

Development of NatureWorks LLC

From Kernel to Pellet

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Lead Chemist
NatureWorks LLC

Frontiers in Biorefining
October 22, 2010





Our Mission

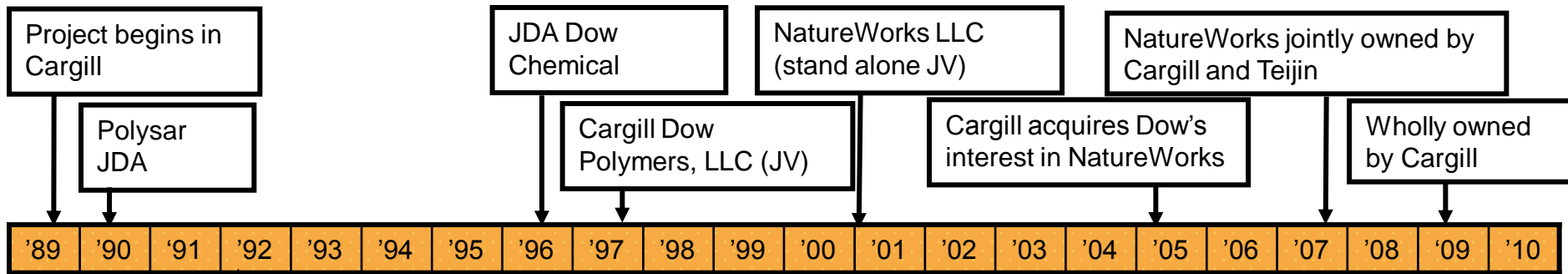
to be the global leader in producing a broad family of performance plastics from renewable resources, dedicated to meeting the world's needs today without compromising the earth's ability to meet the needs of tomorrow.

ingenious materials from plants not oil

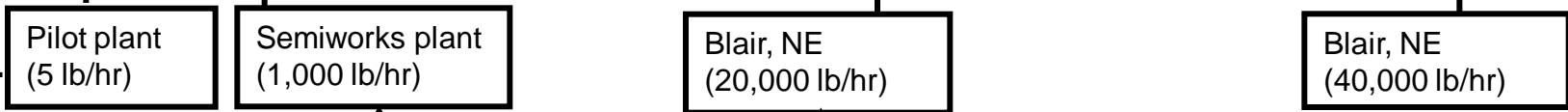


The NatureWorks journey.....

People & Organizations . . .



Plants . . .



Capital . . .



Early history of polylactide polymers

- Lactide monomer production described in 1912
- Polylactide production described in 1932 (Carothers et. al.)
 - Technology developed further by DuPont, with high molecular weight polymers in 1955, but technology appears to have been shelved
 - First commercial application c.1972, with Ethicon Inc. development of resorbable sutures (poly-lactide-co-glycolide)
- Resurgence of interest in 1980's
 - E.S. Lipinsky, “Chemicals from Biomass: Petrochemical Substitution Options”, *Science*, **212**, 1465-1471 (1981) (Battelle Columbus Laboratories)
 - E.S. Lipinsky and R.G. Sinclair, “Is Lactic Acid a Commodity Chemical?”, *Chem. Eng. Progress* (Aug. 1986)



A few key **Nebraska** /US corn statistics:

- 1 bushel (bu) = 56 lbs = 25.4 kg
 - 1 acre = 43,560 ft² = 4047 m²
- 1 ear of corn has 600-900 individual kernels
 - April 15 – June 5 planting season
 - Sept 10 – Nov 25 harvest
- Top 5 producers IA, IL, **NE**, MN, IN (66% of US crop)
 - **9.2 M** acres harvested in 2006 (86.5 M US)
 - **1.472 B** bu in '06 (US 13.1 B)
 - **70% of NE** crop is irrigated (highest in US)
- **160 bu/acre** (US 151.1 bu/acre) (est. 180 bu/acre by 2015)
 - **22.5 degC** avg temp during growth
 - **30"** rainfall annual
 - **1.86 B bu** storage (59% on farm)



What can you get from one bushel of corn?

1.6 Pounds of Corn Oil

Cooking Oil, Margarine, Mayonnaise, Salad Dressing, Shortening, Soups, Printing Ink, Soap, Leather Tanning

AND

13.5 Pounds of Gluten Feed 21% Protein

Livestock & Poultry Feed, Pet Food

AND

2.6 Pounds of Gluten Meal 60% Protein

Amino Acids, Fur Cleaner, Poultry Feed

AND

32 Pounds of Starch

Adhesives, Batteries, **Cardboard**, Crayons, Degradable Plastics, Dyes, Plywood, Paper, Antibiotics, Chewing Gum

OR

33 Pounds of Sweetener

Shoe Polish, Soft Drinks & Juices, Jams and Jellies, Canned Fruit, Cereal, Licorice, Peanut Butter, Catsup, Marshmallows

