The New Biomasssters

Synthetic Biology and the Next Assault on Biodiversity and Livelihoods

etc group

action group on erosion, technology and concentration

"Whoever produces abundant biofuels could end up making more than just big bucks —they will make history...The companies, the countries, that succeed in this will be the economic winners of the next age to the same extent that the oil-rich nations are today."

J. Craig Venter
Synthetic Genomics, Inc., 20 April 2009

About the cover

'The New Biomass Harvest' by the Beehive Design Collective, 2010 – after Alphonse Mucha's 'Autumn' (from The Seasons Series 1896, as shown below). According to historian Vaclav Smil, the 1890s was the last decade in which the global industrial economy ran primarily on biomass. For today's biomass economy Mucha might depict a very different harvest.

Acknowledgements

This report resulted from close collaboration with many allies in civil society who have actively participated in its genesis, research, writing and review. In particular we owe a large debt of gratitude to Dr. Rachel Smolker of Biofuelwatch, as well as to her colleagues Almuth Ernsting and Deepak Rughani. Part of the original research and framing of this report was carried out by Rachel and much of what we learned about biomass we learned first from her. We are also very grateful to Delphine Deryng and Jose Borras Ferran who contributed original research and writing as interns at ETC Group.

Thank you to David Lee and Lara Lucretia and all at the Beehive Design Collective who have not only provided excellent original artwork, but inspiration, camaraderie and some neat phrases. Thanks also to Helena Paul of Econexus for providing comments on very early versions of this report and to Anne Petermann and Orin Langelle of the Global Justice Ecology Project. This report has its roots in a series of meetings organized by civil society to explore the implications of BANG (converging technologies), including an international seminar in Montpellier, France, in November 2008 convened by ETC Group, The What Next? Project, BEDE, Fondation Sciences Citoyennes and subsequent regional meetings convened by (amongst others) Centro Ecológico (Brazil), FASE (Brazil), African Biodiversity Network (Ethiopia), African Centre for Biosafety (South Africa), CASIFOP (Mexico), Alliance for Humane Biotechnology (US), EQUINET, SEARICE (Philippines), Friends of the Earth (US), ICTA (US), Center for Genetics and Society (US) and Movement Generation (US). We are extremely grateful to all of the participants and others who have helped shape our thinking on these matters. ETC Group gratefully acknowledges the financial support of SwedBio (Sweden), HKH Foundation (USA), CS Fund (USA), Christensen Fund (USA), Heinrich Böll Foundation (Germany), the Lillian Goldman Charitable Trust (USA), Oxfam Novib (Netherlands), Ben and Jerry's Foundation (USA) and the Norwegian Forum for Environment and Development (Netherlands).

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Copy-edited by Leila Marshy

Design by Shtig (.net)

Original Artwork by the Beehive Design Collective and Shtig

The New Biomassters: Synthetic Biology and the Next Assault on Biodiversity and Livelihoods is ETC Group Communiqué # 104

First published October 2010
Second edition November 2010

www.etcgroup.org

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The New Biomassters

Synthetic Biology and the Next Assault on Biodiversity and Livelihoods

Overview

Issue

Under the pretext of addressing environmental degradation, climate change and the energy and food crises, industry is portending a "New Bioeconomy" and the replacement of fossil carbon with living matter, now labeled "biomass." The most productive and accessible biomass is in the global South – exactly where, by 2050, there may be another 2 billion mouths to feed on lands that (thanks to climate chaos) may yield 20-50% less. Although this would seem to be the worst time possible to put new pressures on living systems, governments are being told that "Synthetic Biology" – a technology just being invented – will make and transform all the biomass we will ever need to replace all the fossil fuels we currently use. Meanwhile, new carbon markets are turning plant-life into carbon stocks for trading (in lieu of reducing emissions). But, the companies that say "trust us" are the same energy, chemical companies, agribusinesses and forestry giants that created the climate and food crises in the first place.

Amidst rising hunger and climate chaos this would seem to be the worst time possible to put new pressures on living systems.

At Stake

Food, energy and national security. With 24% of the world's annual terrestrial biomass so far appropriated for human use, today's compounding crises are an opportunity to commodify and monopolize the remaining 76% (and even more in the oceans) that Wall Street hasn't yet reached. Industrial sectors with an interest in switching carbon feedstocks to biomass include the energy and chemical, plastics, food, textiles, pharmaceuticals, paper products and building supplies industries – plus the carbon trade – a combined market worth at least $17 trillion.[1]

Actors

The business media report on start-up companies like Synthetic Genomics, Amyris Biotechnologies and LS9 but, behind the headlines, the money to develop synthetic biology is coming from the U.S. Department of Energy and major energy players like BP, Shell, ExxonMobil, chemical majors like BASF and DuPont and forestry and agribusiness giants such as Cargill, ADM, Weyerhaeuser and Syngenta. While initial demonstration facilities are being developed largely in Europe and USA, ultimately 'geography is destiny' for the biobased economy: countries with the most living plants will also end up having the most production plants. Industry is already lining up Brazil, Mexico, South Africa and Malaysia as testing grounds for the new technology. OECD governments, meanwhile, are pumping over $15 billion of subsidies into the biomass economy.

Fora

Even leading companies and scientists involved in synthetic biology agree that some oversight is necessary, and they acknowledge potential new biosafety hazards from novel microbes and plants. Although synthetic biology and the biomass economy will have a massive upstream impact on land use, biological diversity, the environment and human well-being, those implications are being ignored by most governments and researchers. Within the United Nations, only the Convention on Biological Diversity (CBD) is addressing synthetic biology. Despite the implications for food security, the UN Food and Agriculture Organization (FAO) and the Consultative Group on International Agricultural Research (CGIAR) seem blissfully unaware of recent developments.

'Biomassacre' by the Beehive Collective

In the UNFCCC (climate change) negotiations, South governments seem to be unaware that "technology transfer" will be leveraged to extend industry's monopoly over biomass technologies to the South's lands and resources. The implications of the "New Bioeconomy" are so vast that they should be on the agenda of every UN agency and must, especially, be addressed at the Rio+20 Summit to be held in Brazil in 2012.

Policies

Announcements during 2010 that synthetic biology researchers can substantially manipulate DNA to build artificial, self-replicating microorganisms that have never before appeared on Earth have immediate implications for biodiversity, biosafety and national economies. Synthetically constructed life forms should not be released into the environment, and the UN and national governments should establish – at the very least – moratoria to prevent such releases. As urgently, studies must be undertaken to determine the implications of what the U.S. government calls "the bio-based revolution" for climate change, the world's ecosystems, food and energy supplies and for livelihoods and land rights.

Civil society and social movements organized around agriculture, land rights, forest protection, marine issues, emerging technologies, chemical toxins, climate change, energy justice and consumption urgently need to find means to share analysis and co-ordinate resistance in addressing common threats arising from the New Bioeconomy.

Contents

Introduction: Beware Biomass

Around the world, corporate and government strategies to address climate change, energy, agriculture, technology and materials production are increasingly converging around one telling concept: Biomass.

Biomass encompasses over 230 billion tonnes of living stuff[2] that the Earth produces every year, such as trees, bushes, grasses, algae, grains, microbes, and more. This annual bounty, known as the Earth's 'primary production,' is most abundant in the global South – in tropical oceans, forests and fast growing grasslands – sustaining the livelihoods, cultures and basic needs of most the world's inhabitants. So far, human beings use only one quarter (24%) of terrestrial (land-based) biomass for basic needs and industrial production[3] and hardly any oceanic biomass, leaving 86 percent of the planet's full biomass production (both land and sea) as yet uncommodified.

But, thanks to technological changes – particularly in the fields of nanotechnology and synthetic biology – this biomass can now be targeted by industry as a source of living 'green' carbon to supplement or partially replace the 'black' fossil carbons of oil, coal and gas that currently underpin Northern industrial economies. From generating electricity to producing fuels, fertilizers and chemicals, shifts are already underway to claim biomass as a critical component in the global industrial economy. Part I of this report provides an overview of the current situation and what the emergence of a so-called New Bioeconomy means for people, livelihoods and the environment. Part II provides a snapshot of the "New Biomassters" – the industrial players and the technologies they are harnessing.

Biomass:

Living (or once living) stuff; narrowly refers to the weight of living matter (plants, animals, bacteria, fungi, etc.) found in a specific area. Now used by industry to refer to the use of non-fossilized biological and waste materials as a feedstock for the production of fuels, chemicals, heat and power.

Biomass in the making   Photo: Asea

What is being sold as a benign and beneficial switch from black carbon to green carbon is in fact a red hot resource grab (from South to North) to capture a new source of wealth. If the grab succeeds, then plundering the biomass of the South to cheaply run the industrial economies of the North will be an act of 21st century imperialism that deepens injustice and worsens poverty and hunger. Moreover, pillaging fragile ecosystems for their carbon and sugar stocks is a murderous move on an already overstressed planet. Instead of embracing the false promises of a new clean green bioeconomy, civil society should reject the new biomassters and their latest assault on land, livelihoods and our living world.

Note on units:

In this report, *tonne* refers to 1 metric tonne = 1000 kg (2204.6 pounds); *ton* refers to 1 short ton = 2000 pounds (907.2 kg); 1 billion = 1000 million

Illustration: the Beehive Collective

Who are the new BioMassters?

The same transnational companies that fostered dependence on the petroleum economy during the 20th century are now establishing themselves as the new biomassters. When that coup is complete, many familiar corporate players will still be sitting at the head of the global economic order. That their cars run on biofuel, their computers run on bioelectricity and their credit cards are made of bioplastic is not the major issue; they will have achieved a firmer clutch, perhaps even a death grip, on the natural systems upon which we all depend.

Forestry and agribusiness giants that already control land and biological resources worldwide are at the forefront of developing the bioeconomy and the new market in biomass. Familiar names include Cargill, ADM, Weyerhaeuser, Stora Enso, Tate & Lyle, Bunge, Cosan Ltd.

High tech companies (biotech, nanotech and software) are providing the new tools to transform, measure and exploit the biological world, helping to develop genetic information as a commodity. These include Microsoft, Monsanto, Syngenta, Amyris Biotechnologies, Synthetic Genomics, Inc., Genencor, Novozymes.

Pharma, chemical and energy majors are partnering with the new bio-entrepreneurs to switch their production processes and feedstock sourcing. Watch for moves by DuPont, BASF, DSM, Duke Energy, BP, Shell, Total Oil, Chevron, ExxonMobil.

Financial services companies and investment banks are drawing up new ecosystem securities, trading markets and land investments even as previous securities collapse around them: Goldman Sachs, J.P. Morgan, Microsoft.

Consumer products and food companies are turning to bio-based products, packaging and ingredients to make 'green' marketing claims: Procter & Gamble, Unilever, Coca-Cola.

What is being switched?
It's not just biofuels...

"Many think of biomass mainly as a source for liquid fuel products such as ethanol and biodiesel. But biomass can also be converted to a multitude of products we use every day. In fact, there are very few products that are made today from a petroleum base, including paints, inks, adhesives, plastics and other value-added products, that cannot be produced from biomass."
– David K. Garman, U.S. Under Secretary of Energy for Energy, Science and Environment under George W. Bush[4]

"We have modest goals of replacing the whole petrochemical industry and becoming a major source of energy."
– J. Craig Venter, founder Synthetic Genomics, Inc.[5]

A simple way to understand the proposed ambition of the new Biomass Economy is to glance at a list of fossil-fuel dependent products and services currently being produced. Then, imagine each sector switching to living plant matter as a feedstock instead of the oil, coal and natural gas associated with fossilized plant matter:

Transport Fuels

Currently, over 72% of petroleum[6] ends up as liquid fuels for cars, trucks, airplanes and heating. Agrofuels (i.e., biofuels) such as ethanol and biodiesel mark just the beginning of converting the liquid fuel market to biomass. Some next-generation agrofuels are hydrocarbons that have the same chemical properties as gasoline and jet fuel.

Electricity

Coal, natural gas and petroleum are currently responsible for 67% of global electricity production.[7] However, co-firing coal with biomass is on the increase and there is a move to burn woodchips, vegetable oils and municipal waste as the fuel for electricity production. Meanwhile, nano-cellulose and synthetic bacteria are being investigated to make electric current from living cells – turning biomass to electricity without the need for turbines.

Chemicals and Plastics

Currently around 10% of global petroleum reserves are converted into plastics and petrochemicals.[8] However, to hedge against rising petroleum prices and to green their public image, large chemical companies such as DuPont are setting ambitious targets for biomass feedstocks such as sugar and maize for the production of bioplastics, textiles, fine and bulk chemicals.

Fertilizer

Global fertilizer production is an intensive user of natural gas. Proponents of biochar (carbonized biomass) claim that they have a bio-based replacement for improving soil fertility, which can be produced on an industrial scale.

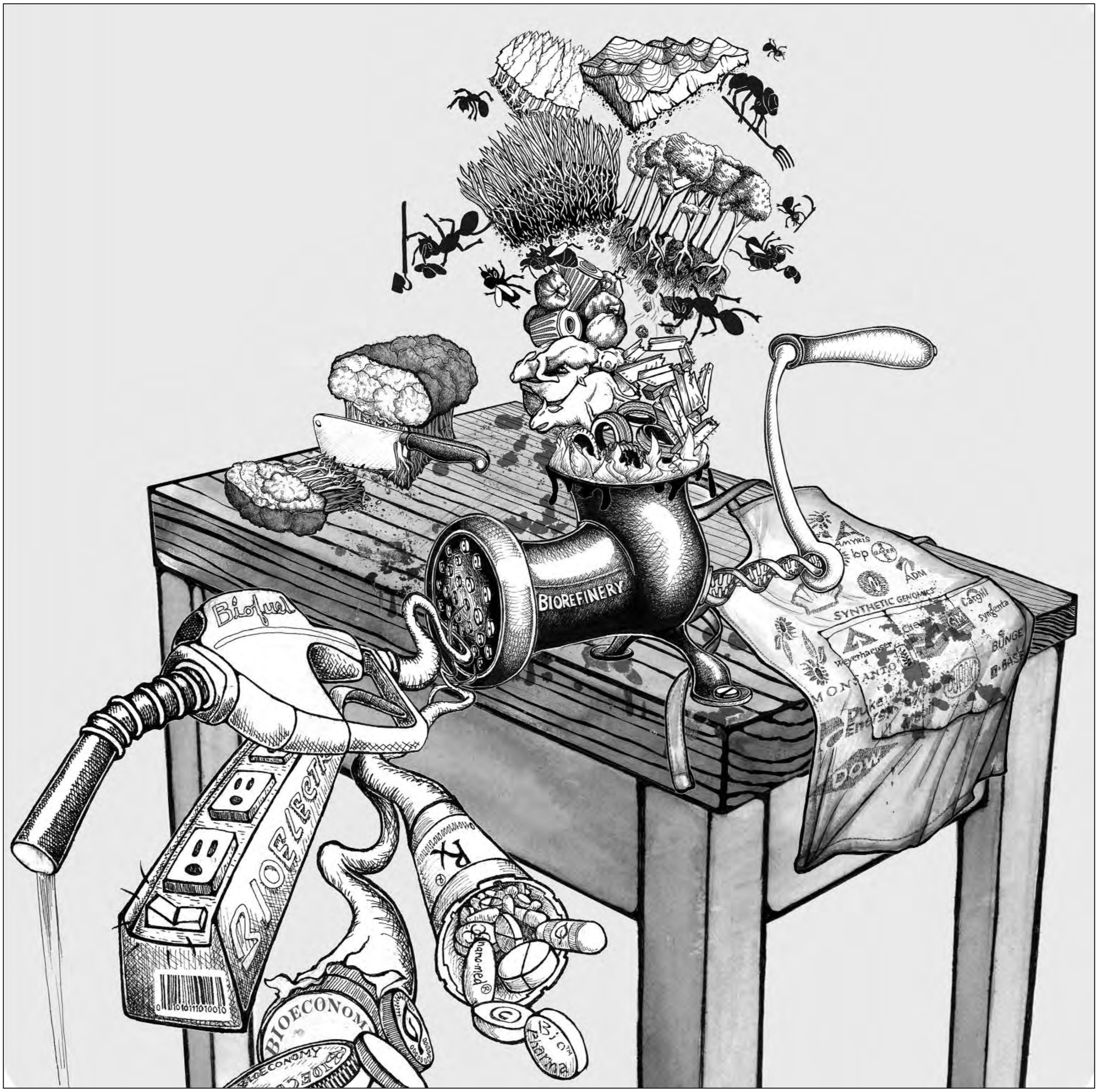


Illustration: the Beehive Collective

Part 1: Here Comes the Bioeconomy

Hunting-and-gathering economies ruled for hundreds of thousands of years before they were overshadowed by agrarian economies, which ruled for about 10,000 years. Next came the industrial ones. The first began in Britain in the 1760s, and the first to finish started unwinding in the U.S. in the early 1950s. We're halfway through the information economy, and from start to finish, it will last 75 to 80 years, ending in the late 2020s. Then get ready for the next one: the bioeconomy.
– Futurists Stan Davis and Christopher Meyer, *Time*, May 2000[9]

It is now over two years since a sharp escalation in food prices created a crisis that broke onto front-page headlines around the world. Suddenly, the diversion of crops for 'biofuels' (dubbed 'agrofuels' by opponents') was a topic of intense controversy and opposition among rural communities, particularly in the global South. While headlines focused on industry's enthusiasm for palm oil and corn ethanol (the 'ethanol rush'),[10] this was only a visible tip of a much deeper transition and trajectory in industrial policy. That trajectory – toward the bio-based economy – is now gathering speed, political clout and many billions of dollars in public subsidy and private investment. Whether it delivers on its promises, the payload of the new bioeconomy carries the same threat to people, livelihoods and the planet as the ethanol rush – but even more so.

