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Synergetic City: Urban algae production as a regenerative tool for a post-industrial city.

Professor Greg KEEFFE [1]

The paper describes a utopian vision of a 'Free Energy City' set in Liverpool, where the old dockyards, redundant space, and the Mersey Estuary have been transformed into bio-productive algae farms, greenhouses and pasture, which work synergistically to provide a carbon neutral solution, to the regeneration of the city..

Liverpool is in dire straits, having lost half its population in 50 years through massive de-industrialisation. Its future looks bleak: any attempt to regenerate the city will have to deal with the huge amount of redundant space in the city, as well as geographic difficulties of attracting new industries. The paper describes the theoretical insertion of a series of glass factories, which produce glass tanks to house algae reactors, that themselves provide the energy to power the glass production. This allows for sustainable infrastructure to be self assembled in an iterative and carbon neutral manner, which once complete, provides more than enough energy to power the new city.

In Free Energy City, the city functions as an energy generator and thrives from its own product with minimal impact upon the planet it inhabits. Alga-culture is the fundamental energy source, where a matrix of algae reactors swamp the abandoned dockyards; which have been further expanded and reclaimed from the River Mersey. Each year, the algae farm is capable of producing over 200 million gallons of bio-fuel, which in-turn can produce enough electricity to power almost 2 million homes.

The metabolism of Free-Energy City is circular and holistic, where the waste products of one process are simply the inputs of a new one. This creates a series of synergies, where livestock farming – once traditionally a high-carbon countryside exercise has become urbanised and sustainable. Cattle are located alongside the algae matrix, and are fed the waste from the bio-oil extraction. The waste gases emitted by farmyards and livestock are largely sequestered by algal blooms, anaerobically converted to natural gas, or are used to fertilize soil in greenhouses to produce food in the city.

The paper is a spatial exploration of the scale of intervention necessary to make carbon neutral cities. It uses a research by design methodology to envisage a new, radical but sustainable future for Liverpool which mitigates the imbalances between ecology and urbanity, and exemplifies an environment where nature and the human machine can function productively and in harmony with one another, where new sustainable lifestyles are not radically different from today's.

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Greg Keeffe is an academic and practitioner who originally trained as an engineer and has 25 years experience in sustainability, energy use and its impact on the design of built form and urban space. He currently holds the prestigious Downing Chair of Sustainable Architecture at the Leeds School of Architecture. Previously he was the Head of Design at the Manchester School of Architecture. Over the past 20 years he has sought to develop a series of theoretical hypotheses about sustainability. Most of his work comes out of a free-thinking open-ended discussion about how things should be. Greg has extensive experience of working closely with architects and planners to develop exciting ways of re-invigorating the city through innovative sustainable interventions, informing his work on the sustainable city as synergistic super-organism. He is author of the book 'Means Means Means'; which develops a model of a new city, as an econose, of mutually compatible functional elements.

He has won international competitions to design carbon neutral neighbourhoods, eg Whitefield Nelson, Lancs, UK and low energy apartments such as Chorlton Park Housing, both of which have been highly rated by Commission for Architecture and the Built Environment in the UK.

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1. Introduction

The production and consumption of energy is the single biggest contributor to anthropogenic greenhouse gas emissions, and is directly linked to a rise in global air temperatures which could be as much as 6.5^{o}C by 2100 (IPCC 2008). Our soaring energy needs have grown in line with a bursting population and present more than just environmental problems. It is certain that our reliance on fossil fuels for the past 150 years has had catastrophic ecological consequences, but as we approach the end of the first decade of the 21st Century fossil fuel reserves are peaking and the country's future energy security is distinctly ambiguous.

When farmed sustainably, bio-fuels offer a robust alternative to fossil fuel energy and do not contribute to the rise in anthropogenic greenhouse gas emissions. However, they traditionally require a large area of land to produce a worthy amount of biofuel and compete with food crops for that land. Algae derived aquatic biofuels offer energy yields over 100 times greater than traditional bio-crops such as rape seed and soya, and do not compete for land with food crops. Scientific research shows that cultivated algae could produce up to 150,000 litres of biodiesel per hectare per year (Briggs, 2004) given a suitable strain, but potentially this figure could reach 5,800,000 litres per hectare with further technological advancement. Could algae offer not only a new sustainable and clean energy source, but also a new impetus to save failing cities?