OR

2.7 Gallons of Ethanol/Alcohol

Motor Fuel Additive, Alcoholic Beverages, Industrial Alcohol

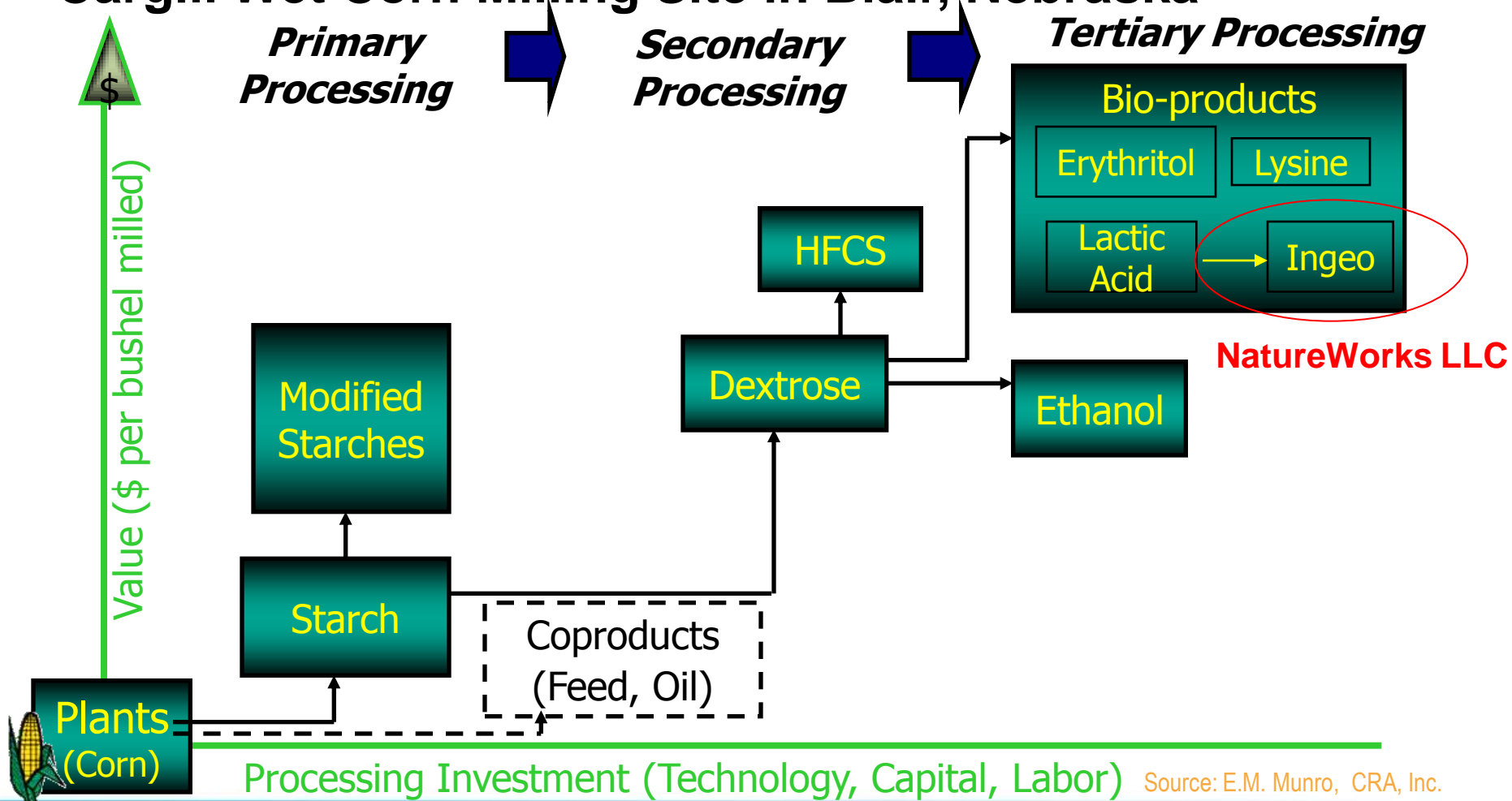
OR

19 Pounds of Ingeo™ Biopolymer

The US uses one billion lbs of starch in corrugated paper every year.



Value Chain Derived from the Cargill Wet Corn Milling Site in Blair, Nebraska

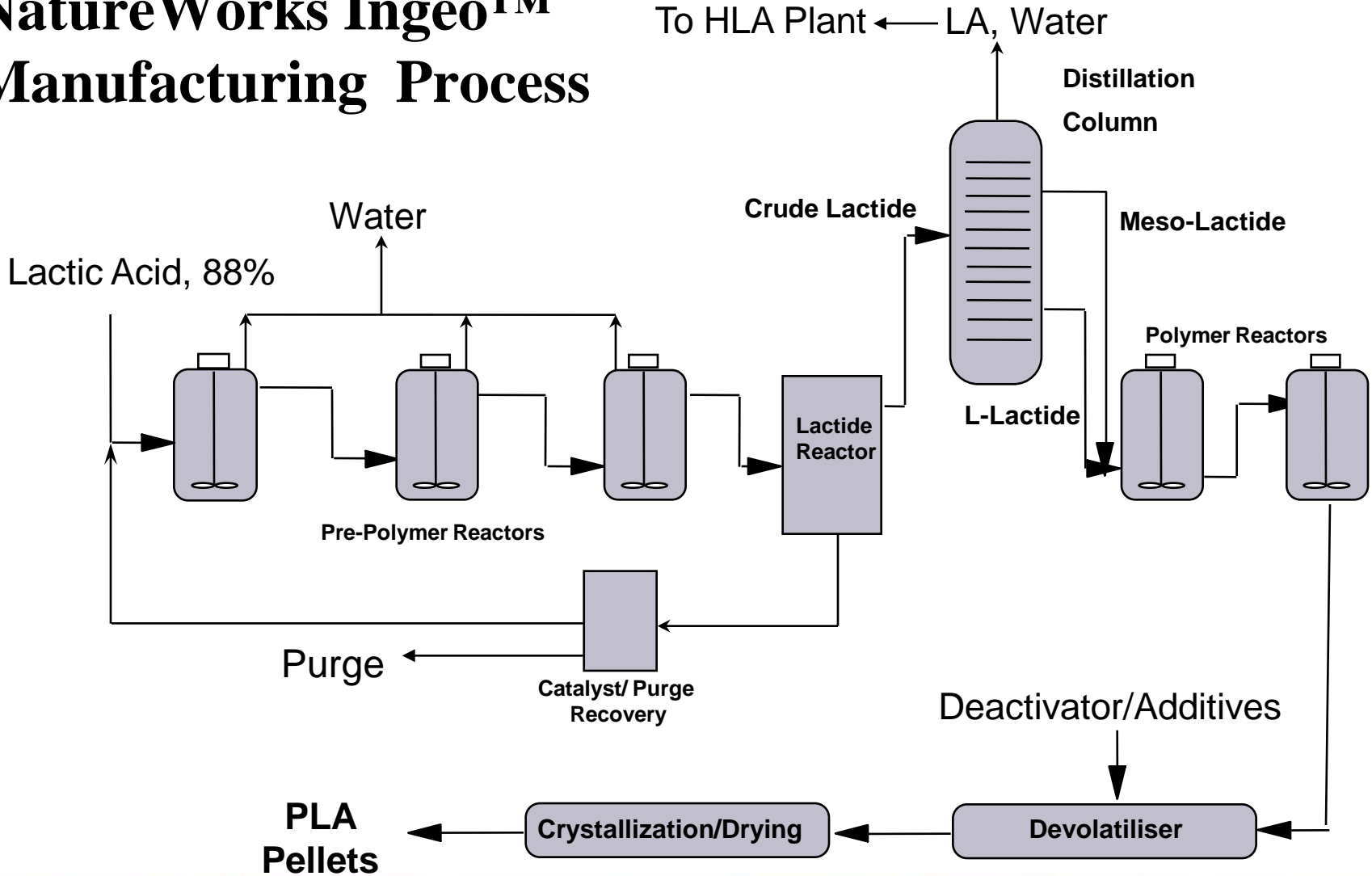


Source: E.M. Munro, CRA, Inc.

