Dream Farm II – A Proposal
How to Beat Climate Change & Post Fossil Fuel Economy

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Why dream farm?
Why do we need George Chan's "zero emission" or "integrated food and waste management system", which I call Dream Farm [1] for short? There are many reasons (see Box 1).

Box 1
Why We Need Dream Farm
No more cheap fossil fuels
United States food sector uses 17 percent and Canada 11.2 percent energy, not including export-import, food-processing machinery and buildings, waste collection and treatment, and roads for transport
Water running out
It takes 1 000 tonnes of water to produce one tonne of grain; aquifers are severely depleted in major breadbaskets of the world
Productivity falling
Grain yields fell for four successive years; world reserves are at lowest levels in 30 years
Loss of croplands from unsustainable practices
The world loses 20 m ha, or 1.3 percent croplands annually from soil erosion and salination; replacing lost croplands accounts for 60 percent deforestation annually, which greatly accelerates global warming
Urgent need to reduce emissions
Food sector in a European country (France) is responsible for more than 30 percent carbon emissions, not including import/export, household use and storage, processing, and imported fertilizers
Global warming threatens food production
Yields fall 10 percent for every deg. C rise in night temperature; the latest prediction is an increase in the earth's average temperature of 1.9 to 11.5 deg. C within this century

We have an energy crisis, and cheap fuel is a thing of the past [2], but our current food system is very energy intensive. The United Nations Environment Programme estimates that the food sector consumes about 10-15 percent of total energy in industrialised countries [3], though only 2-5 percent are on the farm, due to fertilisers, pesticides and machinery. Estimates for the US and Canadian food sector put the figure at 17 percent & 11.2 percent respectively [4, 5], which include total energy consumed on the farm, processing, transport, packaging, and storing farm products, as well as energy used by households to purchase, store and prepare food. The figures do not include energy costs in food-processing machinery and buildings, waste collection and waste treatment, or roads for transport; nor do they include energy consumed in importing/exporting food. The globalised food trade is destroying the livelihood of family farmers all over the world as corporations consolidate control of the commodity market and the food supply chain [6], and subsidized food surpluses are dumped from the rich countries in the North on poor countries in the South [7]. The globalised food trade also wastes huge amounts of fossil fuels and spews extra tonnes of greenhouse gases into the atmosphere.

The depletion of water is most serious, as industrial agriculture is extremely thirsty [8]. It takes 1 000 tonnes of water to produce one tonne of grain [9]; aquifers are pumped dry in the world's major breadbaskets in the United States, China and India [10].

Not only water is depleted but also soil and soil nutrients and fertility, so productivity has been falling. Grain yields fell for four successive years from 2000 to 2003, and the world reserves are still at the lowest levels in 30 odd years.

Unsustainable practices over the past decades have resulted in massive losses of croplands from salination and soil erosion, totalling 20 million ha a year, or 1.3 percent of the world's croplands [11]. Replacing lost croplands accounts for 60 percent of deforestation, greatly accelerating climate change. That is why catastrophes such as hurricane Katrina, floods, droughts and extreme climates are increasingly frequent, impacting further on food production.

There is an urgent need to reduce greenhouse gas emissions to mitigate climate change, and a lot can be done through our food system. An estimate of the French food sector put its carbon emissions at more than 30 percent national total; not including import/export, household use and storage, food processing, and imported fertilizers [12].

Global warming itself threatens food production through the increase in temperature alone. Yields fall by 10 percent for every deg C rise in night temperature; and the latest predicted rise in average global temperature is 1.9 to 11.5 deg. C within this century when carbon dioxide in the atmosphere reaches 560 ppm, double the pre-industrial level.

Veteran world watcher Lester Brown summarises the fallout of the "environmental bubble economy" built on decades of unsustainable exploitation of the earth's resources [10]: "..collapsing fisheries, shrinking forests, expanding deserts, rising CO_2 levels, eroding soils, rising temperatures, falling water tables, melting glaciers, deteriorating grasslands, rising seas, rivers that are running dry, and disappearing species." He warns that the environmental bubble economy is due for collapse, the most vulnerable sector being food; the biggest challenge, therefore, is how to feed the world [13].

He also says we need to restructure the economy at "wartime speed" to one that tells the ecological truth.

What Lester Brown hasn't quite said is that the old economic model is responsible for much human suffering and poverty. The old model not only lays waste to the earth, it lays waste to people and society, and for the same reasons. It is the mistaken fundamentalist belief in the survival of the fittest; competition and exploitation are the laws of the market as much as the laws of nature [14].

Dream Farm a new model

What we need above all is a new model, a new paradigm; and that's what Dream Farm is about. It is a unit of self-sufficiency in energy and food, a nucleation centre of the sustainable food production and consumption system that we need for a post fossil fuel economy, and a microcosm of the new paradigm working in a very concrete way.

That is why ISIS is proposing to set up a Dream Farm II for demonstration, education and research purposes; combining the best and most appropriate technologies to showcase the new paradigm and at the same time, to act as an incubator and resource centre for knowledge and technologies that really serve people and planet.

Mobilising human ingenuity

Figure 1 is a schematic diagram of George Chan's system, which I shall call Dream Farm I.

