Animal Waste to Marketable Products

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ABSTRACT

Results from a recently commissioned commercial-scale plant designed to process 200 t/d of turkey processing waste (offal, blood, feathers, bones, DAF skimming, grease, etc) will be presented. The plant utilizes a unique Thermal Processing technique to convert turkey waste to bioderived middle distillate oil, fertilizer, coke, fatty acids, and a medium to high BTU gas.

The plant is owned by Renewable Environmental Solutions, LLC (RES). RES is the licensee of the technology for agricultural and animal applications. Changing World Technologies (CWT) owns the technology; ConAgra Foods is the agricultural development partner and supplier of the plant site; Kvaerner Process Systems is the engineering firm that performed the detailed plant design; and Gas Technology Institute (GTI) conducted engineering management, due diligence, and oversight for the United States E.P.A. grant that co-funded purchase of the prototype equipment utilized in the plant sited in Carthage, Missouri.

INTRODUCTION AND BACKGROUND

Solid Waste

Fuel, power and industrial chemicals derived from the patented Changing World Technologies (CWT) Thermal Process are renewable because they originate from natural organic waste materials derived from food and agricultural production. CWT and Renewable Environmental Solutions, LLC (RES) work with food producers at the slaughterhouse and finished product levels to improve overall air quality and eliminate the waste liability incurred from processing animals. On average, 40% of a live animal is waste product, allowing for an ample feedstock supply. Agriculture represents over 50% of the estimated 12 billion tons of solid waste produced each year in the U.S. alone **(See** Figure 1**).** These 12 billion tons of solid agricultural waste could produce 24 billion barrels of oil if processed through the CWT-TP.

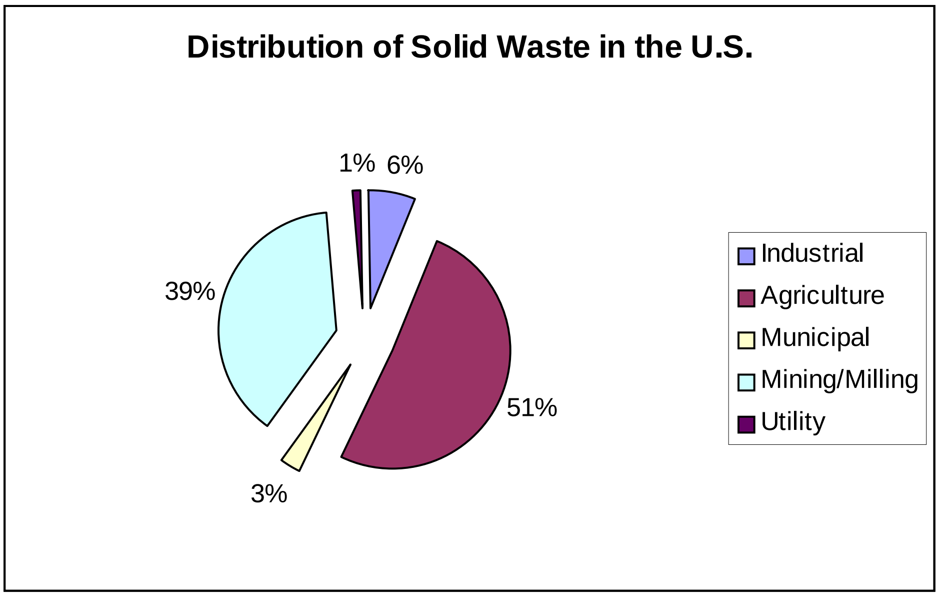


Figure 1. Distribution of Solid Waste in the U.S. (ref 1)

The food processing industry in the U.S.A. generates billion of pounds of organically rich wastes per year. These wastes are associated with both the processing of animal and plant products. The CWT-TP simultaneously alleviates several concerns – the generation of malodorous air emissions associated with rendering plants and the disposal of billions of pounds of food wastes each year (landfill generation of greenhouse gases such as carbon dioxide and methane would be eliminated from these sources). The food processing industry continues to grow and these processors face significant economic and environmental pressures to do something productive with their wastes. The need and climate appear favorable for the food industry to adopt an efficient and economical process to convert food-processing wastes, including turkey-processing wastes into useful, high-value products without discharging odorous pollutants.

An additional drive to seek treatment alternatives is the enforcement of wastewater discharge regulations and escalating sewage surcharges. The food processing industry must seek cost-effective technologies to provide pretreatment or complete treatment of their wastewaters and solid (wet) wastes. The CWT-TP is ideally suited to provide solutions for residuals management to establish beneficial renewable energy solutions. Historically, food processors located within or adjacent to the municipalities have relied on local publicly owned treatment works for wastewater treatment and disposal. Increasingly, this option is becoming less available. During the last five to ten years, enforcement pressure has increased to comply with wastewater discharge permits and with the dwindling federal grants for construction of new and upgraded publicly owned treatment works.

Municipal and regional sewer authorities are requiring industries to reduce their organic BOD and chemical oxygen demand (COD) and solids loading to the sewers. Due to the high BOD concentrations typically contained, especially high-strength wastewaters with high levels of suspended solids, ammonia and protein compounds in food processing wastewaters, this industry is under additional scrutiny. The food processors need cost-effective and application-specific treatment technologies to manage their solid wastes effectively. The CWT-TP is a solids and residual management solution.

