It is dangerous, says Voltaire, to be right in matters
where established men are wrong

Georg-Christoph Lichtenberg

Chapter 17
Energy conservation from renewable resources

The term "energy production," frequently used in connection with microbes, is incorrect. According to the law of conservation of energy, energy cannot be produced in a closed system, but it can be converted from one form to another. To use a "microbial example," part of the energy present in glucose can be converted to the energy present in methane, then into heat when the methane is burned.

What mankind increasingly needs are energy carriers for provision of heat and electricity, for mobility, and for production of goods. The most suitable energy carriers are those with a high energy density. Liquids and gases, or electrical power, are favored for ease of transport. The volume of the energy carriers required globally in 2003 amounted to 15.3 billion tons of coal equivalents (TCE); by 2030 it is expected to increase by 52 percent to 23.3 billion TCE. The proportion of renewable energy carriers was 13 percent in 2003 and will probably reach 14 percent by 2030. In view of this relatively small percentage of renewable energy sources, it is apparent that coal, oil, gas, and nuclear materials will continue to be the predominant energy sources in the near future.

Isn't that a rather conservative point of view? Can't we expect a boost in the use of renewables?

Let's look into renewables without regarding the use of wind, water, and solar energy. Instead, let's concentrate on biological processes. Whenever the use of biomass is being considered, the question of energy density is of increasing importance due to transportation costs. Microorganisms are therefore put to work to convert biomass into liquid or gaseous energy carriers. For example, liquid carriers are ethanol and butanol; gaseous carriers are methane (biogas) and molecular hydrogen. The industrial ethanol production with baker's yeast, *Saccharomyces cerevisiae*, is fully established. In addition, genetically engineered strains of *Escherichia coli* have been developed (see Chapter 16). Butanol is of interest as an energy carrier and, even more so, as a basic chemical for industry (see Chapter 15). However, the major drawback of the acetone-butanol fermentation is the low butanol yield of only a few percent, which makes recovery of butanol quite costly.

Whereas the production of ethanol and butanol requires sophisticated technical equipment and engineered strains of yeast, *E. coli* and *C. acetobutylicum*, the

Discover the World of Microbes: Bacteria, Archaea, and Viruses, First Edition. Gerhard Gottschalk.

production of biogas is comparatively simple. Large vessels called anaerobic digesters are filled with biomass, and the microbial degradation process begins. First, any oxygen present is consumed, then fermentations leading to products such as organic acids and alcohols take place. Eventually the substrates for methanogenesis emerge: acetate, methanol, $H_{2,}$ and CO_2. Then the methanoarchaea take over and produce biogas. The biomass composition has an effect on how much methane there is in the biogas produced. Biogas produced from sugars and carbohydrates consists of approximately 50 percent methane and 50 percent carbon dioxide. When a certain amount of fat is present, the methane yield is higher than 50 percent. As already mentioned, industrial plants for biogas production are rather simple. They can be built to different scales, with small ones to provide biogas for households or large ones to process all the activated sludge continuously produced in sewage plants of large cities. India is famous for its millions of small biogas plants that provide energy for cooking, especially in rural areas. Bioenergy villages have been developed, but there are certain limitations. Bioenergy cities are an illusion because biomass collection and transportation would simply use too much energy in the form of vehicle fuels.

It has been calculated that half the biomass produced on agricultural areas would have to be channeled into the biofuel fermentation industry in order to meet the annual global need for fuel. There we face the problem already mentioned in a previous chapter. Biofuel production must be kept in balance with global food production and may not be carried out at the expense of long-lived biomass.

Ethanol, butanol, and biogas – these will be the major products of the fermentation industry in the future, but it still will be difficult to meet more than 10 percent of global fuel needs with this type of bioenergy. These processes and some new developments were summarized in a report by the American Academy for Microbiology (Microbial Energy Conversion, 2006).

What about biodiesel?

Products recovered from oil plants, such as rapeseed and soybean oils, cannot be used directly as biodiesel. Such oils consists of long-chain fatty acids that are linked to glycerol. A chemical process has to be performed by which methanol replaces the glycerol, so methanol is required for biodiesel production. Glycerol is not only a byproduct of this process but also an important commodity for biotechnology (see Chapter 28). The biodiesel produced is a valuable component of the so-called energy mix but, again, only a small percentage of petroleum-based fuels can be replaced by biodiesel from rapeseed or related plants.

What other biological systems can be used for generation of useful energy carriers?

One of the most interesting processes is using solar energy for cleavage of water to molecular hydrogen and molecular oxygen. In fact, that is what plants and cyanobacteria do (see Chapter 9). They are capable of cleaving water with the help of photosystem II. The molecular oxygen produced in this process is released. The two hydrogen atoms (2H) of water, however, are not converted into molecular hydrogen (H_2) but transferred to carrier molecules, which then serve as hydrogen donors for conversion of carbon dioxide into starch or other cellular constituents. In order to produce O_2 as well as H_2 from water in light-dependent reactions, additional enzyme systems are required that are able to evolve H_2 like the hydrogenases. If the components, photosystem II, ferredoxin as hydrogen carrier, and a suitable hydrogenase, were to be combined, then water could indeed be cleaved in a light-dependent reaction:

$$H_2O \xrightarrow[\text{Photosynthetic apparatus}]{\text{Light}} \boxed{\tfrac{1}{2}\,O_2} + 2H$$

$$2H + \text{Ferredoxin}_{ox} \rightarrow \text{Ferredoxin}_{red}$$

$$\text{Ferredoxin}_{red} \xrightarrow[\text{Hydrogenase}]{} \text{Ferredoxin}_{ox} + \boxed{H_2}$$

That's it!

Unfortunately, this works only in principle. Such a system would only function for a few minutes, mainly because the oxygen formed is so reactive that it would inactivate the whole system (see Chapter 5, "Oxygen is a nasty stuff"). The question is how plants manage to cope with this radical action of oxygen. They have developed a protective system in which the O_2 reacts with a target molecule called D1 protein, which is damaged in the process. A repair mechanism continually replaces damaged D1 protein. It's like having to change the spark plugs of a car every five minutes. Obviously, driving a car under these conditions would not be very convenient and, for similar reasons, the enzyme system explained above would not be suitable for H_2 production. An additional drawback is the oxygen sensitivity of most hydrogenases, which also would be inactivated. This whole field finds broad interest and the research required is nearly unlimited. The sunlight-driven cleavage of water into hydrogen and oxygen would eventually lead to a hydrogen-powered economy. In our opinion, this is the only process of global importance in which biological systems or chemical systems mimicking biological processes could be employed on a large scale for generation of energy carriers. The other energy carriers mentioned operate essentially on relatively narrow roads, whereas what we need is a broad new avenue. Together with endeavors using solar energy in photovoltaic plants or in plants using solar energy to heat liquids, these processes will put the sun at the hub of energy-conservation technologies. And that is exactly what we have to do.