Flexible Packaging
Resource Recovery Alternatives to Landfill
Pilot Program

Flexible packaging has many sustainability attributes including requiring less energy to manufacture, creating fewer GHG emissions, and generating less waste than most other packaging alternatives. Flexible packaging contributes less to landfills even when taking into consideration the recycling rates of other packaging formats.

Additionally, flexible packaging provides excellent product to package ratio and cube utilization as well as superior barriers required to protect and preserve many products and it enables many consumer conveniences such as recloseability and microwavability. These advantages are possible because a large percent of flexible packaging is produced with highly engineered materials. However, most of these packages are difficult to recycle which creates end-of-life challenges for flexible packaging waste.

Therefore, the Flexible Packaging Association (FPA) commissioned the Earth Engineering Center at Columbia University to identify and assess existing and emerging technologies that could utilize flexible packaging as feedstock to produce fuel, energy, or other value added products and provide viable alternatives to the landfill for flexible packaging at end-of-life.

The Columbia/FPA study identified 3 viable technologies for resource recovery from flexible packaging waste: pyrolysis, gasification, and engineered fuel. The Columbia University research was followed by a two phase pilot program: Phase I - utilizing pre-consumer flexible packaging material; and, Phase II - utilizing post-consumer flexible packaging material.

Pilot Program

Four companies were chosen to participate in the FPA Pilot Program: Agilyx Corporation (thermal pyrolysis), Climax Global Energy (microwave pyrolysis), Dongara (engineered solid fuel), and Envion (thermal pyrolysis).

The purpose of the pilots was to:

- Determine if flexible packaging (both post-industrial and post-consumer) would run in the process
- Determine the impact on process efficiency

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- Identify any potential issues in utilizing flexible packaging in these processes

The results of the pilots indicate:

- Both the pre-consumer and post-consumer material performed well in all of the technologies and all of the materials tested were considered perfectly acceptable as feedstocks.
- The oil conversion rates for the two pyrolysis processes were in the typical range or better. There was no negative impact on the engineered solid fuel process efficiency.
- Two issues were identified during the course of the pilots:

  (1) Material handling - A method for shredding and densifying the flexible packaging material needs to be implemented to maximize the oil yield

  (2) PET/PVC levels - Although both pyrolysis processes can run PET and PVC, high levels of these materials have a negative impact on oil conversion rates. However, the level of these materials typically found in the flexible packaging waste stream would be acceptable from an economic perspective.

FPA member companies contributed a variety of structures to serve as feedstock for the Phase I testing program. The material performed well in all of the Phase I pilots, however, the Envion process proved to be more restrictive than the others. Therefore, Phase II pilots were only conducted at Agilyx, Climax Global, and Dongara. The material for Phase II was provided by TerraCycle which collects post-consumer packages from around the world and processes them into resins that can be used to make new products. The mix of packages was chosen to roughly mimic the global consumer flexible packaging volume mix by material as reported by PIRA.

Next Steps

The Flexible Packaging Association pilots has shown that there are technologies available to help divert flexible packaging waste from landfill. The next challenge is to evaluate possible collection systems for flexible packaging waste. FPA has commissioned Columbia University Earth Engineering Center to research the feasibility of various collection alternatives. This research will be completed in early 2012.

A summary of the technologies and the results of the pilots are included in the table on the next page. Company profiles and discussion follow the table. Detailed trial reports are available in the Members Only section of the FPA website, www.flexpack.org, under Sustainable Packaging, then click End-of-Life under the Sustainable Packaging Table of Contents.

FPA Flexible Packaging Waste to Fuel Pilot Program Summary

	Agilyx	Climax Global Energy	Dongara
Location	Portland, OR	Fairfax, SC	Vaughn, ON Canada
Technology	Thermal pyrolysis	Microwave pyrolysis	Engineered solid fuel
Outputs	Synthetic crude oil Combustible gases Char	Condensed Wax Combustible gases Char	Fuel pellets
End Markets	Transportation fuels	Diesel fuel Synthetic lubricant Industrial wax	Fuel pellets
Oil Yield - Typical **Pilot I (post- industrial)** **Pilot II (post-consumer)**	80% 85-90% 70-75%* (*Expected to increase with proper feedstock density levels)	80% 85-90% 85-90%	N/A N/A N/A
Daily Throughput **Feedstock**	20 tonnes 100% Plastic	24 tonnes 100% Plastic	300 tonnes 20-40% Plastic
Modular Expansion	10 tonne increments (4 vessel module)	8 tonne increments (single reactor module)	No
Capital Cost	$4-5MM	$5-6MM	$80-100MM
Business Model	Client owned/operated & Lease to own	CGE owned/operated & JV/Alliance	Dongara owned/operated
Tipping Fees	Client owned so $0 (cost savings no landfill)	$0 if clean (potential cost savings)	$65-70/tonne
Commercial Facilities	Site preparation under way at 2 sites	Site selection underway	Vaughn, ON, Canada

