BIOCHEMICALS FROM CORN: UPDATE 2008

Dr. Dennis J. Miller

Professor of Chemical Engineering, Michigan State University

Brian R. Doidge

College Professor, University of Guelph, Ridgetown (retired)

Ontario Corn Producers' Association (retired)

Funding provided by:

Ontario BioAuto Council

Ontario Agri-Food Technologies

Ontario Ministry of Agriculture, Food and Rural Affairs

Purpose

Provide an overview of:

- World commercial biochemical operations on-stream since 2000
- Current world biochemical commercialization projects
- Worldwide commercialization notes of interest
- Literature review of chemicals from biomass, focusing on 2000-2008
- Economics of biochemicals of interest
- Scan of potential Canadian biochemical marketplace
- Summary of possibilities and marketplace factors
- Contact listing for biobased product companies

Previously Identified Chemicals of Interest

"Biochemicals From Corn", March, 2000

- propylene glycol
- citric acid
- lysine
- glycerol
- lactic acid
- gluconic acid
- sorbitol
- acetic acid

"Top Value-Added Chemicals from Biomass", PNNL, 2004

- 1,4 diacids (succinic, fumaric and malic)
- 3 hydroxy propionic acid
- glucaric acid
- itaconic acid
- 3-hydroxybutyrolactone
- sorbitol
- 2,5 furan dicarboxylic acid
- aspartic acid
- glutamic acid
- levulinic acid
- glycerol
- xylitol/arabinitol

Commercial Biochemical Operations

Polylactic Acid (PLA) from starch:

- **Novamont**, Novara, Italy, 1997, 20,000t *Mater-Bi, Origo-Bi, Biotred*
- **NatureWorks**, (Cargill-Teijin), Blair, Neb., 2002, 140,000t
  PGLA-1 (Cargill-PURAC), Blair, Neb., lactic acid for PURAC
  BASF, Ludwigshafen, Germany, NatureWorks PLA into *Ecovio, Ecoflex*
  Cereplast Inc., Seymour, Ind., NatureWorks PLA into resins, 500 m lbs
- **Hycail bv**, Noordhorn, NL., 2005, 50,000t (high heat resistance)
- **Plantic Technologies**, Victoria, Australia, 2001, non-GMO high amylose
- **bioresins.eu**, Turvey, UK, PLA, PHA, PHBV from corn starch and sugars
- **Galactic**, Brussels, Belgium, lactic acid, PLA, lactates
- **B&G**, Chinese jv with Galactic

Commercial Biochemical Operations

1,3-propanediol (PDO) from corn:

- **DuPont Tate & Lyle**, Loudon, Tennessee, 2004, 100 m lbs
  - **Zemea** higher purity products, personal care, detergents
  - **Susterra** industrial applications, de-icing, anti-freeze, heat transfer
  - polymerized with TPA to create **Sorona** PTT fibres, resins, packaging
  - polymerized with PDO to create **Cerenol** liquid polyol, automotive
  - polymerized with PBT to create **Hytrel** thermoplastic elastomer
  - Ashland Composite Polymers using Susterra to make **Envirez** composites

Commercial Biochemical Operations

Polyhydroxyalkanoate (PHA) from corn:

- **Telles**, ADM-Metabolix, Clinton, Iowa, 2008, 110 m lbs
  - biodegradable bioplastic *Mirel*
  - genetically engineered bacteria produce PHA within the cell
  - competes with large volume petro-plastics (including PET)
  - building block chemical for acrylic acid, 1,3-propanediol, THF, 1,4-butanediol, NMP, and others
- **Metabolix** has now genetically engineered switchgrass to produce PHA directly in the plant's leaves

Commercial Biochemical Operations

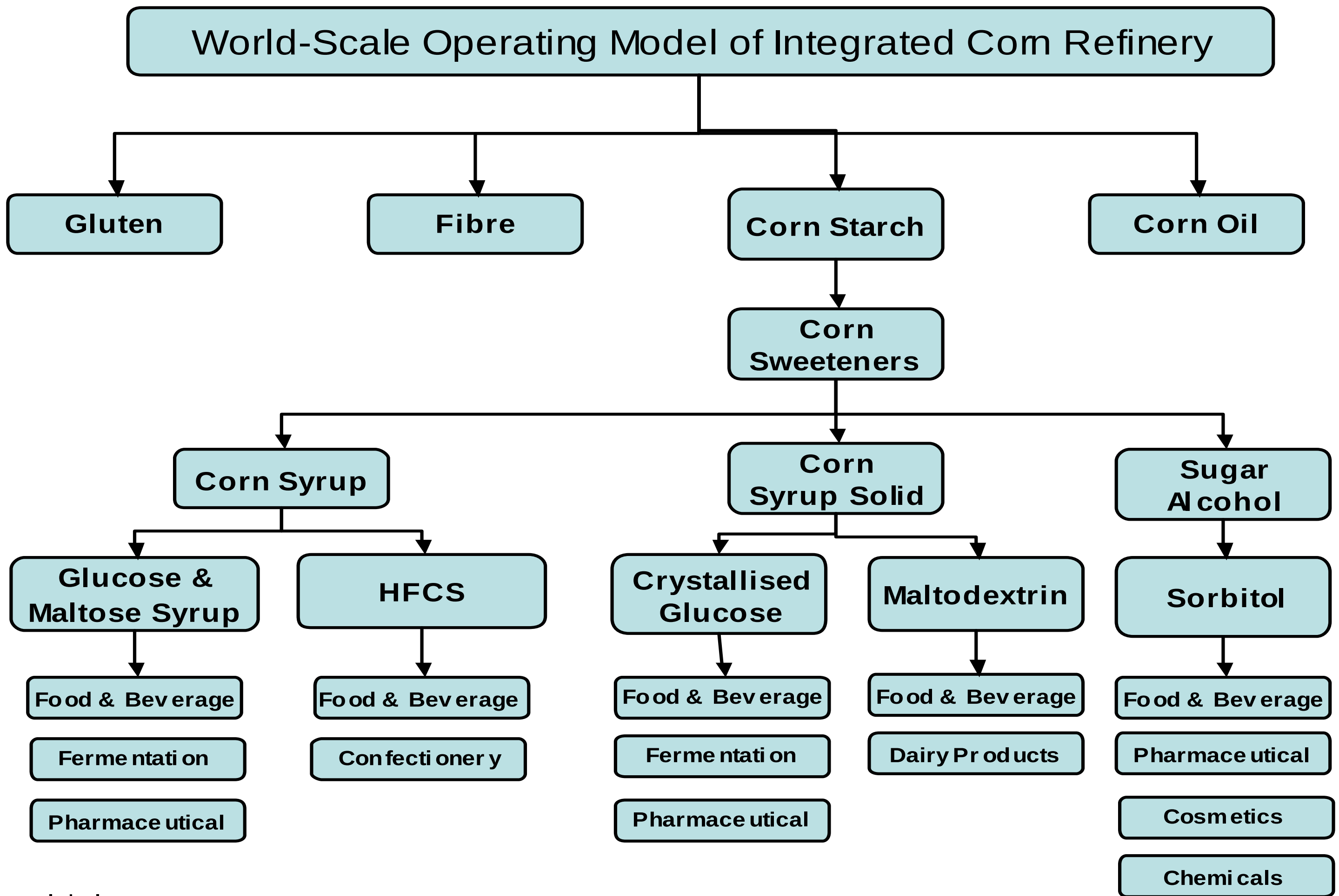
Sorbitol, ethylene glycol, propylene glycol, glycerin:

