Food, Feed, Fiber & Fuel (Plastics-Chemicals)
“New” Missions for Agriculture
Anticipated by Carver and Ford (ca 1942)

Lonnie O. Ingram, Univ. of Florida

George Washington Carver and Henry Ford Shared a Bio-fuel Vision

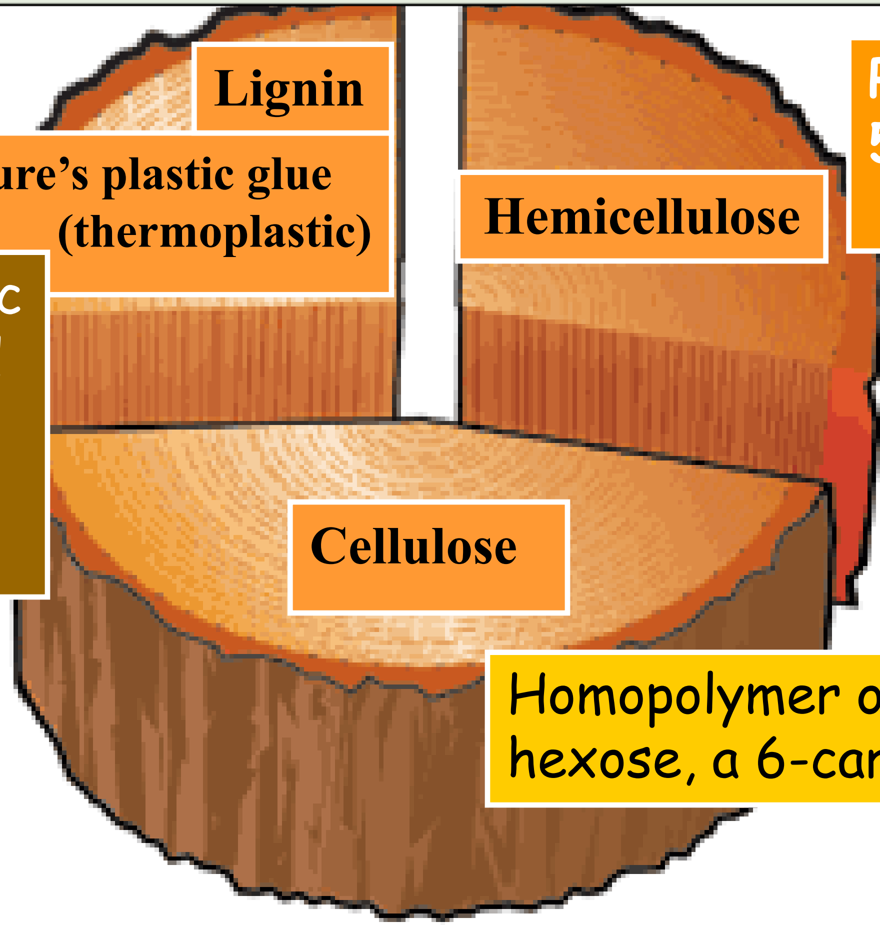
Food
Feed
Fiber
&
Fuel
&
Plastics

George Washington Carver and Henry Ford shared a vision of a future in which agricultural products would be put to new uses: fuels, plastics, solvents, paints.

In 1942, Ford showcased a car with a “plastic body” made from soybeans,
Tubular frame, 30 less weight steel, more flexible and durable.
Designed to run on ethanol instead of gasoline.

This novel idea failed to catch on.

Woody Biomass ~60-70% Carbohydrate (structure)***
Corn ~70% starch (stored energy, C6 glucose)
Sugarcane, energy beets, sweet sorghum - (chemicals)



Primarily pentoses, 5-carbon sugars also 6-C sugars

Black thermoplastic that can be burned to provide energy for ethanol production.

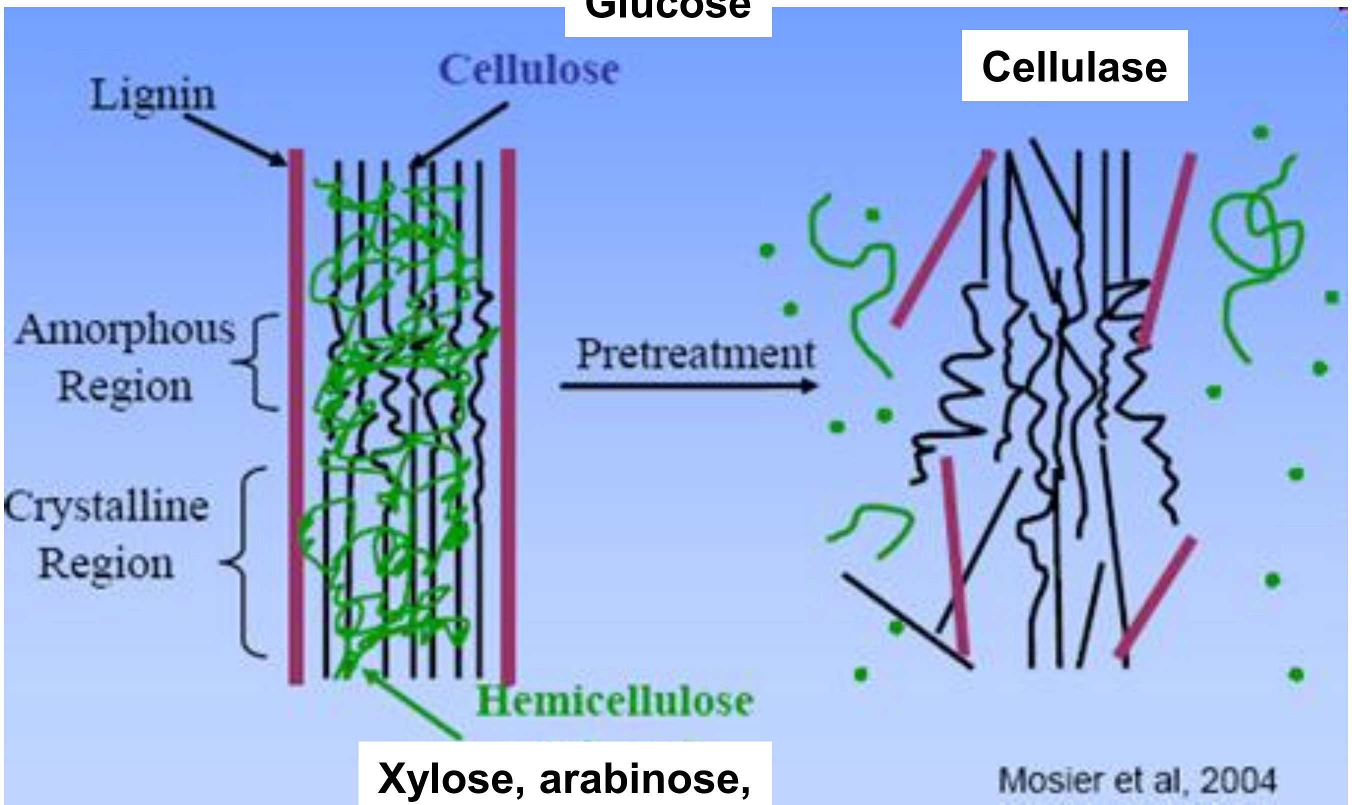
Homopolymer of glucose, hexose, a 6-carbon sugar.

Composition of Lignocellulosic Biomass

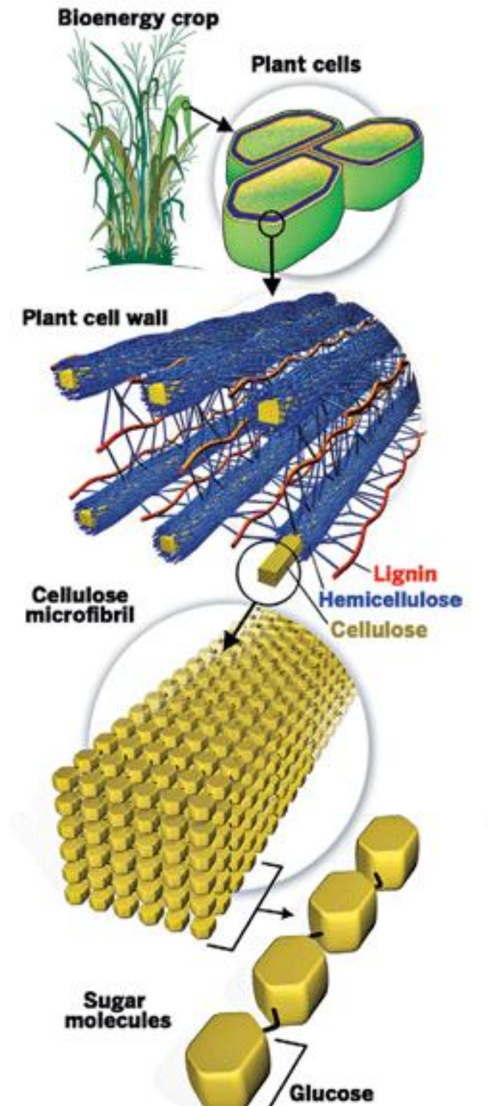
Acid or Base pretreatment is essential for deconstruction of lignocellose.

Glucose

Cellulase



Xylose, arabinose, gal, man, rham

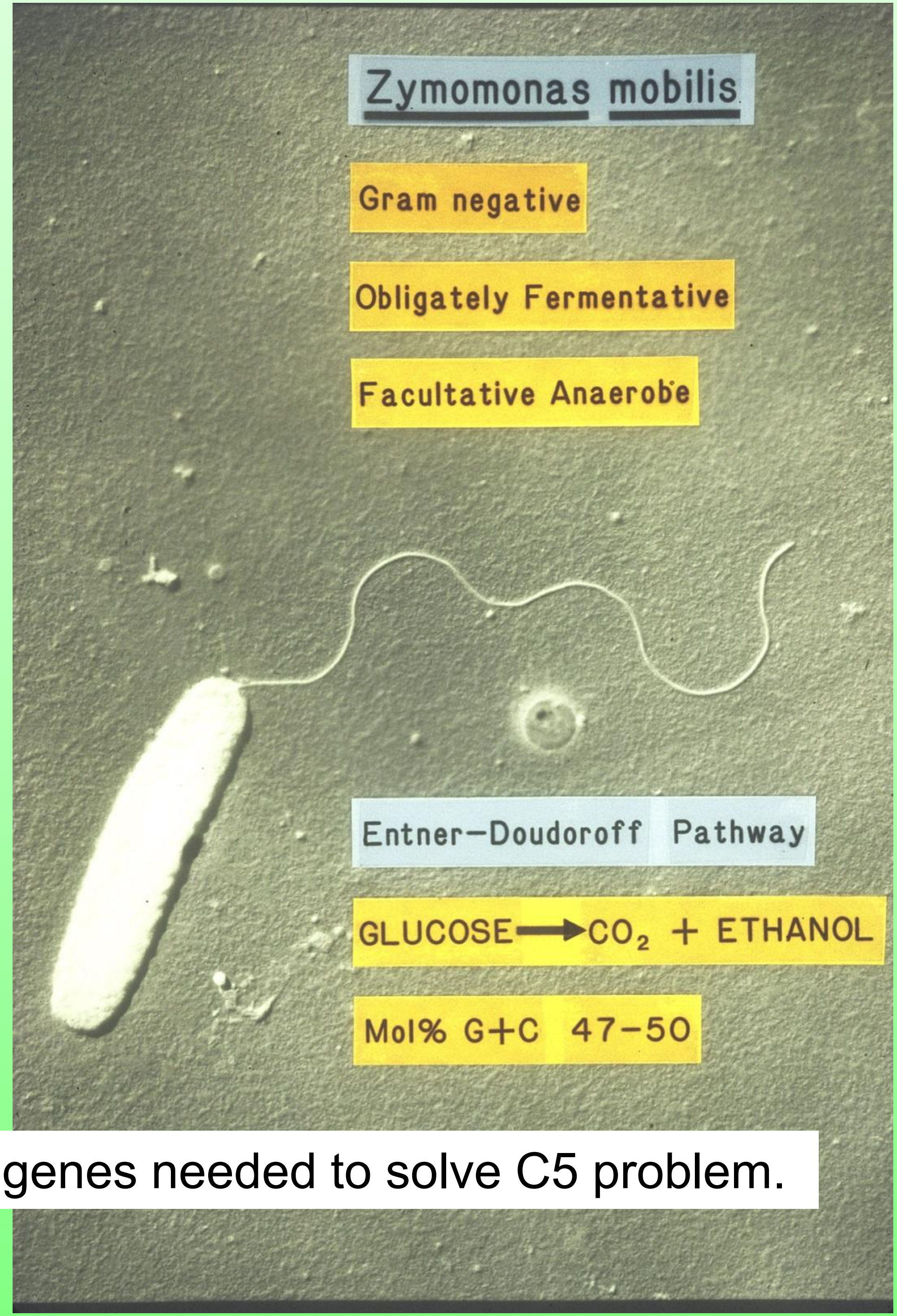


1. Dilute acid pretreatment → syrup of hemicellulose sugars C5 sugars
2. Enzymes to convert cellulose → glucose syrup C6 glucose
3. Biocatalyst that ferments C5 and C6