The rhetoric of a 'new' bioeconomy, however imprecise, is woven throughout current agendas and headlines and wrapped in the post-millennial buzzwords that permeate environmental, industrial and development policies: 'sustainability', the 'green economy,' 'clean tech' and 'clean development.'

Three Bioeconomies

Bioeconomy describes the idea of an industrial order that relies on biological materials, processes and "services." Since many sectors of the global economy are already biologically based (agriculture, fishing, forestry), proponents often talk of a 'new bioeconomy' to describe a particular re-invention of the global economy – one that more closely enmeshes neoliberal economics and financing mechanisms with new biological technologies and modes of production.

It turns out that the term 'bioeconomy' is used to describe at least three distinct but interrelated and mutually reinforcing concepts, all based on the notion that biological systems and resources can be harnessed to maintain current industrial systems of production, consumption and capital accumulation:

Inputs: The Biomass Economy – Sometimes termed the bio-based or carbohydrate economy. The key concept is that industrial production moves from the use of fossil and mineral resources (coal, petroleum and natural gas) toward living biological raw materials, primarily 'biomass' plant matter such as woodchips, agricultural plants and algae.

Processes: The Biotech Economy – As the DNA found in living cells is decoded into genetic information for use in biotechnology applications, genetic sequences are acquiring a new value as the building blocks of designed biological production systems. By hijacking the 'genetic instructions' of cells, plants and animals to force them to produce industrial products, industry transforms transgenic and synthetic organisms into bio-factories that can be deployed elsewhere on the globe – either in private vats or plantations. Nature is altered to meet business interests.

Services: The Bioservices Economy – As ecosystems collapse and biodiversity declines, new markets in ecosystem "services" enable the trading of concocted ecological 'credits.' The declared aim is to "incentivize conservation" by creating a profit motive in order to justify interventions in large-scale natural systems such as hydrological cycles, the carbon cycle or the nitrogen cycle.[11] Like the 'services' of an industrial production system, these 'ecosystem services,' created to privatize natural processes, will become progressively more effective at serving the interests of business.

Illustration: the Beehive Collective

Hidden in the rhetoric of the bioeconomy is an assault on older "bio-based" economies represented by billions of people with preexisting claims on the land and coastal waters where biomass grows. Their knowledge systems and livelihoods are interdependent with a complex array of organisms that sustain us all: the so-called "biomass" (forests, soils, plants and microbes) that has been nurtured for millennia. To those who have found themselves on the receiving end of new industrial waves before, the story of the coming bioeconomy will be familiar. It's yet another heist on the commons that will destroy the resources and territories and sovereignty of small farmers, peasants, fisherfolk, pastoralists and indigenous peoples – those who have been preserving biodiversity and producing our food while not contributing to global warming.

The new bioeconomy as currently envisioned by foresters, agribusiness, biotech, energy and chemical firms furthers the ongoing enclosure and degradation of the natural world by appropriating plant matter for transformation into industrial commodities, engineering cells so they perform as industrial factories, and redefining and refitting ecosystems to provide industrial support 'services.'

What is Biomass?

Strictly speaking, biomass is a measure of weight used in the science of ecology. It refers to the total mass of all living things (organic matter) found in a particular location.[12] Fish, trees, animals, bacteria and even humans are all biomass. However, more recently, the term is shorthand for non-fossilized biological material, particularly plant material that can be used as a feedstock for fuel or for industrial chemical production.[13]

The Bioeconomy, also known as...

In this report we use the terms bioeconomy or biomass economy. Here are some of the terms by which other institutions refer to the industrial vision of turning living biological material into goods and services:

The Biobased Economy – OECD

Knowledge Based BioEconomy (KBBE) – the European Union

Industrial Biorefinery industry – World Economic Forum

White Biotechnology or Industrial Biotechnology – Biotechnology Industry Organization

The Green Economy and Biodiversity Services – United Nations Environmental Programme (UNEP)

The Carbohydrate Economy – Institute for Local Self Reliance

The Bioeconomic Revolution – the Biomass Research and Development Board of the U.S. government

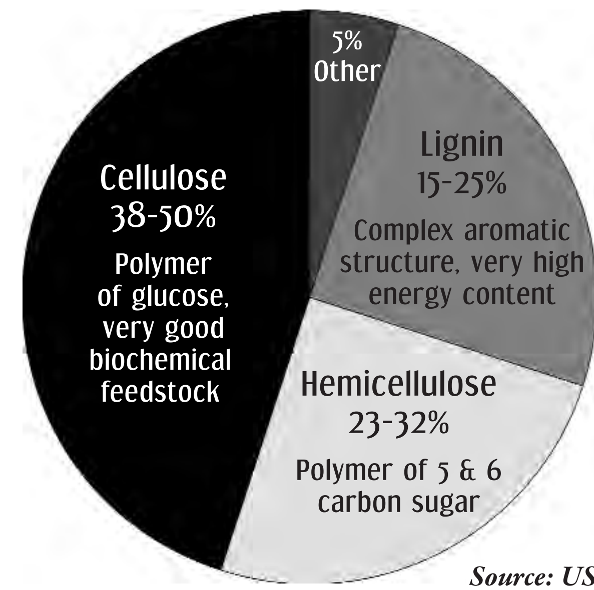
According to the UN Conference on Trade and Development (UNCTAD), "Biomass includes organic matter available on a renewable basis, such as forest and mill residues, agricultural crops and residues, wood and wood residues, animal wastes, livestock operation residues, aquatic plants, fast-growing trees and plants, and the organic portion of municipal and relevant industrial wastes."[14]

On closer examination what governments and industry count as 'biomass' includes tires, sewage sludge, plastics, treated lumber, painted construction materials and demolition debris, industrial animal manures, offal from slaughterhouse operations and incinerated cows.[15]

Plants in particular, have been a source of fuel and material production for millennia but the new use of the term 'biomass' marks a specific industrial shift in humanity's relationship with plants. Unlike the term 'plant,' which indicates a diverse taxonomic world of various species and multiple varieties, the term biomass treats all organic matter as though it were the same undifferentiated "plant-stuff." Recast as biomass, plants are semantically reduced to their common denominators so that, for example, grasslands and forests are commercially redefined as sources of cellulose and carbon. In this way biomass operates as a reductionist and anti-ecological term treating plant matter as a homogenous bulk commodity. Like those other 'bios' (biofuel and biotechnology), the use of the term biomass to describe living stuff is often a red flag that industrial interests are at play.

Cellulose – The Wonder Sugar

"The sturdy oak and the stately palm, the grass that covers the good Earth, the lichens that clothe the rocks, even the minute algae that flourish in the sea, all are manufacturing cellulose. It is the great primary substance of the whole vegetable kingdom."
– Williams Haynes, Celullose: The Chemical that Grows, 1953[16]



If you were to scrape off the thin layer of living material on planet Earth and boil it down to its constituent parts, most of what you would get is one green sugar called cellulose. It is found in all plants, as well as some microbes, as long chains of glucose in a fibrous or occasionally crystalline structure.[17] This common molecular component is rapidly becoming the darling of industry for four reasons:

Abundance: The Earth makes about 180 billion tons of cellulose every year.[18] This makes it the most abundant organic compound on the planet.

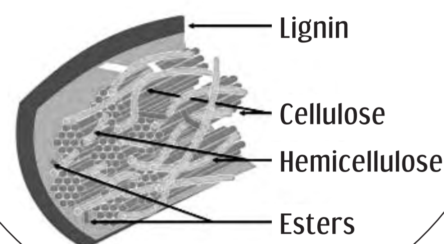
Energy: Cellulose is the principle source of energy for animal nutrition and heat for humans (when plant materials are burned).

Flexibility: Many of the early plastics were based on plant cellulose. Cellulose can be chemically modified and functionalized in different ways to produce new polymers, coatings, oils and combustibles.[19] Recent work has also shown that cellulose nano-fibres can be modified to exhibit further novel properties.[20]

Cellulose is not (necessarily) food: While vegetables and grains have a large cellulosic component, so too, do the non-food components of plants. Biofuel proponents argue that the cellulose found in plant stalks and leaves can be appropriated for industrial use while leaving the fruit or grains in the food supply.

Lignocellulose:

woody material; a tangled matrix of cellulose fibres, hemicellulose fibres and lignin that is the main constituent of the woody part of plants.



But while cellulose may be abundant, one significant catch has been the difficulty of separating it from other plant components (see diagram above). In most instances cellulose is bound within a matrix of compounds known as lignocellulose, which in turn is composed of lignin (a hard, carbon-rich substance) and hemicellulose (a mixture of other sugars).

Breaking cellulose away from lignin and reducing it to simpler sugars requires either an intense heat process or the application of strong chemicals or enzymes, such as those found in the guts of cows and termites. The task of industrially separating cellulose has now become one of the most active areas of research in energy and materials science.[21]

Getting Elemental – "It's still the carbon economy, stupid"

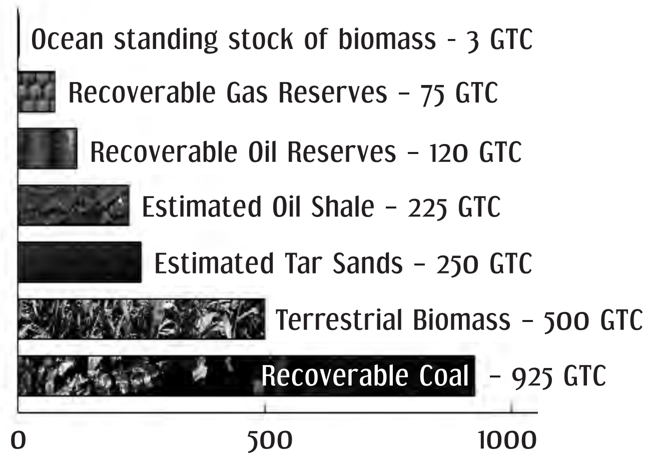
"It is the carbon content of this biomass and its applicability to many uses that make it the valuable feedstock of the future."
– Energy Matters, U.S. Department of Energy's Industrial Technologies Program Newsletter, Summer 2010

"The basis for a bioeconomy is the generation of carbon using renewable resources, like crops and other biomass, instead of relying upon nonrenewable, petroleum-based carbon."
– Georg Anderl, President of BIOWA Development Association, 2004[22]

In an era of increasingly constrained oil supplies, commercial excitement about cellulose as a new 'unconventional' source of carbon is not surprising. Companies involved in biofuels and biomaterials commonly refer to plants simply as a source of carbon molecules, rendering invisible their other components and functions. The accounting of global carbon reserves by energy companies reveals that the billions of tonnes of carbon locked up in global biomass stocks far outstrip known oil and natural gas reserves, rival shale and tar sands combined and are exceeded only by coal deposits. Recoverable global stocks of carbon in all fossil fuels are estimated at 1.1 trillion tonnes[23] while global biomass holds about half that amount of carbon (503 billion tonnes – see graph on the right, How much carbon?). As biofuels business analyst Rosalie Lober notes: "Biofuels are above-ground oil fields, a different kind of proved reserve."[24]

How much carbon?

Estimated global stocks of 'recoverable' carbon reserves



Source: Dr. Jeff Siirola (American Institute of Chemical Engineers), Mark Maslin and IPCC

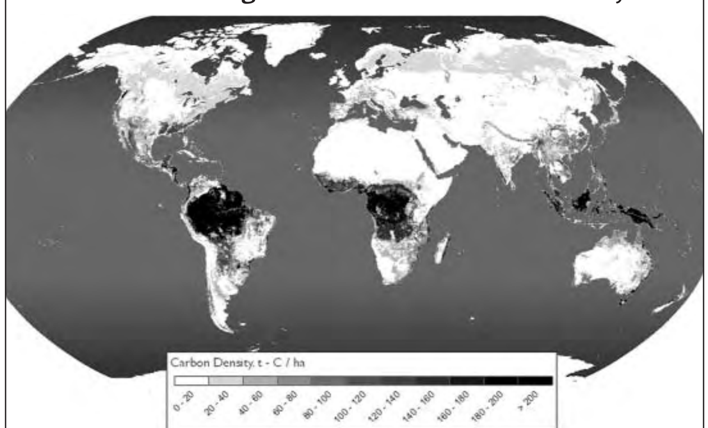
Getting geopolitical – It's all in the South

> ***"If you look at a picture of the globe ... it's pretty easy to see where the green parts are, and those are the places where one would perhaps optimally grow feedstocks."***
> – Steven Koonin, U.S. Department of Energy Under Secretary for Science and former head of research at BP, 2009[25]

> ***"A new international division of labour in agriculture is likely to emerge between countries with large tracts of arable land – and thus a likely exporter of biomass or densified derivatives – versus countries with smaller amounts of arable land (i.e. biomass importers, e.g. Holland). The biggest biomass export hubs are expected to be Brazil, Africa and North America."***
> – World Economic Forum[26]

Where is the Biomass?

Above and below ground biomass carbon density



Source: http://cdiac.ornl.gov/epubs/ndp/global_carbon/FINAL_DATASETS.jpg

While from space the planet may look green and rich with biomass, the dirty little secret of the biomass economy is that – just like fossilized carbon reserves (oil, coal, natural gas) – the living carbon reserves are not equally distributed. Worldwide, land-based vegetation stores an estimated 500 billion tonnes of carbon. However 86% of that (430 billion tonnes) is stored in the tropics and sub-tropics, while boreal and temperate eco-regions store only 34 billion tonnes and 33 billion tonnes, respectively.[27] The tropics is also where biomass replenishes the quickest and where marine biomass, principally phytoplankton, is most productive.[28]

Not coincidentally, these areas of the planet where biomass is already most concentrated are now attracting the interest of companies wanting to produce biofuels, bio-based chemicals and bioelectricity. Brazil in particular has witnessed a massive increase in bioeconomy-driven investment. Indeed the World Economic Forum has suggested that "a new international division of labour in agriculture is likely to emerge" between biomass-producing tropical countries and Northern countries – although what is so new about this division of labour is unclear.[29]

The industry has realized that "geography is destiny," says Mark Bünger, who tracks the bioeconomy as a Research Director at Lux Research. Bünger explained to Technology Review's Antonio Regalado that "only a few places on the planet have the rain, sun, and land mass needed to make biofuels at the scale and price that can have a real impact."[30] While Brazil ranks first, sub-Saharan Africa is a close second, evidenced by a rush of land claims and rising interest in planting sugarcane in the region.[31]

> ***"As we looked at the world and looked at where the lowest cost, largest scale biomass was, we found that Brazil really was the Saudi Arabia of renewables."***
> – John Melo, CEO of Amyris Biotechnologies, Inc.[32]

Sourcing Biomass – A global take

In the near term, nations with significant remaining forests and expanding plantation acreage (Brazil, USA, Indonesia, Canada, Russia and Central African nations) will be jockeying to establish themselves as "the Saudi Arabia of biomass."[33] In time, however, agricultural ecosystems, grasslands, deserts and ocean ecosystems will also increasingly become the targets of the biomass grab. Each of these ecosystems has advantages as a biomass resource. Even though the biomassters claim they will one day be able to use any available biomass, today they are targeting the same plants already being exploited by industrial agriculture and forestry – corn, sugar, soy and fast growing eucalyptus, poplar, oil palm and pine trees.

