Economic Feasibility Study of the Eastern Shore Energy Beet to Bio-Jetfuel Project

Prepared For

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Report Date
August 30, 2017

USDA Grant number 96860116

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Acknowledgements
Advanced Biofuels USA would like to acknowledge the work done by all the parties who participated in the initial stage of the University of Maryland Eastern Shore-based energy beet -to-jetfuel project and for the use of the results of the research derived from this project and from other sources. In addition to those listed above, these include faculty, staff and students of the School of Agriculture and Natural Sciences, particularly Dean Moses Kairo.

Thanks to Patricia Gleason of the US Environmental Protection Agency, Region 3 and Jeff Corbin, Senior Vice-President for Water Quality Markets & Mitigation at Restoration Systems, for information about the nutrient credit trading systems in the Chesapeake Bay watershed.

And thanks to those farmers, landowners, community leaders and interested members of the public who fielded phone calls from us or stopped at the Advanced Biofuels USA information booth at a variety of agricultural events over the past year to share their stories, insights, questions, concerns and ideas related to a possible energy beet-to-jetfuel project in the MId-Atlantic.

Available electronically at https://advancedbiofuelsusa.info/energy-beet-feasibility-study-finds-navy-best-potential-near-term-customer-for-alcohol-to-jetfuel-product/

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Executive Summary: Economic Feasibility Study of the Eastern Shore Energy Beet to Bio-Jetfuel Project

The US Navy has identified a need for renewable jetfuel at the port in Norfolk, Virginia. Renewable jetfuel may also help decarbonize air travel consistent with objectives of international policies, especially the European Union's ETS (emissions trading system). With Norfolk and Mid-Atlantic international airports in the area, could Maryland's Eastern Shore, part of the Delmarva (Delaware, Maryland, Virginia) Peninsula develop an economically viable sustainable alternative jetfuel (SAJF) supply and production chain to serve these markets?

This question was assessed by Advanced Biofuels USA, a nonprofit educational organization, with a US Department of Agriculture Rural Business Development Grant using available product yield and production cost information from Phase 1 of an energy beet project conducted in 2016 by the University of Maryland Eastern Shore.

This project used newly developed energy beets as the feedstock, enzymatic conversion of the biomass to obtain fermentable sugars, and proposed processing of those sugars into oils or ethanol as precursors or biointermediates for jetfuel production. The advantage of energy beets over feedstock such as switchgrass, agricultural/forest residues or woody biomass rests in its lack of lignin, a substance in plant cell walls that is difficult to convert to sugars (biomass recalcitrance).

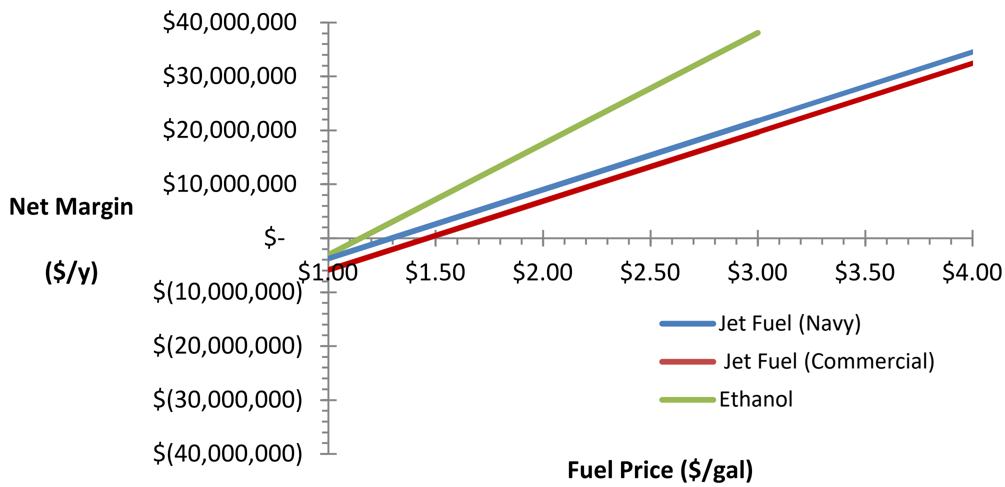
The proposed markets were the Defense Logistics Agency solicitations for the U.S. Navy at Norfolk, and future commercial aviation markets. Alternatively, the ethanol could be used as ground transportation fuel in the Mid-Atlantic markets or in renewable chemical production.

Three aspects of sustainability (economic, environmental and social) have been incorporated into every element of the analysis tailored to the unique characteristics of the region. Specific considerations include:

- Prioritizing potential environmental benefits for the health of the Chesapeake Bay;
- Minimizing stresses on local transportation infrastructure;
- Minimizing processing energy and water use;
- Recognizing the future impact from sea level rise in the area; and
- Maximizing the potential for wealth and job development in an economically depressed part of the Mid-Atlantic Coast.

This study finds that it could be feasible to produce low greenhouse gas emissions advanced ethanol or jetfuel on the Eastern Shore and Delmarva in an economically and environmentally sustainable way for the U.S. Navy solicitation using energy beet feedstock as illustrated in the Energy Beet Biofuel Net Margin Sensitivity Analysis Fuel Price graph.

Energy Beet Biofuel Plant Net Margin Sensitivity Analyses. Fuel Price.



In addition, this could bring economic, environmental and social benefits to the region.

Producing environmental benefits from phosphorus uptake and contributing feed to the existing poultry industry, alongside producing cost-competitive biofuels has the potential to support not only a positive return on investment for a biorefinery, but also for growers and for entrepreneurs servicing this new industry.

The study concludes that:

- The Plant Sensory System energy beets grow well on the Eastern Shore with minimal fertilizer and take up phosphorus at levels sufficient for potential inclusion in nutrient management plans and cap-and-trade remediation credits credits with 50% increase of P uptake by energy beets compared to corn grown in adjacent fields..
- August to December harvest minimizes land use and costs for storage and maximizes beet growth.
- High protein residues from biomass conversion and beet tops could have value as poultry or animal feed. This may allow a 1:1 replacement of Delmarva corn crops with energy beets meaning that no crop displacement would occur with the implementation of this system.
- The Atlantic Biomass enzymatic system successfully converts the beet pulp to sugars that can be fermented into ethanol or oils using processes under study at Purdue University and the USDA Agricultural Research Service National Center for Agricultural Utilization Research in Peoria, Illinois.
- These oils might be converted to jetfuel using existing approved processes.

- Twice as much ethanol can be produced from an acre of energy beets as from an acre of corn.
- Alcohol-to-jet conversion processes under review by ASTM could use energy beet ethanol as a feedstock for jetfuel and renewable chemical co-products.
- The jetfuel market for the U.S. Navy at Norfolk, based on Defense Logistics Agency solicitations, provides a clear demand at a set price for an amount of jetfuel that could be produced and delivered from energy beet feedstock grown and processed on the Delmarva.
- A market for ethanol for ground transportation in the region exists, is growing and could provide customers for energy beet ethanol as the alcohol-to-jetfuel conversion processes mature and ASTM or U.S. Navy approvals are obtained.
- Using barge-based production and transportation could minimize stress on traffic and maximize efficient use of resources.

Overall, the study finds that development of an energy beet-to-SAJF supply and production chain is in its early stages, but could be economically feasible as described above depending on the results of significant research which is needed on a number of fronts. These include:

- Pathways must be submitted and approved for energy beet-based fuels to be able to participate in federal renewable fuel incentives such as the Renewable Fuels Standard, and agricultural programs such as crop insurance and access to Commodities Credit Corporation funds as part of the Farm to Fleet program.
- Continuing to develop energy beet seed stock bred for Delmarva conditions and determining best practices and equipment for planting, harvesting, pest management.
- Clarifying the nutrient management benefits of growing energy beets.
- Establishing use of high protein energy beet residues for poultry feed.
- Building a pilot scale facility to improve sucrose extraction and the enzymatic conversion system and to research enzyme recycling and other ways to reduce the cost of the system.
- Fleshing out, with industry expertise, ideas for barge-based conversion facilities and barge transportation.
- Optimizing the fermentation processes for conversion of energy beet sugars to ethanol (Purdue University) and oils (USDA National Center for Agricultural Utilization Research).

- Recycling enzymes to reduce production costs.
- Optimizing the conversion of ethanol to jetfuel and renewable chemicals (Vertimass).
- Exploring the availability and suitability of local facilities for jetfuel production, with priority given to reviving stranded industrial assets or adding capabilities to existing refineries.

This project, in its initial stages, has engaged a number of renewable fuel industry and academic personnel, with outreach during UMES and USDA events in the region to the agricultural community and occasional interactions with state and federal government agencies and nonprofit organizations. As the project is pursued, involvement should expand to include a wider range of stakeholders who have interest, concerns, suggestions or questions about aspects of the proposed project and who would like to become involved in next steps.

Although they have not been assessed in depth, this report lists some government programs and initiatives that can benefit or shape the development of this project such as programs under the US Departments of Agriculture, Energy and Defense and the Environmental Protection Agency and the state of Maryland such as the nutrient management and trading programs. Evaluation is based on current government policies, regulations and opportunities which are subject to change.

This report provides a description of how a new crop can complement, not disrupt, Delmarva economic activities, revive underutilized or stranded agricultural and industrial assets in the Mid-Atlantic and bring to the region new wealth and jobs based on bio-based industries of the future, starting with high protein feed, sustainable renewable transportation fuels and renewable chemicals. It should be used by farmers, land owners, government officials, economic development staff, community leaders, potential investors, researchers, students contemplating career paths and the general public for information about what it will take to develop a successful sustainable feed and fuel industry on the Delmarva to serve Mid-Atlantic markets.

The study has determined that on the Delmarva it is economically possible for energy beets to be grown and processed into advanced ethanol as a stand-alone product for motor transportation or as a feedstock for renewable jetfuel to meet the needs of the US Navy at Norfolk complementing, not disrupting existing agricultural industries. Alternative markets for commercial aviation biofuel or for ethanol as feedstock for chemical production should give investors and growers confidence as they consider developing a new industry in this area.

Section 1: Purpose and Scope of Feasibility Study of Eastern Shore Energy Beet to Jetfuel Project

Advanced Biofuels USA[1] has performed an independent process-flow and economic analysis of using energy beets grown on the Delmarva Peninsula for the production of biojetfuels and other bioproducts. Data for this analysis was produced from a 2016 test planting and processing of Plant Sensory System energy beets at the University of Maryland Eastern Shore research farm in Princess Anne, Maryland using enzymatic conversion system developed by Atlantic Biomass at Hood College in Frederick, Maryland.

The Delmarva Peninsula was selected as a potential energy beet region because of the economic advantages offered by its close proximity to:

- Immediate US Navy demand for sustainable alternative renewable jetfuel (SAJF) at Naval Station Norfolk in Virginia;
- Potential commercial demand for biojetfuel from airports from New York to Washington, DC;
- Jetfuel refineries in Philadelphia, Pennsylvania.
- Stranded industrial assets in Baltimore, Maryland.

This 2016 UMES energy beet project, described in detail in Appendix 1, was designed to explore three aspects of energy beet agronomy and processing, and identified two additional aspects which could make growing energy beets economically feasible on the Eastern Shore.

Initial Questions:

1) Could energy beets grow in the warm, humid climate of the Delmarva? Sugar beets, from which energy beets are derived, usually grow in colder, drier climates.

2) Could the harvest season for energy beets be extended to 4-5 months reducing storage requirements, decreasing the size of the processing facilities and reducing the amount of capital investment required for processing?

3) Could the use of the beet root polysaccharides, not just the sucrose, be used to increase biofuel production to twice that of corn starch on a per acre basis?

[1] An independent 501(c)3 crop and technology neutral educational nonprofit. www.AdvancedBiofuelsUSA.org

Additional Questions:

1) Could growing energy beets, which take up significant phosphorus from soil, produce cost reductions in nutrient management practices required to reduce phosphorus runoff into the Chesapeake Bay?

2) Could high protein solids produced during the saccharification process be used to supplement nutritional needs of the local poultry industry and provide value-added income for growers and processors?

The analysis of the project was also done recognizing two challenges of the current Delmarva economy:

1) A new crop that could revitalize stranded local agricultural resources while complementing the important poultry industry; and

2) Minimal freight transportation infrastructure.

Examining these factors informed an analysis of whether energy beets grown on the Eastern Shore could be an economically feasible feedstock to produce sustainable alternative jetfuel (SAJF) for the Mid-Atlantic Navy and commercial markets.

1.1 Description of UMES 2016 Energy Beet Test Project

Twenty-five different test varieties of energy beets were planted in mid-April 2016. Harvest took place monthly from August through December. Energy beets samples were harvested and processed to test for sugar and liquid content. Biomass samples were also hydrolyzed to fermentable sugars and these sugars were tested for production of ethanol. Sample beets were also tested for phosphorus content. Specific tasks performed by project partners were as follows.

University of Maryland Eastern Shore: Provided and prepared test plots on experimental farm for energy beet cultivation. Provided faculty expertise, professional farm management services and student research assistants for planting, harvesting, processing and energy beet biomass storage. Provided analysis of phosphorus uptake and use of beet tops.

Plant Sensory Systems: Developed and provided 25 energy beet varieties for planting. Conducted field processing and testing. Provided data on biomass and sugar yields.

Atlantic Biomass: Conducted field and lab analysis of energy beet polysaccharides. Converted energy beet biomass to sugars using proprietary enzymatic hydrolysis enzymes and system.

Purdue University (LORRE Lab): Converted energy beet sugars to ethanol using proprietary microbes.

Potential Partners for Conversion to Jetfuel: As part of the 2016 project, the team explored two potential paths to jetfuel production: alcohol/ethanol-to-jet (ATJ) via a process developed at Oak Ridge National Laboratory and being commercialized by Vertimass in Massachusetts; and sugar-to-jet via conversion of sugars to single cell oils and co-products using oleaginous yeast from the USDA Agricultural Research Service National Center for Agricultural Utilization Research in Peoria, Illinois.

In addition to these jetfuel conversion processes, Appendices 2 and 3 describe ASTM-approved processes for converting oils to jetfuel and illustrates other renewable jetfuel production processes making their way through the ASTM acceptance process.

No federal or state grants were provided for the 2016 UMES project. Individual partners provided their own resources, materials and expertise.

1.2 Results Reported from 2016 UMES Energy Beet Test Project

Plant Sensory Systems (PSS) provided 25 test cross of their Energy Beet seeds for a small (0.2 acre) field trial at the University of Maryland at Eastern Shore (UMES) to evaluate biomass and fermentable sugar productivity as well as phosphorus uptake by the beets. PSS' hybrid beet lines were developed in part through a 4-year $2.1M cooperative agreement between PSS and the U.S. Department of Energy's ARPA-E to develop energy beets for the growing biofuel/bio-based industries. The new hybrid lines have improved genetics to withstand disease and pest pressures associated with hot and humid climates.

PSS' hybrid seeds plus seed from two conventional commercial sugar beet varieties were planted on April 20, 2016. Beets were maintained with little input (herbicides, fertilizer or irrigation) and were harvested at 30-day intervals starting at 120 days after planting.

For each beet, total weight plus independent measures of root weight and shoot weight were obtained. Beets were juiced at the harvest site and °Brix values were determined. HPLC sugar values were obtained on selected samples by Atlantic Biomass both before and after enzyme sugar hydrolysis.

Phosphorus uptake values were determined from the beetroots by UMES. Two PSS hybrid lines, TC10 and TC17, had high sugar content outperforming commercial hybrid lines at the 180- and 210-day harvests. At the 150-day harvest TC10 had the highest phosphorus uptake value (0.35%) as expressed as a percentage of weight. At the 180-day harvest TC17 had the highest phosphorus uptake value at 0.27%.

1.2.1 Biomass Yields

Beets harvest data from August through November 2016 (December 2016 samples were not analyzed for biomass yield) supported a commercial goal of 40 wet tons/acre. This number was derived from samples of ten highest yield crosses ("Top Ten UMES" in Table 1). Of the 25 test-crosses, these 10 were chosen as most representative of what would be used in commercial applications.

Table 1: Average Yields of Top Ten Yield
University of Maryland Eastern Shore Energy Beet Harvests (2016) Test-Crosses
(Test-Cross Name are Proprietary)

Wet Tons/Acre
57
57
42
40.5
37.7
36.5
36
33.3
31.5
31.2
40.27

Plant Sensory Systms, LLC

Individual UMES wet biomass yield numbers are averages from multiple plants harvested from 10 feet of individual test-cross plantings. This was done to average out effects of individual beet sizes. Identification of individual beet varieties is proprietary and omitted from this table.

In order to determine if these yield numbers are comparable to other energy beets being tested in North America, they were compared with non-irrigated wet beet tons/acre data from 2009-2013 "Industrial Beet" Tests conducted in North Dakota by Green Visions and North Dakota State University.

Note that neither of these data sets represent maximum commercial yields but are instead being used to determine the relative status of the respective crops. Results were as follows:

1. Yield data from all 25 test-crosses in the 2016 UMES test, of which not all were selected for peak yields, were very similar to the 5 years of non-irrigated testing in North Dakota.

UMES: 26.9 wet tons/acres
NDSU: 26.2 wet tons/acre.

This indicates that the Delmarva climate and growing conditions are at least as good as "traditional" sugar beet growing areas of the Upper Midwest. It also shows that greater yields are possible when low producing test varieties are not planted.

2. Both UMES and NDSU yields showed the same increase in total biomass (34.6% NDSU, 38% UMES) over commercial sugar beets grown in North Dakota. These results show that Industrial/energy beets are able to significantly increase total sugar and biofuel production over commercial beets which is the argument for planting them.

3. The average of the top 10 UMES yields, 40.2 wet tons/acre, was about 53 percent higher than the North Dakota non-irrigated average. This indicates that Delmarva grown energy beets have the potential for commercially sustainable economic yields.

Table 2: Yields from University of Maryland Eastern Shore Energy Beet Harvests (2016) compared to North Dakota State University Industrial Beet Harvests (2009-2013)

Weight at Harvest: Energy Beet Data	Wet Tons/Acre
UMES Aug 2016 Avg	**19.25**
UMES Sept 2016 Avg	**26.8**
UMES Oct 2016 Avg	**31.3**
UMES Nov 2016 Avg	**30.3**
2016 UMES Harvest Average: No Irrigation	**26.9**
NDSU Industrial Beets: No Irrigation Avg 2009-2013	**26.2**
Top Ten of 2016 UMES Harvest Average: No Irrigation	**40.2**
% Increase over NDSU Non-Irrigated Industrial Beets	**53%**

NDSU Sugar Beets: 2007-2012 Irrigated and Dry	**19.46**
NDSU Industrial Beets: No Irrigation Avg 2009-2013	**26.2**
% Increase over NDSU Sugar Beets	**34.6%**
2016 UMES Harvest Average: No Irrigation	**26.9**
% Increase over NDSU Sugar Beets	**38%**

Source: Atlantic Biomass, LLC

1.2.2 Fermentable Sugar and Biofuel Production

The economic basis of the proposed Delmarva energy beets to bio-jetfuel production system is to use biomass sugars derived from beet root polysaccharides as well as the beet sucrose to produce biofuels. To determine if this hypothesis had value, samples from the 2016 test season were processed with the proprietary Atlantic Biomass sequential enzyme system that releases glucose, fructose, xylose, arabinose, and galacturonic acid monosugars from root polysaccharides. As shown in Table 3, biomass sugars from twelve 2016 samples averaged about 42 percent of total fermentable sugars available in the test energy beets (column 4). Another way to look at this data (column 5) shows the percent increase above sucrose available from biomass sugars. Increases ranged from 26 to 185 percent, depending on time of harvest, with a harvest-wide average increase of over 80 percent. These results indicate that biomass sugars could have a substantial economic impact on per/acre biofuel production.

Table 3: Biomass, Sucrose, and Total Fermentable Sugar Yields from University of Maryland Eastern Shore Energy 2016 Beet Harvests (Specific Test Cross Information Is Proprietary)

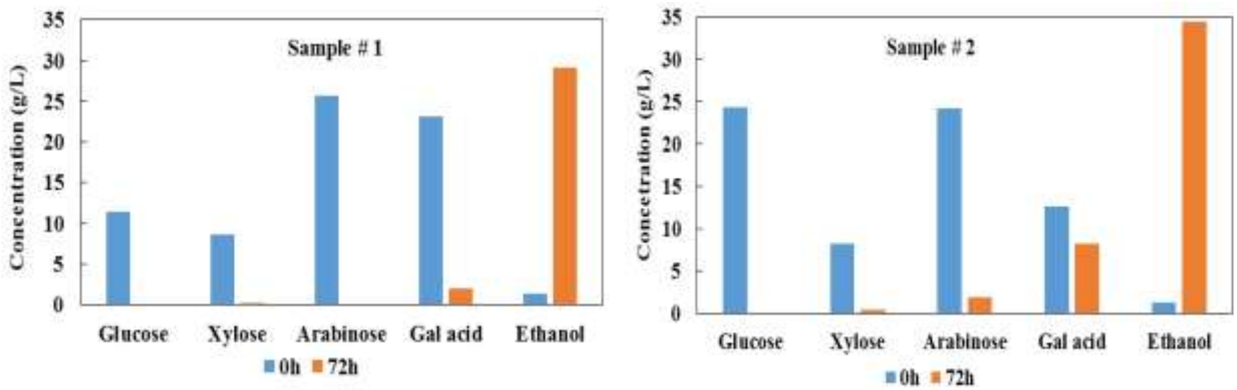
Harvest Month (1)	Total Sugar % of Wet Beet Weight (2)	% Sucrose Sugar (3)	% Enzyme Biomass Sugars (4)	Biomass Sugars: % of Sucrose Sugar (5)
August	**23.2%**	**62.5%**	**37.5%**	**59.9%**
August	**18.4%**	**79.2%**	**20.8%**	**26.3%**
August	**22.3%**	**65.3%**	**34.7%**	**53.2%**
August	**23.2%**	**62.5%**	**37.5%**	**59.9%**
September	**20.7%**	**57.5%**	**42.5%**	**73.9%**
October	**18.8%**	**62.4%**	**37.6%**	**60.2%**
October	**19.0%**	**61.7%**	**38.3%**	**62.1%**
October	**19.3%**	**55.2%**	**44.8%**	**81.0%**
November	**15.4%**	**56.5%**	**43.5%**	**77.1%**
November	**21.9%**	**56.5%**	**43.5%**	**76.8%**
November	**28.1%**	**38.5%**	**61.5%**	**159.4%**
November	**31.0%**	**35.0%**	**65.0%**	**185.4%**
Average	**21.8%**	**57.7%**	**42.3%**	**81.3%**

Atlantic Biomass

However, for the biomass fermentable sugars to have value for the bio-jetfuel project, they must be readily convertible to either the bio-jetfuel or an intermediate feedstock. For this project, the system being developed would use ethanol as an intermediate. (See Section 2.1 for system design details.)

Researchers at Purdue University processed samples of beet biomass sugars produced with the Atlantic Biomass saccharification process with *E. coli* FBR5. Preliminary results (Figure 1) illustrate the potential of this class of bacteria to convert all of the beet sugars to ethanol.

Figure 1: Ethanol Fermentation of Sugar Beet Samples by E. coli FBR5.



Ethanol fermentation of sugar beet samples by *E. coli* FBR5. Hydrolysates were enzyme hydrolyzed by Atlantic Biomass proprietary enzyme process. *E. coli* (1 g/L) was added to the hydrolysates with pH adjusted to 7.0. The final volume for all the samples was 25 mL.

These results show that the combination of the Atlantic Biomass saccharification process with *E. coli* FBR5 fermentation provides the basis for a high yield biomass to biofuel/bioproduct precursor system.

Combining these yield results with the target per acre wet weight yield of 40 tons/acre shows that the Delmarva target yield of 1000 gallons/acre ethanol or 625 gallons/acre of bio-jetfuel is possible (Table 4). Oxygen in ethanol is removed to create the long-chain hydrocarbons of jetfuel, so the yield is lower.

Table 4: Potential Delmarva Ethanol and Bio-Jetfuel Per Acre Yields

Wet Wgt Tons/Acre	% Total Sugars	Tons Sugar/Acre	Gallons Ethanol/Acre@ 15.4 lb/gal (US DOE value)	Gallons Jetfuel/Acre @ 62% Ethanol (oxygen removed)
40	**21.8%**	**8.72**	**1,132**	**702**

In addition, these potential rates of biofuel production indicate that biofuel production of *twice that of corn starch on a per acre basis* would be possible. For example, an average Maryland yield[2] of 152 bushels of corn per acre produces about 2.8 gallons of ethanol per bushel or about 425.6 gallons/acre of ethanol from the corn starch.

An advantage that energy beets have over other "cellulosic" or advanced biofuels feedstock rests in its lack of lignin. Lignin is the substance in cell walls that provides strength, that enables plants to stand upright. A significant amount of the biomass in switchgrass, corn stover and woody biomass, it is very difficult to break down into constituent sugars.[3] Thus, less of the biomass converts to sugars. By using a crop that grows underground and has almost no lignin, nearly all of the biomass is available for conversion to useable sugars without expensive pretreatment.

1.2.3 Phosphorus Uptake

Phosphorus uptake averaged 83 lbs/acre in samples of a range of energy beet varieties, including some control samples as well as those bred for the climate. In 2009-2011 studies of uptake of P for corn, sorghum grass, grain sorghum, soybeans and cowpeas grown on fields at UMES with 25-year histories of heavy poultry manure applications concluded that some genotypes of corn, cowpeas, and fodder soybeans could play an important role in soil nutrient management.[4] The preliminary results from the 2016 energy beet harvests significantly exceeded those of the 2009-2011studies and indicate the potential for energy beets to take up significantly more phosphorus per acre. This also illustrates a need for continued research into the role energy beets could play in soil nutrient management plans on the Delmarva.

