Cellulosic Opportunity

- Over 200 ethanol plants; current US demand of 14B gal/yr
- US Renewable Fuels Standard (RFS) requires additional sources of 16B gal/yr of cellulosic ethanol by 2022
  - **Cellulosic ethanol breakthroughs needed** to meet RFS intent and requirements
  - **Imports as alternative**
- RFS provides premium for cellulosic ethanol, forecast at ~$US 1.00/gal
Cellulosic sugars are structural sugars found in fibrous biomass.

Cellulosic sugars are widespread, but hard to extract.

1st gen sugars

- C6 sugars; easy to extract and ferment
  - (corn – dextrose; cane - glucose)
- Corn, sugarcane

Cellulosic sugars

- C6 sugars; harder to extract and less available
- Corn stover, bagasse, wood

- C5 sugars; hardest to extract and ferment
Cellulosic Sugars Have Attractive Economics

Edeniq’s Cellulosic Sugars will be cheaper than Corn and Cane Sugars
Focus must remain on key profitability barriers

**Costs**
- Capital
- Feedstock
- Enzymes/ Catalysts

**Process Technology Limitations**
- Conversion: process robustness, but..
- Purity: minimally invasive/ destructive (for downstream utility)

**Feedstock Controversies**
- Competition with food uses; alternative land uses

**Investment Readiness Cycles**
Challenge Area: high capital costs

Current Approaches
- maximizing intensity of reactions (reduced volumes, times)
- maximizing utility of existing hardware (e.g., “bolt-on”)

Immediate Development Priorities
- increased solids loadings
- optimization of recycles

Recommendation for CEC Involvement
- fostering partnerships to facilitate technology linkages; unit operations and process equipment integration
Edeniq Bolt-On Design

Block Flow Diagram – Stover Integrated with Corn Ethanol Plant

Edeniq Cellulosic Bolt-on

Stover in

Pre Processing

Water

PreTreatment/Cellunator

Enzymes

Sugars + Solids Slurry

Saccharification

Solid – Liquid Separation

Cellulosic Sugars

Lignin-rich Solids

Solid – Liquid Separation

Fermentation

Water + Ethanol + Solids

Ethanol Product

Ethanol Plant

DDGS
Edeniq’s bolt-on technology: Mechanical Pretreatment with Cellunator

- Wet state
- Right sizes particles
- Reduces viscosity
- Shears fiber
- Accessible enzymes to increased yield
- Homogeneous, stable, high-solids slurry

- Six Commercial Installations
  ✓ Ethanol Facilities
  ✓ 7+ years
  ✓ 99.5% uptime

- Worldwide rights for biofuels and biomass markets
  ✓ IKA Manufacture

- Patent No. 8,563,282
  ✓ Granted Oct ‘13
Challenge Area: high feedstock costs

Current Approaches
- looking for highest value compositions and consistency
- taking advantage of high-volume aggregation availability
- developing partnerships with expertise in both areas

Immediate Development Priorities
- deep understanding of physical and compositional variances
- process adaptability

Recommendation for CEC Involvement
- facilitating process integration partnerships
  (harvest protocols; pre-processing operations)
## Feedstock Assessment Summary

### Yields and Implications for California Feedstock Potential

<table>
<thead>
<tr>
<th>Feedstock Class</th>
<th>Sugar Yield (kg/ton equiv)</th>
<th>Ethanol Potential (gal/ton)</th>
<th>Comments/ Other Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nut Crop Residues</td>
<td>139</td>
<td>19</td>
<td>almond, peanut, walnut husks</td>
</tr>
<tr>
<td>Wood - Citrus</td>
<td>272</td>
<td>41</td>
<td>extensive work earlier in R&amp;D pilot</td>
</tr>
<tr>
<td>Wood - Pine</td>
<td>133</td>
<td>19</td>
<td>useful cellulosic content low</td>
</tr>
<tr>
<td>Other Grain Crops (rice, milo) (2)</td>
<td>182 - 220</td>
<td>25 - 31</td>
<td>projections based on composition</td>
</tr>
<tr>
<td>Corn Stover</td>
<td>260 - 315</td>
<td>36 - 45</td>
<td>extensive CCM work with CA stover</td>
</tr>
<tr>
<td>Energy Cane (3)</td>
<td>460 - 518</td>
<td>66 - 75</td>
<td>cane bagasse</td>
</tr>
</tbody>
</table>

### Notes

1- assumes 92% efficiency of C6 fermentation; 75% for C5
2- high inorganic feedstocks; appear detrimental to Celluntor wear (separate tests)
3- surrogate for energy cane (CA programs in development)

- CA stover has high potential and is already available
- Energy crop projects appear to have the highest process potential; uncertain practicality due to land use issues
- Citrus wood is a possible target, but aggregation logistics uncertain
- Other feedstocks studied are disadvantaged
Challenge Area: high enzymes/catalysts costs

Current Approaches
- engineering of process recycles; increased turnover numbers
- additives that enhance productivity and partitioning
- analytics to enable enzyme-specific improvement targets

Immediate Development Priority
- demonstration of optimized enzyme deployment via advanced recycle strategies