Tequilla

Made by fermentation with
Z. mobilis (and yeasts)
Glucose only

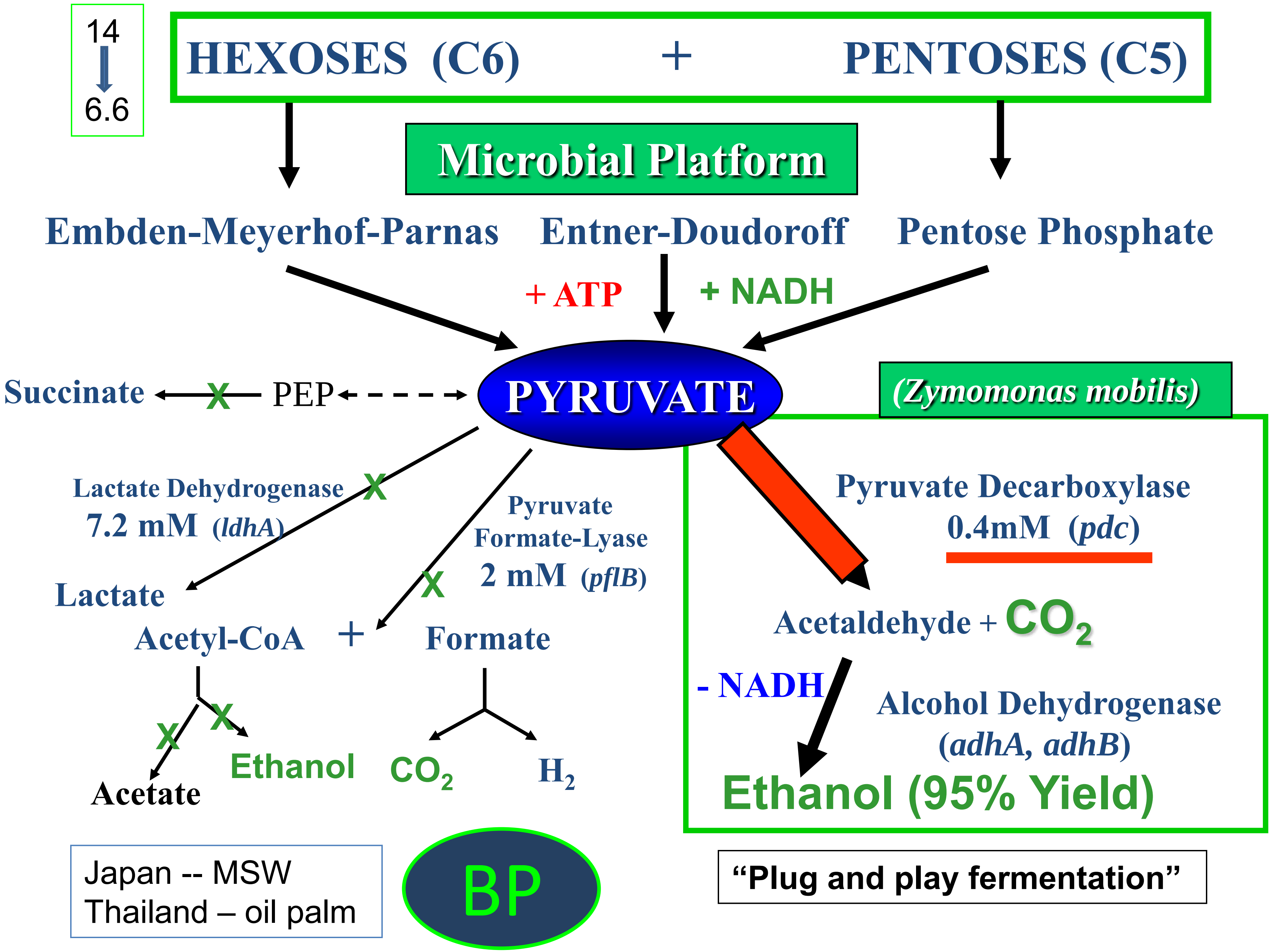
Excellent ethanol production



E. coli -- Ferments all sugar constituents in woody biomass

Mixture of fermentation products

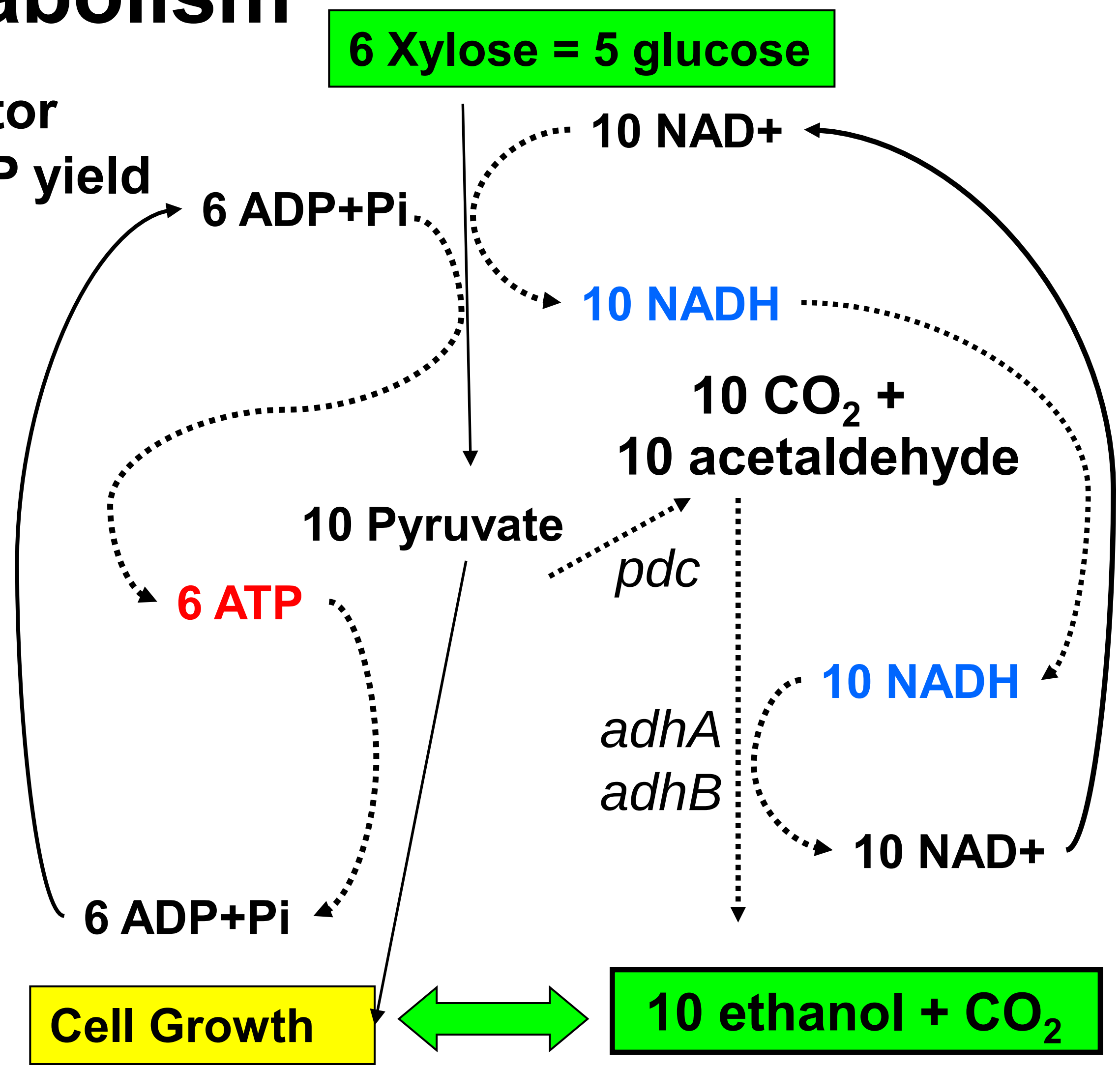
E. coli and *Z. mobilis* contain all genes needed to solve C5 problem.


14
6.6
HEXOSES (C6)
+
PENTOSES (C5)
Microbial Platform
Embden-Meyerhof-Parnas
Entner-Doudoroff
Pentose Phosphate
+ ATP
+ NADH
PYRUVATE
Succinate
X
PEP
(Zymomonas mobilis)
Lactate Dehydrogenase
7.2 mM (ldhA)
X
Pyruvate
Formate-Lyase
2 mM (pflB)
X
Lactate
Acetyl-CoA
+
Formate
X
X
Ethanol
Acetate
CO_2
H_2
Pyruvate Decarboxylase
0.4mM (pdc)
Acetaldehyde + CO_2
- NADH
Alcohol Dehydrogenase
(adhA, adhB)
Ethanol (95% Yield)
Japan -- MSW
Thailand – oil palm
BP
“Plug and play fermentation”

Fermentative Metabolism

No external electron acceptor
Low cell mass ←→ Low ATP yield
High Product Yield

Selecting for faster growth and higher cell densities co-selects for higher productivity and titer (and resistance)