Recent unpublished results of test plots at UMES show the significant difference between P uptake of energy beets over corn or sorghum. Dry samples indicate that the P is located in the solids remaining after conversion of biomass to sugars, not in the sucrose-containing liquid.

Table 5: Phosphorus Removal Rates of Crops Grown at University of Maryland Eastern Shore

Crop		**lbs P/acre**
Corn*		49.2
Sorghum*		38.1
Energy Beets		82.8

Amy Collick, Ph.D., University of Maryland Eastern Shore
* Corn and Sorghum were grown in neighboring plots

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[2] USDA State Agriculture Overview for Maryland 2016. Accessed 7/3/2017 https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=Maryland

[3] Lane, Jim, "MetGen, Sweetwater unlocking lignin – the roughest, toughest, ornieri’st material that ever bushwhack’d a pioneer in the Valley of Death" Biofuels Digest, August 17, 2017 Accessed 8/17/17 http://www.biofuelsdigest.com/bdigest/2017/08/16/metgen-sweetwater-unlocking-lignin-the-roughest-toughest-ornierist-material-that-ever-bushwhackd-a-pioneer-in-the-valley-of-death/

[4] Dadson, Robert B. and Hashem, Fawzy M., Poster: "Potential of Certain Plant Species in Hyperaccumulating Phosphorus from Manure-Enriched Soils" University of Maryland Eastern Shore.

1.2.4 Animal/Poultry Feed

Due to lack of sufficient amounts of protein residuals from conversion of test samples of energy beets to polysaccharides at the time of this study, research has not yet been conducted on the nutritional value of these high protein solids for poultry or other animal feed.

Use of protein co-products as animal feed can be expected as sugar beet pulp from table sugar production and from ethanol production provides feed for livestock in other parts of the US and around the world and high protein distillers grains (DDGS) from corn ethanol production are a significant co-product of corn ethanol production.

Beet tops are used in Germany as animal feed, particularly silage.

Section 2: Implementation

2.1 Proposed Commercial System Design

Based on the results presented above, the team was able to develop a process that could be used for commercial production, illustrated in Figure 2: Delmarva Energy Beet to Biofuel and Bioproducts System: Commercial Design Concept.

Salient features of this process are:

- A stable intermediary chemical was selected to serve as a feedstock for a variety of production options. Ethanol was the chemical selected. Besides being a feedstock for biochemicals and bioproducts, bioethanol has an existing Mid-Atlantic market that can be served while biojetfuel markets develop.
- Separate fermentation processes are used for sucrose and the biomass sugars (polysaccharides) to maximize production and reduce operational costs.
- The system was designed to be used in centralized or decentralized configurations.
- A barge-based modular approach enables scale-up from a 20 MGY facility to completed 100 MGY biorefinery and provides flexibility in processing locations while minimizing the carbon footprint.[5]

[5] The initial module of 20MGY nameplate capacity is consistent with other cellulosic ethanol biorefineries under development such as Dupont Cellulosic Ethanol in Nevada, Iowa (30MGY) and Poet-DSM Advanced Biofuels LLC—Project Liberty in Emmetsburg, Iowa (20-25 MGY). Schill, Susanne Retka andBailey, Ann, "Inside the Cellulosic

- The system takes advantage of just-in-time harvesting beets from August to December, avoiding costly storage expenses.
- A single-cell oil system can also be added to the basic configuration.

2.1.1 Description of Process

The process illustrated in Figure 2 Delmarva Energy Beet to Biofuel and Bioproducts System: Commercial Design Concept begins with "just-in-time" beet harvest using equipment traditionally used for harvesting sugar beets, with greens removed at the field. Trucks transport beets to the processing facility where they are washed and crushed.

Sucrose in solution is squeezed out to follow a yeast fermentation path.

The beet root cell walls (biomass) undergoes enzymatic hydrolysis to convert the cellulose, hemicellulose and pectin into glucose, fructose, arabinose, galactose and galacturonic acid.

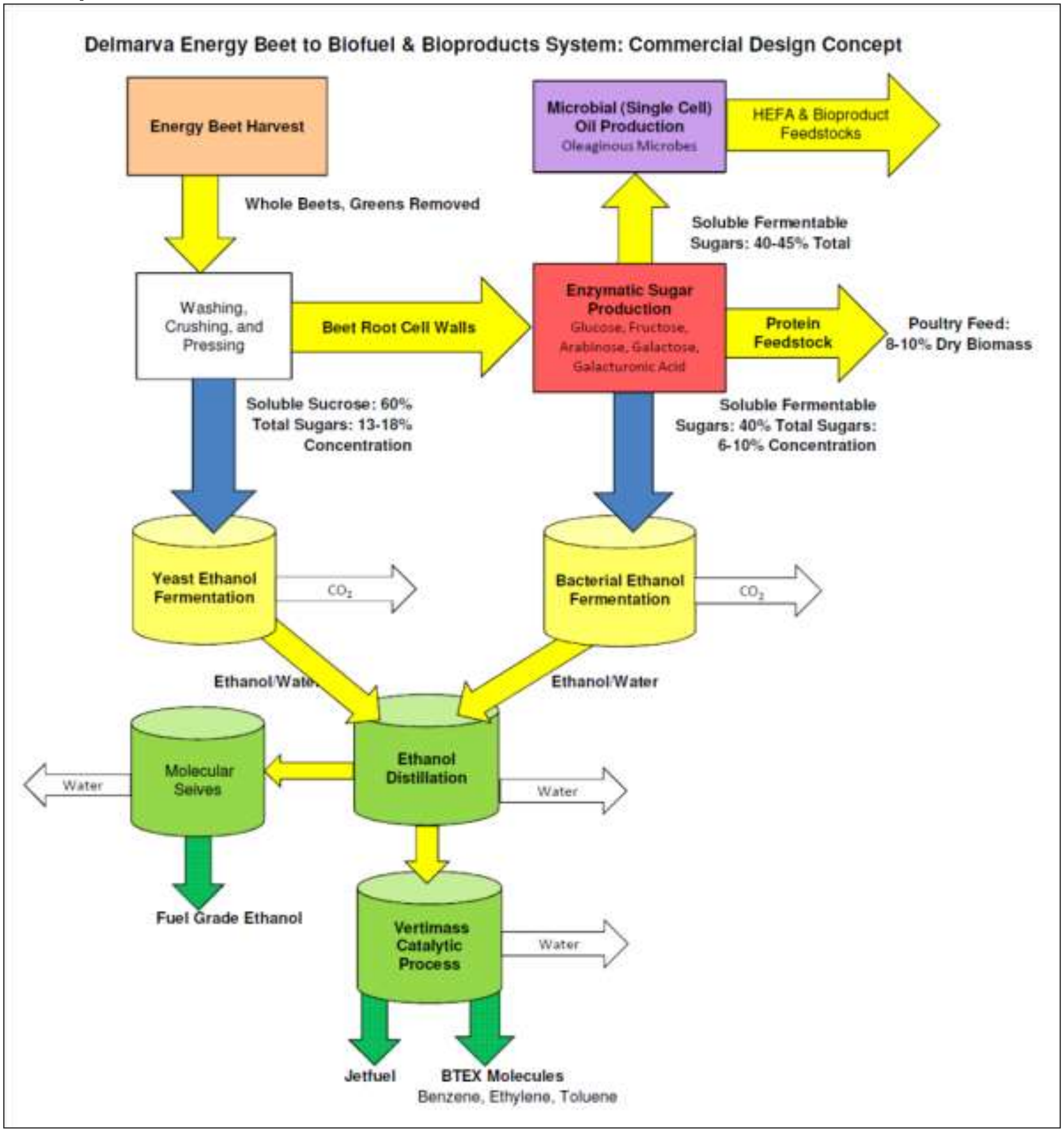
These sugars can then be converted either into oils for jetfuel production in standard, approved processes or they can be converted via bacterial fermentation into ethanol. The two streams of ethanol can be joined for distillation.

If the ethanol will be used for fuel it will go through additional dehydration with molecular sieves. If the ethanol will serve as a feedstock for jetfuel and renewable chemicals, it will be go through an alcohol-to-jet conversion process.

Co-products are CO_2 (from the fermentation step), water (from the distillation and dehydration steps) and high protein solids from the saccharification step.

Industry," Ethanol Producer Magazine, August 2017 Accessed 8/21/2017 http://www.ethanolproducer.com/articles/14479/inside-the-cellulosic-industry

Figure 2: Delmarva Energy Beet to Biofuel and Bioproducts System: Commercial Design Concept



Source: Atlantic Biomass

2.1.2 Acreage Required for Commercial Scale System

Results of the 2016 project indicate that approximately 1000 gallons of ethanol per acre can be produced. This translates into roughly 625 gallons/acre of jetfuel. The difference between ethanol and jetfuel yields is due to the removal of oxygen. Biojetfuel is composed only of long-chain hydrocarbons while ethanol molecules include oxygen. Yields of jetfuel from biologically derived oils also see a similar reduction in yield due to the removal of oxygen from the oil feedstocks. In the proposed Vertimass process, the oxygen is not 'lost,' but used in renewable chemical co-products.

The accepted size of a commercial biorefinery in the United States is 100 million gallons per year (mgy). Using the 1000/625 gallon/acre figure, analysis was done to determine if there is sufficient acreage on the Delmarva to supply a commercial scale biorefinery.

Because energy beets would be a new crop, there is a ceiling on the amount of acreage that could be converted without disturbing existing agricultural industries, in particular, the poultry industry which relies on locally grown corn for feed. Therefore, three assumptions were made to determine the cropland that could be initially available.

1. Approximately 50,000 acres of idle cropland would be available for energy beets.
2. Approximately 10% of rotational cropland would be used to grow energy beets each year in rotation with customary corn and soybeans.
3. Poultry feed protein can be produced from energy beets in amounts sufficient to substitute for that provided by other crops in rotation.

The Delmarva Peninsula, has nearly 1.2 million acres of cropland that could produce sustainable energy beet crops over an extended harvest period. Using about 10 percent of current rotational crop land, along with revitalization of about 40% of idle crop land could successfully integrate energy beet production into the existing agricultural industry.

Results from the 2016 test crop and USDA agricultural census data[6] show how the Delmarva Peninsula can meet these objectives. Note that 70% of the total could be grown in Maryland.

[6] USDA 2012 Agricultural Census https://www.agcensus.usda.gov/Publications/2012/

Table 6: Delmarva Peninsula Cropland Needed for Energy Beet Processing to Ethanol for Jetfuel

See Appendix 4 for county details.

Maryland (Dorchester, Somerset, Wicomico, Worcester, Caroline, Cecil, Kent, Queen Annes and Talbot Counties)		Crop Acres	Idle Acres
Total Acres		764,717	49,573
10% Acres		76,472	
Annual Ethanol @ 1,000 gal/acre			
10% Land in Rotation (Gallons)		**76,471,700**	
40% Idle Land/Year (Gallons)			**19,829,200**
Total Annual Ethanol (Gallons)		**96,300,900**	
Annual Jetfuel @ 625 gallons/acre		**60,188,063**	

Delaware (Kent, New Castle, Sussex Counties)		Crop Acres	Idle Acres
Total Acres		296,896	-
10% Acres		29,690	
Annual Ethanol @ 1,000 gal/acre			
10% Land in Rotation (Gallons)		**29,689,600**	
40% Idle Land/Year (Gallons)			**-**
Total Annual Ethanol (Gallons)		**29,689,600**	
Annual Jetfuel @ 625 gallons/acre		**18,556,000**	

Eastern Shore Virginia (Accomack and Northampton Counties)		Crop Acres	Idle Acres
Total Acres		107,078	784
10% Acres		10,708	
Annual Ethanol @ 1,000 gal/acre			
10% Land in Rotation (Gallons)		**10,707,800**	
40% Idle Land/Year (Gallons)			**313,600**
Total Annual Ethanol (Gallons)		**11,021,400**	
Annual Jetfuel @ 625 gallons/acre		**6,888,375**	

Total Delmarva		Acres	Acres
Total Farmed Acres		1,168,691	50,357
10% Land in Rotation		116,869	
40% Idle Land			20,143

Annual Ethanol @ 1,000 gal/acre		Gallons/Year	Gallons/Year
From 10% Land in Rotation		**116,869,100**	
From 40% Idle Land			**20,142,800**
Total Annual Ethanol		**137,011,900**	
Annual Jetfuel @ 625 gallons/acre			
From 10% Land in Rotation		**73,043,188**	
From 40% Idle Land			**12,589,250**
Total Annual Bio-Jetfuel		**85,632,438**	

USDA 2012 Agricultural Census

The following table shows the amount of jetfuel demand from three potential markets that could be met from energy beets grown on the Delmarva in a system integrated into and complementing existing area agricultural industries.

Table 7: Examples of Jetfuel Demand in Mid-Atlantic Market

Location		**Demand @ 50% BioJetfuel (Gal/Yr)**	**Delmarva + Production (Gal/Yr)**	**% Market**
Dulles Airport		225,000,000	85,632,438	38%
Philadelphia Airport		210,000,000	85,632,438	41%
US Navy Norfolk Depot		146,250,000	85,632,438	59%

2.2 Proposed Transportation System

Most US ethanol production occurs in the Midwest where integrated biorefineries (centralized--containing all processes from feedstock preparation to final fuel) can be located within 50 miles of easily-transported corn feedstock. Because the dis-contiguous smaller farms of the Delmarva, along with the unique characteristics of the Chesapeake Bay topography[7], make it impossible fit this model, a new transportation model consistent with freight movement in the area[8] and mindful of the limitations of existing resources was developed in conjunction with a decentralized "just-in-time" harvest system which should prove more efficient, effective and environmentally sustainable.

[7] Union of Concerned Scientists, "When Rising Seas Hit Home: Hard Choices Ahead for Hundreds of US Coastal Communities (2017)" accessed 8/21/2017 http://www.ucsusa.org/global-warming/global-warming-impacts/when-rising-seas-hit-home-chronic-inundation-from-sea-level-rise#.WZtMpCjfo2w

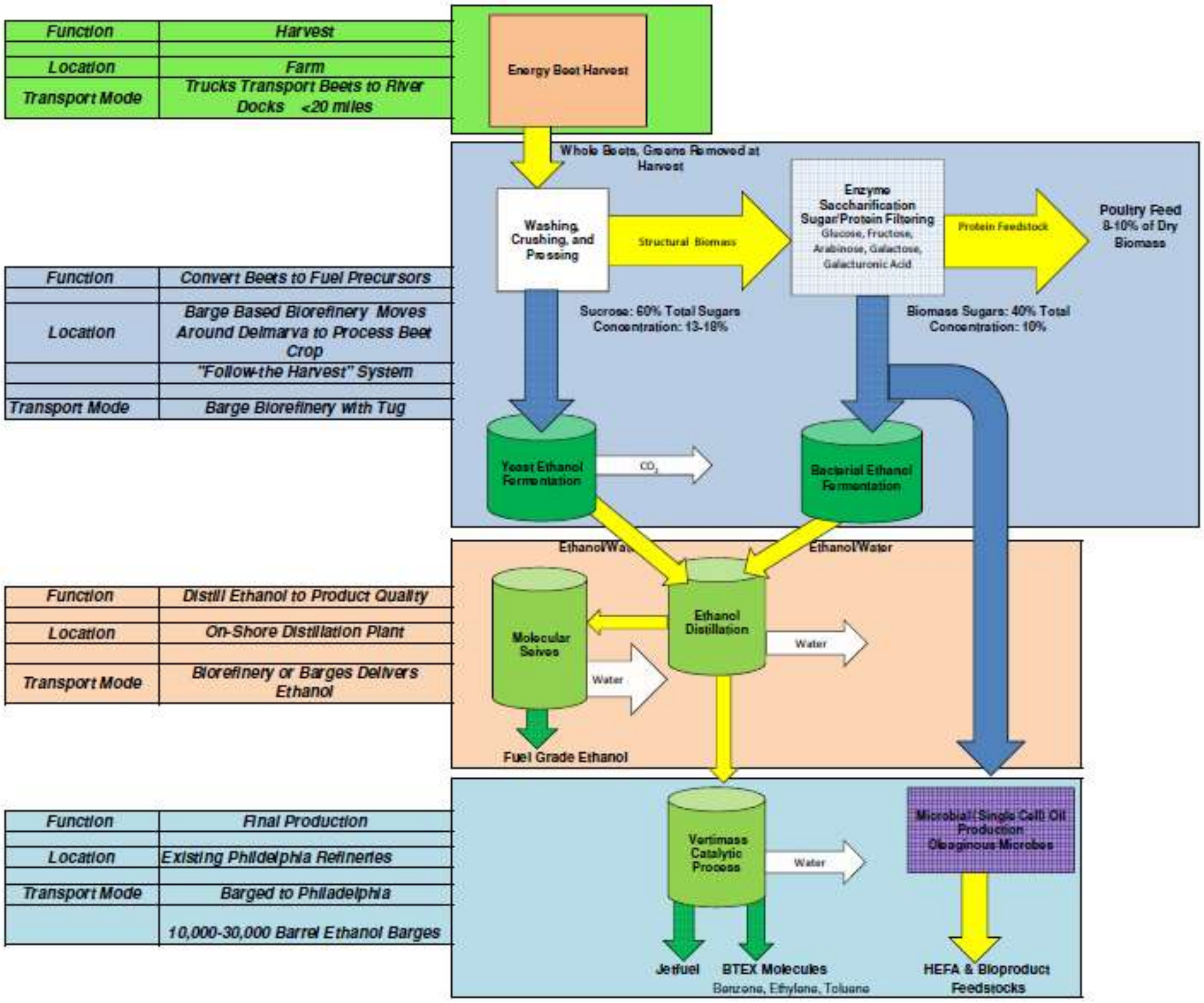
[8] Regional Freight Transportation Study For the Delmarva Peninsula Conducted For The Maryland Department of Transportation October 2010 Accessed 7/5/2017 http://www.swmpo.org/3Content&Pics/Delmarva_Freight_Transportation_Study_Technical%20Report_Final_02142012.pdf

These key concepts and unique resources of the Chesapeake Bay region shaped the development of this new model:

- Deconstruct the “Integrated Biorefinery” concept into production modules that can either be transported for decentralized use or assembled for centralized uses.
- Extend the harvest season to 4-6 months to reduce the daily processing quantities and facility costs from those needed for a traditional short duration harvest.
- Take some processes to disbursed harvest collection points to reduce harvest road transport distances and ship biofuel precursors to larger biofuel “finishing” refineries – often already existing – by rail or water.

Figure 3 illustrates one such distributed process option that would have several processing functions on a biorefinery barge. It would use Delmarva waterways to meet up with harvested beets at existing dockage sites on scheduled “just-in-time” harvest dates. Ethanol and other co-products would be barged to on-shore facilities for final production

Figure 3: Delmarva Barge Based Biorefinery, On Shore Distillation & Final Production



Source: Atlantic Biomass, LLC

The process begins (green section) with transportation by truck from the farm to the initial processing site. This configuration, for reasons described below, locates the conversion of beets to sugars and a biofuel/bioproduct precursor (ethanol) on a moveable barge (purple section) located at local river port docks. Washing, crushing, saccharification, fermentation and recovery of high protein solids takes place on the barge. Ethanol and solids would then be transported for further processing (orange section); ethanol to land-based distillation/dehydration facilities, and solids to an animal feed processing location. Alternatively, the biomass sugars could be shipped for conversion by microbes to jetfuel and/or other bioproducts without being fermented into ethanol. The ethanol, with minimal distillation, could be barged for processing into jetfuel or other bioproducts (blue section); or it could be dehydrated to meet fuel ethanol standards and barged to blenders.

The above system is designed recognizing the energy beets would be grown on dis-contiguous, small (relative to the Midwest) farms throughout the Delmarva. Configured in this schematic to utilize waterway transportation, the concept using existing Delmarva road, railroad and waterway networks options was also considered.

The avoidance of storage facilities for raw beets and juice that are common to traditional sugar beet processing has particular importance. The following capital costs, based on costs developed for a 20 MGY facility by North Dakota State University, are avoided by using a just-in-time harvest.

- Net capital cost for juice storage for summer month operations: $19,181,000 (annual equivalent at 8% and ten years: $2,858,535).
- Capital costs for pile storage: $20,000,000 (amortized at 8% for ten years: 2,980,590/ year for annual equivalent capital cost).
- Operating expenses (without labor or electricity): $900,000.

2.2.1 Roads

The road network infrastructure and capacity in the Delmarva would be stressed with the addition of significant transport of both raw feedstock and intermediate ethanol or finished fuel. Additional road building and maintenance costs could be anticipated. [9]

In areas on the Delmarva that have developed into suburbs of cities such as Annapolis, Maryland and Dover, Delaware, residents, businesses and visitors already experience aggravating traffic jams with extensive road work being undertaken to improve transportation infrastructure. In addition, traffic from Washington, DC, Baltimore and Philadelphia to ocean vacation destinations such as Ocean City in Maryland and Rehoboth, Bethany and Dewey Beaches in Delaware also stresses the road network. The need for widening just over 11 miles of Maryland Route 404, taking it from a 2-lane road to a divided four-lane highway through Queen Anne's, Talbot and Caroline counties, illustrates the pressure on existing roadways.[10] It is not unreasonable to expect that the Delmarva community would not welcome unnecessarily adding long-distance trucks full of beets, ethanol or jetfuel.

In addition, from a sustainability point of view, considering the assumptions made in life cycle analysis models such as GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model) and those used to assess carbon intensity for California's low carbon fuel standard, trucking should be avoided as much as possible,

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[9] Table 10: Annual Highway Congestion Costs, Regional Freight Transportation Study For the Delmarva Peninsula Conducted For The Maryland Department of Transportation October 2010 Accessed 7/5/2017 http://www.swmpo.org/3Content&Pics/Delmarva_Freight_Transportation_Study_Technical%20Report_Final_02142012.pdf

[10] Siegel, Rachel, "Sorry beachgoers, if you take Route 404 to get to the Eastern Shore, it's going to take you longer this summer," The Washington Post, June 29, 2017. Accessed 7/4/2017 https://www.washingtonpost.com/news/dr-gridlock/wp/2017/06/29/sorry-beachgoers-if-you-take-route-404-to-get-to-the-eastern-shore-its-going-to-take-you-longer-this-summer/?utm_term=.246f7e902608

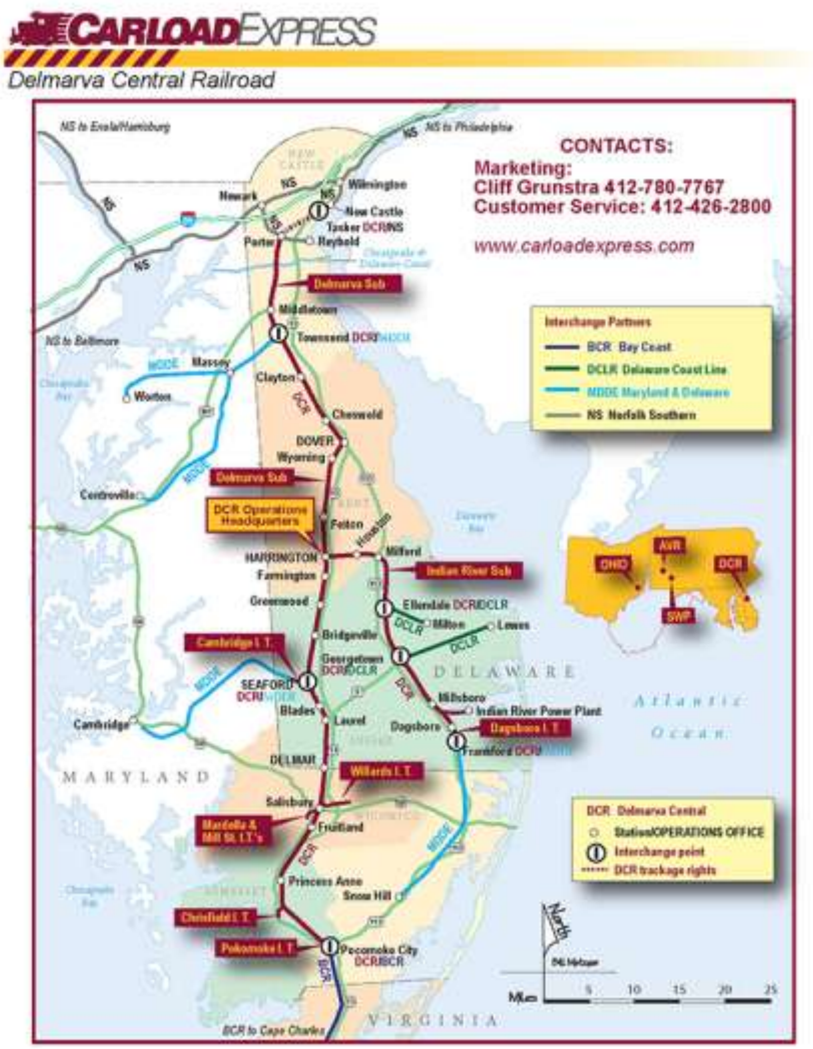
especially if no renewable fuel such as renewable diesel is available to mitigate environmental impacts.

2.2.2 Railroads

While the Delmarva Peninsula has over 200 miles of railroad tracks, it is not served by a Class 1 railroad. Instead, the single-track layout is served by four short-line companies (Figure 4). The primary company, Delmarva Central Railroad, was created from Norfolk Southern properties in late 2016 and is owned by CarloadExpress.[11]

An advantage of this railway net is that it does cover much of the peninsula and connects near Wilmington, Delaware with the extensive Norfolk Southern system.

Figure 4: Delmarva Rail Net



However, there are several drawbacks to the current rail network.