Natural Forests

Making up the largest repository of existing terrestrial biomass, natural forests are indeed experiencing most of the immediate pressure from new biomass extraction. Though forests have been diminished by centuries of unsustainable logging practices, they are still home to millions of indigenous peoples, some of the most diverse ecosystems on the planet, and they play a crucial role in regulating climate. Over time, the political and ecological costs of removing biomass from the world's remaining natural forests may prove too high for a biomass industry to depend on. Already climate change is creating huge stresses on forest ecosystems, so that any amount of biomass removal will increase the risk of fires, pests and soil saturation, among other negative consequences.[34]

Plantations

Monoculture plantations of fast-growing trees rich in cellulose such as eucalyptus, poplar and pine, or oil-bearing trees such as palm and jatropha, are already proliferating, particularly in the global South, often on formerly forested land. Since 1980 tropical forest plantations have expanded by almost five-fold.[35] Pursuit of biomass is accelerating that trend. Largely proprietary, with minimal biodiversity value and significant negative impacts on water and soils, plantation trees and crops will be the major source of biomass for industrial use in the coming decades, disrupting societies and ecosystems, fuelling land and water fights and inequity. The forest industry likes to pretend such plantations should be classified as forests; however, monoculture tree plantations, in terms of ecology, bear little resemblance to natural forests.

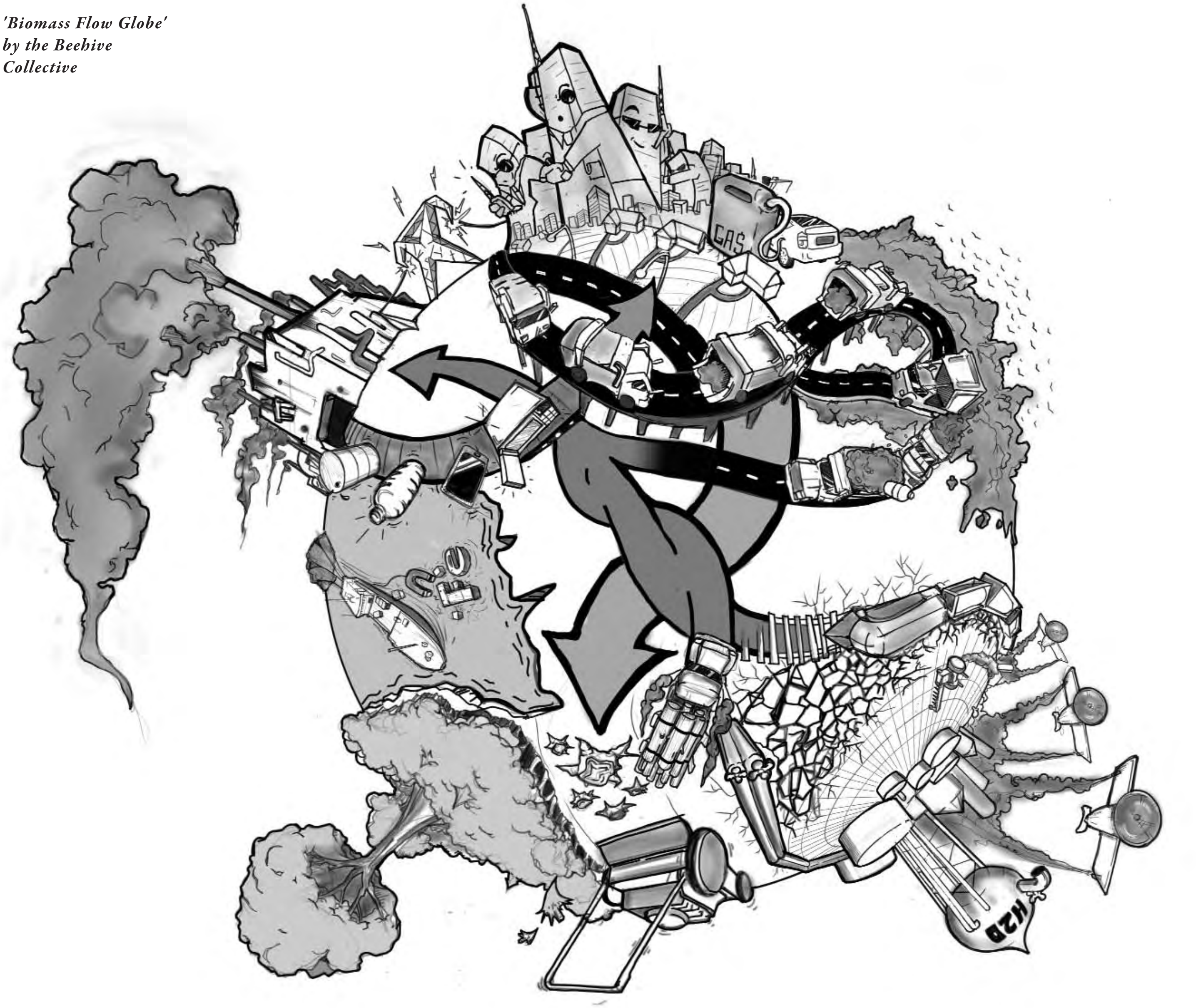
Agri-Ecosystems

The most highly organized and efficient biomass grab on the planet is the 1.5 billion hectares of food and fibre crops.[36] While there are obvious reasons for concern if the primary purpose of agriculture is shifted from food production to materials and energy production, industry views agri-ecosystems as attractive sources of biomass because they are already well designed for harvest, storage and transport to market. In agriculture, the near term focus for biomass markets will be in capturing plant "wastes" from commodity crops, such as corn stover, rice straws, wheat husks and cotton, as well as introducing fast growing cellulosic grasses such as bamboo, switch grass and miscanthus. Unfortunately, the removal of green wastes from the land will likely have significant deleterious effects on agricultural soils; fast growing grasses could increase water use and become invasive. Meanwhile, the pressure to surrender prime soils to biomass production will further erode food sovereignty and conservation measures.

Grasslands

While prairie grasslands and meadows have so far largely been commercially limited to fodder for grazing animals, the search for biomass is introducing a new market for such lands. Regularly mowing diverse low-input prairies for hay has been proposed as an ecological solution for biomass extraction that would allegedly maintain native biodiversity in situ. But the assumption that prairie landscapes can remain biodiverse under such management conditions is contested, as is the potential for any real energy gain.[37] However, as the search for new sources of biomass intensifies, grasslands may become increasingly important in the equation or become increasingly converted to cropping and plantations – with impacts on livestock production, grazing rights, and biodiversity.

'Biomass Flow Globe' by the Beehive Collective



Marine Ecosystems

Algae and seaweeds in the world's oceans account for almost half of annual global biomass production (48.5%), which thus far has been difficult to access for industrial uses or for food.[38] As such, oceans represent a huge untapped resource and the search for biomass is inevitably going to have an impact on marine ecosystems. Current industrial farming of seaweeds and culturing of other algae are small-scale compared to the vast resource available. Oceans are difficult to operate in and largely under common governance, so harvesting a larger share of existing ocean biomass or extending seaweed mariculture may require new technologies and possibly new international legal arrangements. In the near term algae farming will likely expand on land, particularly in desert ponds. However, companies are already experimenting with harvesting wild algae from bays and coastlines for fuel and chemical production (e.g., Blue Marble, Seattle, USA).[39] Others are exploring growing algae in offshore farms and "mowing" the seabed.

Deserts and Wetlands

While not the immediate target for biomass extraction, deserts, marshes and other lands classified as 'marginal' are under pressure as biomass sourcing changes land use and other human activities, such as settlements, are moved into these more remote and more fragile ecosystems. Deserts and drylands, by virtue of ample sunlight, are already being targeted for large-scale algal production in ponds and under glass and may well be sowed with new varieties of grasses and crops engineered to be drought-tolerant. Meanwhile the development of salt-tolerant crop varieties may also invade marshland ecosystems.

Back to the Future? Carbohydrate vs. Hydrocarbon… From cracking oil to hacking plants

Advocates of the biomass economy like to talk of a coming switch from a (fossil based) hydrocarbon economy to a (plant based) carbohydrate economy. Chemically speaking, the difference between a hydrocarbon and a carbohydrate comes down to a few oxygen atoms. Carbohydrates are sugars comprised of carbon, hydrogen and oxygen and are considered organic matter. Hydrocarbons by contrast are composed of only hydrogen and carbon and are classified as minerals.

But historically speaking, and still in local and indigenous communities today, it is plant carbohydrates that have held the upper hand in meeting human needs. As recently as 1820, Americans used two tonnes of vegetables for every tonne of minerals as the raw material for dyes, chemicals, paints, inks, solvents and even energy. By 1920 the ratio had reversed, and by the mid-1970s Americans consumed 8 tonnes of minerals for every tonne of plant carbohydrate.[41] Two factors enabled that most recent switch:

"A third of the world's land is non-arable; 11% is used to grow cereals and other crops and 55% is in pasture, prairie, savannah and forest. It appears there is plenty of land."

– Steven Koonin, U.S. Department of Energy Under Secretary for Science and former head of research for BP, on finding land for biomass crops, 2008[40]

- The higher energy density of fossil fuels: One half-tonne of coal contains the same amount of energy as 2 tonnes of green wood. Coal, and later petroleum (which is denser still and more transportable), took over as the preferred fuel for the industrial revolution.[42]
- The success of petrochemistry: The first synthetic chemists learned to transform coal tar into profitable dyes and, eventually, to 'crack' petroleum into many molecules that could be refined into fuels, waxes, explosives, pesticides, plastics, paint, pharmaceuticals, cosmetics, textiles, rubber, gasoline, asphalt and much more.[43]

Today, however, volatile markets, the money-making potential of carbon markets, the development of new technologies and worries over peak oil are helping drive a switch back to living biomass. In particular, just as 19th century developments in synthetic chemistry made possible the hydrocarbon economy, so today, innovation in synthetic biology is allowing companies to retrofit the hydrocarbon economy to accommodate carbohydrate feedstocks.

Selling the Switch

ETC Group's analysis suggests that what is really driving investment in the new bioeconomy is good old capitalist opportunism. Nonetheless, advocates have plenty of new clothes with which to dress up their old-style imperialism. Below are just a few of the agendas commonly used to justify the new grab on biomass.

1. Sugar Dreams: The carbohydrate economy

The term "carbohydrate economy" was originally coined by activists from the Institute for Local Self Reliance (ILSR) who, in the early 1990s, described a vision of making chemicals and industrial materials from plant materials instead of petroleum.[44] Their interest in bio-based (that is, plant based) materials was driven by the hope that such materials could be designed to degrade more fully in the environment, unlike most petroleum-based plastics.

2. Green Dreams: 'Renewable' resources and the hydrogen economy

Biomass has consistently been included in descriptions and definitions of what constitutes a renewable resource as, theoretically, plants and trees grow back after harvest. Biomass is also occasionally described as a form of solar energy since plants harvest energy from the sun. (See below, "Is Biomass Really Renewable?") Biomass is also regarded as a key resource for developing another 'green' vision, the notion of a 'Hydrogen Economy,' as hydrogen can also be extracted from plants.

Definitions:

Carbohydrates: sugars and starches; organic molecules composed mainly of carbon, hydrogen and oxygen atoms found in living plant material. The most abundant carbohydrate is cellulose.

Hydrocarbon: carbon-rich mineral; a mix of carbon and hydrogen, the term is often used to describe fossil feedstocks such as coal, oil and methane (although there are hydrocarbons that are not fossil fuels).

3. Cool Dreams: The carbon-neutral economy

The contemporary urgency to address the problem of human-induced climate change has put biomass at the centre of government energy policies. Because plants can sequester carbon dioxide from the atmosphere, policymakers have regarded plant matter as a 'carbon neutral' feedstock for energy production, arguing that any emissions released in bioenergy production are re-sequestered with replanting. (See below, "The Carbon Neutral Myth") In 2008, the International Energy Agency (IEA) reckoned that biomass-derived energy represented 77% of global "renewable" energy production.[45]

4. Patriot Dreams: Energy independence

In the U.S. at least, the idea of a home-grown bioeconomy as a patriotic bulwark against terrorism and oil wars has popular appeal. By "reducing dependence on foreign oil," the mantra goes, biofuels and bioplastics strengthen national sovereignty while withdrawing funds from extremist petro-states. This notion cuts across political lines, tapping into anti-war sentiment on the left and jingoism and security fears on the right.

5. Leapfrog Dreams: Clean development and the 'green jobs' movement

How can you help poorer economies 'develop' while avoiding the dirty industries and resource consumption of the developed world? That's the supposed dilemma that advocates of 'environmental leapfrogging' set out to square by using new technologies to create cleaner, greener development. At the UN level, this idea has taken form in UNEP's 'Green Economy' vision. (See below, "The Green Economy") Meanwhile, an emerging 'green jobs' movement argues that the green technologies of the bioeconomy can rescue a stagnating North American and European industrial workforce.

6. Geek Dreams: Converging technologies and 'cleantech'

'Converging technologies' refers to the way in which seemingly distinct technological fields such as nanotechnology, biotechnology, information technology and robotics can combine to create a powerful hybrid technology platform. In European science policy circles, it is proposed that converging technologies could be principally directed to 'sustainable' applications such as bioenergy and 'climate technologies' to drive economic growth.[46]

Senior scientists and venture capitalists in the U.S. have dubbed this next wave of environmental technologies 'Clean Tech' – a multi-billion dollar area of investment that covers biofuels, bioenergy, bioplastics, and most bio-based materials in general, as well as the underlying enabling technologies such as synthetic biology and nanotechnology.

A Grab, not a Switch

Attributing the recent rise of the bioeconomy and burgeoning interest in biomass to green-minded or nationalistic consciousness only is to assume wrongly that the captains of large corporations and OECD economies are moved by such concerns. As with any previous industrial transition, what's behind the dash to biomass is not high ideals but the calculated interest of the corporate bottom line. Far from changing to a new economy, the biomass transition describes the retooling of the same old economy of production, consumption, capital accumulation, and exploitation – only now a new source of carbon is being plundered to keep the industrial machines going.

In economic terms, the effect of turning cellulose and other sugars into viable feedstocks for fuels, chemicals and electricity is to imbue previously unprofitable grasses, seaweed and branches with profit potential. More significantly, any land or body of water that can sustain cellulosic plants acquires an enhanced value as a potential source of biomass, a fact that is already accelerating the global land grab that was originally undertaken to secure food supplies. If the biomass coup is successful, then the technologies of biomass transformation (particularly nanotech, biotech and synthetic biology) become valuable keys to extracting value, and elevating the industries that control them.

It is no coincidence that the most dogged proponents of the biomass economy in the past decade have been not environmental NGOs, but large biotech, chemical, forestry and agribusiness corporations.

Counting the Bioma$$ Economy

Turning straw (and other cellulose) into (financial) gold is not new. A 2008 report from the USDA points out that worldwide, over $400 billion worth of products are already produced annually from biomass including pulp and paper, lumber, paints, greases and lubricants.[47] The only consolidated estimate publically available for how much money can be made from the new bio-based energy, chemicals, plastics, fuels and associated markets is from The World Economic Forum that guesses at a $300 billion dollar market by 2020.[48] A sampling of predictions (below) total around one half-trillion dollars by 2020 – possibly considerably more.

