Mae Wan Ho

Dream Farm

How to Beat Climate Change & Post Fossil Fuel Economy

SUSTAINABLE wORLD

ISP ISIS

Why We Need Dream Farm

No more cheap fossil fuels

United States food sector uses 17% and Canada 11.2% energy, not including export-import, food-processing machinery and buildings, waste collection & treatment, and roads for transport

Water running out

It takes 1 000 tonnes of water to produce one tonne of grain; aquifers severely depleted in major breadbaskets of the world

Productivity falling

Grain yields fell for four successive years, bringing world reserves to lowest levels in 30 years

Loss of croplands from unsustainable practices

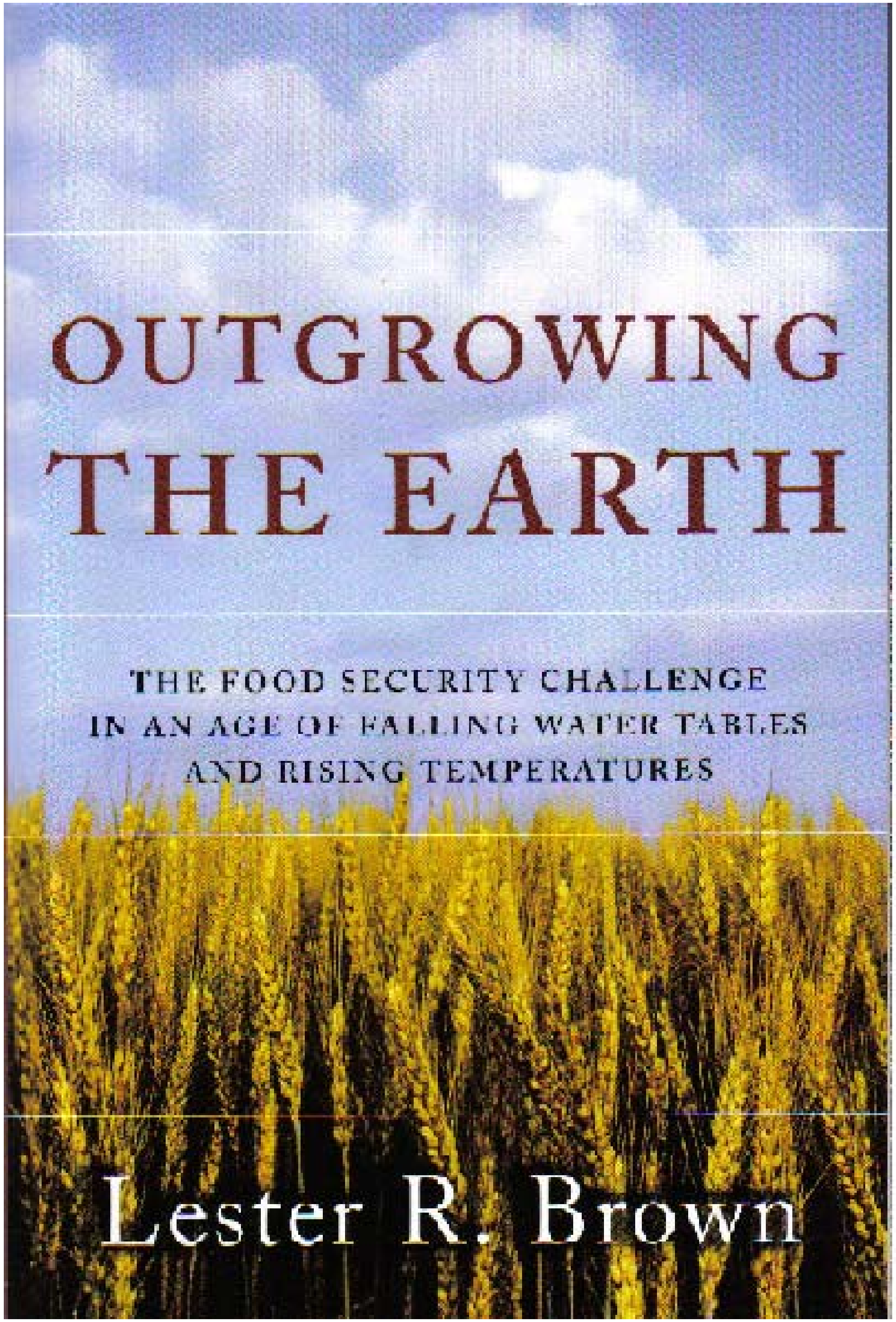
The world loses 20 m Ha, or 1.3% of its croplands annually from soil erosion and salination; replacing lost croplands account for 60% deforestation annually, greatly accelerating global warming

Urgent need to reduce emissions

French food sector responsible for more than 30% carbon emissions, not including import/export, household use and storage, processing, and imported fertilizers

Global warming threatens food production

Yields fall 10% for every deg. C rise in night temperature; predicted rise of 1.9 to 11.5 deg. C within this century in a business as usual scenario

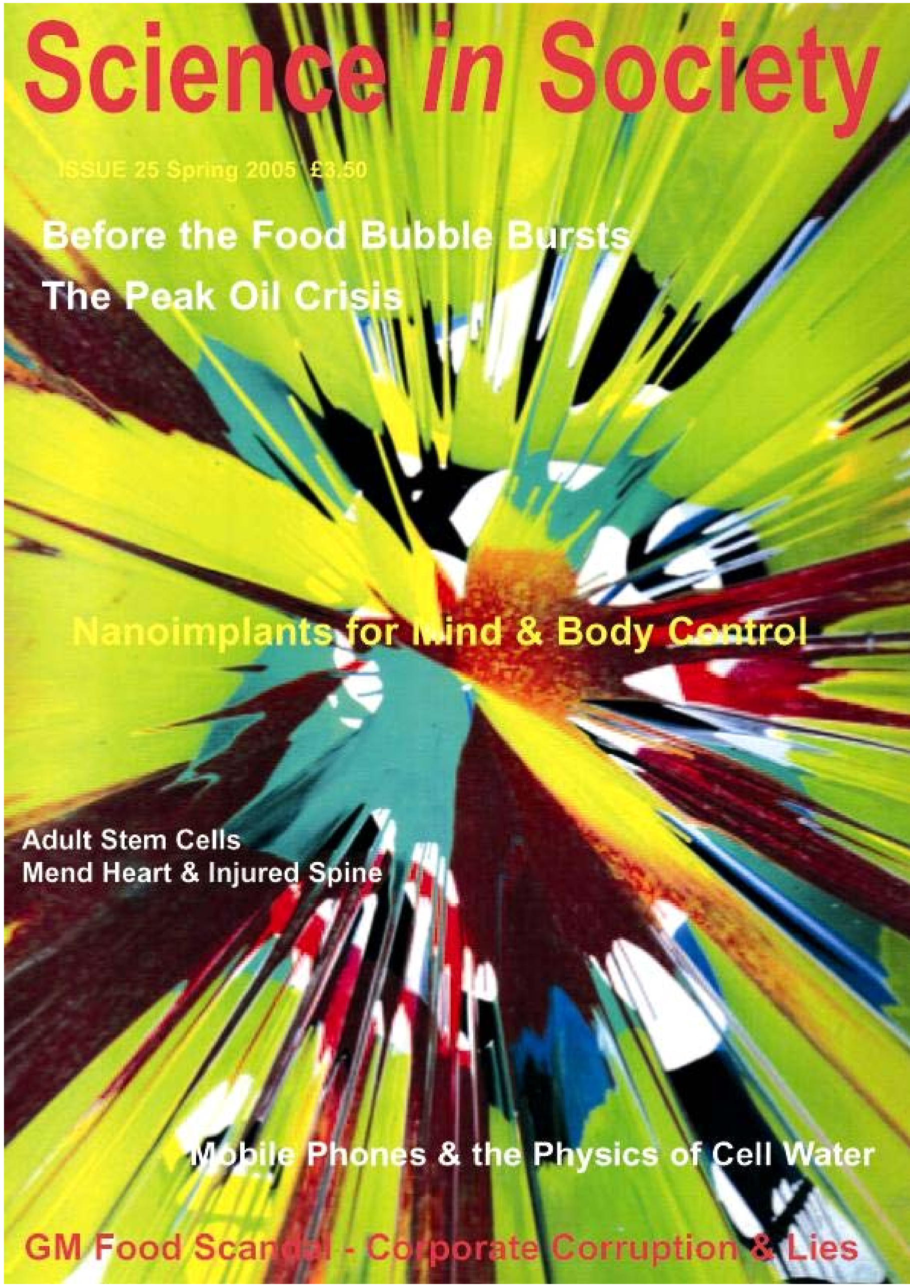


Fallout of the "environmental bubble economy":

"....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."

Lester R. Brown 2004

The Food Bubble Economy

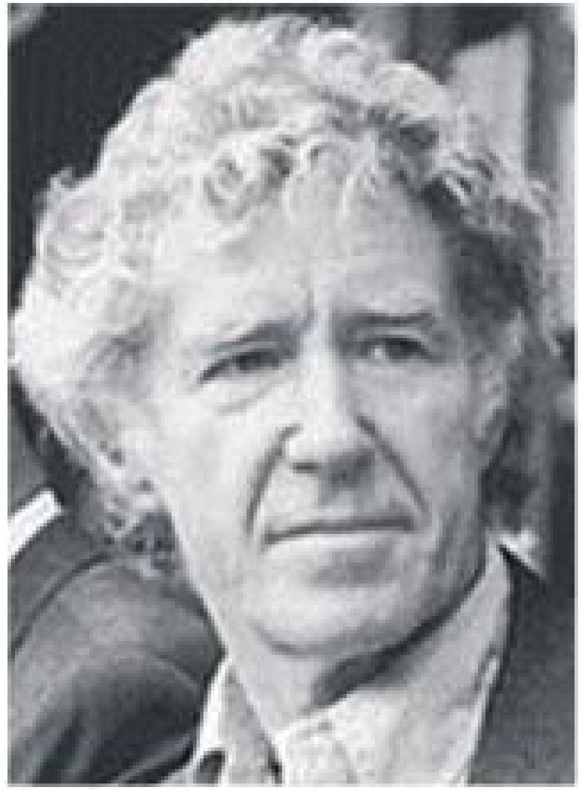


tuing a Planet ble, by Lester /. Norton & -05859-X

lustrial agriculture is ve. It takes 1000 tonnes nne of grain. Worldwide, diverted from rivers or und is used for irrigation; and 10% for residential

of industry are diverting griculture, and countries ports to make up for the s 4 litres of water a day litres are needed to pro- In rich countries where estock, the water need- person can easily reach

re generating conflicts downstream claimants.



the kernels. Similarly, the fertility of rice falls from 100% at 34C to nearly zero at 40C. In north India, a 1C rise in temperature did not reduce wheat yields, but a 2C rise lowered yields at almost all of 10 sites. There was a decline in irri-

ce a tonne of grain. Worldwide, 70% of pumped from underground is used for and 10% for residential purposes.