- A portable Biorefinery composed of beet crushing, biofuel sugar production (saccharification) and possible ethanol fermentation would require several cars to carry the equipment. Plumbing and electrical connections would have to be reestablished at each harvest collection site. Tank cars would be delivered and filled with precursors for shipment to refiners at these collection sites. Sufficient off-line siding capacity would have to be present at these sites.

- Currently, there is insufficient off-line siding capacity that would line up with harvest transfer location

[11] CarloadExpress. Delmarva Central Railroad Accessed 6/5/2017 http://carloadexpress.com/railroads/delmarva-central-railroad/

requirements and that would not affect current rail operation.

- The current low-capacity of the lines combined with switching costs between lines and a chemical and petroleum surcharge of $855/car ($.03/gallon), DCR 2016 freight tariff schedule, would add a considerable transportation fee.
- The cost of switching to the newly required DOT-117 enhanced safety tank cars will have to be addressed and included in transportation cost estimates.

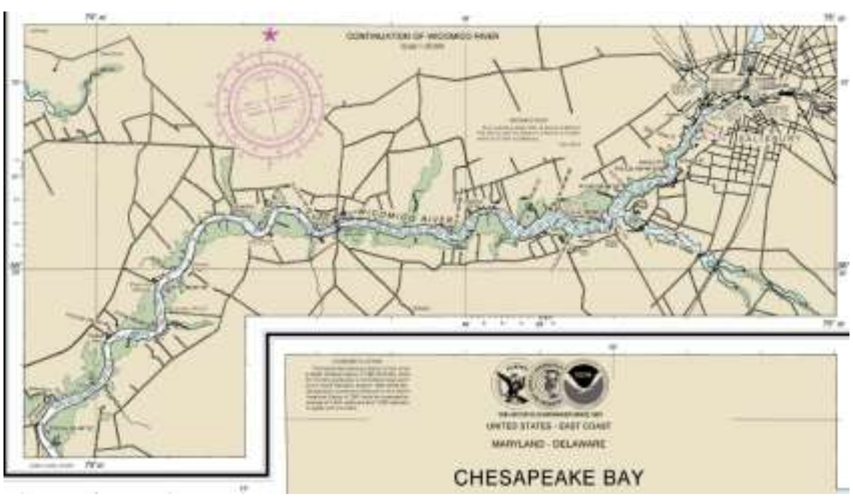
2.2.3 Waterway Transport

While the Chesapeake Bay and the Atlantic Ocean come to mind when Delmarva waterways are thought of, the peninsula is also laced with a number of rivers with commercial traffic channels.

The Delmarva has an historic culture of water-borne shipping. There is substantial barge traffic on these rivers.

For example, because of the absence of pipelines and the lack of rail capacity, oil is barged for Delmarva electrical power and heating from Maryland and Pennsylvania terminals. In addition, Perdue Farms receives Midwestern corn and soybean meal for poultry feed by barge.

Figure 5: Wicomico River Chart to Salisbury, Maryland



Typical of this barge traffic is the Port of Salisbury on the Wicomico River which is located in the middle of the peninsula (Figures 5 and 6). Approximately 800,000 tons/year of barge traffic, both grain and oil are shipped through that port annually.[12]

From a cost perspective, barge rates are about 50% lower than rail and nearly 95% lower than truck rates.[13]

[12] U.S. Energy Information Agency, "Movements by Tanker and Barge between PAD Districts--Fuel Ethanol" Accessed 8/8/2017 http://www.eia.gov/dnav/pet/pet_move_tb_a_epooxe_bmv_mbbl_a.htm
[13] BEACON, "Regional Freight Transportation Study For the Delmarva Peninsula Conducted For The Maryland Department of Transportation," Salisbury University. October 2010 Accessed 7/5/2017 http://www.swmpo.org/3Content&Pics/Delmarva_Freight_Transportation_Study_Technical%20Report_Final_02142012.pdf

Figure 6 : Wicomico River: Barge Dockage at Port of Salisbury

Besides this local barge traffic, ethanol, in 10,000-30,000 barrel barges is delivered to Philadelphia refineries for motor vehicle fuel (E10, E15, E85) from the Great Lakes via the Erie Canal and Hudson River, and from the Gulf Coast. As shown in Table 7 , over 2 million barrels of ethanol were moved to the East Coast in both 2014 and 2015.[14]

Table 8: East Coast Ethanol Movement by Barge[15]

Date	East Coast (PADD 1) Receipts by Tanker and Barge from Midwest (PADD 2) of Fuel Ethanol (Thousand Barrels)
2009	186
2010	335
2011	297
2012	359
2013	356
2014	390
2015	178

Date	East Coast (PADD 1) Receipts by Tanker and Barge from Gulf Coast (PADD 3) of Fuel Ethanol (Thousand Barrels)
2009	1285
2010	1128
2011	1116
2012	939
2013	1146
2014	1826
2015	1980

[14] U.S. Energy Information Agency, "Movements by Tanker and Barge between PAD Districts--Fuel Ethanol" Accessed 8/8/2017 http://www.eia.gov/dnav/pet/pet_move_tb_a_epooxe_bmv_mbbl_a.htm

[15] *Ibid.*

This information shows that two important preconditions for an energy beet-to-biofuel waterway transportation system already exist:

1) A Delmarva barge industry currently exists, and

2) Special purpose ethanol barges already operate in the region.

However, for a waterway system to be considered, two additional questions must be answered.

1) Are there sufficient barge docking/transfer locations to keep field-to-collection point road travel distances under 20 miles?

2) Could an existing barge design be used as the platform for a multiple-process biorefinery?

2.2.3.1 Potential Delmarva Waterway Energy Beet Collection Transfer Sites With Less Than 20 MIles of Beet Road Transport

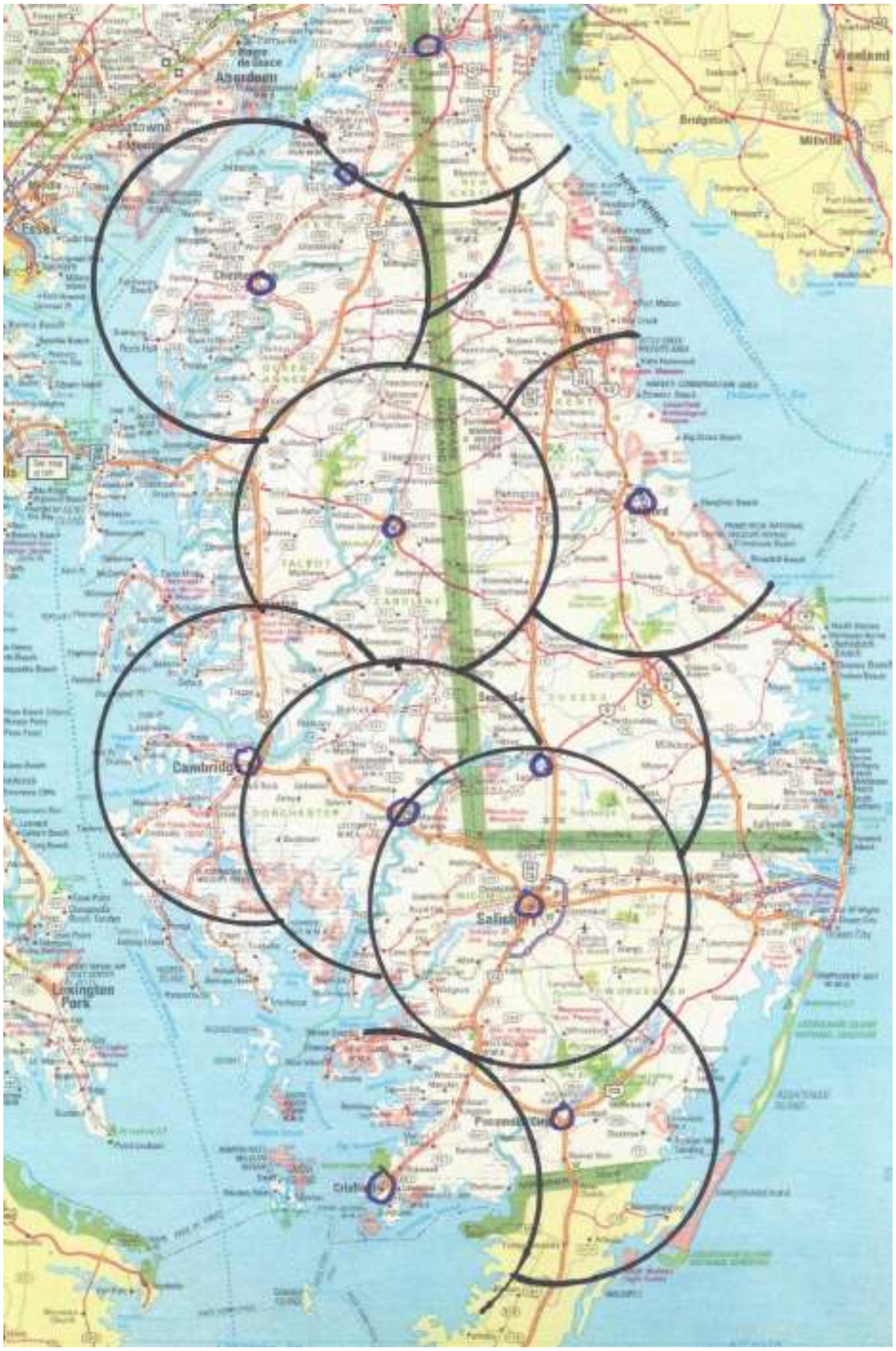
To determine if there are sufficient waterway port or dockage sites within 20 miles of most farm land on the Delmarva, a preliminary analysis was done of the Maryland and Delaware portions of the peninsula which account for 91 percent of total farm land.

Eleven existing ports and/or dockage sites on the Delmarva were selected from maritime charts. Some of these (Crisfield, Cambridge, Chesterton, and Pocomoke City) are historical fishery processing towns, while Vienna is the site of an electrical power plant with a barge transfer facility.

Salisbury has industrial barge transfer facilities as do locations along the Chesapeake and Delaware Canal.

To account for non-direct roads to these sites, 15 mile radius circles, instead of 20, were drawn around each location. Figure 7 shows the results of this preliminary analysis.

Figure 7: Delmarva Energy Beet Waterway System
15-Mile Distances from Beet to Waterway Transfer Sites
Source: Atlantic Biomass LLC



The results of this analysis were promising.

- Approximately 92 percent of the farmland in Maryland and Delaware was within the 15 mile radius circles.
- The primary area outside a 15 mile radius was in northeast Delaware (New Castle County).
- The area near the Atlantic Ocean resorts; Ocean City, Rehoboth Beach, etc., that is beyond the 15 mile radius is largely marshland and not farmed.

Therefore, while additional site work will be required, it appears that an energy beet-to-biofuels waterway transport system based on existing river channels and facilities is possible.

2.2.3.2 Use of an Existing Barge Design as the Platform for a Multiple-Process Biorefinery

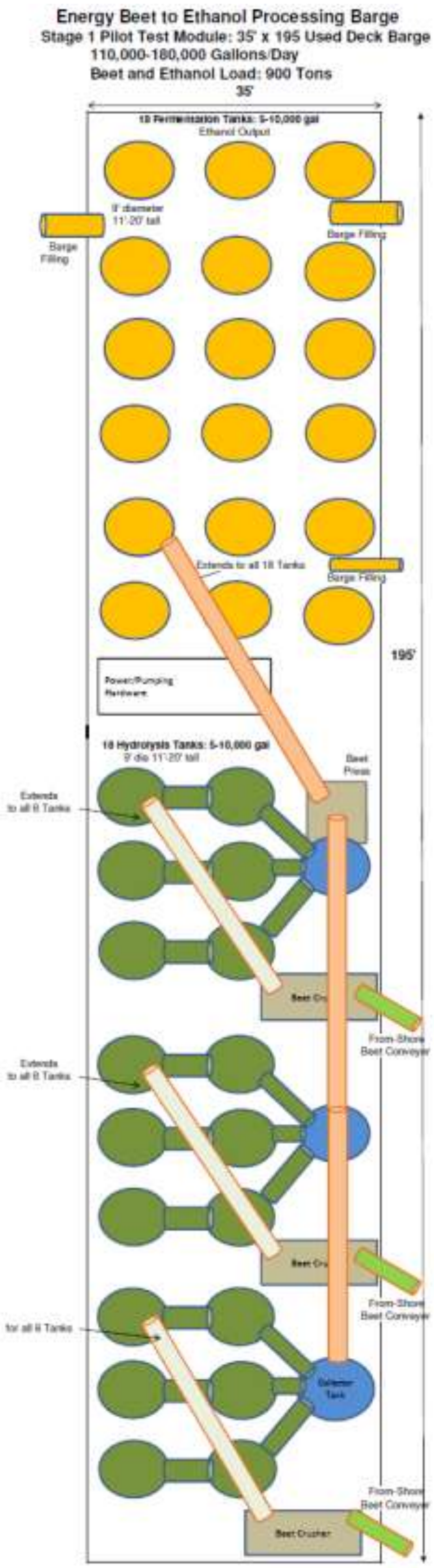
The barge and ship construction industry has acquired a deep portfolio of expertise from fitting complex oil and natural gas processing systems, often requiring high pressures and temperatures, on barges and deep hulled vessels for the petroleum industry. By accessing this knowledge and construction skills the cost of a Delmarva Floating Biorefinery should be minimized.

A cost-effective barge-mounted multifunctional biorefinery would provide the following benefits for the Delmarva project.

- The Delmarva waterways can be used to move the floating biorefinery to multiple locations during the 4-5 month harvest season.
- The waterways provide sufficient docking and out-of-channel room for harvest transfer and processing without interfering with other waterway traffic.
- Used platform barges can be used for the prototype Delmarva floating refinery and early units to reduce costs.
- The components of the biorefinery can stay connected during movement and do not have to be reconnected at each site.
- Multiple barge-based biorefineries could be parked at the same location to increase processing capacity as needed.
- The floating biorefineries could use the Intracoastal Waterway to travel to Florida for energy beet processing in that state during the winter harvest season and to service harvests from potential growing areas in the Carolinas, Georgia, and other Gulf States. This would increase annual revenue for the units.
- The barge-based system, if using marine biofuels like those being developed and tested for freight shipping on canals in the Netherlands, could reduce transportation carbon emissions by up to 25% and also reduce emissions of nitrogen oxides (NOx) and particulate matter.[16]
- Using the ethanol produced onboard the barge for power generation could reduce both electricity costs and carbon footprint.

[16] Holder, Michael, "Heineken cruises ahead with low carbon barge transport pilot," Business Green. June 9, 2017. Accessed 6/9/2017 https://www.businessgreen.com/bg/news/3011601/heineken-cruises-ahead-with-low-carbon-barge-transport-pilot and Mooney, Turloch, "Heineken brews biofuel barge plan to cut emissions," JOC.com. June 9, 2017. Accessed 6/9/2017 http://www.joc.com/port-news/european-ports/port-rotterdam/heineken-brews-biofuel-barge-plan-cut-emissions_20170609.html

Figure 8 Energy Beet to Ethanol Processing Barge Schematic



The initial proposed Delmarva Floating Biorefinery platform would be a 35'x195' decked barge. Given the somewhat tight channels in some of the Delmarva rivers, an articulated design would probably offer the best maneuverability. See Figure 8 for a detailed schematic.

Delmarva Floating Biorefinery Functions and Operational Design

The basic functions of the proposed Delmarva Floating Biorefinery are:

- Transfer Beets to Barge via conveyor
- Wash and Crush Beets
- Transfer Beet Biomass to Saccharification Vessels
- Saccharification
- Transfer Saccharification Liquid to Fermentation Tanks
- Transfer Protein Residues to Barges via Conveyor
- Sugar-to-Ethanol Fermentation
- Transfer of Ethanol to Barges via Pipe

Use of the Modular Design to Reduce Prototype and 1st Generation Construction Costs

The critical process of the biorefinery is a two step saccharification module. Without sugars, fermentation cannot proceed. Therefore, as shown in Figure 8 the design includes many of these modules so that fermentation can continue even if problems develop in some of the modules. Also, to maintain production, three of these modules would be ganged together into a unit that would supply fermentation tanks even if one unit was down.

Another advantage of using relatively small saccharification modules is that one or two units could be built and tested on the barge in conjunction with one or two fermentation tanks. This would not only allow design and operational problems to be identified and corrected at a relatively low cost, but would also save overall costs since the final system would not be built until most, if not all, substantial issues were resolved.

Figure 8 presents a schematic of how these functions could be arranged on a 35'x195' barge. This initial system would produce between 110,000 and 180,000 gallons/day based on the volume of the saccharification and fermentation tanks. Further details of the barge design are proprietary.

Potential Funding Sources for a Delmarva Floating Biorefinery

Due to the part-year production on the Delmarva this floating biorefinery could maximize efficiencies by providing the same biofuel production services further south during other parts of the year.

In addition, the design, technology and engineering could be licensed for use in other parts of the world, such as the river deltas of Africa or Asia, to provide secured biorefining resources to countries trying to build "home-grown" energy industries. The root crop conversion system may be transferrable to crops such as cassava or to the residues from cassava/tapioca processing.

For national energy security and export income, the first of this fleet of floating biorefineries would seem to qualify for funding programs such as the U.S. Department of Transportation Maritime Administration's MARAD Capital Construction Fund. These programs are focused on implementing innovative maritime solutions that would help build the U.S. maritime, agricultural, and energy industries.[17] A floating biorefinery that could bring cost-effective biofuel production to agricultural areas outside the Midwestern Corn Belt would seem to fit that bill.

[17] U.S. Department of Transportation Maritime Administration's MARAD Capital Construction Fund https://www.marad.dot.gov/ships-and-shipping/capital-construction-fund/ and Maritime Administration Strategic Plan: Navigating the Future 2017-2021. Accessed 8/8/2017 https://www.marad.dot.gov/wp-content/uploads/pdf/MARAD-PLAN-2017-2021-FINAL-SIGNED-3.pdf

Section 3: Economic Analysis

3.1 Potential Income, Market Analysis: Nutrient Management and Phosphorus Remediation, Maryland's Nutrient Management and Nutrient Trading Programs

One question posed for this study was: "Could growing energy beets, which take up significant phosphorus from soil, produce cost reductions or economic benefits in nutrient management practices required to reduce phosphorus runoff into the Chesapeake Bay?"

Phosphorus uptake from energy beets from the 2016 harvest, compared to other crops grown in the area, as shown in Table 5, indicates that energy beets exceeded other crops in the amount of P removed from the soil. Except for nitrogen added during field preparation prior to planting, energy beets grown at UMES in 2016 used only the nutrients already existing on the fields. No new fertilizer was added.

Phosphorus (P) has accumulated over time in soils, water, or sediments within the watershed, particularly through decades of use of local poultry manure and litter as fertilizer. This "legacy" P is partly blamed for eutrophication in the Chesapeake Bay, dense plant and algae growth which harms aquatic animal life due to lack of oxygen. Efforts to prevent its runoff or to remove it from the watershed through crop or meat production, or hydrologically in water or sediment are encouraged.[18] Maryland has strict regulations on use of phosphorus in fertilizers in the Chesapeake Bay watershed.[19]

3.1.1 Maryland's Nutrient Management Plan Requirements for Farmland

Estimating the cost or savings that a farmer or landowner would see from growing energy beets as a way to remediate the problem of P runoff is difficult because nutrient management plans are tailored to each farm resulting in a range of costs. In addition, it is hard to quantify the cost of avoiding penalties for failure to have and to implement up-to-date plans. In addition, it is hard to value eligibility for Maryland state incentive programs which are linked to an operator's compliance with nutrient management regulations.[20]

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[18] Smith, Douglas R., "Legacy Phosphorus" Presentation at The State of the Science of Phosphorus Symposium, January 2015 USDA-Agricultural Research Service. Accessed 5/30/17 https://sera17dotorg.files.wordpress.com/2015/02/phosphorus-symposium-proceedings-1-30-15.pdf

[19] Maryland Department of Agriculture, Nutrient Management Program. Accessed 6/5/2017 http://mda.maryland.gov/resource_conservation/Pages/farmer_information.aspx

[20] In FY 2015, MDA issued $30,750 in fines. Those who are not in compliance with nutrient management requirements are ineligible to receive State cost-share from any program funded through the Maryland Agricultural Water Quality Cost-Share (MACS) Program, including the Cover Crop Program, Manure Injection and Incorporation Program, and Manure Transport Program. Nutrient Management Advisory Committee, 2015 Progress Report Implementing Nutrient Management Programs, A Report to Governor Larry Hogan and the Maryland General Assembly. July 1, 2015. Accessed 6/6/2017 http://dlslibrary.state.md.us/publications/Exec/MDA/AG8-804(a)(2)_2015.pdf

One possible way to calculate some of the value would be avoided cost of fertilizer with about $24/acre a typical expense. The avoided cost of expensive infrastructure to mitigate runoff, such as building gypsum curtains or tile drainage management structures, might also factor into calculations of value.[21] Another way to calculate value might be to multiply the 83 lbs/acre uptake by the value of P removed.

Without monetizing the nutrient management value, the main monetary value to farmers from energy beets would come from their sale.[22] Informal discussions with farmers on the Delmarva indicated interest in growing energy beets, a potential cash crop, as part of their nutrient management practices.

Because the value of P uptake as part of nutrient management plans can vary widely for growers, representative value of $50 per acre is used in this study (Figure 15). As the program matures, more data will inform this value.

In addition, sharing of the value with producers who may aggregate credits under Maryland's Nutrient Trading Program[23] could be substantial.

3.1.2 Maryland's Nutrient Trading Program

Maryland's Nutrient Trading Program currently falls under the purview of Maryland's Departments of Environment and Agriculture which describe it as "a public marketplace for the buying and selling of nutrient (nitrogen and phosphorous) credits," and explain, "The purpose of the Program ranges from being able to offset new or increased discharges to establishing economic incentives for reductions from all sources within a watershed and achieving greater environmental benefits than through existing regulatory programs."

Originally focused on point-source pollution such as wastewater treatment facilities, the program is in the process of expanding to include non-point sources, including farmland. These trading regulations have been under development for more than two years and will be administered by the Maryland Department of the Environment.

Credits earned from activities on farmland that meets all nutrient management requirements will be traded, sold and purchased in a system that is currently limited by state and watershed. (Figure 9).

[21] Allen, Arthur, "Gypsum Curtains: Reducing soluble phosphorus (P) losses from P-saturated soils on poultry operations," University of Maryland Eastern Shore, 2015 Accessed 8/16/2017 www.CIG_69-3A75-10-126_Final_Report and Kobell, Rona "Farm sites along upper Choptank to help measure BMPs' efficiency," Bay Journal. August 12, 2016. Accessed 8/16/17 http://www.bayjournal.com/article/farm_sites_along_upper_choptank_to_help_measure_bmps_efficiency

[22] Conversation by Joanne Ivancic with Brooks Clayville, a Maryland nutrient management planner from Snow Hill, Maryland. June 12, 2017.

[23] Rhoderick, John, " Maryland's Nutrient Trading Program: How Trading Works," Presentation, Maryland Department of Agriculture. Accessed 7/6/2017 http://www.mde.state.md.us/programs/water/TMDL/TMDLImplementation/Documents/Webinars/May/Nutrient_Trading_and_Ecosystem_Markets.pdf

Figure 9: Trading Basins for Nutrient Trading in the Chesapeake Bay Watershed

Source: Pinchot Institute for Conservation[24]

One problem these programs aim to address is phosphorus levels in the Chesapeake Bay. Costs to remove P with waste water treatment or to remove P that has run off land into the Chesapeake Bay watershed tributaries are enormous.[25] Studies show that building a facility to remove P from wastewater can cost $100,000 per kg of P removed.[26]

[24] Pinchot Institute for Conservation, "Nutrient Trading in the Chesapeake Bay Region: An Analysis of Supply and Demand." Accessed 8/7/2017 http://www.pinchot.org/gp/Nutrient_Trading

[25] Fears, Darryl, "A dam could derail the Chesapeake Bay cleanup," Washington Post, July 4, 2017. Accessed July 5, 2017 https://www.washingtonpost.com/national/health-science/a-dam-could-derail-the-chesapeake-bay-cleanup/2017/07/04/cd2b4d46-5c1f-11e7-a9f6-7c3296387341_story.html?utm_term=.0d781f74ff98

[26] Nobles, Alecia L., et al., "Investigating the Cost-Effectiveness of Nutrient Credit Use As an Option for VDOT Stormwater Permitting Requirements," Virginia Center for Transportation Innovation and Research, August 2014. Accessed 8/16/17 http://www.virginiadot.org/vtrc/main/online_reports/pdf/15-r9.pdf and Cost Estimate of Phosphorus Removal at Wastewater Treatment Plants: A Technical Support Document prepared for Ohio Environmental Protection Agency by Tetra Tech, May 2013 Accessed 7/6/2017 https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwih5If97vLUAhWJbz4KHePkCXcQFggnMAA&url=http%3A%2F%2Fepa.ohio.gov%2FPortals%2F35%2Fwqs%2Fnutrient_tag%2FOhioTSDNutrientRemovalCostEstimate_05_06_13.pdf&usg=AFQjCNESR_welh3ECPfmPTPyGs_ytnVYmw

Rules and regulations for the Maryland Nutrient Trading Program credits and tools for participating in the Chesapeake Bay watershed credit market are being developed. If the market price of the credits reflects anything close to the costs of extracting P from waste water, growing energy beets as a way to extract P from the watershed could be a key element in the energy beet-to-jetfuel picture, however, because no energy beet industry exists yet, and because rotation crop-based remediation is a relatively new concept, this possibility has not played a significant part in current discussions or negotiations regarding regulations or administration of nutrient management credit trading programs.

