Turning manure into gold

The potential of methane-producing bacteria to meet future energy needs

At a time of global warming, growing environmental concerns and a political situation that is making many industrialised countries critically review their dependency on Middle Eastern oil, the need to develop alternatives to fossil fuels is becoming increasingly important. And this is not just a recurring demand from environmentalists; most industrialised countries signed the Kyoto Treaty, committing themselves to lowering their carbon

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dioxide emissions in the future. Even in the USA, whose current administration snubbed the Kyoto Treaty, the search for alternatives is on. Congress is debating an energy bill that would place more emphasis on 'biofuel', and the Farmer Bill passed last year already includes provisions to increase the amount of 'biobased' products for use in cars and industry.

Of all the alternatives to oil, coal or natural gas, hydrogen is certainly the gold standard. Its combustion process leaves nothing but pure water, and, when used in fuel cells, it can be converted into electricity with an efficiency that makes all other means of electricity production, whether based on oil, coal, natural gas or nuclear fuels, pale in comparison. But the massive costs involved in establishing the infrastructure required to produce, store and distribute hydrogen means that its utilisation is still years away, despite the fact that car manufacturers in both Europe and the USA are already at an advanced stage in the development of hydrogen-powered vehicles. One of the main contenders in the chasing pack is methane—a gas that although not quite as environmentally advantageous as hydrogen, is still relatively clean-burning when compared with

other fossil fuels. What is more, it is easier to handle than hydrogen and the infrastructure required for its distribution could easily be adapted from that already in place for natural gas.

Most methane used today is synthesised from natural gas, of which it is a major component. In addition, the discovery of huge deposits of frozen methane hydrate, trapped in marine sediments, has raised hopes that these could be mined and used for energy production. But both sources present drawbacks. They require large amounts of energy, which increases the costs and diminishes any potential environmental advantages gleaned by using methane as a fuel. More importantly, both methods still negatively affect the balance of carbon dioxide in the atmosphere, and they do not solve the overall problem of fossil fuel reserves running out or becoming economically unviable.

There is, however, a third and largely untapped resource: methane produced by anaerobic digestion (Figure 1). Bacteria in wetlands, rice paddies, cow intestines, landfill sites, and many other places where there is rotting organic material, produce huge amounts of methane that escapes into the atmosphere where it contributes to global warming. It is this biological process that has captured the attention of some researchers, who hope to use methanogenic bacteria for industrial-style methane production. Particularly in the USA, interest is growing in biomethane production as an important part of a 'diverse energy portfolio', as Stephen Zinder from Cornell University in Ithaca, NY, describes it. His group received a US\$837 000 grant from the US National Science Foundation (NSF) last year for research on wetlands, part of a new US\$2.8 million programme for research on methane-producing bacteria. Also, the US Department of Energy's Biological and Environmental Research

announced last year that it would spend a total of US\$103 million on microbial genome research, including research on the production of clean energy. And it is not only within the public sector that interest is growing. Having left Celera last year, J. Craig Venter recently established the Institute for Biological Energy Alternatives. He intends to explore the microbial world, with the ultimate aim of engineering microorganisms to capture the car-

Pilot projects are using the methane produced in waste treatment plants and landfill sites to produce electricity

bon dioxide emitted from power plants and convert it into methane.

The biological option of methane production is clearly the most attractive, both from an economic and an ecological point of view. The methanogenic bacteria that turn biological matter into methane will, in theory, degrade any substrate, including wastewater, agricultural waste and plastics—materials that industrialised countries around the world spend millions trying to dispose of. It also requires no extra energy—just put the waste into an airtight container with a pipe sticking out of the top and collect the methane. The beauty of the process lies in this killing of two birds with one stone: whilst producing energy, it also provides an effective method for waste treatment, and its use of organic matter means that it does not affect the atmospheric balance of carbon dioxide.

The collection of methane at waste treatment plants is nothing particularly new but recent advances, such as continued fermentation processes and the discovery of effective catalysts, have made the process more economically viable. Currently, much of the methane produced

Fig. 1. Anaerobic digestion turns glucose into methane and carbon dioxide.

in such plants is burned at the source to avoid its release into the atmosphere—methane is a particularly obnoxious greenhouse gas, trapping up to 27 times more heat than carbon dioxide—yet this is a total waste of such a high-energy resource. Many of these plants are now realising the advantages of using the methane productively and are burning the gas to heat water. More than 30 pilot projects in the USA alone are also using the methane produced in waste treatment plants and landfill sites to produce electricity by means of a fuel cell. More often than not, the energy requirement of the plant is surpassed and they are able to sell the surplus energy to the local electricity board. In 2001, California policy makers allocated US\$10 million to the California Energy Commission for a dairy farm power production programme, and power produced in these installations is eligible for a supplementary payment of 1.5 cents per kilowatt hour. But many believe that methane has the potential to become an even more widely used fuel, particularly in the automotive industry. Indeed, the public investments in the USA are mere drops in the ocean when compared with the billions that car companies, such as General Motors, Ford and Daimler-Chrysler are already investing in alternative fuel cell technology.

