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Biomass Energy R&D in the San Francisco Bay Area

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Biomass Energy Research in the San Francisco Bay Area

Biomass is plant matter such as trees, grasses, agricultural crops or other biological material. It can be used as a solid fuel, or converted into liquid or gaseous forms, for the production of electric power, heat, chemicals, or fuels. There are a number of ways of getting energy from biomass, and a number of factors influence the efficiency of the conversion process.

All biomass can be easily combusted. The heat of combustion can be used as heat, or can be used to run gas/steam turbines to produce electricity. However, most biomass combustion processes are inefficient and environmentally non-benign. The main pollutants from direct biomass combustion are tars, particulates, and VOCs.

Biodiesels can be made from oils obtained from plants/crops such as soybean, peanuts and cotton. The oils from these sources are mainly triglycerides of fatty acids and not directly suitable as diesel substitutes. Transesterification processes convert the triglycerides into simple esters of the corresponding fatty acids (for example, Fatty Acid Methyl Ester or FAME), which can be directly substitutes for diesel fuels.

Starches, sugars and cellulose can be fermented to produce ethanol, which can be added to gasoline, or used directly as an engine fuel. Fermentation of starches and sugars is established technology, practiced for thousands of years. Fermentation of cellulose to make ethanol is relatively harder, requiring additional intermediate steps to hydrolyze the cellulose first by adding acids or by raising temperature.

Forestry wastes predominantly comprise cellulose and lignin. Lignin cannot be fermented using the current bio-organisms, and, as mentioned above, even cellulose is difficult to ferment directly. In such cases, a suite of alternative technologies can be employed to convert the biomass into liquid fuels. For example, the biomass can be gasified with the use of air/oxygen and steam, the resultant syngas (mixture of hydrogen and carbon monoxide) can be cleaned to remove tars and particulates, the gas can be shifted to obtain the proper balance between hydrogen and carbon monoxide, and the balanced gas can be converted into either methanol or other hydrocarbons with the use of Fischer-Tropsch catalysts. The liquid fuels thus produced can be transported to the point of use. In addition, they can be reformed to produce hydrogen to drive fuel cells.

In addition to agriculture and forestry, a third, and significant, source for biomass is municipal waste. The biomass component of municipal wastes consists mainly of cellulose (paper products and yard wastes) and lignin (yard wastes). This waste can be combusted (see an example below) or gasified, as described above.
All the technologies mentioned above are relatively mature, and are being practiced in some form or another. However, there are other technologies that may be promising, yet present significant challenges and may require more work. An example of this is the use of bacteria to use light to decompose water to yield hydrogen.

In most of these areas, industry and research organizations in the Bay Area are making significant contributions.

The Tracy Biomass Plant in Tracy has been operating since 1990. At the present time, all fuel is processed offsite by independent wood processing companies and delivered to the plant in clean form, such as chips. Slightly less than half the fuel is from agricultural sources, the remainder being urban waste wood. The wood wastes come from all over the East Bay Area, however, the main fuel supply for this plant comes from a fuel supply company in Livermore. The total fuel consumption at this plant is about 100,000-120,000 tons/yr of dry waste wood. The plant is rated at 18.9 MWe.

Even though combustion of biomass is already advanced, researchers are actively looking for ways to improve combustion processes. A group at Stanford University is characterizing the fundamental chemical and physical processes controlling coal-char and biomass-char conversion to gaseous species in the type of environment likely to be established in advanced gasifiers, boilers and furnaces. Design of boilers, burners and gasifiers requires an understanding of processes that control the physical transformations that fuel particles undergo when exposed to hot, oxidizing environments and the chemical reactions responsible for conversion of the solid material to gaseous species and ash. The effort will result in fundamentals-based sub-models for particle mass loss, size, apparent density, and specific surface area evolution during char conversion.

The technology of starch and sugar fermentation for fuel ethanol is mature and being practiced mostly in the corn-belt. However, basic R&D in this area is ongoing. For example, research is currently underway in Stanford University to modify, through genetic engineering, the ability of cells to increase cellulose production. Another group at Stanford is researching ways to improve the conversion efficiency in fermentation processes through both thermochemical and biochemical processes. They are developing hybrid yeast strains capable of fermenting sugars at elevated temperatures and ethanol concentrations from pretreated agricultural and forest residues.

As previously mentioned, lignin cannot be fermented, and cellulose is difficult to ferment. The alternative technologies in this case are thermal, namely, biomass gasification, followed by physical and chemical processing of the syngas, either to make cleaner burning gaseous or liquid fuels or to make electricity through the use of fuel cells. The four key technologies necessary for converting biomass to liquid fuels are: biogasification, gas clean up, shift reaction, and final synthesis. Of these, the last two have been amply demonstrated in the commercial sector. For example, SASOL in South Africa has been using these technologies for decades to produce liquid fuels from coal. The first two have been demonstrated on commercial scale for coal, but not yet for biomass.

Researchers at Lawrence Livermore National Laboratory, in collaboration with the University of Washington, NREL and Idatech, have been working on developing a mobile methanol generator. A mobile unit could be taken to the source of the biomass, where it would convert the biomass to methanol. Once the biomass resource at the given place is depleted, the unit would move to the next location. Since biomass is a distributed resource with low energy density (thus making large scale transportation uneconomical), the mobile unit may serve a niche in some areas of the country (such as remote localities away from the power grid).

In addition, the Direct Carbon Conversion fuel cell, being developed at the Lawrence Livermore National Laboratory, is also a promising new technology that can make a more efficient use of biomass-derived carbon. The idea here is to feed the chars (derived from coal or biomass) to a fuel cell containing molten carbonate matrix wherein the carbon is oxidized electrochemically, generating electricity. Electrochemical oxidation of carbon is inherently more efficient than that for hydrogen because the entropy change in the first case is slightly negative, whereas that for the second case is positive. This means that at least in theory, it is possible to obtain 100% conversion efficiency in case of the carbon fuel cell.

Even though the technology of synthesizing chemicals (such as liquid fuels) is mature, improved fundamental understanding is likely to lead to process improvements. A number of researchers at the Lawrence Berkeley National Laboratory and UC Berkeley are developing novel catalysts for the synthesis of fuels from syngas and carbon dioxide. The present program is focused on the strategic design of novel catalysts of potential interest for the production of fuels and chemicals in an energy-efficient and environmentally acceptable fashion. Of particular interest are the conversion of alkanes to alkenes and functionalized products, and the synthesis of fuels and chemicals from carbon monoxide and carbon dioxide. To achieve these goals a molecular understanding of catalytically active centers is used together with knowledge of how to synthesize unusual chemical and physical environments at such centers. The program involves a synergistic combination of efforts in the areas of catalyst synthesis, characterization, and evaluation. Quantum chemical simulations of catalytically active centers help guide the interpretation of experimental findings and suggest novel structures to be attempted synthetically.

All thermal conversion processes generate hydrogen (as a component of the syngas). However, a research group at Stanford University is exploring ways of generating molecular hydrogen from water via biological conversion of solar energy. The first portion of the project seeks to develop an organism/bioreactor system employing a genetically engineered organism that is effective in the direct conversion of sunlight to hydrogen. The organism will use a shuttle protein, ferredoxin, to transfer electrons from the reaction of water photolysis to the hydrogenase enzyme. However, the first and major problem is that hydrogenase enzymes are inactivated by molecular oxygen. Thus, the initial focus of this part of the project is to establish protein evolution methods capable of evolving a highly active hydrogenase (such as the one from Clostridium pasteurianum) to be insensitive to inactivation by molecular oxygen.