Farming Renewable Energy

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In 1965 the oil company Occidental won concessions to prospect for oil across 5000 km^2 of desert in Libya (blocks 102 and 103). The company discovered approximately 3bn barrels of oil and, at one point, was extracting 800,000 barrels of oil per day (bpd). At this rate of extraction the Occidental field would last for just ten years. During those ten years the sun would radiate 2300 kilowatt hours (kWh) of energy per year onto each square metre of the Libyan desert. The amount of solar energy that fell on blocks 102 and 103 was 31.5bn kWh per day – the equivalent energy provided by 16.5 million bpd or, during the lifetime of the oilfield, the total equivalent energy of 60bn barrels of oil.

This goes some way to show just what an inefficient oil producer nature is. It took hundreds of thousands of years for the many billions of kilowatt hours of the sun's energy to be transformed into a few million barrels of oil. Unfortunately we are consuming that oil in the space of a few decades. At some point in this century the mismatch between production and consumption will become apparent to both the oil producers and energy consumers.

However, while nature struggled to turn solar energy into fuel in an efficient and timely manner, at present, man can do little better. Compared with extracting oil from a well, the cost of collecting solar energy over a wide area is prohibitively high. It costs as little as $3000 to activate (bring into production) a barrel of oil per day, while activating the solar energy equivalent of that barrel of oil can cost as much as $1m. Wind energy fares a little better, but it still can cost over $50,000 to activate the equivalent of a barrel per day of oil in wind energy. On this basis, oil reserves would have to shrink radically before we turned to the large-scale production of energy from renewable sources, and the cost of activating renewable energy would, at first sight, bankrupt the economies of most industrial countries.

Even so, wind energy is proving profitable – in some cases, producing electricity using a wind turbine can cost less than using coal or oil. As well, within a decade, alternatives to silicon crystal based photovoltaic solar collectors will bring down the cost of converting the sun's energy into fuel. Energy farming using second generation solar cells could earn technology vendors over $60m for each pilot sized 1 km^2 energy farm. It is envisaged that there may be as many as ten such, subsidised, farms built around the world that exploit second generation, polymer based, photovoltaic technology. A third generation, nanostructured, photovoltaic technology that uses the sun's energy to split water into oxygen and hydrogen, while currently in an early stage of development, could see commercially viable energy farms coming on stream within two decades.

As power generation using renewable resources involves the gathering of energy over a wide geographic area, rather than a concentrated point such as a wellhead, an agricultural rather than an industrial model should be employed. In this report we examine a new model for the generation of energy – one based on farming rather than extraction.

At A Glance

As renewable energy is gathered over a wide area it is suggested that its production should be based on an agricultural, rather than an industrial, model.

Farmers will find themselves in the same position that oil-producing countries were in during the early part of the last century.

Worldwide adoption of energy farming will have both a political and a geopolitical impact.

The countries most likely to benefit from farmed renewable energy are those in the relatively early stages of transition from an agricultural to an industrial based economy.

Second generation solar farms could be worth $60m each to photovoltaic device developers.

Petrochemical companies should be well placed to exploit the market for third generation solar polymer based devices.

To create a stable market for farmed energy, renewable energy should be competitive at an oil price of $30 per barrel.

This report examines a new model for the generation of energy – one based on farming rather than extraction. It also assesses the impact this model will have on farmers, oil-producing countries and key players in the renewable energy market.

Included in this report are profiles of BP Solar, Nanosolar, Konarka, Proven Energy and Hydrogenics and analysis of the role these companies might play in a farmed energy scenario.

1 Introduction

At some point in history we began taking wood from forests faster than nature could replace it, abandoning a model of energy production based on an agricultural model. Today we are heavily dependent on an industrial model of energy production that is focussed on extraction. During the intervening period we have moved from one natural resource to another: from wood to coal, coal to oil and oil to natural gas. Each fuel has been replaced by, or supplemented with, another that is cheaper, more widely available or more suitable for the needs of the consumer in any particular period. Coal underpinned the industrial revolution, and oil and natural gas enabled us to automate industrial processes during the consumer age. Many people feel we need a new fuel for the Internet age and some believe that hydrogen, produced from renewable sources, is that fuel.

Throughout history each fuel we have used has been replaced by, or supplemented with, another that is cheaper, more widely available or more suitable for the needs of the consumer in any particular period.

Renewable sources of energy, such as the sun and wind, are thinly distributed over wide geographical areas. While fossil fuels are also the product of the sun's energy, time and natural processes have done the work of collecting this energy and concentrating it in a small area. If we wish to power our economies using the energy of the sun and wind we must find a way of gathering that energy. Industrial production – in factories, chemical plants, coalmines or on oilrigs – tends to be concentrated in a small, capital intensive, area. However, agricultural processes are carried out over a wide geographic area and most are, to some degree, based on the collection of the sun's energy, in the form of either foodstuffs or biomass. When looking for a model for the generation of energy from renewable sources it may be better to look to agriculture rather than industry. The adoption of such a model will have significant implications for new entrants and incumbent players within the energy market.

If we wish to use the sun and wind as raw sources of energy then we must find a way of gathering the energy over a wide area. Here an agricultural, rather than an industrial, model of production is more applicable to the production of energy.

Today technologies used to capture renewable energy, particularly solar energy, are prohibitively expensive. However, advances in nanotechnology are leading the way to a new generation of collectors that, while less efficient than conventional silicon crystal devices, are cheaper to produce. Already electricity can be produced using wind turbines for less than the cost of generating it by burning oil or coal. Farmed energy will radically alter the structure and dynamics of the global energy market, representing a threat to established players and an opportunity to new entrants. It will also alter political relationships within, and geopolitical relationships between, supplier and consumer nations.

2 The Consumer Will Remain King

In the wake of the oil supply crises of the 1970s and 1980s, Dr Reinhard Dahlberg drew up an energy strategy based on the production and distribution of hydrogen. The hydrogen would be produced by electrolysis using electricity 'farmed' using solar cells installed over large areas of desert within the solar belt (chiefly the Middle East, North Africa and North America). Dr Dahlberg calculated that 11.5 m^2 of silicon crystal solar cells would be required to generate a supply of hydrogen providing the same amount of energy as a barrel of oil per day.

Dr Reinhard Dahlberg described an energy strategy based on the production and distribution of hydrogen produced using electricity generated by solar cells.

Dr Dahlberg admitted that this concept, labelled 'Large Scale Utilisation of Solar Energy', was a utopian view of future energy supplies. He saw hydrogen as an answer to a wide range of the problems mankind would face in the 21st century. Solar generated hydrogen would halt global warming and ease pressure on conventional energy resources. (It was even suggested waste water generated when hydrogen was consumed would provide a supply of fresh water in drought ridden areas of the world.)

At the time Dr Dahlberg published his report, the silicon based solar cells, while predicted to fall in cost over coming years, were still too expensive to make large-scale solar energy collection viable – even with the oil price projected to exceed $50 per barrel ($100 at 2006 prices). The report, as its title suggested, envisaged hydrogen generation introduced on an industrial scale displacing oil as a primary source of energy in the space of two decades. The industrial model used did not accommodate a scenario whereby hydrogen would be introduced slowly, replacing fossil fuels in selected key areas in the same way oil eroded the market for coal.

In the 1980s large-scale deployment of solar collection technology was uneconomic – even with the oil price projected to exceed $50 per barrel ($100 at 2006 prices).

Today a new generation of solar cells, based on thin film techniques, are coming onto the market. As well, research is being carried out into ways of using nanotechnology to enhance the efficiency and functionality of photovoltaic devices. It is worth, therefore, revisiting the concept of hydrogen generated from solar energy and asking a key question: could hydrogen be produced at a price that would compete in a market where oil falls back to a price of $30 per barrel and could it meet the energy needs of the consumer and industry in the Internet age in ways fossil fuels cannot?