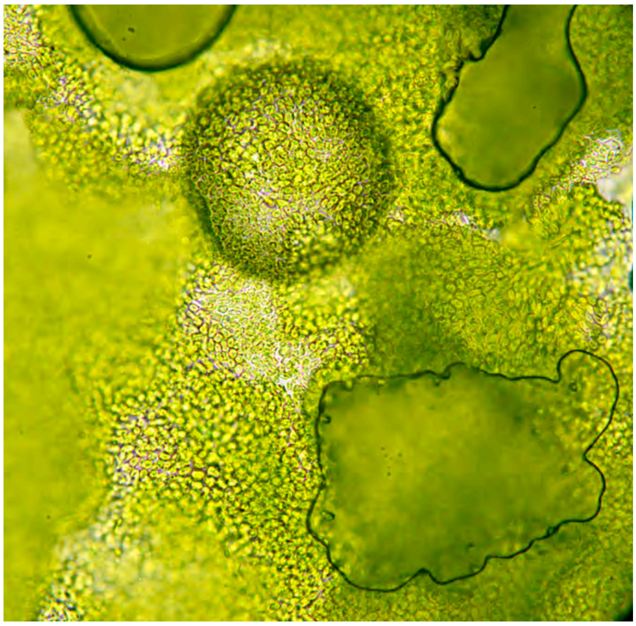

Figure 1   Strathcona refinery, North Central Alberta, Canada. Daily Capacity - 187,000 barrels of crude oil.
Figure 2   Spirulina algae under intense magnification. A biodiverse alternative to fossil fuels.

<u>Liverpool UK</u>

Bio Port Free Energy city is a sustainable urban model set in Liverpool, UK which shows that energy can be produced in such prolific volumes on a city's hinterland and that it can be provided 'free-of-charge'. Liverpool, was at the turn of the 20th Century the Worlds largest port, with 12km of docks, and unrivaled wealth and monument. Its position on the North West coast of England, made it geographically perfect for trade with the Americas.

Figure 3 Liverpool today: dereliction abounds

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However global changes to shipping, and the decline of the Lancastrian cotton industry, and the change of emphasis of the UK's trade from one with America and the colonies to Europe in the latter part of the 20th century, has created a much less triumphant present. Recent times have seen decay, poverty and shrinkage at frightening levels. Nearly half of Liverpool's 28 districts are rated as in the worst 50 in the whole of the UK, with 4 in the bottom 10 for deprivation. In some areas adult unemployment is at 90%. This situation culminated in 2003 when census data showed Liverpool had lost over half its population (some 500,000 people) in less than 50 years. Today over 10 per cent of Liverpool's land area is derelict and abandoned. In 2004 the Commission for Architecture and the Built Environment in the UK stated that space was a luxury in the modern city, however in places like Liverpool the oversupply of land has made spaces become fractured, and land prices plummet: actually space here is a liability. Any new solution to Liverpool's plight must reconfigure the prodigious amount of spare space to re-make a contiguous urbanism.

A new impetus for economic growth and spatial sustainability is needed if this decline is to be halted. This paper describes an ambitious project that uses algae production on a huge scale to develop a new ecology for Liverpool, that is not only environmentally sustainable, but also economically and socially sustainable creating new industries and jobs, and also helping to end poverty in the city, through free heat and power.

Bio-Port Free Energy City is a self-assembly sustainable insertion of glass factories powered by biodiesel from algae arrays in the now redundant natural harbour of the Mersey Estuary, symbiotically combined with urban food production in the vacant urban space. Overall the insertion produces some 4.4TWh's of electricity each year, provided by 6,000 hectares of algae matrix, photovoltaic arrays and an off-shore wind farm. The large scale algae matrix by powering bio-diesel fueled cogeneration plant, produces over 3,400,000,000KWh of electricity and more than 26,500,000GJ of heat per year; enough energy to heat and power over a million homes.

