Changing the Economics of Organic Waste Disposal Using Managed Ecosystem Fermentation

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Abstract: Concentrated organic waste is a major societal problem. It is a disease vector, a source of groundwater contamination, as well as a source of greenhouse gases. Managed Ecosystem Fermentation (MEF) is a technology that converts this societal problem into an economic resource for the community. MEF is a fermentation process that uses over 3,000 species of microbes simultaneously to produce multiple high-value products used in industry and agriculture. The products include fertilizer, high-protein animal feed, volatile fatty acids, longer chain fatty acids, amino acids, enzymes, etc. The values of these products range from $50 to over $16,000 per ton. MEF is an adaptive system that processes non-homogeneous, non-sterile organic waste/s under non-sterile conditions. It converts the waste into industrial products in 24 hours using a microbial system that has worked for millions of years. It is the only known technology that can convert cellulose into protein. Society benefits from converting what is now a cause of disease, groundwater contamination and greenhouse gases into valuable products.

Keywords: Managed Ecosystem Fermentation, enzyme, economic resource, MEF, rumen.

1. WASTE OR RESOURCE?

How residue from various processes is treated is a function of what the residue can be converted into. If it can be converted into something of use, it is called a resource. If it cannot, it is called waste.

Prior to urbanization organic waste was plowed back into the earth and then became an organic fertilizer. This recycling worked for thousands of years. It naturally recycled both the nutrients and microbes back to the soil and thereby restoring the soil fertility. Now, the concentration of population in urban areas has made this recycling of the organic matter economically unfeasible and dangerous to society due to the potential disease vectors and pollution.

Organic waste has been deposited into landfills for at least one hundred years because a process to convert it into an economic resource has been lacking.

For millions of years nature has employed such a technology that converts organic matter into multiple products. It happens in the first stomach of any ruminant animal. Ruminant animals are mammals such as cows that employ rumen in their digestive process to break down cellulose and organic material. The rumen employs over 3,000 species of microbes to convert organic matter into multiple materials. These materials include protein, amino acids, enzymes, peptides, volatile fatty acids, and longer chain fatty acids. This cocktail of proteins and acids are the true food for the ruminant animal. The MEF process has harnessed this ecosystem of microbes to produce multiple high value products used by industry and agriculture today.

2. ECONOMICS AND WELLNESS

Throughout history man has piled waste either to recycle/compost it or just "make it go away". Essentially man has taken the lowest cost approach possible to dealing with the organic waste. Now, the concentration of population results in piles of organic waste of such size that they have become a significant disease vector from three sources.

First, it provides a food source for rats, mice and other vermin. Second, it provides a breeding ground for mosquitoes, roaches, and flies. Finally, it is a breeding ground for various pathogens that are either transmitted by the vermin and insects, or contaminate the air and/or groundwater.

Experience has shown that the improper treatment of organic waste has a negative impact on both the health of the people and the economics of the community. Communities do not thrive in polluted environments.

It is becoming evident that the existing disposal technologies are economically dependent on public monies to work. While these technologies may be disposing or sequestering the waste, no additional economic resource/s is being provided to the community. They are not bringing new revenues into

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the community. These technologies require substantial community resources including land that could be put to more productive use.

A behavioral shift occurs when people go from spending money on a problem to making money from the problem. What was once thrown away is now diverted to profit. The application of Managed Ecosystem Fermentation (MEF) to the problems of organic waste can significantly change the economics of disposal. The MEF process can produce multiple industrial feedstocks that can generate sufficient revenues to change the disposal from an economic burden to an economic resource.

The realities of the negative implications of concentrated organic waste are clear. In order for any new process to effectively address this situation four basic concepts must be addressed:

1. No species can survive in its own waste stream.

2. For a new technology to take hold it must offer the society a better value proposition than the current methods in use.

3. For a technology to make permanent environmental improvements, it must be economically sustainable.

4. Biomass is the only renewable source of organic chemicals available.

Nature already has the technology to address these issues. Nature converts organic matter using microbial ecosystems. They involve multiple species of bacteria, fungi, protozoa, and other microbes interacting in various ways. Examples of natural microbial ecosystems would be in the digestive microbes of ruminant animals such as cows, goats, and sheep as well as the digestive microbes in insects such as termites, or soil bacteria. Our own digestive system is another example of a microbial ecosystem. They are also used in a few industrial processes such as anaerobic digestion and wastewater treatment plants. What has been lacking is a technology that can harness the productive capacity of these ecosystems in a cost-effective manner.