3 Activating Renewable Energy

It costs little more than $3000 to activate a bpd of oil in Saudi Arabia. In the Gulf of Mexico, oil companies are spending up to $10,000 activating a bpd. In New Jersey a small-scale solar energy plant used by Atlantic County to power a waste water plant cost $3.25m and provides the equivalent of 1.03 bpd of oil – an activation cost of $3.16m per bpd. Even if the price of silicon crystal solar cells had fallen to the levels predicted in the 1980s ($15/m² including supporting infrastructure) the hydrogen equivalent of a bpd of oil would cost $31,500 to activate (assuming that a solar plant would have a useful life twice as long as the typical oilfield and that 4200m² of solar cells would generate the hydrogen equivalent of 1 bpd of oil).

It costs little more than $3000 to activate a barrel per day of oil production in Saudi Arabia.

It would cost at least $31,500 to activate the equivalent amount of solar energy even if solar cells only cost $15/m².

To achieve an activation cost of $10,000 a solar cell would have to cost no more than $3/m² or, at spec sheet efficiency of 15%, $0.02/watt. This is several orders of magnitude less than the current price of $4/watt (for the cell alone).

If, however, we look beyond activation costs, the picture looks slightly different. If solar cell arrays could be manufactured for $15/m² (or $0.09/watt) the cells required to generate 1 bpd would require an investment of $63,000. We shall assume the equipment required to convert electrical power into hydrogen from the array would cost $38,000 (in reality this equipment would convert power from a number of arrays).

An oil company may not regard the return on solar power as significant. But a farmer might – especially those working in arid regions.

In this case, an investment of $103,000 would produce the hydrogen equivalent of 365 bpd of oil. If the hydrogen could be brought to the market for the equivalent of $30/barrel, the $103,000 investment would yield $10,900 per annum. An oil company may not regard this as a suitable return on investment, but many farmers would – especially those in dry arid regions.

The situation is similar in the case of wind turbines. A 15 kW turbine costs in the region of $70,000 and produces up to 29,000 kWh per annum if used in a favourable location. To achieve an activation cost of $10,000 for the energy equivalent of 1 bpd of oil, the cost of the turbine would have to fall to £1000. However, if the cost of the mast were reduced to $15,000 it would still generate a return of 5% per annum for the operator (after deducting loan repayments). This assumes the operator could sell energy directly to consumers and not be forced to sell units at a reduced rate to the owner of a power grid.

A medium size 15 kW wind turbine costing under $15,000 would generate a return of 5% per annum for the operator.

4 Why $30 Per Barrel?

The return for the farmer would be even greater if hydrogen could be brought to the market at a barrel of oil equivalent of $50. Advocates of alternative energy, encouraged by the investment community, start to become enthusiastic whenever the oil price strays above $50 per barrel. However, while following long-term trends upwards, oil prices have a habit of falling back sharply during recessions. If the price of a barrel of oil settles at above $60 per barrel, growth in the industrial world will slow or perhaps even come to a stop. There is little point in bringing an alternative fuel to the market at a price consumers in the industrial world cannot afford.

In the long term the price of renewable energy must be less than that of oil – even when oil is cheap. If the industrial world cannot afford oil at $60 per barrel it will not be able to pay $60 per barrel for renewable energy.

Hydrogen has certain advantages over oil – the key one being it does not need refining and is ready to use. However, a barrel of oil is cracked into a range of products including feedstock for the plastics, chemical and pharmaceutical industries as well as heating oil and fuel for the transport sector. Hydrogen may well take market share away from heating oil and benzene, but, in the short to medium term, fossil fuels will still be required to produce plastics, agrochemicals and pharmaceutical products. Under pressure, oil companies could start to regard benzene and heating oil as by-products and dump these on the market at prices that undercut hydrogen.

5 Solar Power – Silicon Crystal Is Not The Answer

5.1 The Price Barrier

Twenty years ago it was thought the price of polycrystalline silicon cells would continue to fall and eventually become cheap enough to make large-scale generation of energy from solar power an economic proposition. It was thought that a form of Moore's law, according to which the power of silicon based microprocessors doubles every 18 months and in so doing drives down the cost of computers, would act on the photovoltaic device market. However, while Moore's law has reduced the cost of IT products it has done so by reducing the amount of silicon required to build a particular device.

Unlike microprocessors the output per dollar of a silicon based photovoltaic device has not fallen significantly since the 1980s. Moore's law is not applicable to solar cells, which cannot double their efficiency every 18 months.

If the efficiency of a solar cell were to double every 18 months from a base of 15% then Moore's law would break down after four years – at the point efficiency exceeded 100%.

While manufacturers are finding it difficult to drive down the cost of polycrystalline cells, a number of companies believe they can use a form of printing or nanotechnology to build polymer based photovoltaic devices. Although, in the medium term, these polymer based devices will only be half as efficient as their polycrystalline equivalents they could be manufactured for a tenth of the cost.

Polymer based photovoltaic devices and nanotechnology should provide a low cost means of capturing solar energy.

Developers of the first generation of polymer based solar collectors are targeting a diverse range of applications, from foldaway collectors that power small electronic devices to construction materials that generate electricity for the occupants of houses. Konarka, one of a number of companies developing plastic based products that turn light into energy, are working on a design for a portable building that generates its own electricity. Another company, Nanosolar, is using nanostructured components to enable it to 'print' the most expensive layers of a solar cell onto a plastic substrate.

A plastic based material that, after being laid out over large areas of land, generated electricity would fit well with the model farmers already use to accelerate the growth of crops. A study showed that it cost under \$1700 to cover 1 km² (0.17 cents per m²) of land with transparent polythene sheet. This price covers both material and labour. However, in the case of polymer based solar cells it would only cover the cost of the substrate. To make the harvesting of electricity feasible the cost of producing a plastic based solar cell would have to be less than \$15/m².

Given the reduced efficiency and the short active life of polymer based photovoltaic material it would be necessary to install solar cell material for \$0.30/m² to compete with the \$10,000 it costs to activate a bpd of offshore oil. Today manufacturers are targeting a price per m² in the tens of dollars and see installation costs pushing the price up over \$100 per m². While this is five times less than polycrystalline based solar collectors, it is too high for large-scale deployments.

It would be necessary to install solar cell material for \$0.30/m² to compete with the \$10,000 it costs to activate a bpd of offshore oil.

5.2 Technical Barriers

In determining the cost of building and operating an energy farm that employs plastic based solar collectors, the durability of the material used has to be taken into consideration. By pushing the expected lifetime of a polycrystalline solar cell to the limit (50 years has been quoted in some cases) energy farms break even. However, it is unlikely that the first generation of plastic based cells would last more than two years in a desert environment. The risk of the material being damaged during storms would have factored into the cost of the farm. The material would most likely be deployed on a rolling basis with recycling of used material to reclaim precious metals – the energy required to do this will also need to be taken into consideration.

The operator of an energy farm employing polymer based solar collectors would need to take account of the reduced durability of the material in desert and semi desert conditions.

As with polycrystalline based cells, some way of removing dust, which causes the efficiency of the cells to fall markedly (up to 75%), will have to be put in place.

From the farmer's point of view, the key difference between deploying plastic based solar cells to harvest energy and polythene to accelerate crop growth would be the cabling of the installation and the risk of injury from the electricity being fed to the hydrogen generation plant.

5.3 Third Generation Polymer Based Cells

Research is being carried out into materials that both collect sunlight and convert water into hydrogen. Here an energy farm would consist of areas of desert covered with a hollow membrane into which water was forced and from which hydrogen was extracted. The key benefit of this technology would be that it did away with the separate electrolysis plant and the cabling of electricity. However, while large-scale commercial production of the polymer based solar cells being developed by Konarka and Nanosolar is between five and seven years away, it could be over two decades before advances in nanotechnology bring third generation hydrogen-producing cells to the market.