It seems like a perfect scenario, yet while politicians and car developers are hopeful about the potential of methane, those with a scientific perspective are expressing severe doubts. Christian Wandrey, Director of the Institute for Biotechnology at the Jülich Research Centre in Germany considers that ‘although there is potential for methane as an energy carrier, this potential is limited.’ Cornell’s Zinder was also sceptical when asked about the potential of methane to become a major energy source, pointing out that

the main problem is still the relatively low price of oil and natural gas.

One of the main drawbacks of the anaerobic system, explained Bernhard Schink of the University of Konstanz in Germany, is that it is ‘comparably slow, as there is little energy available to the organisms,’ and the amount of methane that can be produced is therefore severely limited. Furthermore, methane currently accounts for a very small percentage of the world’s energy resource and there would need to be a massive-scale increase for it to have a significant impact. However, as stated by Schink, ‘Nature has engineered this system very efficiently,’ and he does not think that ‘there is a lot to be done on the basic microbial side’ to improve the process. On the other hand, if engineering improvements are made to significantly enhance the amount of methane produced, and if all waste was treated so as to produce methane and the optimum amount of fuel was collected, then says Schink, ‘there might be a doubling or perhaps even a tripling of its present importance in our society.’ But, according to Wandrey, this is still ‘peanuts’ when compared with the importance of oil and natural gas.

Wandrey also thinks that anaerobic methane production is unlikely to have more than a local impact in industrialised nations as its decentralised means of production in small plants would not be able to compete with the advanced distribution systems of oil and natural gas. ‘It doesn’t make any sense to collect a few

cubic meters of biogas in a village wastewater treatment plant while the Ruhrgas pipeline delivering natural gas from Russia is just a few kilometres away,’ he said. Furthermore, effective methane production from anaerobic digestion requires a constant supply of waste with large amounts of biological material. Drawing from his institute’s experience in building one of the largest anaerobic waste treatment plants in the world, he thinks that this is only suitable in selected scenarios.

The amount of money spent on developing methane as a fuel source does seem to be disproportionate to the scientists’ estimate of its value. Wandrey thus believes that the interest has more of an ideological and political background than an ecological or economic one, particularly in the USA, where he describes their plans for methane development as a ‘bio moon project.’ As the USA accounts for >25% of the world’s energy consumption of oil and natural gas, and recently rejected the Kyoto treaty, they are eager to demonstrate their commitment to addressing environmental problems and, perhaps even more pertinently, are becoming increasingly concerned about their dependency on Middle Eastern oil. Wandrey is equally suspicious of initiatives that support farmers who grow corn to be converted into alternative fuels. He considers it neither ecologically nor economically sound, as the energy required to grow and process the corn is considerably more than that eventually recovered from the fuel. Again, politics

A local power plant—anaerobic digesters in a water treatment plant

plays a role—the main beneficiaries of the Farmer Bill are corn growers in the US heartland who receive massive subsidies from the government. It is perhaps not coincidental that they are also among the Republican administration's most important supporters.

Although the potential of methane does seem to be somewhat overstated, the development of its production and use is nevertheless important. Schink reinforces the fact that 'methane produced in an uncontrolled environment is a problem as it is a greenhouse gas' and goes on to say that, 'every methane molecule that can be produced in a closed system and then burnt to carbon dioxide is of course an

advantage,' especially if energy can be recovered from this reaction. And although Schink and Wandrey do not think that the anaerobic production of methane has the potential to make a large impact in industrialised nations, both suggest that the situation elsewhere is very different. Many less-developed countries do not have the money to import sufficient amounts of fossil fuel to cover their energy needs and efficient systems for energy production and distribution in these nations are few and far between. Such circumstances are an ideal setting for local anaerobic digesters, and the introduction of even a small installation to turn agricultural and human waste into

methane could have an enormous effect on living standards, providing a cheap means for cooking and heating.

Back in the developed world, as oil and natural gas reserves begin to dwindle, the relevance of methane could increase in the future. 'Eventually, the amount [of oil] that could be recovered by drilling will make it a lot more expensive, and at that

The introduction of small anaerobic digesters to locally turn waste into methane could have an enormous effect in developing countries

point, methane will become more economically viable,' Zinder says. The economic viability of methane will increase even further, as the anaerobic method of collection is a cyclic process and not therefore reliant on any kind of methane gas reserve—as long as there is organic matter that can be digested, it will always be possible to produce methane. He thinks that whether political considerations are the motivation or not, the development of alternative fuels is important to reduce the dependence on a single energy source. Certainly, the production of methane from biological sources has ecological advantages compared with fossil fuels and could make an important contribution to solving some of the current environmental problems. 'We can at least provide a clean and efficient energy source and therefore contribute to saving energy,' Schink says.

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