- **Global Sweeteners Holdings Ltd.,** Changchun, China, 2006
  - world-scale corn biorefinery 2.6 m tonnes (102 m bu) of corn-based product:
  - 420,000 tonnes corn starch
  - 180,000 tonnes refined corn starch products
  - 1,020,000 tonnes glucose/maltose syrup
  - 120,000 tonnes maltodextrin
  - 360,000 tonnes HFCS
  - 400,000 tonnes crystalized glucose
  - 100,000 tonnes glutamic acid
  - 100,000 tonnes sorbitol

    used to make ethylene glycol, propylene glycol and glycerin

Commercial Biochemical Operations

Global Sweeteners/Global Bio-Chem, Changchun and Jinzhou, China



www.global-sweeteners.com

Corn Biochemical Commercialization Notes of Interest

- Oct.17, 2008 - Canada bans bisphenol-A
- Sept. 26, 2008 – DuPont/Plantics extend PLA marketing agreement
- Sept. 19, 2008 – DuPont/Danisco/U of Tenn., switchgrass/corn stover ethanol
- Sept. 18, 2008 - US DOC affirmative finding against imported PET
- Sept. 17, 2008 - US DOC affirmative finding against imported citric acid
- Sept. 2008 – ADM/John Deere/Monsanto collaboration on corn stover
- Sept. 10, 2008 – UOP/Ensyn commercialize rapid pyrolysis of biomass to oil
- Sept. 9, 2008 - Dow Corning/Elevance commercialize soy and corn oils
- Aug. 11, 2008 - Metabolix announces PHA in switchgrass leaves
- Sept. 2007 – ADM/ConocoPhillips collaborate on biomass to biocrude
- Aug. 31, 2006 - Dow to close LDPE, polystyrene, acrylate latex, PP, PPG, PG
- June 21, 2004 – SGF/Shell jv produces PTT (PDO + TPA)

Biochemical Commercialization Projects

Levulinic acid, methyltetrahydrofuran (MTHF)

- **BioFine Corporation** process, Glen Falls, NY
  - cellulosic paper mill waste, municipal sludge to levulinic acid
- **Univ. of Nebraska** levulinic acid through extrusion of corn starch
- **PNNL** levulinic acid to MTHF
- **PNNL** glucose from corn milling residue to produce lactic acid, sorbitol, and derived glycols (EP, PG, glycerol)

Biochemical Commercialization Projects

Polyethylene from ethanol

- **Braskem**, Triunfo, Brazil, 2010, 200,000 t/yr
- **Dow Chemical/Crystalsev**, Brazil, 2011, 200,000 t/yr
- **Solvay** (Belgium), **Petrobas** (Brazil), also planning construction

Polypropylene from ethanol

- **Braskem**, Brazil, 2012, 1.3 m tonnes/year

Polyhydroxyalkanoate (PHA)

- **Meridian/DaniMer**, Bainbridge, Georgia, 2010, 270,000 t/yr

Biochemical Commercialization Projects

Polylactic acid (PLA)

- **Pyramid Bioplastics**, Guben, Germany, 2009, 60,000 t/yr
- **PURAC/Sulzer/Synbra**, Etten-Leur, NL, 2009, 50,000 t/yr (foamed)
- **PURAC**, Thailand, 2008, 100,000 t/yr
- **Plantic Technologies**, Jena, Germany, 2010

Propylene glycol (PG)

- **ADM**, Decatur, Illinois, 2010, PG from sorbitol or glycerol
- **Virent Energy Systems**, BioForming Process, PG without hydrogen

Biochemical Commercialization Projects

1,4-Butanediol (BDO)

- **Genomatica**, San Diego, California, commercializing BDO from corn

Succinic acid

- **Diversified Natural Products**, Scottsville, Michigan, DOE process
- **Bioamber, DNP** jv with **ARD**, Pomacle, France, 5,000 t pilot plant 2009
- **MBI**, Lansing, Michigan, SA from ethanol byproduct streams

3-Hydroxyproprionic acid (3-HP)

- **Cargill/Codexis**, 3-HP from corn dextrose for acrylic acid, PDO

Biochemical Commercialization Projects

Butanol

- **DuPont/BP**, Hull, UK, 420 m l/yr ethanol/butanol, 2009/2010

Biogasoline

- **Virent Energy Systems/Shell**, BioForming Process, plant sugars into hydrocarbons, gasoline, diesel, jet fuel

Hydrogen

- **Virent/Shell**, BioForming Process, sorbitol and glycerol to hydrogen
- **Shell/Codexis**, catalytic reaction of biomass to fuel and hydrogen

Isoprene

- **Genencor/Goodyear**, biomass (corn) to isoprene monomer, 2012

Literature review of chemicals from biomass

- Greatly expanded volume of literature from 2000 to 2008 – biobased chemicals now a mainstream topic of scientific and engineering research
  - Chemistry and catalysis
  - Process design and economics
  - Social, political, and environmental issues
- Several large reviews form good starting points
  - Corma,A.; Iborra, S.; Velty, A. *Chem. Rev*. **2007,** *107*, 2411-2502
  - Werpy, T.; Peterson, G. "Top Value Added Chemicals from Biomass." U.S. Department of Energy EERE, 2004. http://www.osti.gov/bridge.

