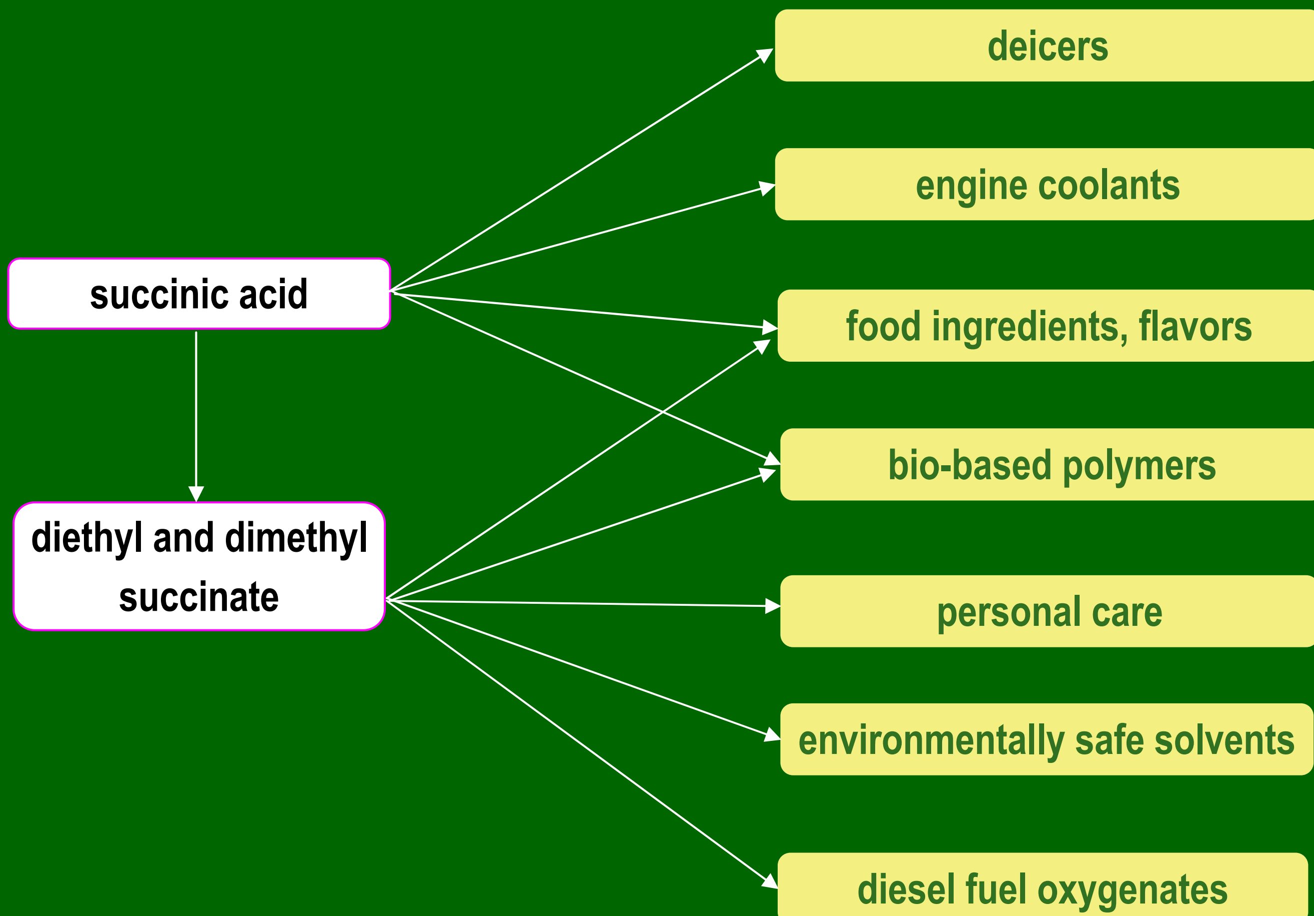
Chemical production combining succinic acid and ethanol