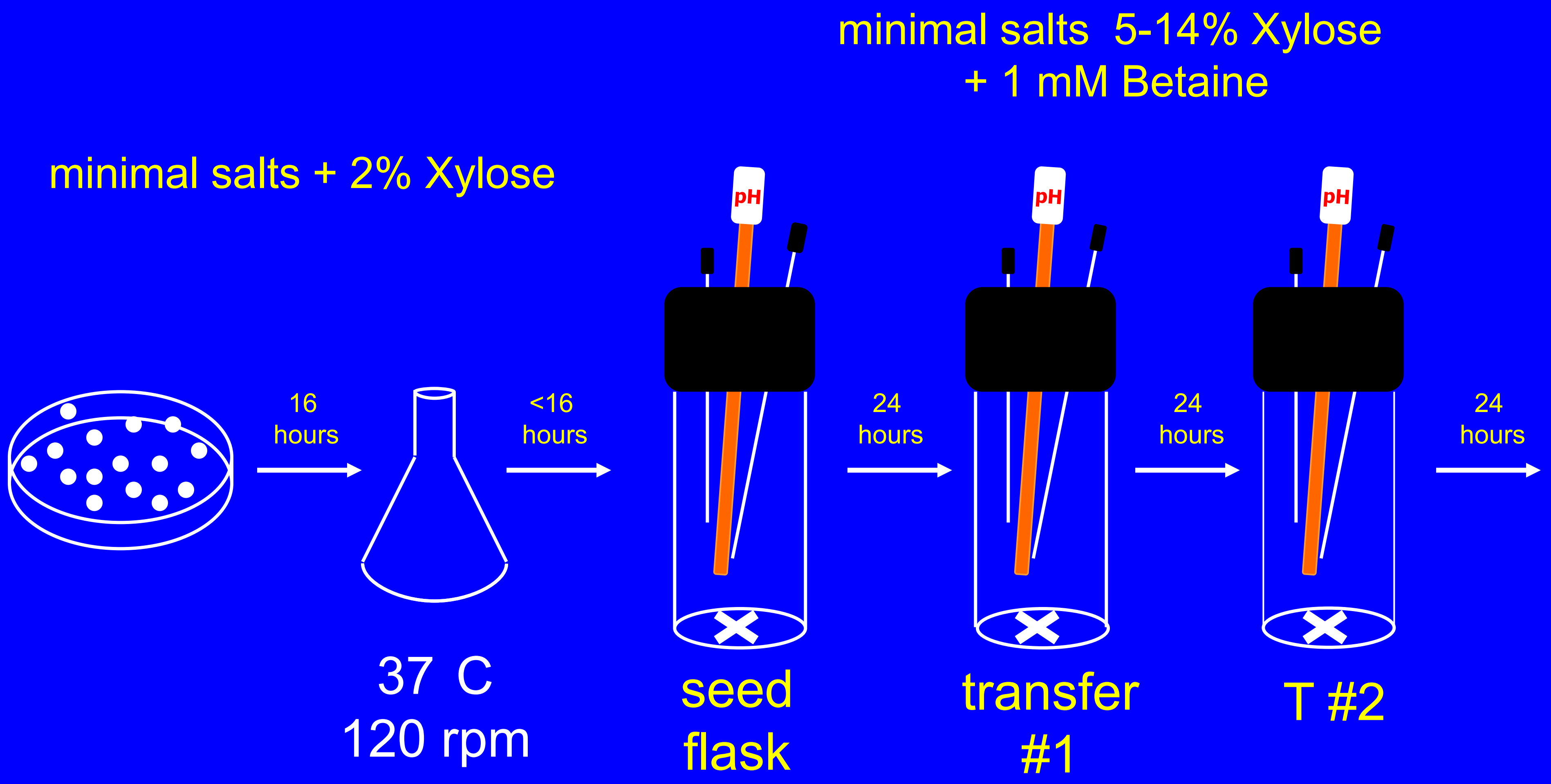


Japan -- MSW
Thailand – oil palm

5% Carbon cell mass
~1 ATP/xylose

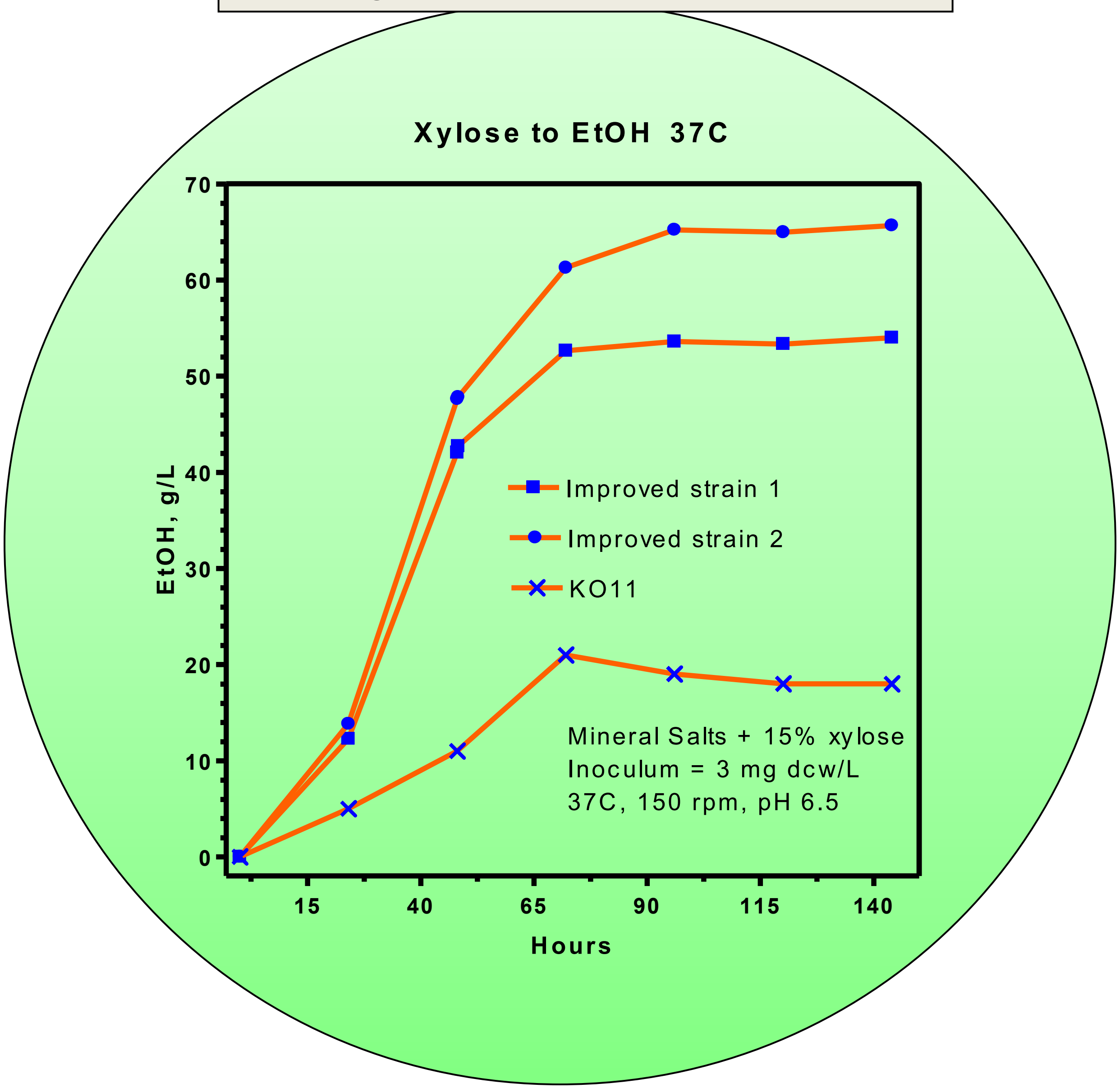
95% Carbon product

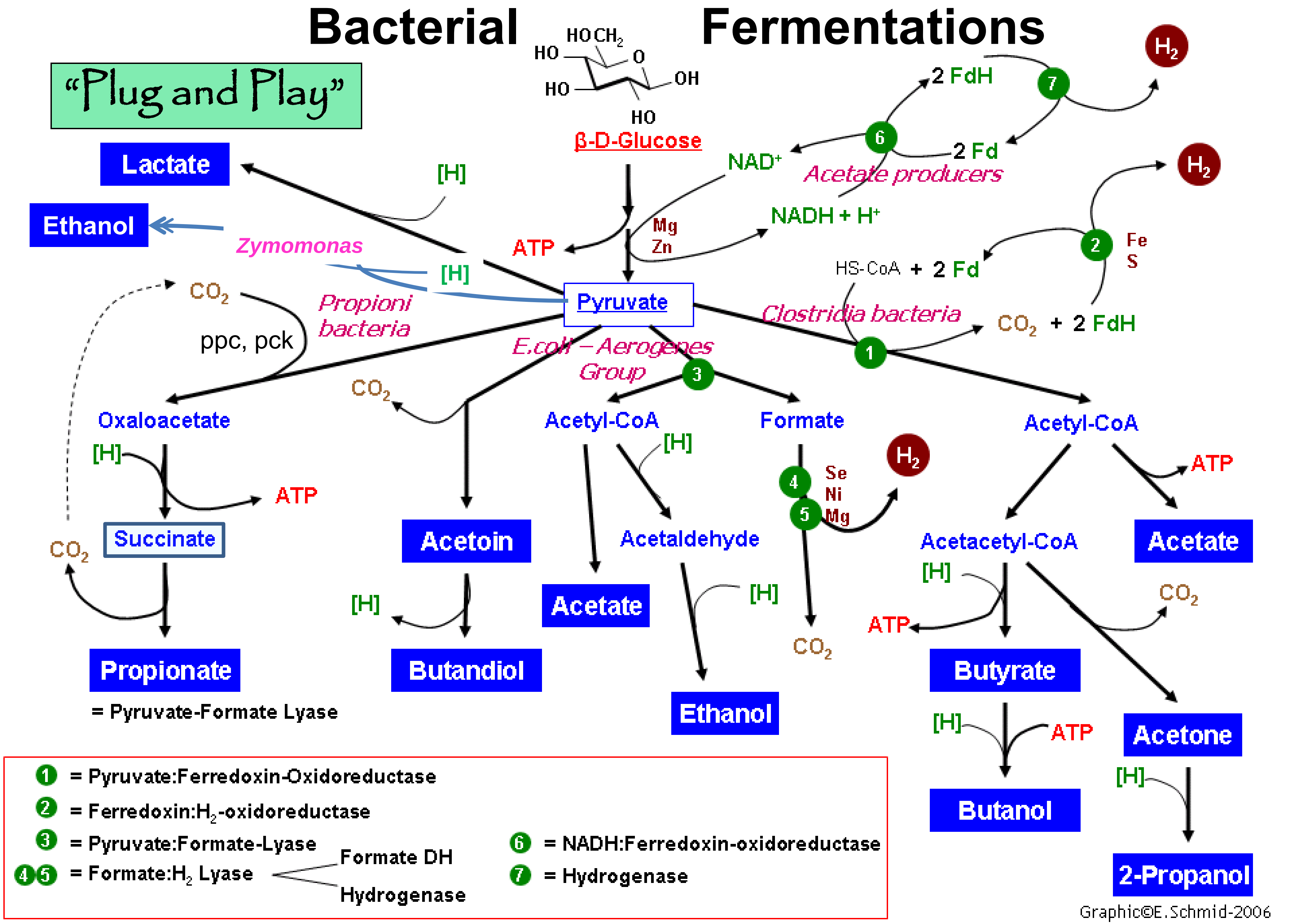
Metabolic Evolution



37 C, pH 6.5, 150 rpm
Inocula: 1:100 to 1:350 dilutions

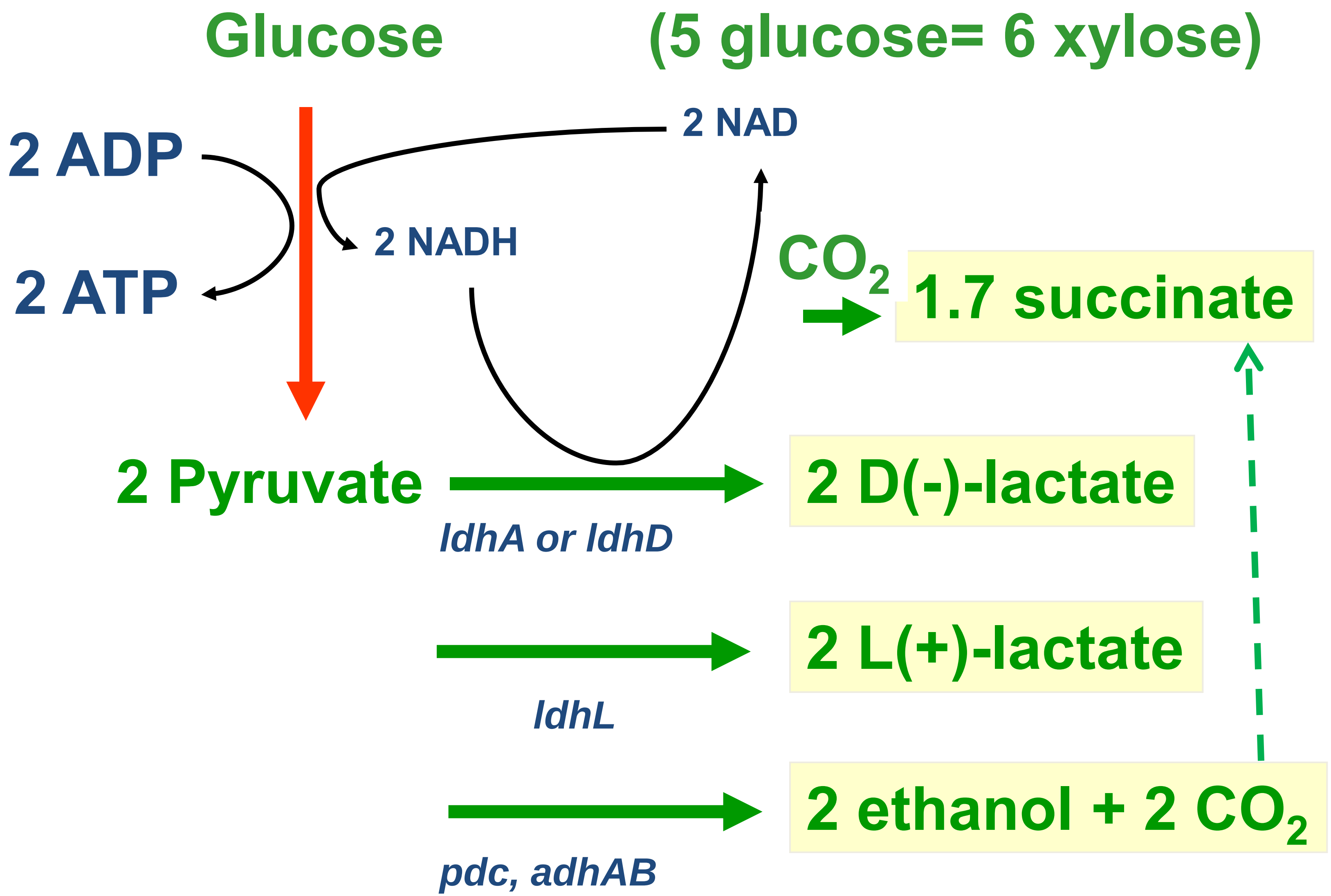
Lab sugar and mineral salts medium





Bacterial Fermentations
"Plug and Play"
HOCH2
HO
O
OH
HO
HO
ß-D-Glucose
Lactate
Ethanol
Zymomonas
[H]
ATP
Mg
Zn
NAD+
NADH + H+
2 FdH
2 Fd
Acetate producers
H2
Fe
S
HS-CoA + 2 Fd
Clostridia bacteria
CO2 + 2 FdH
Pyruvate
CO2