Research is being carried out into materials that both collect sunlight and convert water into hydrogen. However, it could be two decades before these devices reach the market.

6 Wind Energy

For farmers outside of the solar belt – in northern Europe for example – where the amount of available solar energy available is low, wind turbines can be used to generate electricity. This electricity could be used to generate hydrogen, although, as most farmers are located close to consumers, it is usually more economical to feed power into the electricity supply grid. Here again the cost of equipment is a key factor. Unless the farmer has access to large amounts of capital, and can overcome planning restrictions, they will be unable to build the large-scale wind turbines needed to generate electrical energy most efficiently.

For farmers outside the solar belt, where levels of solar radiation are low, wind turbines can be used to generate electricity.

An alternative to large-scale wind turbines is a wind farm built using medium sized turbines. To make this economically viable the cost of a medium size turbine would need to fall from $70,000 to $15,000. Turbine vendors may be able to accommodate such levels of discounting as economies of scale start to impact on the industry and if a significant number of turbines are being located on one site. Sited in a favourable location, 25 wind turbines rated at 15 kW could produce the equivalent energy of 1 bpd of oil. The activation cost of that barrel per day would be $375,000. At $30 per barrel the farmer would derive total revenue over the 20-year life of the wind farm of $210,000 (if the wind farm produced crude oil). However, as the farmer would be selling electricity to consumers at 10 cents/kW, the farm would have a turnover of $1.45m over 20 years or $72,500 per annum. This is an acceptable rate of return considering that the wind farm would break even after eight years (after considering maintenance and operating costs). As well, the farmer could continue to use the land on which the wind farm was located to produce crops.

The key barrier to growth of a farmed wind market is the current restrictions on farmers selling energy directly to the consumer. In Europe especially, individuals generating their own power are required to sell excess power to the grid operators, often for less than the retail price of the energy they are generating.

A barrier to growth will be the inability of the farmer to sell power directly to the consumer.

7 Market Drivers

7.1 Seeking A New Model For Energy Production

Energy production and distribution is dominated by a handful of major corporations and government agencies – leaving little room for new players or entrepreneurs. As reserves of fossil fuels become scarce, both governments and energy providers are becoming increasingly protective over their markets, tightening their grip over new reserves of fossil fuels, refining operations, distribution channels and power grids. This raises still higher the barriers to entry for new players. The only way for the next generation (NextGen) energy company to break into the market is to disrupt the model employed by existing players.

The only way for the next generation energy company to break into the market is to disrupt the model employed by existing players. Farmed renewable energy could be an important component within a new energy production model.

One new model suggested is based on an intelligent grid of distributed power generation – an Internet of energy that will radically shift the balance of power away from large energy companies and government agencies. The new model would favour new entrepreneurial providers – just as the Internet does in the information market. This new model has been closely associated with alternative energy, as this is one of the few sources of energy available to the NextGen provider. After all, it is unlikely NextGen providers would be able to secure supplies of natural gas or oil at a reasonable price, and government agencies are unlikely to approve small-scale nuclear power generation even if private finance is available.

A number of entrepreneurs active in the renewable energy technology market, especially those focussed on photovoltaics, have emerged from the semiconductor and Internet equipment sector. In fact many are based in California's Silicon Valley. They are acutely aware of the impact a new model can have on an established market dominated by monopolistic players. They are also adept at attracting venture capital backing for business plans based on disruptive models.

Many entrepreneurs in the renewable energy technology market, especially those focussed on photovoltaic devices, have emerged from the semiconductor and Internet equipment sector.

With only renewable energy to power their new model of energy production, the NextGen power company has to somehow store and distribute energy that, as it is dependent on the elements, is only available on an intermittent basis. Here hydrogen is expected to play a key role as an energy store. The hydrogen economy, which is being promoted as the energy model of the future, is a relatively minor departure from the hydrocarbon model. It still involves the production of a fuel that is used to power vehicles, generate electricity or heat homes. Despite the radical posturing of 'Hydrogen Economy' advocates, the underlying principle is essentially an 'As Is' scenario within which most incumbent players could continue to operate.

The hydrogen economy is essentially an 'As Is' scenario that, in theory, incumbent players in the energy market would find relatively easy to work within.

7.2 Other, Short-Term, Market Drivers

In the short term, there will be a range of other factors that will drive the market for farmed energy. In the longer term these drivers will become less important, as they are based on forms of financing and consumer behaviour that will not scale as the market grows.

7.2.1 Green Consumers

A growing number of energy consumers are making the choice to use renewable forms of energy as a lifestyle statement or, in some cases, to offset pollution caused by other activities. There are a limited number of consumers and companies who will opt for 'green' energy use, and the majority of energy users will either be disinclined or unable to pay the premium for energy farmed from renewable sources. This remaining group will not start using farmed energy until it is competitively priced against energy produced from fossil fuels or offers greater flexibility of use.

> Apart from early adopters with 'green' lifestyles, most consumers will not start using farmed energy until it is competitive with energy produced from fossil fuels in terms of price and flexibility of use.

7.2.2 Energy Security

The US government will regard a bpd of oil equivalent of hydrogen produced by wind energy on a farm in North Dakota as more secure than a bpd of real oil extracted from a well in the Middle East. There is some incentive to fund secure energy sources and offset this spending by reducing defence expenditure. Other countries wishing to develop secure supplies of energy are, and will be for some time, in a similar position. However, as the amount of farmed energy grows, the incentive to subsidise it will diminish. As well, if a large amount of farmed energy is produced in countries within the solar belt using technology and equipment that is owned and operated by US and European companies it may be necessary to maintain defence expenditure to protect these assets.

> Today there is a security premium, paid in the form of grants and subsidies, for renewable energy produced domestically. This premium will not apply to energy produced in some countries within the solar belt.

7.2.3 The Climate Change Lobby

Today a key driver for the farmed energy market is the realisation that continued use of fossil fuel is contributing to climate change. Energy derived from renewable sources is being subsidised by a tax on energy generation and other activities that emit carbon (the carbon tax). If fossil fuel use declines, and processes such as carbon sequestration become commonplace, then the amount of tax available to subsidise renewable energy projects will fall. At some point, investment in farmed energy will have to be based solely on whether the fuel or power produced is competitive on the world energy market.

> Today energy derived from renewable sources is being subsidised by a tax on energy generation and other activities that emit carbon. This cannot be considered a long-term market driver.

7.2.4 Hydrogen Penetration

Oil producers will be reluctant to develop agricultural based energy production programmes, being, instead, content to manage a lucrative decline in fossil fuel reserves. They may, however, be encouraged to take action when they see hydrogen use around the world increasing. A hydrogen filling station in Saudi Arabia would probably find few takers. However, the impact of this technology on strategists within the Saudi government's energy department would be profound.

> As an increasing number of hydrogen refuelling stations appear around the world, energy producers will devote more time, effort and money to researching ways of producing hydrogen.

8 Farmers Doing It For Themselves

In industrial countries a number of farmers are, to a degree, already engaged in the renewable energy market. Some produce biomass crops which are burnt, as alternatives to coal, oil or gas, to produce electricity. Others lease out some of their land to wind turbine operators. However, this is a relatively low level of engagement which puts them in roughly the same position in the energy market as that in which oil producers found themselves in the early part of the last century. If farmers merely rent their land to power operators, they will face a long hard battle to secure a fair share of energy revenues as the market for farmed energy grows.

In industrial countries farmers are already engaged, to some degree, in the renewable energy market. Some produce biomass crops which are burnt as alternatives to coal, oil or gas, to produce electricity.

An alternative strategy for the agricultural sector would be to organise a farmed energy market board that oversaw all aspects of energy harvested from natural sources. This body would be able to arrange finance and work closely with equipment manufacturers and technology developers. More importantly, such a body would be able to secure favourable terms for energy produced by farmers – including the right to sell energy directly to consumers.