The Neo-Liberal Economic Model & World Hunger

- More than 3 billion malnourished (lacking calories, protein, minerals and/or vitamins)
- 850 million suffer from hunger (protein-energy malnutrition)

The principal cause of hunger is poverty

- 1.08 billion in developing countries live on $1 or less a day
- 798 million are chronically hungry

World hunger facts 2005, Hunger Notes

http://www.worldhunger.org/articles/Learn/world%20hunger%20facts%202002.htm

Dream Farm

Abundantly productive farms with zero input and zero emission powered by waste-gobbling bugs and human ingenuity

Dr. Mae-Wan Ho

Environmental engineer meets Chinese peasant farmers

Doesn't it sound like a dream to be able to produce a super-abundance of food with no fertilizers or pesticides and with little or no greenhouse gas emission? Not if you treat your farm wastes properly to mine the rich nutrients that can support the production of fish, crops livestock and more, get biogas energy as by-product, and perhaps most importantly, conserve and release pure potable water back to the aquifers.

That is what Professor George Chan has spent years perfecting; and he refers to it as the Integrated Food and Waste Management System (IFWMS).

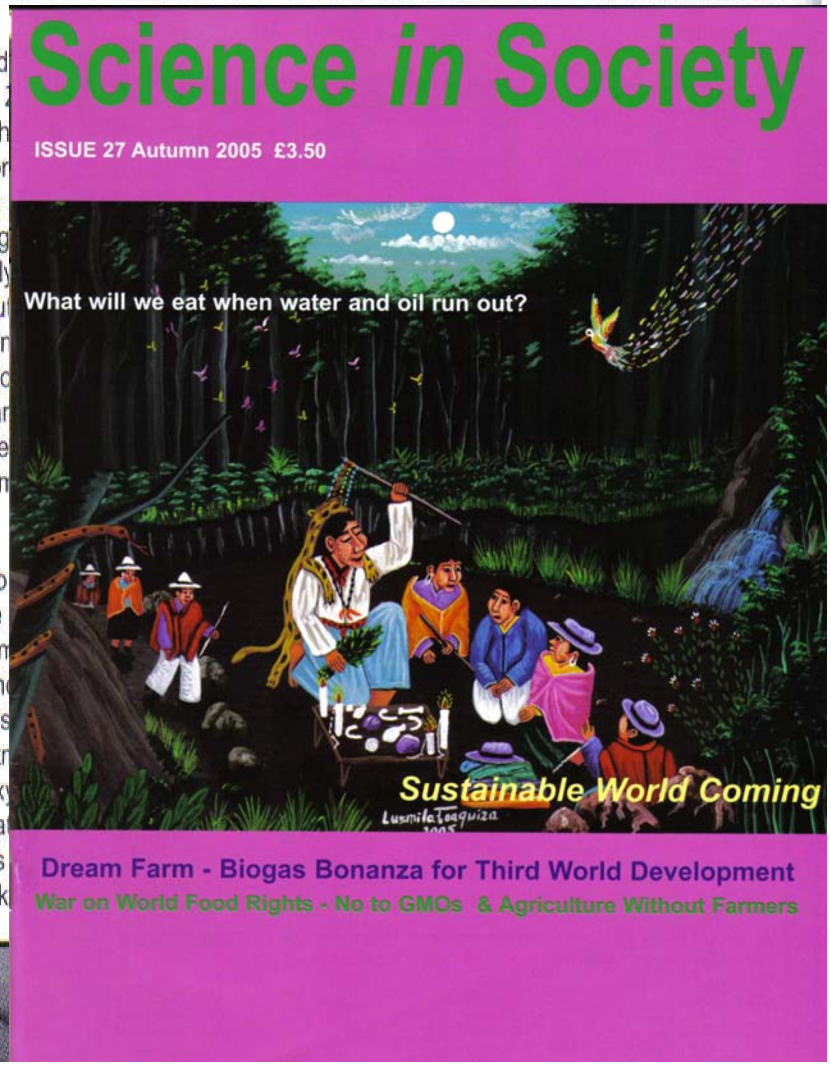
(ZERI) (www.zeri.org).

Chan left China in 1989, and work with Gunter and others in consultancy services. This work h to nearly 80 countries and territor tributed to evolving IFWMS into alternative to conventional farming

The integrated farm typically crops, livestock and fishponds. Bu from farm wastes often spill over in extra production of algae, chic worms, silkworms, mushrooms, ar ables that bring additional income for the farmers and the local comn

Treating wastes with respect

The secret is in treating wastes to loss of valuable nutrients that are to generate further nutrients fron etc., that feed a variety of crops an the same time, greenhouse gases ing the first phase of waste treatr vested for use as fuel, while the ox in the second phase of waste trea gets rid of toxins and pollutants - is photosynthetic algae, so fish stock



Dream Farm II

IREFE - Integrated Reduced Emission Food and Energy Farm

- Maximize Productivity and Balanced Growth
- Minimize Environmental Impacts
  "Zero Emission" "Zero Waste" "Zero input"
- Self-Sufficiency in Food and Energy

Harvesting greenhouse gas from farm wastes for combined heat and power generation and mobile uses, substituting for fossil fuels

Conserving & recycling nutrients for maximum productivity through appropriate integration of lifecycles

Harvesting sunlight through algae to purify wastewater, crops for food and feed, and solar panels for electricity

Conserving and regenerating potable water free of pollutants

Producing food organically with minimum environmental impacts and maximum health benefits

Using energy at the point of generation for maximum efficiency & minimum distributional losses

Producing and consuming food locally for maximum health benefits and minimum environmental impacts

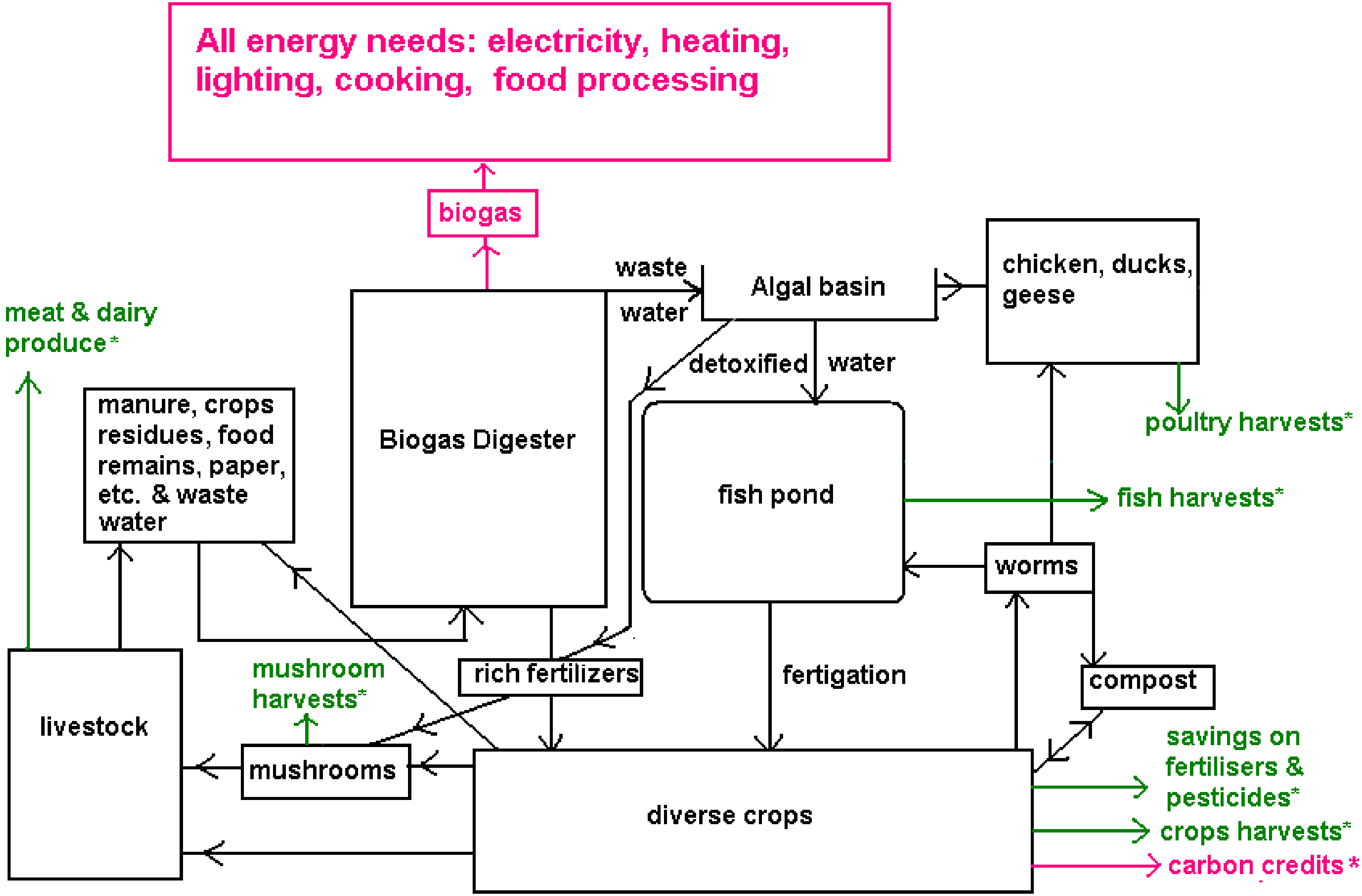
Social, Environmental and Economic Costs of Food Transport in the United Kingdom