Succinic acid product family tree



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BDO/THF is market with the largest near term revenue potential

BDO / THF

- This is a $2.5 Billion market and growing
- The price is linked to the price of natural gas
- Producers are seeking lower cost sources with less price volatility
- 35% of total production is sold on open market ($875M) – seeking to buy at the lowest price

Diethyl Succinate

- These markets need to be created – they don't exist today
- There are several potential applications:
  - Solvents
  - Engine coolants
  - Diesel fuel additive
  - Runway deicer
- DNP is developing more IP / formulations

Succinic Acid

- This is a $20 - $50M market today
- Currently S.A. derived from oil, is expensive
- There are two niche markets for natural S.A.
  - cosmetics
  - food acidulants
- Big potential: S.A. + acetic acid in foods

New Applications Driven by Functionality

- Ester solvents
- Runway and deicing chemicals
- Water treatment chemicals
- Diesel fuel additives
- Polymers

Solvents

- Succinate esters- e.g. diethyl succinate
- Biodegradable, low toxicity, low VOC
- Replacement for chlorinated solvents
- GRAS/Food grade- carriers for flavors,etc
- Already have established positions in coatings and inks
- Miscible in all proportions with ethyl lactate

Aircraft and Runway Deicing Chemicals

- Excellent performance
  - ice penetration/melting
  - non-corrosive
  - non-spalling
  - biodegradeable
- Excellent synergistic combination product with glycols
- Takes advantage of the production of succinate salts
- FAA approved for use on runways