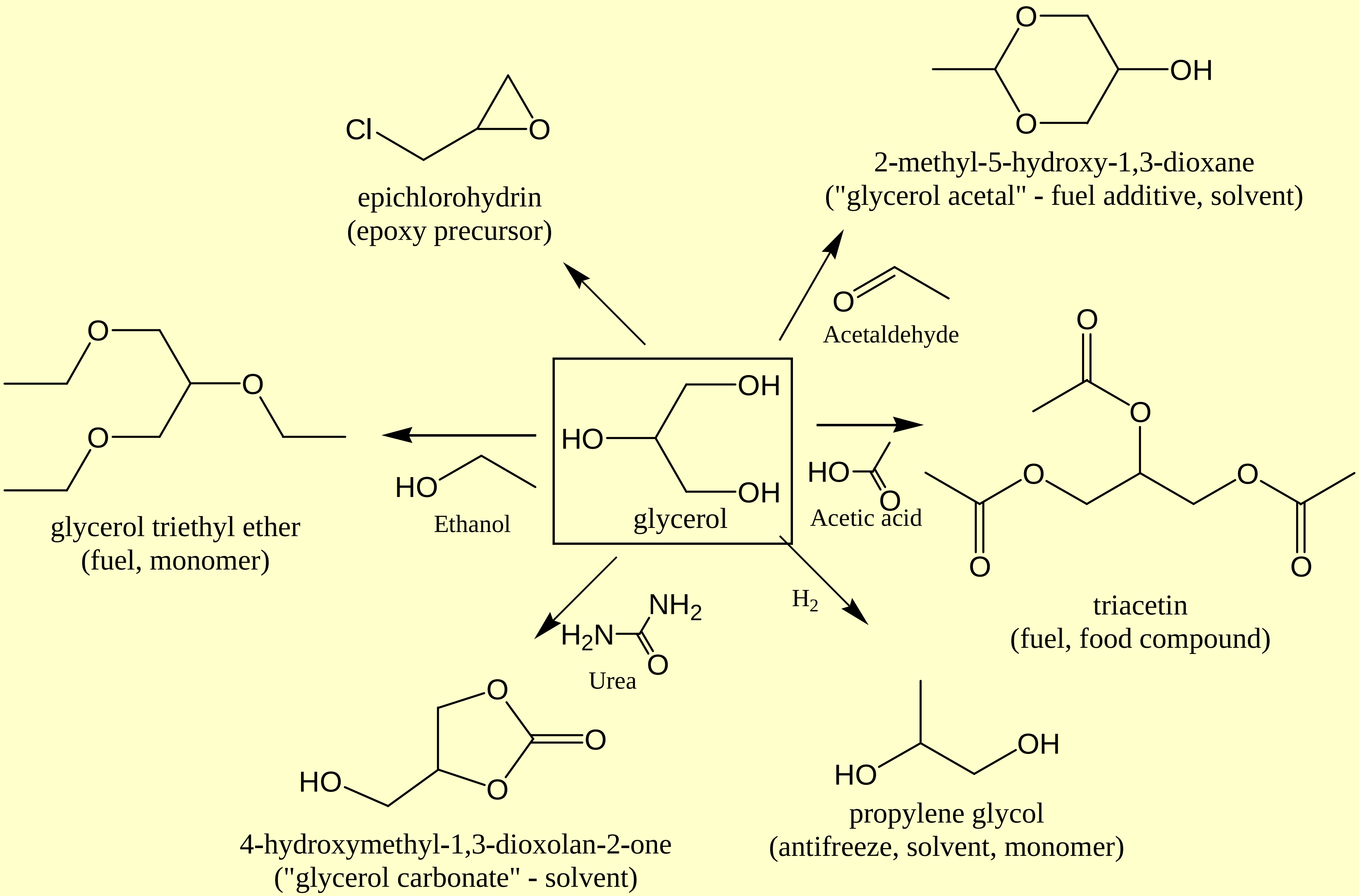
Literature - Thermochemical conversion

- Thermochemical approaches accept all portions of a variety of biomass feedstocks, are known technologies
- Gasification
  - Synthesis gas (CO, H_2 mixture) is platform intermediate
  - Produces fuels and broad spectrum of chemicals (alcohols, CH_x)
  - Capital cost of facility is barrier to commercialization
- Pyrolysis
  - "Bio-oil is platform intermediate; complex mixture of species
  - Low selectivity to specific chemicals
  - Bio-oil upgrading to fuels is current focus
  - Low yield is barrier to implementation

Literature: Glycerol – an emerging feedstock

- Glycerol is byproduct of biodiesel production (0.7 lb/gallon biodiesel) – produced as impure waste stream
- Has significant potential as chemical feedstock (schematic follows)
- Large corporations involved in conversion technologies
  - Dow Chemical (Glycerol to epichlorohydrin for epoxy resins)
  - ADM (Glycerol to propylene glycol)
- Barriers to commercialization
  - Uncertainty in biodiesel as long-term viable biofuel
  - Large uncertainties in glycerol prices over past 2+ years
  - Lack of infrastructure for recovery of glycerol from multiple small biodiesel producers

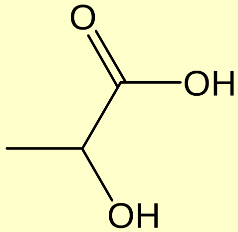
Literature: Glycerol conversion pathways



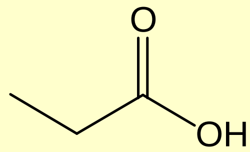
Literature: Organic Acids

- Organic acids produced by fermentation represent a diverse class of platform intermediate chemicals that can lead to a wide variety of petroleum substitutes
- Many acids are produced in high mass yields – an economic plus
- Lactic acid, citric acid, succinic acid are commercialized
- Others are in differing stages of development:
  - Itaconic acid
  - Fumaric acid
  - Butyric acid
  - 3-Hydroxypropionic acid
- Barriers to commercialization
  - Market development for acid or acid derivatives
  - Economics favorable over petroleum-derived routes
  - Uncertainty of new technologies

