Evolving Structure of the U.S. Biorefinery Industry

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Introduction

Conventional resources (mainly fossil fuels) have long been the predominant source of energy and chemicals (Amidon et al., 2008; Naik et al., 2010). However, fossil fuels are finite and not renewable; whereas there is a growing demand for energy and chemicals as economies and populations grow (Kamm et al., 2006). The imbalance between energy demand and supply has prompted humans to look for sustainable and renewable alternatives (Fernando et al., 2006). With various feedstock availability and biotechnology advancement, the structure of the U.S. biorefinery industry has evolved during the past ten years (Naik et al., 2010). Therefore, the major objectives of this poster are to:

- Develop classification strategy;
- Segment the U.S. biorefinery industry based on classification strategy;
- Present characteristics of different categories of biorefineries.

Classification Strategy & Segmentation

- Value stream outputs: biofuels or renewable chemicals;
- Feedstock inputs: first, second and third generation feedstock.

Categories of biorefineries (BR)	Numbers
1st Generation Biofuel BR	N=338
(1st Gen Ethanol BR)	(N=196)
(1st Gen Biodiesel BR)	(N=142)
2nd Generation Biofuel BR	N=63
3rd Generation Biofuel BR	N=14
1st and 2nd Generation Non-fuel BR	N=40
TOTAL	**N=455**

1st Gen Ethanol Biorefineries (Mueller, 2013; RFS, 2014; Wu, 2008)

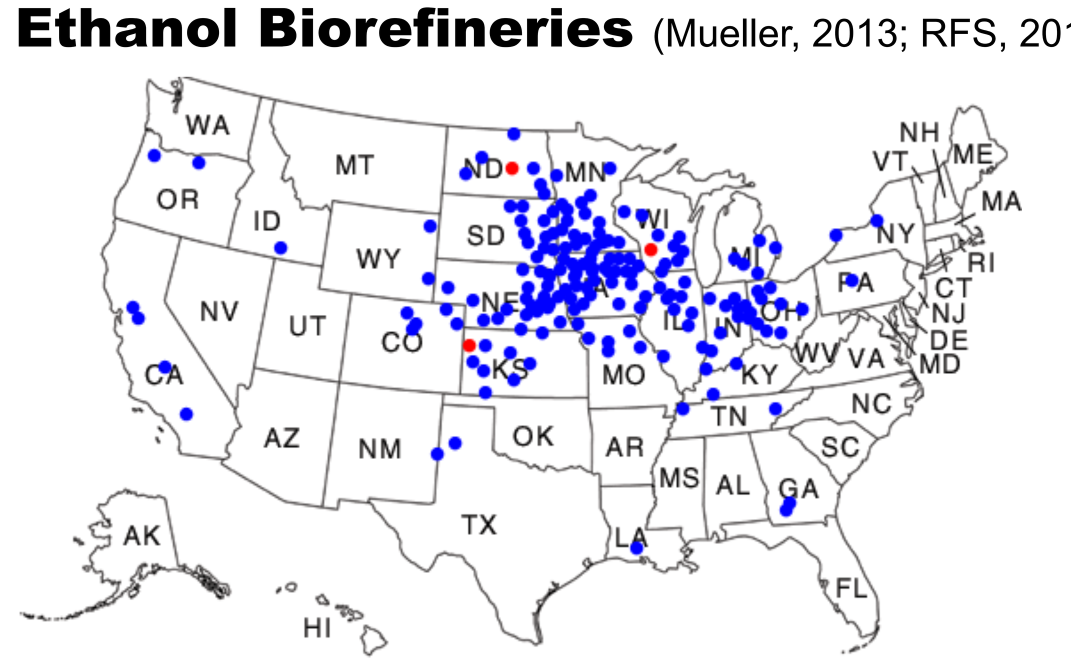

Figure 1. U.S. 1st gen ethanol biorefinery locations (n=196) PR

• 1st Gen operating ethanol biorefinery (n=193) • 1st Gen ethanol biorefinery under construction (n=3)

Dry mill (per bu)			V.S.	Wet mill (per bu)		
Ethanol 2.8 gal.	Distillers' Grains 16 lbs	Corn oil 0.53 lbs		Ethanol 2.7 gal.	Corn gluten 15lb	Corn oil 1.6 lb