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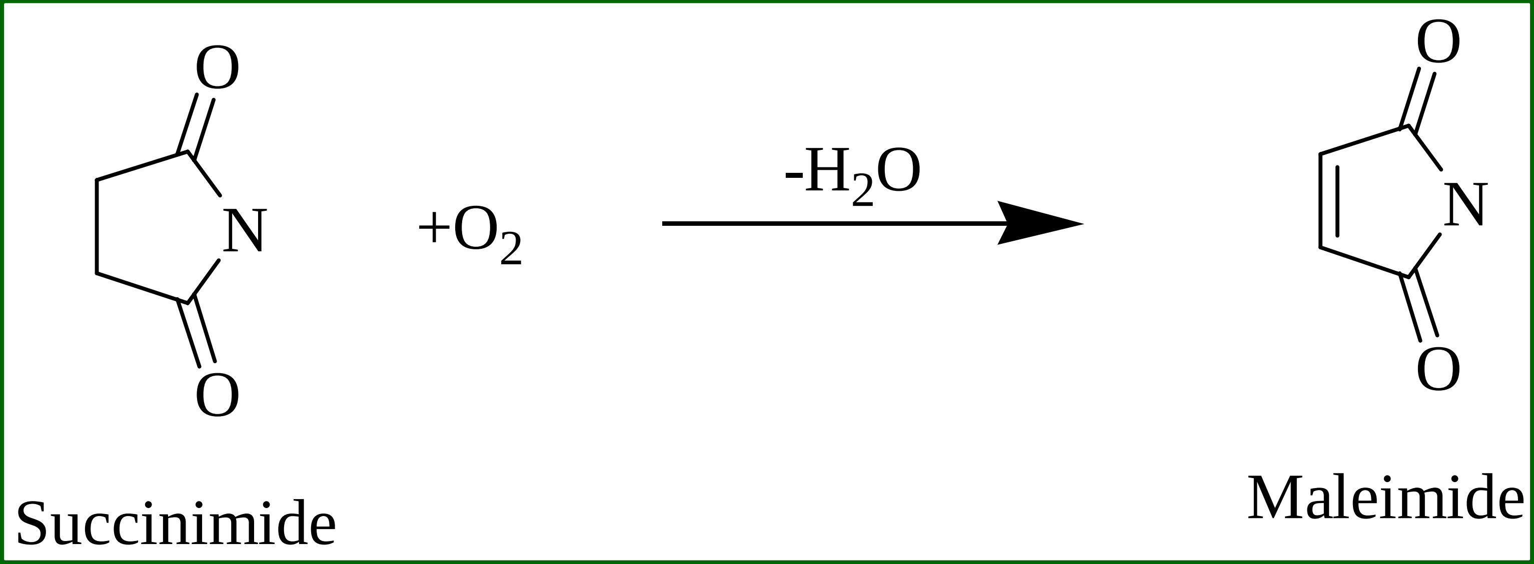
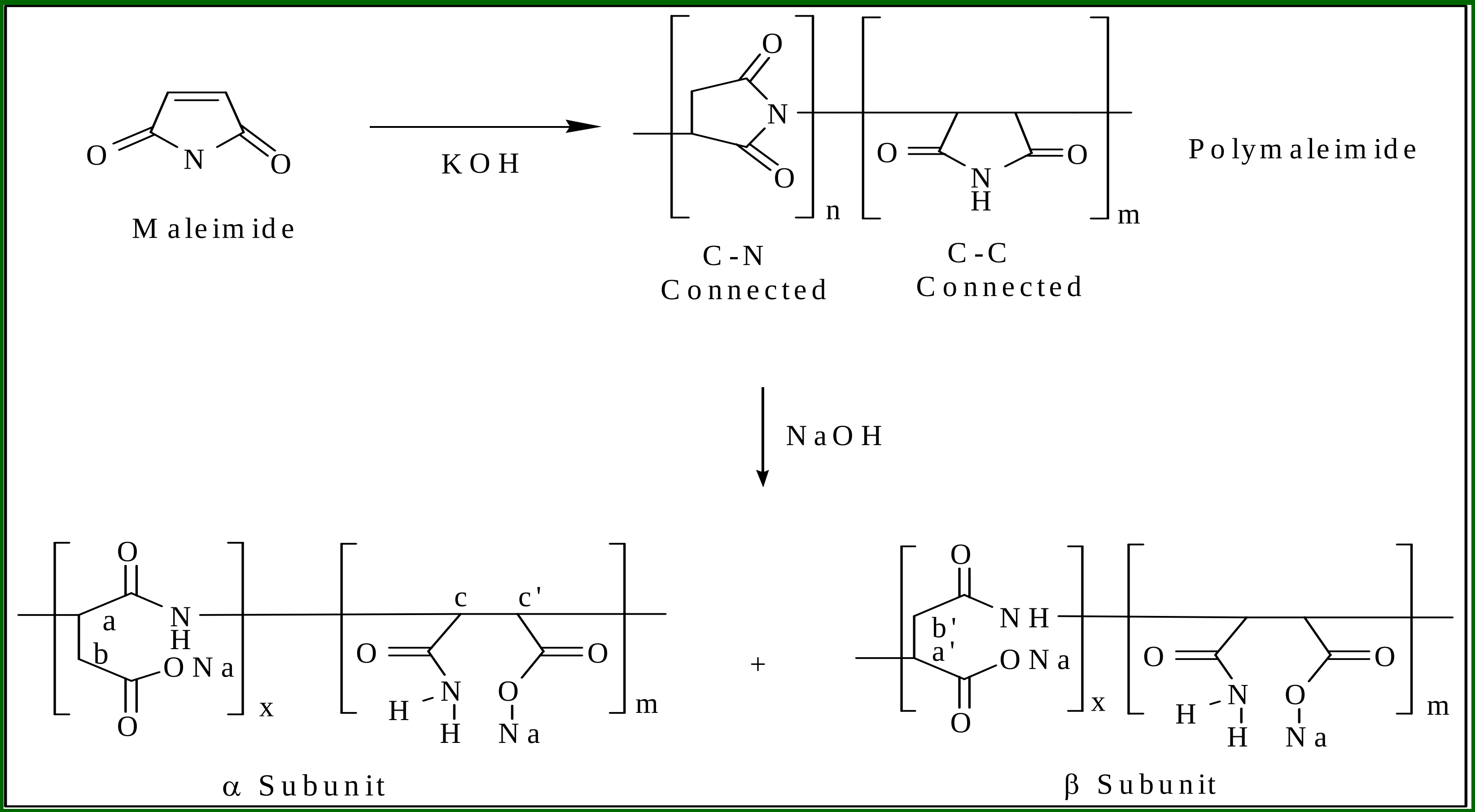
Polymalemide for water treatment