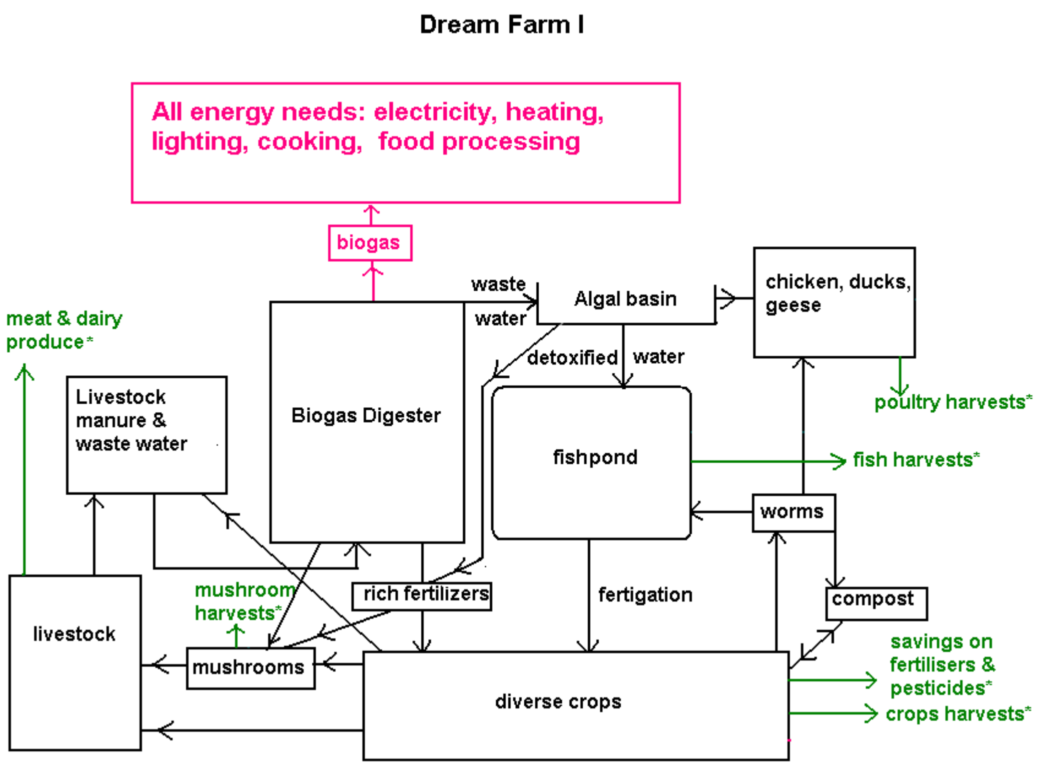

Figure 1. Dream Farm I according to George Chan

The anaerobic digester takes in livestock manure plus wastewater and produces biogas, which provides all the energy needs for heating and electricity. The partially cleansed wastewater goes into the algal basin where the algae produce by photosynthesis all the oxygen needed to detoxify the water, making it safe for the fish. The algae are harvested to feed chickens, ducks, geese and other livestock. The fishpond supports a compatible mixture of 5-6 fish species. Water from the fishpond is used to 'fertigate' crops. Aquaculture of rice, fruits and vegetables can be done in floats on the surface of the fishpond. The anaerobic digester yields a residue rich in nutrients that is an excellent fertiliser for crops. It could also be mixed with algae and crop residues for culturing mushrooms after steam sterilisation. The residue from mushroom culture can be fed to livestock or composted. Crop residues are fed back to livestock. Crop and food residues are used to grow earthworms to feed fish and fowl. Compost and worm castings go to condition the soil. Livestock manure goes back into the anaerobic digester, thus closing the grand cycle. The result is a highly productive farm that's more than self-sufficient in food and energy.

I have described Dream Farm as an "abundantly productive farm with zero input and zero emission powered by waste-gobbling bugs and human ingenuity."

There's a lot of human ingenuity among scientists and engineers and other professionals who would like nothing better than to use their ingenuity for the good of people and planet and to create a sustainable world for all its inhabitants.

Dream Farm II

I was truly inspired by George's work, and the idea of setting up Dream Farm II soon occurred to me. Fortunately, the first person I spoke to about Dream Farm II was Kenneth Spelman; that was in August 2005. I needed a good engineer, and there were two possibilities. I rang Kenneth first and tried the idea on him, and he got very excited right away.

And so over the next months, we assembled a team of potential partners for a proposal to the UK Carbon Trust, which seemed like the ideal funding agency for the project. The Carbon Trust required 50 percent of the funding to come from industry. The companies we approached mostly liked the idea; it was a heady time. We managed to submit the proposal just before the November deadline.

Unfortunately, the proposal failed to get through even the first round. We have since learned that the Blair government's idea of reducing carbon emissions is to build more nuclear power plants [15], and its "energy from waste" programme is limited to burning wastes in incinerators that spew toxic fumes for miles around [16].

But we are not giving up, and I hope you will see why. I take this opportunity to thank Kenneth Spelman, who has undertaken to donate practically all the building works involved for the proposal; our intended partners, Biogas Technology Limited, CHP Services Ltd., and ElmFarm Research Centre; also Peter Saunders, Peter Rae, and others who have given me valuable comments and suggestions. The Carbon Trust proposal [17] was indeed put together with great enthusiasm from everyone concernted and at "wartime speed".

