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Waste to Fuels

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The energy we use comes in a number of forms: electricity, natural gas, and liquid fuels. For transportation purposes, liquid fuels are used almost exclusively. There are prototypes of electric cars and buses that run on natural gas, but all airplanes, and most cars and trucks use liquid fuels. Air travel will always be dependent upon liquid fuels since it would be impractical to try to power airplanes or jets by any other type of fuel. Electric cars have limitations (short available distance driven without recharging, lack of acceleration) and even with the substantial improvements in these vehicles that are expected in the next 10 years, our society will still be dependent on a large number of vehicles which use liquid fuels. These liquid fuels include gasoline, diesel fuel, and jet fuel and may be collectively referred to as transportation fuels. The 1991/92 National Energy Strategy (NES) recognizes the importance of transportation fuels to the economic and social vitality of the U.S. and projects an increase in energy consumption for the U.S. transportation sector in the coming decades. In particular, the NES predicts a higher demand for jet fuel and diesel fuel for transportation fuel usage. (The proportional increase in diesel and jet fuels is due to shifts in personal travel and freight mode choices.) The use of liquid fuels for transportation results in a near complete dependence upon petroleum sources, and in 1990 the U.S. imported 42 percent of its petroleum, see Figure 1. This dependence makes the U.S. reliant on the area of the world that has the most crude oil resources: the Persian Gulf. Dependence on oil imported from the Persian Gulf is expected to increase, since the

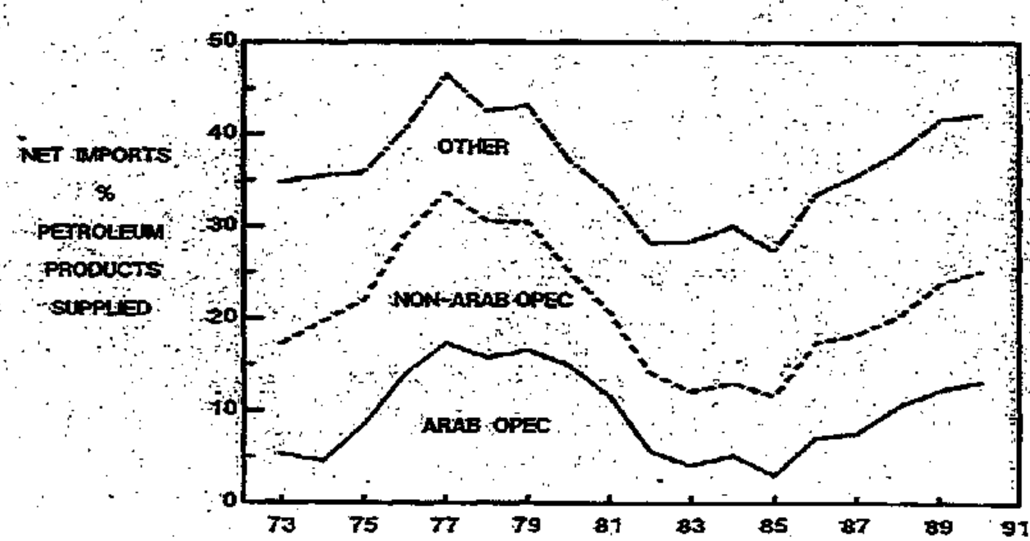

Figure 1. In 1990, the U. S. average consumption of petroleum products was 16,988,000 bbl/day with 42% imported. (EIA Monthly Energy Review, Dec. 1991)

Persian Gulf's share of worldwide production is expected to reach 41 percent by 2010. The NES points out that "inescapable political and economic uncertainties exist for a world heavily dependent on oil imported from that region" (1). It is clear that alternative sources of transportation fuels are necessary.

Several historical examples may be found where the problem of finding alternative sources of liquid fuels has been addressed. During World War II, Germany had large deposits of coal but no crude oil sources and therefore, studied the processes for making liquid transportation fuels from coal. One process they looked at was direct liquefaction of coal which involves slurrying coal in a hydrocarbon solvent and heating to high temperatures in the presence of hydrogen. This process creates a crude oil-like material which can be refined to transportation fuels. One of the most successful processes to emerge from World War II Germany was the Fischer-Tropsch synthesis. Fischer-Tropsch (FT) synthesis is a process for making liquid fuels, primarily diesel fuel, from gasified coal. The South African company, Sasol, started producing diesel fuel by Fischer-Tropsch technology in 1955. In the mid-1970's this effort was increased in order to produce a substantial amount of liquid fuels for South Africa, a country that had coal resources, no petroleum sources, and a lack of trading partners willing to sell them petroleum. This process for making liquid fuels is much more expensive than refining crude oil. Synthetic fuels cost about $40-50 per barrel; crude oil in the early 1990's has been about $20 per barrel. In the 1970's Mobil developed a process called methanol-to-gasoline (MTG) and in 1982 completed such a plant in New Zealand, a country with no petroleum reserves of its own (2). MTG requires methanol as a starting fuel. Methanol synthesis is an established technology that uses CO and H_2 as a starting material. Methanol may be used as a transportation fuel either by mixing with gasoline and used in a conventional engine or alone in a specially designed automotive engine. In New Zealand, methane (natural gas) is used as the starting material for the methanol-producing CO and H_2.