3. BIOLOGICAL BASIS FOR MEF

Nature has developed multiple microbial ecosystems. These ecosystems involve multiple species interacting in complex ways. Many of these interactions are neither known nor fully understood. Regardless of our understanding of these interactions, these ecosystems thrive because of the symbiotic relationship that exists between the multiple species. Each species performs one or more functions within that ecosystem. Whether the species is consuming another species or is being consumed is not relevant. Each species is providing something needed by another species. This is the basis for a self-sustaining ecosystem.

We are exposed to multiple Natural Microbial Ecosystems (NMEs) on a daily basis. NMEs change based on the availability of food, water, heat (energy) and the absence or presence of various chemicals to facilitate the different chemical/biological reactions involved. These various reactions occur without human input. Whenever humans influence these reactions, the microbes adapt in ways that ensure their own survival. The difference between NMEs and MEF is in the management of the process. MEF actively manages the process.

Both natural and managed ecosystems share several common traits:

1. Microbial ecosystems do not require sterilized feedstock. Animals and humans do not sterilize their food. Their digestive ecosystems have evolved to protect the host, yet assist in the nutrition of the host. Essentially, most pathogens find an adversarial microbe inside the ecosystem to consume it.

2. Microbial ecosystems can consume a broad spectrum of organic matter. This permits the ecosystem to survive for years at a time. This is illustrated by the variety of food we eat.

3. Microbial ecosystems are symbiotic. Each microbe is dependent upon its relationships with the other microbes as well as its host environment. These relationships are complex and continuously changing based upon the conditions encountered by each microbe.

4. Microbial ecosystems work because they are focused on their own survival.

5. Microbial ecosystems work because a multi-species system has many more chemical pathways to break down a feedstock than any single species does.

Integrated BioChem, LLC has developed the term Managed Ecosystem Fermentation (MEF) to describe a symbiotic ecosystem that exists solely in an artificial environment. There are four methods that permit control over the ecosystem. First, the chemistry of the feedstock can be altered with various pretreatments to facilitate both processing and output of products. Second, the ecosystem can be biologically altered to change both the yields and outputs. Third, the process can be chemically stimulated. Finally, the containment environment can be modified to alter the results. It is the ability to control the process that influences the economics of the process. These controls permit shifting the product mix from low value materials to higher value products. The shifting is focused on producing more valuable longer chain carbon compounds.

4. MEF VERSUS THE STATUS QUO OF WASTE TREATMENT

Today there are essentially three methods for the disposal of organic matter for which there is no other use: recycle it, burn it, or bury it. Each of these alternatives provides some relief from the waste stream and limited economic benefits. However, none of these methods bring in significant new revenues to the community.

Recycling organic waste can be broken down into two forms: anaerobic digestion and composting. Composting is the aerobic microbial breakdown of the organic matter into compost/fertilizer. This method allows for the re-cycling of both the nutrients and the microbes back into the soil. However, this method has limited effectiveness in the urban environment. The product receives a low value in the marketplace and its market is limited by the cost of transport since organic matter is over 50% water. The cost of transporting water precludes the recycling of the material. Additionally, it requires land and time to accomplish this conversion. Anaerobic digestion is focused on the production of methane. The by-product is a material similar to that derived from composting. In the rural environment, the generation of methane does provide a source of energy for the people. It also permits the recycling of the nutrients and microbes back into the soil. However, in an urban environment the methane generated must now compete with shale gas and methane hydride [1]. At best the methane produced by anaerobic digestion can be used as a cost offset while the residue of the process is still subject to the same economic issues as composting.

The burning of organic waste is intended to convert the organic matter into electricity to be sold to the community. This technology has limited potential because of the significant amount of water that must be displaced from the organic waste itself. Additionally, the burning of organic matter contributes to global warming through emissions of carbon dioxide and other pollutants. The bigger economic issue with burning lies not with the technology itself, but rather with the regulatory environment in which it operates. As the regulations increase, the cost to build and operate these facilities increases. Within the United States, the volatility of the United States tax code makes financing of these facilities a challenge.