The agricultural sector is itself a major user of oil, not just as a fuel but also as a foundation for agrochemicals used in modern farming. A farmed energy body could work to make agriculture self-sufficient in energy, using oil-producing biomass crops as a feedstock for a range of chemicals used by farmers.

This does not mean that farmers should ignore consumers outside the agricultural sector. The 'Hydrogen Economy' opens up a range of new markets that individual farmers could address independently. Recent pilot installations using hydrogen generators powered by wind turbines could lead to farmers providing liquid gas to local filling stations that in turn retail fuel directly to the drivers of hydrogen powered vehicles.

Most governments in the industrial world have to provide some degree of aid to farmers who cannot produce food at world prices. Some farmers are encouraged to leave land fallow for a period or to produce crops that can be used as fuel. Helping the agricultural sector develop an integrated approach to farmed energy may represent a more efficient use of government funds than merely subsidising the production of ethanol or bio-diesel.

Developing an integrated approach to farmed energy may represent a more efficient use of government funds than subsidising the production of ethanol or bio-diesel.

9 Political And Economic Impact

9.1 The Impact On Oil-Producing Countries

At some point in the future, Saudi Arabia may start developing the 120,450 km² of solar farms needed to produce the hydrogen equivalent of 15 million bpd of oil. In the short to medium term, while the cost of activating a bpd of oil is only $3000, it will not move into energy farms in a big way. In the longer term – between 20 and 30 years – the country's oil reserves will begin to run out and activation costs will begin to rise. In the meantime the country may start diverting resources into solar farms. Finance will not be a problem as Saudi Arabia's GDP will continue to rise as world oil reserves diminish.

At some point in the future, Saudi Arabia may start developing the 120,450 km² of solar energy farms needed to produce the hydrogen equivalent of 15 million bpd of oil.

Like other oil-producing countries Saudi Arabia is already marketing energy to the rest of the world. A gradual transformation to supplying hydrogen rather than oil would have little impact on its relations with other countries. Internally the transformation could be quite marked. When a country begins exporting oil, it sees a decline in traditional areas of the economy, often accompanied by a movement of population away from rural areas and into large cities. For Saudi Arabia this process has led to a certain amount of social tension – especially as it has been accompanied by a rising birthrate that has lowered the average age of its population. On the plus side, the oil boom and the wealth it has created has diffused regional tensions within the country itself.

Solar farming would necessitate a reversal of the migration of young people to cities. This would not necessarily ease social stress, and could increase it as entrepreneurs within the country's farming sector become economically empowered.

Social stress may increase as the farming sector becomes economically empowered.

9.2 Impact On Non Oil-Producing Countries

For a number of countries the discovery of oil within their borders has been a mixed blessing – tending to inflate the value of the currency and depress all non-energy producing sectors of the economy. This often has a devastating political and economic impact on countries whose economies have, up to the point where oil was discovered, been based on agriculture. Farming energy could therefore provide a relatively painless route into the energy market for countries whose economies are predominantly agricultural.

The discovery of oil usually has a disruptive and negative impact on a country's economy. Farmed energy may provide a relatively painless route into the energy market in agricultural regions.

From an economic viewpoint, energy would appear to be nothing more than a high value crop that could be exported to developed countries or used to support local industries. Energy may enrich rural communities at the expense of city dwellers who may find they are paying more for food as land is turned over to energy production. This, however, would not be a problem if the land used were arid or semi-desert. Unlike striking oil, which has a sudden and immediate impact on a country's economy, the transition to energy farming would be gradual and simpler for governments to cope with. Earnings from farmed energy should, in theory, be widely distributed to a large number of landowners and operators rather than, as is the case with oil revenues, channelled though one organisation, government department or, in some cases, one person's bank account.

Where countries such as Sudan and Niger would be disadvantaged is in their lack of access to the energy market and resources to develop a renewable energy generation infrastructure. Companies and investors in the developed world would most likely provide these resources. This would put emerging energy producers in the same position as that in which oil producers found themselves when they started granting exploration rights to western oil companies. It will take time for renewable energy suppliers to gain the necessary strength and influence to exact favourable terms regarding rent for land and a share of energy revenue. Over time these countries may also develop a strong industrial sector based around access to low-cost farmer energy.

It will take time for renewable energy suppliers to gain the necessary strength and influence to exact favourable terms regarding rent for land and share of energy revenue.

9.3 Countries In The Middle

There are countries that, while currently having no access to the energy market, do have an established industrial base that would immediately become a consumer of renewable energy and also provide investment for farmed energy projects. China and India both fall into this category, with the latter pursuing an aggressive wind and solar energy strategy to reduce its dependence on imported oil and gas. Both countries have a mixed economy with a large number of people still employed in the agricultural sector and where migration from the countryside to the city is a relatively recent trend.

Neither China nor India would need to look outside their borders to find consumers of energy – meaning they would not necessarily need to convert all the electricity they produced into hydrogen.

Neither China nor India would need to look outside their borders to find consumers of energy, meaning they would not necessarily need to convert all the electricity they produced into hydrogen. Instead electricity would be consumed by industries that earned revenue by exporting manufactured goods to the west.

9.4 Geopolitical Impact

In the short to medium term (10 to 20 years) China and India will benefit from energy harvested from wind or solar farms. In the long term (beyond 25 years) countries that previously had no industrial base will play host to companies that use access to renewable energy to gain a competitive edge over established manufacturers and service companies in colder parts of the world. This is potentially a long-term threat to the industrial world that will see wealth migrate to countries within the solar belt. The problem will start to become particularly acute when new sources of oil and gas become hard to find and activation costs climb.

In the long term, countries that previously had no industrial base will play host to companies that use access to renewable energy to gain a competitive edge over companies in colder parts of the world.

At the root of the problem will be the key difference between fossil fuels and renewable energy sources. The former are transported and then turned into energy while the latter are harvested as energy and then turned into a fuel before being transported. It is cheaper to use renewable energy as close to the point of collection as possible, whereas the marginal cost of transporting a barrel of crude oil to a refinery in another country is not great.

In some respects the growing market for liquid natural gas is encouraging the growth of an infrastructure that could be used to produce, transport and distribute hydrogen generated from renewable sources. One of the attractions of the hydrogen economy is that, to the traditional energy producer, it looks like an 'As Is' scenario that they could accommodate and generate revenue from. However, it is more likely global industries start to migrate towards new sources of cheap power and the amount of energy shipped from one country to another will fall.

Multinational industries will migrate towards new sources of cheap power, and the amount of energy shipped from one country to another will fall.

10 Market Inhibitors

10.1 Competition Begins At Home

Conservation is the curse of the energy market. If the cost of a barrel of oil rises too quickly, or too high, consumers cut back on energy use – as they did in response to the 1970s/80s price rises. Presently there is a lot of slack in the market that could be taken up by reducing plastic packaging, cutting back on personal travel and increasing the efficiency of automobiles, domestic appliances and industrial processes. Not only will the energy farmer find their market squeezed by conservation but also they will have to compete with millions of potential providers who have access to the same technology used to generate energy on farms. While the energy farmer will gain from advances in wind turbine and solar collector technology their customers, who will be using the same technology to heat and light their homes, will require less power from third party suppliers. Some consumers may generate so much energy that they dump the excess power onto the grid.

Not only will conservation programmes limit the market for harvested renewable energy but also the energy farmer will be competing with millions of potential providers who have access to the same technology that is used to generate power on energy farms.

Solar cell vendors are developing technology that can be built into building materials and, as these materials would be deployed close to the point of energy consumption, will command a higher price per square metre than a material sold to energy farmers. The emergence of materials that turn sunlight into hydrogen could impact heavily on the demand for liquid gas for domestic use.