The technologies available to the food processing industry, over and above using existing publicly owned treatment facilities include: landfills, composting, land application, biotreatment, and traditional thermal oxidation treatments. Each has limitations and drawbacks that made the search for alternative processes necessary. That was a driving force behind the demonstration of the CWT-TP technology.

Landfill disposal seems inexpensive but it has the potential for groundwater contamination from leaching, and landfills can create air pollution concerns. Methane loss from landfills is an important contributor to greenhouse gas emissions worldwide. More importantly, valuable natural resources are lost. The landfill is not a solution to waste disposal, it only postpones many problems for future generations. The landfill is a legacy that we leave for our children and grandchildren to solve.

Energy

How much oil we import affects our economy and our national security. Today, half of the oil we use is imported (see Figure 2). This level of dependence on imports (>50%) is the highest in U.S. history, and will increase as we use up domestic resources. The vast majority of the world's oil reserves are concentrated in the Middle East (65% to 75%), and controlled by the members of the OPEC oil cartel (ref 2).

The U.S. depends on oil to move people and goods. Ninety five percent of the energy for transportation in the United States comes from oil. Transportation's demand for oil drives the market. Transportation accounts for two-thirds of total U.S. petroleum use, and nearly all of the high value petroleum products, like gasoline and distillate fuel.

In the past, dependence on oil has cost our economy dearly. Oil price shocks and price manipulation by the OPEC cartel from 1979 to 1991 cost the U.S. economy about $4 trillion, almost as much as we spent on national defense over the same time period and more than the interest payments on the national debt. Each major price shock of the past three decades was followed by an economic recession in the United States. With growing U.S. imports and increasing world dependence on OPEC oil, future price shocks are possible and would be costly to the U.S. economy. Ultimately, the solution to the oil dependence problem lies in technological progress such as CWT's Thermal Process that utilizes renewable feedstock and turns waste into oil, gas, and coke.

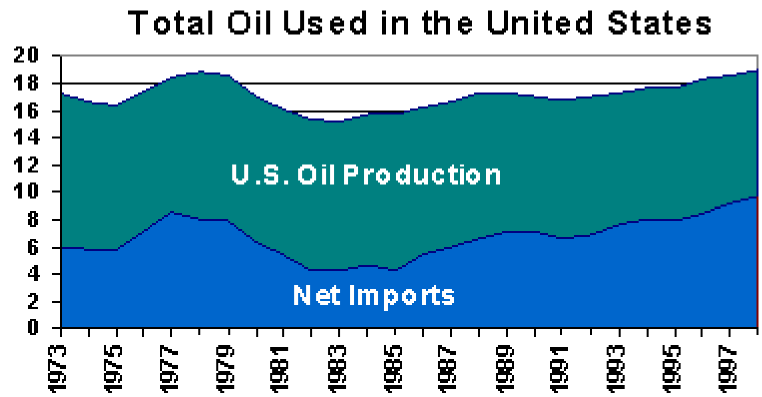


Figure 2. Oil Consumption in the U.S. in Millions of Barrels

Environmental Issues

Preservation and maintenance of clean air, shrinking landfill capacity as well as other forms of waste disposal are problems that must be addressed in communities and businesses all across America. A CWT-TP plant in Carthage, MO will generate positive benefits for the company, the community, the employees of the nearby plants and in a broader sense, the country as a whole.

The CWT-TP demonstration plant in Carthage, MO is an attractive alternative to a rendering plant or to landfilling of the organic wastes. Malodors from rendering plants have prompted communities located near rendering plants to call for more stringent odor control measures. The odors from rendering are generated by raw material transportation and handling, processing, wastewater treatment, and inadequate air emission control systems. Researchers have detected sixteen chemicals as sources of odor at rendering plants. These chemicals are: acetaldehyde, ammonia, butyl amine, butyric acid, dimethylamine, dimethylsulfide, disulfide, ethylamine, ethyl mercaptan, hydrogen sulfide, indole, methylamine, methyl mercaptan, skatole, triethylamine, and trimethylamine. Landfilling the organic wastes has the potential for leaching into the groundwater and also of generating significant quantities of greenhouse gases (methane and carbon dioxide) that contribute to global warming. The CWT-TP process does not have these drawbacks (refs 3-6). Since the CWT-TP is a pressurized closed-loop process, any gases that are generated are collected together, cleaned as necessary, and used as boiler fuel (other plants can use the fuel in a turbine, if the economics justify it). The CWT-TP process operates in a reducing environment that precludes generation of precursors to dioxins as occur during thermal oxidation (combustion) processes.

The agricultural mixed waste biorefinery in Carthage is a showcase for the CWT-TP process that highlights an environmentally desirable method of mixed organic waste processing that reduces the burden on landfills, improves the quality of the air we breather, increases energy independence by production of oil and specialty oil products and generates hydrocarbon gases used for heat and energy requirements.