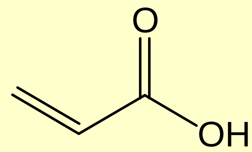
Literature: Organic acids



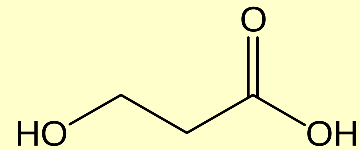
Lactic acid



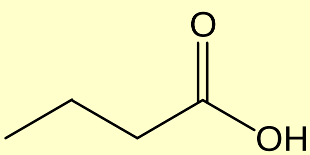
Propionic acid



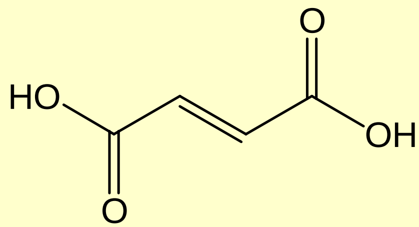
acrylic acid



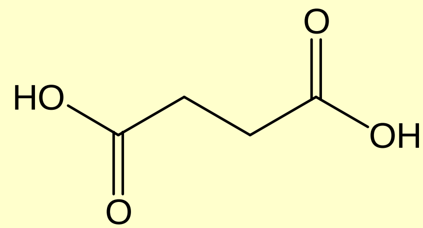
3-hydroxypropionic acid



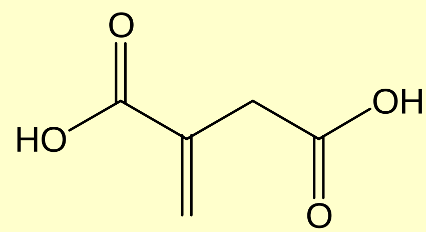
Butyric acid



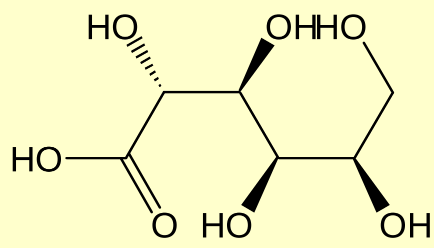
Fumaric acid



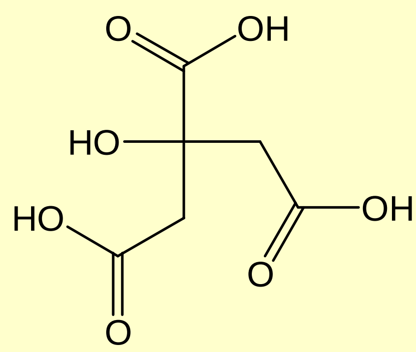
Succinic acid



Itaconic acid



gluconic acid

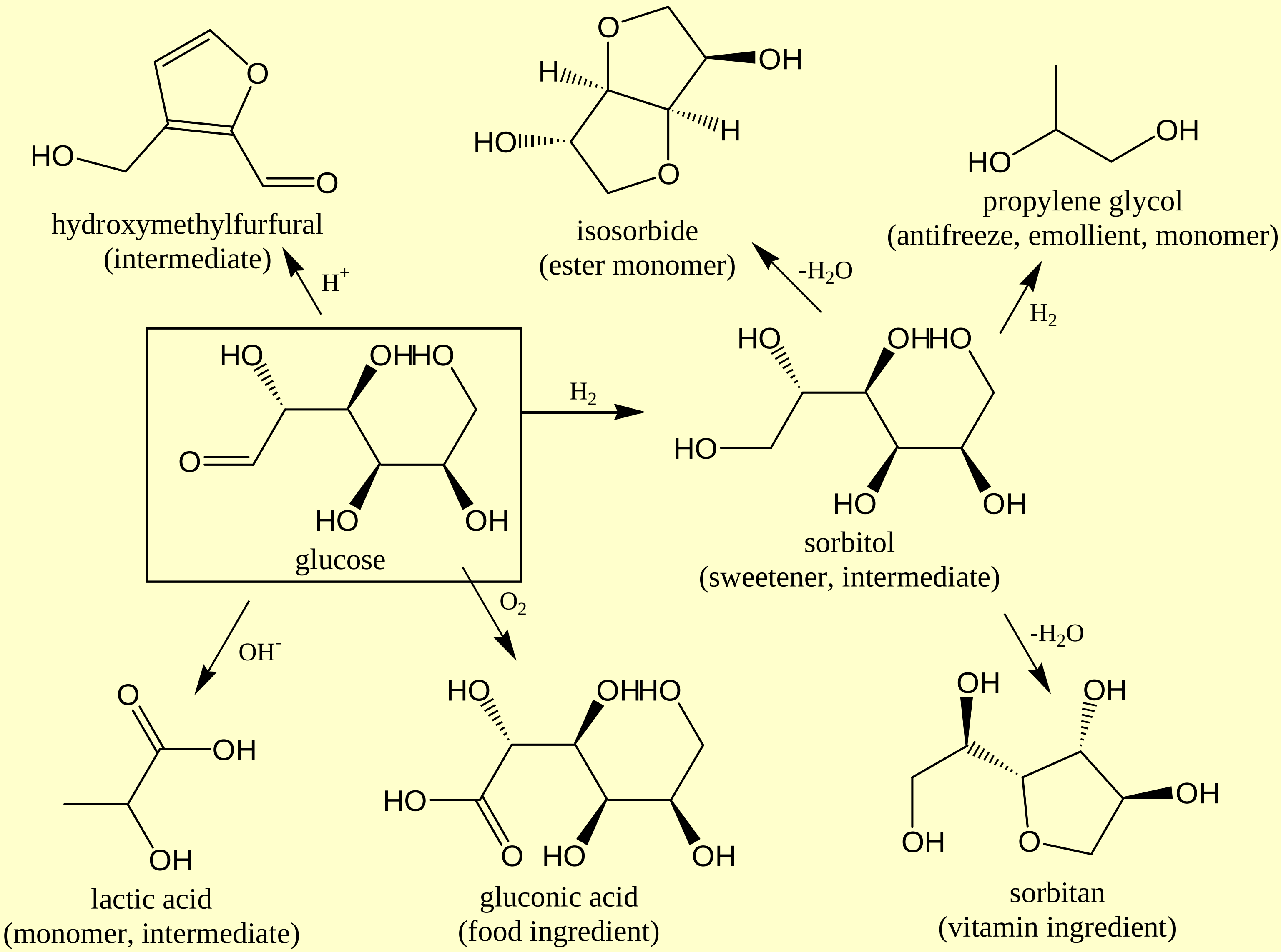


citric acid

Literature: Direct carbohydrate conversion

- Glucose and sorbitol are versatile intermediates for chemical catalytic conversions
- Chemical methods are more rapid than biological conversions – require lower capital, less stringent operation
- Challenge is achieving selectivity to desired products
- New technologies emerging (aqueous phase reforming (AFR) direct to hydrocarbons) that may lead to low-cost, high energy value fuels

Literature: Direct carbohydrate conversion



Canadian Biochemical Marketplace

2007	# of Cos. (> $30k)	Shipments ($ billions)	Dom. Mrkt. ($ billions)	Import Share of Dom. Mrkt
Chemicals & chemical products	2,933	$47.6	$55.4	72.4%
Plastics & plastic products	1,510	$19.7	$26.9	32.0%

- In both the chemical and plastics sectors, Canada exports bulk, base commodities; but, imports complex, engineered products
- Chemical, pharmaceutical, synthetic resin, synthetic fibre sectors characterized by large, foreign-owned multinationals (R&D elsewhere)
- Plastic products sector characterized by small, Canadian-owned firms with little capacity for higher-end R&D, engineered resins, products

Canadian Biochemical Marketplace

2007	Shipments ($ billions)	Dom. Mrkt. ($ billions)	Import Share of Dom. Mrkt
Petrochemicals	$7.13	$5.01	15.6%
Basic organic chemicals	$2.64	$6.15	109.3%
Synthetic resins	$9.56	$8.85	69.8%
Synthetic fibres	$0.70	$0.82	75.7%
Pesticides & ag chemicals	$0.55	$1.40	68.6%
Pharmaceuticals	$8.80	$14.07	85.8%

- Import substitution opportunities exist for biochemicals competing against non-natural gas-based petrochemicals and resins used in the organic chemical, synthetic resins, synthetic fibres, pesticides sectors
- Pharmaceutical sector, heavy foreign multinationals, R&D, but limited volume production of high purity in-house biochemicals

Canadian Biochemical Marketplace

% of Biotech Companies Involved in Industrial Applications	
Canada	8%
US	12%
Germany	14%
China	15%
New Zealand	20%
Australia	24%
Korea	41%

- $1.49b in biotech R&D in Canada, only $37 m in industrial applications
- Switzerland, $0.5b in biotech R&D, $45 m in industrial applications
- Australia, $0.22b in biotech R&D, $36 m in industrial applications
- **1% of Canadian biotech sales in industrial applications vs 22% in Japan**

Canadian Biochemical Marketplace

Canadian Plastic Products Industry, 2007					
NAICS Code	**Establishments**	**Shipments ($ millions)**	**Employment**	**Imports ($ millions)**	**Exports ($ millions)**
3261	1,510	$19,690	92,220	$7,266	$8,621
326111	200	1,930	6,970	467	488
326114	140	1,710	5,180	1,368	1,272
326121	108	1,020	5,020	452	489
326122	101	1,420	4,110	283	282
326130	60	4,690	1,750	565	469
326140	81	820	3,370	69	201
326150	120	940	3,500	265	98
326160	79	830	3,380	396	349
326191	93	660	4,120	66	93
326193	177	3,760	17,650	201	1,991
326198	1,474	6,410	37,150	3,134	2,889