Congestion	£ 5.0 billion
Accidents	£ 2.0 billion
Ghg emission, air pollution, noise, infrastructure	£ 2.0 billion
Total	£ 9.0 billion
Value of agriculture	£ 6.4 billion
Value of food & drink industry	£19.8 billion
Total value of food sector	£26.2 billion

Externalised cost due to food transport is 34% of the total value of food sector

The Validity of Food Miles as an Indicator of Sustainable Development, DEFRA 2005

Dream Farm


All energy needs: electricity, heating, lighting, cooking, food processing
biogas
waste water
Algal basin
chicken, ducks, geese
meat & dairy produce*
manure, crops residues, food remains, paper, etc. & waste water
Biogas Digester
detoxified water
fish pond
poultry harvests*
fish harvests*
worms
livestock
mushroom harvests*
rich fertilizers
fertigation
compost
mushrooms
diverse crops
savings on fertilisers & pesticides*
crops harvests*
carbon credits *

Vir Clar Farm,
Fond du Lac, Wisconsin

Container housing the CHP unit

CHP unit within the container

Energy Yield & Carbon Emissions Saved by Biogas Digester

Energy yield per cow-year **2 063 kWh**

= 620 m^3 = 0.4464 tonnes methane
(assuming 30% efficiency converting to electricity)

= 9.828 tonnes CO_2 equivalent
(global warming potential of 22 for methane)

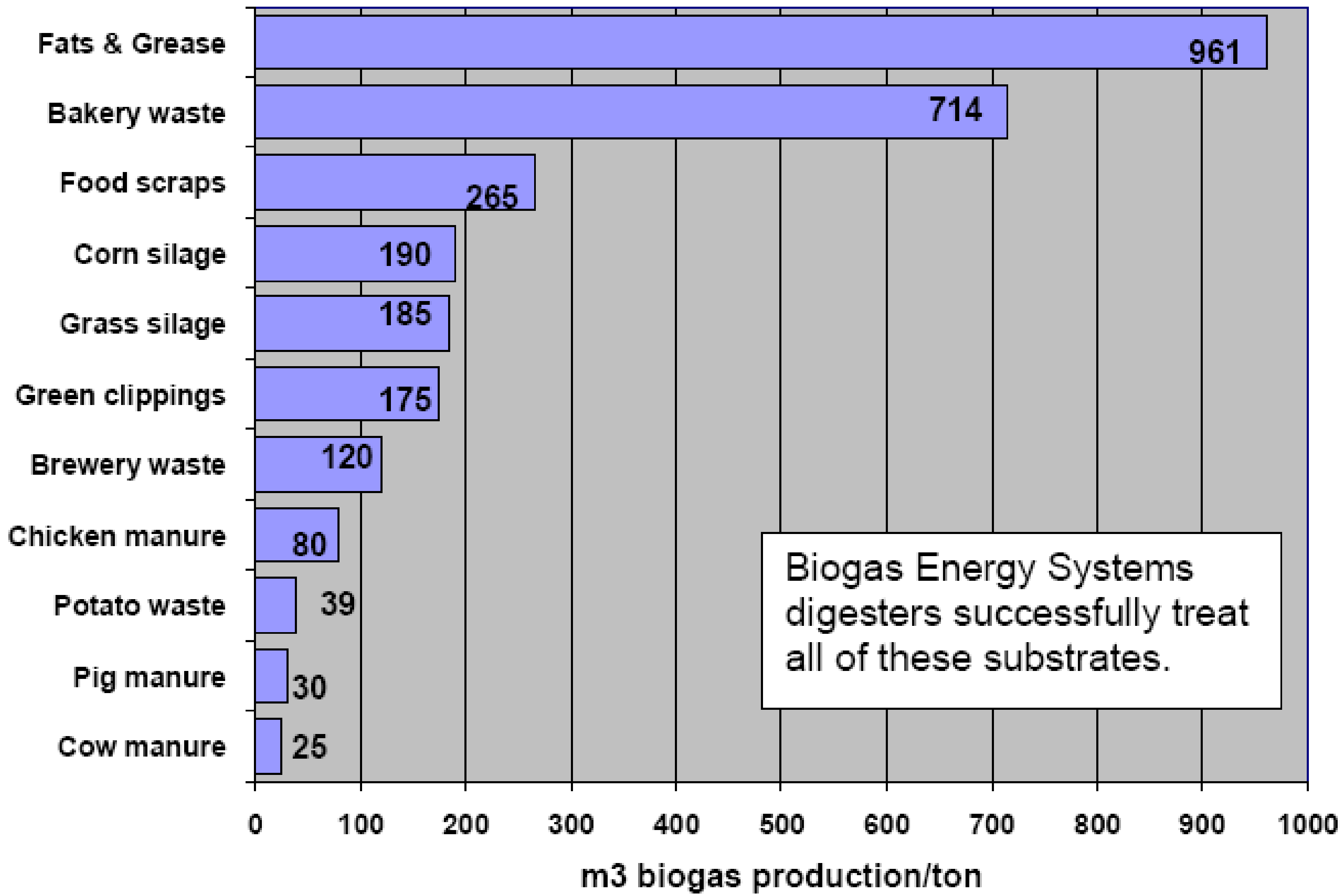
Amount of oil saved per cow-year 0.553 tonne

=1.715 t CO_2 equivalent
(1 tonne oil = 3.1 tonne CO_2 emissions).

Total carbon emission savings **11.543 t CO_2 equivalent**

***

A 100-acre farm with 80 cows could provide >160 000 kWh & save 923.4 t CO_2 equivalent

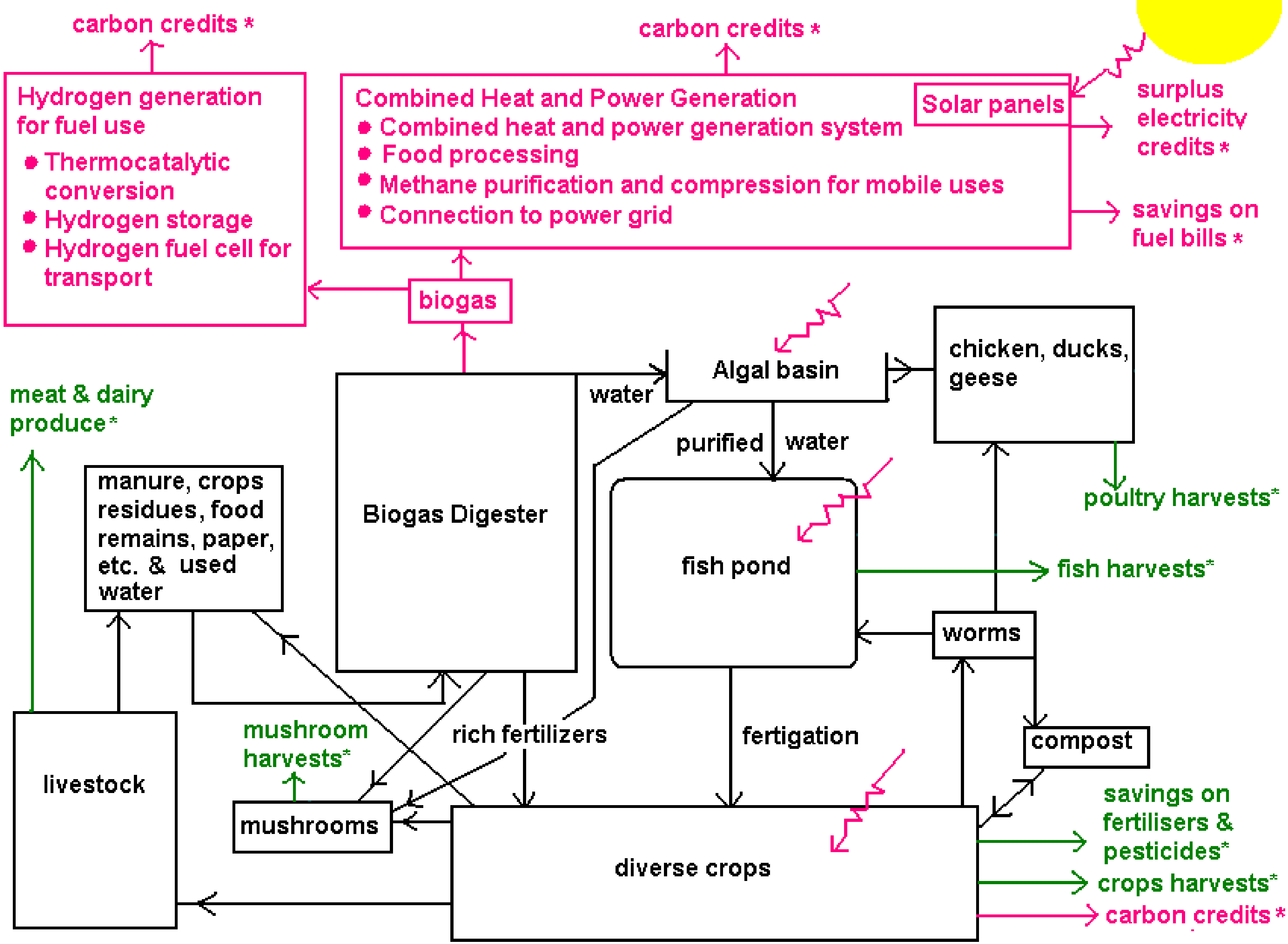

Fats & Grease
Bakery waste
Food scraps
Corn silage
Grass silage
Green clippings
Brewery waste
Chicken manure
Potato waste
Pig manure
Cow manure
961
714
265
190
185
175
120
80
39
30
25
0 100 200 300 400 500 600 700 800 900 1000
m3 biogas production/ton
Biogas Energy Systems digesters successfully treat all of these substrates.