Integrated Reduced Emissions Food and Energy Farm

For the Carbon Trust proposal, we had to call Dream Farm something boring: Integrated Reduced Emissions Food and Energy Farm, *IREFE*, for short. Kenneth's advice was never mention waste, or else the waste bureaucracy will descend on us like a tonne of bricks.

The aims of *IREFE* are: to maximize productivity and balanced growth, to minimise environmental impact, hence "zero emission", "zero waste", and even "zero input" are the ideals; and most important of all, to achieve self-sufficiency in food and energy.

These aims are also the basis of the new economic model, as I shall show at the end of my talk.

But first the practicalities: how are those aims achieved?

First, we harvest greenhouse gas (biogas methane) not just from livestock manure and used water, but also crop residues and certain food wastes, which constitute *feedstock* for the anaerobic digester to produce fuel for all on-farm energy needs and mobile uses for transport and farm machinery, substituting for fossil fuels. Notice how this reduces carbon emissions twice over, first by preventing methane and nitrous oxide from the farm wastes going into the atmosphere, and second from the fossil fuels saved by burning methane instead. *But that's not the only benefit of our approach*, as distinct from the UK government's approach of burning the wastes.

As a result of confining the farm "wastes" in the anaerobic digester, nutrients, especially nitrogen, are conserved, instead of being lost as ammonia and nitrous oxide, a powerful greenhouse gas; or else leached into ground and surface waters as pollutants. These nutrients can now support the growth of algae, fish, livestock etc. for maximum farm productivity.

Harvesting sunlight is what crops do naturally, as do the algae in the aerobic digestion basin that produce all the oxygen needed to purify the partially cleansed water coming out of the anaerobic digester, and the phytoplankton in the fishpond that feed one or more of the several species of fish that co-exist happily in poly-culture. Solar panels can also be used, especially as the new generations of solar panels are much more affordable, durable and easy to install [18].

Conserving and regenerating potable water free of pollutants is a very important aspect of this farm, as water shortage and deprivation are affecting many parts of the world. After being cleansed by the algae, the water goes into the fishpond. From there it can be further polished by various species of aquatic plants before it is returned to the aquifers. Water from the fishpond also returns to the aquifers by being used to ‘fertigate’ the crops, and filtered through the layers of soil and subsoil.

Dream Farm is run strictly on organic principles, because pesticides and other chemicals will kill the bacteria in the biogas digester. There is now substantial evidence that organic foods are healthier; not only free from harmful pesticide residues, but also enriched in antioxidants, vitamins and minerals [19].

Energy is used at the point of generation. This micro-generation is gaining favour all over the world. It doesn’t depend on a grid and is therefore most suitable for developing countries. In developed countries, local micro-generation protects against power failures, not to mention terrorist attacks on the grid and black outs. A study in the UK estimated that up to 69 percent of the energy is lost through generating electricity at power stations and piping it over the grid [20].

What better way to reduce food miles and all the associated environmental impacts of food import/export than consuming locally produced food fresh and full of goodness, instead of goodness knows what?

A recently released report on Food Miles commissioned by UK’s DEFRA (Department of the Environment Food and Rural Affairs) put the direct social, environmental and economic costs of food transport at more than £9 billion each year [21]; with congestion accounting for £5 billion, accidents for £2 billion, and the remaining £2 billion due to greenhouse gas emissions, air pollution, noise and infrastructure damage. The gross value of the agricultural section was £6.4 billion and the food and drink manufacturing sector £19.8 billion. In other words, the £26.2 billion worth of agriculture and the food and drink industry involves externalising £9 billion, or 34 percent of the costs to the taxpayer [22].

Appropriate technologies a matter of design

The anaerobic biogas digester is the key technology in Dream Farm. Digesters can be any size, ranging from small ones buried in the ground serving a single family, which are simple and easy to maintain [23], to mammoth constructions serving the manufacturing or waste-treatment industry.

I found one that treated wastes from a school toilet in Addis Ababa, also buried underground with two covered potholes. Animal manure could be added through one of the holes, and stirred with a wooden stick. The second pothole revealed a pipe and valve, presumably for controlling the flow of biogas.

Another I spotted recently in Kasisi Agricultural Training Centre near Lusaka, Zambia, was no longer in use; it was built next to a pig house, now empty.

Two big ones – 2 500 m^3 each – are installed on a 1 000 acre farm in Wisconsin with more than 1 000 dairy cows [24]. They are fully automated, heated, monitored, with alarm fitted, valves, whistles, what have you. The farmer is reported to be happy with his investment.

But as George has said, the more automated, the more parts there are to go wrong. So the challenge is to design something affordable, easy to use and maintain, on a more human scale.

Pierre Labyrie [25], who works for Eden (énergié, dévelopment, environment) Toulouse, France, an organisation helping farmers to install biogas digesters, tells me that the typical digester installed is 2 000 m^3, even for small farmers with only 100 cows. The reason seems absurd. It is that farmers in Europe are by law required to store four-months worth of manure in slurry lagoons, which has to be that big. Rather than getting the law changed now that fresh manure is being treated and there is no need to store the slurry, they find it simpler to construct big digesters. But that means extra capital and maintenance expenses for the farmer. I have posed this question to the UK Department of Trade and Industry, and am awaiting a reply.