Source: Statistics Canada, Industry Canada, North American Industry Classification System (NAICS) code 326

3261	Plastic Products Industry	326140	Polystyrene Foam Products
326111	Plastic Bags	326150	Urethane and Other Foam Products
326114	Plastic Film and Sheet	326160	Plastic Bottles
326121	Unlaminated Plastic Profile Shapes	326191	Plastic Plumbing Fixtures
326122	Plastic Pipe and Pipe Fittings	326193	Motor Vehicle Plastic Parts
326130	Laminated Plastic Plate, Sheet, Shapes	326198	All Other Plastic Products

Ontario Biochemical Marketplace

Sales of Chemicals and Chemical Products in Ontario ($ millions)					
NAICS Code	**2003**	**2004**	**2005**	**2006**	**2007**
325 Chemicals and chemical products	$21,321	$23,358	$23,612	$22,678	$22,114
3251 Basic chemical	4,127	4,616	4,235	4,811	4,726
32511 Petrochemicals	x	x	x	x	x
32519 Other basic organic chemicals	1,090	1,042	987	842	703
3252 Resins & synthetic fibres and filaments	5,333	5,825	6,204	5,111	4,199
32521 Resins and synthetic rubber	4,693	5,121	5,549	4,550	3,682
32522 Synthetic fibres and filaments	645	703	654	561	518
3253 Pesticides, fertilizers & ag. chemicals	558	559	564	586	714
32531 Fertilizers	544	543	537	532	702
32532 Pesticides and ag. chemicals	14	18	26	54	12
3254 Pharmaceutical and medicine	4,053	5,235	5,468	5,517	6,043
3255 Paints, coatings & adhesives	1,591	1,660	1,759	1,558	1,516
32551 Paint and costing	1,102	1,155	1,205	1,156	1,073
32552 Adhesives	489	504	554	402	442
3256 Soap, cleaning compounds & toiletries	2,577	2,614	2,238	2,457	2,326
32561 Soap and cleaning compounds	1,501	1,360	1,321	1,463	1,487
32562 Toilet preparations	1,076	954	916	993	839
3259 Other chemical products	3,071	3,146	3,142	2,636	2,586
32591 Printing inks	x	308	286	230	253
32599 All other chemical manufacturing	2,694	2,773	2,791	2,357	2,298

Source: Statistics Canada, Table 304-0015, and Cansim database
"x" data suppressed by Statistics Canada to meet the confidentiality requirements of the Statistics Act

Ontario Biochemical Marketplace

Imports of Selected Resins into Ontario ($ millions)					
Resin	**2003**	**2004**	**2005**	**2006**	**2007**
LDPE	$264.1	$272.2	$302.8	$326.4	$260.9
HDPE	241.1	240.3	269.7	303.3	232.4
EVA	45.6	38.7	39.3	40.0	33.7
PP	616.1	660.1	733.0	701.7	676.0
PS	22.3	27.3	27.3	26.2	29.9
ABS	93.2	96.7	97.7	85.7	76.8
PVC	387.8	415.6	447.9	454.9	413.6
PE	345.1	374.3	387.8	397.0	367.7
PET	96.8	80.9	139.5	128.8	165.2
PA	183.6	186.3	212.0	194.2	184.8
Urea resins	25.3	25.1	28.5	15.4	8.6
Melamine	23.7	22.8	22.3	16.6	14.3
Phenolic	33.4	30.4	31.5	28.9	31.2
PU	137.5	135.0	133.2	134.0	122.1

Source: Industry Canada, Statistics Canada, Trade Data Online

PE	polyethylene	UP	unsaturated polyester
PP	polypropylene	UF	urea formaldehyde
PS	polystyrene	PF	phenol formaldehyde
PVC	polyvinyl chloride	MF	melamine formaldehyde
PA	polyamide (nylon)	EVA	ethylene vinyl acetate
PET	polyethylene terephthalate	PU	polyurethane
ABS	acrylonitrile butadiene styrene	PPT	polypropylene terephthalate

Ontario Biochemical Marketplace

Imports of Plastic Film, Plates, Sheets, Foil and Strip into Ontario ($millions)					
Type	**2003**	**2004**	**2005**	**2006**	**2007**
Polyethylene	$302.1	$308.8	$348.2	$351.9	$333.6
Polypropylene	204.4	185.7	164.6	178.0	158.5
Polycarbonate	24.1	27.5	28.1	28.6	22.6
Polyethyleneterephthalate (PET)	125.5	112.8	90.7	88.7	81.4
Polyester	1,155.6	2,081.0	3,473.8	2,532.6	2,208.6

Source: Industry Canada, Statistics Canada, Cansim database

- Both **polyethylene and polypropylene will be made from ethanol in Brazil**
- Toyota says polypropylene accounts for 50% of the total plastics in its cars
- Combined, PP, PVC, PU, ABS account for 80% of the plastics in Toyota cars
- Toyota has targeted **replacing 20% of the plastics in its cars with bioplastics by 2015** targeting interior components initially

Ontario Biochemical Marketplace

Sales of Plastics and Plastic Products in Ontario ($ millions)						
NAICS Code		2003	2004	2005	2006	2007
326	Plastics and rubber products	$15,601	$14,856	$15,330	$15,653	$14,413
3261	Plastic products	12,780	12,132	12,491	12,580	12,045
32611	Plastic packaging, unlaminated film, sheet	1,727	1,740	1,863	1,657	1,686
32612	Plastic pipe, fittings, unlaminated shapes	1,303	1,332	1,310	1,253	1,432
32613	Laminated plastic plate, sheet, shapes	x	335	357	276	193
32614	Polystyrene foam products	280	302	291	348	314
32615	Urethane and other foam products	352	338	355	810	957
32616	Plastic bottle manufacturing	596	595	575	582	551
32619	Other plastic products	8,184	7,486	7,737	7,652	6,909
326191	Plastic plumbing fixtures	195	220	234	240	195
326193	Motor vehicle plastic parts	3,944	3,476	3,497	3,447	3,339
326198	All other plastic products	4,045	3,789	4,006	3,964	3,330
3262	Rubber product manufacturing	2,821	2,723	2,839	3,072	2,368
32621	Tire manufacturing	777	833	867	1,027	608
32622	Rubber and plastic hose and belting	698	599	644	788	656
32629	Other rubber product manufacturing	1,345	1,290	1,327	1,257	1,103

Source: Statistics Canada, Table 304-0015, Cansim database

- Combined, **motor vehicle plastic parts and rubber product** manufacturing (largely automotive), account for $5.7b in sales in 2007, **40% of total sales** for the plastics and plastic products sector in Ontario

Biochemicals From Corn: Update 2008

The opportunities are enormous

Bioproducts and bioprocesses will transform conventional industries that use chemicals and chemical processes.