Tables 9 and 10 show that about 3,500 tons/year of phosphorus would be removed annually by energy beets grown as feedstock for a 115 MGY biorefinery when compared to corn. The annual phosphorus wastewater treatment operations and management costs to remove that same amount of P from water would be about $61.6 million. On a per acre basis this could be about $531/acre**.** This $61 million/year is equal to about 35% of the value of the 115 MGY of ethanol at $1.50/gal. Credits are usually given for each pound of P that is prevented “from making it off the field and into tidal waters.” Since the Delmarva is essentially all tidal, this study assumes full credits.

In Maryland at the present time, a farm can only earn credits after the land is brought into full compliance with nutrient management goals. The specifics of this requirement currently do not apply to other states in the Chesapeake watershed. The baselines in each state, above which credits can be generated, vary somewhat. At the beginning of an energy beet-to-fuel project, it is likely that the nutrient management benefit would be in helping the farm achieve these goals, without generating any excess credits, so the monetized benefits presented here represent the eventual best case upon completion of 100 MGY ethanol production and fully compliant feedstock fields.

Distribution of this income would possibly be shared among the growers and producers recognizing their symbiotic relationship or the potential role of the biofuel producer as aggregator.

Financing of the biorefineries and farming equipment might also be influenced by this element of the system with consideration of vertical integration or creation of a co-operative to facilitate fair sharing of the nutrient trading credits.

Table 9: Anticipated Phosphorus Uptake from Energy Beets Optimized for Eastern Shore Compared to Corn and Sorghum including P/Ton Conversion

	Tons/Acre	Lbs P/Ton	Lbs P/Acre
Corn	5.1	9.65	49.2
Sorghum	6.4	5.95	38.1
Energy Beets	23.9	3.46	82.8
Energy Beets	40	3.46	139

Amy Collick, Ph.D., University of Maryland Eastern Shore

* Corn and Sorghum were grown in neighboring plots

Table 10: Cost to Water Treatment Facility to Remove the Amount of Phosphorus Taken up by Energy Beets from Soil[27]

Total Acreage	116000				
Corn Replacement	Tons/Acre		Total Tons (116,000 acres)		
Increase P Removal					
2016 Harvest	0.017		1,949		
40 Tons/Acre	0.045		5,184		
Average Tons	0.031		3,566		
Average grams/Ton			3,235,334,480		
10 mg/l to 1 mg/L removal rate	grams		Gallons for 1 ton Phosphorus Removal		Gallons Processed to Equal Energy Beet Removal
P reduction/gallon	0.03402		**26,666,226**		**95,100,954,734**
P reduction/liter (g)	0.009				Annual O&M Costs ($648/MG)
					$ 61,625,419
					Annual Payment per Acre
					$ 531.25

27 Tetra Tech, "Cost Estimate of Phosphorus Removal at Wastewater Treatment Plants: A Technical Support Document prepared for Ohio Environmental Protection Agency," May 2013 Accessed 7/6/2017 https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwih5If97vLUAhWJbz4KHePkCXcQFggnMAA&url=http%3A%2F%2Fepa.ohio.gov%2FPortals%2F35%2Fwqs%2Fnutrient_tag%2FOhioTSDNutrientRemovalCostEstimate_05_06_13.pdf&usg=AFQjCNESR_welh3ECPfmPTPyGs_ytnVYmw

With this in mind, and considering that trading programs impose many conditions on the calculation of credit values, including ratios (such as "deliver ratios" calculated for any non-tidal portions), the potential value derived from extracting P from cropland by planting energy beets and converting them to animal feed and ethanol for fuel or chemicals could be substantial compared to the cost of removing the same amount of P by making changes to wastewater treatment facilities or building new wastewater treatment infrastructure to manage runoff from new residential or business/industrial development.

Looking beyond the Maryland program to credit trading opportunities in Virginia where, through a land bank system, perpetual credits for P removal (P removed each year for 100 years) have reached $20,000/lb P removed[28]. If energy beets are grown on the Virginia portion of the Delmarva, they might qualify eventually for participation in the Virginia program.

The value of credits in Virginia, Maryland and Pennsylvania likely would be different and governed in different ways. At this time, trading between states is not available.

In addition to illustrating this as income/acre (Table 9), Figure 10 illustrates potential net margins in terms of pounds of P removed using the Virginia concept of perpetual credits.

The barge-based 20 million gallon per year ethanol plant would require approximately 580,000 metric tons of energy beet per year.

These beets would contain (and remove) 10,440 mt of P from the soil. Most of this would remain in the feed co-product after conversion of biomass to sugars. Some of this P could then leave the Chesapeake watershed in the form of exported poultry products including food and exported manure. For this exported P, a P credit could potentially be sold. Depending on how regulations are written and based on practices in Virginia, the value of the P credit could include adjustments for any P that remains in the watershed due to manure from poultry being fed the co-product feed with the recycled P being used for fertilizer.

Each year that energy beets are harvested for a 20 million gallon plant, 23 million lbs of P would be removed. If planted each of the next 100 years in rotation throughout the Peninsula, then approximately 230,000 lbs of perpetual P could be credited each year to energy beet harvesting if all of the P left the watershed.

A number of caveats should be considered and assumptions researched. For example, will the need for legacy P removal taper off or will the benefit of P removal from

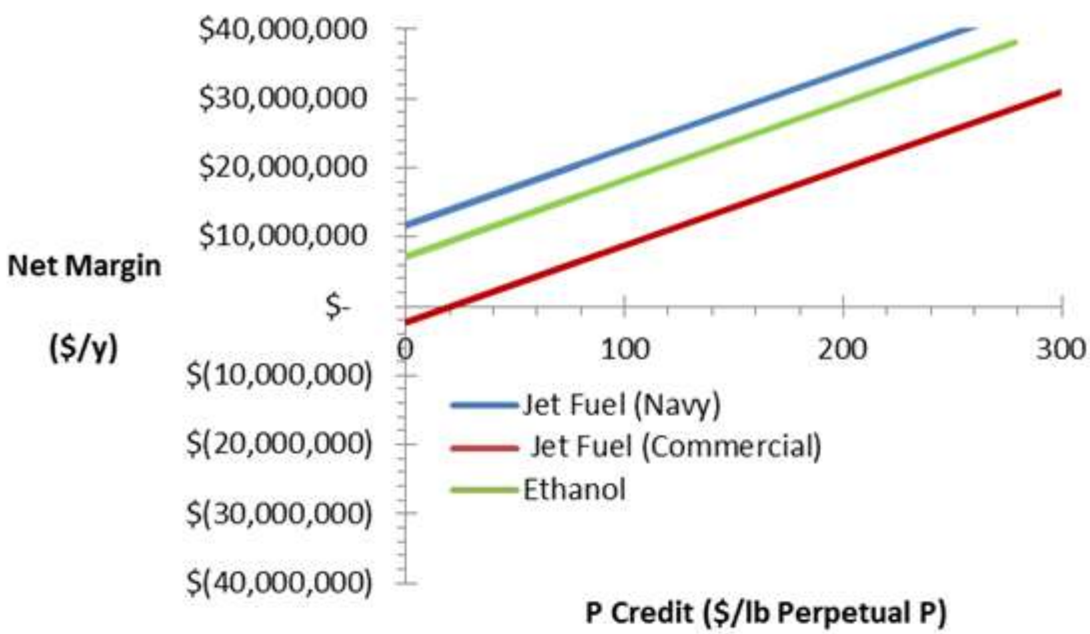
[28] USDA Natural Resources Conservation Service, "Stoking Demand For Nutrient Credits In Virginia: Good News for Farmers and for the Chesapeake Bay." Accessed 7/6/2017 https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/emkts/?cid=nrcseprd354814 and Joanne Ivancic conversation with Patricia Gleason, EPA Region 3, 7/6/2017.

continued use of P fertilizer (including poultry manure) in rotation crops prove to be a long-term benefit.

Even assuming that only 10% of the P removed from the soil leaves the watershed in this form, possibly 23,000 lbs of perpetual P credits could be claimed each year.

In the base case of the model, no P credit is assumed. But if the energy beet-to-jetfuel system could claim these credits it could have a tremendous impact on profitability. Assuming market values for P credits range from 0 to $300 per perpetual P credit, and that a P credit could be taken for 100% of the P removed from the soil, under almost all scenarios the concept would be profitable as shown in Figure 10. If a smaller fraction were removed, the impact on profitability would be proportionally less.

Figure 10: Energy Beet Biofuel Plant Net Margin Sensitivity Analyses. Potential Value of Credit for "Perpetual" (100 year) Energy Beet Removal of P from Chesapeake Bay Watershed



Further Research Needed: Although preliminary research indicates that new varieties of energy beets grown without phosphorus fertilizer on the Eastern Shore take up significant amounts of P when compared to other crops, soil samples before and after planting and testing of the different parts of the beet for P will provide data and information needed to determine if energy beets remediation could meet state nutrient management plan requirements and if the beets reduce legacy P.

This information will impact how growers and land owners can incorporate energy beets into their nutrient management plans and the eligibility of this uptake and removal of P from the watershed for the nutrient trading program.

In addition, regulations now in development should incorporate use of rotation crops as a way to earn credits, relying not on perpetual (100 year) easements or contracts, and enabling continued use of farmland to continue to produce food, feed, fiber and fuel in a manner that removes phosphorus with results analogous to the current practice of converting cropland into forests in perpetuity.

3.2 Potential Income, Market Analysis: Animal Feed from Protein and Beet Tops

Another question for the study was "Could high protein solids produced during the process be used to supplement nutritional needs of the local poultry industry and provide value-added income for growers and processors?"

3.2.1 Poultry/Animal Feed

Delmarva Poultry Industry, Inc., the nonprofit trade association of the meat chicken industry in Delaware, the Eastern Shore of Maryland, and the Eastern Shore of Virginia reported that nearly $1 billion per year is spent on feed ingredients. Delmarva's poultry industry used 85.4 million bushels of corn, 35.5 million bushels of soybeans and 1.7 million bushels of wheat in 2016.[29] If 10% of the land is used to grow energy beets in rotation with these poultry feed ingredient crops, the high protein solid co-product should either serve as a valuable supplement to them or as an equivalent substitute in order to complement, not compete with, this existing dominant Delmarva industry.

Further Research Needed: Assessment of yields and whether the high protein solids remaining after conversion of the energy beet biomass could be used as poultry feed, how that protein might best be incorporated into poultry diets and the commercial value of that feed ingredient is needed.

3.2.2 Beet Tops

With the understanding that all parts of the energy beet have value, Caleb Nindo, Ph.D., Associate Professor & Director at the Food Science & Technology PhD Program at the University of Maryland Eastern Shore has considered three options for using the energy beet "tops" or greens based on traditional uses of sugar beet tops:

- Leaving them on the soil as a soil amendment and winter cover;

[29] Delmarva Poultry Industry, Inc., press release: Chicken Industry, A Mainstay of Delmarva's Economy, Shows Sensible Growth January 17, 2017 accessed 6/6/2017 https://www.dpichicken.org/media/nr_view.cfm?id=564

- Using them for animal feed; and
- Using them in anaerobic digesters.

Dr. Nindo's preliminary investigation, including some conversations with local farmers, led him to conclude that the best initial use of the greens would be for animal feed. He recommended looking at beet greens use in silage as it not only provides feed for animals, but incorporating the beet greens with hay also increases its palatability. This recommendation was seconded by Dr. Jurgen Schwarz, Chair of Agriculture, Food, and Resource Sciences in the School of Agriculture and Natural Sciences, also at UMES. In addition to his academic credentials, Dr. Schwarz brings personal experience of growing up on a sugar beet farm in Germany and confirms the desire of cattle for this type of feed.

Thus, from the animal feed development perspective, silage or hay quality will be improved if energy beet tops are chopped and incorporated into the batches.

At this point, there have been only some experiments with anaerobic digesters on the Delmarva, so no current market exists.

Further Research Needs: To assess the nutritional and commercial value of this choice, further research should explore how the beet tops might affect fermentation time and quality of silage and how this use could lead to increased feed utilization with less wastage of hay. More work is also needed to analyze the nutritional composition of the tops (with respect to their suitability for animal feed formulation). If this initial use proves not as valuable as initially anticipated, the other uses should be explored. Harvesting and transportation of beet tops as well as comparison of the value of overwintering beet tops vs. sowing cover crops also needs study.

3.3 Potential Income, Market Analysis: Ethanol as Ground Transportation Fuel

Besides being used as a jetfuel feedstock, ethanol can be used as fuel for light duty vehicles. Currently more than 2 million gallons of fuel ethanol is shipped from the Midwest to Chesapeake Bay ports each year to be splash-blended to meet E10 (gasoline with 10% ethanol) and other ethanol blend requirements.[30]
Locally produced ethanol could serve the fuel ethanol markets with lower transportation costs.[31]

In addition, as more fuel retailers in the area expand their offerings of higher ethanol blends such as E15, E30 and E85, this market will grow.[32] In mid-2017, The Maryland Grain Producers Utilization Board promoted high octane/high ethanol blends during an

[30] U.S. Energy Information Administration Movements by Tanker and Barge between PAD Districts *Op.cit*.
[31] "Two PA Companies Partner to Fuel Economy," Gant Daily, April 6, 2017. Accessed 6/5/2017 https://gantdaily.com/2017/04/06/two-pa-companies-partner-to-fuel-economy/
[32] Sustainable Energy Strategies, Inc., http://sesi-online.com/index.html

advertising campaign in the Mid-Atlantic. Retail stations will offer 88-octane (E15) for 2001 and newer vehicles, as well as E85 for flex-fuel vehicles.

"There are more than 22 high-octane stations under construction in Maryland and even more in Virginia," said Lindsay Thompson, executive director MGPUB. "The Midwest has had a choice at the pump for years, and now we have one too. Higher blends of ethanol offer owners of unleaded vehicles lower price, cleaner air and higher performance."

This advertising effort is part of a large infrastructure project to install E15 and E85 pumps in the region.[33]

3.4 Potential Income, Market Analysis: Sustainable Alternative Jetfuel (SAJF)

Characterizing the sustainable alternative jetfuel (SAJF) market from a national and regional level provides context for long-term beet-to-jetfuel project success for the Eastern Shore. With commercial and military turbojet and turboprop aircraft consuming the majority of fuel in the form of kerosene-type jet,[34,35] [36]the market opportunity for SAJF is tied directly to the commercial aviation industry and demand from military aviation, specifically, Naval Station Norfolk in Virginia (Norfolk).

3.4.1 Military-First Strategy: Meeting U.S. Navy Demands

Military demand comprises the largest immediate source of demand for biojetfuel. Specific incentives and proximity to the Delmarva provide potential market entry for initial production volumes.[37] The U.S. Navy has set a goal of 50% of total energy consumption to come from alternative sources by 2020 and indicates that renewable fuels help realize energy security goals.[38] Solicitations for 2016 bulk fuel deliveries explained the new biofuel participation.[39] The U.S. Navy has been issuing solicitations

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[33] Maryland Grain Producers Utilization Board, "Maryland grain producers promote E15 across Mid-Atlantic," Ethanol Producer Magazine, March 22, 2017. Accessed 6/5/2017 http://ethanolproducer.com/articles/14225/maryland-grain-producers-promote-e15-across-mid-atlantic

[34] Aviation Technical Review, Chevron Products Company, 2007.

[35] Table 37:Annual Energy Outlook 2017, EIA, 2017.

[36] Because SAJF production for the Eastern Shore substitutes for kerosene-type jetfuel, aviation gasoline and naptha-type jetfuel will not be considered in this analysis.

[37]Annual Energy Outlook 2017, EIA, 2017.

[38] Secretary of Navy Energy Goals, http://greenfleet.dodlive.mil/energy/

[39] As part of the regular bulk procurement for the RMW Program, this solicitation is designed to assist the DON in meeting its goals to increase the use of biofuels. Under this solicitation, DON has a goal that 10% of its total military specification JP-5 aviation turbine fuel and F-76 naval distillate fuel requirements consist of biofuels. The revised F76 (MIL-DTL-16884N) and JP-5 (MIL-DTL-5624V) specifications allow a maximum of 50 percent volume of the finished fuel to consist of synthesized blend components derived from the Hydroprocessed Esters and Fatty Acid (HEFA) or Fischer Tropsch (FT) conversion processes. Offerors are encouraged to submit alternative offers with a minimum of 10% of the permitted blends. Solicitation number SPE600-15-R-0711. Accessed 6/7/2017 https://www.fbo.gov/index?s=opportunity&mode=form&id=cdb3ebc02d977ca6ce6f34416243f2d1&tab=core&_cview=0

for renewable jetfuel since 2014.[40]

Within the Central Atlantic, Naval Station Norfolk has been a leader in promoting biofuels adoption by, among other things, hosting elements of the Great Green Fleet initiative. Norfolk completes over 100,000 flight operations per year. Additionally, Joint Base Andrews (Air Force District of Washington) is comprised of an Air Force and Naval Base located in Maryland. JBA conducted 64,583 aviation operations in 2015 and is projected to conduct 62,305 in 2036.[41] While local military demand may not represent an increasing demand, the military has set specific goals for renewable fuels. Estimates of demand for biofuel which will be blended at up to 50% at Norfolk are 146,250,000 gallons/year of which 85,632,438 gallons/year, or 59% of this market, could be supplied by the Delmarva energy beet commercial facilities and processes described in this study.[42] At $2.18/gallon, listed on recent solicitations from the Department of Defense, this could be a market for locally produced jetfuel.[43]
Updated current standard prices for DLA Energy-procured fuels, effective as of July 1, 2017, have JP5, developed and used by the Navy due to the safety provided by its low volatility, priced at $2.18/gallon.[44]

The U.S. Navy has demonstrated innovation and foresight with respect to advanced biofuels and the ability to execute on that foresight with its Great Green Fleet initiative. The centerpiece of that year-long initiative in 2016 was the John C. Stennis Strike Group that was deployed using alternative drop-in biofuels.

It should be noted that constraints and requirements for federal contracting could limit the overall entry into the military market. For example, fuel specifications, distribution routes, and existing contracts could increase complexity of small quantity sales. Those barriers should be balanced against other market opportunities during offtake review.
With that said, demonstration of economic viability at various stages, and anticipating initial successful production of small quantities of SAJF, would enable early engagement with the military to consider pre-commercial sales that would offer legitimacy and resources to aid commercialization efforts.

The military, airlines, and industry trade organizations have generally identified the requirements for engaging with and selling SAJF. For example, *ASTM 7566 - Standard*

[40] U.S. Energy Information Agency, "Biofuels are included in latest U.S. Navy fuel procurement," Today in Energy, July 25, 2014. Accessed 7/21/2017 https://www.eia.gov/todayinenergy/detail.php?id=17271
[41] APO Terminal Area Forecast (TAF) Detail Report, FAA, 2017. http://taf.faa.gov/
[42] Calculated as 90% of half of total biofuel demand (10% would be F-76 diesel and other half would be demand on West Coast) as described in Tindal, Chris, "DASN Energy Farm to Fleet" Presentation. 2/19/2014
[43] Standard Fuel Prices in Dollars FY2017 Short List www.dla.mil/Portals/104/.../E_16Oct1PetroleumStandardPricesFY17_160929.pdf
[44] The current standard prices for DLA Energy-procured fuels, effective as of July 1, 2017 in Roth, John P. Memorandum, "Fiscal Year (FY) 2017 Fuel Price Change," Deputy Comptroller, Office of Undersecretary of Defense. June 19, 2017. Accessed 6/27/2017 http://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_17Jul1PetroleumStandardPricesFY17_170622.pdf

Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons has been developed and accepted.

In order to facilitate customer adoption, a project should produce fuels that meet already established pathways approved under this standard and, accordingly, will be compatible as a “drop-in” with existing storage, transportation and handling infrastructure and engine requirements.

The alcohol-to-jet conversion proposed for the energy beet process has not yet completed the ASTM 7566 pathway approval process, although the sugars-to-oil-to-jetfuel path might follow the approved Hydrotreated Esters and Fatty Acids (HEFA-SPK) pathway.

Also if energy beets are an approved feedstock, JP5 made from them should be eligible for Commodities Credit Corporation Biofuel Production Incentive payment. The joint USDA and U.S. Navy Farm-to-Fleet Program was announced in December 2013 and added the purchase of biofuel blends into Department of Defense (DOD) domestic solicitations for JP-5 and F-76 fuels. Funds from USDA's CCC are used for this effort to help increase the domestic consumption of agricultural commodities in the biofuel market.

Also, U.S. Navy and Air Force have established a precedent of testing biojetfuel that has not gone through the ASTM approval process by taking ReadiJet® Catalytic Hydrothermolysis Conversion Jet (CHCJ), a 100-percent drop-in renewable jetfuel produced by Florida-based Applied Research Associates (ARA) and Chevron Lummus Global, through the Navy's own alternative fuels test and qualification program

Completion of a life-cycle-analysis documenting the GHG reduction potential and demonstrating that the process, from planting to harvesting to conversion, can be conducted in a sustainable manner and in compliance with environmental rules and regulations would further encourage adoption by offering a clear and compelling story of sustainability for the military as well as commercial airlines to consider in the context of domestic and international goals.

3.4.2 Overview of Commercial Aviation Markets

Two key macroeconomic indicators provide insight into aviation demand:

- Gross Domestic Production (GDP) – Aviation demand generally increases with GDP growth. U.S. GDP is projected to average a low 2.4% growth through 2036.[45]

[45] IHS Global Insight, Dec 2015 World Forecast from *FAA Aerospace Forecast: Fiscal Years 2016-2036*, U.S. Federal Aviation Administration (FAA), 2016.

- Oil Prices –
    - Aviation demand decreases with increasing jetfuel prices which correlate to crude oil prices. Oil prices are expected to increase from the 2016 price of $43 to $100 per barrel in 2023 and $152 by 2036.[46]
    - Low oil prices also discourage innovation and investment.

While the economic forecasts and associated models include many assumptions, understanding the impact of changes allows tracking to forecasted demand. Other drivers influencing jetfuel consumption patterns in the industry include: Technology – More efficient technologies such as engines and airframes can reduce consumption in flight; Operational –Federal Aviation Administration (FAA) initiatives such as optimized profile descent (OPD)/continuous descent approach (CDA) reduces consumption on approach; and Infrastructure – Improved infrastructure can also reduce overall consumption and losses.[47]

3.4.3 Incentives

Around the globe, national and state level programs placing prices on carbon or providing incentives for lifecycle carbon reduction continue to evolve and provide economic drivers for the development of low-carbon transportation fuels. With the recognition that alternatives to liquid jetfuels, such as solar powered airplanes, are not technically viable today, and likely will not be viable for decades to come, policy programs are evolving to preferentially treat the production of SAJF. As indicated in the sections above, competitive pricing will increase the market demand and adoption of SAJF. A number of initiatives are in place to promote the development of SAJF for better cost comparison. Depending upon project specifics, the listed programs could provide a reduced cost of capital or increased revenue to allow for closer price competition with conventional jetfuel.

3.4.3.1 International Policies

Important policy drivers and incentives have been established by international organizations.

- **ICAO** - The United Nations' International Civil Aviation Organization's (ICAO) stated strategic objectives include minimizing adverse environmental effects of civil aviation activities by fostering leadership in aviation-related environmental activities consistent with the UN system for environmental protection policies and practices. Negotiations to recognize the benefits of

[46] *Ibid*
[47] *IATA Sustainable Aviation Fuel Roadmap*, International Air Transport Association, 2015.

biofuels in its Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) are on-going.

- **EU ETS** - Additionally, the European Union has established an emissions trading system (ETS) that is the cornerstone of the EU's policy to combat climate change as a tool for reducing greenhouse gas emissions in a cost-effective manner. The ETS provides the framework for trading emissions which would incentivize adoption of fuels with lower carbon intensity, such as SAJF, in order to meet the caps.

3.4.3.2 United States Policies and Programs

The U.S. has also crafted policy and developed programs related to lower carbon fuels that could incentivize SAJF production and adoption.

- **EPA $C0_2$ Endangerment Findings** -- In 2009, the Administrator of the EPA signed a finding regarding greenhouse gases under section 202(a) of the Clean Air Act, that carbon dioxide ($C0_2$) in the atmosphere threatens the public health and welfare of current and future generations.[48]

  In August 2016 the US Environmental Protection Agency (EPA) issued a finding that Greenhouse Gas (GHG) emissions from aircraft cause or contribute to air pollution (40CFR Parts 87 and 1068 EPA-HQ-OAR-2014-0828; FRL-9950-15-OAR). In that finding, EPA stated that US aircraft contributed 12 percent of GHG emissions from the US transportation sector, 3 percent of total U.S. GHG emissions, and 29 percent of all global aircraft GHG emissions. EPA also announced that regulations to reduce aviation GHG emissions will be forthcoming. The replacement of petroleum jetfuel with a low GHG advanced biofuel could be a possible control measure. By applying GHG emissions findings to transportation in the air as well as on the ground, this finding supports increased use of SAJF.

- **Renewable Fuel Standard (RFS)** – The renewable fuel standard was created under the Energy Policy Act of 2005 (EPAct) and further expanded by the Energy Independence and Security Act of 2007 (EISA), both of which amended the Clean Air Act (CAA). The Environmental Protection Agency (EPA) administers the program. The RFS incentivizes renewable fuel production by obligating a minimum volume of four categories of renewables to replace petroleum-based transportation fuel:

[48] U.S. Environmental Protection Agency, "Endangerment and Cause or Contribute Findings for Greenhouse Gases under the Section 202(a) of the Clean Air Act" Accessed 7/31/2017 https://www.epa.gov/ghgemissions/endangerment-and-cause-or-contribute-findings-greenhouse-gases-under-section-202a-clean

- Biomass-based diesel
- Cellulosic biofuel
- Advanced biofuel
- Total renewable fuel[49]

SAJF and fuel ethanol made from energy beets, once RFS pathway approvals are obtained from EPA, should qualify as advanced biofuel, cellulosic biofuel and/or biomass-based diesel.