It is recognized that simply burying organic waste will lead to groundwater contamination. The technology of landfilling has been created to prevent the contamination. Landfill economics are dictated by the volume of waste a landfill can hold and the surface area needed to provide that volume; the greater the volume the greater the earning potential of the landfill. However, the resources needed to permit, build, operate, and close a landfill are increasing. Nobody wants a landfill in his or her backyard. The economics of this are shown in Figure **1** [2]. Additionally, landfills do not completely encapsulate the waste. There is discharge in the form of leachate that must be treated. Essentially, landfills just entomb the waste.

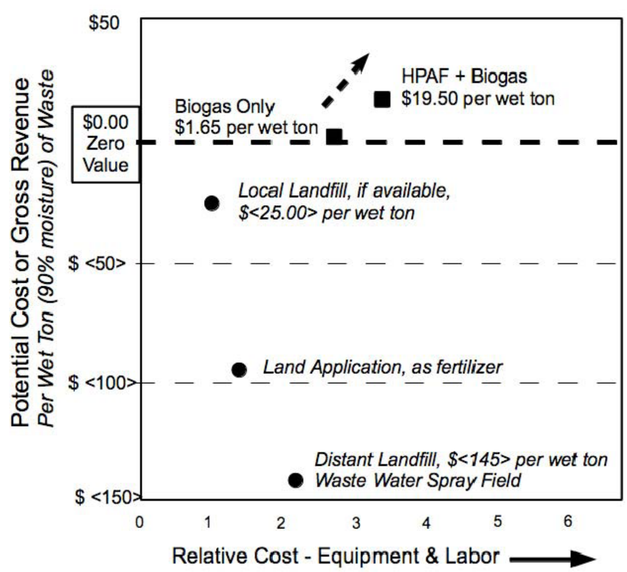

Figure 1: Shifting the economics of waste disposal from a cost to a revenue source [2].

Landfills and MEF operate as semi-anaerobic processes. They both require small amounts of oxygen to work. Both work with a community of bacteria, fungi, yeast, and protozoa. The difference between the two processes is in the amount of fluid available. Landfills operate under the premise the less water the better. In contrast, MEF operates in a totally fluid environment. While both processes produce volatile fatty acids [2] (VFA), there is a significant economic difference between the two based on how these VFAs are handled. In a landfill, the VFAs are allowed to decompose into methane and carbon dioxide. In MEF, the VFAs are extracted for sale. The most significant difference arises in the time to convert the waste into salable product. The economics of this are outlined in Table **1** [2] using the lowest value VFA, acetic acid.

Table 1: A Significant Economic Advantage can be Obtained by Extracting Acetic Acid before it can Decompose into Methane [2]

Economic Loss from Decomposition			
Description	**Acetic Acid**		**Methane**
Formula	$C_2H_4O_2$	⇒	$CH_4 + CO_2$
Carbon Available for Sale	100%		50%
Current Price Per Ton	$600		$156
Time to Produce	48 Hours		4 to 5 Years

The economics illustrated in Table **1** show that it is more efficient to extract the acetic acid from the waste in 48 hours than to wait for the conversion into methane and then into electricity. This result is amplified when the higher value VFAs are considered such as butyric acid. Butyric acid sells between $1,000 and $90,000 per ton based on purity. This extraction cannot be done in a landfill. It can be done using the MEF process.

The differences in economics between landfilling and MEF become more pronounced when the input volume of organic waste is considered. In both landfills and MEF, the VFAs are produced in low concentrations of less than 1%. Initially it makes no sense to consider processing materials at this level. However, Table **2** [2] would suggest that such processing could generate substantial amounts of money.

The key point is that there is a significant economic opportunity available to the waste industry by converting the organic fraction of the waste stream into basic industrial chemicals and enzymes. Figure **2** illustrates the relationship between price and concentration. The more diluted the material, the higher the price per kilogram [3]. However, many of the 30,000 enzymes produced by this process can be extracted with existing technology that is currently used in multiple industries [4].

Table 2: Significant Revenue is Available Even at Low Concentrations [2]

Low Concentrations, High Revenues	
Tons per day of organic waste	1,000
Concentration (%)	0.5%
Tons of product per day	5
Price per ton of product (Acetic Acid)	$600
Revenue per day	$3,000
Days per year	365
Revenue per year	$1,095,000