- Maleimide can be produced directly from diammonium succinate
- Maleimide reaction is simple at high selectivity and conversion
- Maleimide is easily converted to polymalimide and hydrolysed to salt
- Superior properties to commercial polyacrylates

Production of maleimide



Synthesis of Polymaleimide, Sodium Salt



Comparison of synthesized and commercial products

S.No.	Inhibitor	Source	Percent Conversion[1]	C-N Connected Monomer (%)[1]	Molecular Weight[2]
1	PMI_Cu_sys[3]	Synthesized	95.6 ± 0.5	43.2± 0.8	5900± 100
2	PMI_KOH[4]	Synthesized	92.8± 0.3	79.8± 0.9	1100± 180
3	PMI_PbO[5]	Synthesized	99.0± 0.5	38.7± 0.8	11500± 90
4	PAA[6]	Aldrich	-	-	5000
5	PaspAcid[7]	Bayer Corp.	-	-	-
6	Acusol®	Rhom & Haas	-	-	5000

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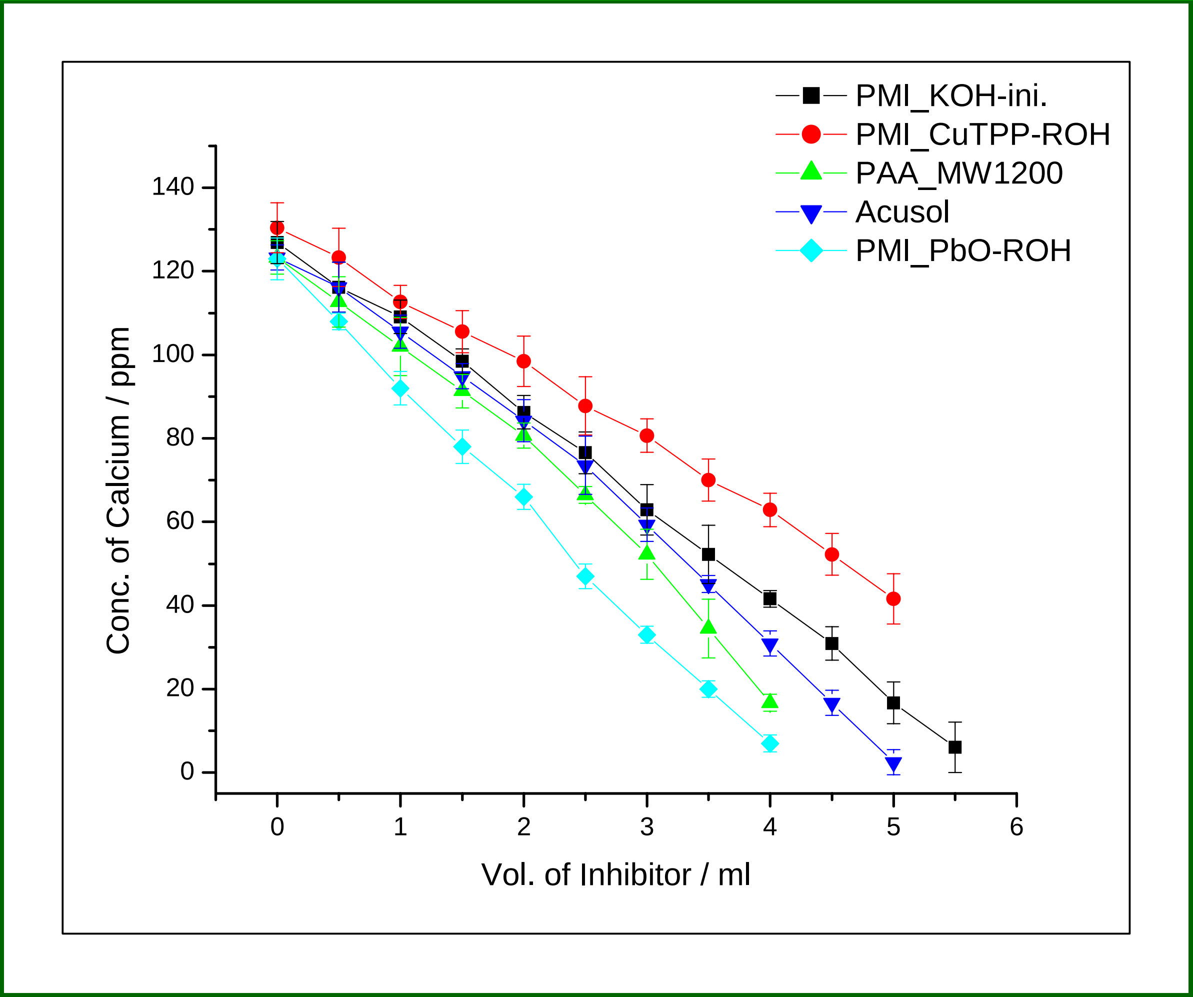
Calcium chelation