Increased use of wind technology will drive down the cost of turbines to the level where small-scale wind farms are cost effective. However, this same technology will also be available to domestic users and will, again, cap domestic demand.

In any scenario where the domestic user is generating their own power, there is the risk that the consumer cuts back on total energy use as they become increasingly unwilling to buy energy from a third party supplier. The consumer will also try to limit use in an attempt to generate income by selling energy back to the grid.

Domestic users generating their own power will cut back on their energy use and limit the energy they buy from a third party supplier.

10.2 Land Use

If there is a global energy crisis the cost of food production will rise and, if artificial fertilisers that are derived from fossil fuels become expensive, the amount of land required to grow crops will increase. This could limit the amount of land farmers can dedicate to energy production. This will not impact on energy farms in dry arid regions or on the use of wind turbines but will decrease the land available for producing energy from biomass. It could also limit the growth of solar energy farms in areas of southern Europe and some parts of the US.

An energy crisis would drive up the cost of fertilisers and cut output of food per acre – in some cases limiting the land available for energy generation.

10.3 Environmental Considerations

The idea that generating energy from renewable resources is a totally 'green' activity is false. Producing semiconductors requires a significant amount of energy that, in the early stage of any large deployment, would come from the burning of fossil fuels. Some chemicals used in the manufacture of photovoltaic cells are extremely toxic. Less energy is used during the manufacture of polymer-based photovoltaic cells but the finished product contains heavy metals. If the material is to be spread over large areas of farmland, there will have to be some way of recycling it when the substrate begins to degrade.

If it expands to its full potential then farmed solar energy would involve the moving of significant amounts of the sun's energy from one part of the globe to another. Although the impact of this energy transfer is likely to be slight it should be taken into consideration.

Worldwide energy farming would move natural energy from one part of the globe to another.

11 Market Growth

Advocates of the 'Hydrogen Economy' seem to suggest that the transition from carbon based fuels to hydrogen should happen overnight. The sheer scale of the infrastructure that would have to be put in place to support this transition often convinces sceptics that the transition will never happen. In reality, the transition is already underway – but will not be completed overnight. After all when Colonel Drake discovered oil in Pennsylvania in 1859 no-one suggested he was wasting his time because the network of refineries, pipelines, interstate highways and millions of motorcars required to turn oil production into a highly profitable industry was not in place. On the other hand, the belief that farmed energy will take decades to make an impact is probably equally misplaced.

Today the renewable energy market is where the oil market was when John D Rockefeller became involved in refining and the price of oil was only a fraction of the cost of the barrel it was transported in.

Today the renewable energy market is where the oil market was when John D Rockefeller first became involved in refining and the price of oil was only a fraction of the cost of the barrel it was transported in. With the exception of a number of wind energy installations, most renewable energy projects are only viable because they are supported by government funding, carbon offsets or by organisations wishing to project a 'green' image. In the longer term, as renewable energy becomes more widely used, these forms of support will become unwieldy. Then large-scale renewable energy generation will have to be profitable in its own right.

11.1 Solar Energy

Farmed solar energy is likely to develop in three distinct phases. The current generation involves, in a majority of installations, the use of polycrystalline photovoltaic arrays to collect solar energy. In some cases, parabolic troughs are employed rather than photovoltaic devices as in the SEGS solar fields in California's Mojave Desert, which supply 350 MW to 500,000 residents, replacing an annual consumption of 2 million barrels of oil. First generation large-scale solar energy installations still look very much like convention power stations, and the cost of the technology employed is a barrier to large deployments that more closely adhere to the farming model. Due to high activation costs, and the cost per megawatt of the energy produced, subsidies will play a key role in the financing and operation of first generation solar energy.

Farmed solar energy is likely to develop in three distinct phases, the timing of which will be determined by the point at which new photovoltaic technology is brought to the market.

Companies wishing to project an environmentally friendly image have built and are operating their own first generation solar energy facilities to offset carbon emissions from other parts of their operations. Oil companies are also investing in first generation projects, with BP setting up a division, BP Solar, dedicated to handling such projects.

Interest in first generation solar, heightened by a steady and sustained rise in the price of oil and gas, has seen demand for polycrystalline photovoltaic cells rise and the cost per watt for solar technology stick stubbornly near the $4 mark. This interest, in the form of investment and research, has spilled over into a family of alternative photovoltaic devices based on polymers and thin film technology. These devices, which can be printed onto a continuous roll of material, promise to reduce the cost of photovoltaic devices by over one-third. Within five to seven years, when polymer based devices become commercially available, the solar power generation market will move into its second generation as a number of operators attempt to build large-scale solar collection farms using the new technology.

When polymer based photovoltaic devices become commercially available, operators will attempt to build large-scale solar collection farms.

The cost of activating and producing second generation solar energy will be too high to compete with energy produced from oil or gas, the reserves of which will be sufficient to meet world demand well into the next decade. However, as the cost of polymer based photovoltaic material falls faster than the cost of crystalline silicon equivalents, an increasing number of organisations will be tempted to experiment with medium-scale deployments – perhaps up to 1 km^2 effective area of solar cell material. The cost of such a deployment would exceed $100m at today's prices and produce the equivalent of 125 bpd of oil in renewable energy. Second generation solar power farming will shift the model of energy generation away from one based on industrial production. The new agricultural model will require large amounts of land and it is unlikely that third party organisations, for example retailers or manufacturers, will build their own second-generation solar energy farms. Instead these organisations will be content to buy megawatts of renewable energy from solar farm operators and leave the actual production to others. From the farmer's perspective, second generation solar will still be too expensive and complex to deploy and they will merely rent land to energy companies.

The cost of activating and producing energy using second-generation solar energy will be too high to compete with energy produced from oil or gas. A typical 1 km^2 trial site would cost in the region of $100m.

Investment by government agencies and energy companies in second generation solar will benefit the photovoltaic device industry. A relatively small photovoltaic technology developer may not generate much profit from manufacturing, or licensing the production of, 1 km^2 of polymer based photovoltaic material. However, the interest, funding and associated research such a project would attract will accerate the growth of the company. As well, experience gained could be applied to other areas of the business such as materials for domestic solar collection and energy-generating building materials.

Investment and experience photovoltaic device vendors gain through involvement in second generation solar projects will accelerate the development third generation solar devices. Research has already begun into ways of extracting hydrogen from water within a membrane that is exposed to sunlight.

Experience gained through involvement in second-generation solar projects will accelerate development of third generation solar cell technology.

This technology that would enable the nanostructured components that split water into hydrogen and oxygen to self-assemble at a molecular level is still in the very early stages of development. If mastered, the technique could be used to produce a material that is relatively simple to deploy and produces hydrogen without the intermediate stage of electricity generation.

Third generation solar energy technology is two decades away but will arrive as the activation costs of declining reserves of oil and gas begin to rise sharply. The use of hydrogen produced using other forms of renewable energy (see wind energy below) will have created a market for its use as a fuel. Oil-producing countries will be looking for alternative energy sources, and petrochemical companies will discover there is synergy between the production of polymer based photovoltaic material, hydrogen production and their existing downstream operations. Many of these companies will purchase specialised material and semiconductor companies with skill sets and patents applicable to the use of nanotechnology for solar energy capture.

Petrochemical companies will discover there is synergy between the production of polymer based photovoltaic material, hydrogen production and their existing operations.

The arrival of third generation solar energy technology will heighten the strategic role of the farmer in the energy production business. It will also increase the importance of the agricultural sector both globally and within individual economies.

Advances, or lack of advances, in material technology, would heavily influence the development of the above scenario. The phased nature of the market growth would provide a roller coaster ride for technology developers, energy companies and investors. There would be periods of boom and bust that characterise other areas of the semiconductor market.

11.2 Wind Energy

The growth path of the wind energy market will be less erratic than that of the large-scale solar energy market. All the key elements are already in place to produce energy from wind either in the form of electricity or as hydrogen. All that remains for the generators to do is increase market penetration and drive down costs.