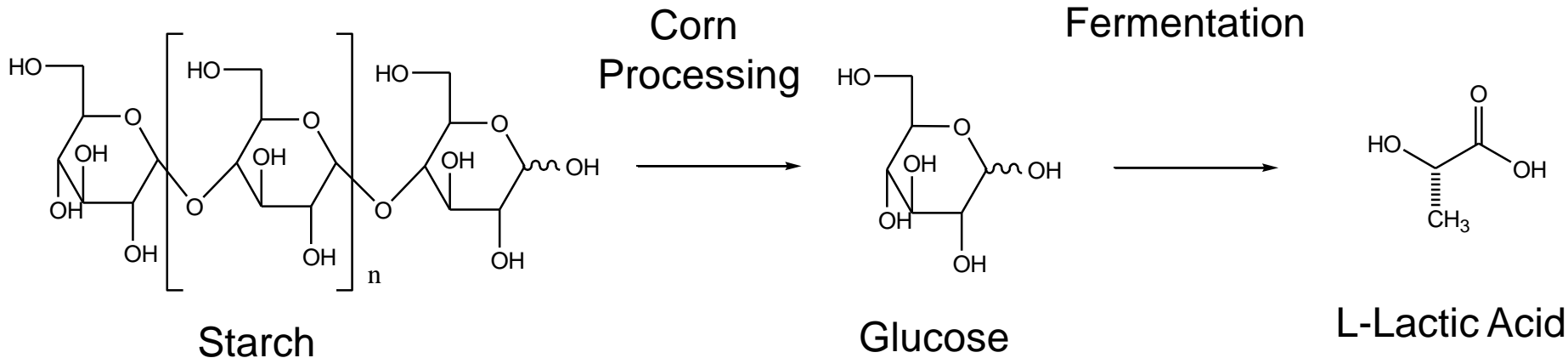
ingenious materials from plants not oil



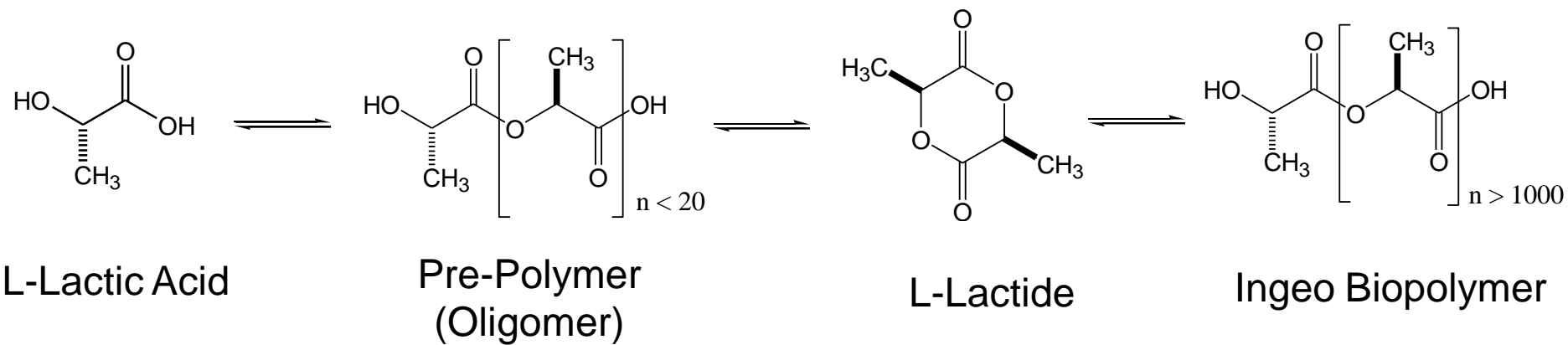
NatureWorks Ingeo™ Manufacturing Process

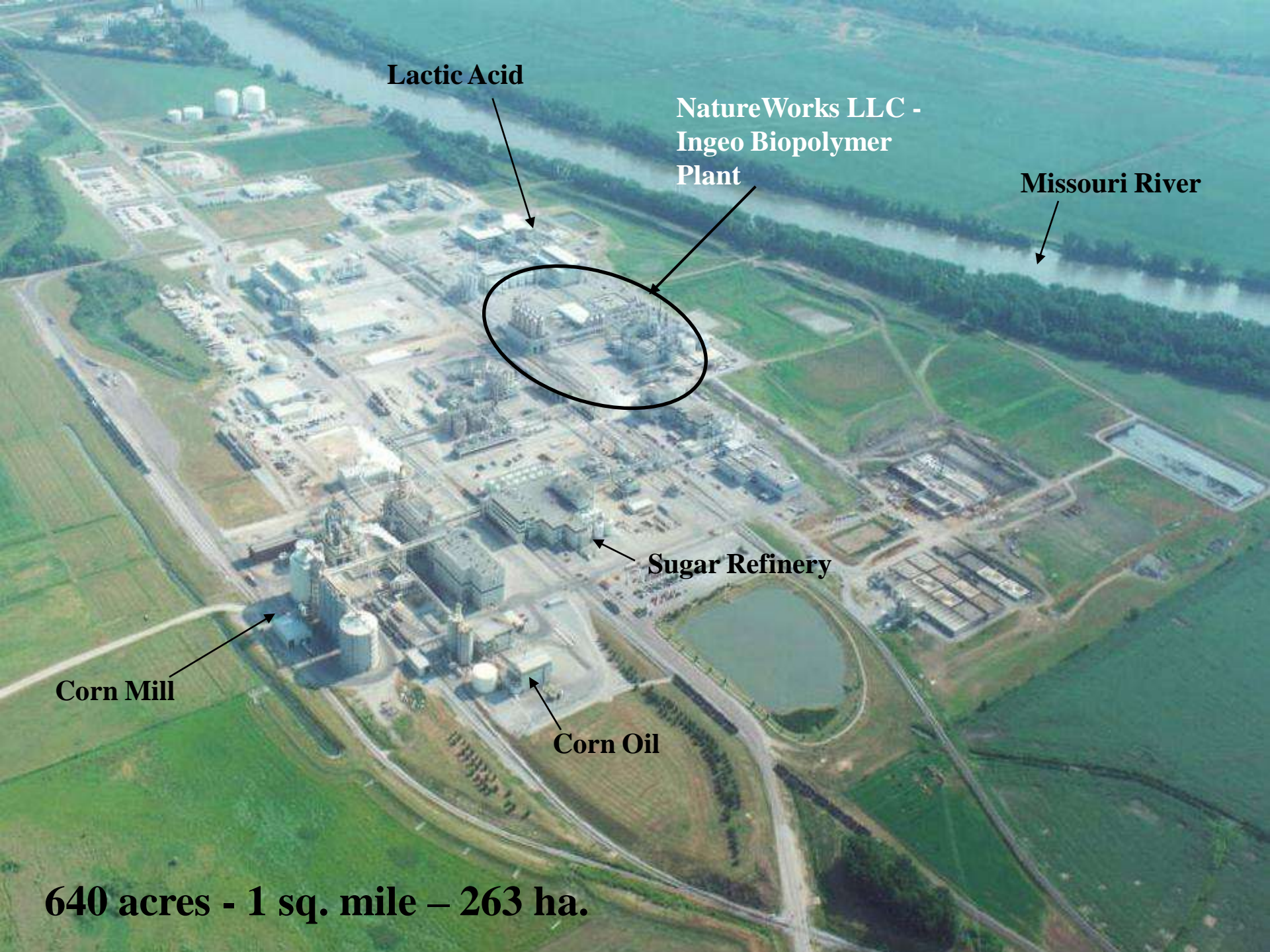


Biorefinery . . .



Chemical . . .





Lactic Acid

**NatureWorks LLC -
Ingeo Biopolymer
Plant**

Missouri River

Sugar Refinery

Corn Mill

Corn Oil

640 acres - 1 sq. mile – 263 ha.