These digesters are not very good to look at. We need landscape architects and engineers to work together to design a beautiful and perfectly functional farm. What can be done besides the main crops and livestock, with trellised fishponds, algae shallows, grazing fields, woodlands, orchards, vegetable, herb and flower gardens….

The company that made the big digesters [24] also provided a combined heat and power generation unit based on an internal combustion engine, which burns the biogas and generates electricity and heat. These heat and power generation units can now produce electricity at about 30 percent efficiency, with 50 percent recovery of power as heat, giving an overall power conversion efficiency as high as 85 percent [26].

Savings on carbon emissions

At an initial stocking rate of 0.8 cow/acre on a 1 000 acre Minnesota farm, 2 063 kWh/cow was produced per year from biogas. I did a little calculation on the energy yield and carbon emissions saved per cow per year. The amount of methane required to generate that amount of electricity is 620 m^3 or 0.4464 tonnes, assuming 30 percent efficiency in converting to electricity. This is equivalent to 9.828 tonnes CO_2 equivalent, using global warming potential of 22 for methane. The amount of oil saved per cow, using the methane as fuel, is 0.553 tonne, which represents an additional 1.715 t CO_2 equivalent saved (1 tonne oil = 3.1 tonne CO_2). Hence the total savings by processing manure produced from a single cow per year, counting only methane is 11.543 t CO_2 equivalent.

A 100-acre farm with 80 cows - a nice size for a demonstration farm, with plenty of room for woodlands, an on-site gourmet restaurant to take advantage of all that lovely fresh organic food plus an analytical research laboratory - would yield more than 160 000 kWh per year in energy and save 923.4 t CO_2 equivalent in emissions.

If all the farm manure produced in the UK – estimated at 200 m tonnes - were to be treated in biogas digesters and the biogas harvested for fuel use, the carbon emissions saved would be more than 14 percent of the national emissions.

But we can do much better than that. When other farm and food residues are included, the yield of biogas can be far higher (see later). A 1 000 t CO_2 equivalent saving a year is quite realistic. The market price (16 Jan 2006) was €23.35 per tonne CO_2 equivalent. So 1 000 tonnes is worth more than 23 000 euros in carbon credits.

(I was informed by UK's Department of Trade and Industry that one would be unable to gain carbon credits in Britain through the Kyoto route, i.e., Clean Development Mechanism (CDM) or Joint Implementation (JL) [27]. CDM projects are in developing countries only, and while JL projects are eligible in developed countries, the UK has not yet signed up to it. One option may be voluntary emission reduction (VERs) credits, which are sold to the retail market for offsetting companies and individual emissions on a voluntary basis. Watch this space)

Livestock manure is in fact rather low down in the league of biogas yield [28]. Fats and grease are way up there with 961 m^3 per tonne. Bakery waste not far behind at 714 m^3. Waste paper, not included in this chart, is also a good substrate for generating biogas (see Figure 2).

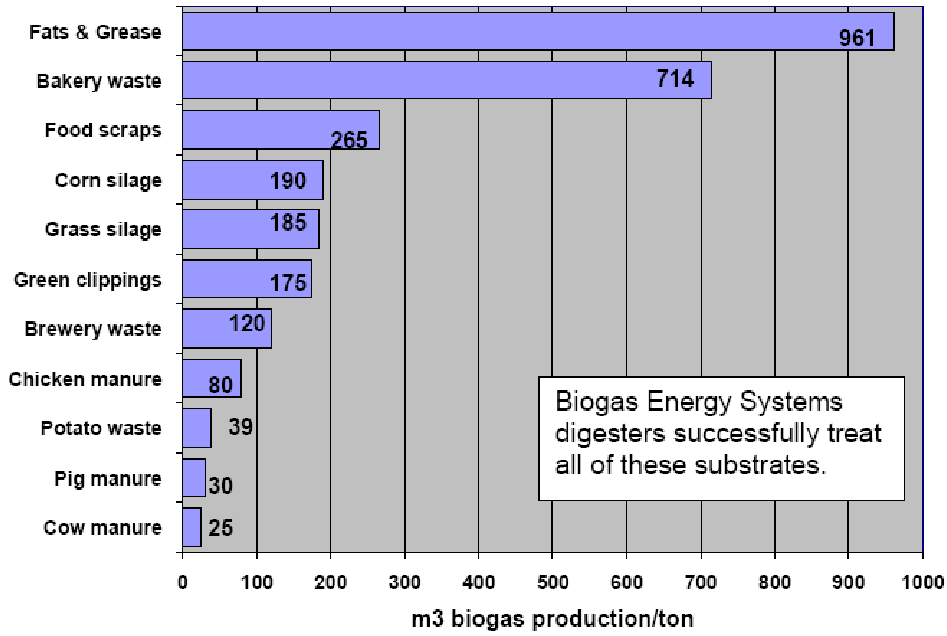

Figure 2. Yield of biogas with different feedstock

As you can see, it is possible to produce an excess of biogas, if that is needed. The incentive for producing more biogas is that methane can be used directly as fuel for cars and farm machinery after being cleaned up and compressed.