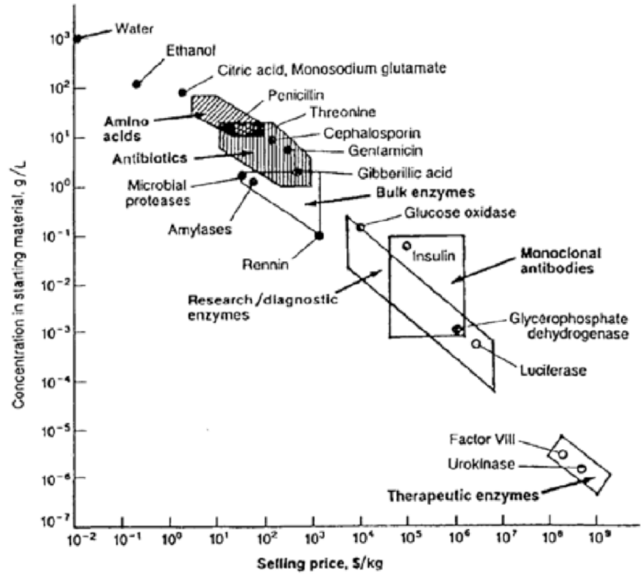

Figure 2: The value of the enzymes increases as the concentration decreases [3].

5. FEEDSTOCK AVAILABILITY

MEF can adapt to a wide variety of organic materials. These organic materials are concentrated within the community at specific locations. In order to derive the most health and economic benefits for the community, it makes sense to locate the processing equipment for MEF at those locations. These sources of organic waste are available at no or even negative cost.

The preferred organic material would be derived from food processing plants. Most of these facilities produce food products for either human or animal consumption. They run on a year-round basis. This organic waste material could be converted into high-

Table 3: Significant Economic Opportunity Exists by Converting the Food Waste into Usable Products [2]

Food Losses for all Categories of Food (Millions of Tons Per Year)			
Food losses, all categories of food	**Europe & Russia**	**North America**	**Industrial Asia**
Processing &Packaging Losses (includes food grade)	76.3	65.1	97.7
Post Consumer at Household Level (OF-MSW)	189.5	197.2	223.6

protein animal feed. The high-protein animal feed derived from the source could be fed to fish, prawns, poultry, hogs, and cattle.

The organic fraction of municipal solid waste (OFMSW) is a major disposal challenge for many communities. Locating MEF processing facilities at either landfill sites or waste transfer centers eliminates the secondary transportation of this material. Locating the MEF processing facilities at either the waste collection centers or landfills automatically extends the life of the landfills. Additionally, the disposal costs to the community could be reduced by up to 25%. Beyond the industrial chemicals and enzymes produced at these sites, there would be a substantial amount of fertilizer available in forms compatible with local agricultural practice. Heavy metals associated with this waste are extracted using ion resin exchange and sold.

The Food and Agricultural Organization of the United Nations estimates approximately one third of the food produced for human consumption is wasted every year [5]. Approximately 850 million tons are generated annually from food processing plants and municipalities in Europe, North America, and industrialized Asia. Table **3** provides estimates as to the amount of material available for potential use with the MEF technology.

Additionally Confined Animal Feeding Operations (CAFO) generate significant amounts of manure per year. The MEF technology could provide the CAFO sites with the means to dispose of both the manure and the animal mortalities. Feedstock derived from CAFO sites would only be used to produce probiotic fertilizer.

MEF offers the potential to convert both the agricultural and municipal organic waste into multiple materials used by society. In particular, the agricultural waste could become a new source of high protein animal feed thereby minimizing the need for soybean meal imports. The municipal waste has the phosphate, nitrate and potassium from the plant material incorporated into its fertilizer. This could become a valuable source of fertilizer for developing economies.

6. THE TECHNOLOGY

MEF process is the industrialization of the first stomach of a ruminant animal (cow, goat, etc.). In a ruminant animal, cellulose is converted into volatile fatty acids and proteins that provide the nourishment for the animal. MEF has moved this cellulosic conversion process out of the animal and harnessed the productive capability of the microbial ecosystem.

The process operates only within a controlled artificial environment. Significant differences come from removing some of the natural control systems of the animal and allowing the microbes to produce under a different environment and control system. This permits the management of the yields of the various natural compounds produced. These chemicals can be extracted from the industrial MEF unit in the separation process and used in industry [6]. But the basic question remains, can rumen (and MEF) survive on garbage? Figure **3** shows cows grazing on garbage in Delhi, India. Cows can live for over 20 years.

Figure 3: Cattle with ruminant stomachs processing food waste.