Bioma$$ electricity – According to Pike Research, the market value of electricity generated from biomass in the United States will increase steadily to $53 billion by 2020, up from approximately $45 billion in 2010.[49] The World Economic Forum puts global value of biomass heat and power combined at $65 billion by 2020.[50]

Bioma$$ fuels – Pike Research claims that biodiesel and ethanol markets account for $76 billion dollars in sales in 2010 and that figure might rise to $247 billion by 2020. The total global biofuels market could surpass $280 billion by 2022.[51]

Bioma$$ and bio-based chemicals – In 2005, McKinsey & Company estimated that bio-based materials and products (for example, bioplastics, bio-derived chemicals, and chemicals refined using biotechnology) accounted for 7% of global sales and $77 billion in value within the chemical sector.[52] By 2008 the value had increased to $170 billion and was predicted to reach $513 billion by 2020.[53] A 2008 estimate by USDA (based on 2006 figures) predicted that bio-based chemicals would account for 22% of all chemical industry sales by 2025.[54] These figures, however, do not distinguish between biomass-based chemicals and biotech-aided production. A study by Frost & Sullivan in March 2009 found that revenues for the global bio-renewable chemicals market (that is chemicals made from biomass rather than petroleum) reached only $1.63 billion in 2008 (only 4% of sales) but may climb to $5.01 billion by 2015.[55] The World Economic Forum reports that bio-based chemicals are expected to increase their share in overall chemicals production to some 9% of all chemicals by 2020 citing a $6 billion figure.[56] According to bullish analysis from Helmut Kaiser Consultancy, bioplastics already account for 10-15% of the total plastics market and could increase their market share to 25-30% by 2020.[57]

The Bioma$$ Boondoggle – One inescapable conclusion from analyzing the biomass economy: at this stage its most aggressive backers are governments that allocate billions of dollars to subsidize biofuels, in particular. Surveys by the World Bank and the Global Subsidies Initiative (GSI) suggest that annual government subsidies for biofuels are currently in excess of $15 billion and could rise to over $50 billion by 2020.[58] "For the years ahead, governments seem to have signalled that the sky is the limit," explains GSI's Director Simon Upton. According to the World Bank, 24 countries have mandated biofuel targets, while 12 countries plus the European Union offer tax exemptions and credits on biofuel use and production.[59]

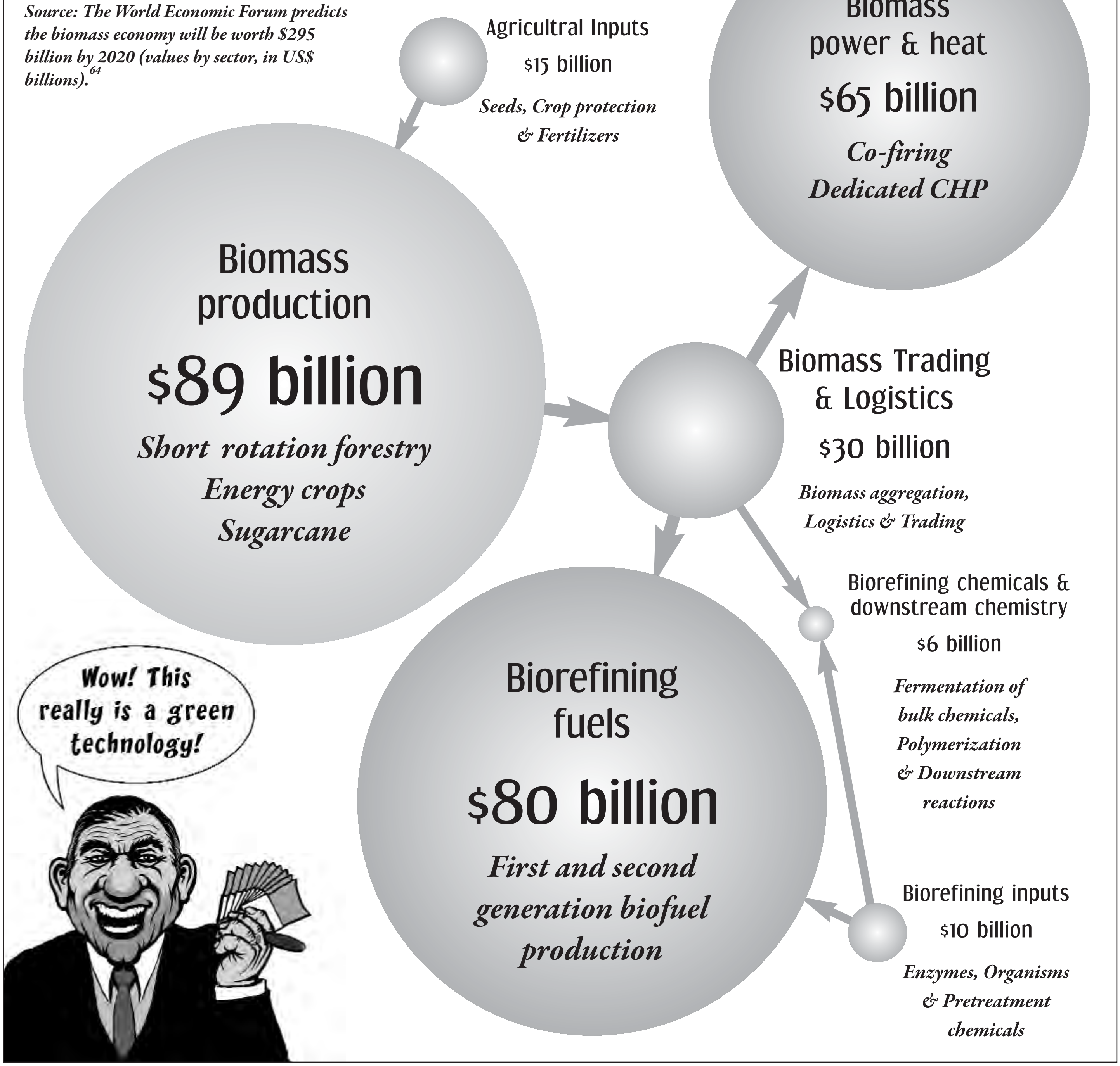
Bioma$$ investments – The emerging biomass industry has positioned itself on a hot spot of venture capital funding – so-called 'clean tech.' A study by Lux Research of over 100 venture capital investments in the biosciences sector documented a marked upturn in investment deals in bioenergy when the U.S. government set ethanol mandates in 2005.[60] Between 1998 and 2008, at least $4.17 billion of venture capital flowed into the field. Many of the leading U.S. venture capital firms that had bankrolled the Internet boom switched over to "environmentally-friendly technologies," particularly solar energy and biofuels.[61] Silicon Valley's Draper Fisher Jurvetson, which originally funded Skype and Hotmail, were among the earliest investors in synthetic biology, providing start-up capital for Craig Venter's Synthetic Genomics, Inc. (focused primarily on biofuels). Another Silicon Valley venture house, Kleiner Perkins Caufield & Byers, whose previous successes include Google, AOL, Amazon.com and Sun Microsystems, had reportedly backed five different cellulosic biofuel companies by 2008,[62] advised by luminaries Al Gore and Bill Joy. Meanwhile, Bill Joy's former business partner Vinod Khosla of Khosla Ventures is dubbed "the baron of biofuels" for seeding over a dozen biofuel startups, mostly in ethanol production, of which at least five are synthetic biology companies.

According to the Renewable Energy Policy Network for the 21st Century (REN21), biofuels received $19.6 billion of asset finance in 2007, though financing dropped to $15.4 billion in 2008 and plummeted to just $5.6 billion in 2009. REN21 sees the trend reversing, however, with large investments in Brazilian biofuels now underway. At the same time, private investments in bioelectricity projects have risen from $9 billion in 2008 to $10.4 billion in 2009.[63]

Bioenergy: energy from biomass; refers to any process that transforms biological material into energy including production and use of biofuels, generation of biomass electricity and biomass for heating and cooking.

Where is the Money in the Biomass Economy?

Projected global revenues in biomass production chain 2010



Source: The World Economic Forum predicts the biomass economy will be worth $295 billion by 2020 (values by sector, in US$ billions).[64]

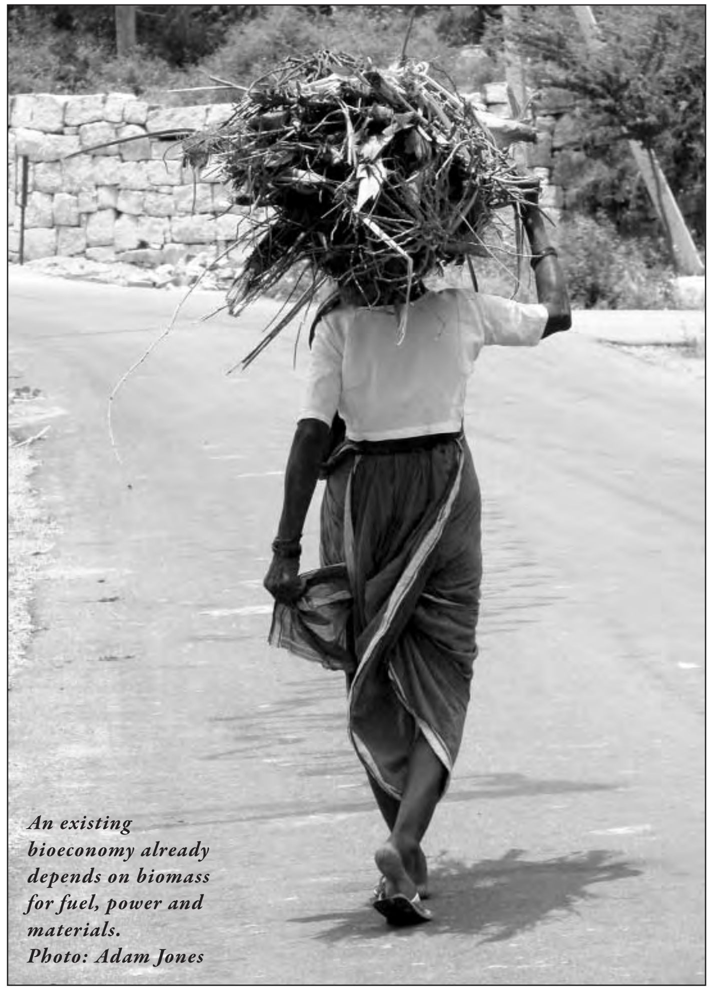
"What if you took half the corn stover off the fields [of Iowa], leaving half for erosion control. How much would you have in any given year? The number comes up to about 24 million tons. If you turn 24 million tons into two cents per pound, that's a billion dollars. What if we could move it further up the value chain and take that 24 million tons and make it worth as much as an ag plastic, worth about $1.50 per pound? Then, you're talking about adding $72 billion to the state's economy. You're in essence almost doubling the state's economy."

– Floyd Barwig, Director, Iowa Energy Center, 2004[65]

Whose Biomass? A tale of two bioeconomies

Evangelists of the new bioeconomy like to frame it as a return to a previous, sustainable economy, in which human civilization relied on the natural bounty of the present rather than robbing from the mineral deposits of the past. But while the global economy as a whole might have taken a century-long detour from that bio-based economy, billions of people did not. They – that is, peasants, indigenous peoples, pastoralists, fisherfolk, forest dwellers and other traditional communities – remained independent of the hydrocarbon economy; however, as climate change accelerates, they are paying its costs...

- Two centuries after the industrial revolution began burning coal, three billion people, two-thirds of whom live in the global South, still depend upon firewood as their primary source of fuel for heat and cooking.[66]
- One hundred thirty years after Edison enabled electricity distribution, 1.6 billion people have no access to electricity whether sourced from coal, wind, water or woodchips.[67]
- One hundred forty years after Siegfried Marcus first attached a combustion engine to a vehicle, 2 billion people still rely on animals as their main source of power for agriculture and transport; indeed, half of the farmland in the global South is tilled exclusively by animals.[68]



An existing bioeconomy already depends on biomass for fuel, power and materials. Photo: Adam Jones

These biodiversity-based economies depend on exactly the same natural resources (plants, land, water, animal products) that the new bioeconomy intends to capture for conversion into industrial chemicals and energy. Moreover, the so-called 'biomass' that industry intends to grab is not only already used as a resource by these communities, but it is also interdependently connected with their cultures and knowledge systems.

"Land best suited for biomass generation (Latin America, Sub-Saharan Africa) is the least utilized."

– Presentation by Steven Chu (now U.S. Secretary of State for Energy) at the Asia Pacific Partnership Conference, Berkeley, USA, 19 April 2006

Marginal Lands for Maximal Profit

Biomass advocates refer to "marginal," "unproductive," "idle," "degraded" and "abandoned" lands and "wastelands" as the target for biomass extraction, claiming that as many as 500 million hectares of abandoned or marginal land are available worldwide for growing biomass crops.[69] Such claims appear to be based on satellite data showing areas of former cropland. However, a closer look at these "marginal lands" from ground level reveals that they are often where marginalized people subsist. Far from being 'abandoned' or 'degraded,' their uses are merely invisible to a system that recognizes only private ownership and industrial agriculture (and carries out its assessments from outer space).

The Land Grab: current rush to buy land in the global South. The past few years have witnessed a massive upswing in the number of deals buying and leasing agricultural land in the tropics by Northern investors and states. The term was coined by civil society organization GRAIN.

Illustration: the Beehive Collective

Table: A tale of two bioeconomies

Biomass-based economies	Biodiversity-based economies
Homogenous - Defines plant and other organic life by lowest common denominators: as undifferentiated providers of 'feedstocks' – sugars, starch, cellulose, oil, etc.	**Heterogenous** - Defines plant life and organic life heterogeneously by differentiating individual species and parts of plants and animals with specific properties and uses.
Monoculture - Organizes large-scale sourcing of monoculture crops, plantations, forest destruction and land clearance.	**Diverse** - Organizes small-scale cultivation of diverse cropping and gathering of wild harvests. When it occurs, land clearance is on rotational or shifting basis.
Market driven - Based on industrial transformation of biomass into bulk commodities for the global market – e.g., electricity, biofuels, bulk chemicals, pharmaceuticals, textiles.	**Subsistence driven** - Based on community or individual transformation of plant and animal materials for personal or community use – e.g., as medicines, food, cultural and spiritual uses.
High tech - Uses, proprietary, capital-intensive technologies to transform biomass – e.g., biotech, synthetic biology, synthetic chemistry. Innovation occurs quickly and diffuses rapidly on a large scale – often prematurely.	**Appropriate tech** - Uses human scale, community-centred technologies to transform plants – e.g., drying, fermenting, cooking. Innovation may occur quickly but on small scales and diffuses slowly to larger scales.
Reductionist – Nature is viewed in terms of its commercial value and profit potential.	**Holistic** - Nature is imbued with cultural and spiritual values and often seen as sacred.

As a coalition of CSOs reports in an investigation of the marginal lands myth: "Communities that use these biodiversity-rich lands for food, income, grazing and medicine do not appreciate the denial of their existence. Nor do they always agree that the conversion of their lands for agrofuel production will bring 'development' benefits."[70] A study by Gören Berndes, who has reviewed 17 bioenergy feasibility studies, found that, "Land reported to be degraded is often the base of subsistence for the rural population."[71]

For example, grasslands are described as "idle" even when they provide subsistence to pastoral peoples and nomads who require extensive grazing coverage to maintain a light impact on delicate ecosystems. Jonathan Davies, global coordinator of the World Initiative for Sustainable Pastoralism, based in Nairobi, Kenya, comments, "These marginal lands do not exist on the scale people think. In Africa, most of the lands in question are actively managed by pastoralists, hunter-gatherers and sometimes dry land farmers."[72] Davies goes on: "Given the current cavalier approach to land appropriation, or the disregard of the land rights of rural inhabitants in many countries, it is inevitable that agrofuel production will be done by large investors at the expense of local communities."

Disturbingly, far from being an innocent oversight, the denial of small farmer and pastoralist rights and the grabbing of their lands appear to be part of the plan. For example, a 2004 report by leading European researchers noted that the bulk of biofuel potential comes from pasture land and asserted that, "A prerequisite for the bioenergy potential in all regions is ...that the present inefficient and low-intensive agricultural management systems are replaced in 2050 by the best practice agricultural management systems and technologies."[73] In other words, "remove the peasantry."

Indeed, what is clear from this emphasis on targeting the lands of marginalized peoples is that the so-called new bioeconomy can only take root by displacing pre-existing bioeconomies.

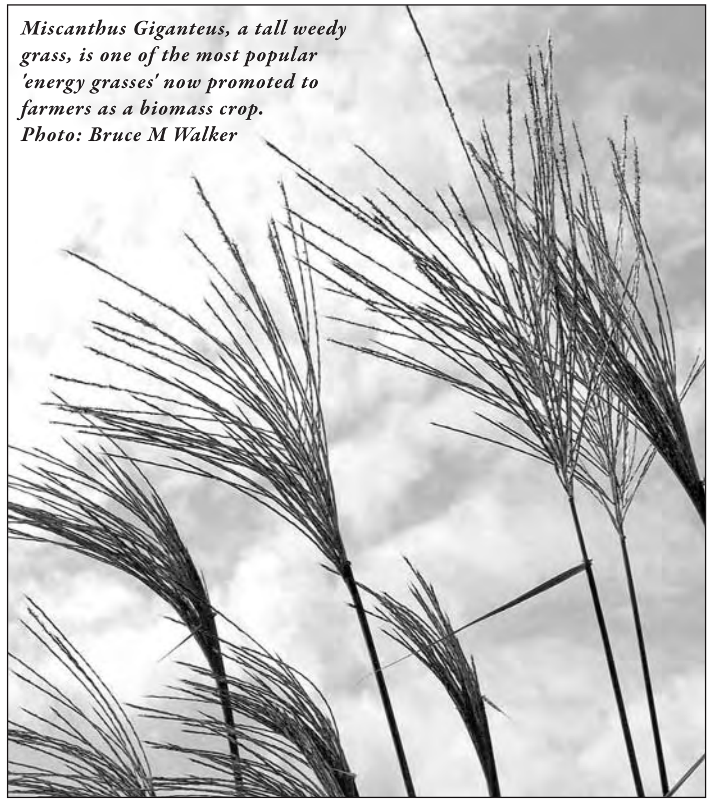
A Land Grab for Biomass

"The vision we have is there is a fantastic opportunity to help some of the African countries to develop new industry by really...um...er...exploring some of the agricultural land they have and creating fantastic employment opportunities. I look at it as this is the best opportunity for the tropics to benefit from the demand of many of the developing countries and the developed world."
– John Melo, CEO of Amyris, Inc.[74]

In 2008, the civil society organization GRAIN lifted the lid on a massive intensification of farmland acquisitions across the global South by rich states and foreign private investors.[75] Two years later, a World Bank report, relying on GRAIN's research, counted 464 projects covering at least 46.6 million hectares of land, largely in sub-Saharan Africa.[76] According to GRAIN, those driving the land grab – in large part investors seeking a safe haven for their money amidst crashing financial markets – are seeking to buy land cheaply and make it economically productive in a short period of time, allowing them to realize as much as 400% return on investment within as few as 10 years.[77]

The emerging biomass economy, with its promise of turning bountiful sugars, cellulose and oil crops into high-value commodities, provides clear incentive for land grabbing. Indeed, a 2010 Friends of the Earth analysis of land grabs in 11 African countries found that at least five million hectares of land – an area the size of Denmark – is already being acquired by foreign companies to produce biofuels mainly for Northern markets.[78] The World Bank calculates that 21% of land grab projects are biofuel-driven[79] and explicitly acknowledges that Northern policies, such as biofuel mandates, have played a key role: "Biofuel mandates may have large indirect effects on land use change, particularly converting pasture and forest land," with global land conversion for biofuel feedstocks expected to range between 18 and 44 million hectares by 2030.[80]

"The expansion of biofuels on our continent is transforming forests and natural vegetation into fuel crops, taking away food-growing farmland from communities, and creating conflicts with local people over land ownership."
– Marianne Bassey, food and agriculture coordinator for Environmental Rights Action/Friends of the Earth Nigeria.[81]



Miscanthus Giganteus, a tall weedy grass, is one of the most popular 'energy grasses' now promoted to farmers as a biomass crop. Photo: Bruce M Walker

A New Trade in Biomass – Shipping Chips

"Wood is very quickly becoming a very important part of the energy mix and in a few years will be a global commodity much like oil."
– Heinrich Unland, Chief Executive Officer of Novus Energy GmbH, Germany[82]

The land grab for biofuels is only a part of the corporate grab on Southern land and resources. This is already underway as cellulose (and woody biomass in particular) takes on increasing industrial value. Perhaps the clearest example is the emergence of a global trade in wood chips, wood pellets and sawdust as a commodity feedstock for biomass burners to produce electricity. This trade is currently relatively small and mostly within Europe (70% in Baltic states); however, a recent industry report foresees an 80 to 150-fold increase in the coming years,[83] with industry admitting that there will likely be a move to produce pellets (compacted sawdust) from fast growing energy crops, ultimately fuelling deforestation.

