Technology Review Fiberight Process for MRC

Dr. Hemant Pendse, FBRI Director
Michael Bilodeau, PDC Director
Amy Luce, TRC Manager, Process Group Leader
Darrell Waite, Formerly Process Manager, Biorefinery and Director of Technology, Old Town Fuel and Fiber, Old Town, ME
James S. Atwell, P. E., Sevee & Maher Engineers, Inc.

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I. Summary:

FBRI was asked to review Fiberight's technology to convert Municipal Solid Waste (MSW) to biofuels and other products. The scope of the review was limited to the biological and chemical conversion of the organic fraction of MSW to liquid fuels and other products. In order to accomplish this task a detailed study of the technology was done which included a site visit to Fiberight's demonstration facility in Lawrenceville, VA. Subject matter experts were consulted to offer comment on process readiness in comparison with similar known biofuel projects and applicable environmental considerations.

The evaluation team concluded that Fiberight's processing technology is sound and capable of converting the insoluble portion of MSW organics to a simple sugar solution. Presently at their pilot plant, Fiberight has successfully used sugar solutions from both the insoluble and soluble portion of MSW to produce biogas through anaerobic digestion (AD). A third party has reported that sugars from the Fiberight process have been used to produce ethanol on a laboratory scale.

1. The equipment and processing steps that constitute the proposed technology are similar to existing equipment and processing steps found today in the pulp and paper industry and in related fields.
2. There are no concerns regarding the scaling up of the technology from the scale demonstrated at the Fiberight facility in Lawrenceville, Virginia, to the scale proposed for the MRC-sponsored facility, particularly for production of biogas and clean sugars. There was no data on Fiberight's operating experience on combustion or gasification of residual post hydrolysis solids at Lawrenceville, VA.
3. Fiberight has demonstrated that its technology can convert the organic fractions of MSW into clean, fermentation-ready sugars without significant inhibitors.
4. The experience at the Fiberight facility in Lawrenceville, Virginia, showed that odor issues are limited to the front-end of trash handling and sorting, with areas beyond the pulp washer are similar to the a paper mill and are relatively odor free. Issues related to air emissions would arise based on combustion or gasification of residual biomass and post hydrolysis solids. Although Lawrenceville VA experience is not directly applicable to Maine's winter operations, Fiberight's experience in Iowa should prepare them in addressing winter operation issues.

The economics of the Fiberight process were outside of the scope of the project and are not reviewed in this report. The claimed hydrolysis efficiency is somewhat lower than that reported for other biofuel feedstock processing technologies, potentially due to the MSW origin. The selection of final products produced from this process will have a large impact on the economics of the project. A Maine specific market analysis is recommended if biomethane, sugars, and biomass are planned to be significant end products from the plant.

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II. Scope:

This review is based on analysis of the elements of the Fiberight technology that involve biological and chemical conversion of the organic fraction of MSW to liquid fuels and other products. The primary aim of this study is to provide the Municipal Review Committee (MRC) with insights regarding the feasibility and viability of the reviewed aspects of the Fiberight technology. Additional limited analysis was conducted to obtain relevant perspectives regarding the Fiberight technology on environmental permitting, host site selection, and technology scale-up issues.

Specific concerns raised by MRC regarding the implementation of new technology in Maine include the following:

1. The extent to which the equipment and processing steps that constitute the proposed technology are similar to, or represent a departure from, existing equipment and processing steps found today in the pulp and paper industry and in related fields.
2. Concerns regarding the scaling up of the technology from the scale demonstrated at the Fiberight facility in Lawrenceville, Virginia, to the scale proposed for the MRC-sponsored facility, with special attention to the continued viability and the potential for changes in performance of the technology at the larger scale.
3. Whether Fiberight has demonstrated that its technology can convert the organic fractions of MSW into ethanol or other liquid fuels or chemical products that meet commercial specifications.
4. Whether the experience at the Fiberight facility in Lawrenceville, Virginia, provides the basis for concerns that an MRC-sponsored Fiberight facility might result in issues related to air emissions, odor emissions, solid or liquid wastes requiring special treatment, or other potential emissions or nuisances.