The MEF process converts organic wastes into metabolites and biomass and has been confirmed using gas chromatography as shown in Figure **4**. The process has been run *in vitro* for 76 days with a daily addition of the feedstocks using residential food scraps,

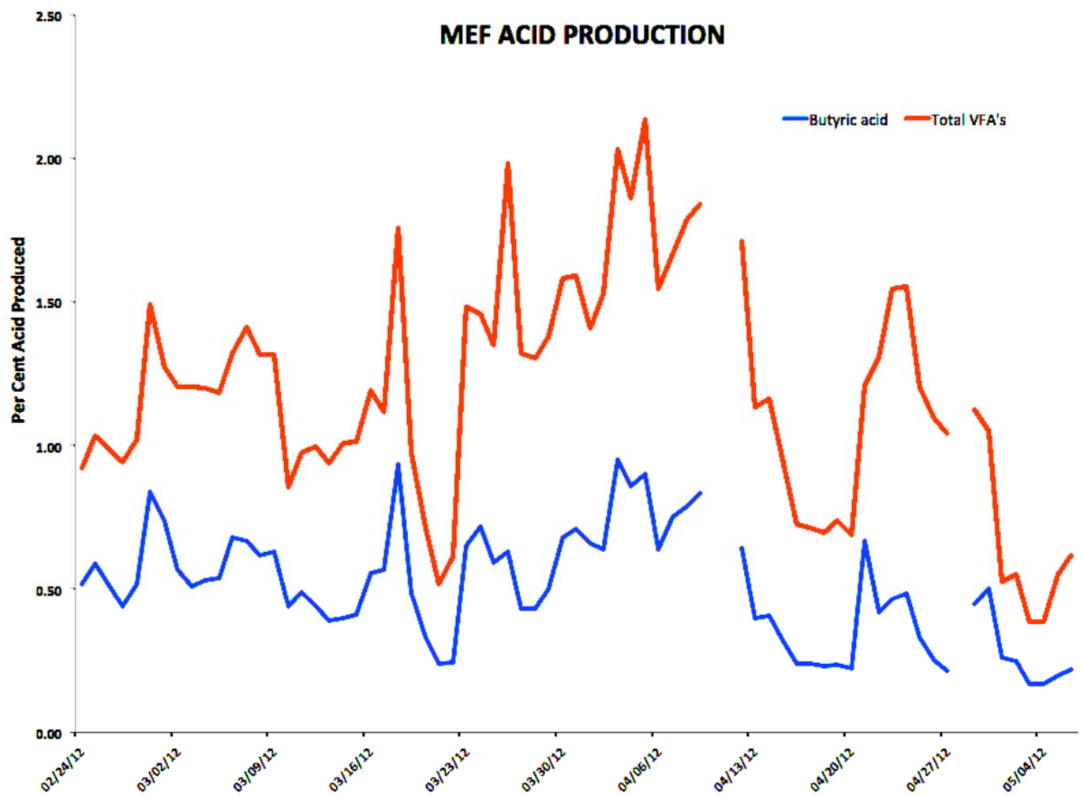

Figure 4: Volatile fatty acid production for a 76 day test period [2].

garbage with newsprint or the sludge from a paper mill. The control of the process is discussed elsewhere [7]. Research has also shown that the process is inherently stable, so remote monitoring and control are technically feasible for MEF processes.

An early video of the MEF fermentation process can be viewed at http://integratedbiochem.com/?page_id=32 and clicking on the video to see the process demonstrated with time-lapse photography. The still image (shown in Figure **5**) from the video shows the conversion of household garbage (left), wood pulp from a paper mill (center), and household garbage with newsprint (right) being digested. This video covers a twenty-four hour period with one frame every 30 seconds.

There are several critical points demonstrated in the video. First, this is a rapid conversion process. The liter bottle in Figure **6** started out as a liter of garbage. It takes approximately 1 day to convert the various wastes into chemicals as seen in photograph. The solid matter on the bottom is organic fertilizer. The liquid above is water, enzymes and proteins. The second point demonstrated is the process does not require complex equipment to operate. Simplicity is the key to making this technology work. Third, the process converts cellulose into salable product. Fourth, there is substantial reduction in the solid matter. Most of the solid matter is less than 20 microns in size. Finally, the process produces a wide array of organic chemicals that are used in multiple industries throughout the world. Some of these high value materials can be seen in Table **4**.

Figure 5: MEF process over 24 hours [2].