Serviceware

Bottles

Rigid Containers

Flexible, Films & Coatings



Consumer Goods

Textile

Apparel



Cards

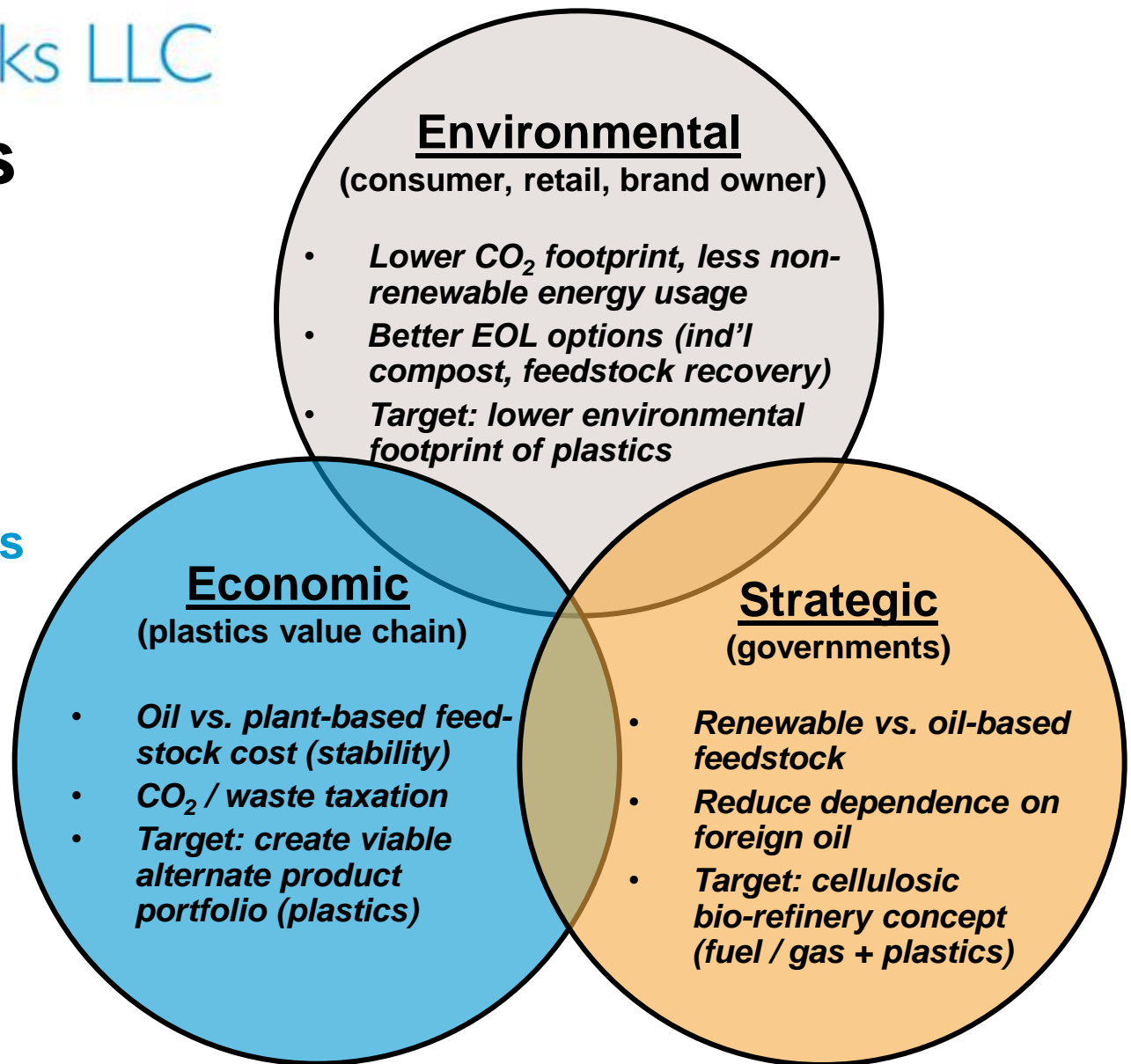


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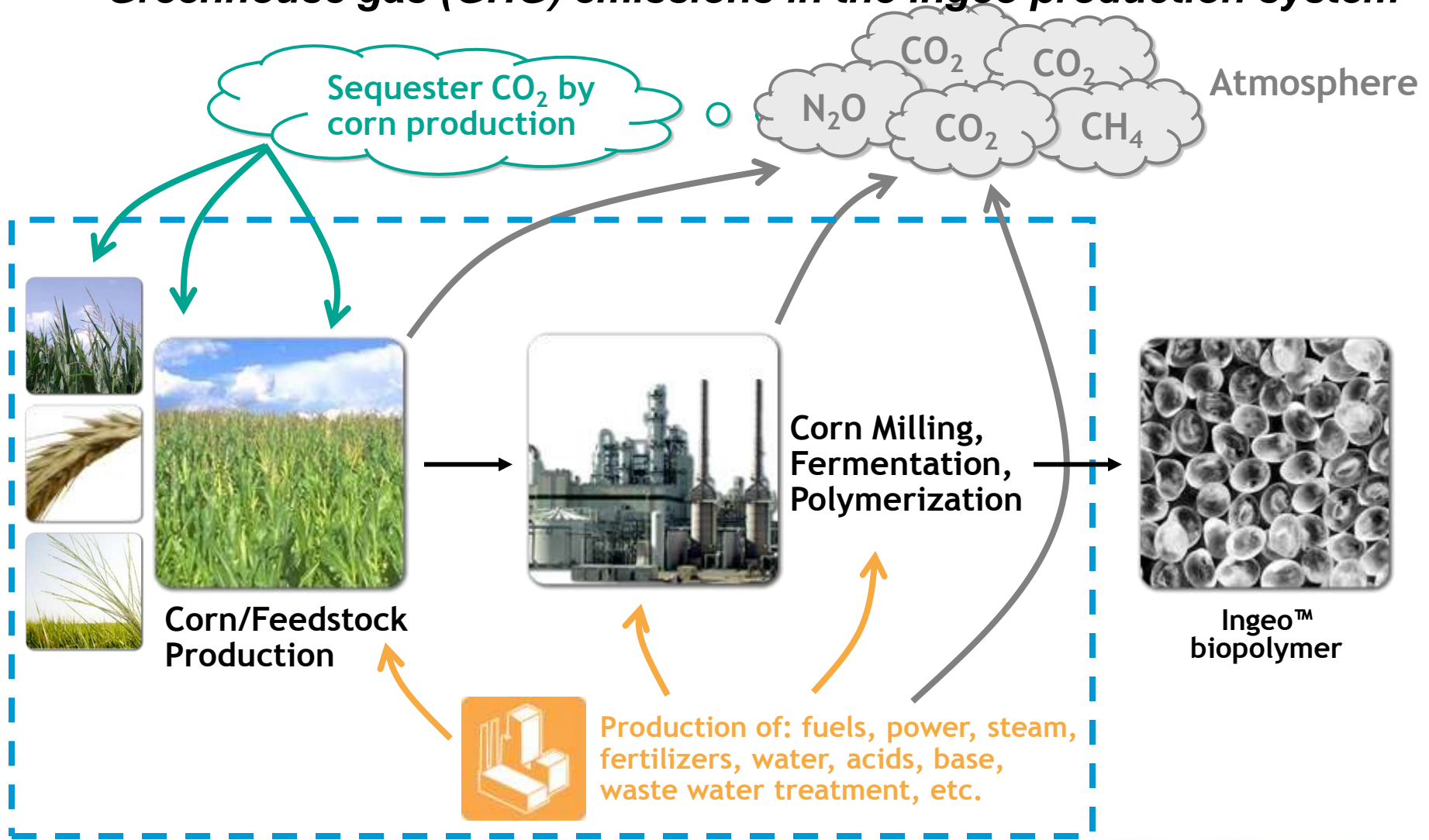


Value Drivers

Despite these
volatile economic
times, **STRATEGIC**
and
ENVIRONMENTAL
growth / value drivers
remain strong ...