Global biochemicals market is predicted to be US$ 280 B by 2010:

–20% (US$ 280B/y) of the global chemical market (US$ 1.4 T/y) will be impacted by bioproducts and bioprocesses

–of this, US$ 160 B/y will be new value created

–estimates from McKinsey Group

Global bioenergy market is predicted to be US$ 150 B by 2050:

–30% of world energy needs will come from renewable resources

–the biomass market to supply this will be US$ 150B/y

–estimates from Royal Dutch Shell

Note: For comparison, the global market for biopharmaceuticals is predicted to be US$ 50 B/y in 2010

- "Biobased Industrial Products & Processes", Industry Canada presentation, April 29, 2003

Biochemicals From Corn: Update 2008

"U.S. demand for biodegradable plastic will grow 15.5% annually through 2012. Gains will be driven by escalating costs for petroleum based resins and growing initiatives that favour renewable resources. Polyester-based and polylactic acid resins will grow the fastest, while starch-based types remain the largest segment."

- "Biodegradable Plastic: US Industry Study with Forecasts for 2012 & 2017",
  The Freedonia Group, Cleveland, Ohio, August 2008.

Biochemicals From Corn: Update 2008

- A very great deal has occurred, **essentially all outside of Canada**.
- Drivers: **escalating price of oil, energy insecurity, environmental degradation**.
- **Pace quickening** due to policy initiatives facilitated by **biotechnology**.
- Main emphasis in biotechnology has been medicines and pharmaceuticals
- But, nations dependant on imported oil (Japan, China, US, Europe) are devoting an **increasing proportion of biotech R&D to industrial applications**.

- **Canada's main biotech emphasis remains medicine and pharmaceuticals** because of preferential tax treatment afforded R&D in those sectors, and an innate industrial inertia in favour of continuing reliance on fossil fuel-based industrial applications because of western natural gas and oil sands development.

- However, **Ontario imports virtually 100% of its oil and natural gas** feedstocks for fuel, chemicals, synthetic resins, plastics, and products
- Ontario industrial sectors are like the situation of Japan, the US, and Europe.

Biochemicals From Corn: Update 2008

• US energy policies, 2008 US Farm Bill = rapid development of **cellulosic ethanol**
• 2008 Farm Bill: imports of sugar > 15% of domestic US market **diverted into ethanol**
• **Impending commercializations** by Metabolix, Codexis, Genencor, Genomatica, Novozyme, a host of US universities will see enormous change:

• **Cellulosic ethanol a commercial reality**, based on switchgrass, wood chips, corn stover, wheat straw, and perhaps miscanthus; but, a major issue will be feedstock accumulation, storage, and handling (i.e. an 80 m gallon switchgrass ethanol facility requires 100 acres of covered storage capable of stacking 25 feet high).

• **Bio-oil refining into gasoline, diesel, and jet fuel a commercial reality** through technologies such as Virent's BioForming process, or Ensyn's direct rapid pyrolysis, or ADM/ConocoPhillips' process all likely based on non-food cellulosic biomass.

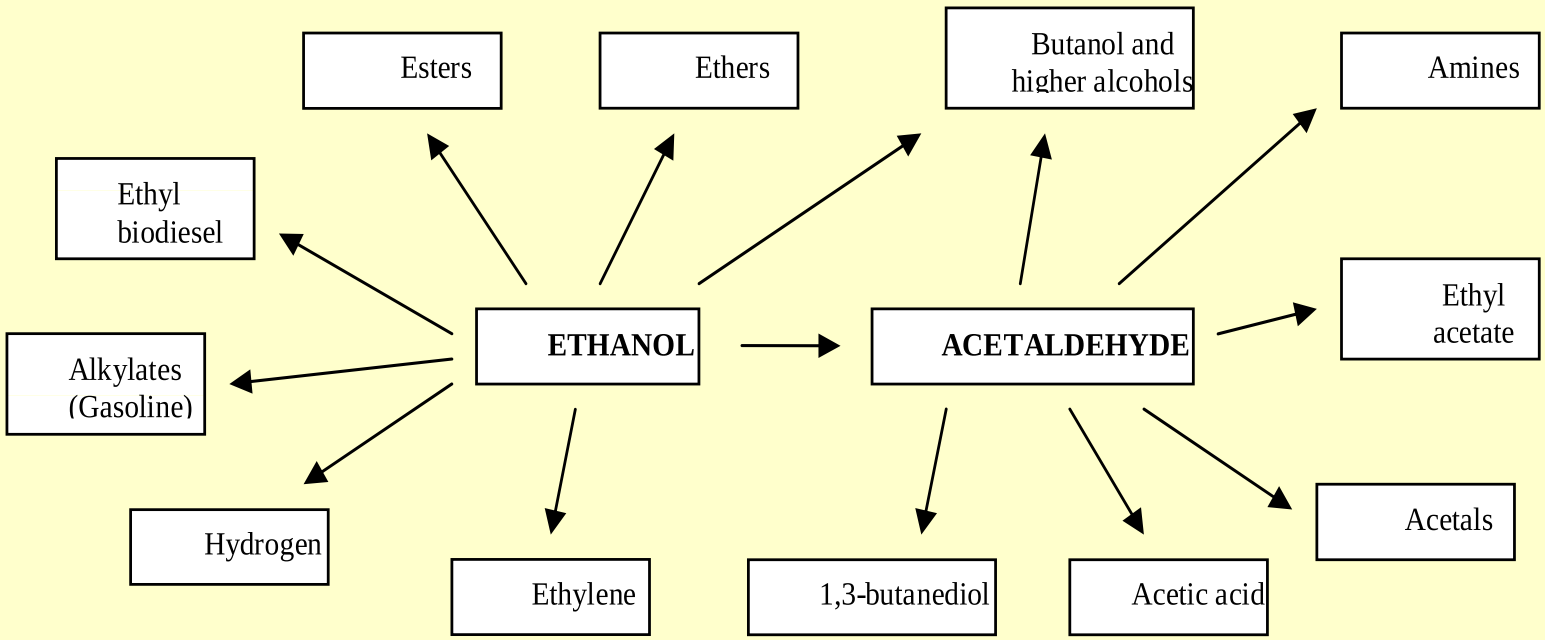
• **Butanol a commercial reality** as in the UK's DuPont/BP collaboration, may replace corn-based ethanol because of better energy conversions, easier handling and transportation, and may be made at converted corn ethanol production facilities.