Potential Carbon Emissions Savings to the UK*

Savings from methane emissions prevented (200 million tonnes manure)	57.024 Mt CO_2
Savings from methane emissions substituting for fossil fuel	9.948 Mt CO_2
Savings from nitrous oxide emissions prevented	27.001 Mt CO_2
Savings from fertilisers manufacture (1.2% national emissions)	7.223 Mt CO_2
Total	101.196 Mt CO_2
UK's national emissions	722.300 Mt CO_2
Potential savings from IREFE farms	14.01%

*Based on DEFRA and other estimates

IREFE - Integrated Reduced Emissions Food and Energy Farm



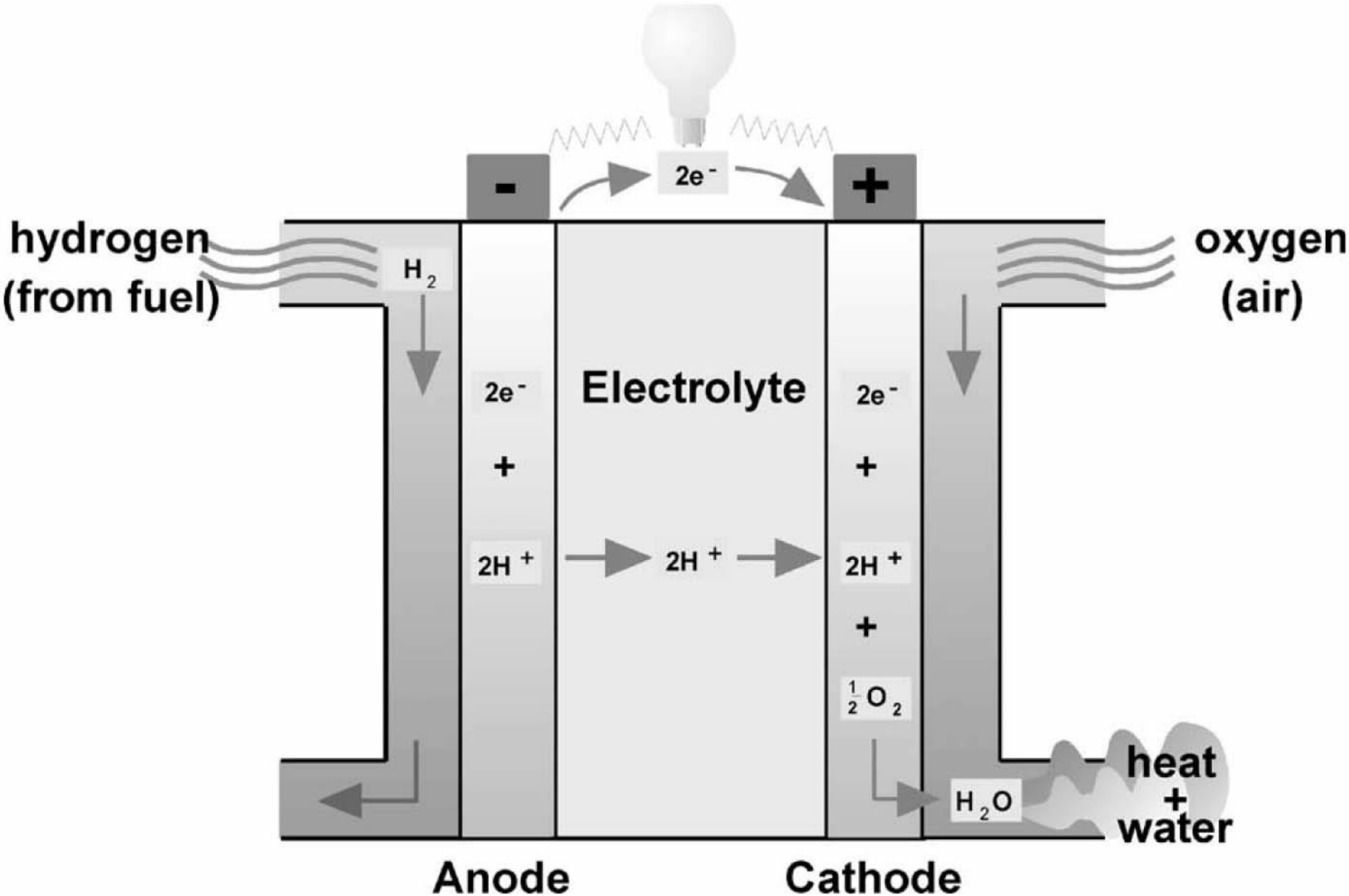
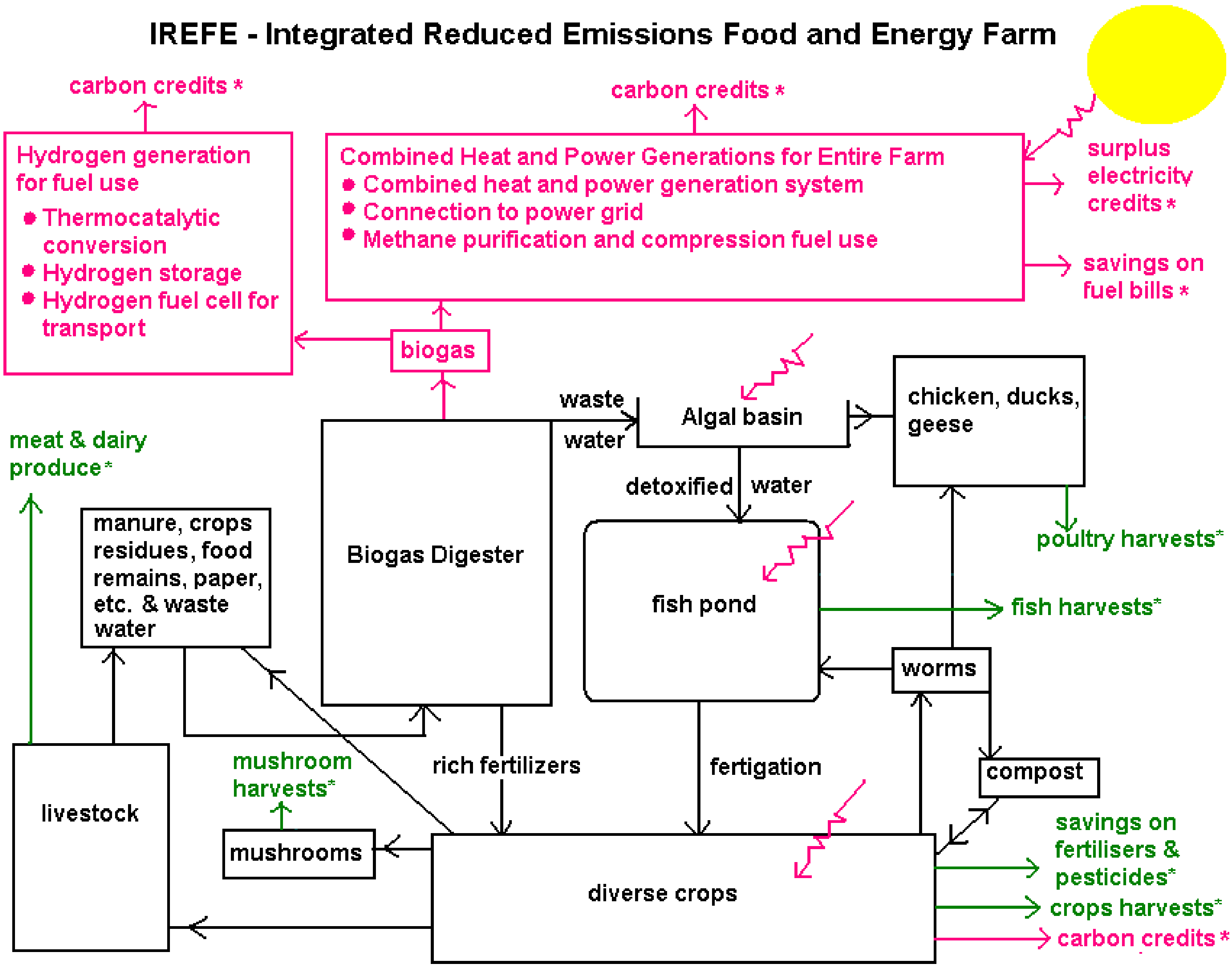


Fig. 2. Schematic of a PEM fuel cell operation. Source: World Fuel Cell Council.

IREFE - Integrated Reduced Emissions Food and Energy Farm



IREFE **puts together in one showcase all the relevant technologies that can deliver sustainable food and farming and a profitable low carbon economy**

IREFE

- Generates all its own energy for heating and electricity, including the ultimate clean fuel, hydrogen, for transport
- Substitutes for fossil fuel use
- Saves substantially on carbon dioxide emissions
- Reduces wastes and environmental pollution to a minimum
- Produces a diversity of crops, livestock and fish in abundance
- Requires little or no external input once established
- Provides employment opportunities for the local community
- Provides a showcase for how appropriate new technologies are implemented
- Provides hands-on education and research opportunities at all levels from infants to university students and beyond

“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.”