Wind energy will follow less of a boom-and-bust growth path than farmed solar energy.

Today one of the key barriers to the uptake of wind energy is the issue of environmental impact and difficulty in obtaining planning approval for large-scale turbines. Over time the public will become more accustomed to seeing wind turbines in the countryside and resistance will ease. Increased use of low cost turbines for domestic energy generation will also lessen the resistance to wind power in general.

A pilot installation that uses wind energy to generate hydrogen is currently being built in Dakota and it is likely similar plants will be deployed in other rural areas around the world.

In the meantime the farmer could build a wind farm using medium sized turbines. This would have less visual impact on the surrounding countryside. The cost of such turbines would have to be markedly reduced to make this economic. Again, the consumer's increasing use of wind turbines for domestic applications should drive down the cost of the technology.

For the farmer, an interesting application of wind energy could be the production of hydrogen, either for use as a store of energy or to sell locally to owners of hydrogen powered vehicles and equipment. A pilot installation that uses wind energy to generate hydrogen is currently being built in Dakota and it is likely similar plants will be deployed in other rural areas around the world. For the individual farmer, success in this area will depend on whether the agricultural sector can force governments to liberalise energy markets and provide energy farmers with direct access to consumers.

It is unlikely that farmers outside the solar belt will choose solar energy over wind as a means of harvesting energy – in the main because they can continue to grow crops or raise cattle on the land where turbines are sited whereas solar collectors displace traditional farming activities.

Energy generation offers the farmer the opportunity to occupy a strategic position within a country's economy – if, that is, the agricultural sector can develop a co-ordinated renewable energy strategy.

If the agricultural sector develops a coherent and integrated renewable energy policy and can produce electricity and hydrogen at competitive prices, wind energy should provide the farmer with a steadily expanding business.

11.3 The End Of Funding

As both solar and wind energy based energy farming reach maturity the industry will achieve a scale where subsidy and government funding are no longer a viable option. There may be an argument for continuing funding of farmed energy produced domestically on the basis that it is from a secure source. However, this may drive up the cost of domestically produced energy to an uneconomic level. Instead governments of industrial countries may need to offer support to companies that are securing sources of renewable energies in the developed world.

As both solar and wind energy based energy farming reach maturity the industry will achieve a scale where subsidy and government funding are no longer a viable option.

The steady expansion of agricultural style production of energy should also enable the renewable energy industry to develop at a steady pace, reducing the need for governments to provide large injections of capital to fund new infrastructure.

12 Conclusions

The extraction of fossil fuel is usually concentrated in a small geographical area and therefore closely resembles other forms of industrial production. However, large areas of land are required to capture thinly dispersed sources of renewable energy – 120,000 km^2 of Saudi Arabian desert would be needed to collect the equivalent of the country's oil output in solar energy. Working such a large area of land is a process akin to farming. It is suggested, therefore, that an agricultural, rather than industrial, model of production is applied to the generation of energy from renewable sources.

As renewable energy is gathered over a wide area it is suggested that its production is based on an agricultural, rather than an industrial, model.

Some farmers are already using their land to 'grow' energy in the form of biomass that is then converted into fuel. While producing biomass requires very little equipment, a significant investment in technology is needed to harvest solar or wind energy. As returns on investment are lower in the agricultural sector than in the industrial sector, generating energy from renewable sources would be more attractive for a farmer than for an oil or gas company.

Some farmers are already involved in the renewable energy market and are growing biomass for fuel operators.

Wind energy generation is already proving a practical business proposition for farmers who rent their land to turbine operators. However, if farmers are to become engaged in the energy generation business they must be able to either market energy directly to the consumer or collectively create an entity that deals with all aspects of agricultural energy production and distribution. The long-term aim of such a strategy would be to make the agricultural sector self-sufficient in energy and to 'crack' oil produced from natural sources such as oilseed rape into products that can then be used by farmers to enhance crop production and to power machinery.

Farmers rent land to wind farm operators but there are ways they could become more engaged in the energy market.

Farmers who use their land to produce energy will be helping to create a new model for energy production and supply. These farmers will find themselves in the same kind of position that oil-producing countries were in during the early part of the last century. They will need to ensure they earn a fair share of the profits made from downstream operations within the energy market.

Farmers will find themselves in a similar position to the one oil-producing countries were in during the early part of the last century.

Farmers who produce energy from natural sources will benefit from new low cost technology developed to harvest solar and wind energy. However, this same technology will also be used by consumers to generate their own energy and may depress prices of both fuel and electricity.

Technology that reduces the cost of producing renewables may have a neutral impact on the energy farmer.

A worldwide shift towards energy farming will impact on politics within energy-producing countries as the influence of the agricultural sector grows and land ownership and control becomes an issue. It will also have a geopolitical impact as countries with predominantly rural economies engage with the global energy market. In the longer term, the industrial world will see a number of key energy dependent industries relocate to the solar belt to take advantage of low cost electricity.

Worldwide adoption of energy farming will have both a political and a geopolitical impact.

For some countries, new to the energy market, energy farming could contribute to stability as, unlike oil revenues, earnings from farmed energy will be more widely distributed throughout an economy.

Energy farming could contribute to economic and political stability.

The countries most likely to benefit from farmed renewable energy are those, such as China and India, that are in the relatively early stages of transition from agricultural to industrial based economies. These are also the countries most eager to find sources of energy that reduce their dependence on imported oil. Present oil-producing countries may be deterred from entering the renewable energy market by the high cost of activating renewable energy compared to the cost of activating a barrel per day of oil.

The countries most likely to benefit from farmed renewable energy are those in the relatively early stages of transition from agricultural to industrial based economies.

Its dependence on semiconductor technology will cause the farmed solar energy market to follow a boom-and-bust growth path similar to that of the IT sector. It is unlikely that the cost of silicon crystal based photovoltaic collectors will fall to the level where their use as a basis for large-scale harvesting of solar energy is economic. Within a decade, advances in nanotechnology could reduce the cost of non-organic solar devices and tempt operators to experiment with medium-scale (1 km^2) solar farms. In the longer term, materials that, when exposed to solar energy, convert water into hydrogen could make energy farms a practical and economic proposition.

Its dependence on semiconductor technology will cause the farmed solar energy market to follow the same boom-and-bust type of growth path as the IT sector.

Trial sites of up to 1 km^2 would be worth \$60m each to second generation solar technology developers although the profits from such projects will be less than those earned by supplying devices for consumer based energy applications.

Second generation solar farms could be worth \$60m each to photovoltaic device developers.

Companies with interests in both petrochemicals and renewable energy generation will be well placed to exploit the market for polymer based photovoltaic devices and nanostructured solar energy collectors.

Petrochemical companies will be well placed to exploit the market for third generation solar devices.

Wind energy, captured using traditional technology, will follow a steadier growth path, with little impact from technological advances. As artificial barriers placed between the wind farm operator and the energy consumer are eroded, the agricultural sector will be able to convert wind power into a range of products. These products will be retailed to consumers, sold wholesale on the energy market or used within the agricultural sector.

Farming wind energy will become practical and economic when farmers are able to sell energy directly to the consumer.

To avoid prolonged boom-and-bust cycles, energy produced using renewable sources must be priced competitively against fossil fuels and, from the consumer's point of view, must provide a better fit with their lifestyle than oil or gas. Renewable energy should be competitive at an oil price of \$30 per barrel of oil equivalent. Consumer posturing and government grants, which currently underpin the market for renewable energy, will not scale to support an entire energy infrastructure. In two decades the farmed energy market should have grown to the point where subsidies and government funding are no longer required.

To create a stable market for farmed energy, renewable energy should be competitive at an oil price of \$30 per barrel of oil equivalent.