Rendering

One approach to disposal of the organic waste generated at nearby poultry processing facilities is to utilize a rendering plant. Rendering plants process or "recycle" animal and poultry by-product materials to produce tallow, grease, and protein meals. A simplified "typical" continuous rendering plant block flow diagram is shown in Figure 3. Sources of emissions from each of the blocks is shown in the Figure.

Volatile organic compounds (VOCs) are the primary air pollutants emitted from rendering operations. The major constituents that have been qualitatively identified as potential emissions include organic sulfides, disulfides, C-4 to C-7 aldehydes, trimethylamine, C-4 amines, quinoline, dimethyl pyrazine, other pyrazines, and C-3 to C-6 organic acids. In addition, lesser amounts of C-4 to C-7 alcohols, ketones, aliphatic hydrocarbons, and aromatic compounds are potentially emitted. Historically, the VOCs are considered an odor nuisance in residential areas in close proximity to rendering plants, and emission controls are directed toward odor elimination. The odor detection threshold for many of these compounds is low; some as low as 1 part per billion (ppb). Of the specific constituents listed, only quinoline is classified as a hazardous air pollutant (HAP). In addition to emissions from rendering operations, VOCs may be emitted from the boilers used to generate steam for the operation (ref 7).

For inedible rendering operations, the primary sources of VOC emissions are the cookers and the screw press. Other sources of VOC emissions include blood and feather processing operations, dryers, centrifuges, tallow processing tanks, and percolator pans that are not enclosed. Raw material may also be a source of VOC emissions, but if the material is processed in a timely manner, these emissions are minimal.

In addition to VOC emissions, particulate matter (PM) is emitted from grinding and screening of the solids (cracklings) from the screw press and other rendering operations such as dryers processing blood and feathers.

The improvements in process and process control have had little effect on the properties of odor. Thus odor is a primary air pollutant emitted from the rendering process. Rendering odors are derived primarily from two areas: the raw material and the cooking/drying process. The high intensity process odors are generally treated separately from the fugitive odors of raw materials. The processing of blood or poultry feathers normally results in more intense odor levels. More specifically high intensity odors include the noncondensables from the cooker exhaust and emissions from the screwpress. Other sources include dryers, centrifuges, tallow processing tanks and the perc pans that are open to the plant atmosphere and receive the discharge from the batch cookers.

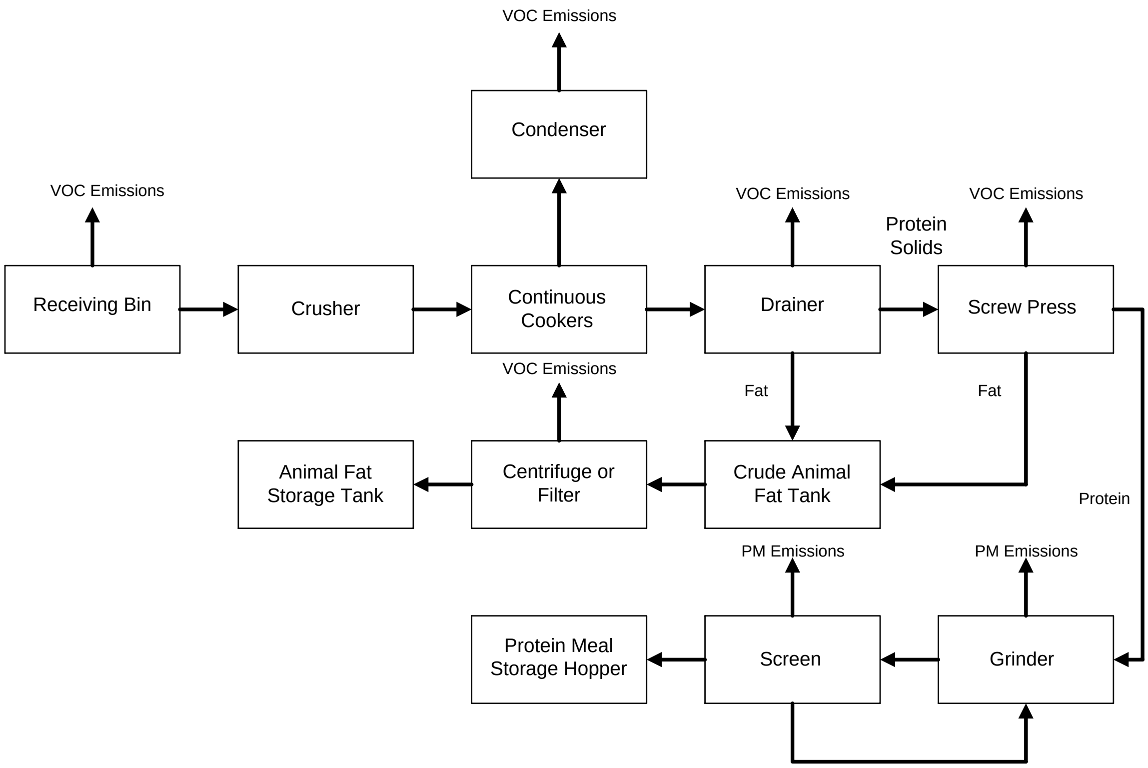


Figure 3. Simplified Block Flow Diagram for a Continuous Rendering Plant

Previous studies have analyzed rendering plant odors by a combination of gas chromatograph and mass spectrometric methods. The primary odorous compounds in rendering plant emissions are as given in Table 1:

Table 1. Odorous Compounds in Rendering Plant Emissions (ref 8)

Compound Name	Molecular Weight	Detection Threshold, (ppm, v/v)	Recognition Threshold (ppm, v/v)
Acetaldehyde	44	0.067	0.21
Ammonia	17	17	37
Butyric Acid	88	0.0005	0.001
Dimethyl amine	45	0.34	--
Dimethyl sulfide	62	0.001	0.001
Dimethyl disulfide	94	0.008	0.008
Ethyl amine	45	0.27	1.7
Hydrogen sulfide	34	0.0005	0.0047
Indole	117	0.001	--
Methyl amine	31	4.7	--
Methyl mercaptan	48	0.005	0.0010
Skatole	131	0.001	0.050
Trimethyl amine	59	0.0004	--

The patented CWT-TP process is an attractive alternative to rendering. (Note: The CWT-TP process removes nitrogen from the feedstock early in the process). By deaminating, in the CWT-TP, waste, such as a poultry offal waste stream, is fed into the process and ammonia and other nitrogen compounds can be collected and recovered.

Mad Cow Disease

Recently there has been concern about using animal matter as a supplement to animal feed that is destined for human consumption. World attention has been focused on outbreaks of Mad Cow Disease, technically called Bovine Spongiform Encephalopathy or BSE. BSE belongs to a class of fatal brain dementias know as “transmissible spongiform encephalopathies” or TSEs. They are remarkably resistant to disinfection, almost impossible to detect in live animals, 100% fatal, and can take years or even decades to incubate before symptoms emerge, giving the disease ample time to spread to others before it is detected.

To this day, no one knows what caused the first case of BSE. What we do know is that the spread of BSE was caused by feeding cows contaminated meat and bone meal proteins derived by grinding and cooking waste animal parts.

In addition to the BSE issue, there have been recent outbreaks of hoof and mouth disease in Europe reported in the news. The United Nations’ world food body warned (March 14, 2001) that foot-and-mouth disease is a global threat from which no country is safe, and it urged countries to adopt tougher counter measures. The world body’s cautionary language came as countries from Australia to the United States banned the import of meat products from Europe, where the disease has spread among herds of livestock. The CWT-TP process is capable of killing the foot-and-mouth disease and offers an alternative to destruction (via incineration and subsequent burial) of the infected herd.

It is apparent that continued re-feeding of animal protein back to the animals that we eat through rendering poses significant risks to us as a society.

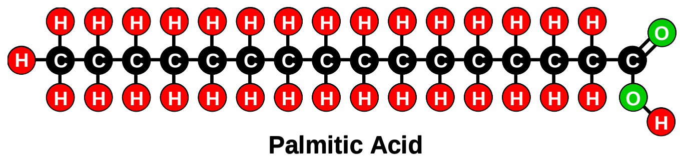
The CWT-TP process is an attractive alternative to rendering. Although the TDP process has not demonstrated (never tested) the ability to kill the prion proteins associated with BSE, it can help stop the disease from spreading. (Note: The CWT-TP removes nitrogen from the feedstock early in the process). By deaminating, protein formation/existence is unlikely if not impossible.) As far as hoof and mouth is concerned, the patented CWT-TP is capable of a complete kill and offers an alternative to destruction (via incineration and subsequent burial) of the infected animals. In the CWT-TP process, waste, such as the Butterball waste stream, is fed into the process and ultimately oils, specialty organic chemicals, coke, and a medium Btu fuel (steam, energy) are produced. The steam can be used in the process. The rest of the products are valuable commodities that can be sold.

RES/CWT will utilize the CWT-TP to convert mixed organic waste from food processing to high value products without discharging noxious gases to the atmosphere. Operation of the demonstration plant and analysis of products confirms these projections.

THE CWT THERMAL PROCESS

Some Chemistry of CWT-TP

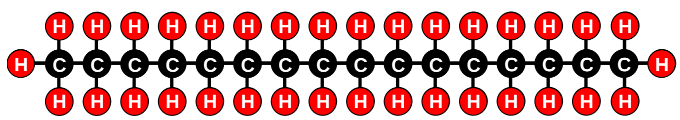
A simplified explanation of the chemistry of CWT-TP generated oil can be made using just one component that is common to plants and animals, fatty acids. Animal fat consists of triglycerides, molecules composed of a glycerol backbone with three attached fatty acids. One typical fatty acid is Palmitic acid:



Palmitic Acid

The Palmitic acid molecule consists of a long chain of carbon atoms with attached hydrogen atoms. At one end is a group consisting of one carbon, two oxygens, and one hydrogen. This is called the “carboxyl” group [-COOH], and it gives the molecule its acidic character. Palmitic acid contains sixteen carbon atoms, so it is designated a C16 fatty acid. Triglyceride fats consist of three fatty acids that are similar to Palmitic acid, although some have more carbon atoms than Palmitic acid.