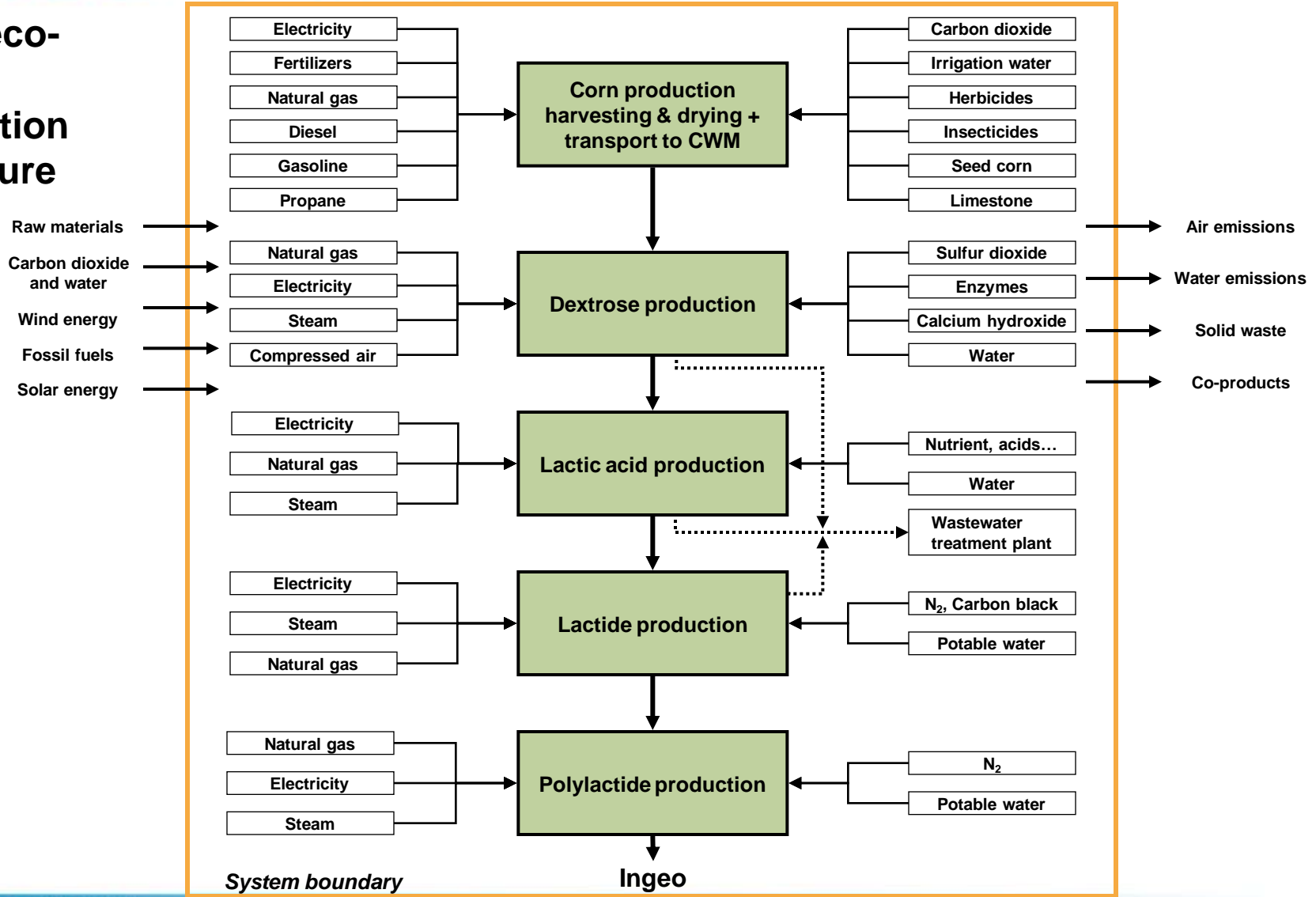


Ingeo Eco-Profile: Greenhouse gas (GHG) emissions in the Ingeo production system

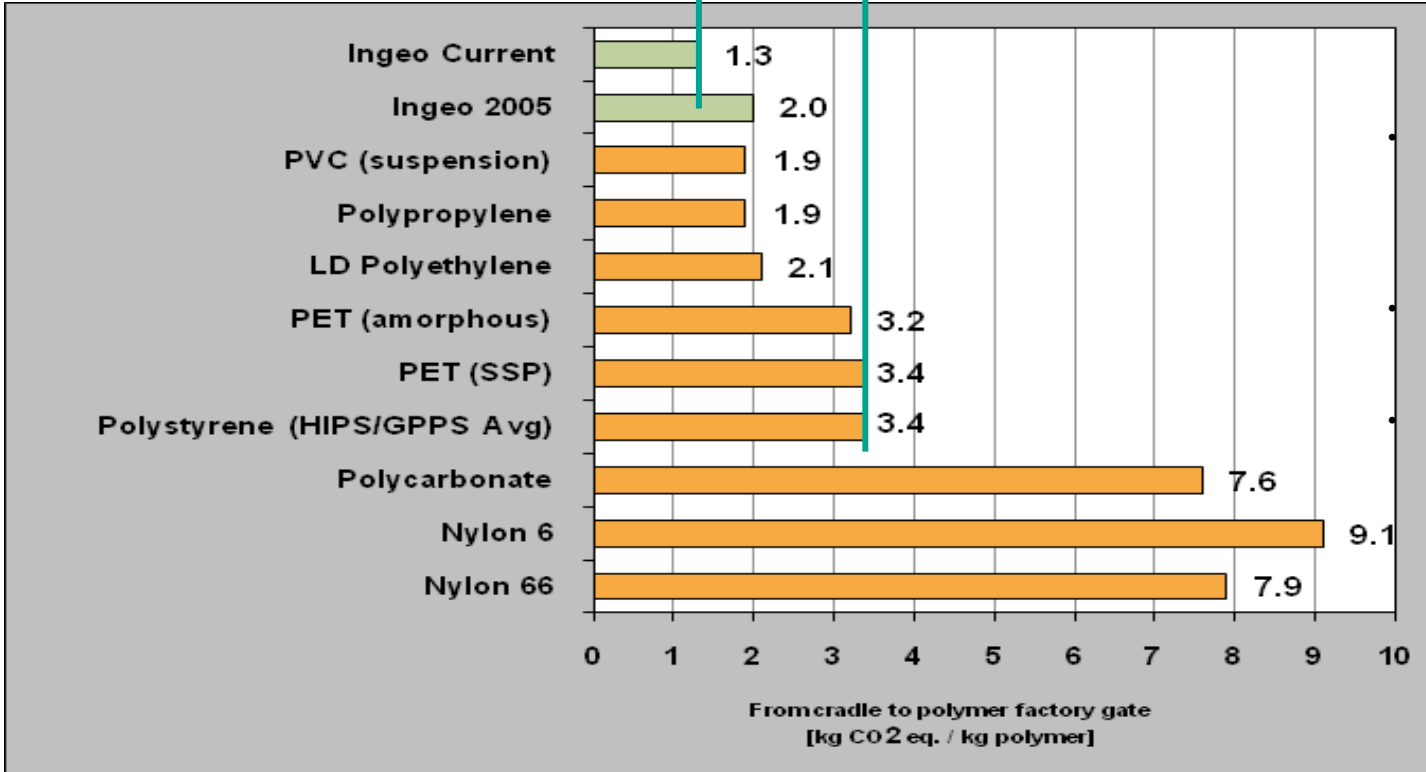
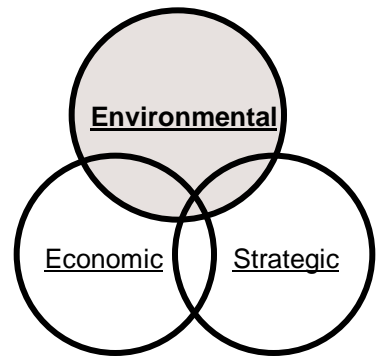


