

Toward the Integrated Production of Cellulosic Biofuels and Biochemicals: Lessons Learned from the U.S. Corn & Cellulosic Ethanol Industries

Min Chen, Ph.D. Candidate

Paul M. Smith, EPP Lead

Michael P. Wolcott, Co-PD

September, 2015

Northwest Advanced Renewables Alliance

PennState









 Inventory, categorize & locate all U.S. biorefineries and consider lessons learned from existing players;

 Examine the role of biorefinery product portfolios and new product/market development to delineate opportunities to add value and mitigate risk.







- 1. Challenges
- 2. Background of & Lessons from Existing Players
- 3. Current Research w/ Objectives
- 4. Research Plan
- 5. Preliminary Results
- 6. Next Steps



FEEDSTOCK



BIOREFINERY



BIOFUEL & CO-PRODUCTS







- Globally, fossil fuels = 87% of energy consumption.
- U.S. = world's #1 crude oil importer in 2013.



Source: http://time.com/67163/why-are-u-s-oil-imports-falling/

PennState





- Uncertain liquid oil supply beyond 2040 (EIA International Energy Outlook 2014)
 - Geo-political issues
- Oil price volatility (EIA IEO 2014)
- GHG emission reduction
 - 05/2015, Intended Nationally Determined Contribution (INDC): 26-28%
 below 2005 levels by 2025



- 08/2015, Clean Power Plan: 32% below 2005 levels by 2030
- 1970 Clean Air Act
- Renewable Fuel Standard (RFS)

Source: <u>http://www.eia.gov/forecasts/ieo/.</u> <u>https://www.whitehouse.gov/the-press-office/2015/03/31/fact-sheet-us-reports-its-2025-emissions-target-unfccc.</u> <u>https://www.whitehouse.gov/the-press-office/2015/08/03/fact-sheet-president-obama-announce-historic-carbon-pollution-standards</u>







BIOECONOMY (def.) "...the global industrial transition of sustainably utilizing **renewable** aquatic and terrestrial resources in **energy**, **intermediate**, and **final products** for economic, environmental, social, and national security benefits."

----- Golden & Handfield (2014)

- 05/2015, EPA proposed
 - 15.93 billon gallons (BG) of renewable biofuels by 2014;
 - 16.30 BG of 2015; and

PennState

• 17.40 BG of 2016.

Source: Golden, J.S., Handfield, R.B. 2014. The emergent industrial bioeconomy. Industrial Biotechnology, **10**(6), 371-375.



• U.S. Biofuels Background: Corn-Grain Ethanol

- U.S. 1st Gen (corn-grain) ethanol industry
 - Alternative to petroleum-based gasoline;
 - U.S. 1st Gen ethanol production: ~ 60% of the world's volume;
 - 1st Gen ethanol: ~ 90% of the total U.S. renewable liquid fuels.





• U.S. Biofuels Background: Corn-Grain Ethanol



Wet mills

- Starch, gluten meal, gluten feed and oil.
- Quickly adapt to changes in market conditions.

Dry mills

- Smaller, less expensive to build (market share = 89% in 2010)
- Distillers' dried grains with solubles (DDGS) and corn oil = 27% of gross revenue.





1st Gen Corn-Grain Ethanol - Challenges

Ethanol "blend wall" - Supply > demand



- Factors constraining the sale of E15 or E85
 - Compatible fueling infrastructure
 - Automaker acceptance of E15 or E85 in today's vehicle
 - Consumer acceptance
 - Policy issues: e.g., EPA cap on 1st Gen ethanol, land use change, and food-vsfuel debate





1st Gen Corn-Grain Ethanol - Challenges

Food-versus-fuel debate

Points

[New York Times, The World Bank and other researchers]:

- Raises food security concerns;
- Increases feedstock prices and thereby food prices.

Sources: Carter CA, Miller HI. Corn for food, not fuel. The New York Times; 2012. Cuesta J. Food price watch. In: The Poverty Reduction and Equity Department; The World Bank; 2014. p. 10. Thompson PB. The agricultural ethics of biofuels: the food vs. fuel debate. Agriculture. 2012;2:339-58.

RFA. Industry resources: Co-products. Washington DC: Renewable Fuels Association; 2014. Cuesta J. Food price watch. In: Department TPRaE, editor.: The World Bank Group; 2014. p. 10. FAO. Radical shift in agriculture critical to making future food systems smarter, more efficient. Available at:

http://www.un.org/apps/news/story.asp?NewsID=49835#.VfHGxxFVikq.

Counterpoints

[Renewable Fuels Association (RFA) and other researchers]:

- U.S. ethanol production: 3% of global grain supply in 2011;
- Only consumes the grain's starch fraction; the protein, minerals, fat and fiber to the animal feed market (DGSS: ~ 1/3 of volume).
- Food price inflation factors: oil prices, speculation and export.
- 01/2015, UN FAO: "food and fuel".