Propioni bacteria
ppc, pck
E.coli – Aerogenes Group
Oxaloacetate
Acetyl-CoA
Formate
Acetyl-CoA
Se
Ni
Mg
Succinate
Acetoin
Acetaldehyde
Acetacetyl-CoA
Acetate
Acetate
Propionate
Butandiol
Ethanol
Butyrate
Acetone
Butanol
2-Propanol
= Pyruvate-Formate Lyase
1 = Pyruvate:Ferredoxin-Oxidoreductase
2 = Ferredoxin:H2-oxidoreductase
3 = Pyruvate:Formate-Lyase
4 5 = Formate:H2 Lyase
Formate DH
Hydrogenase
6 = NADH:Ferredoxin-oxidoreductase
7 = Hydrogenase
Graphic©E.Schmid-2006

UF Engineered Bacteria *for Plastics and Fuel*



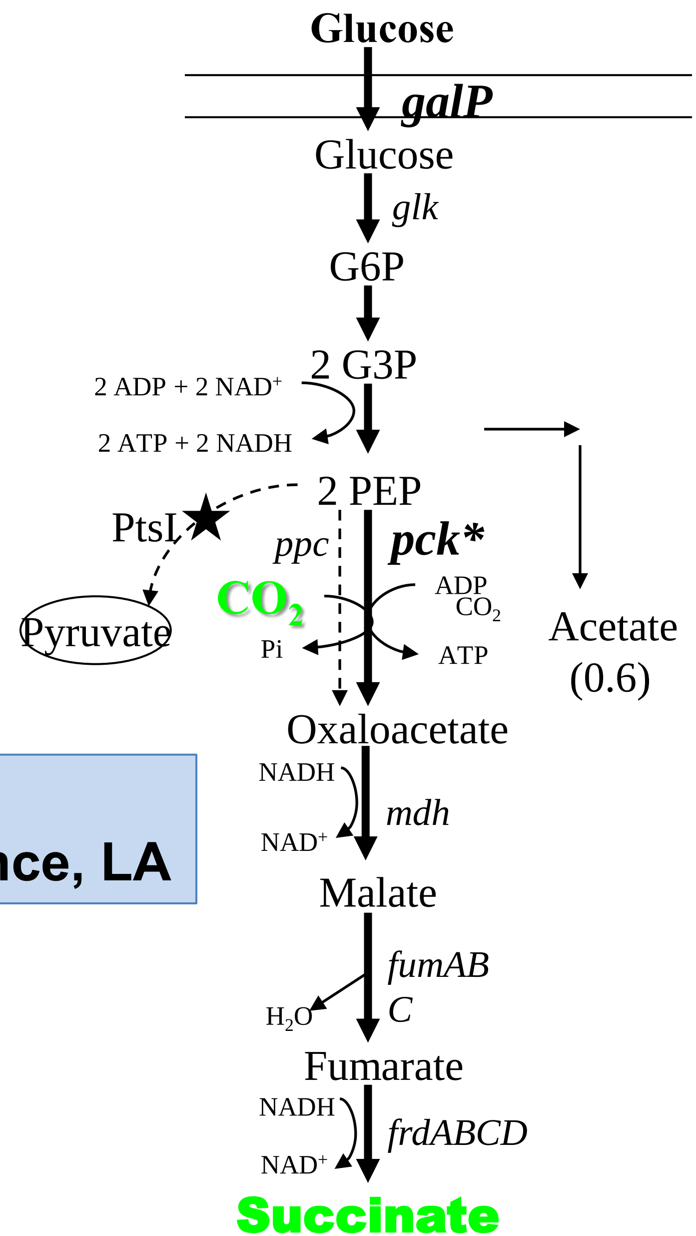
Osaka Japan (also Thailand)