According to industry estimates, wood pellet production, which was virtually non-existent 15 years ago, reached approximately 10 million tons in 2008. It is expected to double within the coming 4-5 years and some industry experts forecast an annual growth of 25-30% globally over the next ten years.[84] Europe's mandated targets for fuel from biomass in particular are driving the search for cheaper woodchips in the global South as well as sourcing from the United States.

- MagForest, a Canadian company operating in the Democratic Republic of the Congo, is reportedly shipping 500,000 tonnes of wood chips annually to Europe.
- IBIC Ghana Limited claims it can export 100,000 tonnes of tropical hardwood and softwood every month from Ghana as biomass feedstock.
- U.S.-based Sky Trading is offering to supply up to 600,000 tonnes of woodchips as biomass from the United States or Brazil.
- According to documents reviewed by The Global Forest Coalition, Brazil is gearing up to meet the European woodchip demand by expanding tree plantations by 27 million hectares, mostly of exotic species like eucalyptus.[85]

Energy crops – Changes down on the farm

Though bioeconomy advocates claim that moving to cellulosic biofuels won't harm food production, nonetheless some pretty major changes are scheduled down on the farm. The intention to remove more straw and stover as well as to increase the amount of land devoted to energy crops (or e-crops) as a viable farm commodity will significantly change land-use patterns and farm systems and introduce additional stresses on rural landscapes.

According to Jack Huttner, formerly of DuPont Danisco Cellulosic Ethanol and now Executive Vice President of Commercial & Public Affairs at U.S.-based Gevo, which is developing next-generation biofuels, making cellulosic biofuels viable requires not only building hundreds of biorefineries but also surrounding each one with thousands of acres of land planted with energy crops such as prairie grass. "We're talking about a fairly substantial transformation of the rural economic landscape," Huttner told BusinessWeek in 2009. Biofuels companies will have to organize farmers to grow millions of acres of a dedicated energy crop like switchgrass. "I'm concerned about organizing basically a new economy," he said, explaining that big players, not small companies, are the only ones that have the capacity to make that happen.[87]

"I think the biggest problem for everybody is how are we going to grow, gather, store, and treat the biomass."
– Brent Erickson, lobbyist for the Biotechnology Industry Organization.[86]

Harvesting, baling, drying and storing vast quantities of cellulosic grasses and corn stover also raise new challenges. Some of the first profits in the new bioeconomy appear ready to flow to equipment manufacturers such as farm equipment maker John Deere, which recently signed a research collaboration agreement with Monsanto and Archer Daniels Midland to capture crop residues. Packing harvested stover tightly enough to be transported economically to a processing plant, for example, turns out to be a major hurdle as does ensuring that the collected biomass dries enough to store without gathering mould and does not contain soil that could interfere with fermentation processes. Sam Acker, director of harvesting & precision farming marketing at Case IH North America, told Corn and Soybean Digest in November 2008 that "it may be difficult for stover to become a major ethanol feedstock based on moisture and densification challenges."[88]

Nor is it clear that the new energy grasses, such as miscanthus or switchgrass, are benign for agri-ecosystems. In September 2006 a team of researchers writing in *Science* pointed out that such grasses are highly likely to become invasive species. "Most of the traits that are touted as great for biofuel crops — no known pests or diseases, rapid growth, high water-use efficiency — are red flags for invasion biologists," said Robert N. Wiedenmann, a professor of entomology at the University of Arkansas who points to Sorghum halepense, or Johnsongrass, as an example of a "seemingly benign" crop introduced into U.S. agriculture that became invasive and now causes up to $30 million a year in losses to the cotton and soybean industries in three states alone.[89]

In August 2009, the U.S. federal advisory board on invasive species sounded its own alarm. "Absent strategic mitigation efforts, there is substantial risk that some biofuel crops will escape cultivation and cause socio-economic and/or ecological harm," warned the Invasive Species Advisory Committee in a white paper, "Cultivating Energy Not invasive Species."[90] The paper points out that "[c]ertain plant species proposed for biofuel production (e.g., reed canarygrass [Phalaris arundinacea], giant reed [Arundo donax], and miscanthus [Miscanthus sinensis]) are already invasive in regions of the U.S. and/or elsewhere in the world."

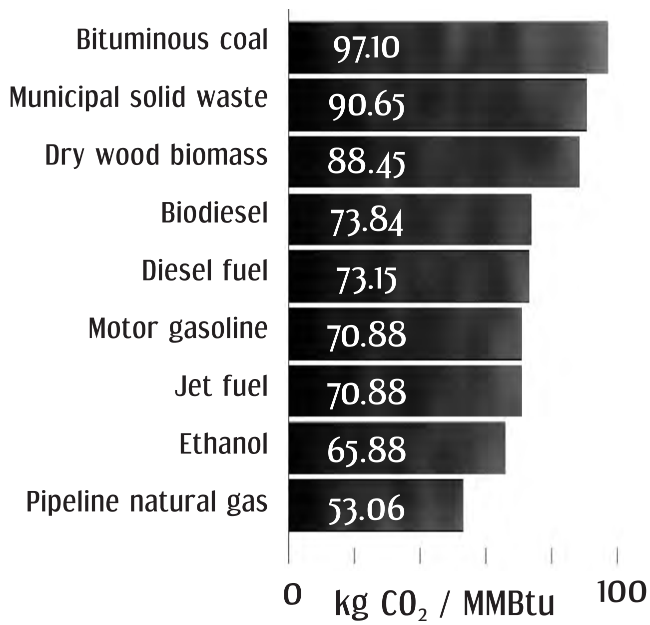
Worryingly, the committee stopped short of advising against using invasive energy crops, recommending instead that breeders of such crops incorporate "desirable traits" to avoid invasiveness such as "sterility or reduced seed production, inability to regenerate by stem fragments."[91] While this refers primarily to the development of sterile cultivars of miscanthus through hybridization, such language may also prove a dangerous invitation to equip biofuel crops with so-called 'genetic use restriction technologies' (GURTS) such as Terminator technology.

Carbon Neutral: net zero emissions of carbon dioxide; refers to processes that overall do not add extra carbon dioxide to the atmosphere. Biomass proponents claim that industrial use of biomass is carbon neutral because growing plants fix carbon dioxide so that biomass-based processes absorb whatever carbon dioxide they put out. This is misleading and usually inaccurate.

"We clutch at straws (and other biomass) in our desperation to believe there is an easy way out."
– George Monbiot, *The Guardian,* 2009[92]

CO_2 emissions from different fuel types

Amount of CO_2 from the smokestack or tailpipe when burning fuel to produce 1 million BTUs:



Sources: (1) Annual Energy Outlook 2010 with Projections to 2035 – May 11 2010 http://www.eia.doe.gov/oiaf/aeo/carbon_dioxide.html (2) EIA Voluntary Reporting of Greenhouse Gases Program Fuel Carbon Dioxide Emission Coefficients, online at http://www.eia.doe.gov/oiaf/1605/coefficients.html

The Carbon Neutral Myth

Many regulators and negotiators at international climate policy meetings now operate on the false assumption that biomass energy does not contribute to global warming because any carbon released from biomass can theoretically be re-fixed by replacement plants. It's a nice theory that breaks down on closer examination. Consider the following:

Burning biomass can release more CO_2 than fossil fuels. This is because much more biomass needs to be burned to achieve the same energy output. According to the U.S. government's Energy Information Administration, burning hardwoods produces slightly less CO_2 per energy unit than coal, but much more than oil or gas. Indeed some analysts assert that smokestack emissions from burning biomass are even higher than burning coal when the humidity (the amount of water still left in the biomass) is high.[93]

Carbon dioxide from biomass is released quickly but may take decades to re-sequester. When burned for energy, a mature tree (80-100 years old) takes minutes to release its full load of carbon into the atmosphere, but its replacement, if grown, takes a full century to re-sequester that carbon. For those 100 years, the CO_2 is still aloft in the atmosphere helping push the climate toward the point of dangerous change, and yet carbon accounting rules treat it as non-existent. (See below, "A Serious Global 'Accounting Error'") Bioeconomy advocates propose replacing mature trees with fast growing varieties such as poplar and eucalyptus, claiming these are more efficient carbon sinks than old forests. Such claims have been roundly rejected in recent years, and the new orthodoxy is that old growth forests are better than new growth at storing atmospheric carbon.[94]

Disturbing soils and changing land use to grow or harvest biomass results in large greenhouse gas emissions. Just the top 100 cm of soil worldwide is believed to store an estimated 1555 billion tonnes of carbon, held in microbes, plant roots, organic compounds present in soil aggregates, insects and other soil fauna.[95] This is more than twice (2.5 times) the amount stored in all worldwide terrestrial surface plants and about the same magnitude as the amount already in the atmosphere. Disturbance of these soils for industrial agriculture, deforestation and chemically intensive monoculture plantations as well as other land-use changes is one of the largest sources of carbon emissions. Even the very conservative 2006 Stern report on the economic costs of climate change estimated that in 2000, land use change was the second largest source of GHG emissions, after the power sector.[96]

According to Stern, a full 18 percent of GHG emissions were the result of land-use changes, with deforestation the largest contributor, accounting for over 8 billion tonnes of carbon dioxide per year.[97] Removing cellulosic material from fields is liable to further degrade soils, reducing their ability to store carbon. Studies have shown that U.S. agricultural soils, for example, have already lost between 30% and 50% of their organic carbon since cultivation began (little over a century ago in many cases). A 2009 paper shows that removing any level of stover (unharvested stalks) that are usually ploughed back into fields would further lower soil carbon levels as well as reduce yields in subsequent years.[98]

Agricultural production and transport of biomass feedstocks is greenhouse gas intensive. According to analysis by the civil society group GRAIN, the industrial food and agriculture system is the leading cause of climate change, generating 44-57% of total global greenhouse gas (GHG) emissions.[99] This estimate includes land clearance, the energy used for seed production, machinery to drill, harvest and transport production, irrigation, emissions from animals, and disturbance of soils from the production and use of pesticides and fertilizers. Forest destruction and plantation management are also associated with major greenhouse gas emissions including from the transport and use of cutting and hauling equipment. Hauling biomass by truck wastes more energy than transporting coal, oil or gas because of the low energy content of the biomass itself. This is particularly true of biomass intended for production of biofuels and bio-based chemicals rather than for bioelectricity. Converting to these end products has a poorer energy conversion rate than combustion and there is generally also a residue left over that needs to be hauled away – adding to the overall energy cost.

Taking cellulosic material from fields for biomass will require more fertilizers to maintain soil fertility. Nitrogen phosphate based fertilizers release nitrous oxide – a greenhouse gas 298 times more potent than CO_2.[100] Global use of fertilizers has already risen 31% between 1996 and 2008 due in part to agrofuel cultivation.[101] Besides their own direct emissions impact, fertilizers are energy intensive (and hence carbon intensive) to produce and apply in the first place. A 1998 study[102] estimated that fertilizer production is responsible for approximately 1.2% of total GHG emissions – equivalent to the full greenhouse gas emissions of Indonesia or Brazil. In the U.S. alone, fertilizer use and production account for thirty percent of energy use in agriculture. Fertilizers can also exert a further (indirect) impact on greenhouse gas concentrations when nitrates leaching from fertilized fields form oceanic dead zones that may also be releasing enormous quantities of CO_2, methane and nitrous oxide.

Vegetation removal for biomass can also worsen climate change by changing the amount of heat that is kept in the atmosphere. In Australia, for example, scientists estimate that the loss of native vegetation reduced cloud formation and meant that less heat was being reflected back to space. This exacerbated the impacts of recent climate related droughts, raising the temperature an additional 2-3 degrees celsius. In Australia these changes contributed to the collapse in agricultural productivity for the region.[103]

A Serious Global "Accounting Error"

Many national and international policy instruments to address climate change are based on the false assumption that energy derived from biomass is intrinsically 'carbon neutral.' The root of this common mistake lies in the carbon accounting practices enshrined in the UN Framework Convention on Climate Change (UNFCCC).

In 2001, the scientific body advising the UNFCC, the Intergovernmental Panel on Climate Change (IPCC) first described the use of biomass for energy as "Low-carbon energy supply systems" and baldly stated that "[l]iquid biofuels when substituted for fossil fuels will directly reduce CO_2 emissions. Therefore, a combination of bioenergy production with carbon sink options can result in maximum benefit from mitigation strategies."[104] By 2007 the IPCC's enthusiasm had dampened a bit: "Biofuels might play an important role in addressing GHG emissions in the transport sector, depending on their production pathway."[105]

Nonetheless, the impression had been well established in the minds of policy makers that promoting biomass energy uses in national strategies was a legitimate, and relatively easy, route to fulfilling commitments related to climate change.