Calculation of the eco-profile means drawing a 'box' around the process from field to factory gate, and rigorously identifying and including anything which crosses the system boundary

Ingeo eco-profile calculation procedure



Greenhouse Gases



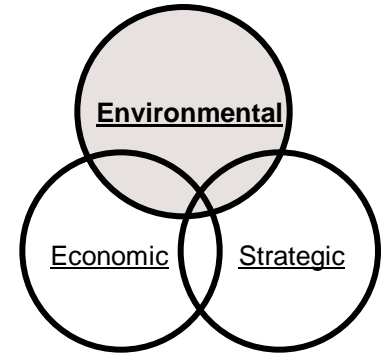
Ingeo: Vink E.T.H. et al. The eco-profile for current Ingeo® polylactide production. Industrial Biotechnology, Volume 6, Number 4, 2010, Page 212-224.

Fossil based polymers:
PlasticsEurope;
www.lca.plasticseurope.org

GWP₁₀₀ factors according to IPCC
(CO₂=1, CH₄=23 N₂O=296)

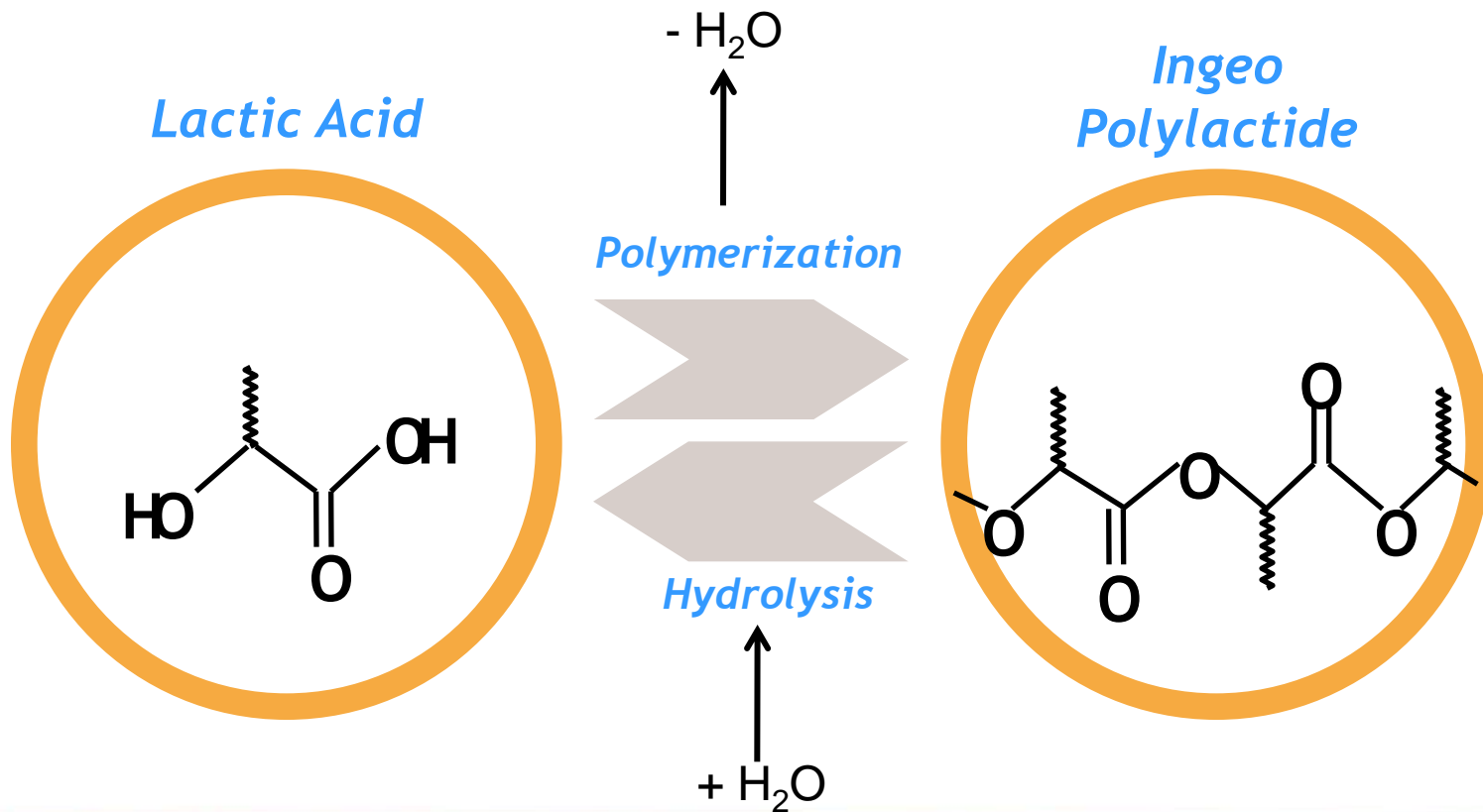
Continuous improvement process
Ingeo 2005 → Ingeo Current → Future Improvement