Vendor Profiles

BP Solar

BP, the UK based oil company, set up its solar energy division 30 years ago and has recently branded it as an autonomous unit. BP Solar plays a key part in the company's 'Beyond Petroleum' strategy whereby the oil producer claims to be preparing for the day when reserves and consumption of oil will be insufficient to support its current business model.

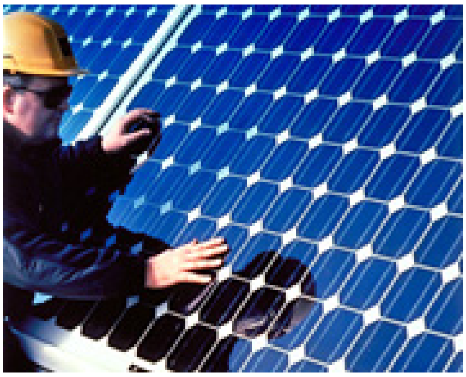
BP Solar has 2000 employees and a strong research team that frequently contribute to the debate on the feasibility of generating renewable energy using sunlight and the role of photovoltaic devices in the process. It also works with the Fraunhofer Institute (Germany) and the Northwestern University (US). It has manufacturing facilities in the US, Spain, India and Australia.

The company is heavily committed to the use of polycrystalline silicon solar cells and the development of new silicon sources and alternative wafer fabrication techniques. It is heavily involved in a number of projects around the world that use large areas of solar cells to generate electricity. BP Solar feels that improvements in device efficiency could offset rising material costs. However, most of these projects require a significant amount of government support.

BP Solar sees the world solar market growing by approximately 30% annually over the next five years and believes that, while this growth will be driven to some degree by improvements in materials and technology, market introduction programmes and government incentives will also play a key role. The company also sees the grid connected sector replacing the off-grid sector as a driver for solar energy generation, with more than 75% of global demand being grid-connected and Japan and Germany accounting for two-thirds of the global market.

BP Solar At A Glance

BP Solar is a key part of the UK oil company's 'Beyond Petroleum' strategy. It has 2000 employees and has a strong presence in the large-scale solar energy generation sector.



Polycrystalline silicon based photovoltaic cells for medium-scale solar energy applications

Analysis

Having one foot firmly in the oil production and petrochemicals market, BP Solar should be well placed to exploit any innovations in polymer based photovoltaic technology that reduce the cost of solar cells. As well, the company's experience in, and penetration of, the market for large-scale solar energy generation plants means it is well positioned to exploit any opportunities that arise in the farmed energy market.

However, by setting up manufacturing units BP Solar is, to a degree, committed to crystalline silicon devices and this may, as happened with early adopters in the semiconductor market, cause it to lose ground if there is a sudden shift towards a radically new technology. A rapid growth of farmed energy based on an agricultural rather than an industrial model could wrong-foot a company deeply entrenched in the industrial sector. However, here BP, albeit in a completely different part of the company, already has significant experience in supplying products to the agricultural sector.

Hydrogenics

Hydrogenics produce a range of fuel cell power modules, hydrogen generation systems and fuel cell test stands. The company sells to the industrial hydrogen market and supports early-adopter demonstration projects requiring fuel cell power modules and hydrogen refuelling infrastructure.

The company is based in Mississauga, Ontario and has operating units in North America, Europe and Asia.

Recently it was awarded a contract by Basin Electric Power Cooperative, of Bismarck, Nevada, to supply an electrolyser based hydrogen refuelling station for installation in Minot, North Dakota. The station will be one of the first US-based hydrogen fuelling stations to use electricity from a wind power resource to produce hydrogen from water.

The hydrogen produced will be used to refuel hydrogen powered vehicles, demonstrating a linkage between wind power and vehicle refuelling. The company claim that the key challenge of this project is to cope with the intermittency and varying outputs of wind power. On the other hand, turning wind power into hydrogen could provide the wind farm operator with an alternative route into the energy market – one independent of a grid operator.

Hydrogenics also supply hydrogen powered vehicles that can be used in demonstration programmes.

Hydrogenics At A Glance

Ontario based supplier of a complete range of hydrogen generating and distribution technology. The company has recently become involved in a project set up to determine the feasibility of using wind energy to produce hydrogen.

www.hydrogenics.com

Hydrogen distribution system for transport applications

Analysis

The choice of North Dakota, where agriculture plays a key role in the state's economy, as a location for a combined wind energy and hydrogen generation project is interesting. It could point the way to the future of farmed energy in countries located outside the solar belt. Wind energy itself is proving one of the most efficient and cost effective ways of harvesting renewable energy, and successes in turning some of this energy into fuel would provide impetus for the hydrogen market.

Hydrogenics is well placed to take advantage of any increase in the take up of hydrogen as a fuel. However, in the longer term the cost of equipment will need to fall before hydrogen generation becomes an economic proposition. Here there is the classic chicken and egg problem, with potential cost reductions coming from economies of scale and economies of scale only being achievable when uptake increases. Wider use of Hydrogenics equipment, as hydrogen generation equipment for domestic use for example, would provide a mass market and resultant economies of scale.

Proven Energy

Proven Energy is a privately owned company based in Stewarton, Scotland. It was formed as a mechanical, electrical and control engineering company and began manufacturing and installing wind turbines and solar photovoltaic panels in 1991. The company manufactures a range of small wind turbines up to 15 kW and provides consultancy, design, resource and site assessment services for small renewable systems.

A large number of Proven Energy sales of turbines to residential users are part funded by 'Clear Sky Grants' whereby the government refunds part of the cost of installation.

Recently Proven has started targeting the agricultural sector with its medium size turbines. The company claims these turbines can, depending on the local wind conditions, provide the power requirements of six typical three-bed houses. With a number of turbines a farmer could, in theory, market power to residents of nearby housing complexes.

The company also markets turbines internationally and has sold a system to Aramco in Saudi Arabia.

Proven At A Glance

The company began manufacturing renewable energy generating equipment in 1991. Based in Scotland it has recently identified the European agricultural sector as a potential market for its medium size wind turbines.

www.provenenergy.co.uk

Proven Energy's 15 kW turbine

Analysis

In theory a farmer could use 25 Proven Energy 15 kW turbines to build a medium size wind farm. They could then sell the electricity generated to the local community or use it to process biomass. While medium size turbines are not as efficient as large-scale turbines they have less environmental impact and are more likely to gain planning approval. As well, installation is relatively simple.

At present there are a couple of hurdles to overcome before a medium size wind farm becomes a practical proposition. One is that each turbine would have to cost less than $15,000. The other is that there is no clear route to the market for the energy the farmer would generate. The cost of turbines will fall as sales rise and economies of scale are achieved. However, forcing grid operators to open up the last mile of their infrastructure will not be easy. A battle as protracted as the one between entrants to the communications market and incumbent telecom providers is likely.

The risk for Proven is that by the time a route to the market has been opened up, the public will have become accustomed to the sight of larger turbines in the countryside, and a window of opportunity for the farmer, and the manufacturers of medium size turbines, will have closed.

Konarka

Konarka was founded in 2001 to exploit work carried out by a team of researchers at the US Army's Natick, Massachusetts Laboratory. This team found a new way to process materials at relatively low temperatures, enabling low cost polymers to be used in the fabrication of photovoltaic cells. The process also enables cells to be manufactured at a higher speed. The company has continued to refine the manufacturing process and increase the efficiency of its photovoltaic products.

The company is aiming its products at a wide variety of markets including consumer electronics – for example at power sources for mobile devices and wearable computers. Konarka see their low cost flexible photovoltaic devices being used as power-generating materials than can be integrated into structures such as bricks, awnings and roofs, enabling buildings to carry with them their own power source.

The company, which is headquartered in Lowell, Massachusetts, employs 32 staff and has attracted $32m of funding. Key investors include EDF, Chevron and the Massachusetts Green Energy Fund.