Indeed, the rules for calculating carbon emissions under the Kyoto Protocol currently go as far as to exempt entirely biomass energy as a source of emissions, regardless of how the biomass is sourced and how much additional carbon is released in that production process. This was the result of a decision made by the IPCC to count the carbon emissions associated with making bioenergy as part of land use changes, rather than counting it under energy uses (to avoid double counting). However the Kyoto Protocol only counted emissions from energy and so biomass energy got a free pass. This exception sets up a powerful economic incentive for nations to switch to the cheapest biomass energy sources available in order to meet carbon dioxide emissions targets and earn carbon credits. According to one recent modeling study, the policy of exempting biomass-derived energy from emissions counting could drive nations to displace virtually all the world's natural forests and savannahs with bioenergy crops. Such massive displacement of forests would release potentially hundreds of billions of tonnes of carbon during a short timescale (less than 20 years) – a scenario that would drive catastrophic biodiversity loss and dangerous climate change within less than a century.[106]

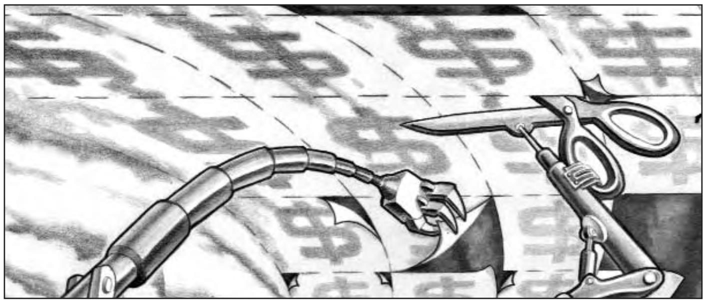
That prospect has so alarmed even proponents of biomass energy that in October 2009 thirteen scientists and policy experts, some of them closely identified with the original Kyoto accounting protocols, warned that the exemption of biomass from carbon accounting protocols was a "far-reaching" and "serious" flaw in the global climate agreement.[107] They proposed that this "accounting error" could be fixed if emissions from biomass energy were measured at the tailpipe or smokestack just like fossil fuels and that any sequestration benefits should be separately measured and credited by accounting the actual land management and production practices for different biofuels and biomass technologies. Drawing an analogy with the recent financial crisis, the authors – mostly advocates of cellulosic biofuels – hinted that this issue of false accounting might eventually discredit the entire biomass agenda. "Just like with financial audits, it's important for carbon audits to be correct from the start," said Michigan State University professor and co-author Philip Robertson. "The promise of cellulosic biofuels is huge for our climate and economy. We don't want to find out later that we've built a new industry on a house of cards."[108]

Trading Biomass-based Carbon

Not only has the UNFCCC falsely blessed biomass as carbon neutral in its emissions accounting, the convention has also set up institutional mechanisms to financially reward the growth of the new biomass economy. While reducing national greenhouse gas emissions (primarily carbon dioxide) had been the centerpiece of the Kyoto Protocol, delegates in the final negotiations acquiesced to proposals by the United States to introduce so called 'flex mex' (flexible mechanisms) that would allow trading in emissions allowances within an established and tightening cap as well as options to monetize biological and geological carbon 'sinks' within those mechanisms.[109]

Article 3.3 of the Convention further allows states to receive credits or debits on their emissions reductions depending on how they managed their own carbon sinks. By 'sinks' the advocates of the 'flex mex' had in mind that plants, soils and oceans naturally sequester carbon dioxide from the atmosphere and therefore argued that measures to protect and enhance sinks, such as growing more trees or reducing soil erosion, should receive tradable credits. These credits could be issued, for example, under the new 'Clean Development Mechanism' (CDM) of the Protocol or under what are known as 'joint implementation' projects. In particular, the CDM encourages investment by Northern companies and states in sequestration or climate mitigation projects located in the global South.

Although agriculture and forest projects were initially restrained to satisfy only a small part of CDM projects, in 2001 more loopholes were opened in the flex mex, allowing for biomass in existing forests to be more easily credited and monetized. Bioenergy firms and biobased chemical companies have since been diligent in lobbying for the CDM to expand its financing to all parts of the biomass economy. From 2005, methodologies were approved for financing the production of electricity from burning plantation residues such as sugar cane, bagasse, rice husks and palm oil fruit bunches. From September 2006, the CDM accepted the use of biomass for hot water production. From 2009, projects that produced biodiesel on so-called degraded lands also became eligible for CDM credits. In February 2010 the CDM board further approved granting credits to electricity power plants for burning biomass, including coal-fired power stations that co-fire with biomass.[110]



'Cutting up the sky,' the Beehive Collective

As of October 2010, 705 biomass projects were either approved or seeking approval for 45 million certified carbon credits under the CDM mechanism, with India (318 projects), China (101 projects) and Brazil (94 projects) taking the greatest share. That amounts to 12.75% of all CDM projects, third only to wind and hydropower projects.[111] At current prices, these credits would be worth around one-half billion dollars adding to the overall value of the biomass economy.[112]

Meanwhile an unregulated 'voluntary' carbon credit industry has emerged outside of the Kyoto framework with entrepreneurial companies, such as Future Forests, linking biomass and bioenergy projects to new carbon credits that could be sold to individual consumers to 'offset' carbon-intensive lifestyles. The World Bank estimates the carbon trade is currently worth $144 billion, with national and regional carbon trading exchanges in full swing in Europe, Asia and North America.[113]

Trading Biomass-based Carbon: Take II – getting REDD-y for a grab

The combination of the UNFCCC's faulty accounting methods and financing of bioenergy projects may already seem like enough of an assault on biodiversity, but the same international forum is about to add insult to injury by introducing a third mechanism to commodify biomass. The so-called REDD ("Reducing Emissions from Deforestation and Forest Degradation") now under negotiation at the UNFCCC attempts to give forest biomass a financial value based on the carbon stored within it. The idea behind REDD is to back living carbon stored in forest biomass with financial securities that can be monetized and traded alongside existing financial commodities. Backers of REDD argue that this will provide a market incentive to prevent logging and deforestation. In making a currency out of biomass, REDD exacerbates the reduction of biodiversity to stocks of commodifiable carbon. While the forestry industry has been accused before of not seeing the forest for the trees, REDD can't even see the trees for the carbon stored inside them. The result of such reductionism is that the implementation of REDD looks likely to harm both natural biodiversity and the communities that rely on it.

Specifically, the UNFCCC's Bali Action plan calls for "policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries." When decoded this so-called "REDD+" paragraph licenses the clearing of traditional people from forests for 'conservation' purposes and subsidises commercial logging operations that meet agreed-upon "sustainable management" criteria. Moreover, by talking of 'enhancing forest carbon stocks,' REDD+ looks set to financially reward the conversion of forest land to industrial tree plantations justified by claims that such plantations store more carbon than what is currently growing. This has serious implications for biodiversity and local communities.

Even before REDD is implemented and agreed, governments, corporations, large NGOs and global institutions are experimenting with this form of biomass-based carbon finance and attempting to set up REDD-like schemes. According to watchdog REDD Monitor, The World Bank has approved 25 projects under its Forest Carbon Partnership Facility and 3 through its BioCarbon Fund, while UN-REDD (UNDP, UNEP and FAO) is running pilot projects in Bolivia, Democratic Republic of the Congo, Indonesia, Panama, Papua New Guinea, Paraguay, Tanzania, Viet Nam, and Zambia, with promises of over $18 million. Governments such as Norway, Australia and Germany have been pledging money for REDD projects in the South as have an increasing number of private corporations. Organisations such as Conservation International, WWF, The Nature Conservancy and Environmental Defense Fund are partnering with corporations including BP, Pacificorp, Merrill Lynch and Marriott Hotels. Voluntary standards are already springing up to define what is 'sustainable' for REDD, and carbon traders such as EcoSecurities and Caisse de dépôt are preparing to start commodifying and profiting from as much of the world's forest biomass as they can get their hands on.[114]

Photo: Orin Langelle, Global Justice Ecology Project

Transferring Biomass Technologies – Climate Technology Initiative

The biomass economy is getting yet another financial boost from the UNFCCC via the climate treaty's activities on technology transfer. The International Energy Agency and OECD established the Climate Technology Initiative (CTI) in 1995 to facilitate the transfer of "climate-friendly" technologies from the North to the South. Unsurprisingly, biomass has played a starring role in the CTI's activities. Its private arm, known as the Private Financing Advisory Network (PFAN), acts as a matchmaking agency connecting Northern investors and technology corporations to Southern projects and brokers "clean energy" business deals. Over one-third of the 60 projects in PFAN's pipeline – accounting for $823 million – are biomass energy projects such as biomass electricity generation, production of wood pellets for industrial burning or biodiesel production.[115]

The Green Economy – A cozy home for the bioeconomy

The multiple crises that wracked the world in 2007-2008 caught the multilateral system by surprise. In the scramble to recover, the UN Environment Programme (UNEP) launched its Green Economy Initiative (GEI) in 2008 to assist governments in reshaping and refocusing policies, investments and spending toward "businesses and infrastructure that deliver better returns on natural, human and economic capital investments, while at the same time reducing greenhouse gas emissions, extracting and using less natural resources, creating less waste and reducing social disparities."[118]

The "green economy" received an official UN stamp with the launch of its "Global Green New Deal for Sustainable Development" in 2009. The deal aims to target stimulus spending at 1 percent of the world's GDP (totaling around $750 million), and institute changes in domestic and international policies to support the green economy.

InfraREDD – Mapping the biomass

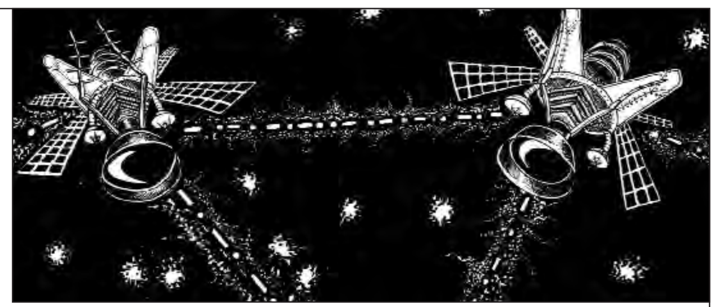


Illustration: the Beehive Collective

Satellites and fixed-wing aircraft can now combine to map and monitor (in three dimensions) biomass and lands to be identified, managed and exploited in the new biomass economy. Cameras mounted on light aircraft, including helicopters, can use hyper-spectral imaging to analyze visible and infrared wavelengths that reveal variations in vegetation. Precise light measurements expose soil nutrients, identifying not only the type of surface vegetation but what lurks beneath and therefore what could grow there. The technology was originally developed to find burial sites but has branched out to service a multitude of interests from archaeologists to the CIA.

For land grabbing investors, looking to economically 'improve' so-called marginal lands, the value of such biomapping is considerable. The near-term possibilities include the aerial identification of proprietary crops and the opportunity to triangulate on soils, bugs or plants offering industrial uses. After the biodiversity is pinpointed and pocketed, the land can be used for other purposes.

In particular the biomappers are targeting carbon. In September 2010, the Carnegie Institute at Stanford University announced that, with WWF and the Peruvian government as partners, it had mapped over 16,600 square miles of Amazonian forest (about the area of Switzerland). While satellites mapped vegetation and recorded disturbances, the satellite images were complemented by a fixed-wing aircraft deploying Carnegie's proprietary LiDAR technology (light detection and ranging) to produce 3-D representations of the area's vegetation structure. On the ground, scientists converted the structural data into carbon density aided by a modest network of field plots. Carnegie's novel system brings geology, land use, and emissions data together to advise the government of Peru – and anyone else with access to the data – that the region's total forest carbon storage weighs in at about 395 million tonnes. The IPCC estimate for carbon storage in the surveyed area was 587 million tonnes. Under REDD-type programmes, Carnegie's high-resolution approach could yield more credit per tonne of carbon.[116] For those looking for biomass feedstocks, it tells them what is available to buy. The system is also cheap. Peru's map cost 8 cents per hectare and a similar map in Madagascar was only 6 cents.[117] Of course, in the world of biomass feedstocks and carbon trading, the issue is how much biomass can the land produce?

A 2009 report by HSBC Global Research showed that G-20 governments have already allocated more than $430 billion in fiscal stimulus – equivalent to about 15 percent of the total $2.8 trillion – in the areas of climate change and other "green" themes.[119] Many of the projects may not be new but may be existing projects relabeled to fit the "green" criteria.

The green economy has received wide support across the UN, with the Environment Management Group (EMG) – the UN body that coordinates the direction of all environment-related specialized agencies – adopting the GEI in its biennial work programme to assess how the UN system can more coherently support countries in making the transition to a green economy. Not surprisingly, the push for the green economy has been met with enthusiasm from governments wanting to appear to be taking action on climate change and recover their economies. The UN system's new embrace of "green" will ensure a warm welcome for the bioeconomy. Along with international environmental governance, the green economy is one of the two main themes of the UN Conference on Sustainable Development (Rio+20) in 2012.

"Almost all of the arable land on Earth would need to be covered with the fastest-growing known energy crops, such as switchgrass, to produce the amount of energy currently consumed from fossil fuels annually."
– U.S. Department of Energy[120]

Already, there are points of convergence between the bioeconomy and the green economy. The key architects of the GEI are also the main authors of The Economics of Ecosystems Services and Biodiversity (TEEB), which provides the conceptual anchor for REDD (and REDD+ and other mutations) and the fledgling concept of "biodiversity offsets," making up one facet of the bioeconomy: the biodiversity services economy. Biorefineries and bio-based production are among the models of "green innovation" explicitly endorsed by the GEI. Having raised nearly one-half billion dollars in such a short time from fiscal stimulus packages extended by rich governments, the green economy is the perfect feedstock to fuel the engines of the bioeconomy.

Watts, megawatts (MW), gigawatts (GW) and terawatts (TW): units of power; a watt describes the rate of energy use. Megawatts are millions of watts; gigawatts are billions of watts and terawatts are trillions of watts. Typically a household light bulb continuously uses 25-100 watts; a large commercial building such as a shopping centre or factory consumes energy at the rate of megawatts; the very largest power plants such as nuclear facilities might produce gigawatts of energy. Terawatts are usually used only to describe aggregate global or regional energy use.

Busting the Earth's Biomass Budget?

With biomass touted as the new feedstock of a global post-petroleum economy, it is essential to ask the question: Does sufficient biomass exist on the planet to achieve such a historic transition? For comparison, when global society last relied on plant matter as the primary source for its energy needs, in the late 1890s, world consumption of energy is estimated to have been 600 gigawatts.[121] Today's estimates of world energy consumption range between 12 and 16 terawatts – at least a twenty-fold increase in demand over the previous "biomass economy." That energy output is met almost entirely from fossil fuels, with just a sliver of nuclear, hydro and biomass power in the mix (around 1.5 terawatts).[122] According to MIT energy economist Daniel Nocera, global energy use is further projected to add at least an additional 19 terawatts by 2050.[123]

Theoretically, that global energy use could be met by biomass. Every year, just over 100 billion tonnes of carbon locked up in 230 billion tonnes of new biomass is added to the planet, amounting to about 100 TW of energy from the Sun.[124] That is approximately 6 times the current global power consumption, or 3-4 times global power consumption projected for 2050.[125]

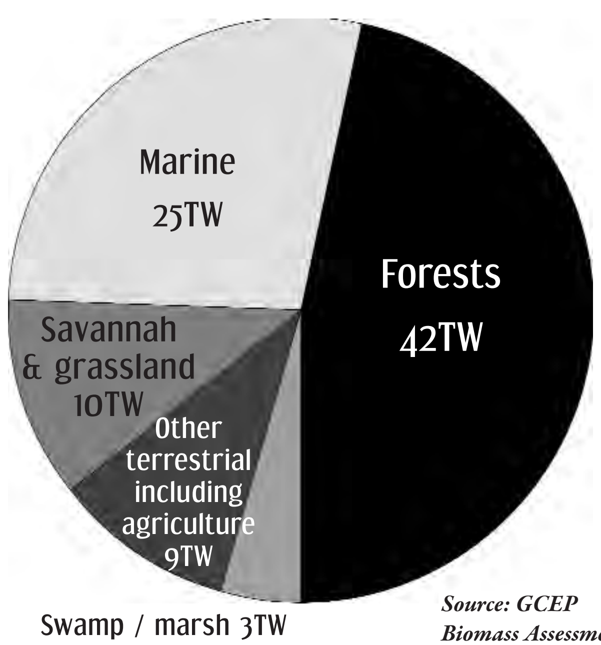
However, that global biomass is not so readily available:

- Almost half (100 billion tonnes) of that biomass is in the ocean, much of it locked up in microbes and algae that are not easily accessible (e.g., in deep oceans and sediment).
- Of the remaining 130 billion tonnes grown on land, human societies already use up 24% of that annual biomass growth (31.2 billion tonnes) for food, lumber, firewood and other human needs (this is known as HANPP – Human Appropriation of Net Primary Productivity).[126]
- The remaining 98.8 billion tonnes of annual biomass is facing competing demands. The United Nations predicts the human population will expand to an estimated 9 billion people by 2050. This means more demand for food, feed, fibre and land. Economists predict for example that the use of wood (e.g., for lumber) is likely to grow by 50-75% by 2050.[127] The pulp industry is planning a total of more than 25 million tonnes of new pulp capacity, an average of five million tonnes extra per year.[128] Meanwhile the FAO predicts that firewood use in Africa alone will increase 34% by 2020.[129]

- Moreover, as climate change continues to take its toll, additional stresses on forest and agricultural ecosystems may severely reduce their productivity, while higher global temperatures and more frequent El Niño events will put forest biomass at greater risk for fires. Meanwhile climate-change related upsurges in crop disease and parasites, and the impact of elevated CO_2 on plant growth and flooding, may further reduce actual biomass production.
- Studies measuring human appropriation of global biomass conclude that, on average, for every tonne of biomass that is directly used by human society, a further 5 tonnes are lost 'upstream' from land use changes, processing and waste.[130] One sobering implication is that calculations of biomass feedstock requirements for new bio-based developments may need to be multiplied by six or more to provide a true picture of their impact on the biosphere. Since the energy stored in annual global production of biomass is about one-sixth of current global energy needs, this suggests that the upstream impacts of switching entirely to bioenergy could entirely devour the Earth's annual biomass production.