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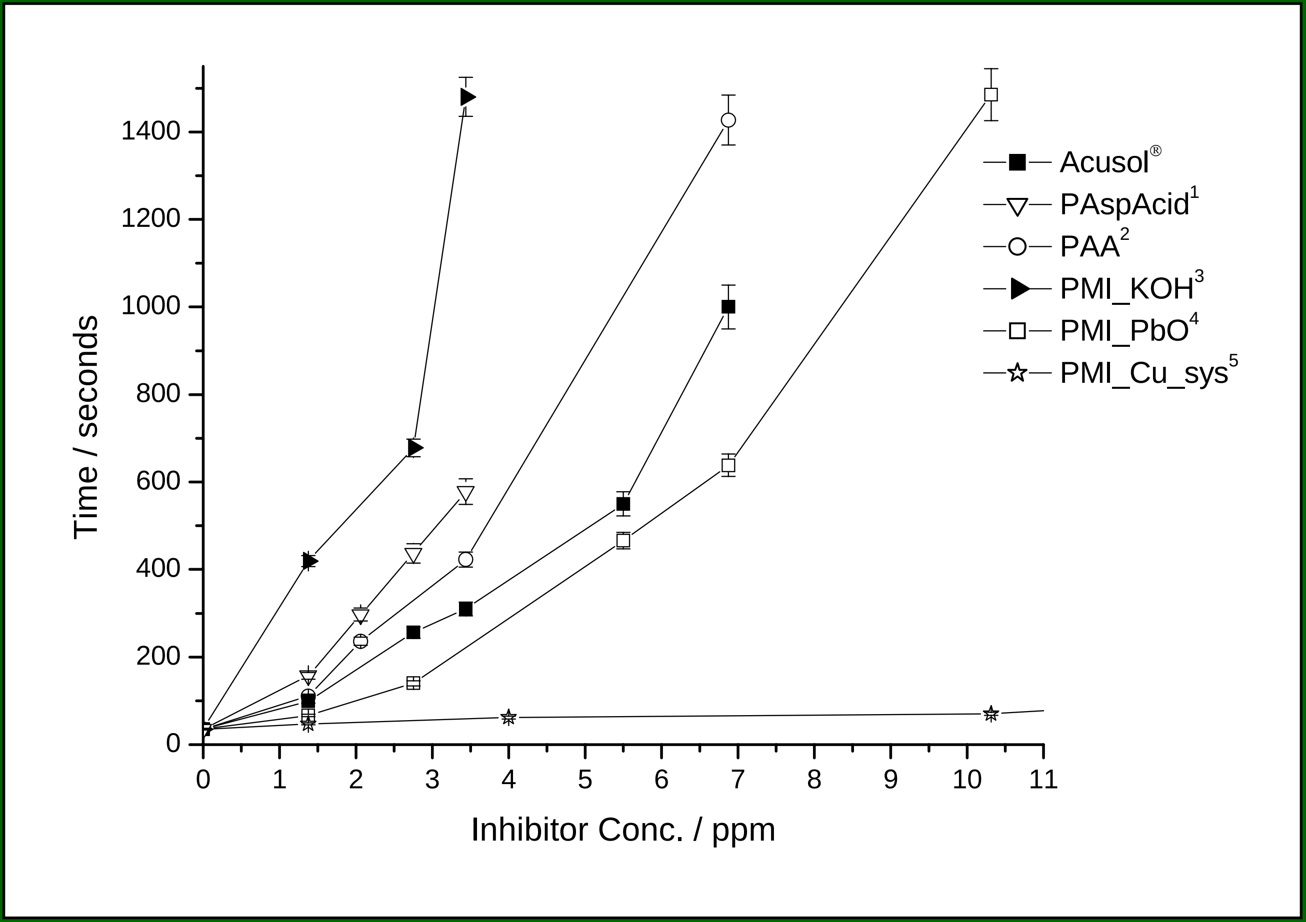
Calcium carbonate crystallization inhibition



