State-of-the art Production of fuel ethanol using Granular Starch Hydrolyzing Enzymes (GSHE)

Bioenergy-1
From Concept to Commercial Process
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Presentation Outline

- Introduction
- Benefits of No-cook Process For Glucose Using GSHE in Alcohol Fermentation
- What Is GSHE?
- How Does GSHE Work?
- Process Conditions for GSHE
- Summary
Applications Of Glucose From Starch

BioFuel,

17 Billion Liters

500,000 MT (1.25 Million MT Glucose)
250,000 MT (320,000 MT)
70,000 MT (150,000 MT)
70,000 MT (100,000 MT)
500,000 MT (600,000 MT)
10 Million MT (10 Million MT Glucose)

1.5 Million MT (2 Million MT)
500,000 MT (600,000 MT)

Sorbitol
MSG
Lysine
Citric Acid
Ascorbic Acid
Gluconic Acid
Lactic Acid
High Fructose

Future Growth
Significant Growth Potential
Agricultural Raw Materials For Fuel Alcohol Production

Grains Used For Ethanol

- Corn
- Wheat
- Sorghum
- Rye
- Barley
- Triticale
- Rice
Conventional Ethanol Production Process

- **Grinding Slurry Tank**
  - Water
  - Thermo-Stable Alpha Amylase
  - Glucoamylase
  - Yeast

- **Liquefaction**
  - JET COOKER
    - >100 °C
    - 5–8 MIN

- **Saccharification**
  - Secondary Liquefaction
    - 95 °C
    - ~90 MIN
  - 60 °C
  - 8–10 HRS (optional)

- **Fermentation**

- **Distillation & Dehydration**

- **Storage Tank**

- **DDGS**

- **Milo, Corn, Wheat, Rye, Barley, Tapioca**

* pH adjustment steps are not shown
Liquefaction

Picture of a typical jet used in primary liquefaction

Starch

Combining Tube

Liquefied Starch to Hold Loops

Steam

Drawings copied with permission of Hydrothermal Corp.
Starch Degrading Enzymes

- alpha-amylase
- glucoamylase
- fungal amylase or beta-amylase
- pullulanase

Thermal Energy Destroys the Granular Structure of Granular Starch resulting in solubilization
Energy Costs ($/MM BTUs)
Forecast Assumes 5% Increase Per Year

Source: Historical: DOE
Forecast: GCOR Estimate

- Natural Gas ($/MM BTUs)
- Electricity ($/MM BTUs)
- Total Gas Cost/Gallon
- Electric Cost/Gallon
- Total Energy Cost/Gallon
Liquefaction Energy Cost ($/Gallon of Ethanol)

GCOR Estimate: Assumes 10% of Gas Energy Per Gallon
STARGEN™ Enzymes: No Cook Process

Granular Starch Hydrolyzing Enzymes & Application For Hydrolyzing Granular Starch in Ethanol Production
Granular Starch Hydrolyzing Enzymes: Glucoamylases and Alpha Amylases

Catalytic domain

Granular Corn Starch

Linker region

Starch Binding Domain

A. niger Glyco-hydro-15

SBD

Glucose
Potential Benefits of STARGEN™ Enzymes

- **Energy Saving** — Elimination of Jet Cooking
- **Reduction in Osmotic Stress/Reduction in By-products Formation** — Glycerol, Organic Acids, etc.
- **Capacity Increase** — High Density Fermentation - Higher Alcohol Yield
- **Carbon Conversion Efficiency** — Higher Yield
- **Reduction of Yeast Growth Inhibitors** — High Glucose, Maillard Products, etc.
- **Saving on Operational Cost** — Labor, Time, Chemicals
- **Elimination of Calcium Addition** — Reduction of Calcium Salt Formation
- **Value Added By-product (DDGS)** — Higher Protein Content
- **Process Simplification** — Reductions in Unit Operations
- **Saving on Capital Cost** — Capacity Increase/New Plant
Comparison of Soluble Starch and Granular Starch Under Yeast Fermentation For Ethanol