Biogas digestion is certainly a far better way of getting energy from wastes than just burning wastes. It also makes nonsense of the 'biofuels' that the UK and other governments are supporting, such as making ethanol out of maize and soybean [29], especially the glut of GM maize and GM soybean that Monsanto can't sell. Even ethanol from agricultural wastes is not sustainable, because you lose irreplaceable soil nutrients and generates pollutants.

Highly productive self-sufficient farm, research centre & incubator for new technologies, new ideas

A schematic diagram of Dream Farm II (Integrated Reduced Emissions Food and Energy Farm, IREFE) is presented in Fig. 3. This is an improved version of the one submitted to the Carbon Trust, mainly in the addition of solar power.

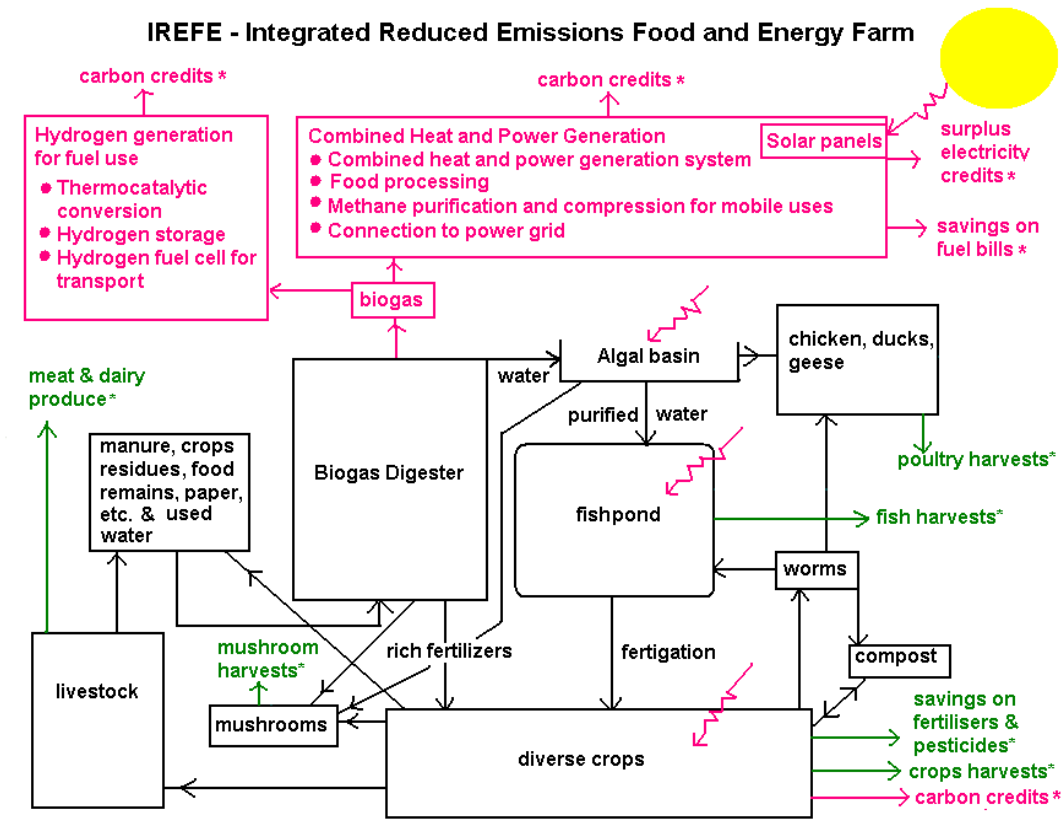

Figure 3. Dream Farm II

As mentioned, new generations of solar panels are cheaper and easier to install and maintain, and there is no reason not to include them as a core technology for generating energy alongside the biogas digester. (We shall definitely need extra energy for the on-site gourmet restaurant and the analytical lab.)

Our approach is to get the farm up and running on core technologies while newer technologies are integrated or substituted at the periphery as time goes on. As said, we want the farm to serve research/education purposes and as an incubator and resource centre for new technologies, new designs, new ideas.

For example, combined heat and power generation is currently done using an internal combustion engine, which is noisy, and produces some noxious fumes. The ideal is to have heat and power generation with a fuel cell.

Fuel cells are theoretically highly efficient and emission-free. A fuel cell generates electricity, operating on pure hydrogen, and produces nothing but water as by-product.

In a proton-exchange membrane fuel cell (PEMFC) most suitable for on-farm use, a proton-conducting polymer membrane separates the two electrodes, typically made of carbon paper coated with platinum catalyst [30].

On the anode (negative electrode) side, hydrogen dissociates into protons and electrons. The protons are conducted through the membrane to the cathode (positive electrode), but the electrons travel to an external circuit to supply electrical power before returning to the fuel cell via the cathode.

At the cathode catalyst, oxygen reacts with the electrons and combines with the protons to form water. A fuel cell typically converts the chemical energy of its fuel into electricity with an efficiency of about 50 percent. (The rest of the energy is converted into heat.)

New generations of fuel cells are under development that can take methane and reform it into hydrogen inside. The farm in Wisconsin tried out a prototype, but it did not perform as well as the internal combustion engine [31]. A major problem was that the biogas had to be substantially cleaned up before it could be fed to the fuel cell, leading to great losses of methane [32].