If one disregards the carboxyl group, the Palmitic acid molecular structure looks like a hydrocarbon molecule with sixteen carbon atoms. Petroleum fuels (fossil fuels) are mixtures of long and short-chain hydrocarbons. Cetane is often used as a characteristic molecule of the mid-range of diesel fuels. Its molecular structure is:

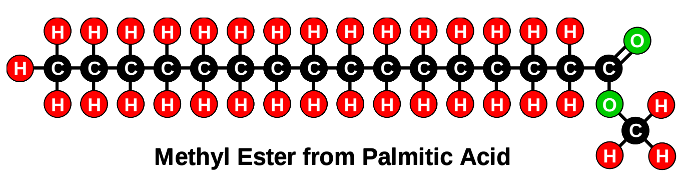


Cetane

The molecular structure of Palmitic acid looks very similar to that of Cetane, but with a carboxyl group at one end instead of the methyl group [$-CH_3$].

Cetane is a C16 hydrocarbon. For diesel fuel, the typical hydrocarbon range is from about C8 through C28. Soot and smoke from diesel combustion is primarily due to the longer chain hydrocarbons, or the higher C-number hydrocarbons.

There are bio-derived fuels that can be made from fatty acids by substituting a [$-CH_3$] group for the hydrogen atom [-H] in the carboxyl group on the fatty acid. The simplest fatty ester that could be formed from Palmitic acid is:



Methyl Ester from Palmitic Acid

One advantage of converting the fatty acid to an ester when making a bio-derived fuel is that handling and storage are easier. Table 2 below shows the melting points for Cetane, Palmitic acid, and the ester from Palmitic acid.

Table 2. Selected Chemical Melting and Boiling Points

	Melting Point °F	Boiling Point °F
Cetane, $C_{16}H_{34}$	65	549
Palmitic acid	144	664
Ester of Palmitic acid	86	783

Cetane is a liquid under normal conditions, particularly in a mixture. Palmitic acid has a much higher melting point, well above the normal storage and handling temperature for diesel fuel. This acid would be solid, or semi-solid, and difficult to handle. The advantage of the ester over Palmitic acid is fairly clear. The ester has a much lower melting temperature. However, one disadvantage of the ester is also clear. It has a higher boiling point, so it will require more energy to vaporize before combustion.

The CWT-TP transforms animal and vegetable fats into hydrocarbons that have twenty or fewer carbons. The CWT-TP derived oil is called TDP-40, and it is a mixture of C20-minus Bio-Derived Hydrocarbons. The pour point of TDP-40 oil is -17°F. The boiling points for 75% of the components of TDP-40 oil are lower than for Cetane.

TDP-40 oil has superior handling and combustion characteristics to the fatty acids and fatty esters. TDP-40 oil is the lightest of the bio-derived fuels. This is due to the second stage of TDP processing that breaks fatty acids into smaller hydrocarbon molecules.

The available waste feedstocks from biomass and other organic wastes will offer a renewable source of energy.

Process Description

A schematic block flow diagram of the TDP process is shown in Figure 4. Operation of the proposed RES Thermal Processing facility will serve to convert organic waste streams into valuable products. The CWT-TP process consists of three main steps: 1) pulping feedstock and then heating the resultant water slurry under pressure to the 1st stage reaction temperature, 2) flashing the slurry to a lower pressure and separating the 1st stage oil from water, and 3) heating the 1st stage oil to higher temperature to crack the oil into light hydrocarbon leaving a solid product. The process temperatures for the initial slurry phase of processing are between about 200^{o}C to 300^{o}C (392^{o}F to 572^{o}F). For the second processing stage the temperatures are near 500^{o}C (932^{o}F).

All produced gases go to process heat or steam generation. Future plant will have the additional option of generating electricity on site based upon the economics of onsite use. Any shortfall in electric power will be purchased from the grid.