III. Process Review:

The Fiberight process description with a process flow diagram is reproduced as Appendix A. This was extracted from the information packet submitted to Maine DEP by MRC on September 26, 2014. Based on a site visit by Michael Bilodeau, this process flow has changed slightly, and the updated process flow is described in his site visit report in Appendix B.

A. Front-end Separation System

Review of the US EPA Decision document[1] dated June 2012 indicated that approval of the "Fiberight Separation Plan" means that separated-MSW feedstock produced according to the submitted separation plan for Blairstown, Iowa, with its associated addendum, qualifies as renewable biomass. Thus, Fiberight may use such separated-MSW to produce certain renewable fuels that generate RIN credits. The Fiberight Separation Plan was deemed to be equivalent to a fully functional municipal recycling facility (MRF) as a front-end to their waste-to-energy plant. Fiberight had assumed no prior separation of the waste stream. This is important for the communities not served by curbside recycling. The Fiberight Separation Plan provided for separation of recyclable aluminum, ferrous and other metals, plastic containers, film plastic, glass, aggregate, and organics to the extent reasonably practicable. Fiberight proposes to produce 'recovered recyclables' as products for end markets. The significance of a fully functional MRF as a front-end can be evaluated by the MRC to the extent curbside sorting and recycling practices are applicable to the anticipated waste stream coming to the proposed facility.

Once the initial recyclables have been recovered, the MSW is processed in a pulper at 160°F to 180°F with the addition of water and heat. This creates conditions to allow the organic, primarily food and paper, to break down forming a fine particulate biomass. Once the biomass is produced, it has a much smaller particle size than the remaining materials allowing a high level of separation in standard MRF equipment. The biomass is cleaned in a two-stage washing tunnel where first the soluble organics are removed for the feed to the anaerobic digester, and then the high-cellulose biomass pulp is separated from any small inorganic contamination.

B. Conversion of MSW Organics

For the present review, we focused on evaluating the proposed technologies for conversion of MSW organics, including: (1) soluble organics derived from organics in the mixed MSW, and (2) insoluble organics derived from cellulosic waste, compostable or soiled fiber, and low-lignin yard waste. Fiberight proposes to convert wash water rich in dissolved organics into biogas, and convert washed and pre-treated cellulosic solids into a filtered and concentrated sugar solution.

The biogas can be upgraded on-site to pipeline quality methane-rich gas for injection into a natural gas pipeline or further compressed for use in CNG (compressed natural gas) vehicles as one or more co-products. The sugar solution will be concentrated and sold to a third party as cellulosic sugar.

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[1] http://www.epa.gov/otaq/fuels/renewablefuels/documents/fiberight-decision.pdf

1. Anaerobic Digestion

Fiberight proposes to use a "liquid-only" high capacity anaerobic digestion (AD) system to process wash water rich in dissolved organics derived from mixed MSW. This type of reactor system is claimed to produce clean water that can be reused in the washing process and not generate significant quantities of digestate. It should be noted that Fiberight proposes to process only 'soluble' organics in their AD system.

Commonly AD systems have been used to process both dissolved solids as well as suspended solids. When total solids level is less than 15 wt % the digestion is called 'wet', and when total solids level is 25-30 wt % it is called 'dry'. Often, dewatered solid organics are subjected to composting.

The most suitable feedstock for current commercial Anaerobic Digesters is often described as:

- Animal waste and biowaste from wastewater treatment plants
- Food and kitchen wastes from restaurants, canteens, food markets, and municipal source- separated food wastes.
- Organic waste from food processing industry, slaughter houses, etc.

Source Separated Organics are comprised of food waste, paper napkins, and used kitchen paper, as well as green waste. The "all other" fraction is the waste that remains after the recyclable and compostable materials are separated at the source by the citizens at curbside. Most AD plants process "source separated organics (SSO)" but attempts to process organics separated from mixed MSW have proven to be quite challenging. These reported operational problems often come from suspended solids in the feed.