Methane can also be purified and compressed as fuel for mobile use: to run cars and farm machinery. Cars run on biogas methane are available in some countries and gaining in popularity, especially in Sweden [25], which already has biogas methane refuelling stations dotted around the country.

Another route to go is to convert the methane to hydrogen at high efficiency using a new solar-assisted thermocatalytic process [33], and then use the hydrogen to run vehicles. Yet another route is to have a two-staged anaerobic digestion, the first stage at slightly acidic conditions, which optimises the production of hydrogen, with a second stage under neutral pH for methane production [34].

Hydrogen storage is still a problem, though it is a very active area of research at the moment. Tanked hydrogen is being used to run buses all over the world, but for smaller vehicles in particular, the ideal is to store hydrogen in a lightweight solid absorbent and use that with a fuel cell. There are promising developments in those areas also [35].

Benefits of Dream Farm II

It is clear that as far as energy is concerned, *IREFE* is not only self-sufficient, but can also export electricity to the grid. Some of the energy can be used to heat the biogas digester, to make it work more efficiently. Surplus electricity can also be used to recharge hybrid gas-electric cars.

As far as food is concerned, there is a complete menu, limited only by the imagination and industry, rich enough to supply an on-site organic gourmet restaurant, all for free. I am thinking of the fishpond possibilities: fresh water oysters and other bivalves, crayfish, prawns, silver carp, grass carp, what else? Specialty mushrooms, rucola, mange tous peas, salad greens, orange beetroot, blue potatoes… plenty of room for research and innovation there.

There’s certainly enough food to spill over to local villages, schools, old people’s homes, nearby cities, delivered fresh everyday.

In short, Dream Farm is exactly what we need to feed the world, mitigate climate change and for everyone to thrive in good health and wealth in all senses of the word in a post-fossil fuel economy.

Unfortunately, our government prefers other solutions to the energy crisis. It doesn’t realise there is a food crisis yet, and is emphatically against UK being self-sufficient in food.

When asked about UK’s food policy, a DEFRA spokesperson wrote on behalf of the Minister for the Environment Elliot Morley [36]:

“Supporting greater UK self-sufficiency in food is incompatible with the concept of the European single market, in which different countries specialise according to comparative advantage. In an increasingly globalised world the pursuit of self-sufficiency for its own sake is no longer necessary nor desirable.”

Dream Farm and the new paradigm

What really excites me about George’s dream farm is that it demonstrates concretely a theory of the organism that I first presented in the second edition of my book *The Rainbow and the Worm, the Physics of Organisms*, published in 1998 [37].

Also at around the same time, I proposed that we could look at sustainable systems as organisms. This idea has been developed more completely in a paper published with theoretical ecologist Robert Ulanowicz in the University or Maryland [38].

The important features of zero-emission systems are the same as those of the zero-waste or zero-entropy model of organisms and sustainable systems. Entropy is made of dissipated energy, or waste energy that is useless for doing work, and simply clogs up the system, like ordinary waste.

The zero-entropy model predicts *balanced* development and growth as opposed to the dominant economic model of infinite, unsustainable growth. This immediately disposes of the myth that the alternative to the dominant model is to have no development or growth at all.

The key to how organisms survive and thrive is the same as what makes a system sustainable. It is to maximise reciprocal, cooperative and synergetic interactions rather than the competitive, to use the output of each cycle to feed another, and closing the entire cycle in a balanced way.

Just think: if your liver is competing with your brain or any other organ of your body, you won't have long to live; it is cancer by another name. It is the same with an ecosystem and an economic system.

Let me explain these ideas with a few evocative diagrams. The dominant model of infinite competitive growth is represented in Figure 4.

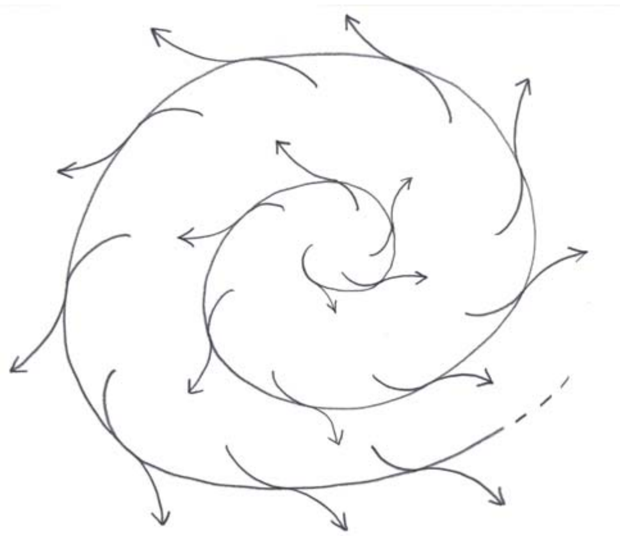

Figure 4. The dominant economic model of infinite unsustainable growth that swallows up the earth's resources and exports massive amounts of wastes and entropy

The system grows relentlessly, swallowing up the earth's resources without end, laying waste to everything in its path, like a hurricane. There is no closed cycle to hold resources within, to build up stable organised social or ecological structures.