Mishwa and LOI

Marubeni Ethanol

Purac D-Lactic Acid
Ricardo and LOI

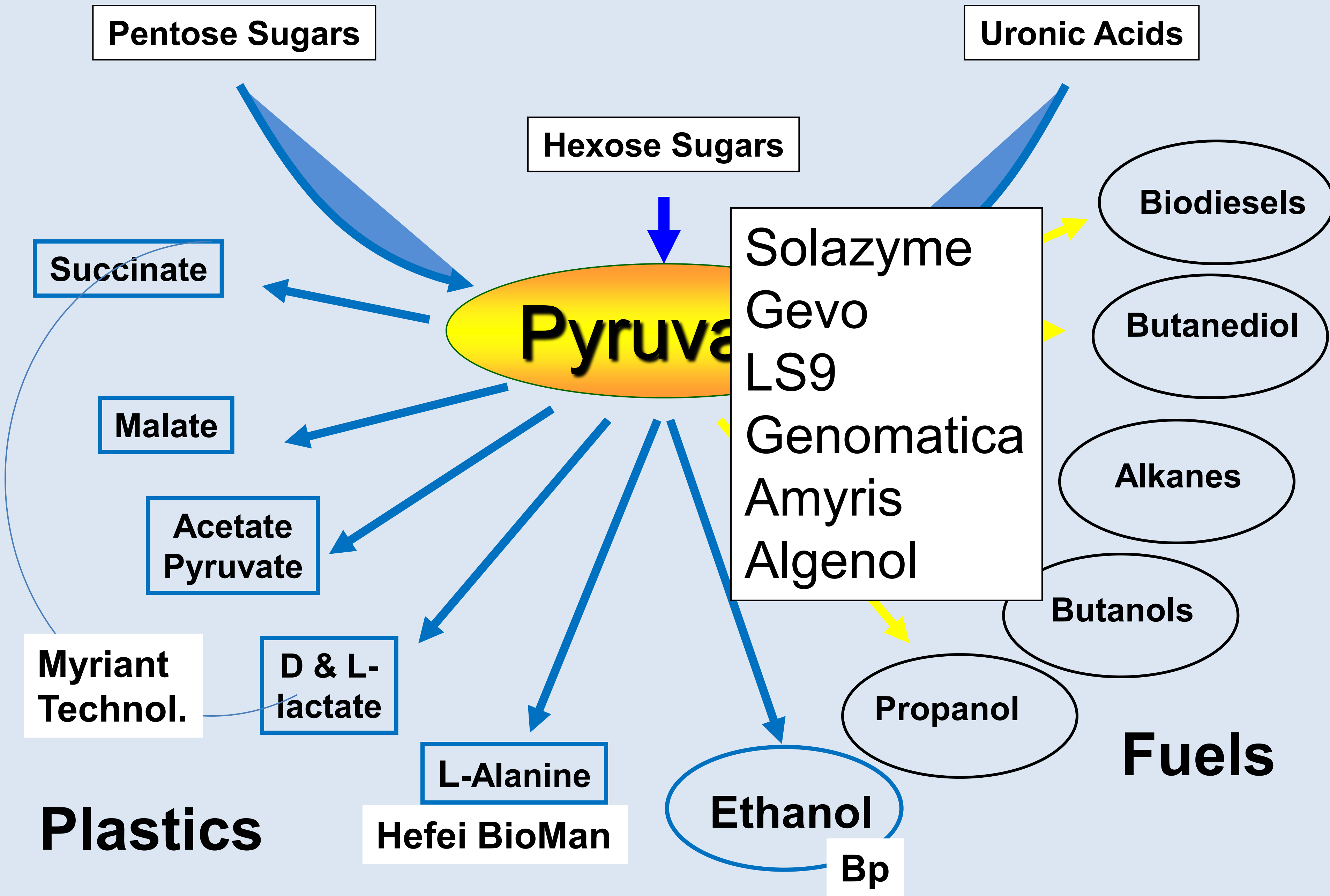
1 lb sugar → 1.17 lb succinate



30 mil lb/yr
Lake Providence, LA

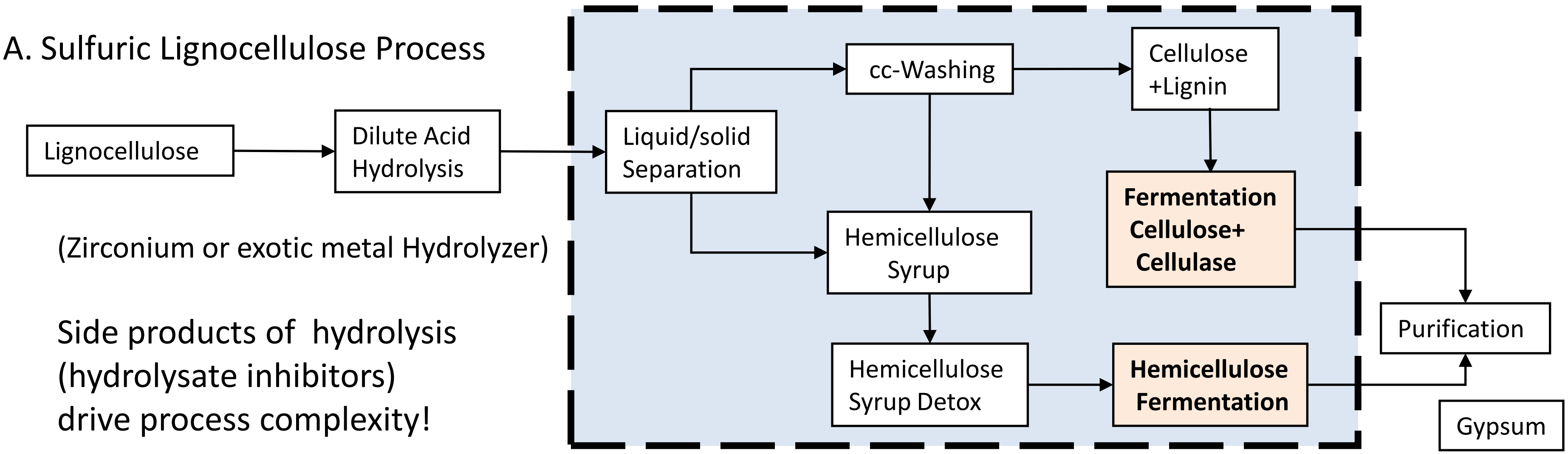
Licensed from Univ. Florida

Renewable Fuel and Chemicals

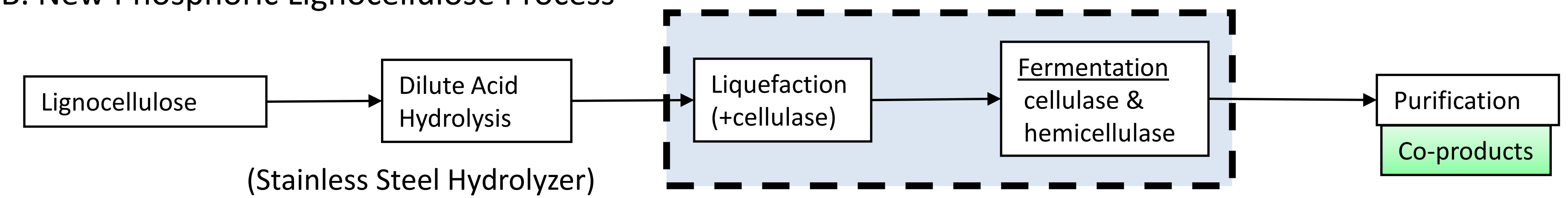


Non-food Sugars for Bioproducts

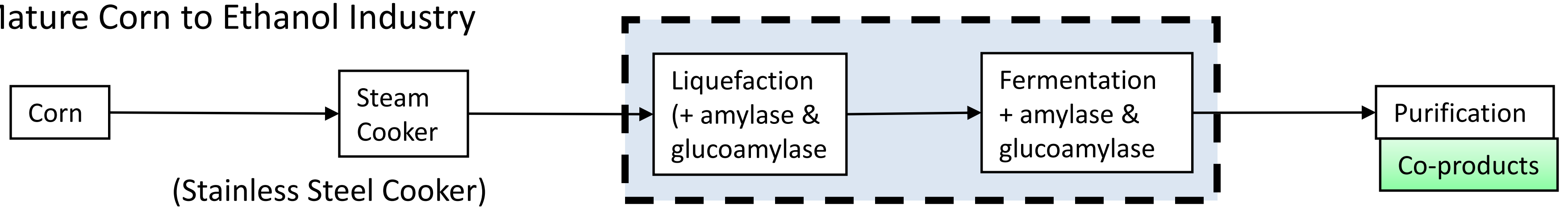
A. Sulfuric Lignocellulose Process



B. New Phosphoric Lignocellulose Process



C. Mature Corn to Ethanol Industry



Phase I: State Board of Regents -Legislature/DOE EERE
Campus Biofuels Lab - Unit Ops (50 lb batches)

Dr. Guido Zacchi, Lund Univ.

Research Advances Required for Process Simplification:

1. Developed biocatalysts with improved resistance to hemi toxins.

2. Replaced Sulfuric with less aggressive acid – Phosphoric

    Gypsum piles replaced with crop fertilizer

    Eliminate Zirconium

    Lower the level of inhibitors

3. Solved mixing and pumping issues with high fiber solids   10-20% dw

    (Liquefaction tank; 6 h residence) Velcro → flowable "marbles"

4. Developed process using only fertilizer chemicals

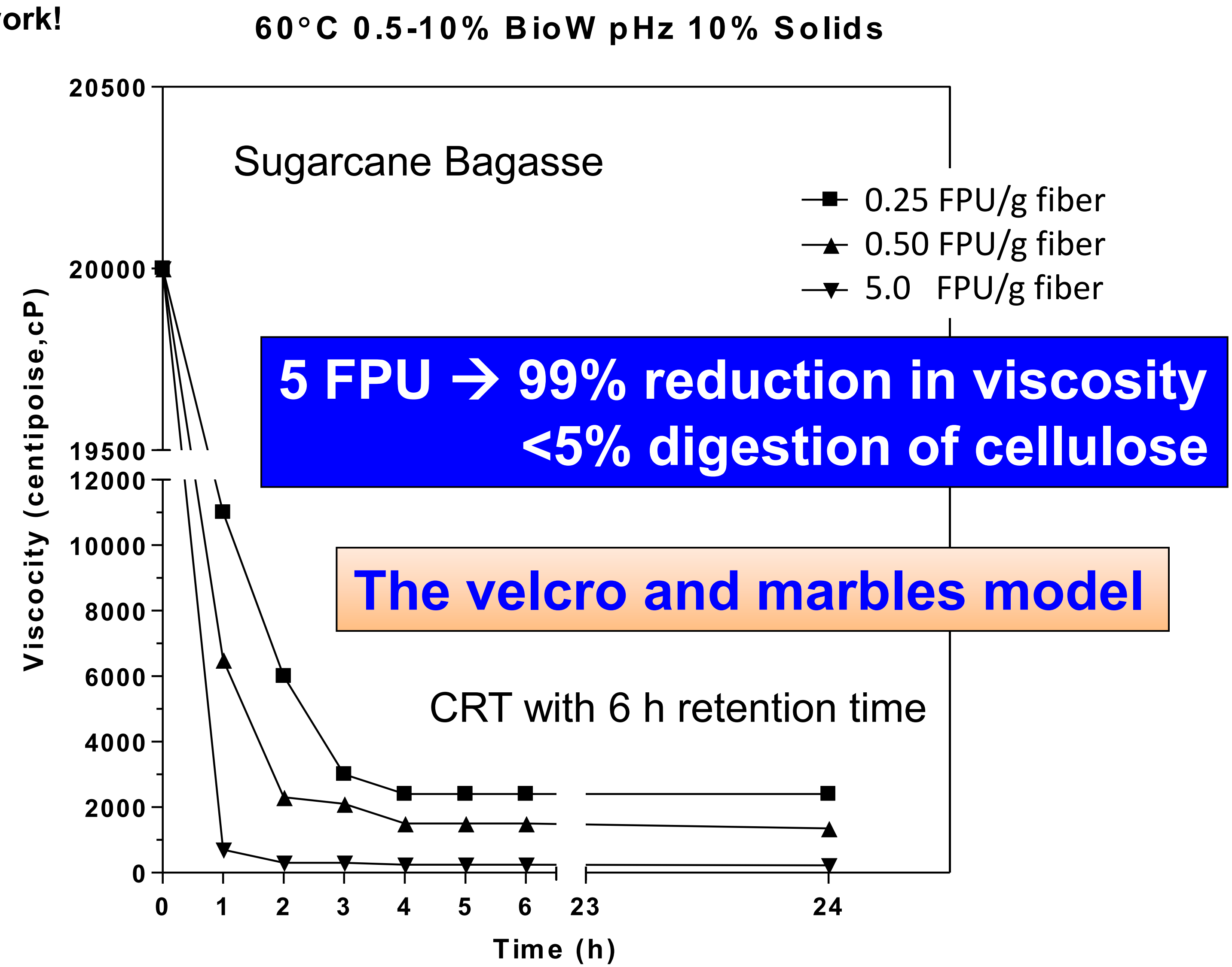
    (N,P,K,Mg,S,trace metals)   Coproduct → New crops

→ Eliminated fiber separation, detox, separate fermentations, & identified value for all process materials.

Mixing & Pumping: Liquefaction with Cellulases

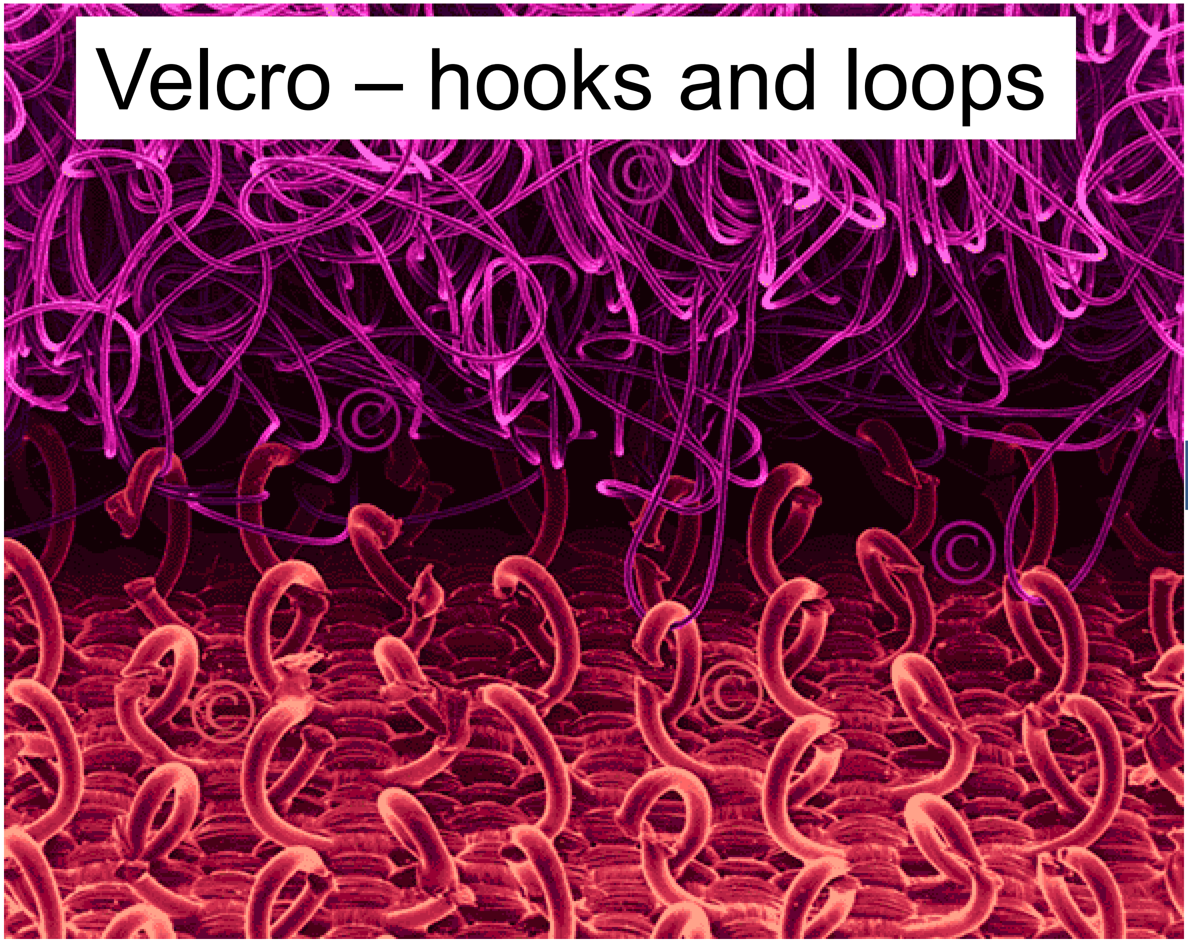
Pumps that did not work!