7. THE RESOURCE WITHIN

Understanding why organic waste can be viewed as an economic resource comes from the understanding

Figure 6: One liter of converted food waste [2].

where this organic matter fits within the chemical world we inhabit. Cellulose, carbohydrates and other organics can be converted into the basic chemicals we use on a daily basis. Nature does this biologically with processes that have worked for millions of years. The compounds produced in one step become feedstock for the next step. Essentially, nature uses a multi-step process to break down the longer chain carbon materials and convert them into shorter chain compounds. Ultimately, the material is broken down to a point to where it can be recycled back into plants that convert these shorter chain materials back into longer chain carbon compounds.

The MEF process leverages the natural process from a ruminant animal to break down the organic waste into compounds that are used in industry and agriculture today. These organic compounds include volatile fatty acids, longer chain fatty acids, proteins, enzymes, peptides, and amino acids. MEF controls the fermentation process by continuously extracting the VFAs, proteins, etc. The MEF core process can be seen in Figure **7**.

The key to understanding the economic potential of the MEF process is in recognizing that it is not what the process produces but rather what can be made from the products produced. Figure **7** illustrates the opportunity that exists through the conversion of the initial outputs into the multiple products used today. MEF produces basic feedstocks used in multiple industries.

While the production of fertilizer and animal feed provide the basis to make the disposal of organic waste viable, the additional value inherent in the MEF output stream is that the opportunity exists to make higher value products available as separation technology improves.

One of the important features of any ecosystem fermentation is the diversity of microbes, and therefore

Table 4: Market Prices and Applications of some of the Enzymes Produced by MEF in 2011 [2]

Markets Prices for Enzymes & Amino Acids in MEF processes		
Enzyme or Amino Acid	**Price per Ton**	**Application**
Alpha-amylase	$15,000	Textiles, Starch syrups, laundry and dish washing detergent, fermentation of ethanol, animal feed
Cellulase	$16,636	Cellulostic ethanol production, laundry detergent, textile finishing, animal feed
Pepsin	$2,000	Cheese production
Lysozyme	$11,800	Antibacterial (germicidal in dairy industry)
Hemicellulase	$3,790	Baking, fruit juice, wood pulp processing.
Aspartic Acid	$2,150	Acrylic acid
Lysine	$2,400	Nylon precursor
Proline	$2,800	Catalyst in biological reaction
Carbohydrases	$500	Tank cleaners, pulp and paper, textiles, fermentation ethanol
Penicillin acylase	$6,400	Chemical synthesis
Histidase	$16,000	Cosmetics
Peroxidase	$6,100	Laundry and wood pulp bleaches
Alkaline protease	$280	Detergent

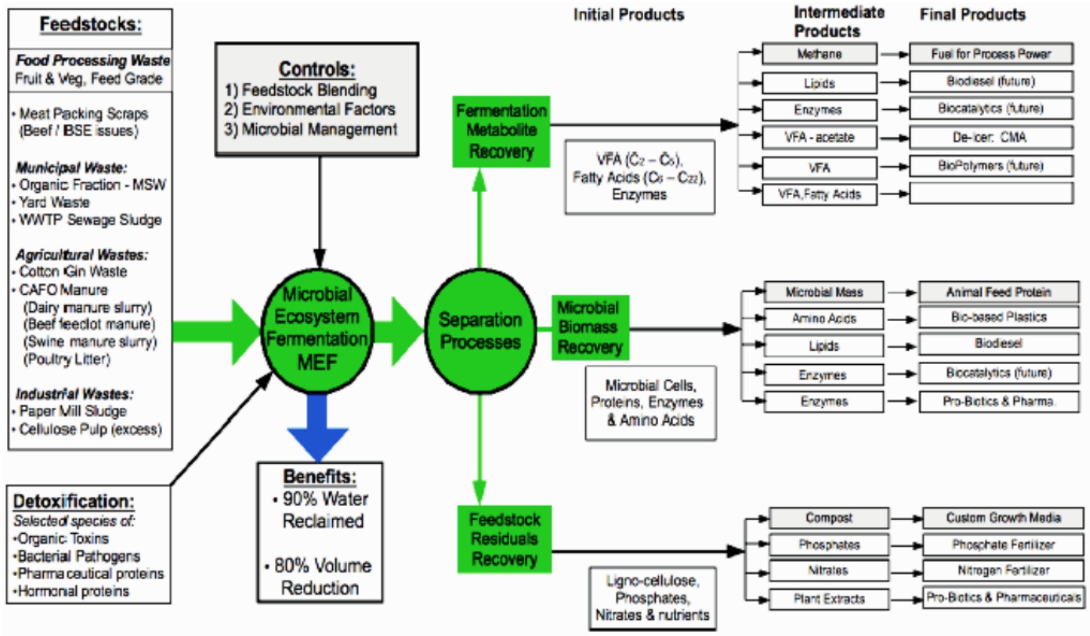

Figure 7: MEF process from waste to products [2].