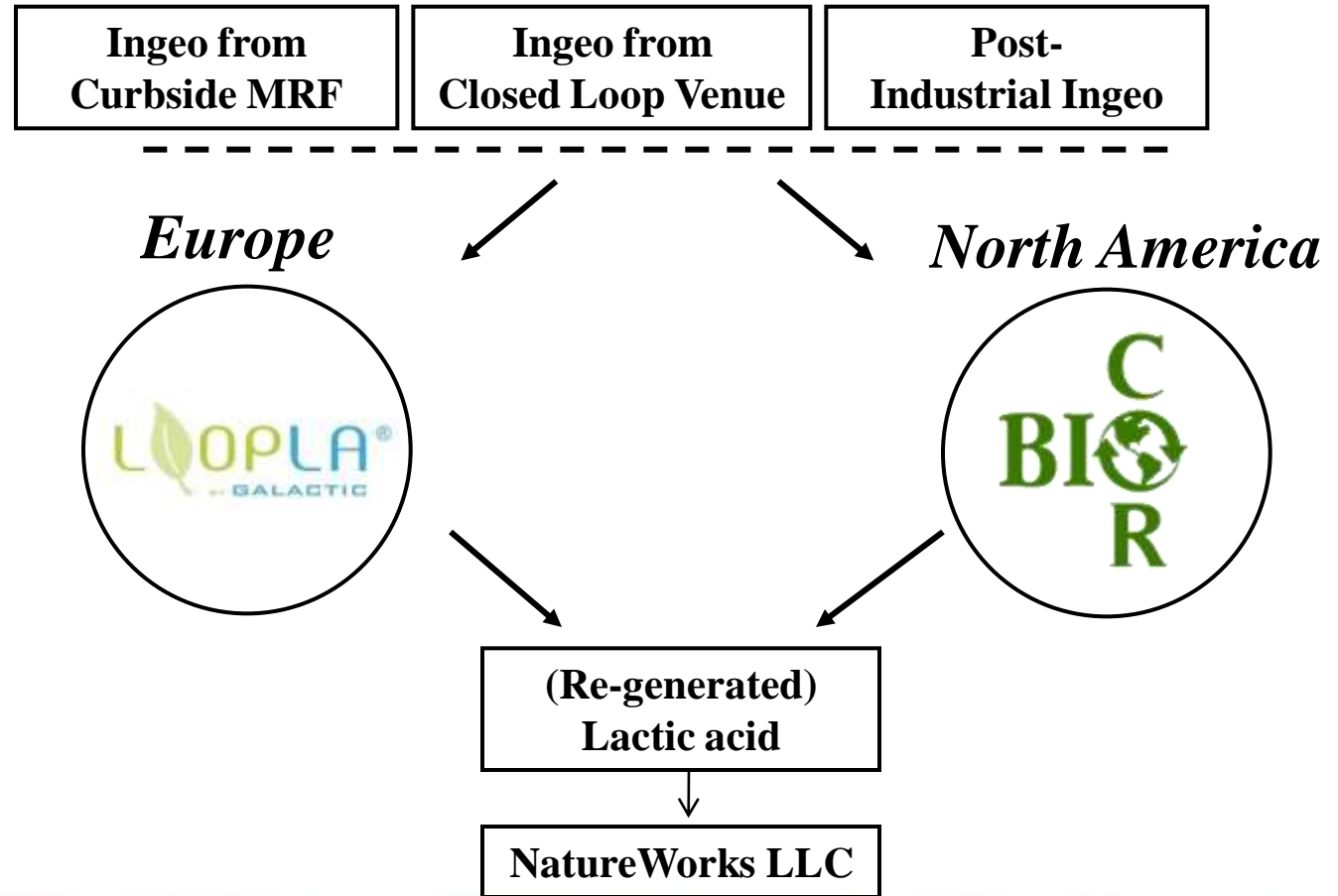
A new paradigm for Cradle-to-Cradle materials recycle . . . “Feedstock Recovery”

Ingeo is a bio-polymer made from lactic acid



A new paradigm for Cradle-to-Cradle materials recycle . . . “Feedstock Recovery”

Used Plastic
as Feedstock



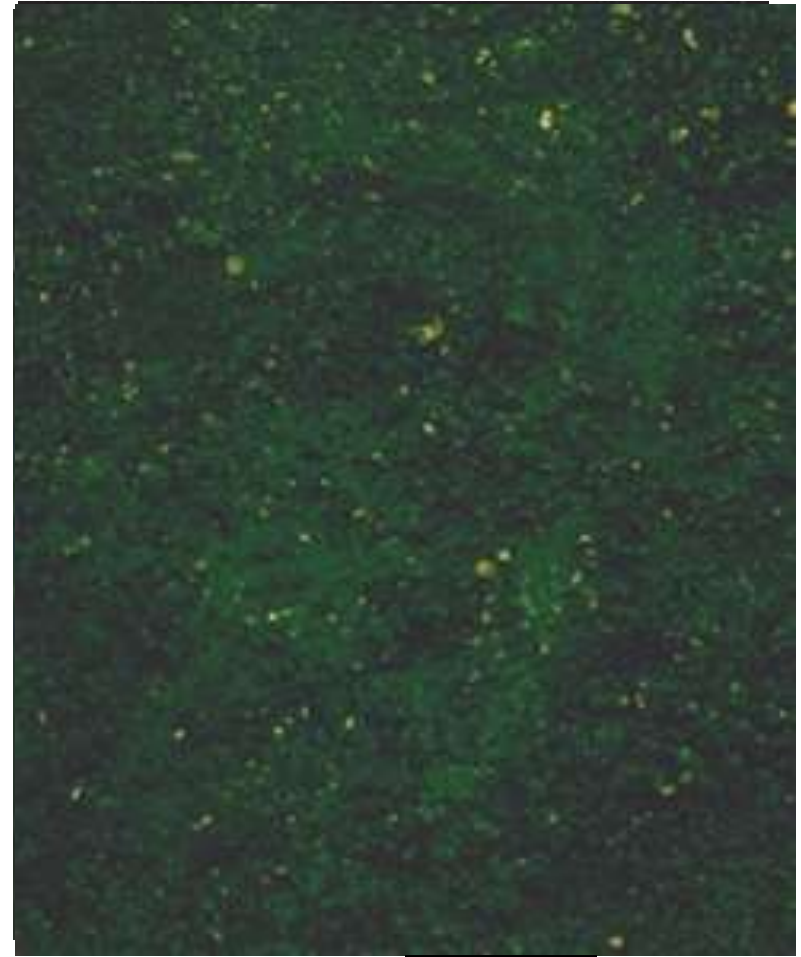
3rd-Party
Processor

End User



Biodegradation

- Specific Conditions requirement allows for products to be designed for normal use
- Requires the specific conditions of high temperature and moisture found in municipal compost systems