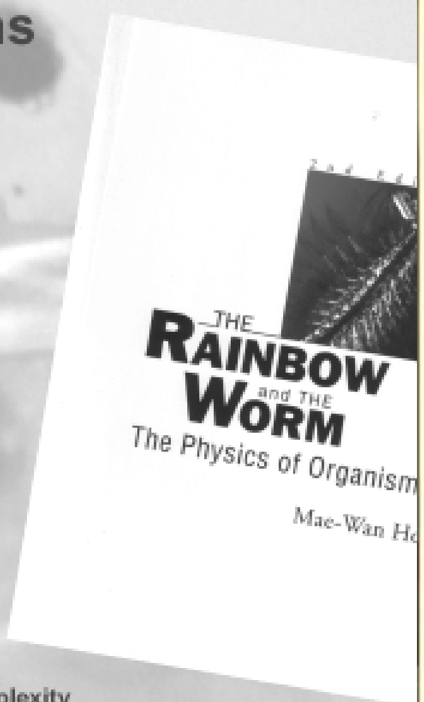
UK Department of the Environment Food and Rural Affairs (DEFRA) spokesperson on behalf of the Minister for the Environment Elliot Morley, March 2005

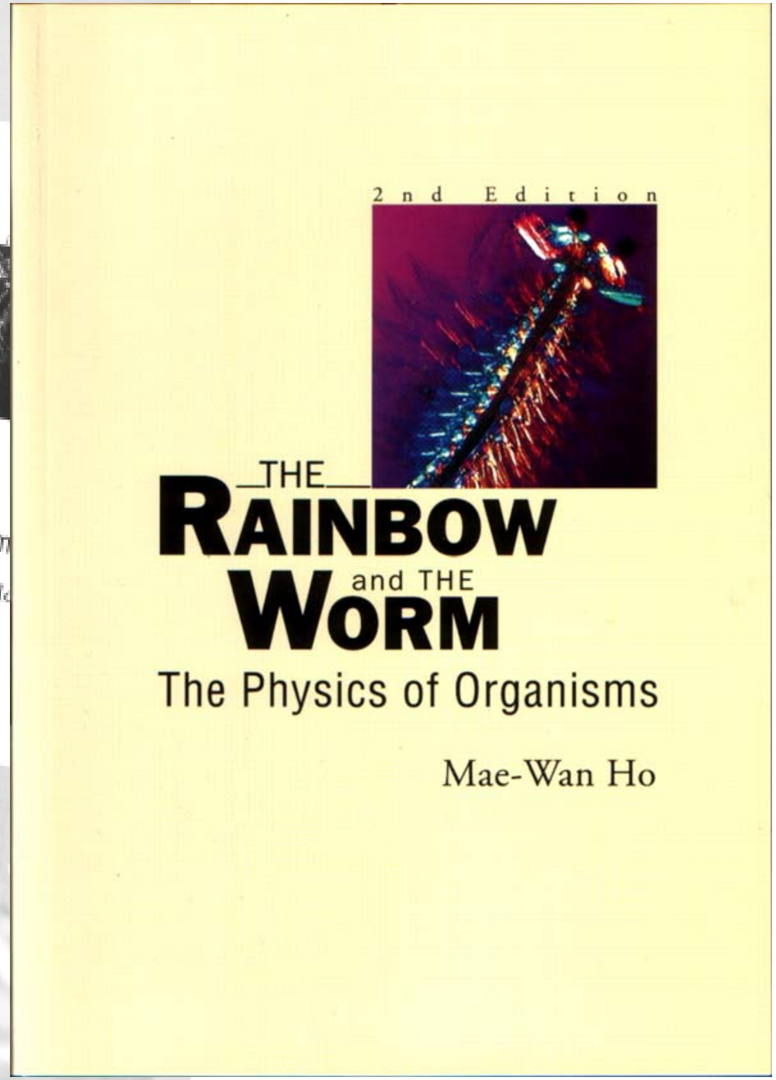
The **Rainbow** and The **Worm**

The Physics of Organisms

by **Mae-Wan Ho**
Institute of Science in Society

Readership: General





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- What is It to Be Alive?
- Do Organisms Contravene the Second Law?
- Can the Second Law Cope with Organized Complexity?
- Energy Flow and Living Cycles
- How to Catch a Falling Electron
- Towards a Thermodynamics of Organized Complexity
- The Seventy-Three Octaves of Nature's Music
- The Coherent Excitation of the Body Electric
- How Coherent is the Organism?
- Life is All the Colours of the Rainbow in a Worm
- The Liquid Crystalline Organism
- Crystal Consciousness
- Quantum Entanglement and Coherence
- The Ignorance of the External Observer

A serious, in-depth enquiry into Schrödinger's question, "What is Life?" and at the same time, a celebration of life itself

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Sustainable systems as organisms?

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Abstract

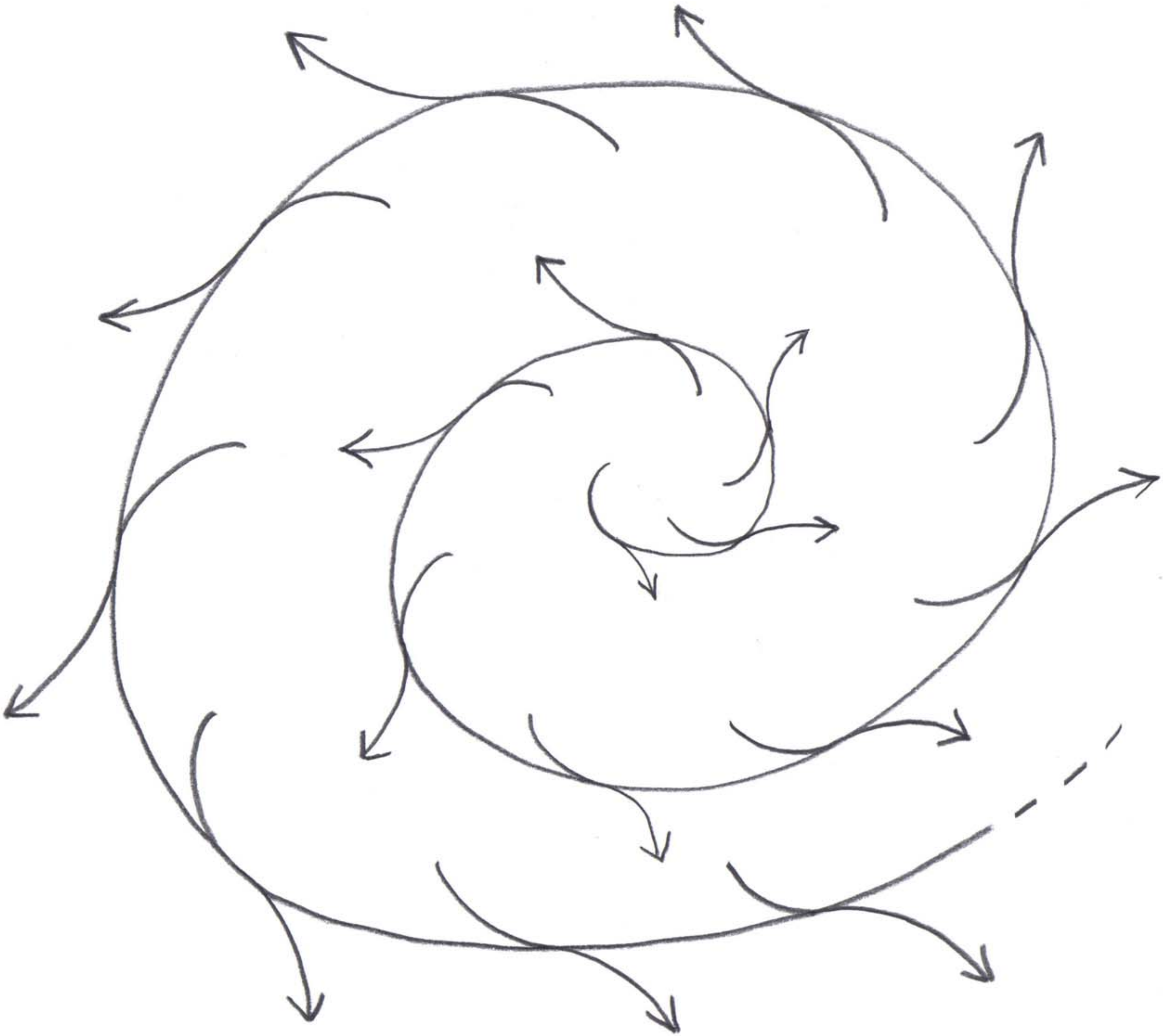
Schrödinger [Schrödinger, E., 1944. What is Life? Cambridge University Press, Cambridge] marvelled at how the organism is able to use metabolic energy to maintain and even increase its organisation, which could not be understood in terms of classical statistical thermodynamics. Ho [Ho, M.W., 1993. The Rainbow and the Worm, The Physics of Organisms, World Scientific, Singapore; Ho, M.W., 1998a. The Rainbow and the Worm, The Physics of Organisms, 2nd (enlarged) ed., reprinted 1999, 2001, 2003 (available online from ISIS website www.i- sis.org.uk)] outlined a novel "thermodynamics of organised complexity" based on a nested dynamical structure that enables the organism to maintain its organisation and simultaneously achieve non-equilibrium and equilibrium energy transfer at maximum efficiency. This thermodynamic model of the organism is reminiscent of the dynamical structure of steady state ecosystems identified by Ulanowicz [Ulanowicz, R.E., 1983. Identifying the structure of cycling in ecosystems. Math. Biosci. 65, 210–237; Ulanowicz, R.E., 2003. Some steps towards a central theory of ecosystem dynamics. Comput. Biol. Chem. 27, 523–530].