1st Gen Biodiesel Biorefineries (NBB, 2014) (ASTM D 6751)

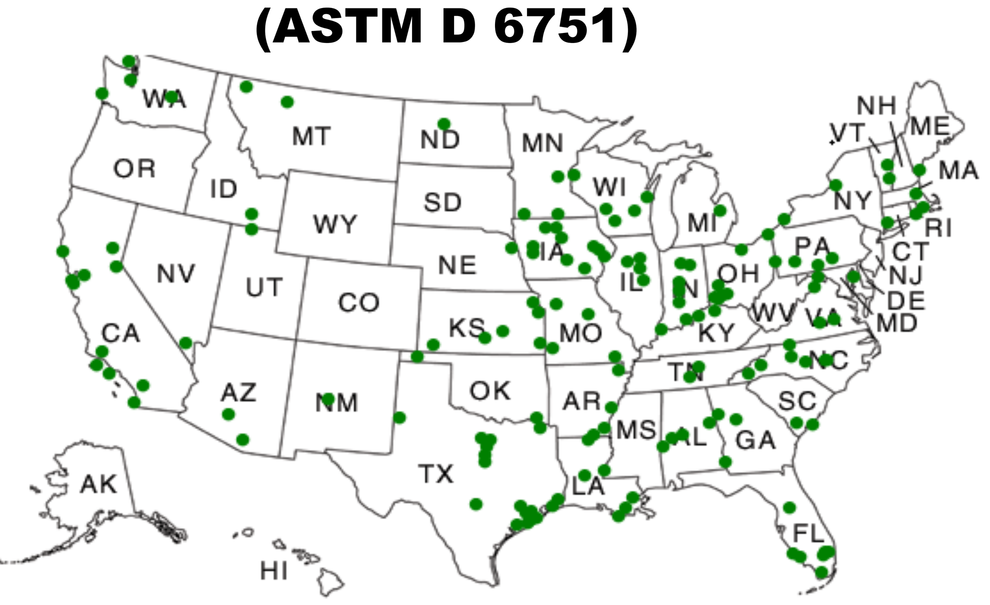

Figure 2. U.S. 1st gen biodiesel biorefinery locations (n=142) PR

Vegetable oils Recycled cooking oils Animal fats	Trans-esterification →	Methyl esters (Biodiesel) & Glycerin

2nd Generation Biofuel Biorefineries (BiofuelsDigest, 2013)

Figure 3. U.S. 2nd generation biofuel biorefinery locations (n=63) PR

Technologies	Process	Biorefineries (n=63)
Biochemical	Direct Sugars to Hydrocarbon (DSHC)	Amyris, LS9*, LanzaTech, RSA [n=5]
	Enzymatic Hydrolysis/ Fermentation	Abengoa*, BlueFire Renewable*, Edeniq, Parabel, Fiberight*, Lignol, Logos Tech, BP, Verenium, Inbicon, American Process*, Dupont, Novozymes, POET-DSM*, Beta Renewables, Sweetwater [n=21]
	Consolidated Bioprocessing (CBP)	Aemetis, Renmatix*, Mascoma* [n=5]
Thermo-chemical	Fischer-Tropsch/Gasification	Green Biologics, haldo-Topsoe, Fulcrum Bioenergy*, Maverrick-Synfuels*, Tentech, TRI, ADM, Enerkem, ICM, Primus Green Energy, REII, ZeaChem [n=15]
	Pyrolysis	KiOR**, GTI, CooPlanet [n=5]
	Alcohol to Jet (ATJ)	GEVO, Cobalt, Shell-Virent [n=3]
Bio/Thermo-chemical	Syngas Fermentation	Coskata*, INEOS Bio* [n=4]
	Bioforming	Virent [n=1]
Other	Catalytic reforming of sugars	Virdia [n=1]
	Genetic Engineering	OPX Biotech [n=1]
	Hydroprocessed Esters and Fatty Acids (HEFA)	Honeywell's UOP, Dynamic Fuels [n=2]

* 2 locations ** 3 locations

3rd Generation Biofuel Biorefineries (BiofuelsDigest, 2013)