Biochemicals From Corn: Update 2008

Corn ethanol facilities will have to look at **switching to other products**, or to the **production of biochemical co-products** in addition to ethanol:

- **Butanol** based on the DuPont/BP process instead of ethanol
- **Bio-polyethylene** from ethanol as commercialized by Braskem, Dow, Solvay, and Petrobas in Brazil. Bio-polyethylene might be an attractive opportunity for Ontario ethanol producers especially because of the closure of the Cochin ethylene pipeline from western Canada into Sarnia in 2006. Dow Chemical's closure of its Sarnia ethylene product production in April 2009 opens opportunities for alternatively sourced bioethylene and products.
- **Bio-polypropylene** from ethanol as commercialized by Braskem.
- Co-products in addition to ethanol might be:
  - **succinic acid** (MBI process, or DNP process), then **1,4-butanediol** (BDO), and **succinic salts** as de-icing agents for airplanes, airports, and highways
  - **ethyl citrate** as a substitute for bisphenol-A
  - **ethyl lactate** as a solvent and cleaner

Biochemical Commercialization Platform: Ethanol



Scheme 2.14 Ethanol as a platform for chemicals production

Biochemical Commercialization Platform: Ethanol

Economics of Triethyl-Citrate Production
(25 MM lb/yr plant located adjacent to ethanol facility)

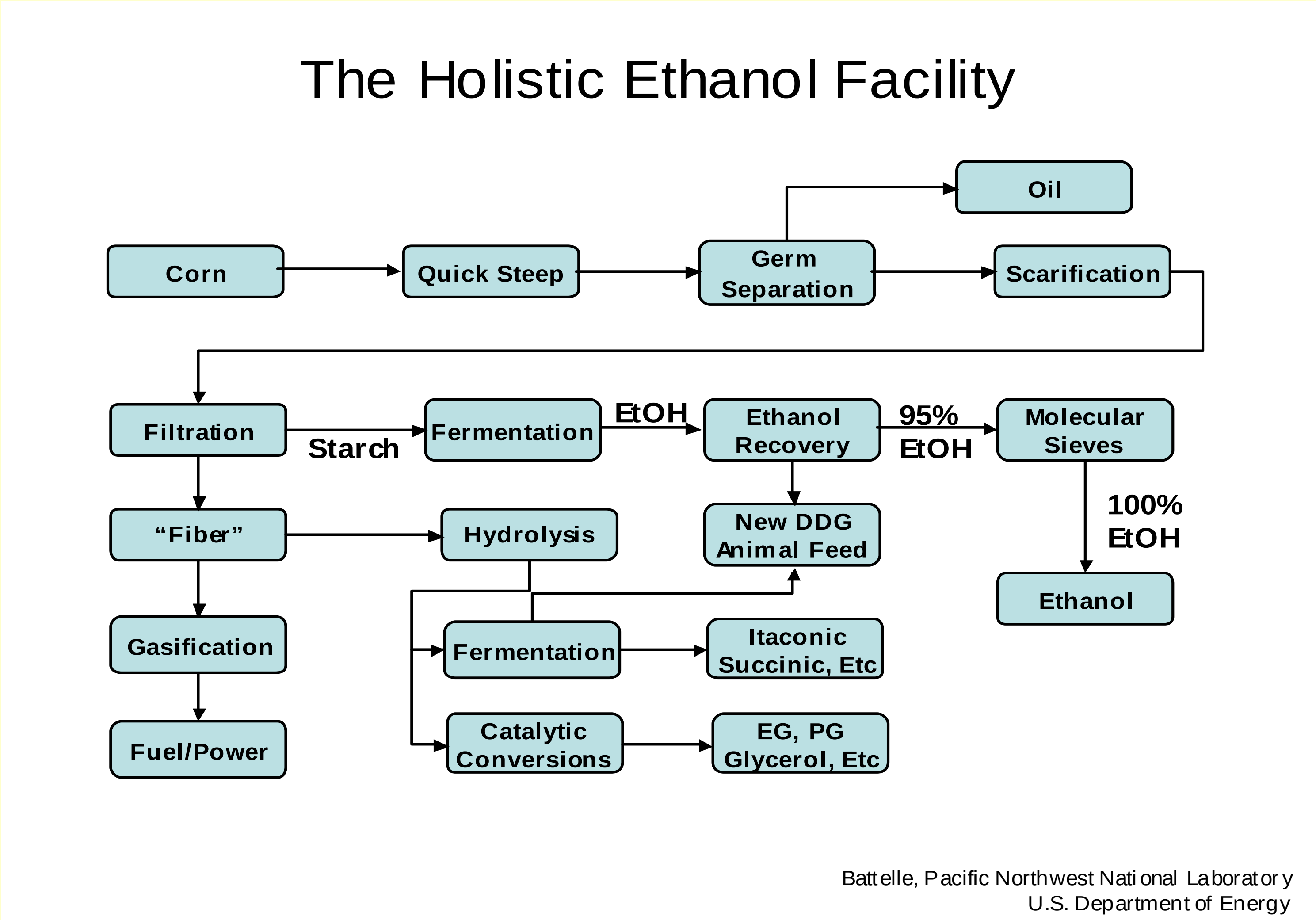
No.	Description	$ (US) / lb TEC
1	Total raw material costs (ethanol + citric acid) Citric acid ($0.60/lb, 0.7 lb CA/lb TEC) Ethanol ($0.25/lb, 0.5 lb EtOH/lb TEC)	0.545
2	Total capital investment: $17.8 million (Installed equipment ($7.7 million) plus site costs ($5.1 million) plus working capital ($5 million)) Plant life is 10 years.	0.071
3	Utilities (steam, natural gas, electricity)	0.10
4	Labor	0.04
5	**TOTAL PRODUCTION COSTS (Sum of 1 - 4)**	**0.756**
6	Internal Rate of Return on Investment per Year: 30% ($17.8 million total capital investment)	0.21
7	Taxes (@ 40% of IRR)	0.086
	REQUIRED TRIETHYL CITRATE SELLING PRICE	**$ 1.052**

Biochemical Commercialization Platform: Ethanol

Economics of Ethyl Lactate Production
(25 MM lb/yr plant located adjacent to ethanol facility)

No.	Description	$ (US) / lb EtLA
1	Total raw material costs (ethanol + lactic acid) Lactic acid ($0.50/lb, 0.76 lb LA/lb EtLA) Ethanol ($0.25/lb, 0.39 lb EtOH/lb EtLA)	0.48
2	Total capital investment: $12.6 million (Installed equipment ($4.6 million) plus site costs ($4.0 million) plus working capital ($4 million)) Plant life is 10 years.	0.050
3	Utilities (steam, natural gas, electricity)	0.07
4	Labor	0.04
5	**TOTAL PRODUCTION COSTS (Sum of 1 - 4)**	**0.64**
6	Internal Rate of Return on Investment per Year: 30% ($12.6 million total capital investment)	0.170
7	Taxes (@ 40% of IRR)	0.068
	REQUIRED ETHYL LACTATE SELLING PRICE	**$ 0.878**

Biochemical Commercialization Platform: Ethanol



Biochemicals From Corn: Update 2008

Corn wet milling facilities producing glucose, HFCS, and dextrose might be forced to diversify into other biochemicals:

- Research claims **HFCS shuts down the leptin inhibitor function** which could force wet millers to look for additional product opportunities from glucose and other wet milling co-products.
- **Dow Corning/Elevance Renewable Sciences** collaboration on corn oil.
- **US trade action against citric acid imports**, alternative usages for dextrose
- **US trade action against PET** encourages biopolymers from glucose, sorbitol, and/or dextrose offering the added advantage of being renewably-based and perhaps biodegradable.