Biorefinery Models:

- 1. Cellulosic Alcohol
 - "Bolt-On" vs.
 - "Stand Alone"
- 2. Cellulosic Hydrocarbon





• "Bolt-On Cellulosic Alcohol" Biorefineries (n=11)

- Added to or co-located with existing corn-grain ethanol biorefineries;
- Advantages: Shared supply-chains, distribution channels and capital costs (lower investment risk).

Companies	Location	Product	Capacity (gallons/ year)
Abengoa	York, NE	Ethanol	20,000
ACE ethanol	Stanley, WI	Ethanol	Up to 3.6 million
ADM	Decatur, IL	Ethanol	25,800
Aemetis	Keyes, CA	Ethanol	NA
Flint Hills	Fairbank, IA	Ethanol	NA
Front Range	Windsor, CO	Ethanol	Up to 3.6 million
Gevo	Luverne, MN	iso-butanol	0.6~1.2 million
ICM	St. Joseph, MO	Ethanol	NA
Pacific Ethanol	Boardman, OR	Ethanol	Up to 3.6 million
POET-DSM	Emmetsburg, IA	Ethanol	25 million
Quad-County Corn Processors	Galva, IA	Ethanol	2 million
ICM	St. Joseph, MO	Ethanol	NA







Companies	Location	Product	Capacity (gallons/year)
Abengoa	Hugoton, KS	Ethanol	25
American Process	Alpena, MI	Ethanol, acetic acid	0.7
	Thomaston, GA	Ethanol, succinic acid, BDO	Up to 0.3
Beta Renewables	Clinton, NC	Ethanol, lignin	20
Bluefire Renewable	Fulton, MS	Ethanol	19
	Anaheim, CA	Eulanoi	200 lbs/day
Butamax	Wilmington, DE	n-butanol	NA
Canergy	Imperial Valley, CA	Ethanol	25
Coskata	Madison, PA	Ethanol, ethylene	NA
DuPont Biofuel Solutions	Nevada, IA	Ethanol	30
Enerkem	Pontotoc, MS	Ethanol and methanol	10
Fiberight	Blairstown, IA	Ethanol	6
INEOS	Vero Beach, FL	ethanol	8
Mascoma	Kinross, MI	Cellulosic biofuel	20
Maverick Synfuels	Brooksville, FL	Mixed alcohols	NA
Mendota Bioenergy	Five Points, CA	Cellulosic ethanol	15
ZeaChom	Boardman OD	Ethanol & biochemicals	0.25
ZeaChem	Dualuman, UK		25





• 2nd Gen (Cellulosic) Alcohol – Entry Barriers

(1) Feedstock costs = 30 - 65% of total cellulosic ethanol prod'n cost;

- Low bulk density; High moisture content.
- (2) Sustainable feedstock supply
 - Seasonal effects harvesting, collecting, preprocessing, storing, transporting
- (3) Technical obstacles
 - Tough, complex cell wall structure & the separation of lignin.
- (4) Policy uncertainties reduced RFS2 mandate:
 - Advanced biofuels: from 3.75 BGY (2007) to 2.68 BGY (2015)
 - Cellulosic biofuels: from 1.75 BGY (2007) to 33 MGY (2015)
- (5) Compete with 1st Gen ethanol for market share
 (6) Ethanol "blend wall"







•

Biorefineries	Location	Production (MGY)	Date
Abengoa Bioenergy	Hugoton, KS	25	Oct.19, 2014
INEOS Bio	Vero Beach, FL	8	July 31, 2013
Quad County Corn Processors	Galva, IA	2	July 1, 2014
POET-DSM	Emmetsburg, IA	25	Sept.3, 2014
DuPont	Nevada, IA	30	Expected 2015

Transition to drop-in cellulosic hydrocarbons





"Cellulosic Hydrocarbon" Biorefineries (n=13)

Same molecules as petro-fuels; compatible w/ existing infrastructure.

"Biomass-derived, hydrocarbon-based fuel will soon slip seamlessly into everyday use."

---John Regaluto, U.S. NSF's (bio)catalysis program.

AmyrisEmeryville, CARenewable diesel from farneseneCoolPlanet Energy SystemsAlexandria, LARenewable jet fuels & gasoline	
CoolPlanet Energy Systems Alexandria, LA Renewable jet fuels & gasoline	
Emerald Biofuels Chicago, IL Renewable diesel	
Envergent (UOP & Ensyn) Kapolei, HI Green diesel & jet fuel	
Fulcrum BioEnergy Storey County, NV SPK jet fuel or renewable diesel	
Haldor Topsoe Inc. Pasadena, TX DME	
KiOR Columbus, MS Cellulosic gasoline & diesel	
LanzaTech Soperton, GA Drop-in jet fuel via Alcohol-to-Jet (ATJ))
Red Rock Biofuels Fort Collins, CO Drop-in jet, diesel and naphtha fuels	
Sundrop Biofuels Longmont, CO Green gasoline	
SynTerra CA & OH Synthetic diesel fuel	
Terrabon, Inc. Bryan, TX Renewable gasoline & chemicals	
Virent Madison, WI Renewable diesel, jet fuel & gasoline	



PennState



To scale-up (commercialize) 2nd Gen (cellulosic) biofuels...