These three processes, MTG, FT, and methanol synthesis, have a common feedstock: carbon monoxide (CO) and hydrogen (H_2). Synthesis gas, the term for a mixture of carbon monoxide and hydrogen, may be derived from a number of sources including coal, natural gas, and biomass. There are two ways to make synthesis gas. One way to produce synthesis gas is by gasification, a process of heating coal or other carbonaceous materials such as wood, bagasse (sugar cane agriculture waste), or rice husks to high temperatures in the presence of a moderate amount of oxygen. The gasification process produces primarily carbon monoxide and hydrogen with carbon dioxide and water being byproducts. A CO and H_2 mixture is a combustible gas with a medium BTU content (low BTU content if there is too much CO_2 present) which may be burned and used as a gaseous fuel similar to natural gas or may be catalytically converted to liquid fuels.

Synthesis gas may also be made by mixing methane (CH_4) with steam over a catalyst. This process is call steam reforming.

$$CH_4 + H_2O = CO + 3H_2$$

In practice the ratio of hydrogen to CO is not usually as high as 3:1. Because CO_2, carbon, and other byproducts are made the ratio of hydrogen to carbon monoxide is about 2.2:1.

All three liquid fuels, diesel, gasoline and jet, are different chemically. Gasoline is a mixture of branched-chain paraffins (isooctane gives the best "octane" rating), cycloparaffins, and aromatic compounds. Recent legislation calls for a lower percentage of aromatics in gasoline in order to decrease ozone-depleting pollution from auto exhaust. Diesel fuel is made of primarily aliphatic paraffins ($C_{16}H_{34}$ is the standard for the "cetane" number, a rating for diesel fuel analogous to the gasoline "octane" number). A number of combustible mixtures are used for preparing jet fuel. Some types are blends of gasoline and light hydrocarbons and others are special kerosine mixtures.

The CO and H_2 may be converted to diesel-fuel-type products by Fischer-Tropsch synthesis:

$$nCO + 2H_2 = -(CH_2)_n- + nH_2O$$

The products of FT synthesis are unique: they are almost exclusively straight chain alkanes with a smaller portion of straight chain olefins. It is a relatively straightforward procedure to refine the waxes to an all diesel mix.

Methanol may be synthesized from CO and H_2:

$$CO + 2H_2 = CH_3OH$$

Methanol may be used as a liquid fuel, either alone or as an additive to gasoline. Gasoline may be made from methanol using the Mobil methanol-to-gasoline catalyst called ZSM-5. This catalyst makes hydrocarbons of varying length but the most commonly found product has eight carbons: octane and isooctane.

As summarized above, there are a number of processes for synthetically producing liquid transportation fuels. A number of "waste" resources can be used as the starting material for these liquid fuel syntheses.

Landfill Natural Gas

About 1-1/2 to 2 years after waste has been laid down in a landfill, a gas is generated from the anaerobic decomposition of the biodegradable wastes (usually fats, carbohydrates, proteins, and other complex organics). This gas is usually about a 50/50 mix of carbon dioxide and methane. After a landfill closes, gas production declines and eventually stops since no additional waste is added to replace that which has already been decomposed.

Landfill gas (LFG) is an environmental hazard as well as a nuisance. Since it is 50 percent methane, it is an explosive gas. The landfill gas also includes small amounts of volatile organic compounds that are both toxic and ozone depleting. Natural gas is a greenhouse gas that is 25 times worse than carbon dioxide. Landfill gas is one of the largest sources of methane in the atmosphere. In addition, there is a very unpleasant odor associated with landfill gas.

Capture and use of this gas not only solves an environmental problem, but provides a source of energy. However, there are a number of obstacles to using landfill gas. Unlike natural gas that is in deep pockets of the earth, there is no way of storing landfill gas. It must be used as it is made. To contribute to a natural gas pipeline, expensive clean up of the feed gas must be made and a pipeline must be nearby. The most inexpensive way to use landfill gas is to burn it as a boiler gas for industrial heating or for making steam. However, this option requires that the landfill be located close to an industrial source that needs the boiler gas or steam on a round-the-clock basis. Electricity may be generated using either turbines or, for smaller gas flows, internal combustion engines. However, the LFG can be corrosive (since chlorinated waste will contribute to the formation of hydrogen chloride and other corrosive gases), which requires special (expensive) turbines and equipment. Another option is to use landfill gas to make liquid fuels which may be stored and transported easily. In Pueblo, CO, Fuelco Development Corp. uses LFG to make diesel fuel using Fischer-Tropsch synthesis. In California another company is also planning to use LFG to make diesel fuels.