The renewable volume obligations (RVO) are tracked via renewable identification numbers (RINs). The requirements create a market for the RINs which can be traded to satisfy the obligations. The RINs derive value in the market for renewable fuel producers that can satisfy the regulatory assurances. Essentially, RINs provide a monetary incentive per gallon of renewable fuel produced.[50] Depending on the biofuel (RIN) category, RINs have generated close to $2.00 per gallon.[51] The production incentives under the RFS deliver substantial revenue premiums for the alternative jetfuel production pathways currently approved by ASTM (D7566).

Due to the volatility of RINs values, this analysis does not include potential income derived from RINs sales.

- **Commodities Credit Corporation (CCC)** – The CCC is a government-owned and operated entity established to assist in the development of new agricultural commodities. The CCC provides assistance through loans, purchases, and payments[52] and is particularly relevant to the Farm to Fleet program.

- **Biomass Crop Assistance Program (BCAP)** – The U.S. Department of Agriculture (USDA) administers the BCAP via the CCC and provides financial assistance in the form of matching payments and annual payments. The assistance is directed to owners and operators of agricultural and non-industrial private forest land who wish to develop biomass feedstocks. BCAP does not provide matching payments for the establishment of annual crops and,

[49] U.S. Environmental Protection Agency, "Overview for Renewable Fuel Standard." Accessed 8/21/2017 https://www.epa.gov/renewable-fuel-standard-program/program-overview-renewable-fuel-standard-program

[50] U.S. Environmental Protection Agency, "Renewable Identification Numbers (RINs) under the Renewable Fuel Standard Program." Accessed 8/21/2017 https://www.epa.gov/renewable-fuel-standard-program/renewable-identification-numbers-rins-under-renewable-fuel-standard

[51] Progressive Fuels Ltd., "PFL Weekly Recap." http://www.progressivefuelslimited.com/web_data/PFL_RIN_Recap.pdf and Research Gate, Figure 2: Historical RIN prices. https://www.researchgate.net/figure/274142356_fig8_Figure-2-Historical-RIN-prices-Prices-presented-here-are-simple-averages-of-the

[52] U.S. Department of Agriculture Farm Service Agency, "About the Commodity Credit Corporation." Accessed 8/21/2017 https://www.fsa.usda.gov/about-fsa/structure-and-organization/commodity-credit-corporation/index and Federal Register, "Notice of Funds Availability (NOFA); Farm-to-Fleet Feedstock Program Biofuel Production Incentive (BPI)," December 29, 2016. Accessed 8/21/2017 https://www.federalregister.gov/documents/2016/12/29/2016-31582/notice-of-funds-availability-nofa-farm-to-fleet-feedstock-program-biofuel-production-incentive-bpi

therefore, during the early years of developing a test crop, only annual payments may be available.[53]

- **Loan Guarantee for Renewable Energy & Efficient Energy Projects** – The U.S. Department of Energy provides as much as $4 billion in loan guarantees to support innovative, renewable energy and energy efficiency projects in the U.S. that reduce, avoid, or sequester greenhouse gases, including drop-in SAJF. These loans are intended to support renewable energy and energy efficiency technologies that are catalytic, replicable, and market ready. The Renewable Energy and Efficient Energy solicitation is authorized by Title XVII of the Energy Policy Act of 2005 through Section 1703 of the Loan Guarantee Program.[54]

- **Low Carbon Fuel Standard (LCFS)** – California has established the LCFS to reduce carbon intensity of its transportation fuel pool by 10% by 2020. The program provides incentives for fuels used in California with reduced carbon intensity compared to conventional fuels. Similar to the RFS, the requirements and market provide a financial incentive per gallon for producers and importers of renewable fuels with reduced carbon intensities. Efforts are currently underway to amend the program to include similar incentives for jetfuel as the program does not currently do so. [55]

- **Biodiesel and Renewable Diesel Tax Credit --** Although currently expired, the $1/gallon biodiesel and renewable diesel blenders tax credit, usually shared 50/50 between blenders and producers,[56] may be reinstated (as it has been three other times) either as a blender's credit or as a producer's credit. Legislation for reinstatement specifically includes jetfuel.[57] This analysis includes the full credit in the incentive analysis for jetfuel producers.

3.4.4 U.S. Market

With the macroeconomic and additional drivers as a foundation, both the Federal Aviation Administration (FAA) and Energy Information Administration (EIA) project increased air travel and jetfuel consumption despite increasing efficiency and fuel prices.

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[53] U.S. Department of Agriculture Farm Service Agence, "Biomass Crop Assistance Program." Accessed 8/21/2017 https://www.fsa.usda.gov/programs-and-services/energy-programs/BCAP/index

[54] U.S. Department of Energy, "Renewable Energy & Efficient Energy Projects Solicitation." http://energy.gov/lpo/services/solicitations/renewable-energy-efficient-energy-projects-solicitation

[55] California Environmental Protection Agency Air ResourcesBoard, "Low Carbon Fuel Standard." https://www.arb.ca.gov/fuels/lcfs/lcfs.htm

[56] Irwin, S. "Implications of Changing the Biodiesel Tax Credit from a Blender to a Producer Credit." *farmdoc daily* (5):142, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, August 5, 2015. accessed July 5, 2017 http://farmdocdaily.illinois.edu/2015/08/implications-of-changing-biodiesel-tax-credit.html

[57] Joanne Ivancic conversation with Anne Steckel, National Biodiesel Board, July 2017.

- FAA cites anticipated U.S. carrier passenger growth of 2.1 percent per year through 2036.[58]

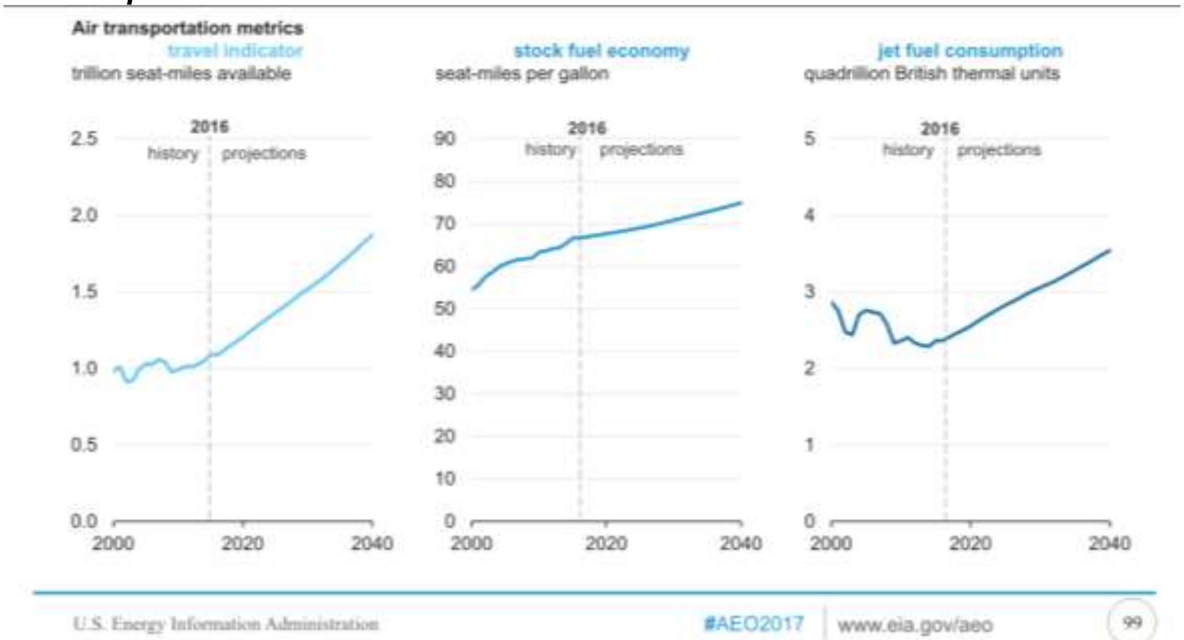
- Cargo traffic is expected to grow at an average annual rate of 3.5 percent through 2036, with the domestic portion growing at a 3.3 percent rate.[59]

- FAA also projects an average annual jetfuel consumption rate of 1.5% per year through 2036 increasing the current 21 billion gallons to 28 billion gallons.[60]

- EIA projects an increase of jetfuel consumption of 40% from 2016 to 2040 citing demand outpacing efficiency improvements [61]

Figure 11 displays the increased efficiency projected for the next thirty years alongside the jetfuel consumption representing primary demand for U.S. commercial aircraft.

Figure 11: Efficiency Projected over Next Thirty Years alongside the Jetfuel Consumption Demand for U.S. Commercial Aircraft



In addition to the projected increase in seat miles, freight revenue ton-miles are projected to nearly double through 2040. The increase in both freight revenue ton-miles and seat-miles, as shown above, leads to the increase in jetfuel consumption.

While the aviation industry and related jetfuel consumption is projected to increase for the next 20 years, it can be reasoned that U.S. jetfuel production of conventional, or

[58] U.S. Federal Aviation Administration, "FAA Aerospace Forecast: Fiscal Years 2016-2036," 2016
[59] *Ibid*
[60] *Ibid*
[61] Energy Information Agency "Annual Energy Outlook 2017," 2017.

SAJF, would increase from the current level of 23 billion gallons per year to match the demand.

Alternatively, pricing may increase if supply is constrained (due to increased or volatile crude prices or refinery capital costs, unfavorable regulatory or geopolitical events) thereby impacting demand but potentially creating additional opportunities for alternatives production.

Given the size of the market and the policy and environmental considerations described above, a public/private apparatus for fostering and commercializing viable technologies has been established through programs such as the U.S. government's Farm to Fly 2.0 initiative, which has stated goals of expanding the bioeconomy, rural development, and job creation, as well as furthering the country's energy security by producing environmentally friendly fuels.

Also, trade organizations like the Commercial Aviation Alternative Fuels Initiative (CAAFI) and Airlines for America (A4A) have taken the initiative to interface with technology developers and airlines to bring SAJF to market. In addition to the GHG reduction benefits, airlines are also motivated to commercialize economically viable sustainable fuels to diversify their supply of jetfuel and mitigate volatility in the conventional jetfuel market. Increasing the supply and geographic diversification of production of jetfuel, which is approximately 35% of an airline's cost to operate, is a powerful value proposition for airlines. Airlines are also hoping to avoid government imposed emissions mandates or other programs that may hamper growth.

While drop-in fuels can be transported long distances via pipeline, rail, and ship; the majority of jetfuel, 62%, is consumed in the same region where it is refined with the largest production facilities located near large airports.[62] A Delmarva energy beet-to-jetfuel project can be positioned to take advantage of these goals and industry motivations with its novel combination of hybrid beets and conversion technologies and its strategic location. Consequently, understanding the regional demand for jetfuel in the Mid-Atlantic provides a better-defined market for a project on the Eastern Shore.

3.4.5 Mid-Atlantic Regional Market

The Eastern Shore of Maryland offers quick, easy access to the Mid-Atlantic markets as it is located four hours or less from eight major metropolitan areas including New York City, Newark, Philadelphia, the District of Columbia and Baltimore.
The diversity and accessibility of local fuel distribution channels - including truck, rail and barge - positions an SAJF project well for downstream supply chain integration.

[62] Davidson et al., "An Overview of Aviation Fuel Markets for Biofuels Stakeholders," National Renewable Energy Laboratory, July 2014.

The many long-distance trucking firms in the area have access to major highways and convenient access to Interstate 95.

The region also enjoys a wealth of industrial, business and technology parks that may offer synergies as specific siting evolves and expands. International airports in Baltimore (BWI), Washington, DC (DCA and IAD) and Philadelphia (PHL) are located within a couple hours' drive.

Class I freight carriers CSX and Norfolk Southern have operations in the region, and the Delmarva's single-track layout is served by four short-line companies. The Chesapeake & Delaware Canal in Cecil County offers global cargo options by barge and the deep-water Port of Baltimore is close by.

Agriculture, fishing and tourism are the primary economic drivers in the area.

In short, the Eastern Shore offers a rural area in close proximity to major markets and airports and has the infrastructure and expertise necessary to serve those markets with SAJF.

Commercial Airlines

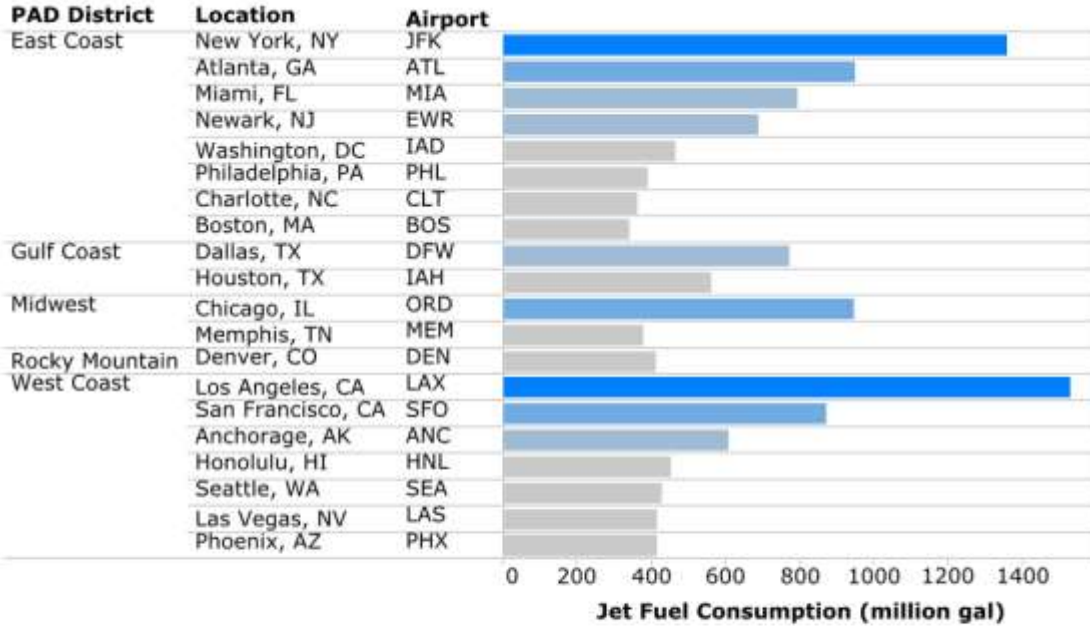
The EIA defines regions as Petroleum Administration Defense Districts (PADD). The U.S. East Coast comprises the East Coast region or PADD 1. PADD 1 is further subdivided for additional detail. Maryland, Delaware, New Jersey, New York, and Pennsylvania are included in PADD 1B: Central Atlantic. Virginia is in PADD 1C. PADDs are shown in Figure 12 below.

Figure 12: Petroleum Administration for Defense Districts

Source: EIA, 2012 https://www.eia.gov/todayinenergy/detail.php?id=4890

The largest airports and associated consumption within each PADD are displayed in Figure 13 (from the National Renewable Energy Lab (NREL) report *An Overview of Aviation Fuel Markets for Biofuels Stakeholders* dated July 2014.

Figure 13: Jetfuel Consumption Dispensed by Airport in 2012 for Selected Airports



Source: Airlines for America Unpublished, Adapted from *An Overview of Aviation Fuel Markets for Biofuels Stakeholders,* National Renewable Energy Laboratory (NREL), July 2014.

Figure 13 does not include two major airports in the region: Ronald Reagan Washington National Airport (DCA) and Baltimore Washington International Airport (BWI). While actual jetfuel consumption at DCA and BWI was not available, the fuel consumption is expected to follow Washington Dulles International Airport (IAD) based on a relatively similar level of departures.

A primary policy driver for SAJF use stems from international pressure to reduce carbon emissions associated with aviation. The policy would be expected to influence demand at international airports in the project region. Accordingly, DCA may not realize the same pressures but the management under the same airport authority as IAD may drive some other practical considerations for SAJF.

Looking at projections by FAA for air travel at these airports and EIA for jetfuel consumption in these PADDs, the East Coast jetfuel consumption should track the overall consumption increases. EIA estimates the following for each subdivision of PADD 1:

Table 11: PADD Jetfuel Consumption Projections

PADD	2015 Consumption (million gallons)	2036 Consumption (million gallons)	Annual Growth
1A: New England	444	555	1%
1B: Central Atlantic	3,319	4,074	0.9%
1C: Lower Atlantic	2,733	3,740	1.5%
Total	6,496	8,369	1.2%

Source: Adapted from AEO 2017, EIA

While PADD 1 tracks the overall U.S. consumption patterns, the Central Atlantic shows a lower annual growth rate but relatively large projected increase of 755 million gallons over twenty years.

Similar to the EIA, FAA forecast information also projects a slightly lower annual growth for operations as detailed in Table 12.

Table 12: PADD Major Airport Operations Projections

PADD	Airport	2016 Total Operations	2036 Total Operations	Annual Growth
1A: New England	BOS	372,019	548,852	2.0%
	EWR	413,813	582,154	1.7%
	Subtotal	785,832	1,131,006	1.8%
1B: Central Atlantic	BWI	247,576	357,512	1.9%
	JFK	442,630	643,891	1.9%
	PHL	412,749	443,608	0.4%
	Subtotal	1,102,955	1,445,011	1.4%
1C: Lower Atlantic	ATL	876,785	1,265,594	1.9%
	CLT	545,602	777,569	1.8%
	DCA	299,899	308,706	0.1%
	IAD	299,118	384,397	1.3%
	MIA	409,119	563,001	1.6%
	Subtotal	2,430,523	3,299,267	1.5%

Source: *Adapted from APO Terminal Area Forecast (TAF) Detail Report*, FAA, 2017. http://taf.faa.gov/

As detailed in Table 12, the Central Atlantic is projected to see a 1.4% annual growth rate in operations through 2036 for selected airports. Though technically in PADD 1C, DCA and IAD are located close to the Delmarva. At 1.3% IAD shows a similar projected growth rate as PADD 1B.

Table 13: PADD Major Airport Primary Carriers

PADD	Airport	Carrier	Share
1A: New England	BOS	JetBlue	30.00%
		American	22.57%
		Delta	12.31%
	EWR	United	50.22%
		ExpressJet	9.90%
		American	7.96%
1B: Middle Atlantic	BWI	Southwest	70.24%
		Delta	7.87%
		American	6.33%
	JFK	JetBlue	37.60%
		Delta	29.35%
		American	16.39%
	PHL	American	44.76%
		Wisconsin	9.21%
		Southwest	8.84%
1C: Lower Atlantic	ATL	Delta	72.53%
		Southwest	10.77%
		ExpressJet	6.11%
	CLT	American	60.37%
		Delta	3.40%
		Wisconsin	1.98%
	DCA	American	28.11%
		Southwest	15.24%
		Delta	11.23%
	IAD	United	43.01%
		Mesa	21.38%
		American	4.71%
	MIA	American	72.02%
		Delta	12.09%
		United	4.85%

Source: Source: November 2016 Carrier Shares, Bureau of Transportation Statistics, February 2017. https://www.transtats.bts.gov/airports.asp?pn=1

This projected growth rate agrees with that of the projected jetfuel consumption when considering efficiency improvements. The overall growth in the regional market presents opportunity for SAJF to meet a portion of the increasing demand starting at an additional twenty-nine million gallons per year.

The increased demand will be spread across carriers at each airport. The top three carriers and representative share is summarized in Table 13, PADD Major Airport Primary Carriers.

While the top carriers are subject to change, Table 13 provides reference for potential customers that may drive the projected increase in conventional and, possibly, SAJF demand.

With goals and strategies in place, adoption by the industry and military continues to grow. Table 14 details existing offtake contracts. Only Altair has actually supplied fuel per the contract. Others are under development.

Table 14: SAJF Contracts

Airline	Supplier	Volume [t/yr]	Feedstock / product	Duration	Start delivery	Contract date
United	Altair	17 000	HEFA	3 years	2016	2013
Cathay	Fulcrum	100 000	Waste	10 years	2019	2014
FedEx/Southwest	Red Rock	10 000	Forest residues	8 years	2017	2014
United	Fulcrum	270 000+	Waste	10 years	2019	2015
JetBlue	SG Preston	100 000	HEFA	10 years	2019	2016

Source: Fact Sheet – Alternative Fuels. IATA, November 2016.

Though details on contract structure are limited, the majority of airlines have contracted for the SAJF to be blended at the fueler level. As a practical matter, this requires establishing business relationships with these fueler companies, as well.

In addition to the contracts in place, the FAA has set a 5% target for biofuel implementation by 2018.[63] While more carriers are purchasing SAJF, the U.S. does not require any greenhouse gas (GHG) reductions from the aviation industry specifically. With the competitive nature of aviation and no mandates, SAJF must still compete on price. Currently, SAJF is more expensive than conventional jetfuel.[64] As such, the SAJF demand will increase as pricing becomes more competitive with conventional jetfuel. All indications are that the industry will only accomplish its carbon goals if alternative sustainable aviation fuels become readily available and cost competitive by 2030 unless policy drivers to decrease carbon footprints via imposition of penalties increase.

Looking ahead, the proceedings at the 39th ICAO General Assembly in October/November of 2016 set the stage for the formation of the new, global carbon neutral growth from CNG2020 scheme, CORSIA. This larger scheme will contemplate individual airline responsibility for meeting global carbon neutral growth and emissions reduction goals from 2020, and is anticipated to include accounting mechanisms to credit airlines for emissions reductions associated with the purchase and use of SAJF.[65]

As mentioned briefly, additional distribution studies may be required for specific project locations. In general, a network of barge, pipeline, rail, and truck is used for SAJF. The infrastructure is in place to serve larger airports in the region; however, specific location and economics should be considered in combination with offtake agreements. Barriers for distribution could be addressed via discussions with other airport operators or individual feasibility studies. Lessons can be learned from Los Angeles, California

[63] International Air Transport Association , "IATA Sustainable Aviation Fuel Roadmap," 2015.
[64] Fact Sheet – Alternative Fuels. IATA, November 2016.
[65] Murdock, Sandy, "Carbon Offset & Reduction Scheme For International Aviation—Promise Or Performance?" JDA Journal, October 11, 2016. Accessed 8/21/2017 http://jdasolutions.aero/blog/carbon-offset-and-reduction-scheme-for-international-aviation/ and de Jong *et al*. "Life-cycle analysis of greenhouse gas emissions from renewable jet fuel production," Biotechnol Biofuels (2017) 10:64

and Oslo, Norway, the only airports which currently have permanent SAJF blending operations; and from Seattle-Tacoma International Airport in Washington which has recently published a study.[66]

While the higher-level market opportunities take general infrastructure into account, distribution networks could impact specific customer demand and would require evaluation on an individual basis.

3.5 Potential Income, Market Analysis: Use of Ethanol as Feedstock for Bio-based Chemicals and Products

Should the market for ethanol as transportation fuel or feedstock prove weaker than expected; or during the period where regulatory and industry approvals are being pursued, the ethanol produced from the energy beets might serve as a feedstock for other bio-based chemicals and products. For example, the platform chemical ethylene can be further refined into a plastic material, polyethylene.[67]

Another example is provided by Greenyug LLC, a startup technology development company headquartered in Santa Barbara, California. They have been talking with Archer Daniels Midland Co. about building a bolt-on addition to an ADM ethanol biorefinery in Nebraska using a technology tested in India and designed to convert nondenatured ethanol into ethyl acetate, a product used in coatings, paint and cleaning products.

Another example comes from Braskem, the largest petrochemical company in Latin America. Braskem has been converting sugarcane-based ethanol into polyethylene at its facilities in Brazil for several years.[68]

Daniel Lane and Joel Stone of Lee Enterprises Consulting provide detailed considerations for transitioning ethanol refineries to biochemical plants.[69]

[66] Klauber, Adam, *et al.* "Innovative Funding for Sustainable Aviation Fuel at U.S. Airports: Explored at Seattle-Tacoma International." Rocky Mountain Institute, SkyNRG. July 2017. https://www.rmi.org/insights/reports/innovativefunding-sea-tac-2017/

[67] Voegele, Erin "Feeding the Chemical Market," Ethanol Producer Magazine, March 5, 2012 Accessed 6/5/2017 http://www.ethanolproducer.com/articles/8617/feeding-the-chemical-market

[68] Geiver, Luke "Ethanol's Opportunity in the Chemical Market," Ethanol Producer Magazine, April 24, 2017 Accessed 6/5/2017 http://ethanolproducer.com/articles/14263/ethanolundefineds-opportunity-in-the-chemical-market

[69] Lane, Daniel and Stone, Joel "Opportunities to Transition Ethanol Facilities to Biochemical Refineries," Biofuels Digest, April 20, 2017 Accessed 6/5/2017 http://www.biofuelsdigest.com/bdigest/2017/04/20/opportunities-to-transition-ethanol-facilities-to-biochemical-refineries/

Section 4: Putting It All Together: Costs and Income

Growing energy beets on the Delmarva Peninsula could have significant value as part of nutrient management plans to improve the water quality in the Chesapeake Bay; and the greens and protein solids from processing the energy beets could prove valuable as animal feed, particularly poultry feed, although more research is needed to quantify these values.

Even without quantifying the value of nutrient management, Eastern Shore growers could find value in adding energy beets to their crop rotation practices considering an average of recent years (USDA monthly averages from May 2014 to May 2017) corn prices and average Maryland corn production.

Table 15: Comparison of Potential Maryland Farm Income from Corn and Energy Beets

$ Bushel of Corn	$ 3.93
Bushels/Acre	152
Total Income	$ 597
Energy Beets @ 1,000 gal/acre	$ 1,050
% Income Increase	$ 453
	76%

Projections of potential income and economic feasibility from animal feed and ethanol or jetfuel produced from the energy beet sugars is based on process flow models created by Dr. Fred Michel, Associate Professor of Biosystems Engineering at Ohio State University's Ohio Agricultural Research and Development Center.

