

10-Slide Guide to Cellulosic Ethanol



Past, Present & Future

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History of Cellulosic Ethanol in the US

- ▶ WWII - Cartridge Belts Degrading in SE Asia
- ▶ Fungus Isolated
- ▶ US Army Natick Labs begin to characterize *Trichoderma viride*
- ▶ *T. viride* QM9414 isolated as hyper-cellulase producing strain - Elwyn Reece and Mary Mandels
- ▶ Oil Embargoes - Gas Shortages and Lines
- ▶ Gasohol
- ▶ Cellulase characterization - Virginia Tech University: Ross Brown, George Emert, Ernie Gum, Sharon Shoemaker
- ▶ Gulf Oil Corporation, Katzen International, Purdue University, Rutgers University, UC Berkley
- ▶ SSF patented
- ▶ Solar Energy Research Institute (SERI)



History of Cellulosic Ethanol in the US

▶ 1980 - 2000

- ▶ Oil Glut - Prices crash
- ▶ *T. viride* QM9414 renamed *T. reesei*
- ▶ New cellulolytic *Clostridium* sp. named *C. ljungdahlii*
- ▶ Genetic engineering opens new opportunity to advance cellulase production
 - ▶ Cetus, Genentech/Genencor
 - ▶ RUT C30, L27

▶ 2000 - Present

- ▶ DOE expands development efforts including strain improvement, commercial demonstration and pilot operations
- ▶ RFS 1 and RFS 2 mandate cellulosic ethanol production
- ▶ RINs, LCFS, Climate Change
- ▶ Production of fuel ethanol - mostly from corn/milo - rises to ~15BGY - very little cellulosic ethanol production
- ▶ Failures - Successes



Abengoa - Hugaton
Bankruptcy - Assets Sold

POET-DSM Project Liberty
Increasing Ethanol Production
Enzyme Production Expansion



Cellulosic Feedstocks

- ▶ **Agricultural Crop Residues**
 - ▶ Corn Stover, Wheat Straw, Corn Kernel Fiber
- ▶ **Energy Crops**
 - ▶ Switchgrass, Energy Sorghum, Miscanthus, Hybrid Poplar/Willow
- ▶ **Municipal Solid Waste (RDF)**
- ▶ **Commercial Waste Streams**
 - ▶ Pulp and Paper Mills, Sawmills, Used Pallets, Construction Waste
- ▶ Most widely used, Seasonal byproduct production, Extensive storage required
- ▶ Higher production/acre, Slow adoption without long term contracts, No/Little alternative uses
- ▶ Daily production, Concentrated by population density, Regular collection, Established central sites, Tipping fees, Classification required, Contaminating materials, Garbage stigma
- ▶ Greatly reduced numbers of pulp mills and volume of waste feedstock, Dried wood

Conversion Technology

▶ Biochemical Conversion

- ▶ Milling
- ▶ Pretreatment
 - ▶ Autohydrolysis
 - ▶ Dilute Acid Steam Explosion
 - ▶ Ammonia Steam Explosion
 - ▶ Organosolv, Ionic liquids, etc.
- ▶ Hydrolysis
 - ▶ Cellulolytic Enzymes
- ▶ Fermentation
- ▶ Product Recovery

▶ Thermochemical Conversion

- ▶ Milling
- ▶ Combined Heat and Power (CHP)
 - ▶ Combustion
 - ▶ Gasification/Pyrolysis
- ▶ Syngas Conversion
 - ▶ Fischer-Tropsch
 - ▶ Fermentation
- ▶ Product Recovery

Co-Products/By-Products

▶ Co-Products

- ▶ Yeast Single Cell Protein
- ▶ Lignin-based chemicals/materials
- ▶ Biochar

▶ By-Products

- ▶ Boiler Fuel
- ▶ Vinasse-like soil amendment

Cellulosic Development and Commercialization

- ▶ Gen 2 Cellulosic Biomass Leaders
 - ▶ Commercial Operations
 - ▶ POET-DSM Project Liberty IA
 - ▶ Iogen- Costa Pinto BRAZIL
 - ▶ Planned Commercial Plants
 - ▶ Aemetis - Riverbank CA
 - ▶ Clariant Sunliquid - ROMANIA
 - ▶ Comet - CANADA
 - ▶ Fiberight - Hampden ME
 - ▶ Synata Bio, Hugaton KS
 - ▶ Scale Up Development
 - ▶ Anellotech - Pearl River NY
 - ▶ ICM - St. Joseph MO
- ▶ Gen 1.5 Corn Kernel Fiber Leaders
 - ▶ Back End Commercial Processes
 - ▶ EdeniQ - Intellulose - multiple sites
 - ▶ Quad County Corn Processors - Cellerate - Galva, IA
 - ▶ Under Construction - D3Max - Badger State Ethanol WI
 - ▶ Front End Commercial Processes
 - ▶ Planned Construction - ICM Element - Colwich KS