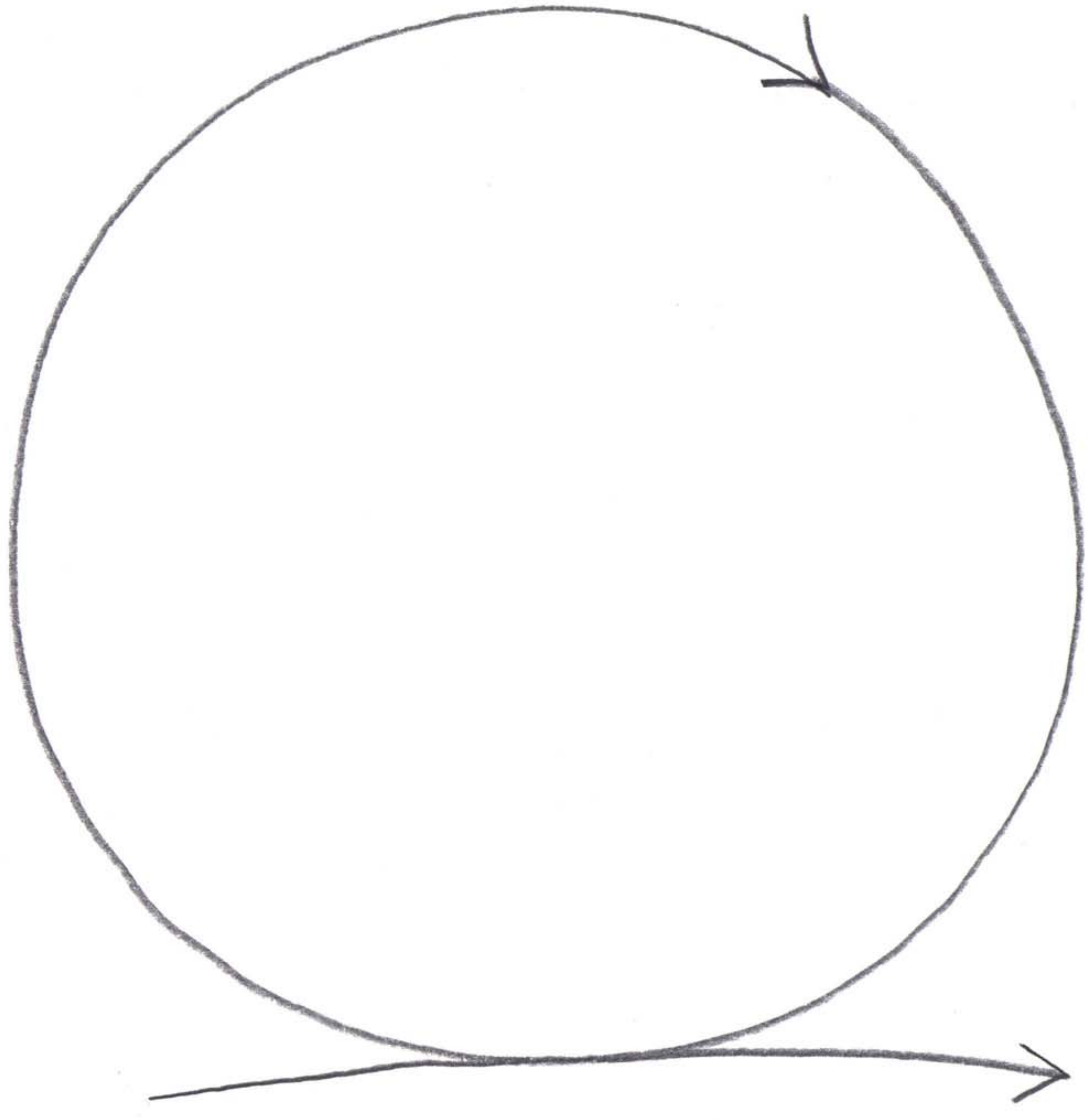
The healthy organism excels in maintaining its organisation and keeping away from thermodynamic equilibrium – death by another name – and in reproducing and providing for future generations. In those respects, it is the ideal sustainable system. We propose therefore to explore the common features between organisms and ecosystems, to see how far we can analyse sustainable systems in agriculture, ecology and economics as organisms, and to extract indicators of the system's health or sustainability.

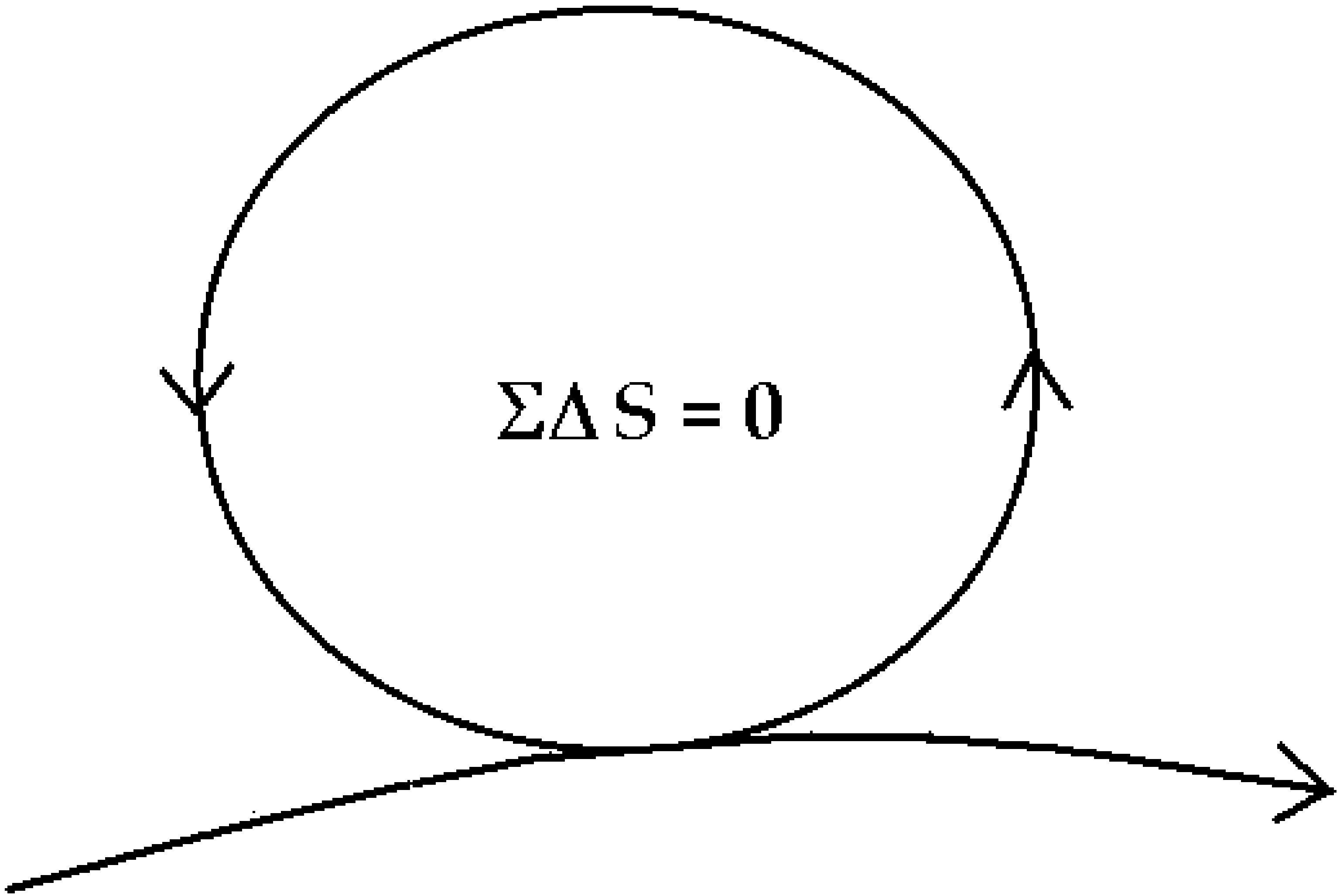
We find that looking at sustainable systems as organisms provides fresh insights on sustainability, and offers diagnostic criteria for sustainability that reflect the system's health.

In the case of ecosystems, those diagnostic criteria of health translate into properties such as biodiversity and productivity, the richness of cycles, the efficiency of energy use and minimum dissipation. In the case of economic systems, they translate into space-time differentiation or organised heterogeneity, local autonomy and sufficiency at appropriate levels, reciprocity and equality of exchange, and most of all, balancing the exploitation of natural resources – real input into the system – against the ability of the ecosystem to regenerate itself.