Recommendation for CEC Involvement
- support for analytical expertise development; fostering world-class, broadly available, enzymatic fundamentals resources
Proprietary Additives

- Proprietary additives increase C6 conversion
- Additives recovered and recycled in Edeniq process
Challenge Area: Conversion; process robustness

Current Approaches
- intimate integration of pretreatment and hydrolysis; continuous processing
- advanced reactive separation engineering – capturing valuable intermediates while continuing to drive conversions

Immediate Development Priority
- optimization of operating space: conversion, purity, throughput – vs. capital requirements

Recommendation for CEC Involvement
- support for chemical reaction engineering expertise; extending feedstock studies to rheology (in process) studies
Hydrolysis Process Innovations

Proprietary continuous reactor
Cooperations with major suppliers to access latest enzymes
Edeniq has developed enzyme enhancers
  • Increases activity of conventional enzymes
  • Allows reduction in enzyme loadings
  • R&D underway to improve performance
Enzymatic cocktails and process conditions optimized for each feedstock and process
Standard operating conditions
Saccharification yield targets
  • C6: 80%
  • C5: 70%
Optimizing enzyme recycle
Challenge Area: Product quality; purity

Current Approaches
- benign preprocessing and pretreatment operations that are minimally destructive
  … retaining highest intermediate values
- focus on purity indices most critical to downstream processes

Immediate Development Priority
- optimized integration of all preprocessing and pretreatment unit operations
  … complete in-line processing

Recommendation for CEC Involvement
- support for differentiating equipment development;
  fostering world-class process engineering expertise resources
Hydrolysis Equipment Innovations

Tilted configuration of two-phase saccharification auger

SmartFlow TFF filter and housing assembly – in tandem with hydrolysis system operations
Challenge Area: Feedstock controversies

Current Approaches
- aggressive assessment of a wide range of non-food resources
- attention to holistic LCA assessments and C.I. rankings

Immediate Development Priority
- extend “bolt-on” process configuration to a wide range of non-food, low C.I., economically-strategic feedstocks

Recommendation for CEC Involvement – support for step-wise technology roll-outs that will ultimately enable the most carbon-friendly scenarios; retention of expertise and focus on world-class LCA and C.I. assessment capabilities; enabling progressive feedstock acquisition partnerships that foster this expertise
Feedstocks Tested

- Sugar cane bagasse
- Corn Stover
- Wood chips (various types)
- Switchgrass
- Energy Cane
- High Biomass Sorghum
- With and without pelletization
Bolt-On Extension Example

- **Mixed Comp Feedstock**
- **Tubers**
  - **Fructose Sugars**
  - **Residuals (Fiber, Protein, etc)**
  - **Stalks**
  - **Fiber (Structural Carbohydrates)**
- **Optional Food Processing**
  - **Ethanol Production Process**
  - **Fuel Alcohol**
  - **Energy Production**
  - **Animal Feed**
  - **Food Products**
Edeniq’s Bolt-On Celluosics Process Incorporates Innovative Technology

- **Fully continuous** pre-treatment and saccharification
- **Cellunator™** - and additional shear/ pretreatment elements
- Process to increase enzyme efficiency, *reduce enzyme costs*
- **SmartFlow** solid-liquid separation to produce solids-free sugars solution (exclusive license)
- **Leverage existing** fermentation, distillation capacities
Visalia pilot plant successes

- DOE-funded CCM plant operational since March 2012 – up to 2 tpd
- Pretreatment optimization to maximize conversions in practical timescales
  - \( C_6 \) and \( C_5 \) saccharification \( \sim 75\% \) maintained over extended periods
  - \( C_6 \) fermentation conversion \( >90\% \) in \(<30\) hrs
- Integrated process water recovery and recycle fully operational
- Simultaneous saccharification and fermentation feasibility proven
- 1500-hour DOE Performance Test successfully completed – corn stover
- DOE targets of \( >1000 \) hrs; \( >90\% \) up-time: reached and exceeded

- Operational parameters and baseline design kinetics established for scale-up to continuous processing and bagasse demonstrations
- Facility transitioned for validation of bolt-on commercial applications
Edeniq’s bolt-on technology: Integrating cellulosic sugars into existing biorefineries

- Com, sugarcane
- Cellulosic feedstock
- Existing Biorefinery
- Edeniq cellulosic sugar production
- Downstream Products: gasoline, plastic, tires, fertilizer
Key Challenges Identified; Ongoing Support is Critical

- Costs: Capital; Feedstock; Enzymes/Catalysts
- Process Technology Limitations
- Feedstock Controversies
- Investment Readiness Cycles

Support from the CEC – specifically via the ARFVTP – has been instrumental in forwarding these critical development programs.

Ongoing support is requested and recommended:
- establishment of sustained core competencies
- facilitation of critical partnerships in the value chain
- attacking identified toughest technical issues head-on
- continued emphasis on holistic LCA evaluations
Solution: Renewable fuel. Sugar is the new oil.

Oil Reserves

Biomass and Agriculture

Renewable and Secure
Unlocking the Sugar Conversion Process

Mechanical Processes

Technologies for Producing Lower Cost, High Purity Sugar

Biological Processes

Enable Biorefineries to Become More Profitable and More Competitive