Company Profiles

Agilyx

Agilyx's vision is to economically convert difficult to recycle waste plastics into crude oil through a patented system that is scalable, versatile, and environmentally beneficial. Their technology is a patented thermal pyrolysis process that is clean, energy efficient and modular (skid based for ease of transport and assembly). It is designed to use mixed plastics (types 1-7). The main differentiating intellectual property in the Agilyx process is around the condensation/separation process which "puts the molecules back together in a form that the refinery likes". This process serves three main purposes, enabling the phase change, separation of the oil and water and the sequestering of additives which are then filtered out of the solution. The filtered solution is cycled back through the process in a closed loop system therefore no waste water is produced. The chemical make-up of the aqueous based condensing fluid is held as a trade secret and is the key to driving the effectiveness and efficiency of this process.

The process is energy efficient requiring only 1 BTU of energy input (natural gas and electricity) to generate 6 BTU's worth of crude oil. Oil yield is roughly 80% depending on input materials and bulk density of feedstock. (PET and PVC reduce yields due to their low hydrocarbon content.) The system has been through a complete HAZOP study and the results integrated into the design. There have been 5 engineering revisions (REVs) over the last 5 years with each revision incorporating efficiency improvements. The pilot plant in Portland is REV 4. Agilyx is currently selling REV 5 with two commercial installations due to be completed by year end (an 8 vessel unit and a 16 vessel unit). Work on REV 6 is underway.

Agilyx's preferred business model is customer owned facilities. The client buys a system from Agilyx who builds and installs the machinery at the client's site, trains the operating staff and secures an oil off-take agreement with a local refinery. The model calls for the system to be priced near cost and the main profit for Agilyx to come from a license fee tied to oil revenue. This leaves Agilyx with a vested interest in ensuring that the system operates as designed. The client benefits include a new revenue stream from oil sales and a cost savings opportunity due to avoidance costs associated with sending material to landfill. Agilyx also offers "a lease to own model" where they provide the up-front capital. An entry level system consists of 8 vessels, the minimum size needed to be commercially viable, which will process 20 tes. of plastic per day and produce 118 barrels of crude oil per day. The system can be installed on a light industrial site. Expansion is in 4 vessel increments. Capital cost is between $4-5MM for an 8 vessel system. Typical payback on an 8 vessel system is 3-4 years with an IRR in the 25-35% range and a typical revenue stream of $3-4MM per year.

Agilyx is well established and is positioned to commercialize and expand in the near term with a strong management team, solid engineering, and a professional organization. They are well funded, securing $22MM in capital this past April 2011. Their major investors include Waste Management, Total, and Kleiner Perkins. Agilyx has 5 year off-take agreement in place with Tacoma refinery. It has processed more than 1MM lbs of plastic and sold more than 120,000

barrels of oil to date from its pilot facility. As part of the package Agilyx will secure on behalf of the client the off-take agreements for the oil produced in the systems that it sells and installs. Before proceeding with a project Agilyx runs the project through a comprehensive financial model to look at the profitability for the client as well as Agilyx.

Key advantages to Agilyx's technology and business model include:

- A clean (low emissions, no wastewater), energy efficient (needs only 1 BTU of energy input to generate 6 BTU's worth of crude oil) process designed to use mixed plastics (types 1-7).
- Flexible packaging was shown to be a very acceptable feedstock for this process in our pilot runs.
- Low capital cost plants ($4-5MM) with a modular design and small footprint.
- Long term off-take agreements with local refineries are part of the package.
- Provides a new revenue stream to clients through oil sales.
- Provides cost savings due to avoidance costs associated with sending material to landfill.