a diversity of enzymes, the primary tools of the microbes. As an example, rumen, the digestive microbial ecosystem for cattle can contain over 30,000 enzymes [8]. Enzymes are known to catalyze over 4,000 biochemical reactions, and likely many more. The value of enzymes comes from their ability to lower the energy required for a specific biochemical reaction. Table **4** shows the market price (prices as of 2011) of some of the more important enzymes found in rumen and expected in MEF working with organic wastes feedstocks.

MEF has demonstrated the ability to produce protein suitable for fish food as shown in Figure **8**. This ability to produce protein from cellulose suitable for animal feed opens the potential to make more animal protein available at lower costs.

Figure 8: Microbial protein produced from the MEF process [2].

Additionally, MEF has demonstrated the ability to extract cellulase. Cellulase is the most expensive ingredient in the production of cellulosic ethanol. This is illustrated in Figure **9**. Being able to produce cellulase in large quantities now permits the conversion of waste newsprint into multiple high value industrial chemicals.

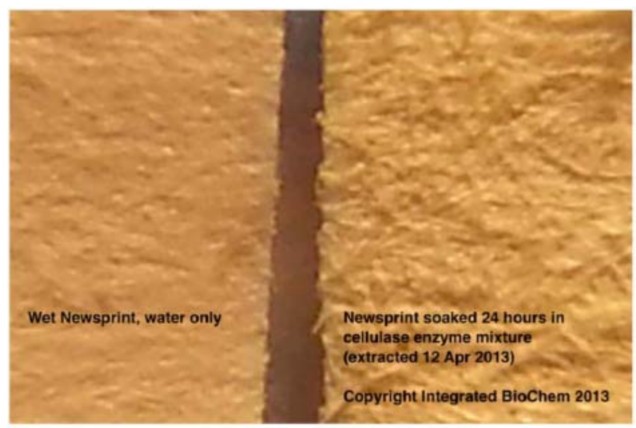

Figure 9: Enzymatic consumption of waste newsprint with cellulase extracted from the MEF process.

These products would include longer fiber cellulose for reuse in local paper mills, sugars that could be converted into biofuel, and lipids that could be converted into biodiesel.

8. SUMMARY

The MEF technology has advanced to the point of being awarded a patent by the United States Patent Office on February 5, 2013 (U.S. Patent 8,367,372).

The technology is in the engineering scale-up phase of its development. The design efforts are focused on standardizing the equipment to facilitate deployment. The MEF production units are being designed to go into a standard 40 feet (12.2 meter) shipping container. This criteria facilitates manufacturing, shipping, installation and operation. It also permits the scaling of the technology to the requirements of the specific location.

The MEF technology integrates a natural process with today's separation methods to focus on providing a more complete solution to the disposal of organic waste. The technology changes how waste is viewed as there are now multiple products that can be produced from the material. This provides the economic incentive to bring private capital to bear on a public problem.

The benefits available to society by shifting the value of organic waste are significiant. First, a disease vector is eliminated. Second, a source of ground water contamination is eliminated. Third, a source of greenhouse gases in eliminated. Fourth, a new source of protein is available for animal feed to increase local production of fish, prawns, poultry, hogs or cattle. The increase in affordable animal protein could make a significant improvement in public health. Fifth, a new source of fertilizer is available thereby reducing the need to import phosphate, nitrate, and potassium. Sixth, new jobs are created in the manufacturing of the production units as well as in local operation. Finally, foreign currency can be brought back to the community through the sale of the higher value feedstocks produced that are not used within the community.

SYMBOLS & ABBREVATIONS

$C_2H_4O_2$ = Acetic Acid

CH_4 = Methane

CO_2 = Carbon Dioxide

$\Rightarrow$ = Converts into

CAFO = Confined animal feeding operation

MEF = Managed Ecosystem Fermentation

NME = Natural Microbial Ecosystem

OFMSW = Organic fraction of municipal solid waste

VFA = Volatile fatty acid

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