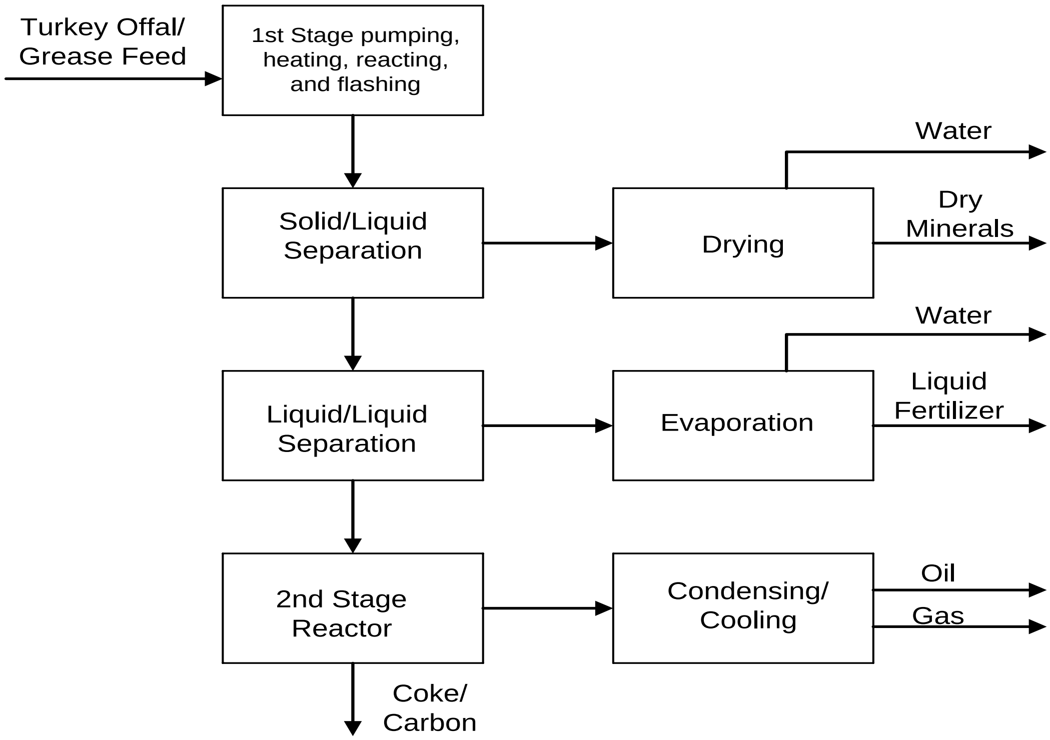


Figure 4. General Schematic Block Flow Diagram of TDP Plant

COMMERCIAL BIOREFINERY IN CARTHAGE, MO

Material and Energy Balances

Estimated feed and product distributions from processing 200 tons/day of turkey offal and grease waste in a CWT-TP biorefinery based in Carthage, MO are shown in Figure 5. For illustration purposes it is convenient to separate the feed into several components, namely water, organics, minerals, and ammonia. The sulfuric acid is added to neutralize the ammonia (derived from animal protein) and the resultant $(NH_4)_2SO_4$ is recovered as a product. The yields show approximately 69.8 t/d (about 500 barrels) of bioderived oil. Other products are the dry minerals, a liquid fertilizer, fuel gas (used internally), and a solid coke/carbon product. Figure 5 illustrates one example of a material balance from the plant. The plant can be operated at different conditions and can produce a varied slate of products depending on the market prices. For example, the plant can be operated such that no oil is produced. The oil would be processed to produce fuel gas and coke/carbon.

The energy efficiency of the plant can be calculated in several ways depending on what aspect of performance is of interest. The energy efficiency that is probably of most interest is the energy in the combustible products that leave the plant divided by the total energy input. The energy input includes the energy in the dry feed, the electric power used, and any purchased natural gas that must be fired (in this case no natural gas is required).

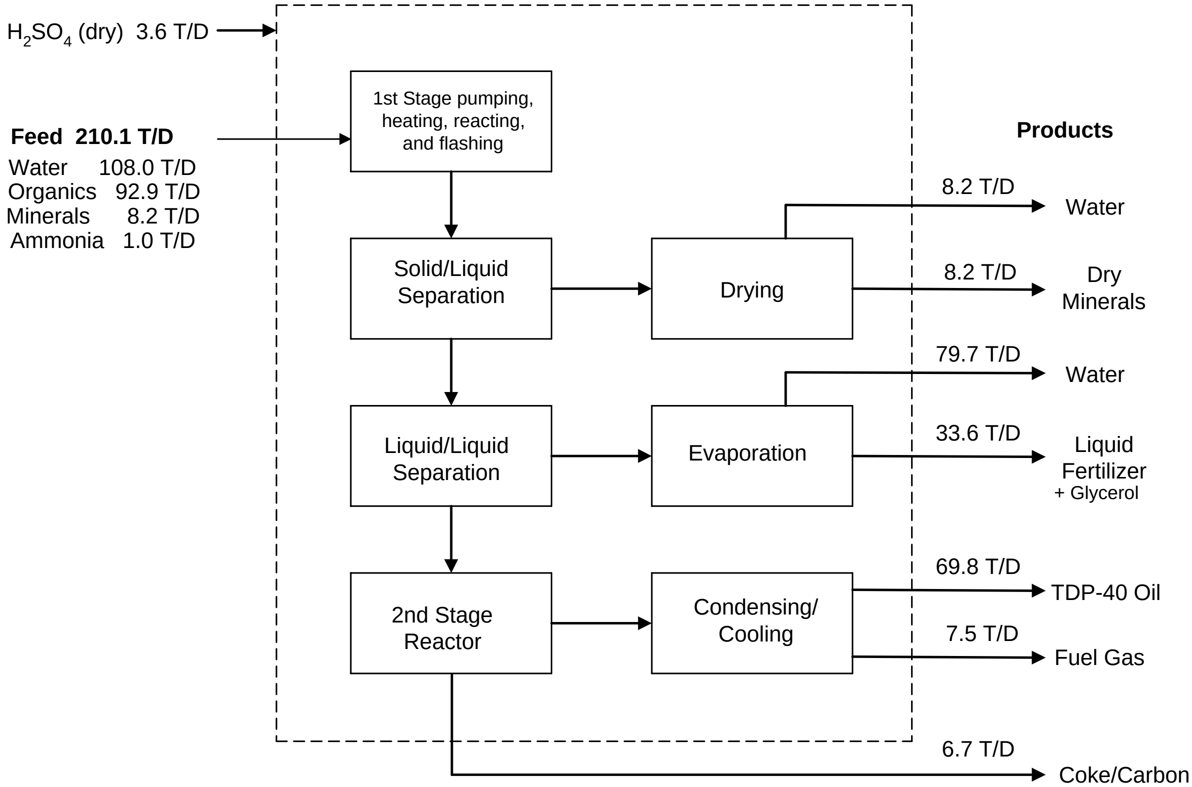


Figure 5. Material Balance Illustration

Energy efficiency for this design of the CWT-TP process is about 85%. Some of the CWT-TP fuel-gas must be used to operate the plant and, of course, pumps, motors, and some heaters require electric power.