Day **47**

Beyond 2010: NatureWorks Looking Forward

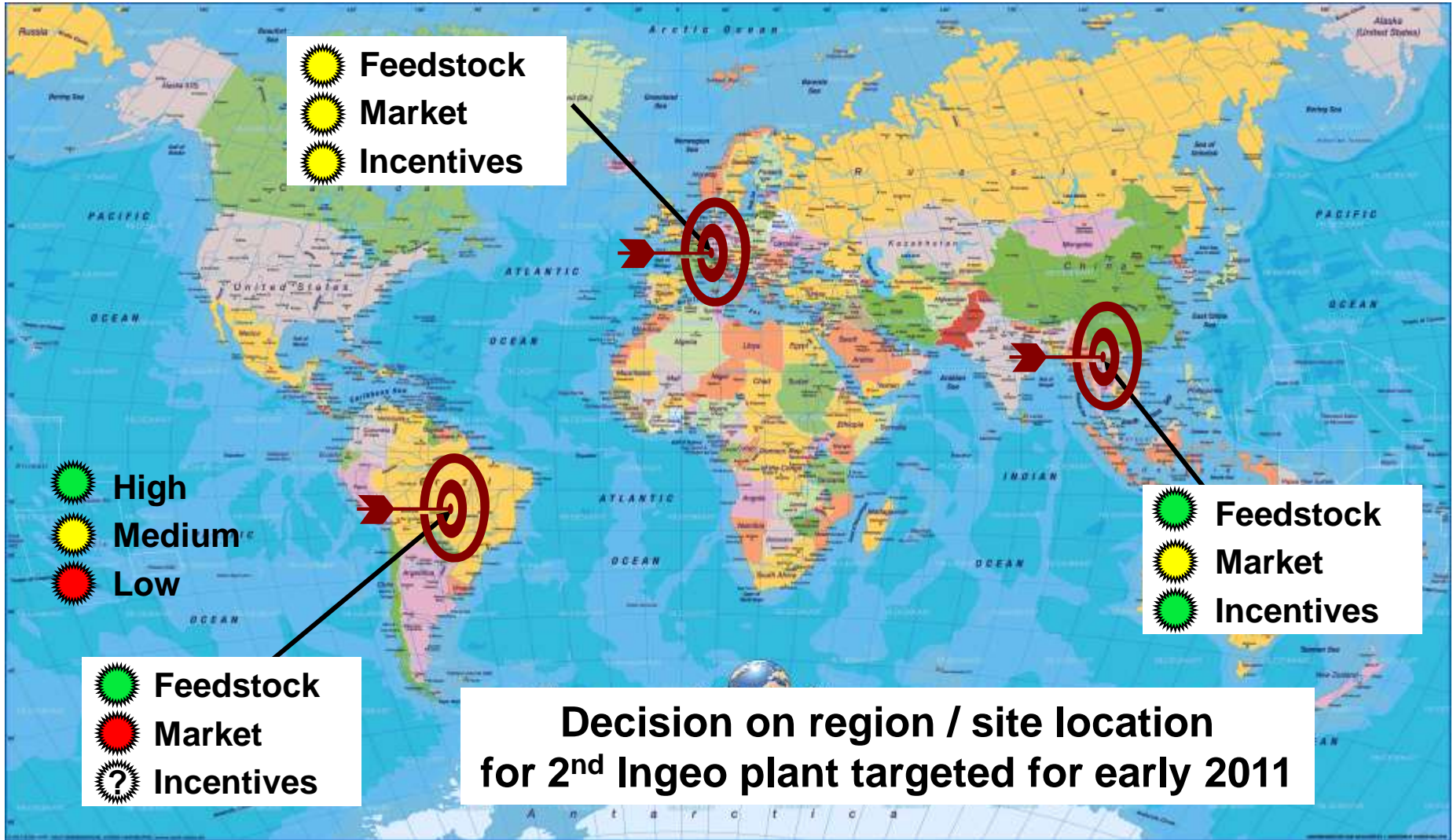


**Globalizing the
Manufacturing Platform**

**Broadening Products
& Applications**

**Cellulosic
Feedstocks**





Broadening Products & Applications

Broadening from ...

Our current platform of competitively-priced polymer grades optimized for use in specific segments ...

NatureWorks

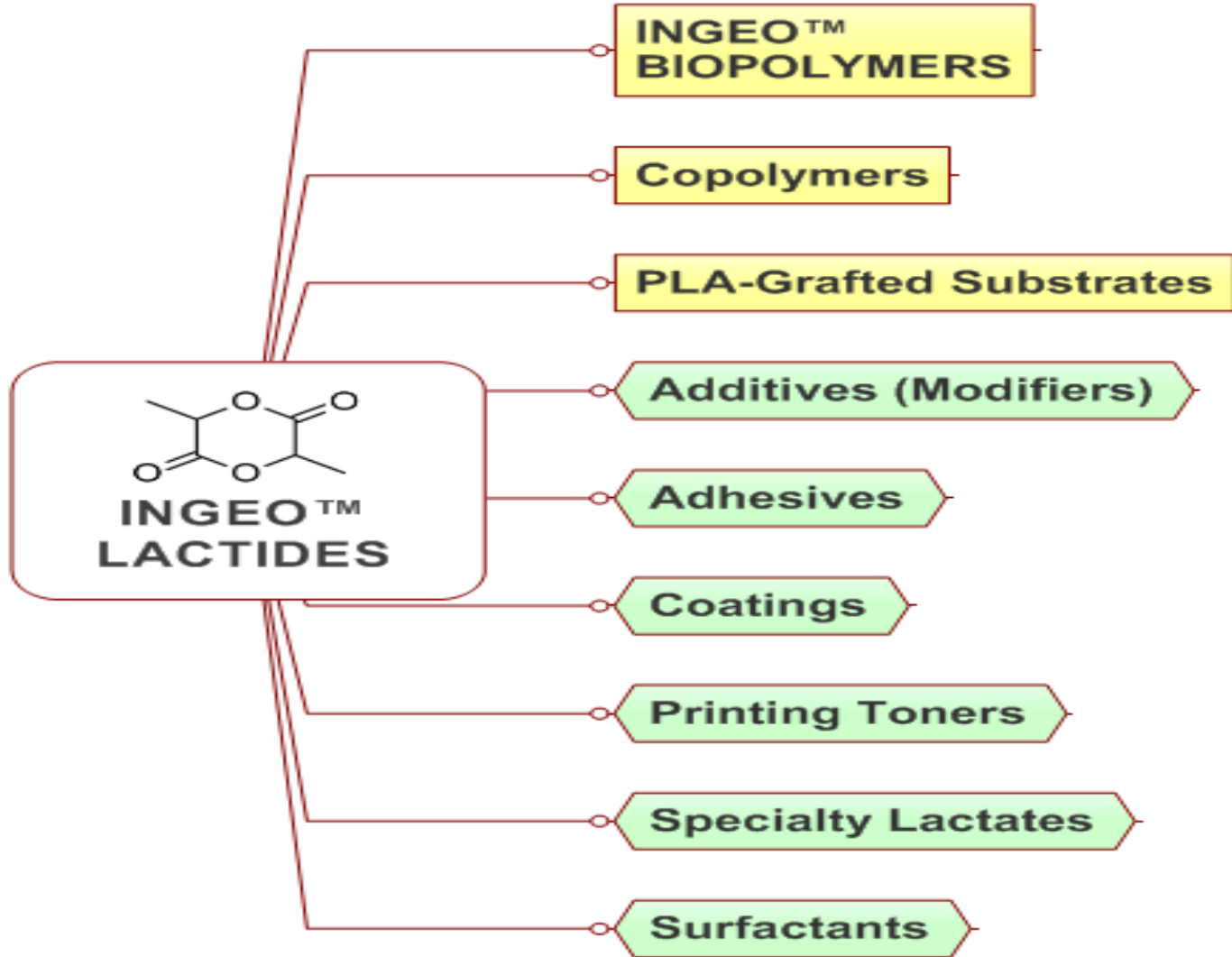
Ingeo Poly lactides

Ingeo Lactides

- 8000 Series - foam
- 7000 Series – ISBM Bottles
- 6000 Series – fibers/nonwovens
- 4000 Series - films
- 3000 Series – Injection Molding
- 2000 Series - Thermoforming

To ...

Offering new resin products / polymer-grade lactides to enable further global growth of the industry



Where we're going ...

Where we are today ...



- Our footprint is small. At full capacity, Ingeo™ represents:
 - < 0.2 % of 2007 US corn production (< 0.05 % of global corn production)
- Ingeo is feedstock agnostic. 2nd plant will use most abundant local industrial sugar or starch source.
- 2nd-generation technology is becoming an industrial reality ...





Thank You

NatureWorks LLC
Ingeo Biopolymer Plant