Rotary lobe
Gear
Diaphragm
Progressive cavity
Centrifugal
Peristaltic



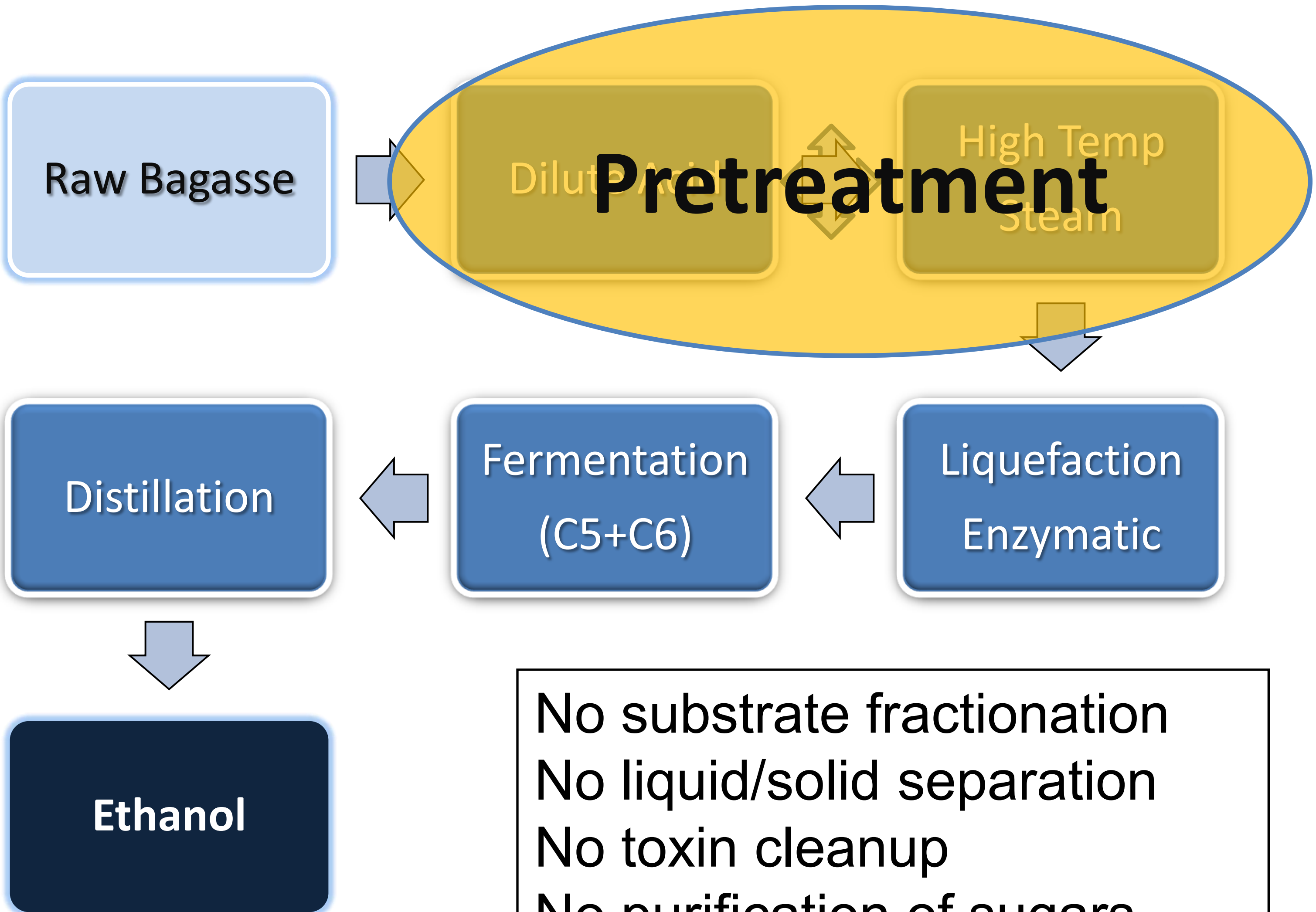
Claudia

Model →CSTR – 6 hr residence



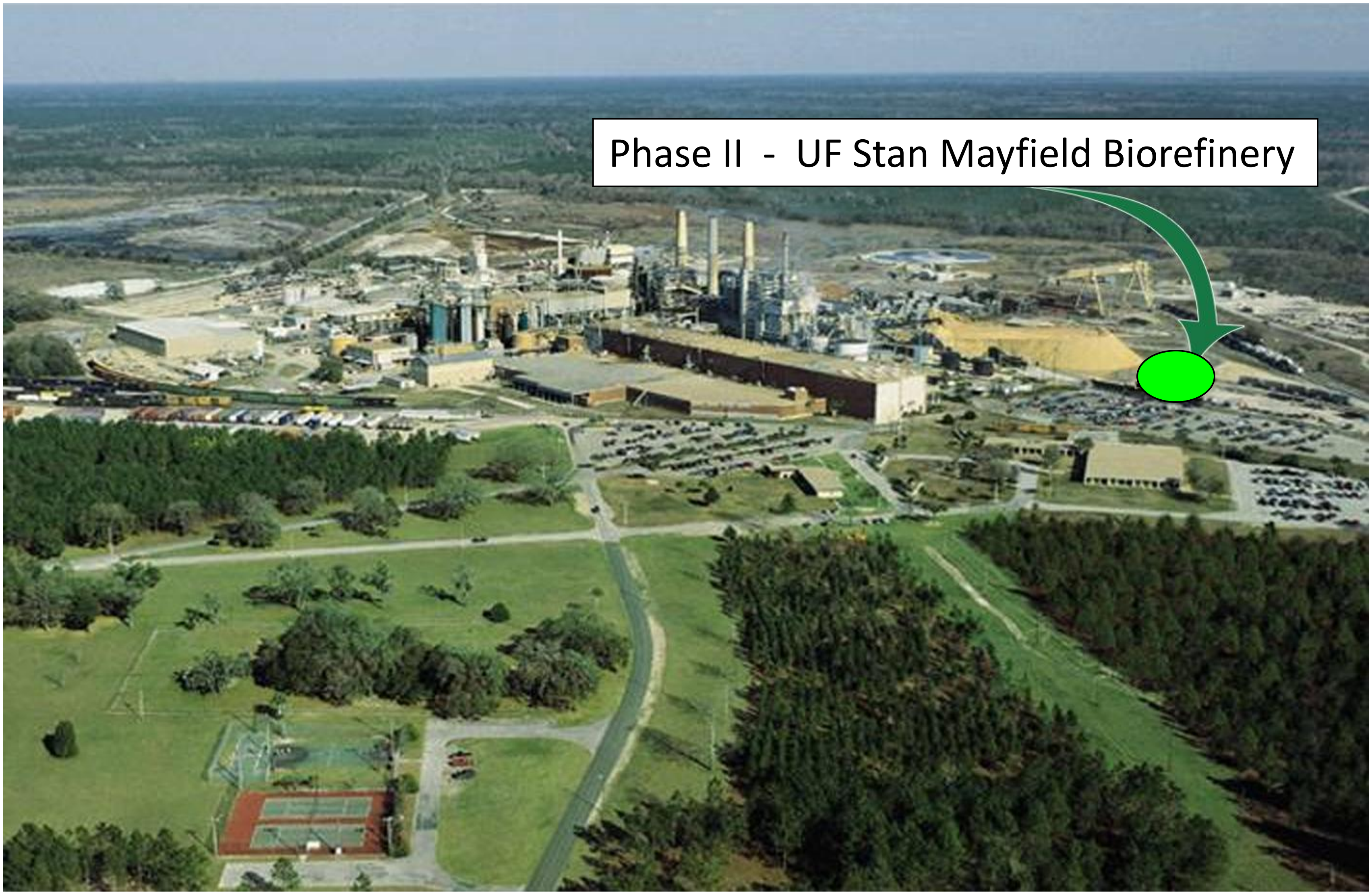
After liquefaction
(cellulase)

http://www.architerials.com/



No substrate fractionation
No liquid/solid separation
No toxin cleanup
No purification of sugars
No Zirconium or exotic metal

Buckeye Technologies, Perry, Florida (dissolving pulp)



Stan Mayfield Biorefinery Pilot Plant

with Buckeye Technologies, Perry FL

Size: 3 tons of cellulosic biomass/day for Bagasse; ~ 5 tons/day for Wood

Woody Residues

Woody Crops and Trees

BKI materials

Sweet Sorghum and Related sugar crops

Sorg

Partial Sa

Her

Fuel Ethanol

CO_2

arbon equestration

Lignin Fertilizer Co-products

ducts

Organic acids, Plastics

Seed Plant for Commercial Development

Capacity (lignocellulose)

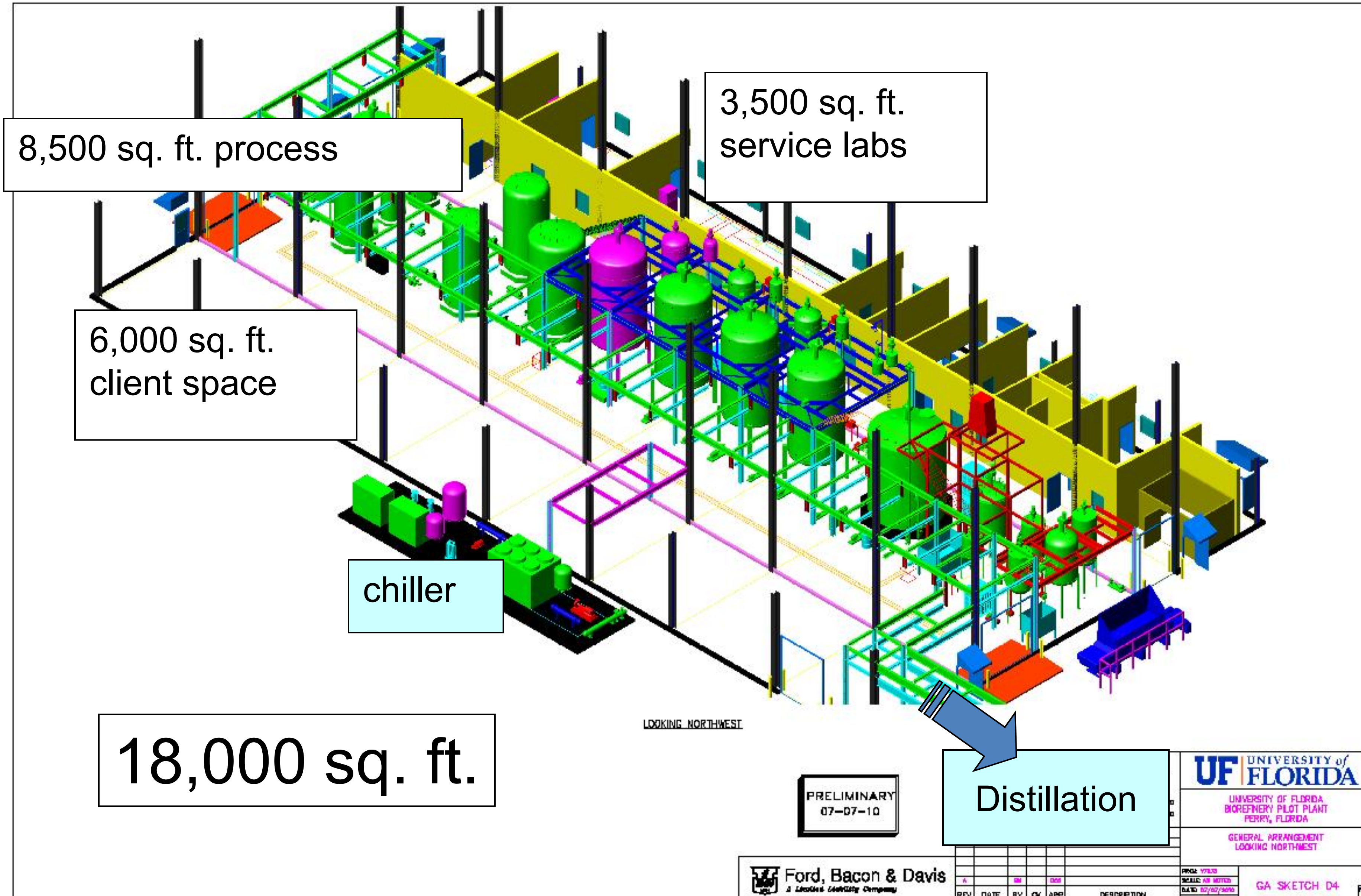
Up to 100,000 gal Et / yr or up to 1.0 mil lb lactic / yr