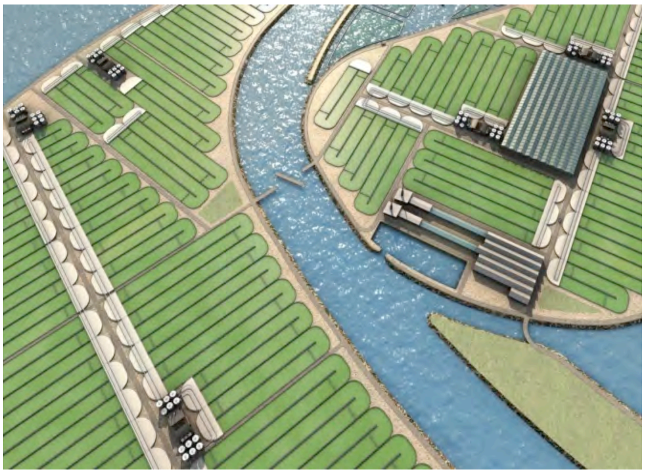
2. Algaculture

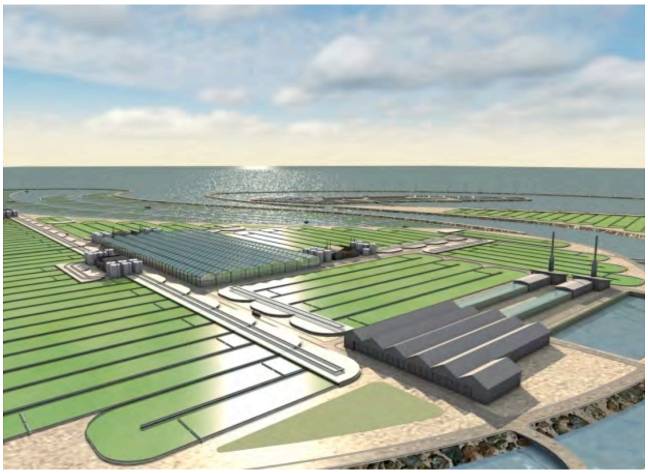
Microalgae are an aquatic biofuel, exceptionally rich in bio-oil and natural hydrocarbons and can double their volume up to four times daily; a significant advantage over traditional bio-crops which are usually harvested no more than once or twice a year. At a time of climatic crisis one of the most relevant qualities of algae is its inextricable appetite for carbon dioxide which together with sunlight is used during photosynthesis. The synergy between carbon sequestration and natural algal-oil production is highly profitable: as more algae is cultivated, more oil is produced, but more importantly more carbon dioxide is removed from the atmosphere and converted to oxygen. Unlike terrestrial energy crops, algae have a continuous production cycle and sequester the carbon equivalent of twice their own weight – roughly one tonne of marine algae biomass to two tonnes of carbon dioxide (GHGMP, 2008).

There are said to be over 100,000 strains of algae, which vary immensely according to shape, size, colour and biological make-up. Seaweed is a typical form of algae, but so too is the thick green sludge which can often be found resting on the surface waters of freshwater swamps and ponds. It is the strains found in these thick sludges *or* blooms that contain the most natural oil and hydrocarbons. A strain suitable for biofuel cultivation must not only have high lipid oil content, but also have a fast growth rate to secure maximum energy yields. Two of the most productive strains are Spirulina and Botryococcus Braunii, which produce natural oil up to 45 per cent of their dry weight.

It is possible to mimic the aquatic environments in which the algae grows in glass bioreactors, *or* 'raceway ponds', which are effectively translucent cultivation tanks for growing algae. Once established, the thick green biomass is removed from the surface water and pressed to separate natural oil from waste pulp which itself has multiple applications from animal feed and fertiliser to soap and cosmetics. Once a crude bio-oil has been extracted, it can be processed into bio-diesel and used to fuel reciprocating engines producing heat and electricity, or simply used as carbon-neutral transport fuel.

There are 6,000 hectares of bioreactors in Free Energy City, constructed on over 190 hectares of existing derelict dockyards and further land reclaimed from the Mersey Estuary and Liverpool Bay. The energy is produced cleanly in vast quantities, superfluous to society and the city system, but wholly carbon-neutral provided by a constantly expanding algae matrix which not only produces enormous volumes of naturally cultivated energy, but also act as a colossal carbon sink which utilises the waste gases of the city in its photosynthetic growth cycles. The algae matrix is an organic energy factory which grows symbiotically with urban growth, absorbing increasing volumes of carbon as the urban realm and algae matrix mutually expand.