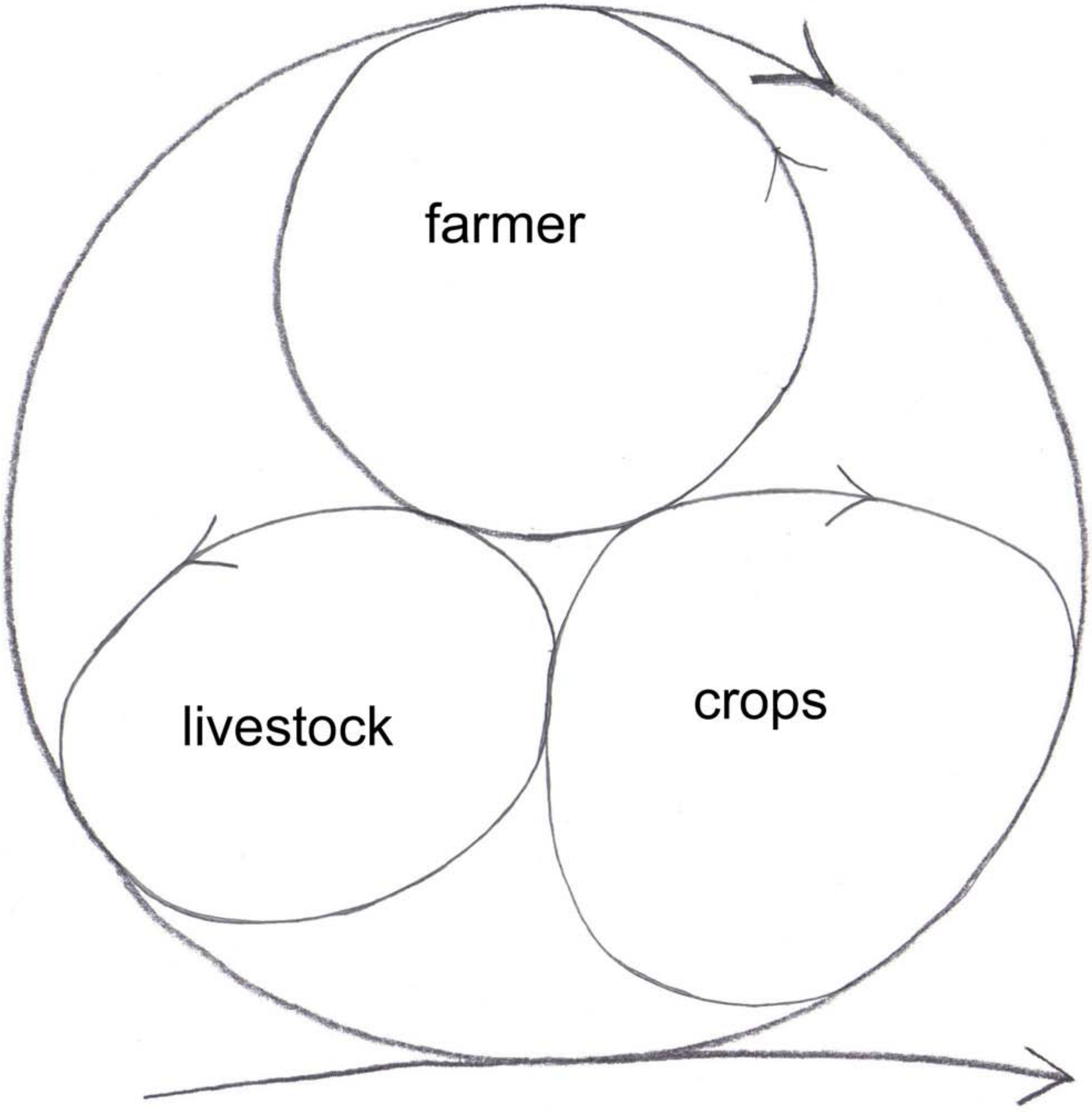
Keywords: Thermodynamics; Organised complexity; Cycles; Coherent energy storage; Indicators of sustainability; Minimum dissipation

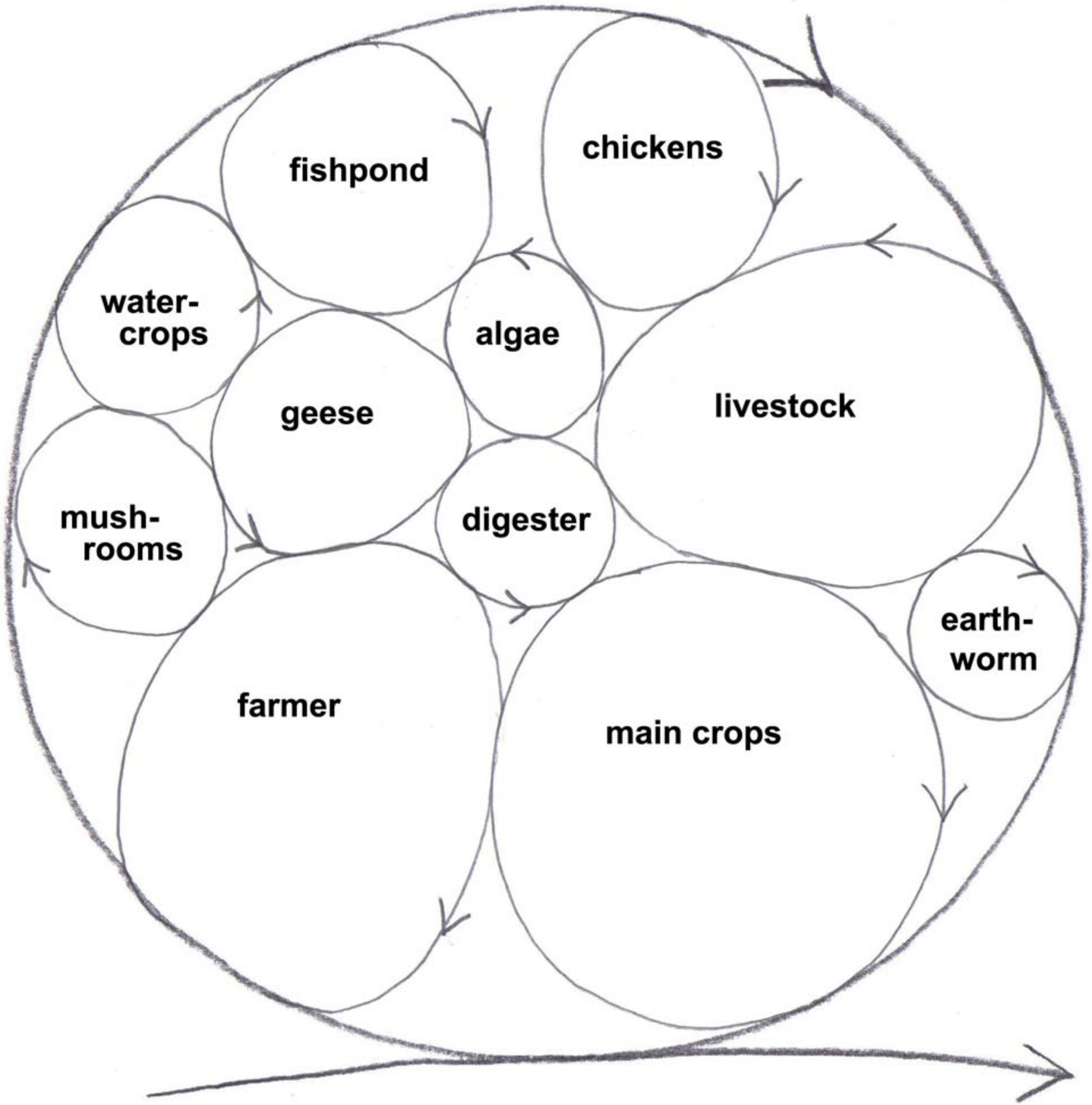


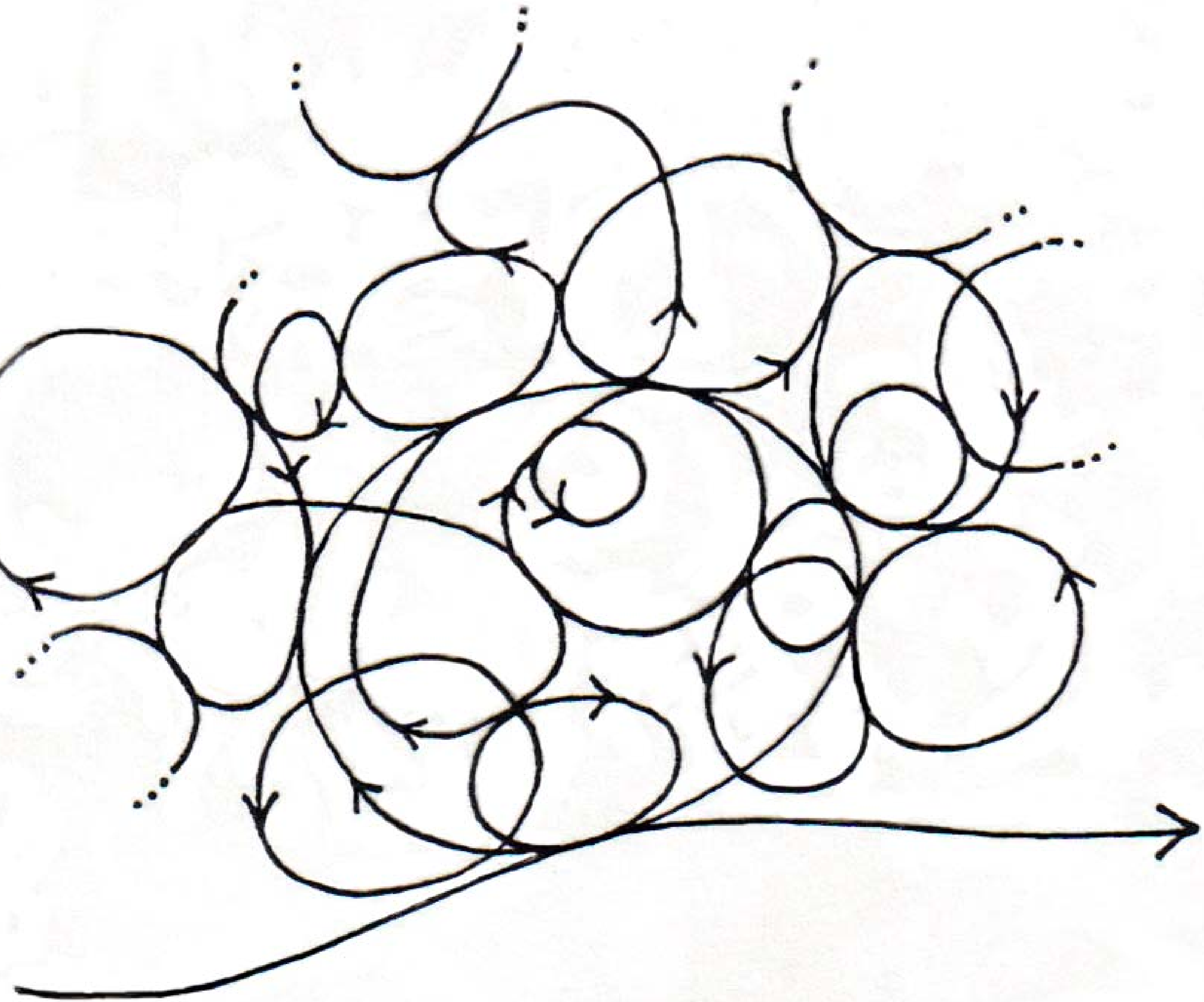




ΣΔS = 0


farmer
livestock
crops


fishpond
chickens
water-
crops
algae
geese
livestock
mush-
rooms
digester
earth-
worm
farmer
main crops



Energy, Productivity & Biodiversity

Generations of ecologists have puzzled over the causes of biodiversity and its relationship with productivity.