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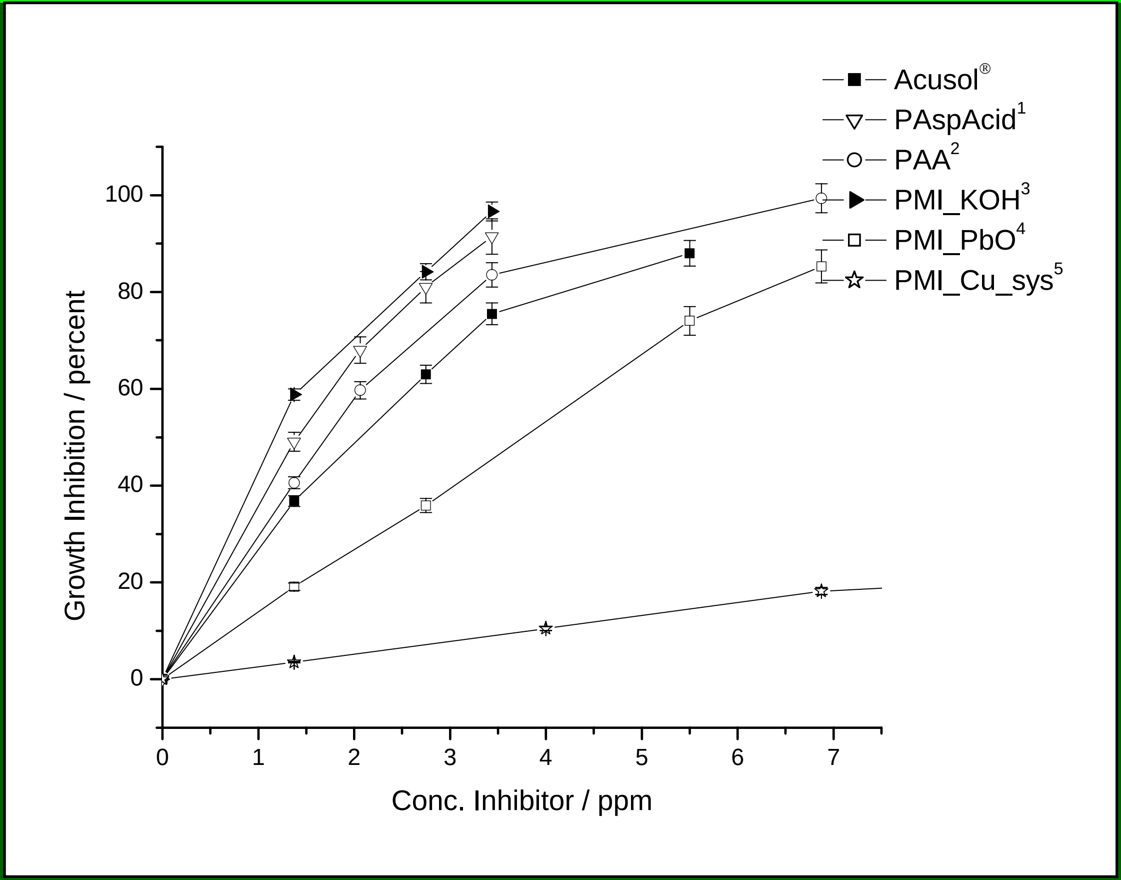