The following tables and figures incorporate different economic scenarios depending on a range of types and costs of production.

Because research on energy beet cultivation and processing into animal feed, biochemical intermediates or transportation fuels remains preliminary, with the decentralized barge-based model apparently most suitable for the system developed during the UMES project, that is the focus of this initial feasibility analysis.

The interactive model developed by Dr. Michel for this analysis can be used with data developed as research continues. The following illustrations are based on both data developed during the 2016 UMES energy beet project and on assumptions developed from extrapolations for the following reasons.

4.1 Grower's Perspective of Costs and Income

Uncertainty is expected for the production of any new crop. Additionally, for energy beets, no beet biomass saccharification facility exists on the Delmarva or anywhere else; nor has the ethanol-to-jetfuel process been commercialized.

Although the specific processes are new, much of the equipment and facilities from planting through final processing are either available "off the shelf" (even used) or have been used in similar processes.

Table 16: Costs for Delmarva Energy Beets and Sugar Beets (USDA Average)

Costs($/acre)	USDA	Delmarva	Comment
Seed	53.74	53.74	
Fertilizer	120.14	60.00	Lower fertilizer due to excess P in soil
Chemicals	79.04	79.04	
Custom operations	31.89	31.89	
Fuel, lube, and electricity	90.30	90.30	
Repairs	64.92	64.92	
Freight and dirt hauling	30.89	26.89	Lower cost for longer season
Miscellaneous	4.18	4.18	
Interest on operating capital	11.02	11.02	
Hired labor	33.92	25.00	Lower labor due to longer season
Opportunity cost of unpaid labor	113.68	83.78	
Capital recov of machinery/equipment	204.64	103.74	Use some existing equipment Due to smaller farm size, each farm not expected to own/operate own beet planting/harvesting equipment
Opportunity cost of land (rental rate)	149.65	100.00	Cheaper land
Taxes and insurance	19.84	19.84	
General farm overhead	32.90	32.90	
Coop share	12.83	12.83	
Total Production Cost	**$1054**	**$800**	
Profit	$250	$250	
Cost to Ethanol Plant	**$1304**	**$1050**	

Also, costs of equipment, facilities and services are extrapolated from existing uses. Thus, expenses related to some equipment used in beet processing and beet processing experiments, capital and operating costs of ethanol-producing biorefineries and jetfuel refineries, etc., are used in these calculations.

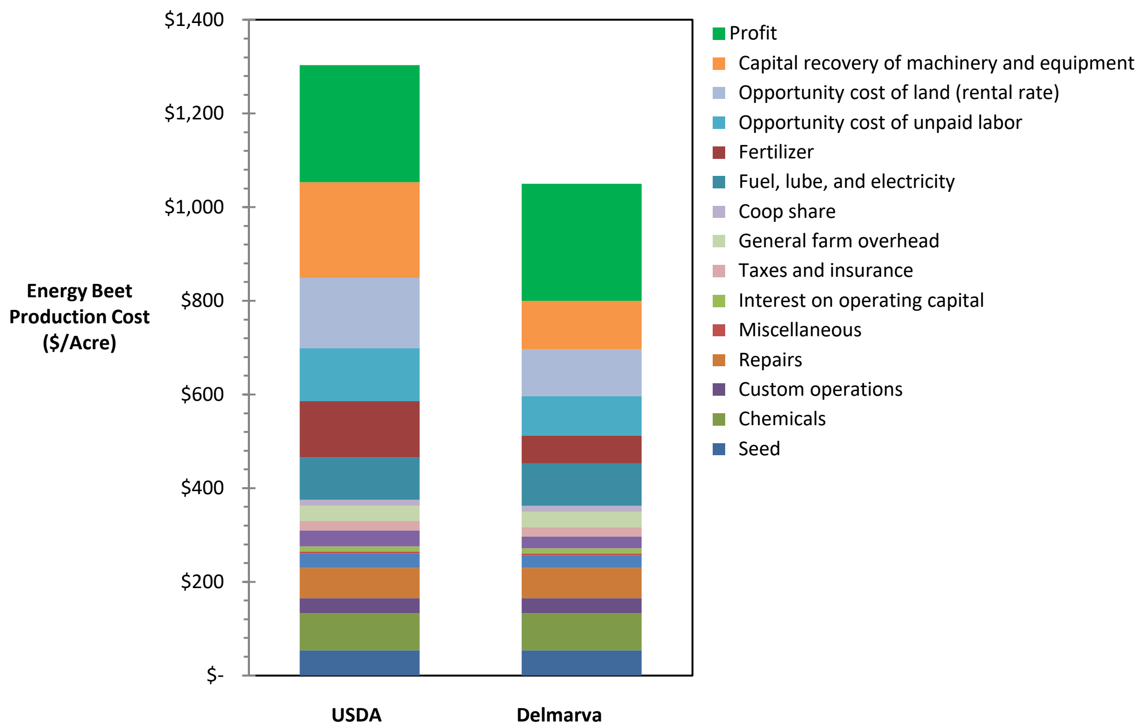
Given these considerations, Table 16 lists production costs on the Delmarva compared to production costs for sugars beets in the US for table sugar production, along with notes about adjustments made to reflect characteristics of the Delmarva that are significantly different from the upper Midwest. For example, because the energy beets have been developed to use less nitrogen and because this project intends to be used to take up existing legacy phosphorus, fertilizer costs have been lowered.

In addition, from conversations with farmers, and economic development and agriculture professionals in the Delmarva, we have developed an assumption that profit of $250/acre would be acceptable.

Also, because other key factors such as cost of oil, price of gasoline, price of ethanol for fuel, and such vary, a range of these factors is often calculated.

As discussed above, the Delmarva region should be able to accommodate 100 MGY ethanol production while complementing, not disrupting, existing agricultural industries, improving environmental conditions and creating wealth. Because the facility would be operating only half the year, the model extrapolates construction and operating costs of a facility of twice that size.

Figure 14: Production Costs for Delmarva Energy Beets and Sugar Beets (USDA Average)

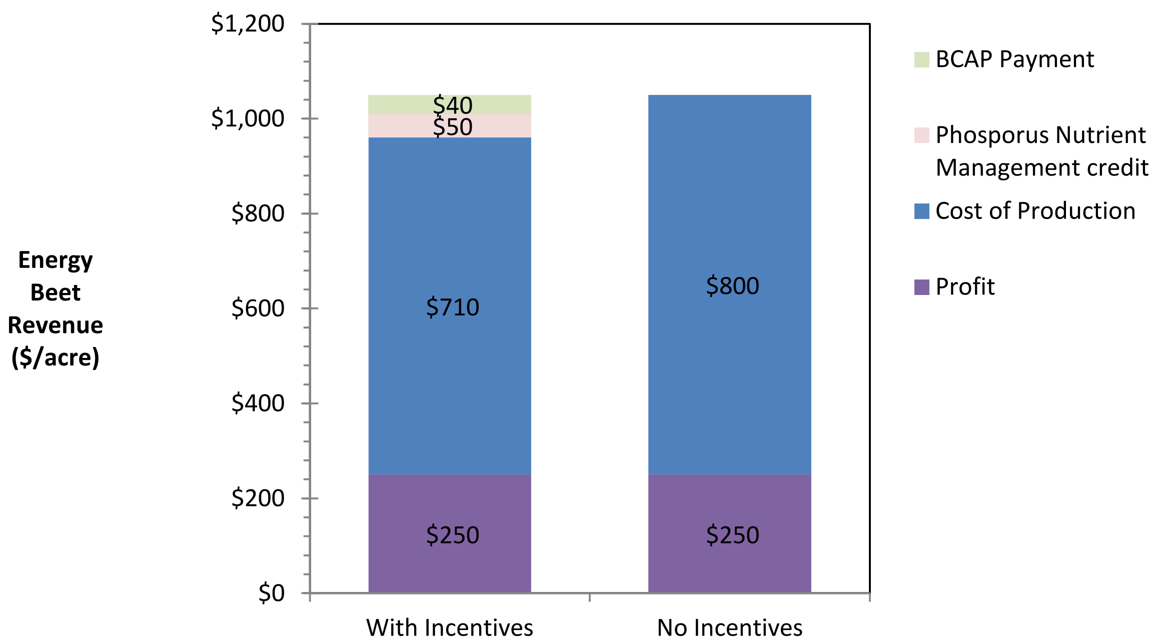


As discussed above in Section 3.4.3 Incentives, the Biomass Crop Assistance Program (BCAP) provides financial assistance in the form of matching payments and annual payments to owners and operators of agricultural land who wish to develop biomass feedstocks. BCAP does not provide matching payments for the establishment of annual crops such as energy beets, however, during the early years of developing a test crop, annual payments of $40/acre may be available.

Availability of crop insurance may increase the willingness of farmers to try a new crop. Authors of a feasibility study involving energy beet-to-jetfuel options in Florida noted that although suitable federal programs do exist, there has not been a specific finding that the energy beet growers could apply to these programs. They called for clarification of eligibility for these programs or efforts to secure eligibility for energy crops. [70]

Also, growers may derive some benefits related to their required nutrient management plans. Because growing energy beets requires less fertilizer, including them in a nutrient management plan may help to hold down costs. In addition, there might be some credit trading financial opportunities from growing this crop. An amount of $50/acre was determined to represent the potential monetary value of the nutrient management benefit to growers. Section 3.1 Potential Income, Market Analysis: Nutrient Management and Phosphorus Remediation provides details.
Figure 15 illustrates the grower's perspective comparing the cost of production of energy beets on the Delmarva with and without the BCAP and nutrient management incentives.

Figure 15: Cost of Production for Delmarva Energy Beets with and without Farmer Incentives.



4.2 Renewable Fuel Producer's Perspective of Costs and Income

Comparing Figure16 and Figure 17 and considering the series of graphs in Figures Series 18, it is clear that without incentives (or increased oil/commercial fuel prices),

[70]Treasurer Coast Education, Research & Development Authority, "Farm to Fly Florida: Feasibility Study Report," p. 41. Accessed 8/7/2017 http://www.treasurecoastresearchpark.com/farm-to-fly-feasibility-report/

producing jetfuel for the commercial market, even the advanced low carbon emission jetfuel from energy beets on the Delmarva, is pretty much out of the question, although ethanol production will be possible.

The eventual goal of 100 MGY ethanol production (200 MGY nameplate capacity with 6 months operations) will be achieved, using the barge-based system described in this study, by phased-in implementation in a modular fashion. Thus, the following base case calculations are for a biorefinery barge of 20 MGY (40 MGY nameplate capacity). To reach full capacity, 5-6 barge units would be used.

The following calculations using a price of $1.28/gallon of petroleum jetfuel which is representative of the price in mid-summer 2017. Combining such an affordable price of petroleum jetfuel, even with the incentives, making SAJF for the commercial market is not the best financial option now.

Although, as described in Section 3.4 Potential Income, Market Analysis: Sustainable Alternative Jetfuel (SAJF), airlines have expressed interest in using renewable fuels, to compete with the military market and with the market for fuel ethanol, they will have to pay premiums and create incentives.

The strategy discussed in Section 3.4.1 U.S. Navy Military-First Strategy, to sell into the military market makes more sense, particularly with a price set annually by the Defense Logistics Agency that aims to spread the risk of lower or higher fluctuations in the price of oil. In the most recent solicitation, the Defense Logistics Agency set the price of jetfuel used by the Navy (JP5) at $2.18/gallon.

If energy beets are approved as a feedstock for JP5, Biofuels Production Incentive (BPI) payments would be available.

Two of the incentives, the cellulosic biofuels producer tax credit ($1.01/gallon of cellulosic biofuel) and the bio-based diesel (and jetfuel) tax credit ($1.00/gallon) are uncertain as both expired as of the end of 2016 and have not yet been renewed, although in the past they have been included in some end-of-year legislation.[71]

Clearly, without policy support, growing energy beets for fuel ethanol would be the best option from a financial point of view.

An important benefit to producing a jetfuel feedstock (ethanol) with market options including fuel ethanol and ethanol as a feedstock for renewable chemicals is that this allows for a phased-in transition to using ethanol as jetfuel feedstock. The entire ethanol production system can be constructed and implemented to make revenue-

[71] Janssen, Eric, "US biodiesel blenders tax credit should be considered despite lapse: expert," Platts, March 31, 2017. Accessed 7/4/2017 https://www.platts.com/latest-news/agriculture/houston/us-biodiesel-blenders-tax-credit-should-be-considered-21325186

producing products while waiting for the jetfuel conversion technologies to mature and for regulatory approvals to be obtained and markets to develop.

A table with details of income and costs is in Appendix 5.

Figure 16: Revenue for the Production of Biofuels from Delmarva Energy Beets.

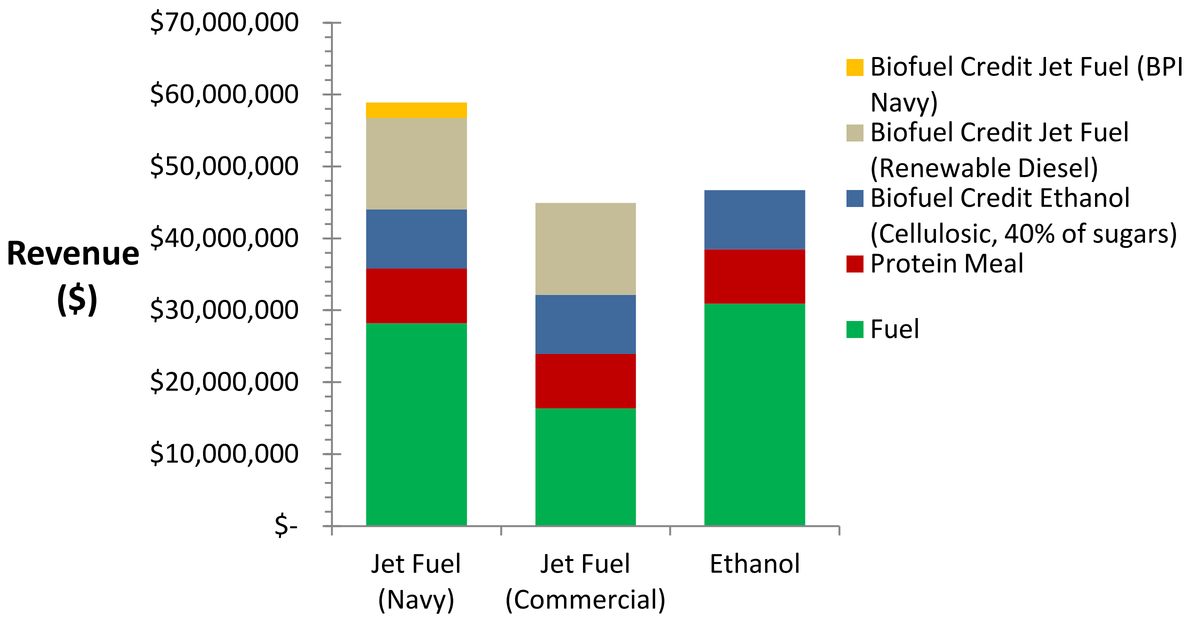


Figure 17: Biofuel Production Costs from Delmarva Energy Beets

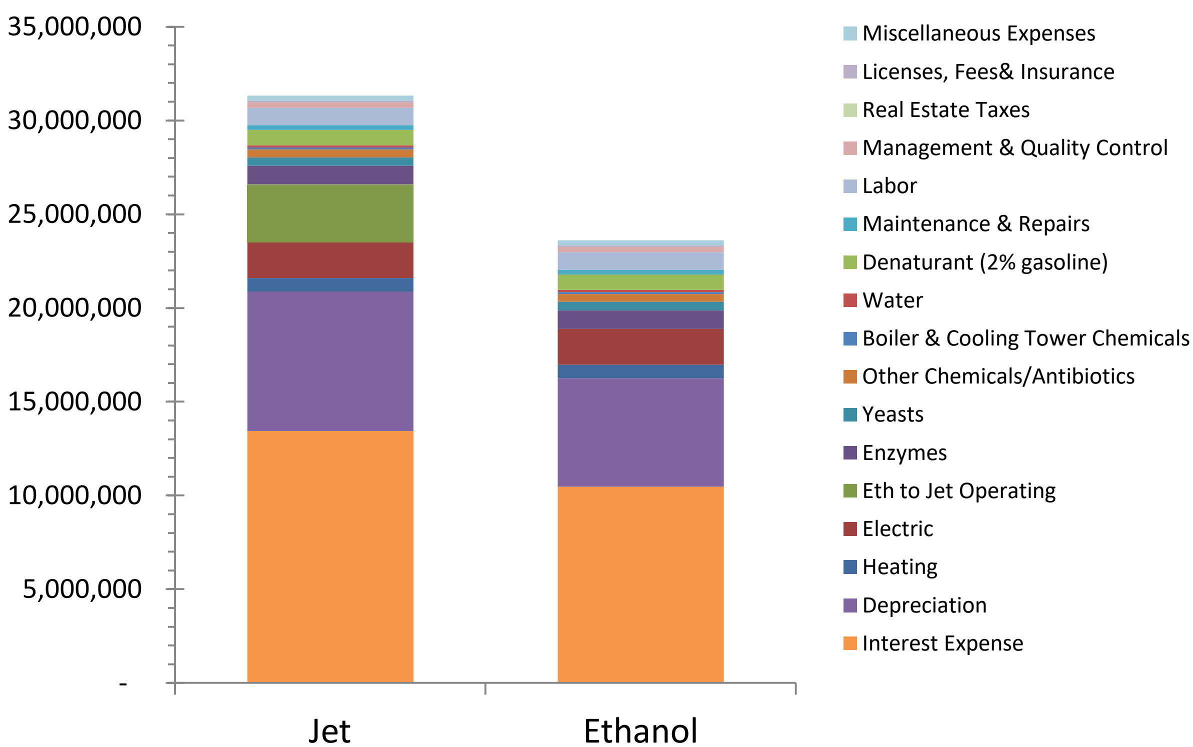


***Figure Series 18: Energy Beet Biofuel Plant Net Margin Sensitivity Analyses Series*.**

Profitability for a potential energy beet industry will be influenced by capital costs (Figure 18A), production costs (Figure 18B), months of operation per year of the processing plant (Figure 18C), and fuel prices (Figure 18D). The suggestion in these figures that Navy jetfuel production will lead to greater profitability is a result of including the biofuel credits which may be available from the US Renewable Diesel and BPI Navy programs. Both credits have been available (on a per gallon produced basis), may be renewed, and are direct add-ons to the profitability of energy beet fuels. Without these credits, fuel ethanol is the most profitable product among those considered.

Capital costs of production are a highly significant influence on the profitability of energy beets. Only fuel prices seem to have a greater influence (Figure 18D), especially the price of fuel ethanol.

The number of months that a processing plant could operate using freshly harvested or stored beets is highly influential for 1 to 4 months of operation and less significant for 5 to 11 months of operation. This is equivalent to the influence of plant capacity or capital utilization considerations in other industries.

In general, lower capital costs, lower production costs, greater plant utilization, and higher fuel prices result in greater profitability for the industry, as expected.

The crossover into profitability indicated by the sensitivity plots, supports optimism that a valuable industry can be grown on the Delmarva producing energy beets and processing them into ethanol for Mid-Atlantic motor transport market with the opportunity to further process the ethanol into jet fuel for the U.S. Navy solicitation. The commercial jet fuel market is less certain at this time. Using ethanol as a feedstock for producing industrial chemicals such as ethyl acetate could provide an alternative market.

Figure 18A: Energy Beet Biofuel Plant Net Margin Sensitivity Analyses. Effect of Plant Capital

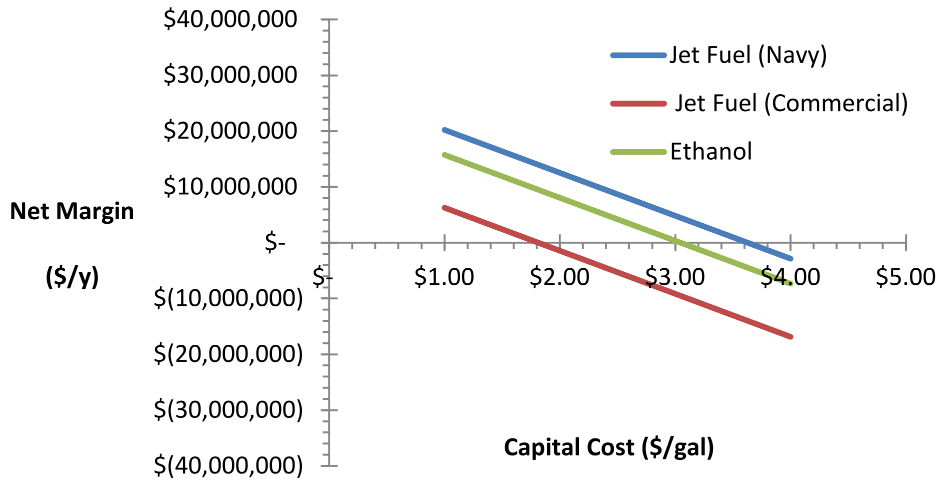


Figure 18B: Energy Beet Biofuel Plant Net Margin Sensitivity Analyses. Energy Beet Production Cost ($/Acre)

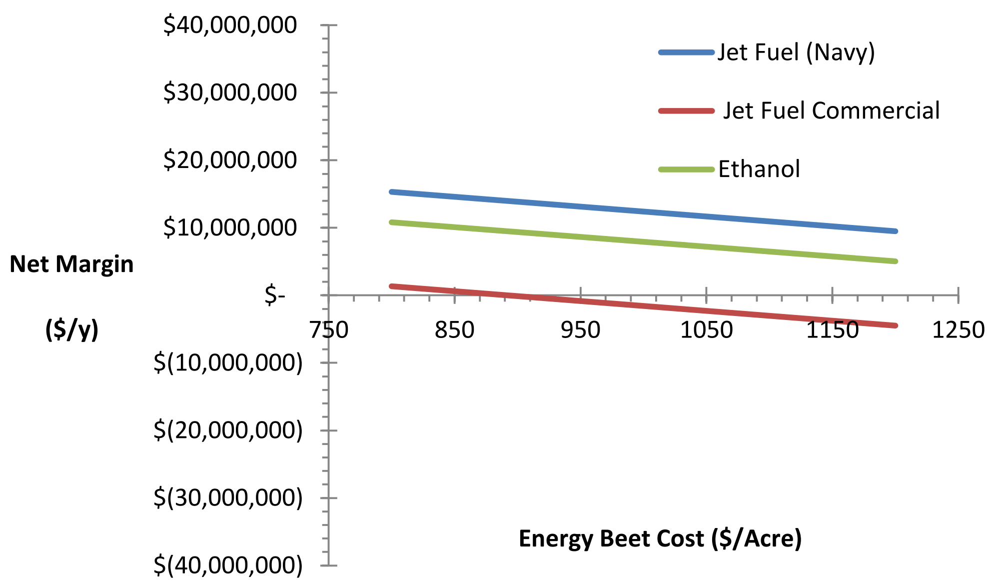


Figure 18C: Energy Beet Biofuel Plant Net Margin Sensitivity Analyses. Operational Percent of the Year (Months)

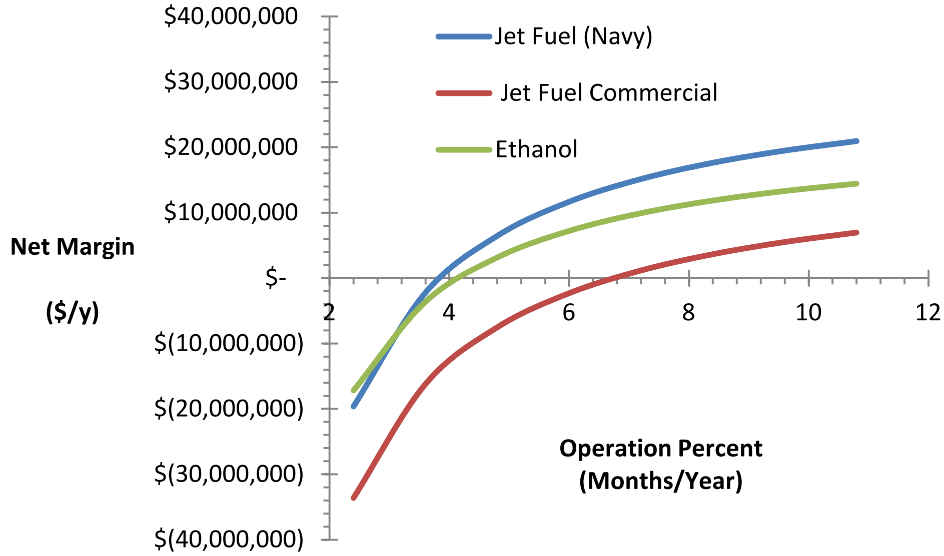
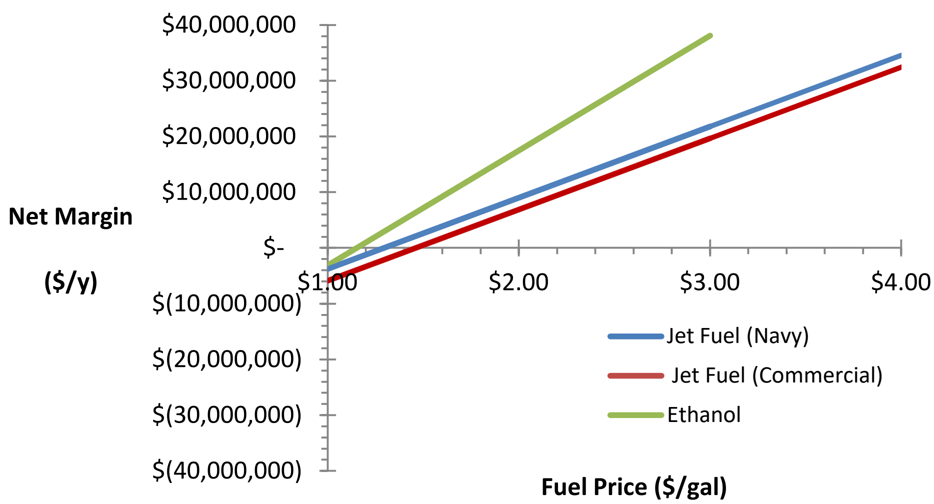


Figure 18D Energy Beet Biofuel Plant Net Margin Sensitivity Analyses. Fuel Price.