Climax Global Energy

Climax Global Energy's vision is to convert landfill-bound plastics into high value synthetic wax for the diesel, synthetic lube and industrial wax markets. They run a patented microwave pyrolysis process that is clean, energy efficient and modular. Their differentiating intellectual property is in how they utilize microwave technology to provide for high efficiency energy absorption which is used to "crack" the polymers not to heat the material. In this process wavelengths can be adjusted to provide for preferential cracking. The process accepts mixed plastics and only takes 10-15% of the stored energy potential of the plastic to run. The main output from CGE's process is a condensed wax product. Unlike the end product of traditional thermal pyrolysis systems which can only be used for the production of fuel, CGE's condensed wax end product can be used in the production of high value synthetic lubes and industrial waxes in addition to the production of diesel. This has been confirmed by direct customer and commercial lab testing. The quality levels of CGE's condensed wax end product allow for direct blending into refinery units which makes it a cost effective feedstock for refiners by lowering their processing costs. In addition to the condensed wax, light gases such as methane, butane and propane are produced, captured and used back in the process

Wax yield is roughly 80-85% depending on the material make-up of the feedstock with PET and PVC reducing yields. If the level of PET in the feedstock mix warranted it, the process could be modified to capture terephthalic acid separately, so that the full value of that material can be realized. The same could be done for aluminum. These modifications would be made only if it made sense from an economic standpoint based on the expected feedstock make-up and cost impact of the modifications.

CGE's preferred business model is for CGE to build, own, and operate the waste to fuel plants although they are also open to discuss joint venture and alliances. Their entry level system is a module containing 3 parallel reactor vessels. Each 3 reactor module designed to handle 25 tes/day of plastic waste yielding 5 tes of wax product for every tonne of input plastic. The plant can be easily expanded as demand increases by adding reactors or modules. Capital cost is $5-6MM per three reactor module. The current business model calls for a zero tipping fee for material that arrives without the need for additional sorting at CGE which provides a potential cost savings to clients due to avoidance costs associated with sending material to landfill. If additional sorting is required the tipping fees would be set to cover those costs.

CGE has a seasoned management team. The CTO and COO are from Foster Wheeler and each have 25+ years engineering and technical experience in the power generation industry, the CEO is from Merrill Lynch where he was a Managing Director in Mergers & Acquisitions. They have raised $6MM in capital and the reactors for first commercial plant have been ordered. Round 2 of capital raising has begun with a target of raising an additional $8MM. The first commercial plant is targeted for Fairfax, SC with potential sites being evaluated. Additional plants will be built near sources of feedstock.

Key advantages to CGE's technology and business model include:

- A clean energy efficient process designed to use mixed plastics
- Flexible packaging showed very good yield rates in our pilot runs
- Low capital cost plants ($5-6MM) with a modular design and small footprint
- The potential of higher margin value added products for the synthetic lube and industrial wax markets which strengthens the business case.
- No tipping fee for material that arrives without the need for additional sorting at CGE which provides a potential cost savings to clients due to avoidance costs associated with sending material to landfill.
- Experienced management team

Dongara

Dongara's process and business model are very different from that of pyrolysis systems. The Dongara plant is a large scale facility (runs 300 tes/day) whose purpose is to take the trash of a municipality or region, minus the recyclables and bio-waste (which are collected separately in Canada), divert it from the landfill, and turn it into an engineered solid fuel. In a sense it is a landfill replacement.

The major process flow is as follows:

- Tipping – Trash come in from the surrounding municipalities
- Shredding – First shredding step larger screen size
- Sorting/Separation – Takes out metals, glass, and ceramics
- Downsizing – Further shredding and screening
- Drying – gets the material to the proper moisture level for pelletizing
- Pelletizing – fuel pellets formed and cut

There is also a secondary additive line which enters the main flow at the downsizing step. The additive line has its own shredder with a fairly small screen size. This additive line allows segregated material to be blended with the main line in controlled percentages. This is where a segregated stream of flexible packaging can add value to Dongara's fuel pellet. The main municipal waste stream makes a pellet with an energy value of around 8-9,000 BTU. Flexible packaging has an energy value of around 18,000 BTU. By blending in flexible packaging at pre-set percentage Dongara can create a pellet with a higher BTU value which has more value per volume than the standard pellet. The packaging material also helps in the drying process in that it has a very low moisture level compared to the main waste stream.

Dongara's technology and business model have several key differences to that of the pyrolysis systems:

- High output – the Dongara plant runs at a rate of 10-15,000 tes/hour, 100,000 tes/year
- High capital cost - the cost of the plant was close to $80MM
- Tipping fees critical part of the economics – Current tipping fees are $65-70/te
- Its main feedstock material is municipal trash. Plastics are just an additive to the main feedstock source verses pyrolysis which has a feedstock that is 100% plastic.

This process could be an alternative as an outlet for large scale post consumer collection especially in regions that choose this method as an alternative to landfill for their municipal waste streams or if the capacity of higher value added technologies is not established or available. Segregating flexibles may make the economics of one of these plants more viable due to a higher value end-product but this would need to off-set the additional cost of collection and separation of flexibles in these municipalities rather than just processing the flexibles in the main garbage stream. (The Vaughn plant processes flexibles as part of the current municipal waste stream.)