Figures 4 and 5 Visualisations of the Free Energy City algae matrix, including bioreactors, CHP processing plants, glass furnaces and super-greenhouse constructed on reclaimed land from the River Mersey estuary.

The algae matrix, which includes processing plants, storage tanks and reciprocating engines, produces 150,000 litres of biodiesel per hectare per year (NREL, 1998) equating to a total of 900 million litres across the entire energy farm. In *layman's terms*, just one hectare of algae would produce enough fuel for a family car to travel round the world 75 times. The matrix is split into a relay of sectors, each covering 138 hectares, with their own bioreactors, processing plants and a 9MW CHP reciprocating engine. Over 20 million litres of biodiesel per year are cultivated by each sector which generates 78MWh of electricity and 611TJ of heat equivalent to the power demand of over 23,000 homes.

Figure 6 Free Energy City masterplan, highlighting bioreactors, processing plants, glass furnaces and super-greenhouse.

3. Cityscape Integration & Urban Synergy

3.1 Self-assembly

One of the key ideas for Bio-port is the idea of self assembly. The insertion begins with the development of a glass recycling centre. This then produces the glass which is the major component of the bioreactors and food producing greenhouses. The algae arrays, then start producing energy for the glass production, which helps create more algae plants. In its final form, bio-port has 10 glass recycling facilities, capable of recycling the whole of Europe's glass, easily transported to and from the facilities by boat. The production of free energy is a catalyst for self-generated industry, both new and old. Europe's glass production can operate from Liverpool, exploiting the opportunity for free energy and low carbon credentials. Titanium and recycled aluminum is smelted in carbon neutral blast furnaces which is in turn used to manufacture in-situ greenhouses that populate decayed realm across the city's 28 wards. Liverpool is a city of diamonds, made from pieces of carbon graphite using huge amounts of free electricity to alter their atomic structures. Homes are heated for free; electrical appliances are used without concern for soaring energy bills. Transport in and around the city is carbon neutral, run on electricity and bio-diesel; electric moving pavements replace buses - Liverpool is carbon-neutral.

3.2 Glass Production

Float glass is one of the most commonly used materials in construction today, but its manufacture is one of the most energy intensive industries of our time. The service life of a float line does not usually exceed ten years, and it is feasible therefore that within that time all float glass produced in Europe could shift to Liverpool and be manufactured using carbon neutral ‘free’ energy. The transport costs associated with float glass are astronomical, but as Liverpool is a port city these costs are alleviated by utilising the existing dock infrastructure to ship glass around Europe.

There are ten glass plants in Bio-Port Free Energy City which produce 256,000 tonnes of glass a year. Each plant uses 2000 cubic metres of natural gas and 2 tonnes of bio-oil an hour, all of which is carbon neutral and free-of-charge. The algae matrix provides the energy for each float plant - specifically bio-oil, oxygen and electricity which accounts for 381 acres of algae bioreactors in total per plant. The natural gas consumed by each plant is provided by six 4,000,000 litre anaerobic digesters which together process the manure of 6200 cattle and produce 2000 cubic metres of organic and renewable bio-methane a year. The cattle in Free Energy City have a symbiotic relationship with algae as their waste gases are largely absorbed by the algal blooms and converted to oxygen. The gases are in fact a nutrient source to the algae which flourish as a result of their presence.