Landfill gas is captured by drilling perforated pipes down into the landfill as shown in Figure 2. This is more difficult than first appears since a landfill may be filled with virtually anything and drilling may be blocked by concrete blocks or other impenetrable objects. All landfills have gas, but how much gas is very difficult to predict. In addition, the supply of landfill gas over the course of the landfill's producing lifetime will vary. The variation and unpredictability in supply must be considered when planning an end use for the landfill gas (3,4).

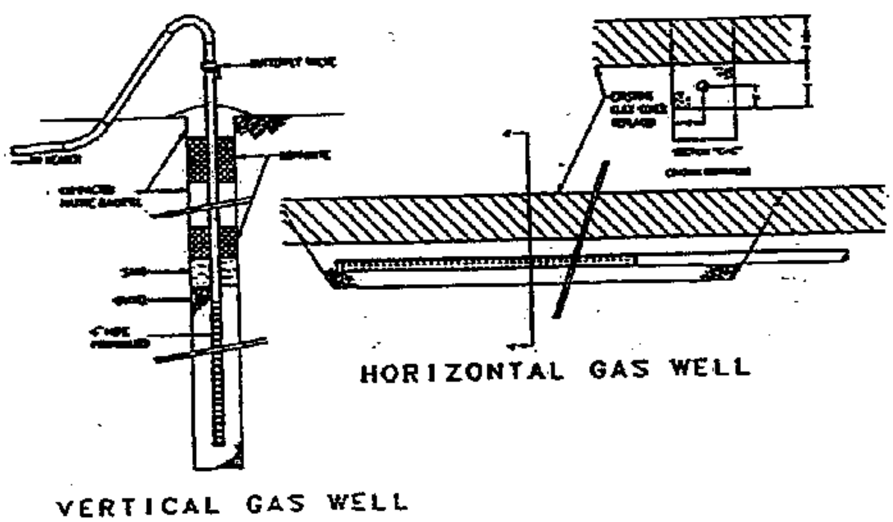

Figure 2. Landfill gas well types. Taken from Reference 3.

Methane from Waste Treatment Plants and Agricultural Wastes

An experimental plant in France has demonstrated the ability to anaerobically digest the organic portion of municipal solid waste. This gas is similar to landfill gas in its composition (54% methane; 46% CO_2; trace organic components; trace hydrogen sulfide) and may be used to generate electricity, may be cleaned up and added to existing an natural gas pipeline, or may be converted to liquid fuels (5).

Agricultural wastes may also be anaerobically digested to produce methane. The National Renewable Energy Laboratory conducts research in "anaerobic digestion" of wastes. This includes development of photoenhanced processes that use photosynthetic bacteria that will speed up the rate of anaerobic digestion (6).

Synthesis Gas from Sugar Cane Waste and other Agricultural Products

Gasification of bagasse, or sugar cane waste, is a process undergoing demonstration in Hawaii by the US Department of Energy. The gas being made (CO, H_2, and CO_2) is presently being burned to make electricity. Gasifiers for other agricultural products are also being developed. The possible sources of feedstocks are nearly endless including aquatic plants, agricultural residues, food processing wastes, woody plants, grasses, and wood chips. The gasified product may be converted to electricity, burned for process heat, or made into liquid fuels. Since the gasification product includes carbon monoxide and hydrogen, the production of liquid fuels is always an option.

Tires

Tires are difficult and expensive to dispose of. The price of tire disposal ranges from $0.50 - $1.00 per tire which makes it an attractive fuel source since it is not just free, but it is a feedstock which brings in money. Several methods for using tires as an energy source are being used and additional methods are being developed. Most methods require initially shredding the tires before using. In England an electricity plant is being built that will burn tires as fuel for steam generation (7). Tires may also be burned along with coal in coal-fired electricity plants. Other methods for converting tires to energy involve pyrolyzing tires (heating to high temperature in the absence of oxygen) which makes a crude oil-like material, which can be added to a refinery stream for the production of fuel oil. A problem with using tires is that transportation of tires to a central energy-producing location and the shredding of the tires are both expensive processes.

Conclusions

One of the difficulties for the development of waste and biomass energy resources is the small scale on which each energy source is based. In the U.S., the energy industry (utilities, gasoline and diesel suppliers, etc.) is made up of very large corporations. The biomass and waste sources of energy usually represent small amounts. For example, the facility in Pueblo, CO, that makes diesel fuel from landfill gas produces about 120-200 barrels of diesel per day. (A large refinery would process about 250,000-500,000 barrels of oil per day; a small refinery would process about 30,000 barrels of oil per day.) The tire burning plant in England will produce 25 megawatts of electricity. (A coal burning plant would be about 200-300 megawatts, a nuclear plant about 1000 megawatts.)

However, there are many opportunities to use waste to produce fuels. Only a few have been mentioned in this paper and they are examples leading primarily to transportation fuels. As the environmental cost of our waste disposal increases along with the cost of our nonrenewable energy sources the use of alternative sources will become increasingly attractive.

Acknowledgement

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