Figure 4. U.S. 3rd generation biofuel biorefinery locations (n=14) PR

Algae Products	End-use Markets	Biorefineries (n=14)
Lipids/Oils	Algae oil substitution of vegetable oil feedstock for biodiesel production;	Aquatic Energy, BARD, Cellana, Joule Unlimited, Phycal, Sapphire, Solazyme Inc.
Carbohydrates	Substitution of agricultural sourced feedstocks for conversion of carbohydrates (sugars) to bioethanol;	Algenol,
	Production of bio-based polyolefin plastics as fossil fuel alternative.	Elevance, SOLIX BioSystems
Proteins	Animal food market	BioProcess Algae, Kent BIoEnergy
Hydrocarbons	Production of renewable distillates via gasification and F-T synthesis for substitution of diesel fuels	Heliae, Sapphire

1st & 2nd Non-fuel Biorefineries (Mirabal, 2013)

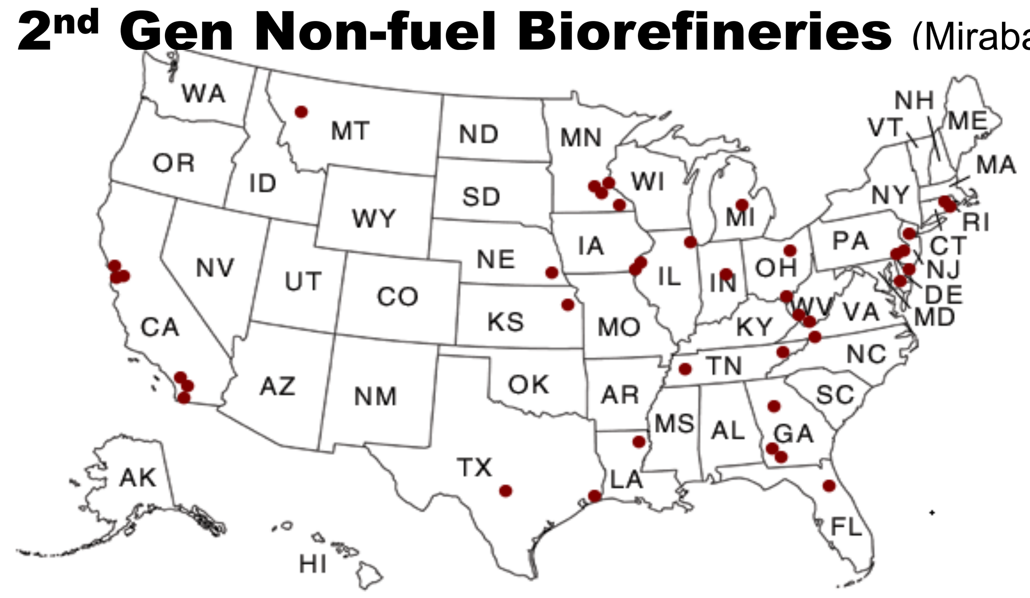

Figure 5. U.S. 1st & 2nd gen non-fuel biorefinery locations (n=40) PR

Non-Fuel Products	Biorefineries (n=40)
Bio-rubbers	EcoSynthetix, Yulex
Cellulose acetate (CA)	Celanese Acetate, Innovia Films, Rotuba,
Sugar acids	Rivertop Renewables, Segetis, Verdezyne
Polyamide (PA)	Arizona Chemical, Arkema SA, Dupont, Rennovia, RTP
Polyethylene terephthalate	TORAY
Polyhydroxyalkanoates (PHAs)	Meredian, Metabolix, Newlight Technologies, Telles
Polylactic acid (PLA)	ECOSPAN, NatureWorks, PURAC
Polyolefin (PP, PE)	Braskem***, FKuR Plastics, Flex-O-Glass, Laurel
Polyols/Polyurethanes	Butamax, DOW, Ingredion, PolyOne
Starch blends	Cereplast, Starch Tech Inc., Teknor Apex
Succinic acid & derivatives	BioAmber, Genomatica, Myriant,
Sulfur compounds	Blue Marble Biomaterials

*** 4 locations

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NARA
Northwest Advanced Renewables Alliance

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