By contrast, the archetype of a sustainable system is a closed lifecycle (Fig. 5), it is ready to grow and develop, to build up structures and perpetuate them, and that's what sustainability is all about. *Closing the cycle creates a stable, autonomous structure that is self-maintaining, self-renewing and self-sufficient.*

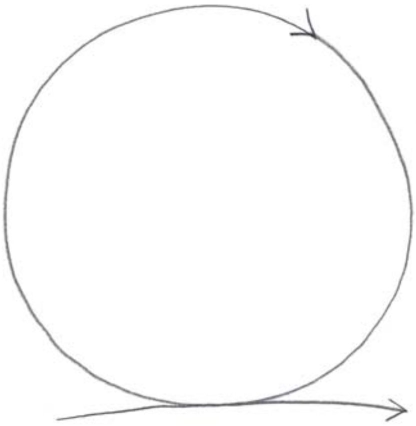

Figure 5. The sustainable system closes the energy and resource use cycle, maximising storage and internal input and minimising waste, rather like the life cycle of an organism that is autonomous and self-sufficient

The technical way of describing the balance is the zero-entropy or zero-waste ideal (Fig. 6). No waste or disorganisation in the system. Even the waste exported to the outside is minimised in a healthy system. The more we approach this ideal, the better the system can develop and grow.

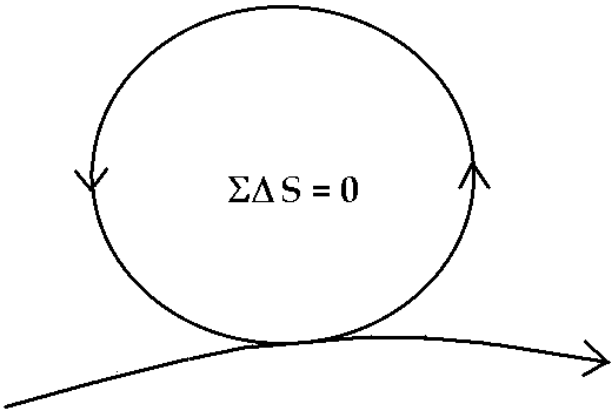

Figure 6. The zero-entropy model of a sustainable system

The system's cycle contains more cycles within, they help one another thrive and flourish, as in the minimum integrated farm with farmer, livestock and crops (Fig. 7). The farmer tends the crops that feed the livestock and the farmer; the livestock returns manure to feed the crops. Very little is wasted or exported to the environment. It can perpetuate itself like this, or it can grow.

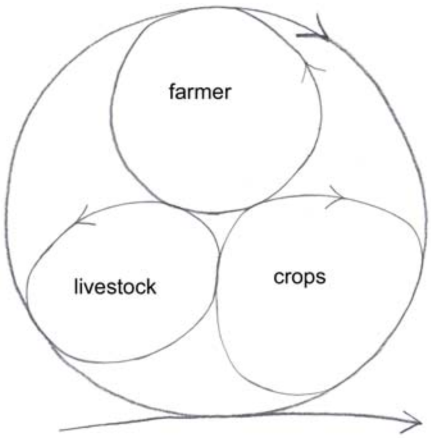

Figure 7. Integrated farming system that closes the cycle thereby minimizing input and waste

It can grow by incorporating more lifecycles, more farmers or farm workers. The more lifecycles incorporated within the system, the greater the productivity (Fig. 8).

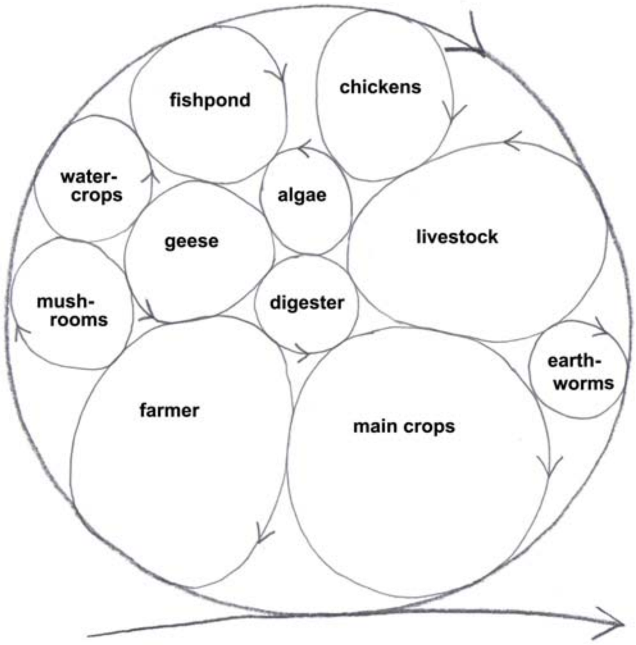

Figure 8. Increasing productivity by incorporating more lifecycles into the system

That is why productivity and biodiversity *always* go together. Industrial monoculture, by contrast, is the least energy efficient in terms of output per unit of input [39], and less productive in absolute terms despite high external inputs, as documented in recent academic research [40]. Actually the lifecycles are not so neatly separated, they are linked by many inputs and outputs.

A more accurate representation (Fig. 9) is what I have drawn in my book the *Rainbow Worm* [37] to show how the energy yielding processes are coupled to the energy requiring processes in the organism. As one winds down another winds up, and *vice versa* later on. This kind of reciprocity is operating all the time in our body.