For Fiberight's 'soluble organics only' feed case, AD operations are expected to be more efficient and less problematic. Our site visit indicated that Fiberight has accumulated significant operating experience on biogas production with a small commercial AD installation, using a 8,000 gallon Voith[2] R2S reactor with a maximum capacity of 1,320 lb COD/day. Based on the initial work with Voith, they found there was a limitation of 500 ppm in the feed to the AD. Fiberight now is working with Hydrothane who also supply Expanded Granular Bed (EGB) systems. Fiberight claims this system can tolerate suspended solids up to 2,500 ppm and gives more flexibility. This type of AD is in Fiberight's plan for their site in Iowa. The scale up of the AD is not expected to be an issue. Fiberight's proposed plans for Maine include possible biogas upgrading for input to a natural gas pipeline or production of CNG.

2. Enzymatic Hydrolysis to produce clean sugars

Fiberight proposes to use washed MSW-derived pulp press cake (over 40 wt. % solids) for producing clean fermentable simple sugars. The key step is the thermo-mechanical pretreatment involving pH adjustment and cooking at 260°F for 30 min residence time using steam injection in a pressurized vessel,

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[2] http://www.vp-environmental.com/en/Industrial_Environmental/Wastewater/Anaerobic_Biological_Treatment/R2S-Anaerobic_Reactor.html

followed by low consistency (3 to 4 wt.%) refining and dewatering that produces clean and sterile MSW-derived pulp press cake. This MSW-derived pulp is similar to what Old Town Pulp mill was using out of their brownstock washers as far as suitability for hydrolysis is concerned. Actual hydrolysis efficiencies, enzyme loading requirements, and cleanliness of resulting sugars are expected to be quite different for MSW-derived pulp versus brownstock (unbleached chemical) pulp.

Fiberight has an active partnership with a major enzyme supplier (Novozymes) for hydrolysis of pretreated MSW-derived pulp. Unhydrolyzed solids can then be separated from sugar solution using a filter press. Filtered sugar solution can be concentrated using evaporators and/or membrane filtration with evaporator condensate being reused onsite.

This portion of the processing is similar to the brownstock pulp hydrolysis scheme planned for the Old Town mill. The brownstock pulp contains liberated virgin wood fibers from woodchips with lignin and some hemicellulose removed in the black liquor through the chemical pulping process. The black liquor solids are burned in a recovery boiler at a pulp mill providing steam and power. After cooking, the pulp is washed to remove spent chemicals and dissolved lignin prior to hydrolysis. Hydrolysis efficiency for the brownstock pulp is found to be 90% to 95% on the basis of complex carbohydrate content in the brownstock. Resulting simple sugars then need to be cleaned to remove various potential inhibitors.

Fiberight has partnered with Andritz, a major supplier to the pulp and paper industry, to supply the cooking systems for their full scale plants.

The MSW derived insoluble organics are subjected to the thermo-mechanical pretreatment outlined above to prepare the pulp for hydrolysis. Hydrolysis efficiency for the carbohydrate in the MSW-derived pretreated pulp is in the 40 to 50 w/w% range as reported in Michael Bilodeau's site visit report in Appendix B. For example, with hydrolysis feed containing 80% carbohydrates one would get 60% mass out as unhydrolyzed solids at 50% hydrolysis efficiency. The efficiency is low in comparison with virgin cellulosic undried pulp, due mostly to a phenomenon known as hornification. When cellulosic pulp fibers are dried in papermaking, the internal volume of the fiber shrinks. When the fibers are rewetted, they do not swell to the original volume. This lack of swelling to the original state is known as hornification. Due to this occurrence, the enzymes don't have easy access to all of the fiber surfaces, like they do in undried virgin pulp. Fiberight uses some refining to open up the fibers for better enzyme efficiency and is working on a plan to improve this process. Improvements in enzyme technology could aid in the conversion efficiency in the future. The unhydrolyzed solids can be used as biomass fuel if dewatered to low enough moisture content, and burned onsite for steam and power needs of the facility. The resulting sugars need to be evaluated for fermentation yield using selected microbes. Fiberight has reportedly benchmarked such sugars for fermentability to ethanol with the help from Novozymes.