Current Process Using Conventional GA

Granular Starch with Conventional- GA

Granular Starch with Granular Starch Hydrolyzing Enzymes

% Ethanol V/V

Hours

DP>3 w/v
Glucose w/v
DP3 w/v
DP2 w/v
Etoh v/v

DP2 w/v
Glucose w/v
DP>2 w/v
DP2 w/v
Etoh v/v

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STARGEN™ Enzymes

- Alpha-amylase helps in granular starch hydrolysis
- AG-I has strong granular starch hydrolytic activity
- AG-II has weak granular starch hydrolytic activity
Synergy: Alpha Amylase + Glucoamylase

Incubation of Granular Starch with Purified GSH- Glucoamylase and Purified GHS- Alpha Amylase at pH 5.0, 32°C, 4 Hours

Mg Glucose Released in 4 Hours

AA

GA

AA+GA
SEM of Granular Corn Starch Treated with Purified Glucoamylase, pH 4.5, 32°C

Granular Corn Starch

2 Hours Incubation

4 Hours Incubation

Electron Micrograph Images courtesy of Dr. David Johnston & Dr. Peter Cooke — United States Department of Agriculture’s Eastern Regional Research Center
SEM of Granular Corn Starch Treated with Purified Alpha Amylase, pH 4.5, 32°C

Granular Corn Starch

2 Hours Incubation

4 Hours Incubation

8 Hours Incubation

Electron Micrograph Images courtesy of Dr. David Johnston & Dr. Peter Cooke – United States Department of Agriculture’s Eastern Regional Research Center
Enzymatic Drilling of Granular Starch

Granular Starch + STARGEN™ 2 Hours

Granular Starch + STARGEN™ 4 Hours

Granular Starch + STARGEN™ 8 Hours

Electron Micrograph Images courtesy of Dr. David Johnston & Dr. Peter Cooke – United States Department of Agriculture’s Eastern Regional Research Center
STARGEN™ Enzymes

A proprietary blend of granular starch hydrolyzing alpha amylase from *A. kawachi* and glucoamylase from *A. niger*
Effect of Particle Size: Laboratory Scale (32% DS, STARGEN™ 001)

% thru 30 mesh
- #6: 54.0%
- #4: 65.7%
- 2.0 mm: 85.9%
- 1.5 mm: 89.8%
- 1.0 mm: 93.3%

% residual starch
- #6: 22%
- #4: 16%
- 2.0 mm: 9%
- 1.5 mm: 13%
- 1.0 mm: 10%

Effect of pH on Ethanol Yield and Residual Starch Content in Distiller’s Grains

- % Ethanol
- % Residual Starch

Mash pH

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Conventional Ethanol Production Process

**Grinding Slurry Tank**
- Water
- Liquefaction
  - Thermo-Stable Alpha Amylase
  - Glucoamylase
- Saccharification
  - Yeast
- Fermentation
- Distillation & Dehydration
- Storage Tank

- *Milo, Corn, Wheat, Rye, Barley, Tapioca*
- Water
- **Jet Cooker**: >100° C, 5-8 min
- **Secondary Liquefaction**: 95° C, ~90 min
- **60° C**: 8-10 hrs (optional)

*PH adjustment steps are not shown*
Low Energy Ethanol Production Process

- **Grinding Slurry Tank**
- **Water**
- **Alcohol Recovery**
- **DDGS**
- **STARGEN™ & Yeast**
- **Saccharification & Fermentation**
- **Distillation & Dehydration**

Milo, Corn, Wheat, Rye, Barley, Tapioca

* pH adjustment steps are not shown
STARGEN™ Has Potential to Transform the Ethanol Industry!

- No Cook = Less Energy Input
- Fewer Side Products = Higher Ethanol Yield
- Fewer Process Steps = Less Equipment
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