Up to 400 gal ethanol/day or 5,000 lb of organic acids

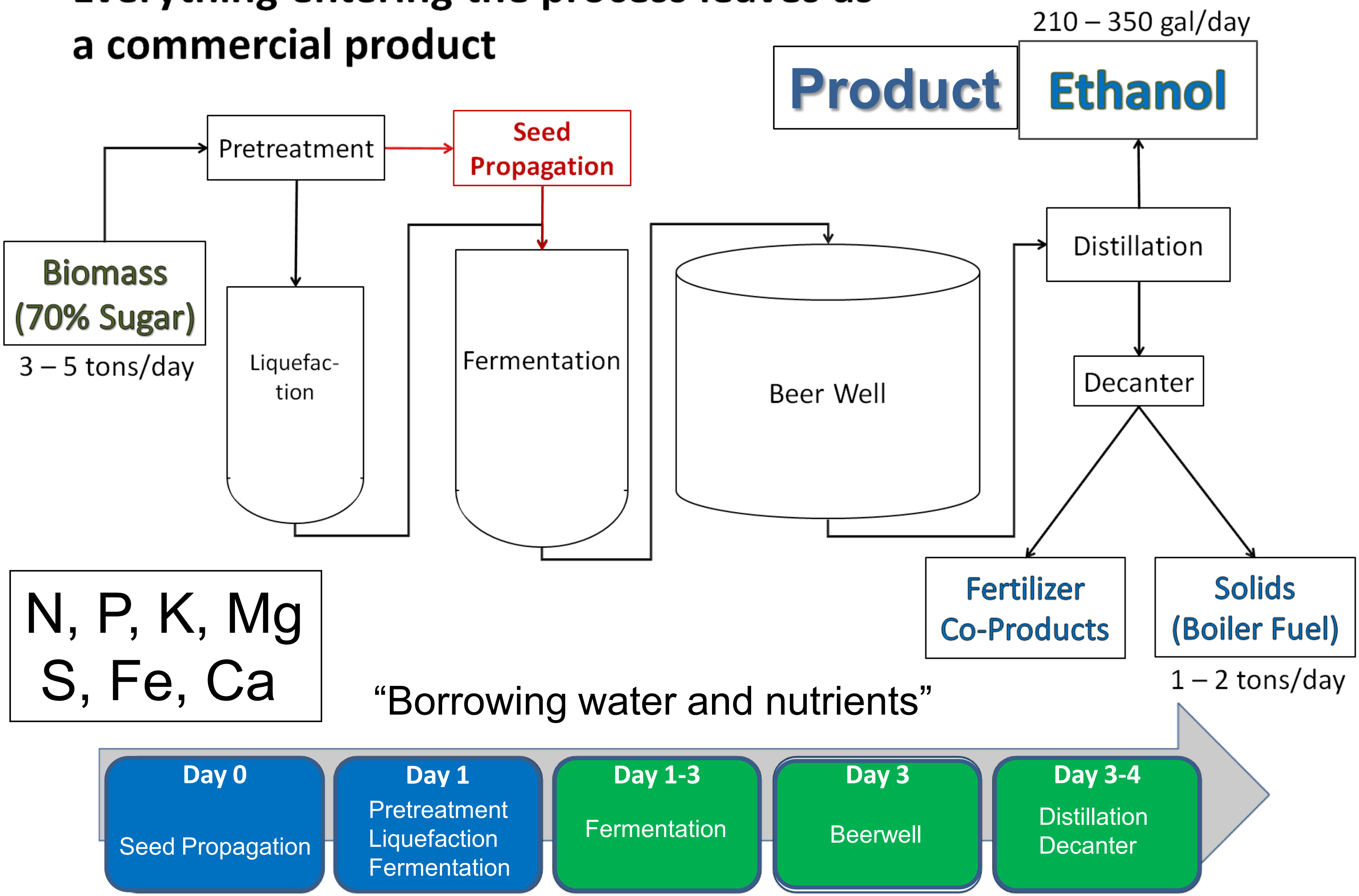
Process borrows water and nutrients that are used to grow new energy crops.

UF UNIVERSITY of FLORIDA IFAS

U F Stan Mayfield Biorefinery



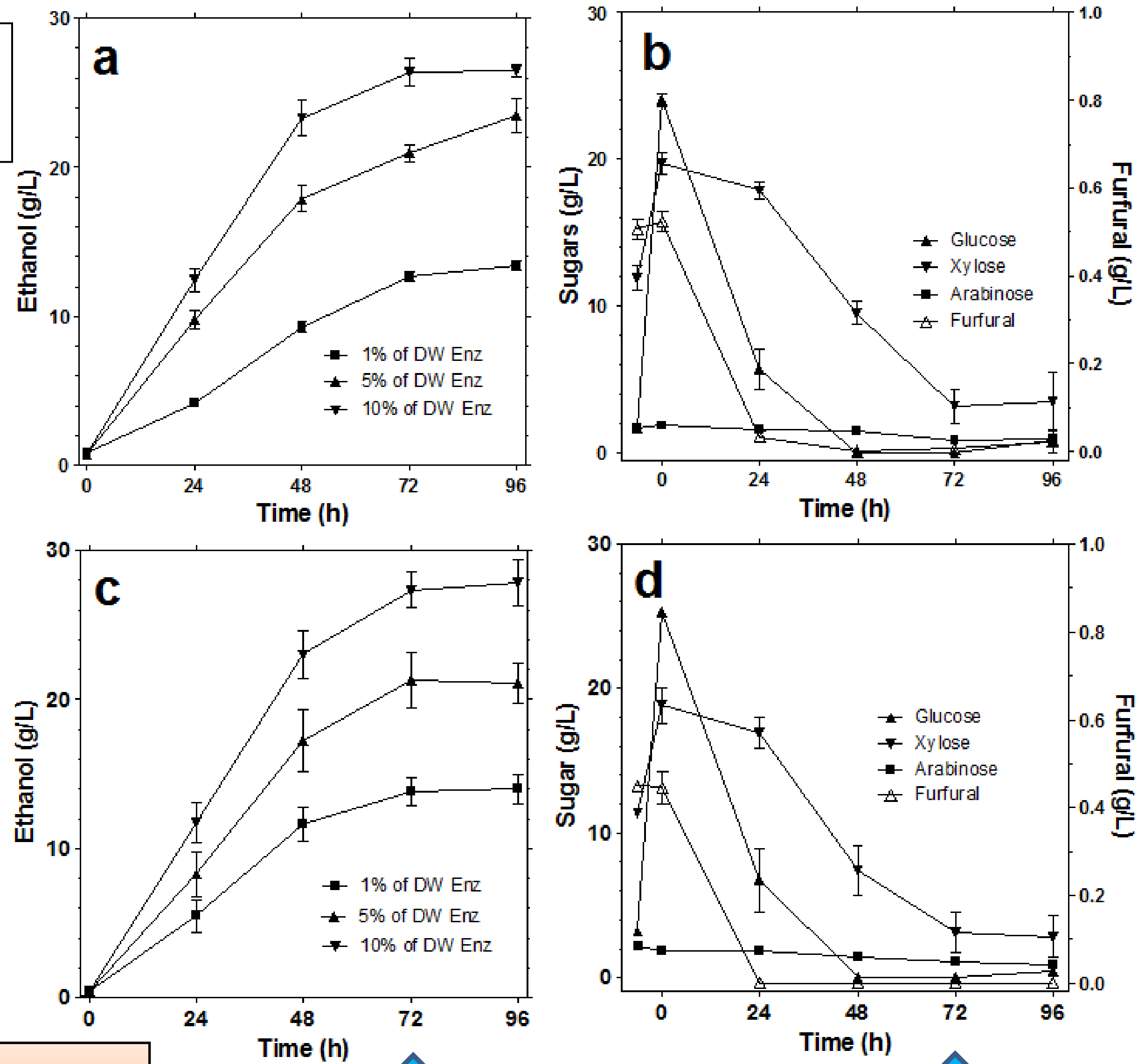
Everything entering the process leaves as a commercial product