Fiberight has accumulated operating experience on a 1500 gallon hydrolyzer and associated pre-treatment set up in their pilot facility, using current technology. No scale-up issues are anticipated for these steps.

3. Utilization options for MSW derived sugars

Fiberight and Novozymes have carried out a number of bench scale tests converting sugars produced from Fiberight's biomass pulp. The results demonstrate that the conversion of the C6 sugars to ethanol is within industry standards. Technology for fermenting sugar into ethanol, irrespective of the source of sugar, can be supplied by a yeast supplier as long as sugars meet the minimum quality specifications and are available at the required feed rate in a reliable fashion to support the installed processing capacity. Fiberight is planning to ferment sugars to ethanol in the plant in Iowa, but is not planning this step in Maine.

As part of Fiberight's development process, modifications were made to the plant in Blairstown to allow the plant to run paper mill sludge. Conversion efficiencies of the mill sludge were low, possibly due to the use of an early generation enzyme during hydrolysis where the sugars were produced and then fermented to ethanol.

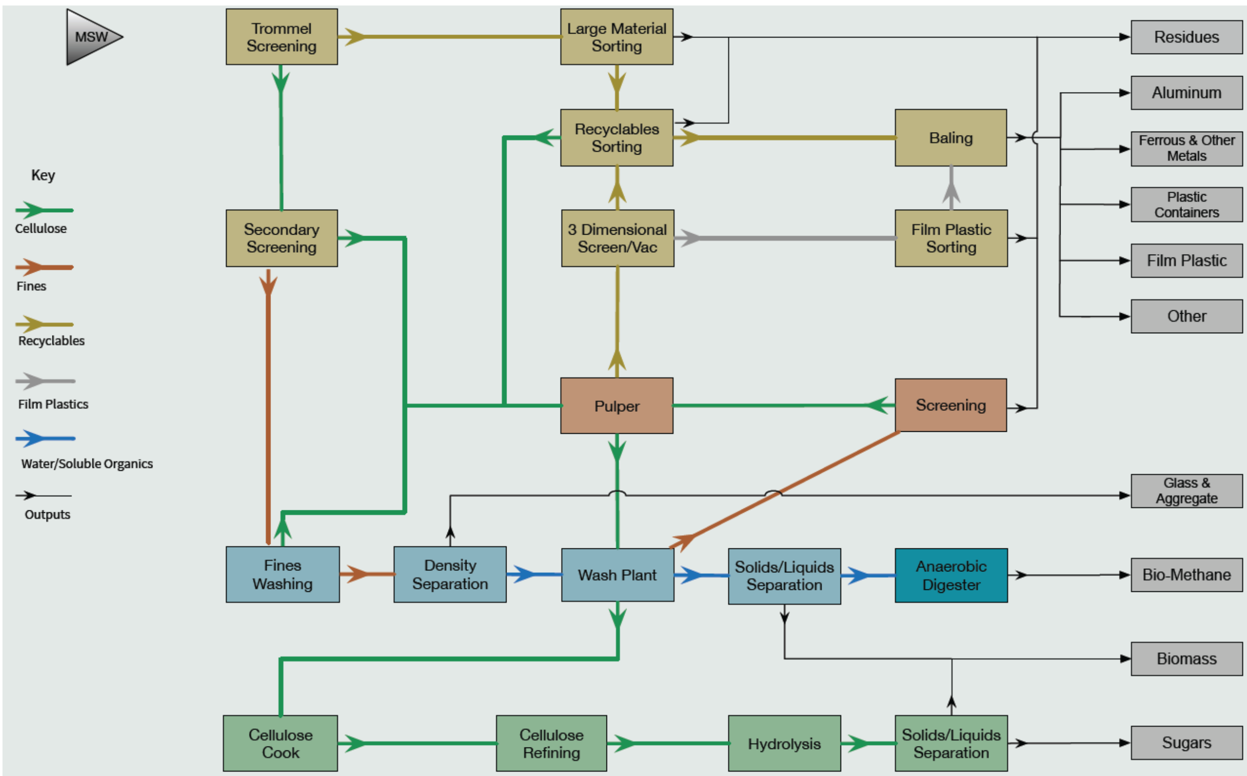
The proposed product of the Fiberight processing in Maine is a concentrated, filtered, clean simple sugar solution for off-site use. Another option involves processing simple sugars from the hydrolyzer in the AD system as soluble organics on-site for additional biogas production. Fiberight claims this is likely the option they will choose during 3 of the winter months in Maine due to the short supply of natural gas in Maine. Both of these alternatives would avoid the technical risk and capital investment associated with the fermentation and upgrading of ethanol. Darrell Waite's report on proposed MSW sugar utilization in Appendix D cautions having sugars as an end product due to lack of market for cellulosic sugars. Fiberight claims they have an interested party for the sugars produced in their plant in Virginia and is looking into the market for the Maine sugars with multiple parties. Transportation of the clean sugars to the end user will need to be evaluated for cost and possible contamination.