Dr. Mae-Wan Ho investigates.

"The secret of life is not to be found in the molecular nuts and bolts in living organisms. Instead it may be in how organisms use energy, giving concrete meanings to renewable living energy and sustainability"

Luminescence by LiPeon

"Why are there so many kinds of animals?"

This was the question asked by distinguished ecologist Evelyn Hutchinson in 1959, the centenary of Darwin's *Origin of Species*, a question that has remained as enigmatic today as it was then.

There are about a million described species of animals, three-quarters of them being insects, of which disproportionately large numbers belong to the order Coleoptera, or beetles. In contrast to land animals, there are far fewer species in the sea.

Hutchinson considered a number of possible explanations. Could food chains or feeding relationships suffice? If one supposes an energy conversion efficiency of 20% at every link of the chain, and each predator being twice as big as its prey, the fifth animal link will have a population of one ten thousandth (10^{-4}) of the first, which is about as long as it would get. Food chains could hardly generate a great deal of biodiversity.

Natural selection isn't going to help; an overly efficient predator will simply eat itself out of prey, thus breaking the link and making itself extinct in the process. While lengthening the chain is difficult, shortening the chain is not, the most dramatic example is the whale-bone whale, which can feed largely on plankton.

What about the diversity of terrestrial plants which provide a variety of different structures - bark, leaves, flowers and fruits - for different animals to feed on? A major source of biodiversity of land animals was indeed introduced by the evolution of almost 200 000 species of flowering plants, and the three-quarters of a million species of insects are a product of that diversity. But then, why are there so many different kinds of plants?

Part of the answer is that instead of linear food chains, nature is replete with food webs. Most predators eat more than one species of prey, which reduces the danger that it will eat its prey and itself extinct. So, at least part of the answer to why there are so many kinds of animals and plants is that biodiverse communities are better able to persist than less diverse communities. And that was the origin of the idea that complex ecosystems are more stable, which has been hotly debated to this day. While it may be intuitively obvious that the more flexible the links in the food web, the less likely they will break; mathematicians find it extraordinarily difficult to represent such flexibility, and more so, to agree on what constitutes stability, let alone complexity.

Energy available?

Going back to biodiversity, ecologists have long noticed that while a hectare of tropical rainforest contains an estimated 200 to 300 species of trees, the same area of temperate forest contains only 20-30 species. One hypothesis is that diversity is ultimately determined by the amount of energy available to an ecosystem. Support for this idea came from measures of productivity and biodiversity in different ecological communities. Productivity is the rate of production of biomass by an ecosystem, and is in general determined by the rate of energy supply.

High proportions of land and freshwater species on earth do occur in the tropics, which receive the highest amount of the sun's radiant energy. Average species richness increases from high to low latitudes and this has been documented for a wide spectrum of taxonomic groups, including protists (single-celled organisms), trees, ants, woodpeckers and primates, and for data across a range of spatial resolutions. Species richness also appears to increase with energy, measured as mean annual temperature, and evapotranspiration.

But that doesn't seem to be the whole story. The relationship between diversity and productivity was found to vary at different spatial scales. At large geographical scales, such as across continents in the same latitude, diversity generally increases with productivity. At smaller local scales (metres to kilometres), several different patterns emerge.

Early studies found biodiversity peaking at intermediate levels of productivity in a unimodal curve (a curve with a single hump). More recent reviews came up with a variety of relationships, with diversity increasing, decreasing or remaining unchanged as productivity increases. Although some of these patterns suggest that energy is causally involved, other factors may also be important, such as environmental heterogeneity: spatial or temporal variation in the physical, chemical or biological features of the environment.

Complexity of the environment?

In a simple lab experiment, the bacterium *Pseudomonas fluorescen* was used to test the relationship between environmental heterogeneity and diversity. This bacterium is known to rapidly differentiate into distinct 'morphs' in different microhabitats in unmixed culture vessels. One major morph flourishes at the interface between air and the liquid growth medium, another does best in the centre of the culture vessel and a third occupies the bottom of the vessel. The researchers found that there are further variations within each major morph, so that a total of ten types can be distinguished. Shaking the vessel eliminated environmental heterogeneity and, with it, diversity. With a gradient of productivity, a unimodal diversity curve was obtained. In other words, diversity increased with energy available up to a peak, and then decreased as available energy increased further.

Ecosystems typically consist of plants and animal species of vastly different sizes, from big mammals to birds, insects and microbes in the soil, which would use resource that matches their size. Thus, the more finely the species can divide up space and resources, the more species can coexist in the same habitat. But how best to represent this environmental heterogeneity?

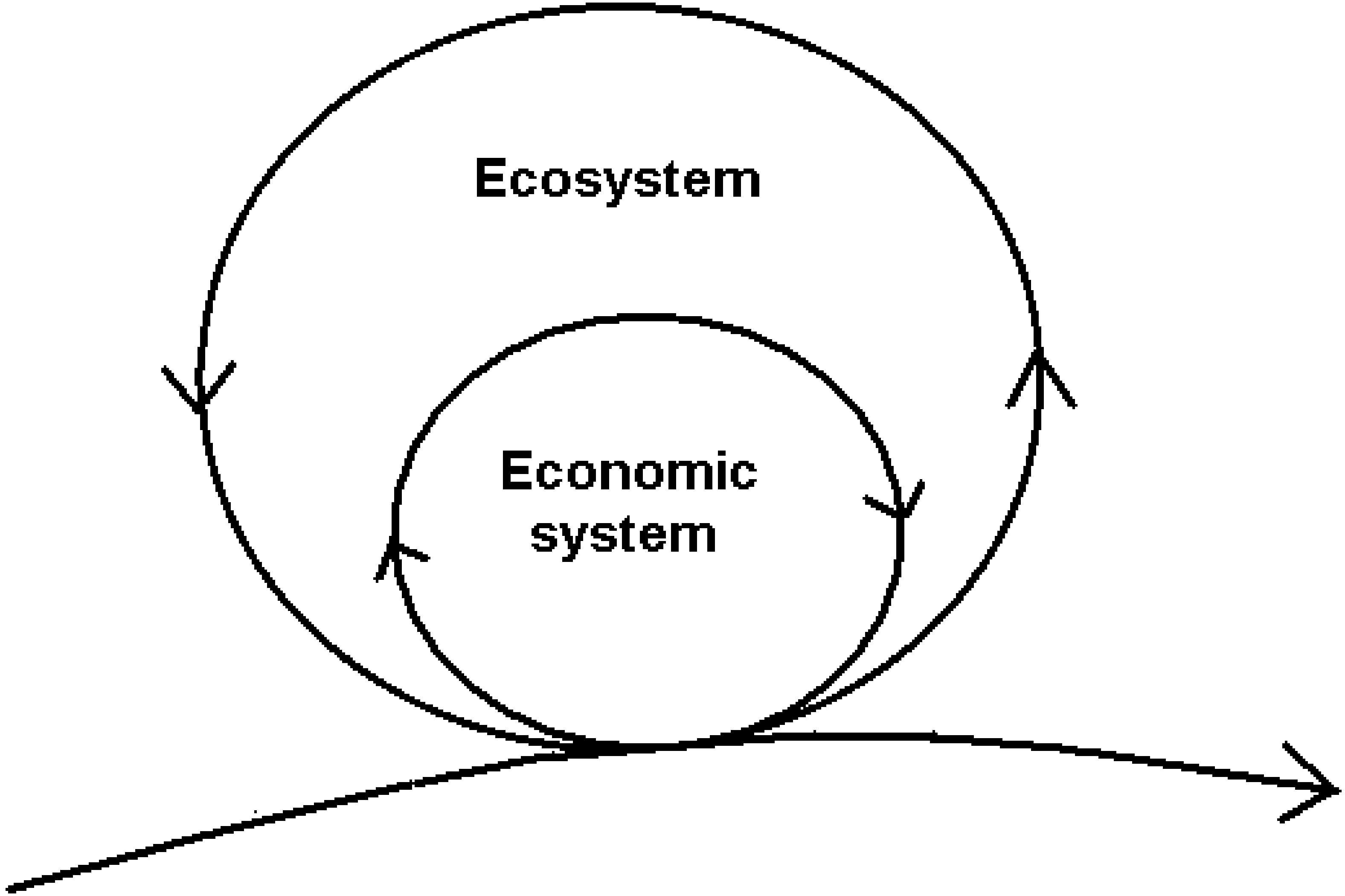
Mark Ritchie from the University of Utah, Logan, in the United States, and Han Olff in Wageningen Agricultural University, in the Netherlands, reasoned that the distributions of habitat, food and resources often appear to be statistically self-similar over three to four orders of magnitude. If so, their volume or area can be described with fractal geometry.

A fractal is a structure that has dimensions in between the usual 1, 2 or 3, and 'self-similar' refers to the property that the structure appears the same over many scales. Typical examples are fern leaves, branching blood vessels and the coastline.

In a fractal environment, body size determines the abundance of food and resources that a species perceives, and it sets limits to the similarity in body size between any two species. Ritchie and Olff derived a body size ratio between species of adjacent sizes that declines with increasing organism size. That in turn predicts how diverse the community can be.

Thus, energy, productivity and environmental heterogeneity all appear to play a role in creating biodiversity.

In the next article ("Why are organisms so complex?" this series), I shall show how biodiversity and productivity are intimately linked through energy capture and storage in a sustainable system.


Ecosystem
Economic
system

ISIS

Institute of Science in Society

www.i-sis.org.uk