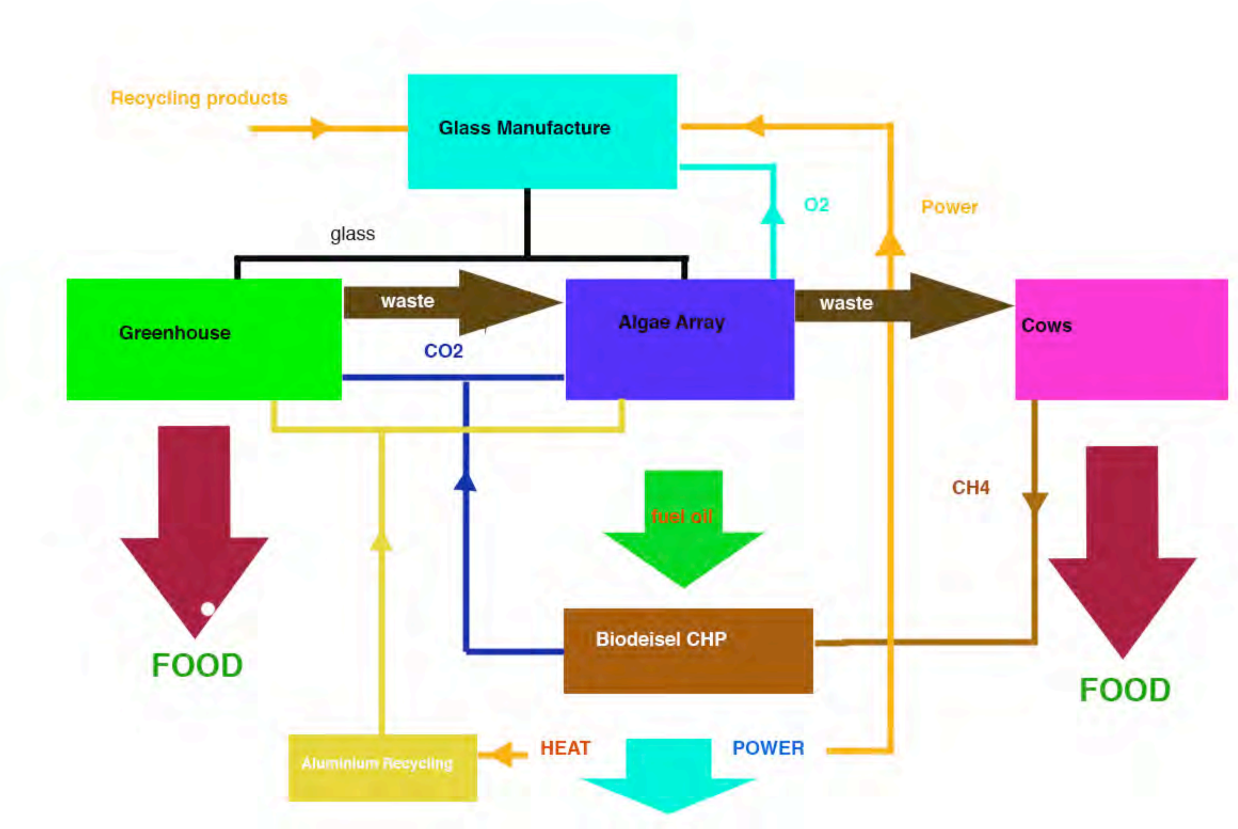


Figure 7. Resource cycle networks in Bio port

Glass produced in Free Energy City is used to construct each algae bioreactor which multiply as more glass is produced. There are a number of key synergies between glass manufacture and algae in Free Energy City, firstly in terms of productivity – the more algae that is cultivated, the more energy can be produced and thus the more glass can be manufactured; which produces more bioreactors. Manufacturing glass produces prolific volumes of waste gases, but as with the power plants in Free Energy City, these waste gases are recovered via flue extract systems and injected directly back into the algal blooms. Not only does this minimise the amount of carbon dioxide admitted into the atmosphere, but also acts as a vital nutrient source to the algae.

Figure 8 The key synergies of Free Energy City

Soda ash is a fundamental constituent of glass, and is provided naturally within the energy matrix by a co-operative of kelp-farms. Kelp is an immensely biodiverse seaweed macroalgae which produces not only bio-oil, but also soda ash when dehydrated. The kelp in Free Energy City utilise a marine location off the coast of the algae matrix, and grow as Sargussum Fulvellum forests up to 20 metres deep, chosen for their rapid growth rates and resilience to cooler waters. The kelps grow up a network of seeded ropes suspended in the ocean, harvested by reaping vessels up to four times a year. The kelp is made up of 90 per cent water, but the remaining 10 per cent contains the valuable commodities which when distilled and fermented produce natural bio-oil. Of that 10 per cent, two thirds is processed as bio-oil and the remaining third consists of organic soda ash which is used to make glass. This translates to approx 80,000 tonnes of soda ash and approx 160,000 tonnes of bio-oil which could produce enough electricity to power over 200,000 homes.