IV. Site infrastructure and permitting needs:

As shown in an overall process flow diagram below (See Appendix A and B for process descriptions), a variety of processing options raise certain site attributes that need to be considered early. The process description supplied by Fiberight does not adequately specify on-site waste water treatment and disposal needs. Furthermore, solid waste disposal to a landfill is also not clearly specified. A full mass and energy balance should be obtained and reviewed because it is needed to fully understand impacts on air, water and landfill as well as process energy requirements. With the elimination of ethanol production from the scope of the Maine project, now there is no product with current established markets in Maine. There appears to be a significant reliance on emerging Maine markets for biomethane produced from AD, sugars produced from hydrolysis, and residual unhydrolyzed biomass. It is unclear what portion will be used onsite versus sold.

Fiberight is exploring the use of paper mill sludge at their Iowa plant. A possibility of accepting pulp or paper mill sludge to supplement MSW derived organics may be an interesting option, but avoidance of current landfilling in favor of transporting sludge to the proposed Fiberight facility combined with on-going pressure to reduce cellulose losses from mills into waste sludge raises various practical business issues.

A report by Sevee & Maher Engineering, Inc. (SME) in Appendix E offers more information on details of permitting requirements. Once the material and energy balance information is complete along with equipment selection and sizing, the permitting process should begin in order to meet the project deadlines. The permitting process could take an estimated 6 months to one year. As mentioned in the SME report in Appendix E, the Fiberight site proximity to Acadia National Park and Moosehorn Preserve could raise air emissions concerns.



Site selection criteria should include consideration of the following attributes:

1. Access to waste water treatment – industrial preferred or municipal with adequate capacity.
2. Access to natural gas pipeline
3. On-site natural gas usage
4. Good road for truck traffic and rail access
5. Industrially permitted site for air and water emissions and deployment of MSW Organics conversion technologies
6. Distance away from residential and retail zones or other environmentally sensitive areas.
7. Space for co-location with users of recovered materials.
8. Shielded from public view.
9. Pine Tree or other incentivized zone is a plus.

V. Technology Readiness and Project Implementation Considerations:

Proposed process technology for converting MSW derived organics into biogas and MSW cellulosic sugars has been clearly identified by Fiberight, with several aspects already deployed at pilot or small commercial scale. Processing equipment used for MSW pulping, washing, pretreatment, hydrolysis, and anaerobic digestion at the Fiberight pilot plant in Lawrenceville, VA is sufficiently similar to what has been deployed in pulp and paper industry so that scale up risk is not an issue. Appendix B gives detailed notes from the November 2014 site visit, and Appendix C provides comments on MRC site visit report of December 2013 as an update.