Metso, Norcross, GA

Reducing Fermentation Times

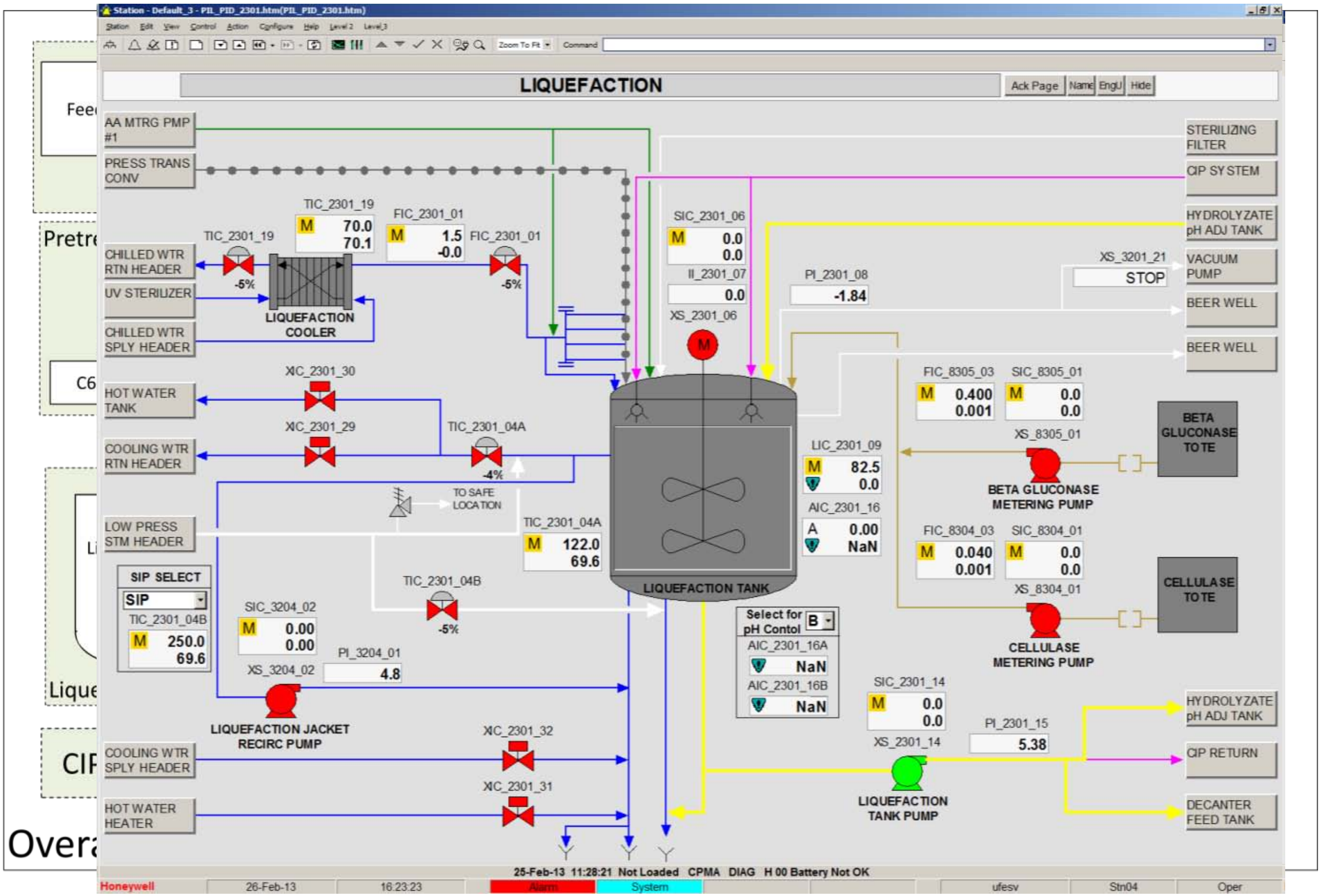
80-88 gal/dry ton bagasse



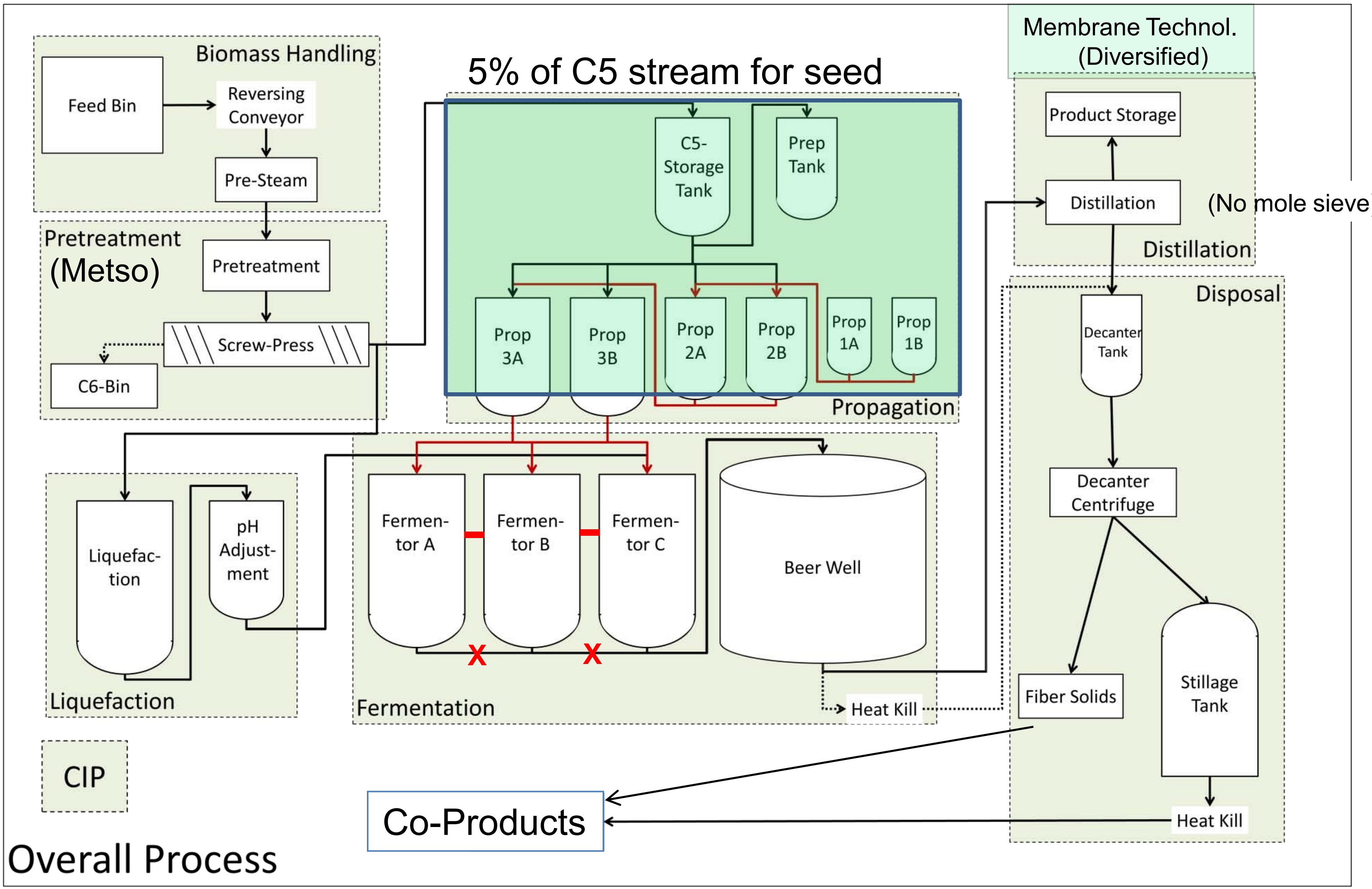
Sugarcane Bagasse (South Florida)

Sweet Sorghum Bagasse (M31E, Citra FL - Dr. John Erickson)

Stan Mayfield Biorefinery

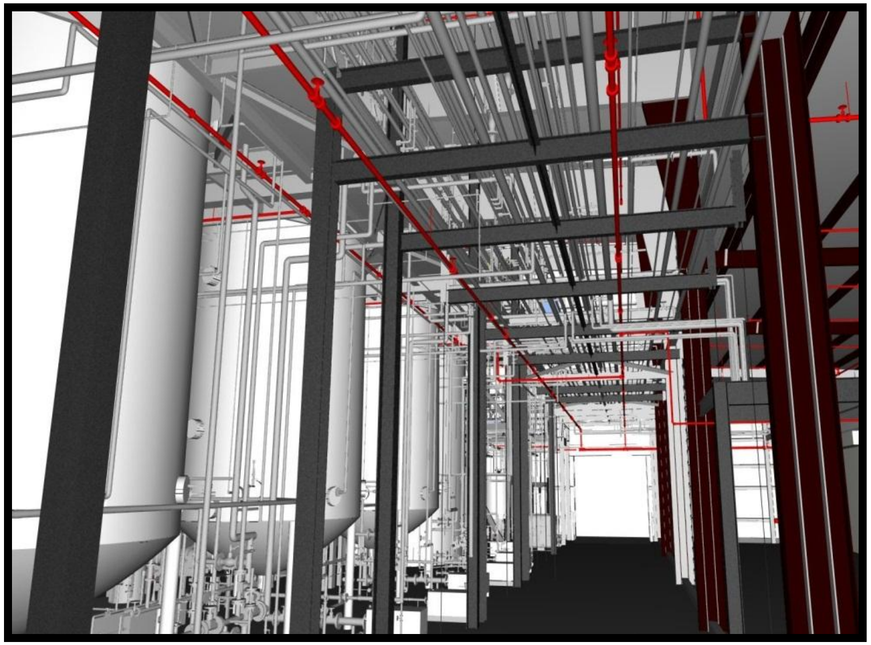


UF Stan Mayfield Biorefinery

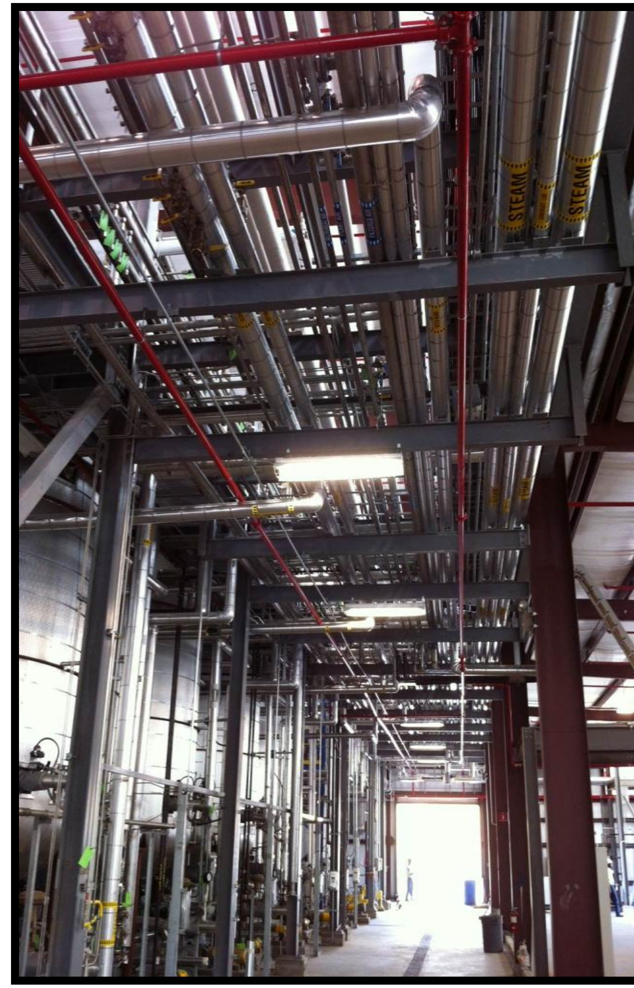


UF Stan Mayfield Biorefinery

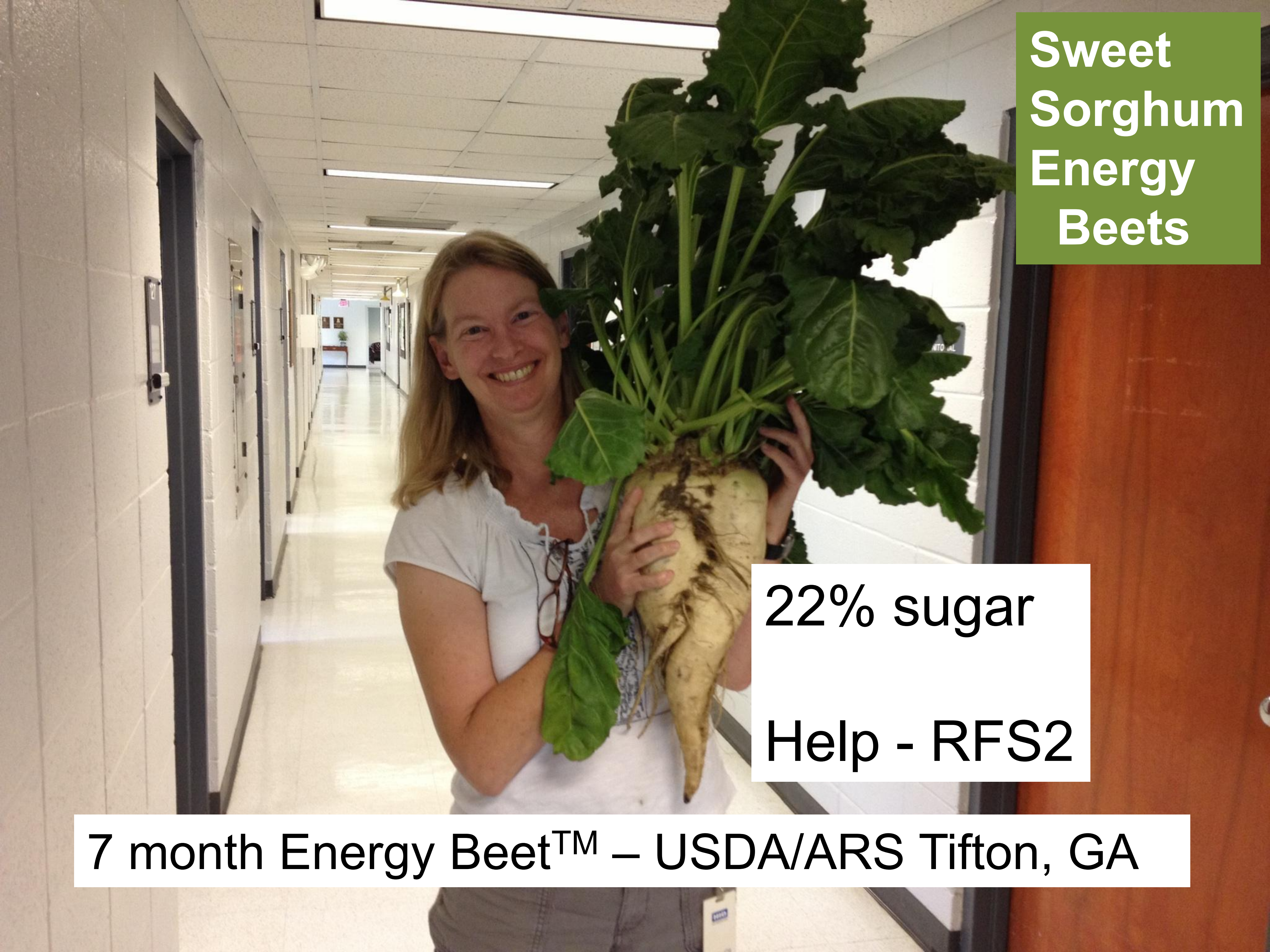
I-Pad Model (in Silico)



Thank you



I-Pad Photograph


Sweet Sorghum Energy Beets
22% sugar
Help - RFS2
7 month Energy Beet^{TM} – USDA/ARS Tifton, GA