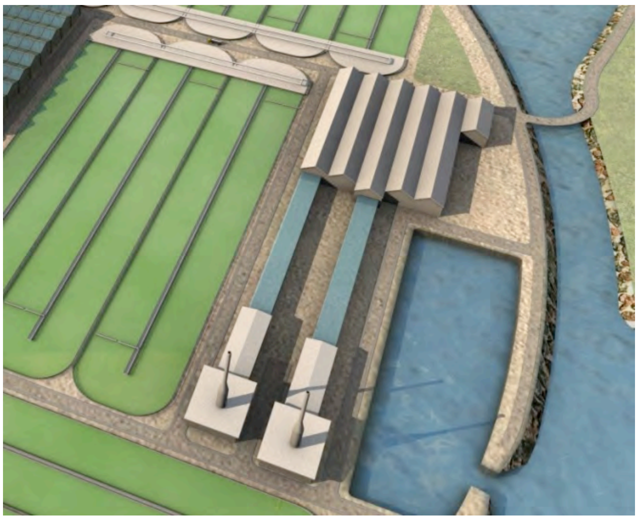


Figure 9 Kelp grown in marine environment using seeded ropes.
Figure 10 Glass furnace set within the algae matrix, where waste gases are sequestered by open-air glass bioreactors.

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The impact of the relationship between glass and algae extends much further than their mutual boundaries. As more bio-oil is produced using glass bioreactors, more land can be reclaimed using this bio-diesel ensuring that the process is kept carbon neutral. In sync, as more land is reclaimed more bioreactors can be installed thus more energy produced, in turn providing more fuel for more glass furnaces within the matrix.

The installation of the huge array in the estuary, also helps with another developing issue with regards Liverpool's precarious position, that of storm surges. The arrays create a barrage to the sea, that can help to alleviate this threat to the historic merchant city near the sea.

3.3 Greenhouse Regeneration

At a time where land is precious, food is short and energy is expensive and volatile, new synergies for growing food and energy must be established. The UK is a comparatively small island for its population and it is a near impossible challenge to grow the volume of food needed to sustain 61 million people, let alone produce their energy as well. If we are to attain a sustainable urban future, urban areas need to rationalise their hinterland to provide both food and energy in a synergistic fashion.

Approximately 11 million square metres of Liverpool is considered decayed and unprogrammed space (Save Liverpool Docks, 2008). The derelict space within each ward can be used to farm fresh produce in greenhouses manufactured within the algae matrix. Anfield is the 'tomato ward' where streets of derelict terraces are turned into linear greenhouses which imitate the physique of terraced heritage, but with glass instead of crumbling brick. The greenhouses are filled with towering organic vines that in total produce over 12 million tomatoes per year sold through farmers' markets locally and further afield. The process is organic and carbon neutral; high protein waste algae and recovered carbon dioxide is used to fertilise the vines, and eleven hives house over 6,000 bumble bees which pollinate the plants throughout the year.

Each greenhouse is heated during the winter by waste heat from Anfield's biodiesel combined heat and power plant, which is fuelled by biodiesel produced in the algae matrix. Carbon dioxide is recovered from the flue and routed directly to the base of each vine, which not only stimulates growth but also minimises carbon emissions from the energy manufacturing process. By turning vacant plots into organic vegetable factories, a pro-active advance on regeneration occurs where not only the aesthetic is substantially improved, but also the nature of regeneration becomes purposeful and productive.


Figures 11 and 12 Anfield: Tomato Ward – 462 tons of glass; 18,000 square metres of greenhouses; 43,000 tomato vines

3.4 Energy Eccentrics

The notion of 'free energy' is a direct result of maximising a city's potential to grow energy on its immediate hinterland, which as shown can be feasibly achieved when a synergistic and mutual balance is reached between man and nature; energy and algae. Energy is sold free-of-charge within the city not only as an asset to the city's inhabitants, but also as a source of economic growth and urban regeneration. Liverpool is a city of turbulent economic heritage which has led to vast areas of derelict and worthless urban space. However, the 'free energy' urban philosophy challenges this.