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Diesel fuel additives

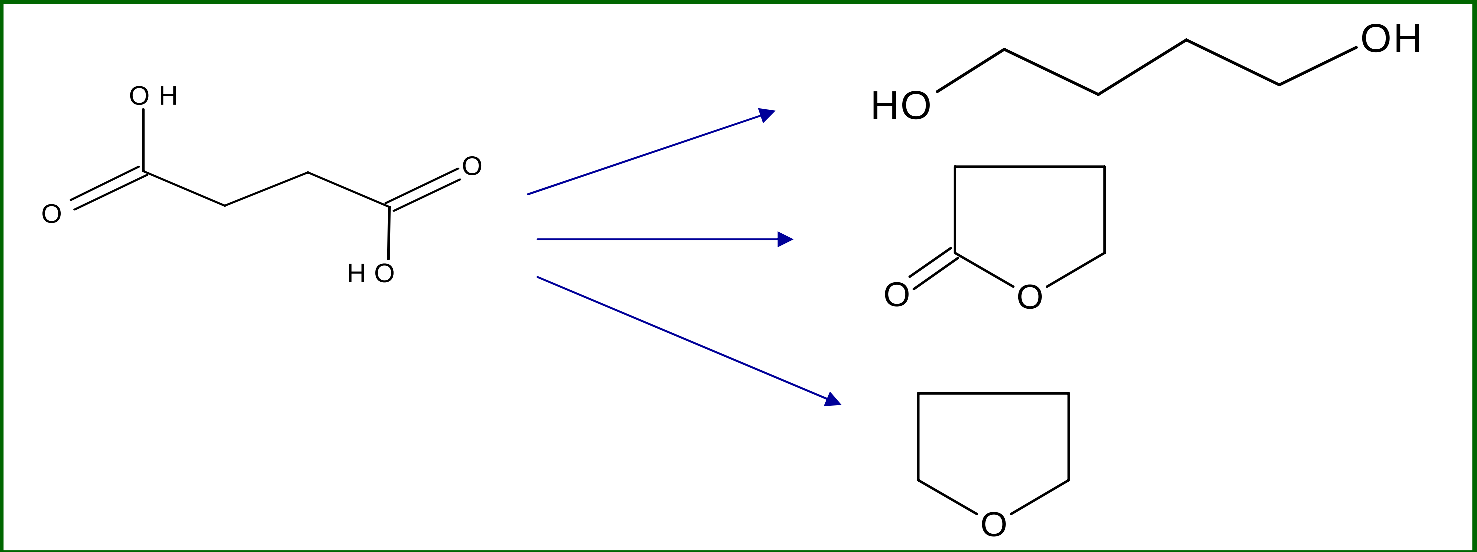
- Diesel engines are much more efficient than gasoline engines
- Oxygenates are needed to reduce particulate emissions while maintaining low NO_x
- Ethanol has miscibility problems requiring additives and pre-ignition problems due to high octane number
- There is a need for new oxygenates

Dialkyl succinates for diesel fuel oygenates

- Miscible with diesel fuel
- Low volatility results in no pre-ignition problems
- Engine trials with MK-1 (Swedish Environmental Class 1) fuel show significant reductions in particulate emissions
- Direct addition to diesel fuel without modification appears possible