In 2004 the California Energy Commission set aside funds from its Energy Innovations Small Grant Program for Konarka. This grant was to be used to accelerate the company's work on creating aesthetically integrated plastic photovoltaic devices for the domestic roofing market.

Analysis

Work on applications such as electricity-generating tents and clothing could pave the way to the development of low cost materials for use in large-scale energy farming. Low cost in this case is in the region of $10 per square metre of material, with an efficiency of approximately 7%.

It has to be kept in mind that this material is unlikely to be as durable as polycrystalline silicon based devices. Konarka are at an early stage of product development and the majority of the company's earnings are likely to come from consumer-orientated applications.

However, involvement in a farmed energy project, or any other large-scale application of polymer based photovoltaic material, would provide the company with the resources and incentive to lower the cost, increase the efficiency and enhance the durability of its product.

Konarka®

Konarka At A Glance

Based in Lowell, Massachusetts the company has 32 employees and is exploiting research into low cost polymer based photovoltaic devices. The company is also developing a material for self-powered tents that could, in principle, also be used to gather solar energy over a wide area.

www.konarka.com

Energy-generating material to power buildings

Nanosolar

Nanosolar is claiming that it has leapfrogged a stage in the development of high-throughput thin film process technology for solar cells and has a process that can produce devices that are as efficient and long-lived as conventional silicon solar cells.

The company was formed in 2002 and has many of the characteristics of a typical Silicon Valley start-up. It is headquartered in Palo Alto, California, and has received financing from technology investors including Benchmark Capital, MDV, and the founders of Google. Nanosolar has over 62 patents, regarding commercially relevant aspects of printable solar cells, either issued, licensed, or pending.

Key components in the company's process technology are proprietary techniques that use novel nanostructured components to facilitate 'printing' or solution-coating of the most expensive layers of a solar cell. Nanosolar claim that these printing processes are simple and robust in comparison with other thin film deposition techniques, such as vacuum, and enable a high process throughput with roll-to-roll production methods.

Nanosolar has developed a suite of capabilities for creating nanostructured components via molecular self-assembly. Molecular self-assembly techniques provide the capability of designing and creating nanostructured materials with novel properties. Such techniques generally rely on recipes that control the precise, bottom-up chemical assembly of molecules into geometric structures composed of many molecules.

Analysis

In theory, advanced forms of molecular self-assembly could be used to create catalysing components within a hollow membrane. When such a membrane was exposed to sunlight any water passing through it would be split into oxygen and hydrogen. The theory that underpins this technology has been known since the 1970s and it is only with the emergence of nanotechnology that it is anywhere near becoming a practical reality. However, it is still in the very early stages of development within university laboratories and is unlikely to see the light of day as a commercial product for two decades.

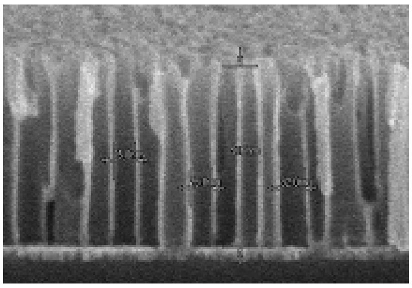
In the meantime, companies such as NanoSolar will be earning revenues from polymer based photovoltaic devices that undercut polycrystalline devices on price and may eventually match them in efficiency. The company has correctly identified that high efficiency of a solar cell does not necessarily equate to lower cost electricity production.

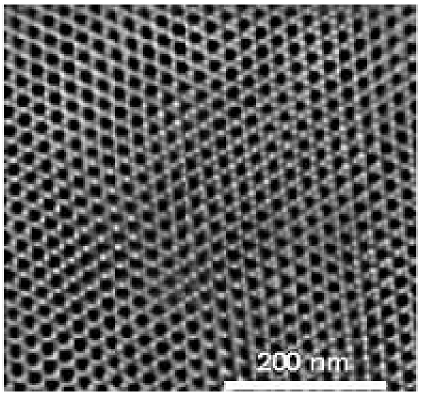
In the longer term, companies that gain key skills in nanotechnology and carve out a niche in the solar energy market will be well placed to exploit any step change in photovoltaic device technology.

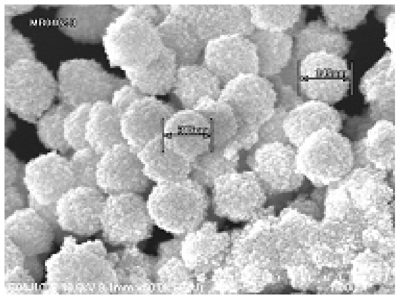
Nanosolar At A Glance

Formed in 2002 to exploit a range of thin film processes that can be used to produce low cost photovoltaic devices. The company is located in California's Silicon Valley and is financed by a range of investors who are heavily involved in the high technology industry.

www.nanosolar.com







Nanostructured materials

Dr Reinhard Dahlberg

Dr Reinhard Dahlberg's concept of 'Industrial Scale Solar Power Generation' – using solar energy to extract hydrogen from water as a means to replace rapidly depleting supplies of oil and gas – was based around the following assumptions and calculations:

Global radiation in tropical and sub-tropical regions is 2300 kWh/year.m²

A solar cell with a 15% spec. sheet efficiency would have a real world efficiency of 8%. It was assumed that an efficiency of 85% could be achieved for the electrolysis process, meaning 3.3 kWh of energy would produce 1 m³ of hydrogen that itself would have 3 kWh of energy.

Then:

> 1 m² of solar panel produces 184 kWh/year
> Which produces 184/3.3 = 56 m³ hydrogen/year
> 56 m³ × 3 kWh = 168 kWh
> 1 barrel of oil = 1910 kWh
> So 1 m² of solar collector produces the equivalent of 168/1910 barrels of oil per annum.
> Or **11.5 m²** of solar panels produces the equivalent energy of 1 barrel per annum of oil.

Dr Dahlberg's report followed hard on the heels of the Global 2000 report, which predicted a significant shortfall in basic resources would impact on the world economy in the early part of the 21st century. Along with other advocates of the use of alternative energy, Dr Dahlberg saw the need for rapid introduction of large-scale renewable energy programmes with little room for organic growth driven by market dynamics. Such programmes were seen as solutions to a wide range of environmental and economic problems. Dr Dahlberg suggested that the water produced when consumers used the hydrogen would provide a source of clean water.

The only solar cell commercially available when Dr Dahlberg produced his report was based on polycrystalline silicon – the price of which was predicted to fall to as little a $15/m² by the time large-scale installations were built. This has not happened and the price of oil, another predicted driver for large-scale solar energy, actually fell in real terms during the two decades after the report was published. Only recently has the price of oil risen to the point where it again acts as a driver for the development of alternative energy generation.

In 1986 a comprehensive analysis of Dr Dahlberg's concept was undertaken by George Bouziotus of Imperial College, London. This analysis took into consideration alternative methods of producing hydrogen using solar energy – including direct conversion using sunlight. George Bouziotus also created a number of computer models that were used to assess the feasibility of large-scale solar utilisation of solar energy and the use of hydrogen as a fuel.

At A Glance

Dr Dahlberg, a specialist in photovoltaic materials, advocated the use of solar energy to replace diminishing oil reserves. Large-scale solar would be deployed in desert regions within the solar belt.

Large-scale solar energy farm based on conventional photovoltaic technology

Solar farming would dominate large areas of the solar belt

Analysis

Dr Dahlberg's report was published at a time when industrialised nations were coming to terms with the fact that their economies were highly dependent on finite resources, the price and supply of which were not under their control. At that time it seemed only urgent and radical action would prevent a meltdown of the world economic system. Many of the alternative energy initiatives that started life during that period ended when it became clear the energy crises of the 1970s and 1980s were the beginning of a long-term trend as opposed to a step change in the energy market.

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