A review of 16 global assessments of biomass availability notes: "In the most optimistic scenarios, bioenergy could provide more than two times the current global energy demand, without competing with food production, forest protection efforts and biodiversity. In the least favorable scenarios, however, bioenergy could supply only a fraction of current energy use, perhaps even less than it provides today."[131]

Net productivity of different types of biomass expressed as power (terawatts)



Source: GCEP Biomass Assessment

Ecosystems Count First

Why such a wide range of estimates for the potential of biomass to meet energy needs? The short answer is that some energy economists have simply failed to see the forest for the trees. Living biomass stocks cannot be counted in the same manner as fossilized oil and coal reserves. The economic value of harvested plants as industrial raw materials for food, feed, fibre, chemicals and fuel must be weighed against the vital ecological value of living plants.

Earth-systems studies that attempt to measure the current health and resiliency of ecosystems and biodiversity offer stark warnings. The 2005 Millennium Ecosystem Assessment concluded that 60% of the world's ecosystems are already in decline.[132] While the "Living Planet Index," a measure of trends in biodiversity, based on tracking 1313 terrestrial, marine and freshwater species, reports that between 1970 and 2003, the index dropped 30 percent, meaning ecosystems are generally in steep decline.[133] The World Conservation Union has reported that overall, nearly 40% of species evaluated are threatened with extinction.[134] Current extinction rates are now over 1000 times higher than background rates typical over the Earth's history, and land-use changes, including deforestation and agricultural expansion, are regarded as the leading cause. Meanwhile, it is estimated that at least a further 10-20% of remaining forest and grassland will be converted to human uses by 2050.[135] As well, the UN estimates that two-thirds of the countries in the world are affected by soil desertification, affecting more than 4 billion hectares of agricultural land, which supports over one billion people.[136]

Especially telling are the metrics from other measures, for instance the Ecological Footprint, developed by the Global Footprint Network.[137] This measures human (over)use of the Earth's biocapacity. The term 'biocapacity' refers to the natural production of biomass carried out by cropland, pasture, forest or fisheries while absorbing human wastes. Overuse of biocapacity damages ecosystems and drives them into decline. It turns out that since the late 1980s, we have been in "Earth overshoot"[138] with an industrial footprint larger than planet's biocapacity. In fact, since around 2003 we have reached a shocking 25% overshoot, "turning resources into waste faster than nature can turn waste back into resources."[139]

Net Primary Production: annual volume of biomass; the full amount of new biomass growth (mostly plantlife, but also animal, bacterial and other growth) produced by the planet in one year; amounts to around 230 billion tonnes of living matter.

If we continue on the current trajectory, we will be using twice the Earth's biocapacity by 2050 – an untenable proposition.

"Recent proposals of massive bioenergy schemes are among the most regrettable examples of wishful thinking and ignorance of ecosytemic realities and necessities. Their proponents are either unaware of (or deliberately ignore) some fundamental findings of modern biospheric studies."

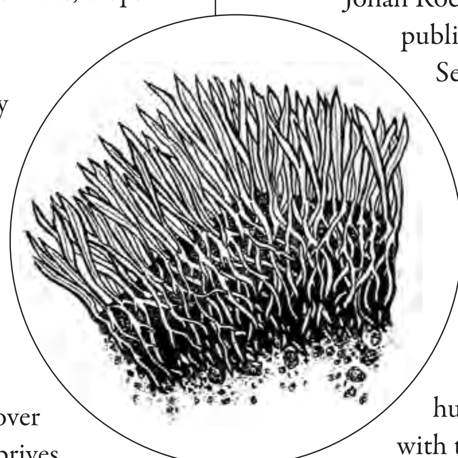
– Professor Vaclav Smil, Distinguished Professor of the Environment, University of Manitoba.[140]

Is Biomass Really 'Renewable'?

As global renewable energy targets turn out to be mostly padded with straw (and other forms of biomass), environmental groups and communities affected by new biomass processing plants have begun lobbying for biomass to be removed from the definition of renewable energy, for good reason. Using plants as an energy source differs from solar, wind and tidal energy, which might better be termed 'perpetual energy sources' since their utilization doesn't diminish overall stocks. Trees, crops and other plant life, by contrast, can be exhausted by over-appropriation. More importantly, so can the soils in which they grow and the ecosystems from which they are taken.

Numerous studies have shown that land-use changes and land management practices associated with biomass extraction can weaken and destroy ecosystems and water tables, rendering them non-renewable. Taking vegetative cover from the land hastens soil erosion and deprives soils of nutrients while fast growing tree plantations or monoculture crops can deplete water aquifers.

In April 2009, an alliance of 25 U.S. environmental and conservation groups wrote to Congress asserting, "Biomass should not be considered renewable because the removal of biomass, even 'residues and wastes' from forests, grasslands or soils, depletes nutrients and results in declining fertility and biodiversity. While it is possible to re-grow trees and other plant matter, it is not possible to recreate healthy ecosystems."[141]



Planetary Boundaries for Biomass Extraction?

As industrial policies associated with the biomass economy press on, conservationists fear disaster. For example, in the Amazon Basin, expansion of sugar cane and soya (in part for biofuels) is driving deforestation to the point where a massive "dieback" (region-wide death of trees) is considered likely.[142] The potential impact of such an Amazon dieback would be a global catastrophe, given its role in regulating rainfall and weather over much of South America up through the U.S. Midwest and even as far as South Africa.[143]

What such a dramatic impact tells us is that measures of ecosystem functions and biocapacity, while useful, provide an incomplete picture of the real limits to biomass extraction and an unrealistically linear view of how ecosystems function and how they can collapse. Just as the threat of an Amazon dieback cannot be measured from a global 'biocapacity' index, so there are likely many more ecological 'tipping points' which, once crossed, could push ecosystems into collapse, causing devastating non-linear effects. We may never see these tipping points coming until it is too late.

In an attempt to raise awareness of catastrophic tipping points, a group of Earth-system and environmental scientists, led by Johan Rockström of the Stockholm Resilience Centre, published a paper in the journal *Nature* in September 2009 that proposed the establishment of nine "planetary boundaries."[144] These are a set of thresholds or tipping points beyond which changes in biophysical processes could throw the entire planet into "unacceptable environmental change." The authors described these boundaries as the edges of a "safe operating space for humanity," stating that human interference with the biosphere needs to remain within these limits if we are to keep the planet in roughly the same stable and familiar state it has been for the past 10000 years. According to their estimates, at least three of the nine planetary boundaries they identified have already been breached. While the Rockström paper sets no explicit planetary boundary for human appropriation of biomass, keeping within several of the boundaries identified (such as land-use change and nitrogen overuse) looks ever more untenable given future biomass harvest projections.

Illustration: the Beehive Collective

Not Enough Biomass? Let's boost it…

The fact that planet Earth doesn't have enough biomass on the books to safely transition to a biomass economy is not lost on the new biomassters. Some answer that switching to biomass is just a temporary measure en route to a solar-powered or more genuinely renewable energy future. In other words, going overdrawn at the biomass bank is more like going into debt for a bridging loan. Others are proposing something more like inflation – boosting the quantities of global biomass, and particularly cellulosic biomass, by technological means. Doing so will introduce new risks and it is not reasonable to believe that growing industrial quantities of "extra" biomass could in some way reverse that biodiversity decline. As Almuth Ernsting and Deepak Rughani of Biofuelwatch point out, the contradiction remains that "despite the overwhelming evidence that industrial agriculture and industrial forestry are rapidly depleting the biosphere, soils and freshwater worldwide at an ever faster rate, it is proposed that both can be expanded further to somehow make the biosphere considerably more productive than it has ever been before."[145]

As the quest for biomass intensifies, expect to see more of the following biomass boosting strategies:

Genetically Engineered Trees – Biotech companies such as U.S.-based Arborgen, Inc. are pushing ahead with bioengineering fast-growing trees for the new biomass markets. In May 2010 Arborgen received clearance for environmental release of 260,000 cold-tolerant eucalyptus seedlings across 9 U.S. states, bringing the fast growing species to more northern latitudes than were previously possible. Meanwhile, scientists at Purdue University have developed a fast growing poplar tree with reduced lignin that they claim will be perfect for cellulosic biofuel production. They claim that changing the lignin composition of trees could increase the annual yield of cellulosic ethanol from poplar from 700 gallons per acre to 1000 gallons per acre.[146] Ironically, removing lignin from trees also appears to reduce their carbon sequestration capacity. According to one study, low lignin trees accumulated 30% less plant carbon and 70% less new soil carbon than unmodified trees.[147]

Biomass or Biomassacre?

To reprise the question: Does sufficient biomass exist on the planet to switch to a bio-based economy?

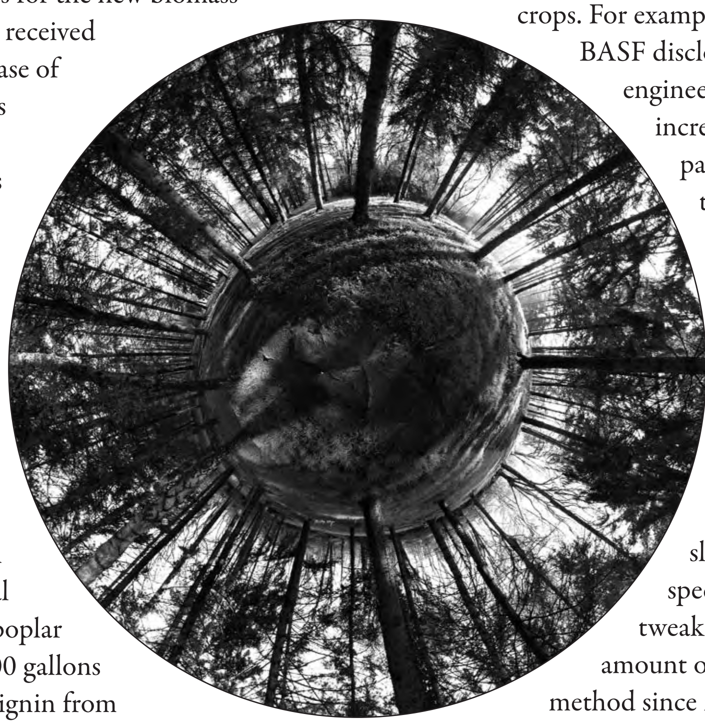
The answer is clearly 'No.'

The alarming notion of "Earth overshoot," the rapid decline of global ecosystems and the approaching threat of catastrophic tipping points tell us that attempting to set an 'acceptable level' of biomass extraction is as inappropriate as forcing a blood donation from a hemorrhaging patient.

Already struggling to maintain life support, the planet simply does not have any biomass to spare. Until industrial civilization significantly reduces its existing ecological footprint, we are critically overdrawn at the biomass bank and moving deeper into ecological bankruptcy and possible collapse for which there is no bailout.

Genetically Engineered Biomass Crops – While plant breeders have been trying to increase yield for centuries, the focus has always been on increasing the seeds and fruit of food crops. Now, with cellulosic biomass gaining value, agribusiness is working on increasing the quantity of stalks, leaves, husks and other cellulosic components of common agricultural crops. For example, a suite of patents filed by BASF discloses methods of genetically engineering corn and other crops for increased biomass yield.[148] The patents also claim ownership over the biomass itself when produced in maize, soybean, cotton, canola, rice, wheat or sugarcane.

Engineering Photosynthesis – According to some scientists, the natural process that turns sunlight and CO_2 into biomass in most plants is sluggish and inefficient and can be sped up with a little genetic tweaking. Surprisingly, reducing the amount of chlorophyll in leaves is one method since more sunlight passes through upper leaves to reach lower leaves. According to *New Scientist*, experiments with mutant soybeans that contained only half the chlorophyll produced 30% more biomass.[150]



Photomontage: Karl Adam

Other tricks yet to be perfected include changing the type of photosynthesis to a process that more efficiently converts carbon to sugar. Recent experiments with rice seemed to work in the lab, but not in the field. Nonetheless, the International Rice Research Institute (IRRI) in 2008 launched a new initiative, funded by the Bill & Melinda Gates Foundation, to switch the photosynthesis mechanism in rice. In November 2009, CIMMYT (International Wheat and Maize Improvement Center) launched their Wheat Yield Potential Consortium to do the same for wheat.[151] Others are altering photosynthesis in other ways. For example, scientists at the J. Craig Venter Institute have been developing synthetic strains of algae and bacteria that use photosynthesis to produce hydrogen instead of oxygen. While this approach doesn't yield much biomass, if successful, it could yield a highly prized (and priced) fuel that only produces water when it burns.[152]

"We can fly much better than birds, so why not try to make a synthetic process that turns carbon dioxide and sunlight into energy better than a leaf?"
– Dr. Michele Aresta, director of Italy's National Consortium on Catalysis[149]

Illustration: the Beehive Collective

Terminator Plants – According to GMO grass expert, Albert Kausch of the University of Rhode Island, rendering plants sterile is a sure-fire way of increasing their biomass. Sterile plants that do not use their energy to produce flowers can use it instead to produce more biomass. That at least is the claim made in a patent application on sterile biofuel plants filed by Professor Kausch and a colleague.[153] The patent application not only claims ownership of the methods for increasing biomass through sterilization, but also over any plants produced, thereby directly grabbing the biomass itself. Kausch, who is working with Vekon Energies of Germany, has also received $1.5 million from the U.S. Environmental Protection Agency to fund his work on what he calls the 'golden switchgrass' project.[154]

Climate Ready Crops – Another option for increasing global biomass is to genetically equip crops to grow in inhospitable conditions – for example, in saline soils, marshlands or deserts. Such 'abiotic stress resistant' crops that can survive salt, waterlogging, drought or reduced nitrogen input are being developed and marketed by agribusiness giants as 'climate ready' because they could theoretically adapt to rapid climatic changes. However, such crops may equally be regarded as biomass-ready since they may make it possible for formerly "marginal" lands to be made productive, giving the land traditionally used by poor people and peasants over to the profit of corporations. Analysis by ETC Group has so far uncovered 262 patent families of climate-ready crops dominated by six corporations (DuPont, BASF, Monsanto, Syngenta, Bayer and Dow) and their partners (principally Mendel Biotechnology and Evogene). Once again the patent claims extend beyond methods to the biomass itself.[155]

Algae – Whereas a tree may take decades to grow and grasses and crop will take months, algae doubles its mass daily which means that boosting algal production is many orders faster than trying to increase other biomass feedstocks. Algae also can be grown in oceans, ponds, deserts and wetlands and so, bioeconomy advocates claim that algae feedstocks don't compete with food production. This isn't quite true since current algae production competes for water, nutrients and even land (see below for detailed discussion of algae).

Geoengineering the Planet with Biomass

Talk of boosting global biomass or "improving" photosynthesis to absorb more carbon represents attempts to reengineer global primary production beyond the constraints of nature. Planet-altering technologies of this scale are known as geoengineering and are gaining prominence, particularly in the context of the climate crisis. While the most high-profile geoengineering schemes propose reducing the amount of sunlight in the atmosphere to cool the planet, a second class of geoengineering schemes, dubbed biogeoengineering, is under active consideration by governments and scientists. These attempt to capture or boost terrestrial biomass production to sequester carbon dioxide (CO_2).

Ironically, the planet itself has probably already responded to rising atmospheric carbon by boosting biomass. "Between 1982 and 1999, 25 percent of the Earth's vegetated area experienced increasing plant productivity—a total increase of about 6 percent,"[157] explains Ramakrishna Nemani, a biospheric scientist at NASA Ames Research Center. However, there are probably upper limits to biomass production imposed by soil and ocean nutrition, water availability, heat and sunlight. Nonetheless, biogeoengineers are proposing schemes to speed up the carbon cycle, biomass growth and sequestration, not for energy or materials production but for climate-engineering purposes.

"The name of the game is not optimization of fuel production from biomass, but the optimization of the use of biomass for carbon removal from the atmosphere."
– Stuart Strand, researcher at the University of Washington[156]

Examples of biogeoengineering include:

Biomass Dumping

Two U.S.-based geoengineers propose continuously dumping biomass in the deep ocean as the most efficient way to "scrub" CO_2 out of the atmosphere. Professors Stuart Strand of the University of Washington and Gregory Benford at the University of California–Irvine dub their biogeoengineering project CROPS (Crop Residue Oceanic Permanent Sequestration) and calculate that if 30 percent of the world's agricultural crop residue (straw, leaves and stover) were transported to the sea and dumped in the deep ocean, 600 million tonnes of carbon would be removed annually from the atmosphere, decreasing atmospheric carbon by 15 percent. One proposal involves dumping 30% of U.S. agricultural residue 4 meters deep in a 260 square kilometer patch of seafloor in the Gulf of Mexico. "What is put there will stay there for thousands of years," asserts Strand, claiming that the seafloor is too inhospitable for biomass to decompose.[158] Some marine ecologists disagree: "The deep sea is not a lifeless cold dark empty place – it is filled with animals that are evolved to take advantage of whatever food drifts down from above, terrestrial or not. For example, wood that falls into the deep sea gets eaten,"[159] explains Miriam Goldstein of the Scripps Institution of Oceanography. Biomass dumping field trials have already begun off the coast of Monterey, California, USA.[160] Strand and Benford claim there are no legal restrictions on dumping organic farm matter at sea.