Section 5: Further Research Needed

An energy beet to jetfuel project at its early stages presents opportunities to develop and improve on the initial proposal, and to create new businesses and products, to participate in emerging markets not only for ethanol, biochemicals or jetfuel, but also for phosphorus remediation credits, etc.

Following the flow of the value chain from seed to sky, the following research and investigations are needed.

5.1 Seeds

Plant Sensory Systems continues to work on improving varieties of energy beets that will use less nitrogen fertilizer and grow better in Delmarva conditions. Tests at UMES provided assurance that this crop could flourish as a feedstock for biofuels and other bio-based products.

5.2 Agronomy

Because only a small experimental plot was grown in 2016, planting, weeding and harvesting was done manually. The University of Maryland Eastern Shore in collaboration with USDA Extension can conduct the following research, outreach and education related to the practical aspects of growing energy beets on the Delmarva:

1) Developing energy beet seed stock for the Mid-Atlantic Coastal environment;
2) Assessing planting and harvesting equipment and practices based on existing sugar beet industry and tailored to Delmarva conditions such as size of fields, soil characteristics, extended growing/harvest season;
3) Assessing needs for and appropriate use of herbicides, pesticides and fertilizer;
4) Determining if cultivation of energy beets could be achieved according to organic regulations that would apply to animal feed co-products;
5) Assessment of environmental effects of disturbance of the soil during harvest;
6) Developing and evaluating nutrient management practices with energy beets;
7) Exploring new business opportunities and financing options such as cooperatives, vertically integrated businesses and more;
8) Creating educational materials and conducting educational events about this new crop and its potential markets.

5.3 Animal/Poultry Feed

UMES also has extensive experience working with the local poultry industry on issues related to nutrition and poultry feed. The solids that remain after the energy beet root biomass is converted to fermentable sugars are similar to the non-fermentable components of the grain ethanol production process which are rich in essential nutrients such as protein, fibre, vitamins and minerals in a highly concentrated form known as Distillers Dried Grains with Solubles (DDGS).

Although grain-based DDGS have extensive testing and use as poultry feed, no such research has been conducted on the solids remaining from energy beet conversion. Because no pretreatment chemicals or antibiotics are used in the Atlantic Biomass process, no harmful substances should hinder their use as animal feed. Identification of the composition of these solids and its potential value as a locally-grown nutritional supplement for the poultry industry is needed.

With regard to the beet tops, further research should explore how the beet tops might affect fermentation time and quality of silage and how this use could lead to increased feed utilization with less wastage of hay. More work is also needed to analyze the nutritional composition of the tops (with respect to their suitability for animal feed formulation) and to compare the use of beet tops for winter cover with cover crops.

5.4 Nutrient Management Plans

To enable growers and land-owners to incorporate the phosphorus uptake benefits of energy beets into their nutrient management plans, more research into the amounts of P that are taken up by the specific varieties developed for the region is needed. Before and after soil samples are needed for a range of soil types to determine if energy beets remediation could meet state nutrient management plan requirements. More exploration about whether and how the beets take up P from deep soils with their long tap roots should be undertaken.

5.5 Nutrient Management Cap-and-Trade Credits

Because the Chesapeake Bay watershed nutrient management trading program is in the early stages of development, values for phosphorus credits cannot be determined with any certainty. With credits in current systems ranging from a perpetual contract at $20,000/lb P removed in the Virginia program to $3/lb of P removed in the current Pennsylvania program, and with all programs currently undergoing transitions, future assessments should provide more certainty.

5.6 Production Improvements

This analysis was based on extrapolating from similar existing systems such as cultivation of sugar beets and fermentation of ethanol. As the energy beet-to-ethanol-to-jetfuel process is developed on a pilot scale, and as the first 40 MGY nameplate capacity (20 MGY over 6 months operation) barge is constructed and operational, many improvements and efficiencies will be tailored to these innovative processes.

One crucial improvement is in the optimization of enzymes and their efficient use.

This analysis has been based on optimal enzyme costs of $.05/gallon of ethanol produced. Currently, enzymes for the conversion of the cellulose, hemicellulose and pectin in the biomass cost $.15/gallon of ethanol produced. No enzymes are used in the fermentation of the sucrose which is 60% of the energy beet sugars.

Figure 19 shows the impact of the cost of enzymes on ethanol production profits; Figure 20 shows the relationship of enzyme costs to ethanol production costs. Together, they illustrate the need for development of lower cost enzymes and the ability to recycle enzymes. Atlantic Biomass is currently working on this research at Hood College in Frederick, MD. With adequate funding they anticipate achieving $.05/gallon ethanol enzyme costs.

Figure 19. Impact of Enzyme Costs on Ethanol Production Margins

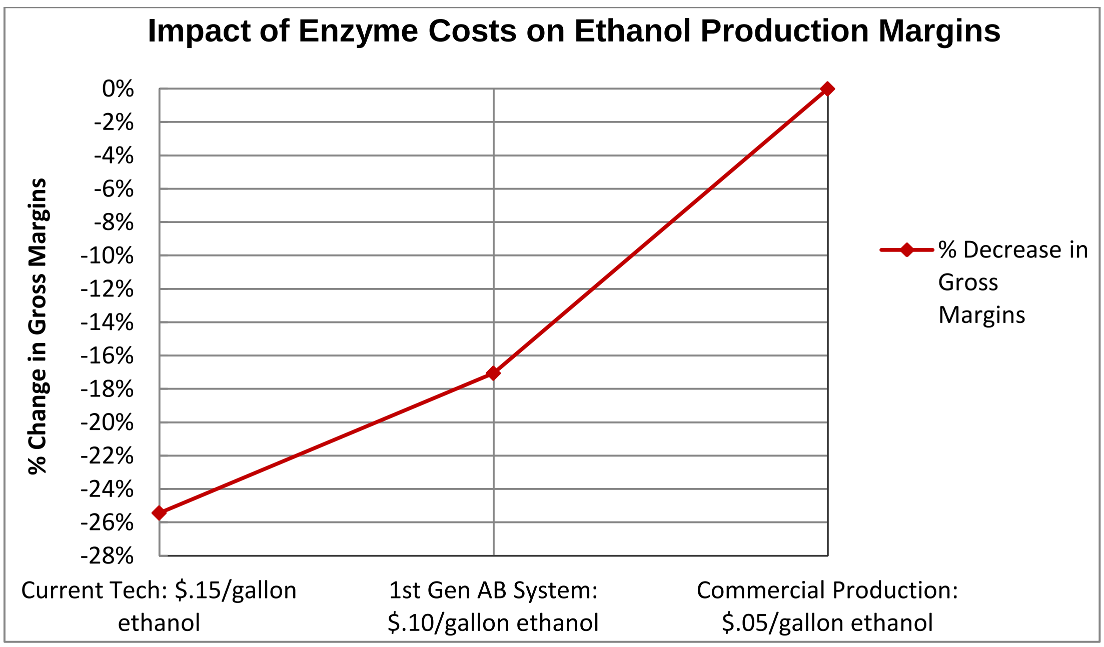
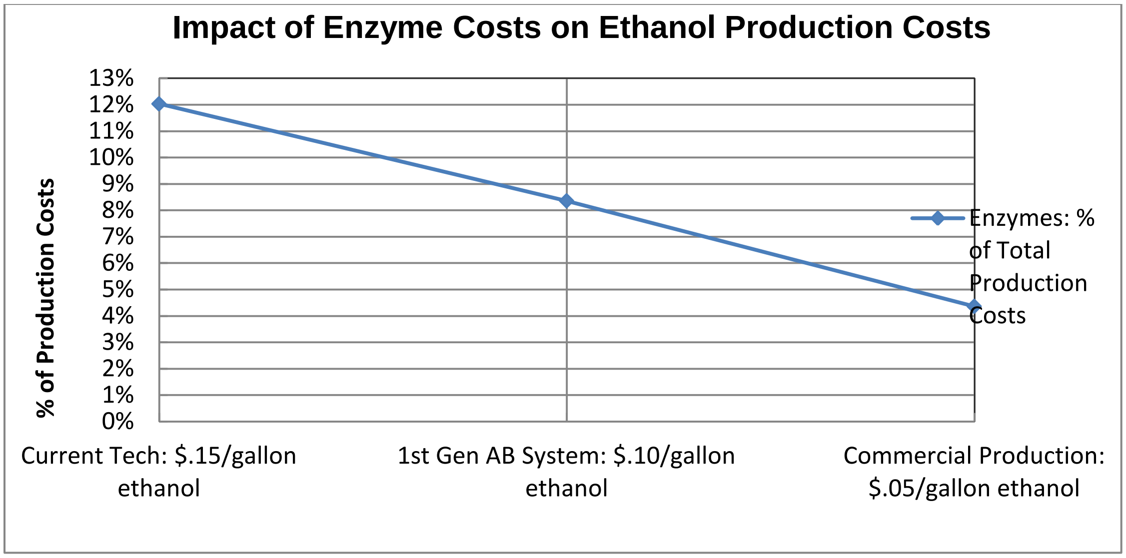


Figure 20: Impact of Enzyme Costs on Ethanol Production Costs



Section 6: Recommendations and Conclusions

This study finds that it could be feasible to produce low greenhouse gas emissions jetfuel on the Eastern Shore and Delmarva in an economically and environmentally sustainable way for the U.S. Navy solicitation using energy beet feedstock. In addition, this could bring economic, environmental and social benefits to the region.

Producing environmental benefits from phosphorus uptake and contributing feed to the existing poultry industry, alongside producing cost-competitive biofuels has the potential to support not only a positive return on investment for a biorefinery, but also for growers and for entrepreneurs servicing this new industry,

Specific findings include:

- The first test crop in 2016 at the UMES research farm using test-crosses provided by Plant Sensory System grew well with no phosphorus fertilizer. The beets took up phosphorus at levels that could prove to make growing them part of approved nutrient management plans, perhaps eligible for cap-and-trade remediation credits.
- Test yields indicate that 136,000 acres, approximately 10% of the current rotational crop and about 25,000 acres of currently uncultivated pasture land, could provide feedstock to produce 136 MGY ethanol or 86 MGY SAJF.
- Staged August to December harvest minimizes land use and costs for storage and maximizes beet growth.

- High protein residues from biomass conversion and beet tops could have value as poultry or animal feed.

- The Atlantic Biomass enzymatic system successfully converts the beet pulp to sugars that can be fermented into ethanol or oils using microbes under study at Purdue University and the USDA National Center for Agricultural Utilization Research in Peoria, Indiana.

- Existing ASTM approved processes might convert these oils to jetfuel.

- Twice as much ethanol can be produced from an acre of energy beets as from an acre of corn based on total wet weight/acre of some test-crosses 40 tons or more and using 15.4 lbs/sugar per gallon of ethanol for calculations. Ethanol projected yields are about 1,000 gallons/acre from both types of sugars compared to about 450 gallons/acre from corn starch.

- Alcohol-to-jet conversion processes under review by ASTM could use energy beet ethanol as a feedstock for jetfuel and renewable chemical co-products.

- A number of steps must be taken for energy beet-based fuels to be able to participate in federal renewable fuel incentives such as the Renewable Fuels Standard, and agricultural programs such as crop insurance and access to Commodities Credit Corporation funds as part of the Farm to Fleet program.

- The jetfuel market for the U.S. Navy at Norfolk, based on Defense Logistics Agency solicitations, provides a clear demand at a set price for an amount of jetfuel that could be produced and delivered from energy beet feedstock grown and processed on the Delmarva.

- A market for ethanol for ground transportation in the region exists, is growing and could provide customers for energy beet ethanol while waiting for the alcohol-to-jetfuel conversion processes to mature and ASTM or U.S. Navy approvals to be obtained.

- Using maximum truck harvest distances of 20 miles along with barge-based production and transportation could minimize stress on traffic and maximize efficient use of resources.

- New business opportunities could be created to plant, harvest, transport and process energy beets, as well as to revitalize underused or stranded agricultural and industrial resources.

Implementing this project, currently in its very early stages, requires additional research and development. It also would benefit from taking steps to become eligible for government incentive programs.

Recommendations for additional research include:

- Continuing to develop energy beet seed stock bred for Delmarva conditions and determining best practices and equipment for planting, harvesting, pest management.
- Clarifying the nutrient management benefits of growing energy beets.
- Establishing use of high protein energy beet residues for poultry feed.
- Building a pilot scale facility to improve sucrose extraction and the enzymatic conversion system and to research enzyme recycling and other ways to reduce the cost of the system.
- Fleshing out, with industry expertise, ideas for barge based conversion facilities and barge transportation.
- Optimizing the fermentation microbes for conversion of energy beet sugars to ethanol (Purdue University) and oils (USDA National Center for Agricultural Utilization Research).
- Optimizing the conversion of ethanol to jetfuel (Vertimass and other companies).
- Recycling enzymes to reduce production costs.
- Exploring the availability and suitability of local facilities for jetfuel production, with priority given to reviving stranded industrial assets or adding capabilities to existing refineries.

In conducting this study a number of renewable fuel industry and academic personnel were involved, with outreach during UMES and USDA events in the region to the agricultural community and occasional interactions with state and federal government agencies and nonprofit organizations. If the project is pursued, involvement should expand to include a wider range of stakeholders who have interest, concerns, suggestions or questions about aspects of the proposed project and who would like to become involved in next steps. In addition to landowners, farmers and government agencies and elected officials, this should include other community leaders, environmental groups, the Defense Logistics Agency and airline and airport representatives.

Appendix 1: UMES 2016 Energy Beet Test Project Partners and Their Roles

University of Maryland Eastern Shore and Its Agriculture Extension Service

The University of Maryland Eastern Shore (UMES), an 1890 Land Grant historically black college/university, served as the hub for the 2016 energy beet to jetfuel project research and demonstrations.

UMES's key resources include facilities for feedstock testing and development; an extensive agricultural faculty with years of experience with Chesapeake Bay remediation projects, including with bioenergy crops; poultry feed research facilities and expertise; and the University of Maryland US Department of Agriculture Extension (UME) service which is focused, among other things, on improving the economic conditions of Eastern Shore rural and minority communities.

Specifically, with adequate funding, UMES can conduct the following research, outreach and education:

1) Developing energy beet seed stock for the Mid-Atlantic Coastal environment,
2) Developing best agronomic practices for the energy beets,
3) Developing and evaluating nutrient management practices with energy beets,
4) Developing and testing beet protein residues for poultry feed,
5) Extension and outreach services through UME
6) Developing and hosting a pilot facility for developing and testing integration of logistics and processing steps from raw biomass to precursor grade ethanol for this and other biofuel and bioproduct projects.

Of note, focusing bioenergy crop and biofuel production activities at the university offers research opportunities for undergraduate and graduate students, building a knowledgeable, sophisticated workforce in the area.

The Extension Service can engage with regional growers, the existing poultry industry, community leaders, potential investors and other stakeholders from research to implementation with targeted educational programs and other information. This will include preparation and distribution of information on the agronomics and economics of raising energy beets so that growers will be able to make informed planting decisions. It will also include programs and materials about options for financing and investing in the variety of local business opportunities related to this project.

Plant Sensory Systems

Plant Sensory Systems, LLC (PSS) of Baltimore, Maryland has developed specific strains of energy beets bred to use less nitrogen than traditional sugar beets from which they are derived and to thrive in hotter, moister climates than where sugar beets are traditionally grown, making them more suited to the Mid-Atlantic Coastal climate. These varieties of energy beets have been successfully tested not only in the experimental plot at UMES, but also in test farms in Florida and Arkansas. Research on the energy beets is also conducted at the greenhouses in Beltsville, Maryland.

PSS has received federal and state grants, including a prestigious ARPA-E grant from the US Department of Energy, and has secured several evaluation and licensing agreements with international companies, including DuPont Pioneer, Syngenta Biotechnology, Bayer CropScience, and Scotts Miracle-Gro.

Key to PSS's energy beet commercialization work is Just Beets LLC whose principal has been engaged promoting the use of beets as a source of sugar for ethanol, advanced biofuels and bio-based products since 2007.

Atlantic Biomass

Atlantic Biomass, LLC (AB) with labs at Hood College in Frederick, Maryland, has developed a proprietary sequential enzyme saccharification system that converts biomass into fermentable sugars without pretreatment. Grants from the Maryland Technology Development Corp. (TEDCO), National Science Foundation and Maryland Industrial Partnerships (MIPS) supported this research.

Using a modification of directed evolution, Atlantic Biomass, in conjunction with Hood College, genetically engineered a thermostable pectin methylesterase (PME) JL25 with activity at 65^{o}C. This modification was made so the enzyme could be used in commercial sugar beet sucrose refineries, thereby utilizing the energy contained in the sugar beet pulp as it leaves the sucrose diffusion process to speed sacacharification. Details on this enzyme are included in, Chakiath et al. “Thermal Stabilization of *Erwinia chrysanthemi* Pectin Methylesterase A for Application in a Sugar Beet Pulp Biorefinery.” Appl. and Env. Micribiol. 75:7343-7349, December 2009.

AB's proprietary sequential enzymatic hydrolysis process uses both commercially available enzymes and an enzyme developed at their labs at Hood College in Frederick, Maryland.

AB processed samples from the 2016 UMES energy beet harvest to extract sucrose and to convert the beet biomass into the fermentable sugars glucose, arabinose, and galacturonic acid using the AB sequential enzyme process. AB also provided technical analysis of yields and conversion rates of the energy beet 2016 tests.

As part of the process research with the UMES 2016 Energy Beet crop, AB simulated the beet biomass pressing step to determine the percent total wet biomass that would flow through the two processes. Less than 3% of the total biomass was lost during the process.

Table A1 Averaged Values of the UMES Test Energy Beet Sugars

Fermentation Flows	Sucrose Production	Biomass Sugars
	Pressed Liquid	Pressed Biomass
% Total Biomass Wgt	52.3%	47.3%
Sugar % Wet Wgt	15%	14%
% Dry Biomass		23%

The absence of an acid or temperature based pretreatment reduces energy use and the cost of removing pretreatment chemicals. This enzymatic conversion technology also eliminates formation of fermentation inhibitors in the sugar-to-ethanol part of the process.

Further Research Needed: AB is currently researching enzyme recycling technologies which would decrease operating costs.

Purdue University

Indiana's Purdue University's contributions to the beet-to-jetfuel value chain are the organisms and technologies Purdue researchers have developed for the bioconversion of the broad range of energy beet sugars to ethanol.

With the National Center for Agricultural Utilization Research in Peoria, Illinois, they have also worked on microbes that ferment these sugars to single cell oils.

US Department of Agriculture Agricultural Research Service, National Center for Agricultural Utilization Research

US Department of Agriculture Agricultural Research Service, National Center for Agricultural Utilization Research in Peoria, Illinois, can provide, from its collection, organisms and technologies for the bioconversion of the broad range of sugars found in energy beets to ethanol, single cell oil, and value-added bioproducts.

This NCAUR collection is one of 33 International Depository Authorities (IDAs) entrusted with storing and distributing patented microbes, cell lines and other biological materials in accordance with the Budapest Treaty of 1980.

Conversion of Sugars to Ethanol (Purdue University and NCAUR)

The sugars resulting from the enzymatic hydrolysis of the energy beet biomass have many possible uses. They could be used as precursors, intermediates or building blocks of biochemicals, bioplastics or any number of products. The 2016 UMES energy beet project focused on fermenting the energy beets to ethanol or oils as feedstock for jetfuel production.

Purdue University has developed organisms and technologies for the bioconversion of the broad range of sugars found in energy beets to ethanol, single cell oil, and value-added bioproducts.

Specifically, distillers' yeast, commonly used for sucrose and glucose ethanol production, is unable to ferment arabinose or galacturonic acid produced from the saccharification of energy beet biomass.

To determine potential ethanol production from sucrose and the more "non-traditional" bioproduct sugars (arabinose and galacturonic acid which is produced from pectin) Purdue University used NCAUR *E. coli* FBR5, which is engineered for selective ethanol production, to ferment the sugars produced by Atlantic Biomass from beet conversion.

These developments are ground-breaking for a number of reasons.

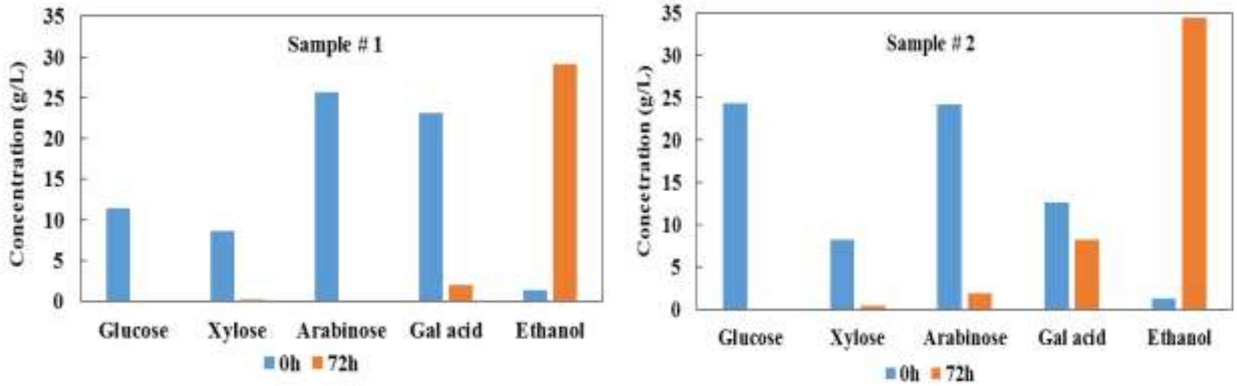
For one, research concerning the fermentation of arabinose and galacturonic acid has been limited by low concentrations of these sugars in most biomass feedstock (Ingram et al., 1987; Sedlak and Ho, 2001; Nahar and Pryor, 2013) compared to the high levels of these sugars resulting from the enzymatic hydrolysis of the energy beet biomass and available for fermentation.

Also, strains developed for conversion of pectin hydrolysates to ethanol include ethanologenic Gram negative bacteria (e.g. *E. coli*), *S. cerevisiae*, and *Z. mobilis*. Ethanologenic *E. coli* and related gram negative bacteria (Edwards and Doran-Peterson, 2012) are the only class of ethanol production strains that have been demonstrated to convert all the sugars found in pectin into ethanol.

Thus, these bacteria will be used with the energy beet soluble sugars. As can be seen in the process diagram Figure A1.1, any high protein solids that could be used for animal feed have been extracted before this fermentation step so restrictions relevant to other processes that use post-fermentation solids for animal feed are not relevant here.

Researchers at Purdue processed samples of beet sugars produced with the Atlantic Biomass saccharification process with *E. coli* FBR5. Preliminary results (Figure A1.1) illustrate the potential of this class of bacteria to convert all of the beet sugars to ethanol.

Figure A1.1. Ethanol fermentation of sugar beet samples by E. coli FBR5.



Ethanol fermentation of sugar beet samples by *E. coli* FBR5. Hydrolysates were enzyme hydrolyzed by Atlantic Biomass proprietary enzyme process. *E. coli* (1 g/L) was added to the hydrolysates with pH adjusted to 7.0. The final volume for all the samples was 25 mL.

These results show that the combination of the AB saccharification process with *E. coli* FBR5 fermentation provides the basis for a high yield biomass to biofuel/bioproduct precursor system.

Further Research Needed: Additional findings from this research identified the following production impediments that will need to be resolved in order for the system to be economically sustainable:

- A cost-efficient method to extract soluble sucrose before enzyme hydrolysis will have to be developed.
- Reducing enzyme costs will be addressed through improvements in enzyme recycling as well as improvements in pectinase and arabinase performance.
- Improved *E. coli* ethanol tolerance to allow higher ethanol levels from fermentation will reduce distillation costs.

Conversion of Sugars to Single Cell Oils and Co-Products Using Oleaginous Yeast (USDA ARS)

In addition to following a sugars-to-ethanol-to-jetfuel path, a sugars-to-oil-to-jetfuel path may be followed.

Energy beet fermentable sugars, i.e. arabinose, xylose, galacturonic acid, and glucose, may produce single cell oils, triacylglycerols (TAGs), which can be catalytically converted to jetfuel. This conversion of sugars to oils may be accomplished by oleaginous yeast from the NCAUR collection.

The triacylglycerols (TAGs) are similar in composition to that of vegetable oils (Jim et al., 2015) and, therefore, can be converted to jetfuel using already established technology.

When nitrogen starved, oleaginous yeasts form TAG containing granules that can account for 20-70% w/w of their dry weight. NCAUR has a collection of oleaginous yeast that have been selected based upon ability to grown on hydrolysates, ferment mixed sugars, and produce high titers of lipids. These yeasts should be ideal for use on beet hydrolysate because it is expected to be less inhibitory than the switchgrass hydrolysate that has been used in previous experiments.

Further Research Needed: To confirm the efficacy of this process, the galacturonic acid in the beet hydrolysate needs to be tested to develop the production of meso-Galactarate (e.g. mucic acid, GalAA) and L-galactonate (L-GalOA).

These platform chemicals could significantly add to the profitability of the overall system because their price is expected to be less volatile and they can be produced from galacturonic acid at near 100% theoretical yields.