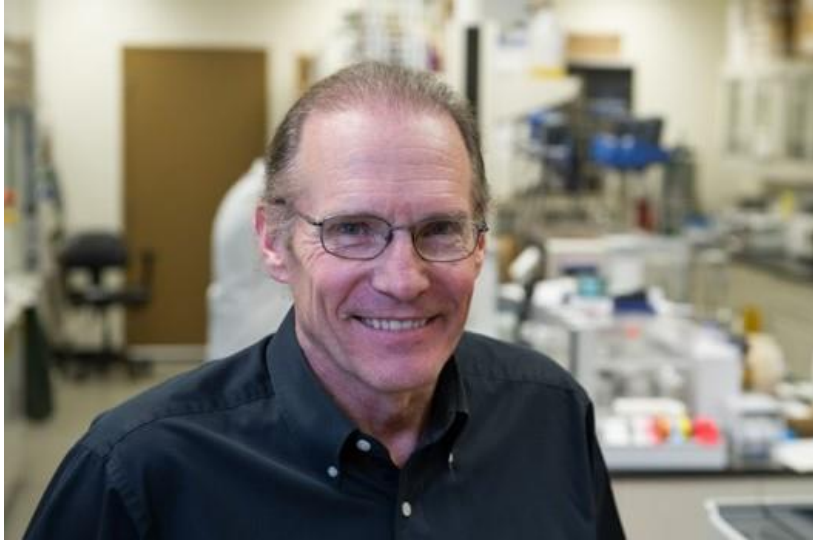
Opportunities for Improvement

- ▶ Logistics
 - ▶ One-pass harvest - feedstock doesn't touch the ground
 - ▶ Mobile pretreatment/densification at the feedstock site
- ▶ Materials Handling
 - ▶ Removal of inert, abrasive materials without significant feedstock loss
 - ▶ Improved pumpability
- ▶ Conversion Technology
 - ▶ Biochemical
 - ▶ Pretreatment reliability
 - ▶ Thermochemical
 - ▶ Catalyst robustness
- ▶ Co-Products/By-Products
 - ▶ Lignin upgraded to value-added chemicals

Conclusions

- ▶ Commercial Failures Outnumber Successes
- ▶ Cellulosic US Ethanol Production ~0.1% Total US Ethanol Production
- ▶ Technical Progress Being Made at Commercial Scale
- ▶ Need Improved Feedstock Quality/Logistics
- ▶ Front End Challenges Significant But Not Insurmountable
- ▶ Pretreatment Scale, Controls, Reliability Still a Concern
- ▶ Gen 2 Capital Requirements a Significant Barrier

Thank You!



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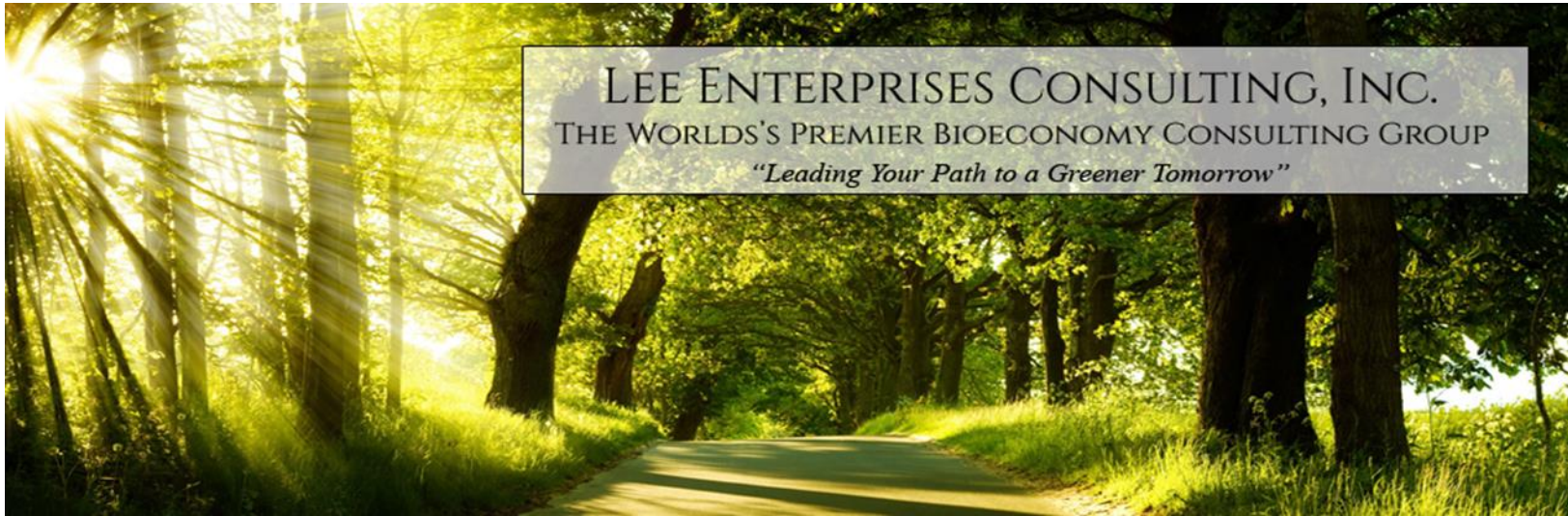


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Consulting/advisory services to developers, companies, and investors in the US and internationally



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