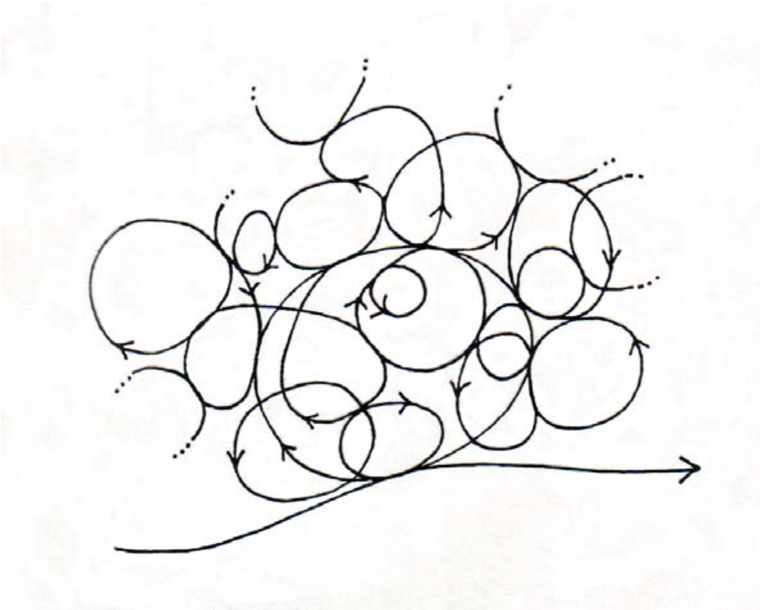

Figure 9. The many-fold coupled lifecycles in a highly productive sustainable system

The big lessons of Dream Farm

Dream Farm teaches us some big lessons. The first lesson is the importance of biodiversity. Dream Farm is based on biodiversity and promotes biodiversity. Generations of indigenous farmers have always known that biodiversity and productivity go together; not just because it safeguards against crops failing, but it is nature's way of maximising the reciprocal, synergistic relationships that make species thrive better together [41]. Now, academic ecologists in the University of Minneapolis have discovered the same thing. Bio-diverse plots are more productive than monoculture plots improving year by year [40]. This may be the real answer to the question posed by Evelyn Hutchinson, one of the greatest ecologists of the last century: Why are there so many species?

Another big lesson from Dream Farm is that the carrying capacity of a piece of land is far from constant; instead it depends on the mode of production. A Dream Farm can be 2, 3, 10 times more productive than a monoculture farm, creating more jobs, supporting more people. I know a Japanese farmer who supports his family of 9 on 2 hectares, sells rice, ducks, ducklings and provides organic vegetable boxes for 100 [42].

The argument for population control has been somewhat over-stated by Lester Brown and others [8, 10]. I like the idea of "human capital" to counter that argument. It isn't population number as such, but the glaring inequality of consumption and waste by the few rich in the richest countries that's responsible for the current crises.

To recap: sustainable development or *balanced* growth is achieved by closing the overall production cycle, then using the surplus nutrients and energy to support increasingly more cycles of activities while maintaining internal balance and nested levels of autonomy, just like a developing organism. The 'waste' from one production activity is resource for another, so productivity is maximised with the minimum of input, and little waste is exported into the environment. One often hears critics of the dominant model say that sustainable development is an oxymoron. But I have just shown it is not. Sustainable development is the alternative to the dominant model of unlimited, unsustainable growth. The same principles apply to an ecosystem, or an economic system that is of necessity embedded in the ecosystem [43, 44].

When you see the economic system embedded like this in the ecosystem, it becomes clear why the economic system has to generate minimum waste to be sustainable; because the waste doesn't go away, it comes back from the ecosystem into the economic system. And this happens through the instrument of money, as I shall explain.

Money, energy and entropy

The circulation of money in real world economics is often equated with energy in living systems. But all money is not equal. The flow of money can be associated with exchanges of real value or it can be associated with sheer wastage and dissipation; in the former case, money is more like energy, in the latter case, it is pure entropy or waste. When the cost of valuable (non-renewable) ecosystem resources consumed or destroyed are not properly taken into account, the waste burden falls on the ecosystem. But as the economic system is coupled to and dependent on input from the ecosystem, the waste burden exported to the ecosystem will come back into the economic system as diminished input, so the economic system becomes poorer in real terms.

Transaction in the financial or money market creates money that is completely decoupled from real value, and is pure entropy produced within the economic system. This artificially increases purchasing power, leading to over-consumption of ecosystem resources, again impoverishing the economic system as a result.

The unequal terms of trade imposed by the rich countries of the North on the poor countries of the South through the World Trade Organisation is another important source of entropy. That too, artificially inflates the purchasing power of the North, resulting in yet more destructive exploitation of the earth's ecosystem resources in the South.

The New Economics Foundation has shown how money spent with a local supplier is worth four times as much as money spent with non-local supplier [45], which bears out my analysis. It lends support to the idea of local currencies and the suggestion for linking energy with money directly [46]. It also explains why growth in monetary terms not only fails to bring real benefits to the nation, but end up impoverishing it in real terms [47, 48].

We need something like Dream Farm not only to feed the world, or to mitigate climate change, or to avert the energy crisis. Yes, it is all of those and more. Most important of all, we need to mobilise human ingenuity and creativity, to make us go on dreaming and working for a better world.

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