Examples of potential uses include:

- GalAA is an isomer of the top renewable chemical glucaric acid and has potential for production of nylon (Deng et al., 2016, Zhang et al., 2016).
- L-GalOA has potential use as a potential chelator and acidifier and, furthermore, is a precursor for production of L-ascorbic acid (e.g. L-galactono-1,4-lactone) (Kuivanen et al. 2012; 2014).

Yarrowia would be used as the host strain because it is already used industrially for production of organic acids (e.g. citric and isoctiric), is generally recognized as safe, and is the only oleaginous yeast for which there is a well developed genetic system (Madzak, 2015).

Vertimass

Vertimass, LLC has licensed and developed an Oak Ridge National Laboratory catalytic system that converts ethanol into jetfuel. The Vertimass technology is based on a new class of hetero-bimetallic catalysts that directly convert ethanol into gasoline, jetfuel, and/or diesel fuel blend. The catalyst, to which Vertimass has a worldwide exclusive license, has been proven with both cellulosic and starch ethanol.

Before aircraft can use SAJF, it must meet specifications defined in ASTM Standard D7566 and the specific annexes to the standard which apply to the various processes for producing SAJF.[72] Vertimass has begun the process of ASTM approval of the projection pathway and product for sale of the Vertimass product as a SAJF fuel.

The Vertimass process has a unique combination of a number of important attributes including:

1) Single step bolt-on conversion,

2) No hydrogen addition,

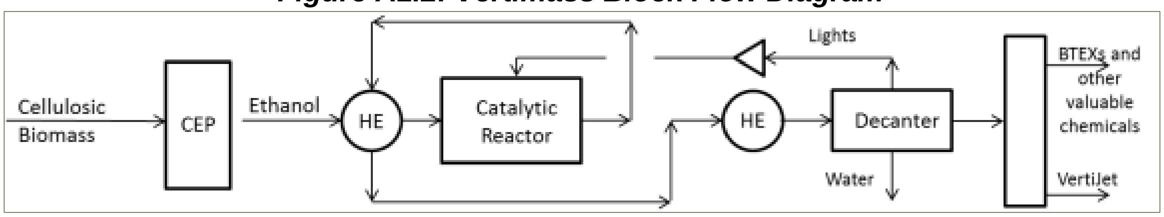
3) High yields of targeted liquid products with virtually complete ethanol conversion,

4) Reaction at atmospheric pressure and 400-450^{o}C,

5) Replacement of mole sieves and potentially rectification through ability to process 5 to 100% ethanol concentrations, and

6) Low CAPEX and OPEX.

Figure A1.2: Vertimass Block Flow Diagram



Further Research Needed: Maximizing BTEX yields and separating BTEX from the bulk product will allow the system to achieve two significant and complimentary objectives:

1) Reduce the breakeven selling price of fuel blend stocks so they can compete with components derived from low cost petroleum through increased revenues from sale of high value co-products (~twice the value of fuels) and

2) Increase the amount of Vertimass product that can be blended with jetfuels by removing BTEX for sale.

3) Commercial aircraft can only use fuel that is approved for use in the engine and aircraft operating manuals, as only this type fuel is proven to enable the performance and operability guaranteed by the certification of the aircraft. All of the major engine and aircraft manufacturers require usage of fuel which meets the requirements of ASTM D1655 (at a minimum). SAJF or synthetic fuels produced from sources other than petroleum via biochemical or thermochemical processes, must meet the requirements of ASTM D7566 as part of D1655 approval.[73]

72 Commerical Aviation Alternative Fuels Initiative, "Frequently Asked Questions." http://www.caafi.org/resources/faq.html#Alternative

73 *Ibid.*

Appendix 2: Conversion of Oils to Jetfuel (Various ASTM-Accepted Processes)

A number of processes are used to convert oils to jetfuel. Since 2009, ASTM has approved five including Fischer-Tropsch (FT-SPK), and Hydrotreated Esters and Fatty Acids (HEFA-SPK), which can use oils to make jetfuel.

- For **FT-SPK**, approved in 2009 up to a 50% blend, a carbonaceous source (biomass like forestry products, grasses, or MSW) is gasified at high temperatures (1200-1600° C) into carbon monoxide and hydrogen primarily, and the gas is then converted to long carbon chain waxes through the Fischer-Tropsch (FT) Synthesis. The wax is then cracked and isomerized to produce drop-in liquid fuels essentially identical to the paraffins in petroleum-based jetfuel, but does not include aromatic compounds.
- In **HEFA-SPK**, approved in 2011 up to a 50% blend, natural oils are converted from lipids to hydrocarbons by treating the oil with hydrogen to remove oxygen and other less desirable molecules. The hydrocarbons are cracked and isomerized, creating a synthetic jetfuel blending component. [74]

[74] *Ibid.*

Appendix 3: Illustrations of ASTM and Navy Production Pathway Approval Processes

These slides from a March 2017 presentation by Commercial Aviation Alternative Fuels Initiative executive director Steve Csonka and Nexant principal Ron Cascone illustrate sustainable alternative jetfuel conversion technologies and their approval status or progress toward ASTM approval.[75]

Figure A3.1 Sustainable Alternative Jetfuel Approved Pathways: Annexes to ASTM D7566: D1655 Fuel Following Blending

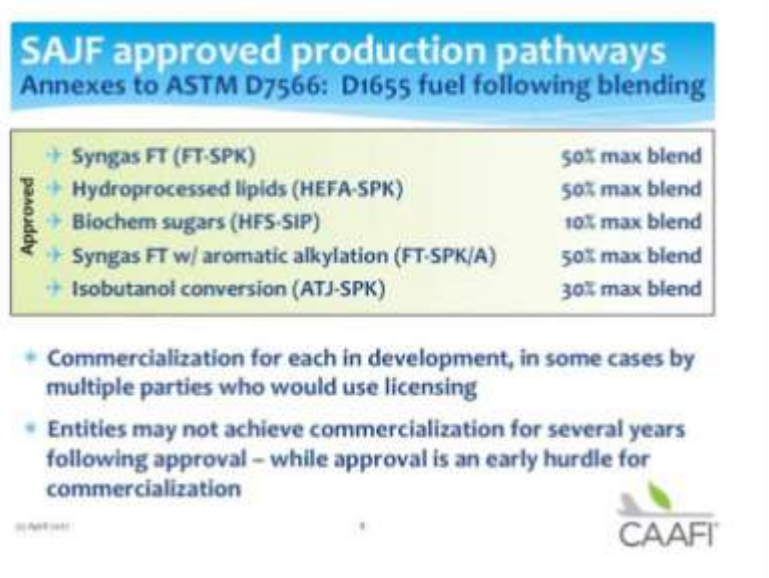
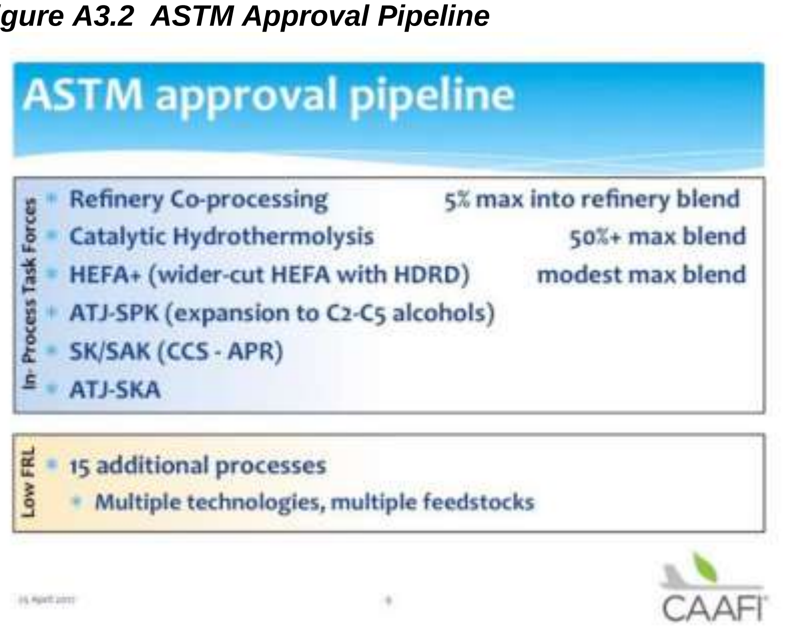
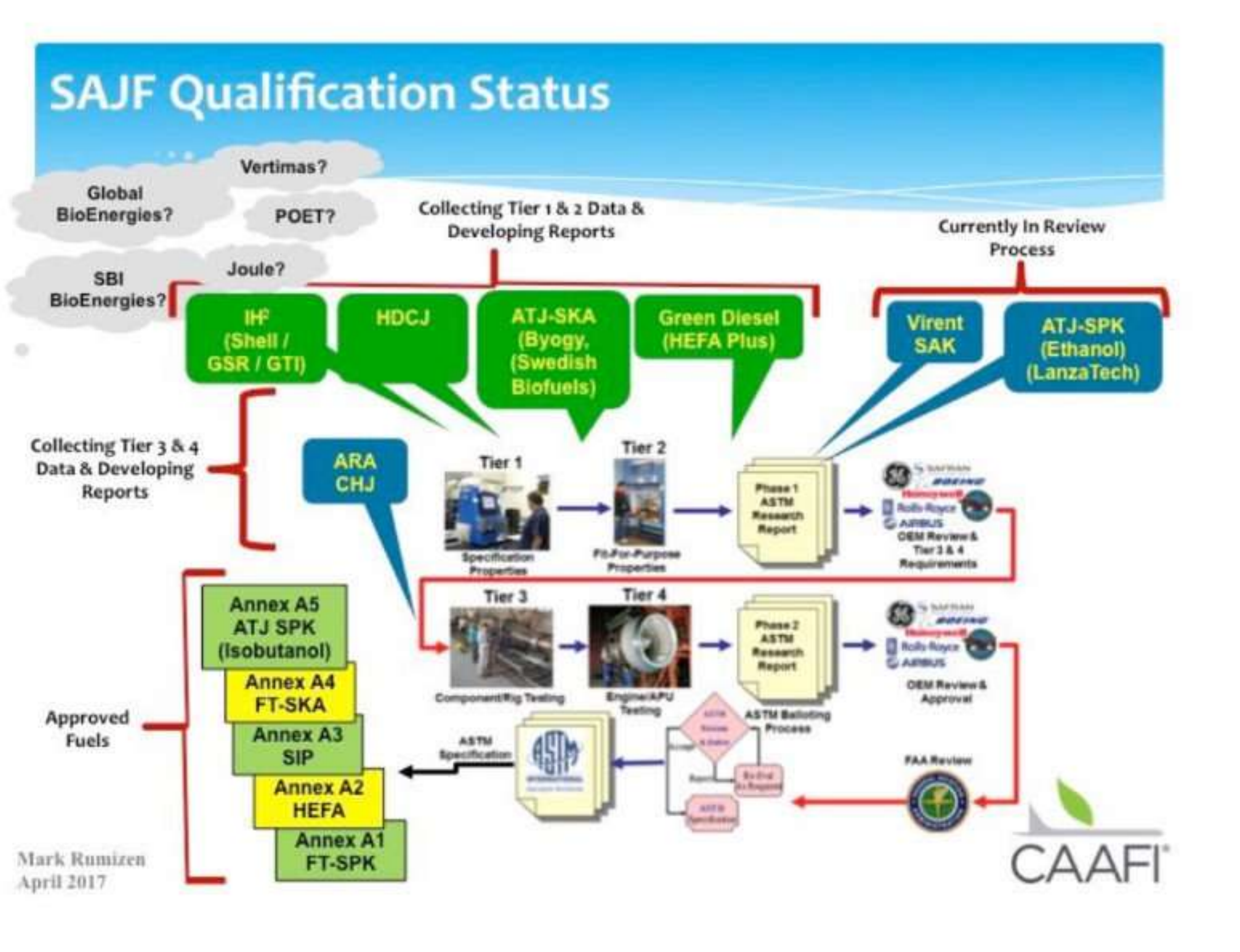


Figure A3.2 ASTM Approval Pipeline



[75] "Skybound: The Digest's 2017 Multi-Slide Guide to Sustainable Aviation Fuels," Biofuels Digest. April 27 2017 Accessed 8/1/17 http://www.biofuelsdigest.com/bdigest/2017/04/27/skybound-the-digests-2017-multi-slide-guide-to-sustainable-aviation-fuels/

Figure A3.3: ASTM Qualification Status for Sustainable Alternative Jetfuels Proposed and in Process



This graphic from the US Navy illustrates the progress made and expected for qualifying jetfuel for use by the military.

Figure A3.4: Navy Synthetic Fuel Qualification Roadmap

Chris Tindal Director for Operational Energy, DASN Energy Farm to Fleet presentation [76]

[76] "Strength through choice: The Digest's 2017 Multi-Slide Guide to the US Navy's military biofuels program" presentation by Chris Tindal March 2017 at Advanced Biofuels Leadership Conference in Washington, DC. Accessed August 1, 2017 http://www.biofuelsdigest.com/bdigest/2017/07/30/strength-through-choice-the-digests-2017-multi-slide-guide-to-the-us-navys-military-biofuels-program/

Appendix 4: Delmarva Peninsula Cropland Needed for Energy Beet Processing to Ethanol for Jetfuel

Table A4.1 Delmarva Peninsula Cropland Needed for Energy Beet Processing to Ethanol for Jetfuel

Maryland

County		Crop Acres	Idle Acres
DORCHESTER		91,954	9,208
SOMERSET		36,407	2,393
WICOMICO		56,094	5,383
WORCESTER		71,339	4,572
CAROLINE		121,386	6,252
CECIL		54,778	2,831
KENT		104,639	5,707
QUEEN ANNES		129,940	8,758
TALBOT		98,180	4,469
Total Acres		764,717	49,573
10% Acres		76,472	
Annual Ethanol @ 1,000 gal/acre			
10% Land in Rotation (Gallons)		**76,471,700**	
40% Idle Land/Year (Gallons)			**19,829,200**
Total Annual Ethanol (Gallons)		**96,300,900**	
Annual Jetfuel @ 625 gallons/acre		**60,188,063**	

Delaware

County		Crop Acres	Idle Acres
KENT		103,114	
NEW CASTLE		39,643	
SUSSEX		154,139	
Total Acres		296,896	-
10% Acres		29,690	
Annual Ethanol @ 1,000 gal/acre			
10% Land in Rotation (Gallons)		**29,689,600**	
40% Idle Land/Year (Gallons)			**-**
Total Annual Ethanol (Gallons)		**29,689,600**	
Annual Jetfuel @ 625 gallons/acre		**18,556,000**	

Eastern Shore Virginia

County		Crop Acres	Idle Acres
ACCOMACK		64,271	628
NORTHAMPTON		42,807	156
Total Acres		107,078	784
10% Acres		10,708	
Annual Ethanol @ 1,000 gal/acre			
10% Land in Rotation (Gallons)		**10,707,800**	
40% Idle Land/Year (Gallons)			**313,600**
Total Annual Ethanol (Gallons)		**11,021,400**	
Annual Jetfuel @ 625 gallons/acre		**6,888,375**	

Total Delmarva

		Acres	Acres
Total Farmed Acres		1,168,691	50,357
10% Land in Rotation		116,869	
40% Idle Land			20,143

Annual Ethanol @ 1,000 gal/acre		Gallons/Year	Gallons/Year
From 10% Land in Rotation		**116,869,100**	
From 40% Idle Land			**20,142,800**
Total Annual Ethanol		**137,011,900**	
Annual Jetfuel @ 625 gallons/acre			
From 10% Land in Rotation		**73,043,188**	
From 40% Idle Land			**12,589,250**
Total Annual Bio-Jetfuel		**85,632,438**	

USDA 2012 Agricultural Census

Appendix 5: Base Case Values, References for Sensitivity Analysis

Table A5.1 Base Case Values for Sensitivity Analysis

Income ($/yr)	Jetfuel (Navy)	Jetfuel (Commercial)	Ethanol
Fuel	28,213,863	16,341,061	30,886,582
Protein Meal	7,569,000	7,569,000	7,569,000
Biofuel Credit Ethanol (Cellulosic, 40% of sugars)	8,236,422	8,236,422	8,236,422
Biofuel Credit Jetfuel (BPI)	2,106,465	-	-
Biofuel Credit Jetfuel (Renewable Diesel)	12,766,454	12,766,454	-
***P Credit (cap and trade**) see separate analysis	0	0	0
Costs ($/yr)			
Heating	720,687	720,687	720,687
Electric	1,907,761	1,907,761	1,907,761
Ethanol to Jet Operating	3,088,658	3,088,658	-
***Enzymes**	1,647,284	1,647,284	1,647,284
Yeasts	453,003	453,003	453,003
Other Chemicals/Antibiotics	411,821	411,821	411,821
Boiler and Cooling Tower Chemicals	102,955	102,955	102,955
Water	123,546	123,546	123,546
Denaturant (2%gasoline)	823,642	823,642	823,642
Depreciation	7,440,235	7,440,235	5,792,950
Maintenance & Repairs	257,388	257,388	257,388
Interest Expense	13,439,347	13,439,347	10,463,846
Labor	926,597	926,597	926,597
Management and Quality Control	280,038	280,038	280,038
Real Estate Taxes	200	200	200
Licenses, Fees & Insurance	82,364	82,364	82,364
Miscellaneous Expenses	277,979	277,979	277,979
TOTAL ($/yr)	31,983,508	31,983,508	24,272,064
VARIABLES AND CAPACITIES			
Fuel (type)	0	0	$-
***Fuel Price ($/gal)**	2.21	1.28	1.50
***Operating (% of year)**	0.50	0.50	0.50
Interest on Loan (%)	8.50%	8.50%	8.50%
Loan and Depreciation Period (y)	15	15	15
***Capital Cost for plant ($/gal ethanol)**	2.71	2.71	2.11
***Beet Price ($/acre)**	1,050	1,050	1,050
Fuel Produced (gal)	12,766,454	12,766,454	20,591,055
Nameplate Capacity (gal)	41,182,110	41182109.85	41,182,110
Net Margin	11,683,696	$(2,295,571)	$7,194,940

* denotes variables that were used for sensitivity analysis.

There are no confidence intervals in the values used in the model. They are not averages from which a mean and standard deviation could be developed nor significance evaluated.

The model was developed based on various literature values from published models of corn ethanol production and energy beet ethanol production, from USDA energy beet production cost data, and other sources (see below). The variation in profitability was compared by changing critical values that had a large impact on profitability (eg. capital cost). The ranges chosen were ones that were considered to be reasonable by the feasibility study team.

Here is the sugar beet commodity cost and return data from USDA for the Great Lakes region. This region was chosen due to it is similar climate wise to Delmarva. The most recent data is from 2007.

https://www.ers.usda.gov/webdocs/DataFiles/47913/RNCSugb.xls?v=42856

The foundation of the energy beet ethanol plant cost model is a spreadsheet developed as part of a study by the University of Minnesota Department of Applied Economics (Tiffany and Eidman, 2003). This study examined economic factors associated with success or failure of dry-mill ethanol plants utilizing corn as a feedstock. The model was validated by comparing results to those compiled by a group of 200 farmers and ethanol plants in Minnesota. The spreadsheet model was modified to account for the use of energy beets as the feedstock and updated for current prices of energy and other costs. Baseline conditions including capital cost per gallon of capacity, ethanol yield per ton of Energy Beets and other values are shown in Table A5.1. The model was used to predict the financial performance of a modern, 20 million gallon per year, energy beet to ethanol plant. Sensitivities were determined and graphed to demonstrate the respective influence of beet price, P credit, fuel price (ethanol and jet fuel), capacity factor (months of operation), capital cost per gallon, and loan and depreciation period. Multiple plants of this size could be constructed to give a 100 million gallon per year capacity.

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Appendix 6: Maryland's Nutrient Trading Program

Description provided by Maryland's Department of the Environment and Agriculture[77]

Maryland's Nutrient Trading Program is a public marketplace for the buying and selling of nutrient (nitrogen and phosphorous) credits. The purpose of the Program ranges from being able to offset new or increased discharges to establishing economic incentives for reductions from all sources within a watershed and achieving greater environmental benefits than through existing regulatory programs.

In January 2008, the Maryland Department of the Environment (MDE) issued a policy document entitled "Maryland Policy for Nutrient Cap Management and Trading in Maryland's Chesapeake Bay Watershed" that represented the initial phase of the State's policy development on nutrient trading (referred to as Phase I). That document described the purpose and form of nutrient trading in Maryland and set forth the fundamental principles and guidelines for Maryland's trading programs. It also spelled out the requirements and procedures for nutrient trades between wastewater treatment plants (point source-point source trading). With the issuance of this policy, wastewater treatment plants can begin requesting approval for trades with other wastewater treatment plants.

Phase II was initiated by the Maryland Department of Agriculture (MDA) in the fall of 2007 to address the opportunity for trading between point and nonpoint sources, such as agricultural operations. The requirements and procedures for point—nonpoint agricultural trading were issued in April 2008 in two draft documents: *The Maryland Policy for Nutrient Cap Management and Trading in Maryland's Chesapeake Bay Watershed Phase II A—Guidelines for the Generation of Agricultural Nonpoint Nutrient Credits*, and *Phase II B—Guidelines for Agricultural Nonpoint Credit Purchases.* Specifically, these documents provide a mechanism for generating credits from agricultural sources that can be purchased by point sources and other interested buyers, and they describe how credits will be exchanged between buyers and sellers.

Point Source Trading

The key principles of the Phase I - Point Source Trading policy are basic. They call for all new and expanded point source nutrient loads to be fully offset, require all trades to be consistent with local county water and sewerage plans, but do not allow trading in lieu of required Enhanced Nutrient Removal (ENR) upgrades. In addition, point source trades will be implemented and enforced via National Pollutant Discharge Elimination System (NPDES) permits, and trades have to be consistent with Total Maximum Daily Loads or TMDLs. The cornerstone of the policy's key principles is that trades must

[77] Maryland Nurtient Trading, "What is Maryland's Trading Program?" http://www.mdnutrienttrading.com/ntwhatis.php accessed 6/20/2017

protect local water quality as well as provide adequate public outreach/stakeholder participation. Phase I Policy also addressed point source baseline requirements.

Trading is structured through “Units of Trade” called a credit, which is equal to one pound of nitrogen or phosphorus delivered to the main stem of the Bay per year. Credits will be traded within defined trading areas. At this time, these areas are defined as: the Potomac basin; the Patuxent basin; and everywhere else within the state.

Credits can be generated in a variety of ways. These include upgrading an existing minor wastewater treatment plant to BNR (Biological Nutrient Removal) or ENR status. Also, an existing wastewater plant can be retired and have its flow sent to a BNR or ENR facility or an existing Onsite Sewage Disposal System (OSDS) can be retired by the connection to public sewer or cluster treatment. ENR facilities may generate point sources discharge credits by reducing effluent concentration or maintaining flow at less than the design flow basis of the waste load allocation. In addition, a facility may opt to have land application of wastewater with pretreatment and nutrient management controls.

There is a way, too, for an Onsite Sewage Disposal System (OSDS) to earn nitrogen credits. The credit calculation for an OSDS assumes hookup to a WWTP discharging nitrogen at 4 mg/L. If the System is within the Critical Area the potential credits are 12.2 lbs/yr; if it is within 1,000 feet of any perennial surface water the credit would be 7.5 lbs/yr; and then 4.6 lbs/yr everywhere else. It should be noted that commercial OSDS credits will be higher and determined on a case-by-case basis.

One of many important elements is the length of time a trade will last – or its “trade duration.” The wastewater treatment plants will strive to buy credits to offset growth. The agreements they make will be a contractual arrangement that will last for 10 years. During this time they will also develop a plan that will put them into a position to acquire the credits for the next 10 years after the initial contract has expired.

Nonpoint Source Trading

Maryland’s Phase II Trading Program’s is directed towards the inclusion of agriculture into the process. That is where point source and agricultural nonpoint source can start trading. Policies have been developed that define two basic components of this phase of the program. They provide guidelines for the Generation of Agricultural Nonpoint Credits (selling credits), and guidelines for the Exchange of Agricultural Nonpoint Credits (buying credits).

One of the key principles established for Agricultural Nonpoint Source Credit Generation is that agricultural operations must first meet baseline requirements before generating credits. Farm operations must meet the level of nutrient reduction called for in the Tributary Strategy for their basin. Where a TMDL is required, they must meet the level of reduction prescribed in the related documents. Additionally, credit generators must be in compliance with all federal, state and local laws and regulations.

For agricultural operations, certain land use (such as crop conversions) and agronomic practices (cover crops, reduced fertilizer application, and manure export), along with structural BMPs (riparian buffers, livestock fencing, etc.) are eligible to produce credits. To qualify, these practices must be certified and inspected. They also must be built and operated according to USDA/NRCS specifications. Each practice will have an annual verification carried out by technically competent reviewers who may be representing the state, a third party, or the seller. This verification will insure that the BMP or practice is being maintained in accordance with the specifications. Credits will only be generated once the BMP is installed and functioning as designed and approved. Landowners or farmers cannot use federal or state cost-share funds to generate credits and cannot generate credits by retiring farmland from active production. All reductions must result in a net decrease in nutrient loads entering the water and be consistent with Phase II trading policy requiring a 10% retirement ratio.

To participate in the Agricultural Nonpoint Source component of Maryland's Nutrient Trading Program, landowners, farmers, or aggregators will utilize a web-based nutrient trading application tool to calculate baseline eligibility and credit potential. Local Soil Conservation Districts can help in accessing the tool and providing assistance to those interested in pursuing the process. Once credits have been certified and approved, they can be posted on the Maryland Nutrient Trading Program's Marketplace. In the Marketplace participants can post and exchange information with potential buyers on credit availability, credits desired, quantity, and price. To enable effective management and communication of Maryland's Nutrient Trading Program, the Marketplace will include a Trading Registry that will catalogue all registered credits and approved trades.