The energy efficiency of the CWT-TP process is generally fairly high because most of the water that enters the plant leaves as a liquid rather than as water vapor. This is because the CWT-TP process is designed to use the steam that is generated internally to heat the incoming feedstock.

Energy efficiency is only one measure of the performance of the plant. For the CWT-TP plant shown in Figure 6, "economic" efficiency is more important. To achieve this, additional equipment is incorporated in the design to produce a saleable dry mineral product and a glycerol plus $(NH_4)_2SO_4$ product. A plant designed for a different feedstock, such as tires or plastics, would have less equipment, and even higher energy efficiency.

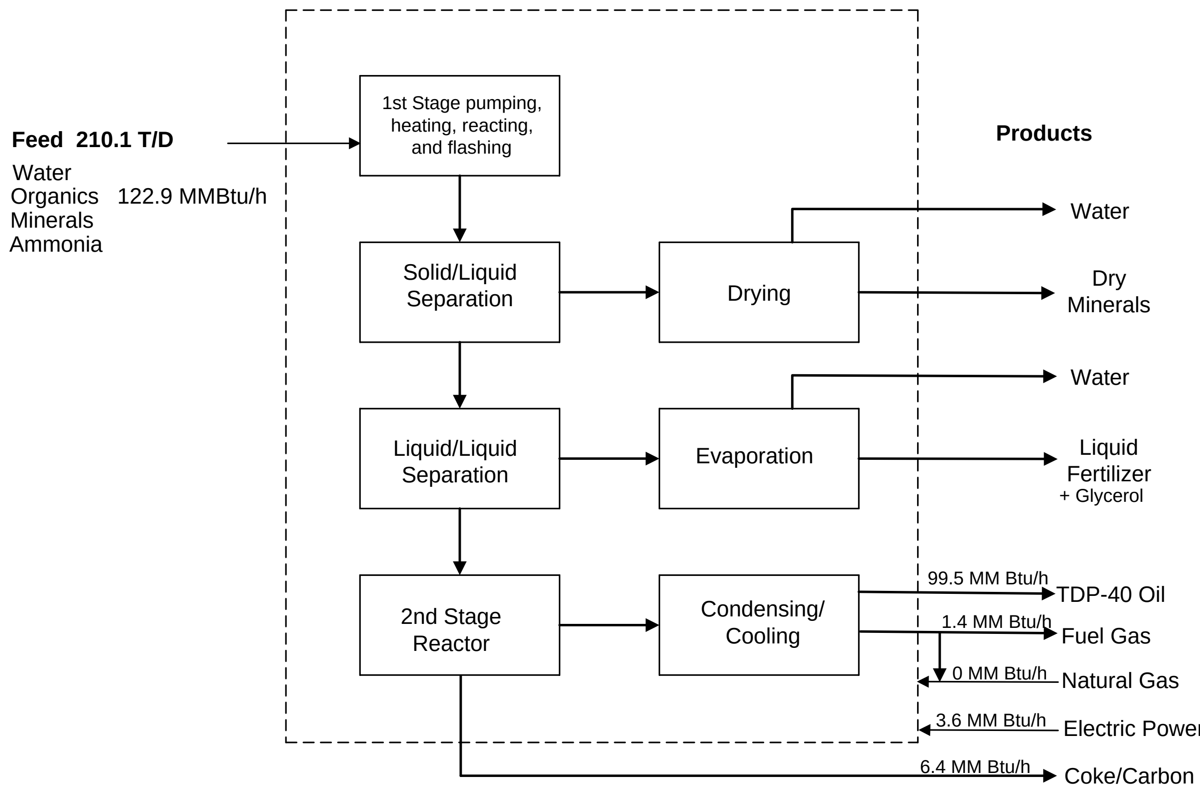


Figure 6. Energy Balance Illustration

PRODUCT PROPERTIES

PRODUCT OIL – API 40+

The product oil produced from the Carthage, MO plant is a high value crude oil that may be compared to diesel fuel. Both diesel fuel and TDP-40 consist of mixtures of hydrocarbons. The range of carbon chain lengths for diesel fuel is from about 10 to 30, with a small portion falling outside this range. Cetane, with a carbon chain length of 16, is used as a standard for diesel combustion characteristics. Cetane would be referred to as a C-16 hydrocarbon. TDP-40, and other bio-derived fuels such as bio-diesel, have shorter chain lengths and a narrower range of chain lengths. The dominant carbon chain lengths of bio-derived fuels are between 15 and 19, with only a very small portion above C-20. This difference in carbon chain lengths will cause some differences in combustion characteristics that can translate into improvements (reductions) in combustion pollutant emissions.