Fiberight has been working with a number of strategic equipment suppliers, including Vickers Seerdrum for a continuous pulper, Milnor for the two-stage washing unit, Andritz for the cooking and refining stages, Proquip for mixing, HydroThane for the EGB (expanded granular bed) reactors for the AD plant, and Novozymes for the enzyme and technical support. These relationships are valuable assets. Fiberight is also working with an independent engineer (Black & Veatch) in connection with an USDA loan guarantee application for the Iowa project. The Independent Engineers report on Fiberight's Iowa project will provide significant information that would useful for evaluating a business case for the proposed project for MRC in Maine. Such a report may contain details on the material and energy balances, along with estimates of CapEx and OpEx, for various process blocks in the Fiberight process flow diagram.

The proposed technology is close to beginning construction for commercial deployment in Iowa, although we have not seen a detailed resource loaded construction schedule with a specific starting date. The next step for the Maine project is to clearly define the scope of the project in terms of the final products and end users/customers. There is still some uncertainty regarding what is going to be used on-site and what is going to be sold and in what form. Once that is defined, there should be a deeper dive for the capital required for process technology implementation. A table showing the DOE[3] Class 5 Concept Screening study is shown in the table below. Based on the fact that the Iowa project is at or near the Class 2 level, there will be many similarities for the Maine project and the planning time should be reduced. It would still require resource commitments on Fiberight's part dedicated to advancing the Maine project. Another planning stage process used for construction projects is Front End Loading and it has 3 levels, of which level 3 is defined below. This will need to be completed to have all basic data/information to file for permits. Once FEL 3 is complete, the permitting will take conservatively 12 months for a greenfield site. Often the permitting needs to be completed before major equipment can be ordered. Major equipment may have lead times as long as 12 - 18 months. As an example, evaporators are typically 15 +/- 3 months for delivery. The major lead time items will drive the schedule. A project completion schedule for startup of operations by April 1, 2018 appears to be aggressive, but still realistic.

[3] https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-21

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**DEGREE OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 70%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	70% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Notes: [a] The state of process technology and availability of applicable reference cost data affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

Front-End Loading (FEL) 3: Project Planning[4]

This stage is referred to as the project planning stage. The beginning of this phase is defined as the point at which one alternative evaluated during FEL 2 has been selected for further definition, with the goal of taking it to an authorization board for funding. During this phase, most project teams grow in size due to the increased amount of engineering work to be completed prior to authorization.

The goal of FEL 3 is to develop a set of engineering documents (design basis package) that incorporate site-specific conditions and a plan for executing the project, such that reliable cost and schedule estimates can be established. Typically at the FEL 3 stage the cost estimates reflect an accuracy of between ±10 to 20 percent accuracy. The product of this phase will allow a detailed package to be presented at the authorization gate. The specific deliverables for the FEL 3 stage are:

- Complete P&IDs
- Detailed Equipment Specification

[4] http://www.ipaglobal.com/Services/Individual-Capital-Project-Services/FEL-3

- Procurement Plan
- Detailed Scope of Work (including quantities)
- Critical-Path Method, Resource-Loaded Schedule (including startup activities)
- Authorization-Grade Estimate (±10 to 20 percent accuracy)

The end of FEL 3 occurs when the project is authorized and the project team receives funding to move into detailed engineering. This corresponds to Class 3 accuracy.

An immediate recommendation is that an owner's or lender's representative, similar to what DOE and USDA require for their programs, be secured for the Maine project. This representative should have the capability to complete or review the Front End Loading (FEL 3) process for the Maine project, which is the common capital project process today. This representative should focus on an Independent Engineering Review and Risk Management for the MRC. The timing of this is critical because it is an incremental, cumulative process that builds upon early tasks to complete later, more complicated tasks.

VI. List of Appendices

A. Fiberight Process Description

B. Notes from visit to Fiberight pilot plant in Lawrenceville, VA Nov. 11, 2014

C. Report on Trip to Fiberight Facility in Virginia with Mike Bilodeau's comments and updates

D. Fiberight Technology Evaluation of Conversion of MSW Organics into Ethanol

E. Site Infrastructure and Permitting Considerations