"High production and initial construction **costs** for untested technologies and processes on a large scale increases **risk** and affects the willingness of investors to underwrite projects."

> ----- USDA Economic Research Service "Next Generation Biofuels: Near-Term Challenges & Implications of Agriculture", 2010.







To add value & mitigate risks, we are examining:

integrated production of value-added non-fuel co-products; strategic relationships with potential buyers.



• U.S. Biochemical Market Projections

- "Do you expect to offer (use) more sustainable versions of chemicals (to make your products)?"
 - 72% of Chemical <u>Producers</u>; and
 - 76% of Chemical <u>Customers</u> closer access to end-use consumers who are demanding renewables.



Source: ICIS. Sustainability survey: Green concepts take firm root. ICIS Chemical Business; 2013. p. 27-30. Nexant. 2014. Final report: Renewable chemicals & materials opportunity assessment.





Collaborative Channel Strategies

 "Collaboration across the value chain is/will be high or very high today/ next 5 years".

<u>2012</u> & <u>2017</u>

- 74% & 90% of Chemical Producers with their Customers
- 35% & 59% of Chemical Producers with their Suppliers

Collaborative Benefits/Obstacles–Chem. Mfrs./Customers:

Benefits of Collaboration:

- #1 = Sales growth & innovation
- #2 = Reduced costs
- #3 = Reduced risk

Obstacles to Collaboration:

- #1 = Trust
- #2 = Ineffective governance
- #3 = Lack of collaboration strategy

Source: ATKearney. 2012. Collaboration: A new mantra for chemical industry growth. The sixth Chemical Customer Connectivity Index. 12 pp.







Scale-up of 2nd Gen cellulosic biofuels & biochemicals:

1) Examine **factors** affecting the scale-up of the U.S. 2nd Gen cellulosic biofuels industry;

2) Identify & evaluate **drivers & barriers** for the integrated production of cellulosic biofuels and biochemicals; and

3) Estimate the **likelihood of success** for three biorefinery **scenarios** in the next five years.

- Scenario 1: Production of 2nd Gen (cellulosic) biofuels ONLY;
- Scenario 2: Production of 2nd Gen (cellulosic) biochemicals ONLY;
- Scenario 3: Integrated production of 2nd Gen (cellulosic) biofuels AND biochemicals.







Strategic Relationships:

1) Identify the **Type & Structure** of collaborative relationships; and

2) Examine **Factors and Activities** impacting collaborative relationships.









PH I – Population Identification

PH II – Integrated 2nd Gen Cellulosic Biorefineries











Fig. 1. U.S. corn ethanol BRs (n=207)



Fig. 2. U.S. biodiesel BRs (n=154)



Fig. 3. U.S. cellulosic & algae BRs (n=41+6)





Qualitative e-survey: Academic and industrial experts (n=18, response rate~40%)

- **e-Survey Instrument**: 12 questions
- Survey Implementation:

First contact: Invitation email with a cover letter & survey link.

(Link: <u>https://www.surveymonkey.com/r/integrated_biorefinery</u>)

- Second contact: Follow-up reminder.
- Third contact: Thank you.









Preliminary Results



Fig. 3. Drivers for the integrated production of cellulosic biofuels & biochemicals

Fig. 4. Barriers to the integrated production of cellulosic biofuels & biochemicals







- Complete the Integrated 2nd Gen Cellulosic Biorefinery Questionnaire
- Strategic Relationships
 - Quantitative Questionnaire
 - Qualitative Interviews





Quantitative paper-survey:

- Survey Population: USDA AFRI CAPs Annual Meeting Attendees
 - 1. **NewBio** PSU et al., @ Morgantown, WV, Aug. 3-5.
 - 2. **IBSS** led by UT et al., @ Auburn University, AL, Aug. 10-14.
 - **3. AHB** led by UW et al., @ Seattle, Sept. 9-10.
 - 4. NARA led by WSU et al, @ Spokane, Sep. 15-17.
 - 5. BANR led by CSU et al., @ Missoula, MT, mid Oct.
- Survey Instrument: Paper-based; 13 questions incl. demographics, scale-up factors for the cellulosic biofuels industry, factors to the integrated production, and projections;
- Survey Implementation: Questionnaire provided to all attendees.





Quantitative paper-survey:

Potential Venues:

- 2015 Nat'l. Advanced Biofuel Conf. & Expo, Omaha, NE, Oct. 26-28.
- ✤ 2015 ABLC Next Conf., San Francisco, CA, Nov. 2-5.
- Paper-Survey Instrument: under development
- Survey Implementation: Questionnaire provided to all attendees

Qualitative interviews:

- Population: Bio-based chemicals from quantitative phase
- Interview Instrument: 8 open-ended discussion questions
- Interview Implementation: Conducted at industrial conference(s)