Table 3. Distillation (D-86) of Product Oil

Recovery, Volume Percent	Temperature, ^{o}C (^{o}F)
I.B.P.	52 (125)
10	71 (160)
20	104 (220)
30	138 (280)
40	168 (335)
50	204 (400)
60	232 (450)
70	260 (500)
80	304 (580)
90	349 (660)
Total Recovery, Vol. Pct.	95%

A common method of classification for petroleum is the PONA system – PONA is an acronym for paraffins, olefins, naphthenes, and aromatics. Paraffins are straight-chain or branched hydrocarbons in which there are no double or triple bonds between carbon atoms. Olefins are similar to paraffins, but they contain at least one multiple bond in their chemical structure. Naphthenes are saturated hydrocarbons, just like paraffins, but they incorporate a ring of carbon atoms into their chemical structure. Aromatics contain a benzene ring in their structure. A PONA classification of the TDP 40 oil is shown below in Table 4.

Table 4. Classification of TDP-40 Oil by PONA

PONA, wt%	D-5443 method
Paraffins	22
Olefins	14
Naphthenes	3
Aromatics	6
C14/C14+	55
TOTAL	100

The oil classification is useful for predicting fuel performance when used in combustion, e.g. as a diesel fuel replacement. The classification is also a useful prediction for fuel refiners or blenders in determining product distribution in a refinery or specialty chemical plant.

Figure 7. Oil Storage Tanks at Carthage

The product oil classification distribution resembles a typical delayed coker output. The output contains light and heavy napthas, a kerosene, and a gas oil fraction. There are essentially no heavy fuel oils, tars, asphaltenes, or waxes present.

SOLID PRODUCTS, CARBON AND MINERALS

The fixed carbon solids produced by the CWT thermal process have multiple uses – as a filter, a fuel source and a fertilizer. The highest value for the carbon products would be as activated carbon to be used in wastewater cleanup as a filter medium. The lowest value use of the carbon product is as a fuel. With a heating value of approximately 27.9 MJ/kg (12,000 Btu/lb, pure carbon is 14,093 Btu/lb, ref. 9) the carbon product could be substituted for coal use. The fixed carbon production from the process will assist in sequestering CO_2, a global greenhouse gas that contributes to global warming.

The mineral/micronutrients that comprise the typical mineral mix from the Carthage, MO plant are shown in Table 5. Of major interest are the N, P, K elements that comprise the fertilizer. The calcium in the mix comes from the bones of the animals. The N, P, K, Ca components represent nearly 80% of the total fertilizer. The mineral product acts as a naturally self-limiting, slow release soil amendment that puts the essential nutrients back in the soil. The minerals will help to rebalance macronutrients and replace depleted essential micronutrients in the soil, encouraging healthy plant growth and development.

Table 5. Typical Mineral Mix From Plant

Mineral/Micronutrient	**CONCENTRATION, KG/TONNE (LBS/TON)**
Nitrogen (N)	60 (120)
Phosphorus (P)	380 (760)
Potassium (K)	10 (20)
Calcium	340 (680)
Chloride	2 (4)
Copper	0.1 (0.2)
Iron	2 (4)
Magnesium	13 (26)
Manganese	0.2 (0.4)
Silicon	9 (18)
Sodium	9 (18)
Sulfur	6 (12)
Zinc	0.8 (1.6)
Fixed Carbon	20 (40)
Organic Matter	147.9 (295.8)
Total	1,000 (2,000)

SUMMARY

Solid waste disposal problems, energy shortages (primarily oil) and/or high petroleum prices, environmental issues such as shrinking landfill capacity, foot and mouth disease, and Mad Cow Disease (technically, bovine spongiform encephalopathy) can all be addressed by a simple innovative technology known as the CWT Thermal Process. The CWT-TP takes waste material and converts it into saleable products. A liability is transformed into an asset. The technology was initially tested on small batch reactors, then a 1-t/d continuous unit, then a 7 t/d continuous pilot plant, and finally to a 200 t/d commercial unit. Development work and commercialization of a plant that uses animal waste and grease as a feedstock has progressed fastest because there was an end-user champion that wanted to be proactive with waste disposal. Additional plants are in various stages of design and construction.

The continuous unit at Carthage, MO has recently completed shakedown and is operational. Products from the plant include a biodiesel fuel, called TDP-40, a premium diesel that can be used as a blended fuel, a chemical feedstock, or as a stand-alone fuel to generate steam and/or power in a diesel engine. Product solids can be used as nutrients or soil amendments and sold as fertilizer. Any carbon present can be used as fuel, or used for activated carbon.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support from the U.S. EPA Region VII for cofunding, through a grant, the purchase of some of the prototype equipment used in the Carthage, MO plant. The authors would also like to thank Senator Christopher "Kit" Bond and Congressman Roy Blunt, both from Missouri for their help in making the Carthage, MO plant a reality and for their continued interest and support of the CWT-TP technology.

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