Free Energy City leases land to newcomers and outside investors to the city, at a cost substantially less than their annual energy bills. In this way energy intensive manufacturers' such as Pilkington Glass, British Steel, or De Beers Diamonds flock to Liverpool in a bid to capitalise on free energy, and by doing so increase land values across the city as the urban economy thrives. The capital raised from land leasing schemes pays for the running costs of the energy matrix, which after initial outlays are largely constant. As previously discussed, there are approximately 11 million square metres of derelict land in Liverpool. If a quarter of that space was assigned to new commercial & energy intensive infrastructure, rentals inclusive of carbon neutral energy could be as little as 100 Euros per square metre per year.

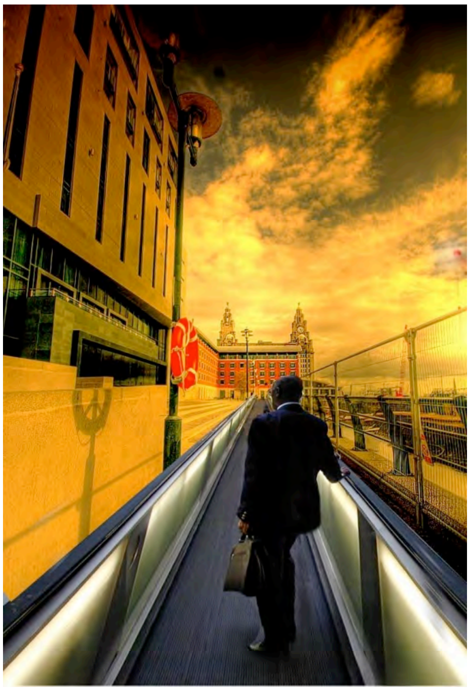

Figure 13 Electric moving pavements at Pier Head, Liverpool. Figure 14 With 'Free Energy' why not install under-lawn heating & use the garden all year round?

In its current state, Liverpool would only consume 50 per cent of the 4.4TWh produced (BERR, 2006) on the city's hinterland, and there remains at least 2.2TWh's of electricity per year, equivalent to the electrical consumption of over 650,000 homes to be directed to fresh and innovative purposes as well as commerce and industry. This provides unique opportunities for influxes of energy intensive operations and services to the city such as an electrically driven mono-rail transit system which provides inhabitants with free carbon-neutral transport between the centre and its suburbs. The city is bustling with electric hybrid vehicles, especially in light of current fuel prices and irregularity in petro-diesel markets. On a domestic level free electricity offers Liverpudlians new luxuries such as under-lawn heating in gardens, and an average saving of £1500 per year of utilities bills; as well as over £2000 on transport fuel, which leaves a significant portion of disposable income to be spent elsewhere.

5. Paradigm Shift

Energy is a constantly fought over commodity, but Free Energy City demonstrates that by rationalising a city's immediate hinterland, whether rooftops, rivers, estuaries or even derelict realm, into urban energy farms, such a prolific amount of energy can be produced that it becomes a clean and 'free to use' asset. By running cities autonomously on decentralised independent networks, current alternatives like nuclear are completely redundant not only on efficiency and production grounds, but on ecological terms also. Farming algae to provide energy could not get more sustainable; algae are nature's answer to an enormous human race. The solution is symbiotic – the more algae we farm, the more carbon we absorb, but perhaps more important to the synthetic system the more energy we produce.

Despite sometimes alternative media reflection and ambiguity, the future of our energy production will be renewable, not simply because the ice caps are melting, but because such a terrific volume of energy can be produced using renewable resources like algae. To run the United Kingdom solely on algal blooms, a farm roughly the size of Norfolk would have to be harvested. But to think that the oceans already exist as a giant algae farm - in fact 90 per cent of the oxygen we breathe is produced by surface borne ocean algae; and the oceans are over seventy thousand times larger than Norfolk. Algae energy has quite simply staggering potential.