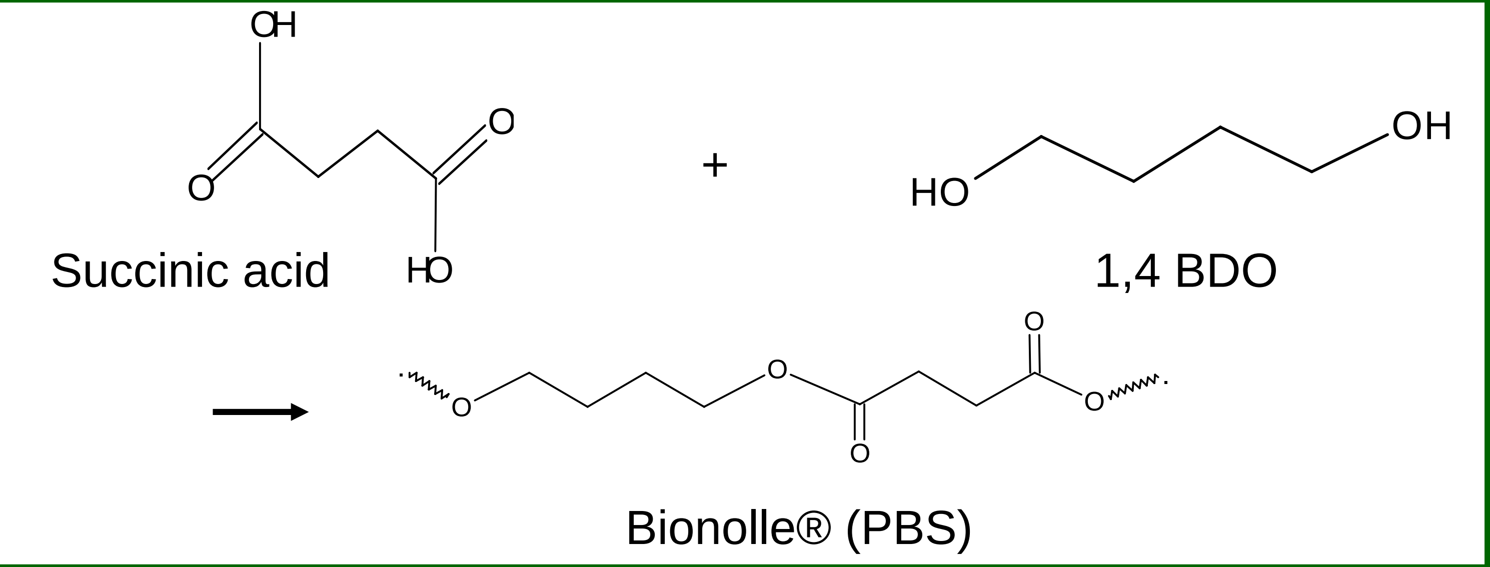
Biodegradeable/ biobased polymers

- Main hydrogenation products are 1,4 butanediol, gamma butyrolactone, and tetrahydrofuran and are produced as a mixture.
- These are commodity chemicals.



Showa's Bionolle®

- Bionolle® is polybutylene succinate (PBS)
- PBS is a polyester produced by polymerization of succinic acid and 1,4 BDO



Status

- A starch based plant has been announced at the 5.000 MT scale in France.
- Continued R & D is underway to reduce costs and to optimize for forest biorefinery feedstocks through MSU, LTU, DNP SWEDEN AB, and other partners.
- New platforms are under development

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Conclusions

Benefits of Forest Biorefinery:

- **Protects the Core**: Increases the profits in support of traditional forest products production
- **Ecofriendly**: Transportation fuels, power, and bioproducts from a carbon-neutral, renewable resource
- **Low Capital**: Use existing pulping equipment and infrastructure for production of new, high value-added products besides traditional wood and paper products
- **Synergy**: Full integration of the traditional forest products and new bioproducts will lead to synergies
- **Self-Sufficiency**: Replacement of imported fossil fuels by domestic renewable fuel
- **Employment**: Preserves and creates jobs in rural forest-based communities

Thanks and questions……..