Biochemicals From Corn: Update 2008

- **Glucose or sorbitol to propylene glycol (PG)** using ADM's process, or Genomatica's process to **1,4-butanediol (BDO)**

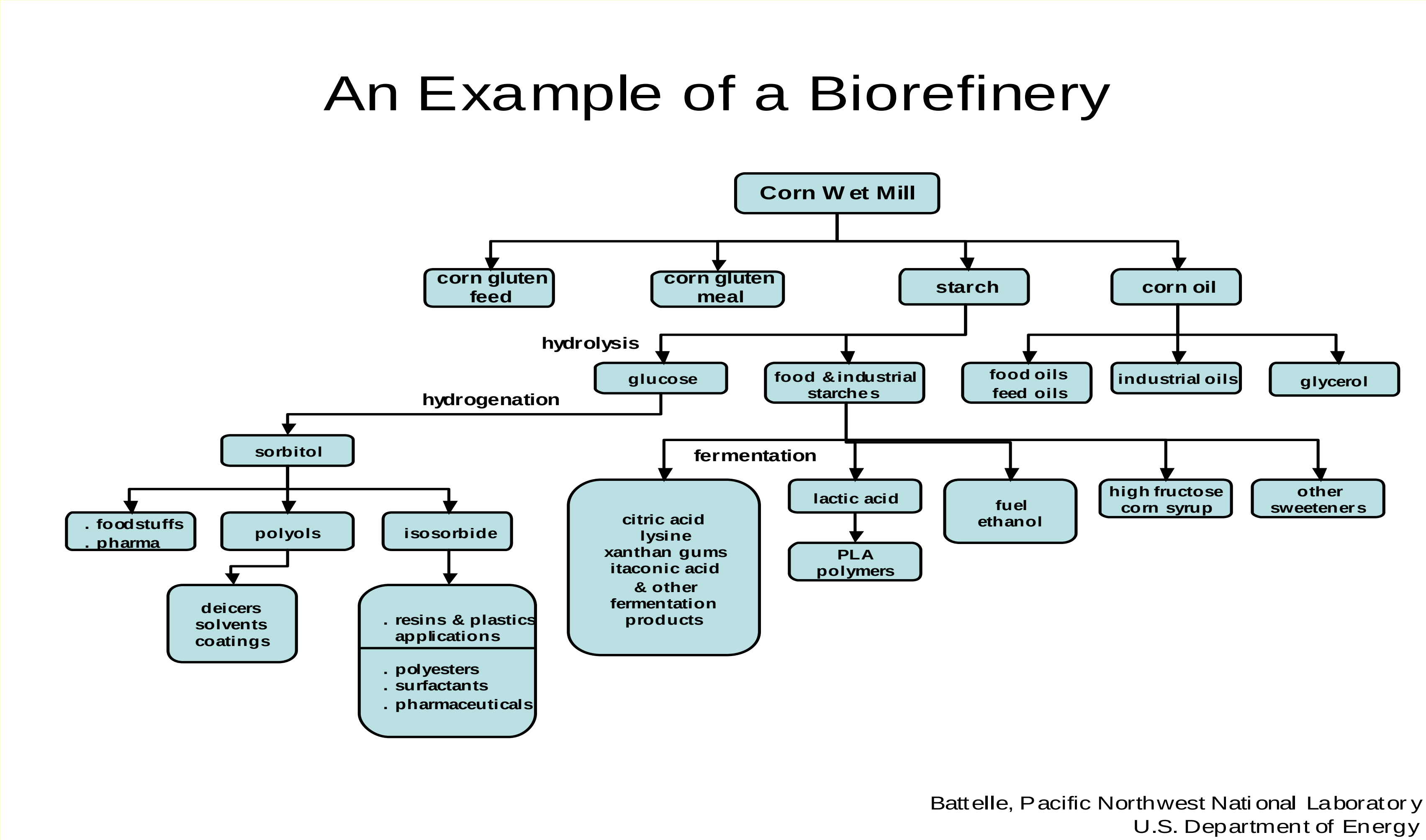
- **Ban on bisphenol-A** huge opportunity for biochemical replacements
  - **glucose to HMF to levulinic acid to diphenolic acid**,
  - or the adoption of **triethyl citrate** as a plasticizer.

- Shell/Virent/Codexis process converting **sorbitol into hydrogen**
  - massive prospects as fuel and as a chemical process ingredient.

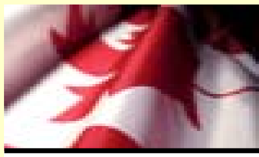
- Cargill/Codexis **dextrose to 3-HP to acrylic polymers and acrylamide**

The US Department of Energy's waiver of patent rights constraint on commercialization outside the US highlights the huge impediment created by Canada's lack of biotech R&D on industrial applications.

Biochemical Commercialization Platform: Corn Wet Milling



Biochemicals From Corn: Update 2008



But the threats are significant

- Major corporations in the US, Germany and Japan are positioning themselves for the emerging biobased economy - patents and people
- Canadian chemical process industries have been relatively slow to investigate the benefits/advantages of bioproducts and bioprocesses
- Threat:

Canadian companies may be left producing petroleum-based commodity products that compete only on price at a time when environmental pressures are growing and competition from low-wage countries is increasing.

- "Biobased Industrial Products & Processes", Industry Canada presentation, April 29, 2003

Biochemicals From Corn: Update 2008
KEYS FOR MOVING FORWARD

Collaborations between enzyme or process developers, corn refiners, and chemical companies or resin manufacturers or plastic product companies.

Examples abound:

Dow Chemicals/Crystalsev (polyethylene from ethanol)

Pryamid Technologies/German Bioplastics (PLA)

PURAC/Sulzer Chemtech/Synbra Technology (PLA and foamed PLA)

Diversified Natural Products/ARD (succinic acid)

Cargill/Codexis (3-HP)

DuPont/BP (butanol)

Shell/Virent/Codexis (bio-gasoline, hydrogen)

Genencor/Goodyear (isoprene)

Biochemicals From Corn: Update 2008
KEYS FOR MOVING FORWARD

It appears there are many foreign biotech companies with commercializable industrial applications (Metabolix, Genencor, Novozymes, Genomatica, Codexis to name only a few) seeking willing corn refiners and downstream users such as chemical, resin, or plastic product manufacturers.

The thrust will have to come from existing Ontario corn refiners (ethanol producers and corn wet millers) who recognize the threats and opportunities they face in the immediate future, and from downstream users in Ontario who respond to market realities and policy opportunities (prohibitive cost of petroleum-based feedstock, inability to source petroleum-based feedstock, biodegradability, renewable resources, bisphenol-A ban).

Biochemicals From Corn: Update 2008
KEYS FOR MOVING FORWARD

Direct Ontario and Federal government investment crucial, for example:

- SGF in Quebec with Shell in the manufacture of PTT

- SGF in Quebec with Interquisa in the manufacture of PTA

- German government and Plantic Technologies in the manufacture of PLA

- China and Global Bio-Chem/IPCI in the manufacture of sorbitol, polyols, PG

- US government in defining and funding the thrust toward corn ethanol, and now biodiesel and cellulosic ethanol as well as a whole range of industrial biochemicals from corn.