Synergy is ubiquitous in Free Energy City, and as a result the urban realm grows naturally without compromising its carbon-neutral physique. As each stakeholder within the synergy expands, whether biofuel production; land reclamation; glass manufacture; kelp farming, even recovered heat and carbon dioxide, the holistic synergy expands with it. As a result, the algae matrix will expand naturally further into the Liverpool

Bay and the Irish Sea, cultivating more and more energy as it grows. Urban growth is a direct result of farming algae energy on the city's hinterland, which is used to attract new investment to the city. Uniquely however, the carbon sink of the algae matrix expands in parallel with urban growth and the carbon emissions associated a sprawling city.

In Free Energy City, energy is not associated with anthropogenic global warming. In fact it is quite the opposite: the model shows that specific renewable energy production can facilitate massive carbon sequestration and multiply biodiversity within urban space. Free Energy City represents a paradigm shift from urban consumption to urban production, where abundant volumes of carbon-neutral energy, organic produce and industry have become symbiotic partners in a dynamic and sustainable urban model. It is the contemporary result of this mutual and symbiotic relationship that must become ubiquitous if humanity is to continue indefinitely within the self-regulating system that is 'Gaia'.

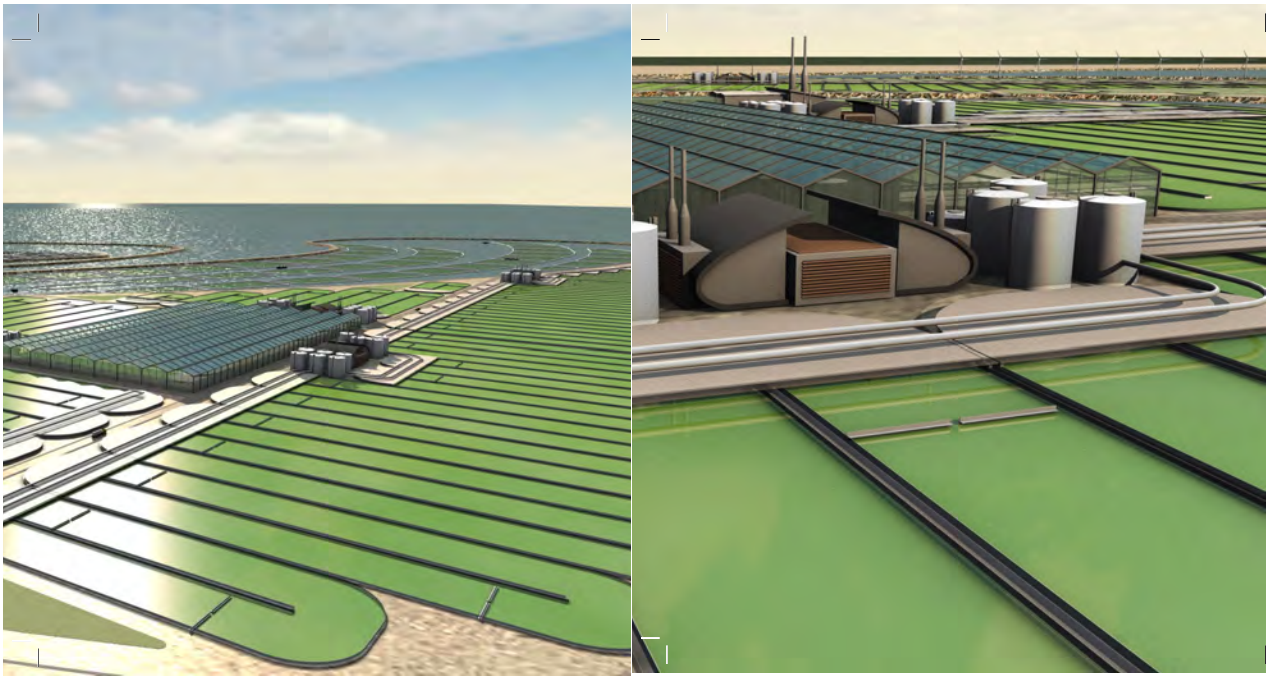

Figure 15. Bioport Algae arrays, kelp farms and glass recycling facility.

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