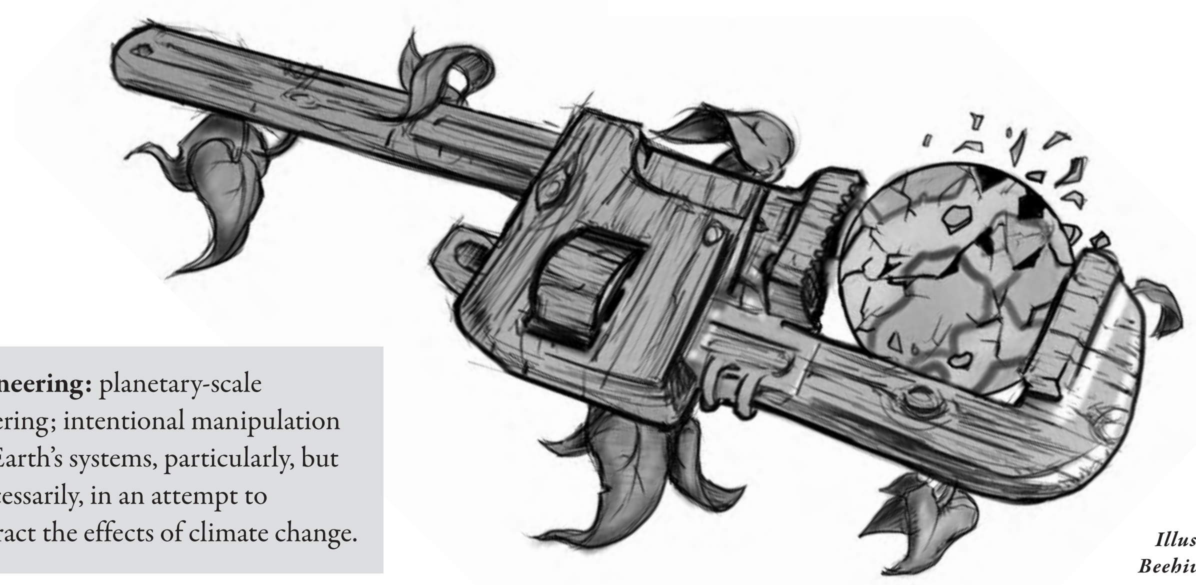


Illustration: the Beehive Collective

Geoengineering: planetary-scale engineering; intentional manipulation of the Earth's systems, particularly, but not necessarily, in an attempt to counteract the effects of climate change.

Ocean Fertilization (Marine Algae)

A different form of ocean dumping for geoengineering proposes the dumping of iron, urea and other nutrients to stimulate rapid growth of plankton (algae). The theory of ocean fertilization: nutrient additions to the seas will prompt massive plankton blooms, which will rapidly absorb CO_2 and then fall to the ocean floor, sequestering the carbon.[161] That adding iron, phosphate or urea to oceans prompts algal blooms is well proven both by international experiments in ocean fertilization and by the existence of vast ocean dead zones where agricultural run-off gives rise to algae. That the artificially-produced blooms will permanently sequester carbon dioxide is much more controversial. Artificial plankton blooms appear to have a different ecological structure than natural blooms, can give rise to hazardous species and lead to release of potent greenhouse gases such as methane and nitrous oxide.[162] They may also lead to de-oxygenation of the water, suffocating biodiversity. Although the Convention on Biological Diversity declared a de facto moratorium on ocean fertilization activities in 2008, private companies such as Climos, Ocean Nourishment Corporation (ONC) and Planktos Science are still hoping to profit from ocean fertilization. Both ONC and Planktos Science are also interested in utilizing the resultant biomass for other uses (increased fish stocks and biofuels).

Illustration: Liz Snook

Biomass Energy with Carbon Sequestration (BECS)

While burning biomass for electricity is often presented (wrongly) as 'carbon neutral' some biomass advocates claim that the process could even be made 'carbon-negative' with additional technological tweaking. To achieve this they suggest bolting 'carbon capture and storage' (CCS) technology to biomass burners or to biofuel production facilities.[163] While CCS doesn't yet and may never exist as a commercially feasible technology because of the large environmental risk it implies, the idea of chemically scrubbing CO_2 from smokestacks and then burying it underground in liquid or solid form is front and centre of OECD responses to climate change. For would-be geoengineers the claims that Bio Energy with Carbon Storage (BECS) scrubs carbon twice (once when the biomass grows and a second time when the CO_2 is stored) are very appealing. In a series of essays on "biospheric carbon stock management," the Peter Read of New Zealand's Massey University proposed growing 1 billion hectares of fast growing plantation trees for electricity generation and carbon capture as a geoengineering scheme that might restore the atmosphere to lower carbon levels.[164] He and other BECS proponents have also suggested that turning biomass into charcoal for sub-soil burial (biochar) could also cool the planet if carried out on a sufficiently large scale.

The New Biomass Economy: 10 Myths

1. Basing our economy on biomass is natural: we've done it before and it's time to do it again.

The Claim: Our economies have used biomass as their key feedstock in the past and indeed the economies of many traditional societies still subsist largely on biomass. Basing our economies on organic, natural materials provided by ecosystems is an option that operates in harmony with the limits of nature's bounty.

The Reality: It is disingenuous, or naïve, to argue that small-scale biodiversity-based economies are exemplars for the industrial-scale transformation of large quantities of undifferentiated biomass for the global market. When the global economy last ran primarily on plant matter (in the 1890s), it required one-twentieth the energy it consumes today. Even then, contemporary economists worried about the land use implications of maintaining sufficient biomass supplies. There is nothing natural or sustainable about industrial-scale extraction of timber or modern industrial monoculture farms and plantations. Environmental history teaches us that when natural resources are overexploited, the result is often civilization collapse.

2. Biomass is a carbon-neutral energy source and a solution to climate change.

The Claim: Since the carbon released by burning biomass can be sequestered by replacement plants, using biomass for energy results in no net emissions of carbon to the atmosphere, and therefore does not contribute to anthropogenic global warming.

The Reality: Burning biomass can release even higher amounts of carbon dioxide at the smokestack or tailpipe than burning fossil resources, since plant material has a lower energy density. The released greenhouse gases will not be absorbed by replacement plants any time soon. In the case of long lived species, especially trees, the amount of carbon released is not likely to be absorbed quickly enough to prevent a dangerous rise in global temperatures. Furthermore, producing biomass-based products or energy involves increasing other sources of carbon emissions, which can be considerable, in particular, emissions from soil as a result of land use changes, emissions from agricultural practices, including the use of fossil-based fertilizers and pesticides and emissions from the harvesting, processing and transporting of the biomass.

3. Biomass is a renewable resource.

The Claim: Biomass is composed of living (or once living) organisms, mostly plants, which can be grown in a short period of time, unlike mineral resources that can only be replaced over geologic time. The biomass economy is therefore a "steady-state" economy.

The Reality: While plants may be renewable in a short period of time, the soils and ecosystems that they depend upon may not be. Industrial agriculture and forest biomass extraction rob soils of nutrients, organic matter, water and structure, decreasing fertility and leaving ecosystems more vulnerable or even prone to collapse. Associated use of industrial chemicals and poor land management can make things worse. In practice, therefore, biomass is often only truly renewable when extracted in such small amounts that they are not of interest to industry.

4. There is enough biomass, especially cellulosic biomass, to replace fossilized carbon.

The Claim: Our planet has abundant annual production of trees, plants, algae, grasses and other cellulosic sources, often grown on unproductive and marginal lands, which are available for transformation into cellulosic fuels, chemicals and other materials. The net primary production of the planet is five to six times larger than what would be required to run the entire economy on biomass-derived energy.

The Reality: Far from having enough biomass to supply a biomass-based economy, we are already deeply overdrawn at the biomass bank. Human beings already capture one-quarter of land-based net primary production for food, heat and shelter. Attempts to define a limit for human use of natural resources beyond which ecosystems lose resilience and begin to break down reveal that we consumed past such limits twenty years ago and are now in severe 'Earth overshoot.'

5. We can increase biomass yields over time.

The Claim: Unlike fossil and mineral deposits, which are finite, it is possible to increase overall yields of biomass through careful management of unproductive lands, increased inputs of fertilizer, or through re-engineering plants and algae to increase yields. In this way, a biomass-based economy doesn't have the same constraints of scarcity as fossil-based economies.

The Reality: Global production of biomass is already at historically high levels and there are limits to the quantities of biomass that the planet can surrender. These limits are dictated by availability of water, certain minerals and fertilizers, and the health of ecosystems. Global shortages of phosphate, for example, may not receive as much attention as peak oil but will exert a significant drag on attempts to artificially boost yields. Nor is there much 'unproductive' land available. On closer inspection, such lands are often the basis of subsistence livelihoods that feed the majority of the world's poor. Attempts to push land to deliver higher yields may destroy the fertility of the soil altogether.

6. Cellulosic fuels and chemicals solve the "food vs. fuel" dilemma.

The Claim: While using food sugars and oils such as corn, canola and palm as biomass feedstocks may directly compete with food uses and push up food prices, using the cellulosic portion of crops does not, and it turns waste materials (such as husks and stover) into a valuable second income stream for farmers. Meanwhile, wood chips, cellulosic grasses and other energy crops can be sourced from lands that are not used for food production, boosting the rural economy while protecting food security.

The Reality: While we may not eat the cellulosic parts of plants, they provide a valuable service in returning nutrients, structure and fertility to agricultural soils. Removal of these 'agricultural wastes' on the scale envisioned will likely lead to a decline in yields, a dramatic increase in synthetic fertilizer use, or both. Nor is it true that cellulosic crops and plantations do not compete with food crops for land use. We are seeing lands that currently supply food to poor and marginalized peoples being converted to bioenergy crops. That trend can be expected to intensify as cellulosic crops gain economic value. Cellulosic crops also compete with food crops for water and nutrients.

Origami: Elkosi

7. Bio-based plastics and chemicals are more environmentally friendly than fossil fuel-based chemicals.

The Claim: Because the basic components of chemicals and plastics derived from biomass are starches and sugars rather than fossil minerals, it is easier to design green chemicals and bioplastics that fully decompose back into their constituent parts and do not have the toxicities of fossil-derived chemicals and polymers.

The Reality: While it may be true that, in some cases, biomass-derived plastics and chemicals can be designed to be less toxic and persistent in the environment, it is not true generally. DuPont's propanediol polymer (Sorona), a leading commercial bioplastic, turns 150,000 tonnes of biodegradable food (corn) into 45,000 tonnes of non-degradable plastics annually. Increasingly, chemical companies are devising ways to produce extremely toxic compounds such as PVC from biomass sugars rather than hydrocarbons. As the chemical industry moves toward bio-based production, we will see many of the same toxic compounds on the market produced from new carbon (plants) instead of fossilized carbon (petroleum).

8. Biomass is good for the global economy, aiding economic development in the South and creating "green jobs" in the North.

The Claim: As "clean energy" industries take root worldwide, they will deliver hi-tech, skilled jobs that are also environmentally sound. New manufacturing jobs using bio-based processes qualify as 'green jobs,' providing employment opportunities while reforming polluting industries. Biomass manufacturing also offers a potential economic boost for rural and Southern economies, which can earmark land for growing profitable biomass crops and plantations and can build biomanufacturing facilities close to large sources of cellulose and other biomass. Bioenergy may also earn extra money for development under the Kyoto Protocol's Clean Development Mechanism (CDM).

The Reality: Biomass technologies are largely subject to patents and other proprietary claims, and attempts by countries to develop bio-based manufacturing industries will be subject to royalties and/or licensing fees. Industrial agriculture and plantations are already controlled by a handful of transnational companies. Moreover, there is no reason to presume that biorefineries and monoculture plantations of energy crops are in any way 'green' or safe for workers. In addition to the harmful effects to humans and the environment of chemical inputs and monoculture production techniques, synthetic organisms may also prove both environmentally damaging and risky for workers' health. Brazil provides a real-world cautionary tale: the conditions of those who cut sugarcane for bioenergy (currently ethanol) involve exposure to high levels of agrochemicals and dangerous air pollution. Far from helping marginal communities, new bioenergy plantations, accredited under the CDM or other mechanisms, may directly encroach upon the lands of peasants and small producers, robbing them of control over food production, water and the health of the ecosystems in which they live.

9. A Biomass economy reduces the political instability/wars/terrorism associated with petrodollars.

The Claim: Wars over oil, natural gas and other fossil resources have been a dominant feature of the late twentieth and early twenty-first century. Inflated profits from petroleum extraction in the Middle East and elsewhere have indirectly bolstered extremist groups and fuelled geo-political tensions. Oil companies have been dismissive of human rights and territorial claims of indigenous and traditional communities in their race to control the remaining pockets of oil and gas. Unlike fossil resources, biomass is more evenly distributed across the planet and would allow industrial economies to achieve energy independence, cutting off the flow of cash to unstable regions of the globe.

The Reality: Removing fossil hydrocarbons from the global energy mix (even if it were possible or likely) would not magically dissolve geopolitical tensions. Like fossil resources, biomass is also unevenly distributed around the globe, and there is already a scramble to secure and control the land, water and strategic minerals, as well as the intellectual property, that will enable the new biomass economy. Fights over scarce freshwater resources and over oceans and deserts may become more common, particularly as algal biomass technologies mature. Agribusiness, forestry companies and the sugar industry are no more respectful of human rights and sovereignty claims than Big Oil has been: for communities fighting cellulose plantations, land grabbing, water theft, or illegal logging, the wars over biomass have already begun.

10. Biomass technologies need support as a transitional step to a new mix of energy sources, including nuclear power, wind, "clean coal," etc.

The Claim: Faced with enormous energy challenges, global society must change how we produce energy. However, it is too early to know what the new energy mix will be, as the relevant technologies are not yet in place. While biomass may in the end play only a small role in the new energy economy, its advantage is that it can be quickly deployed now as a stop-gap energy source while society transitions to more long term solutions that are not yet fully developed or need more time for scale-up, such as hydrogen power, nuclear fusion and 'clean coal.' The enormity of the energy transition challenge means that biomass technologies must be explored and developed in order to increase the range of options available.

The Reality: At its root, global society is faced with not simply an energy crisis but a crisis of overproduction and consumption. Gauging the value of a biomass-fuelled economy against other inequitable production models, such as nuclear power or carbon capture and storage, is missing the point. Reduction in overall energy demand is more politically unpalatable but ecologically critical. Boosting support for decentralized peasant agriculture, which does not fuel climate change and assures food sovereignty, is another means to address our global crises.

Part II – The Tools and Players

In an apt fable for today's bioeconomy, the dwarf Rumpelstiltskin exacted a very human cost for his technology of spinning straw into gold. Illustration of Rumpelstiltskin from Household Stories by the Brothers Grimm, 1886.

The New Bio-Alchemy – Tooling up for the grab

Dreams of transforming cheap biomass into valuable commodities are nothing new. In a German folk tale collected in the 19th century, a dwarf named Rumpelstiltskin spins straw into gold. Rumpelstiltskin was, in part, a caricature of contemporary alchemists (alchemy meaning 'transformation') who sought ways to turn base natural materials into highly valued products. Indeed, an entire branch of alchemy, Spagyrics, was dedicated to transforming plant matter to higher purposes.[165] Some of the central alchemical quests, such as the search to develop panaceas and to create a universal solvent that would reduce all matter to its constituent parts, have echoes in today's efforts to develop plant cellulases (enzymes that break down cellulose) and transform straw into cellulosic fuels and materials. There are four broad platforms for transforming biomass.

Combustion

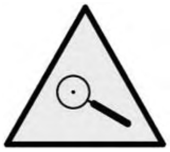
The easiest way to derive value from a pile of biomass is to put a match to it: burning extracts the highest energy yield from biomass. Examples of combustion techniques include open combustion (burning with oxygen), pyrolysis (burning without oxygen), biomass gasification (burning at very high temperatures with controlled amounts of oxygen) and plasma arc gasification (heating biomass with a high voltage electrical current).

Chemistry

Just as petroleum chemists have perfected the 'cracking' of complex hydrocarbon molecules into simpler molecules using heat, pressure and acid catalysts, similar techniques can be used to break down carbohydrates in biomass for transformation into fine chemicals, polymers and other materials. Thermochemical techniques (such as the Fischer-Tropsch process) transform lignocellulosic material into hydrocarbons. The extraction of proteins and amino acids yields valuable compounds. Fermentation techniques, sometimes combined with genetic engineering and synthetic biology (see below), can also produce proteins that can be refined further into plastics, fuels and chemicals.

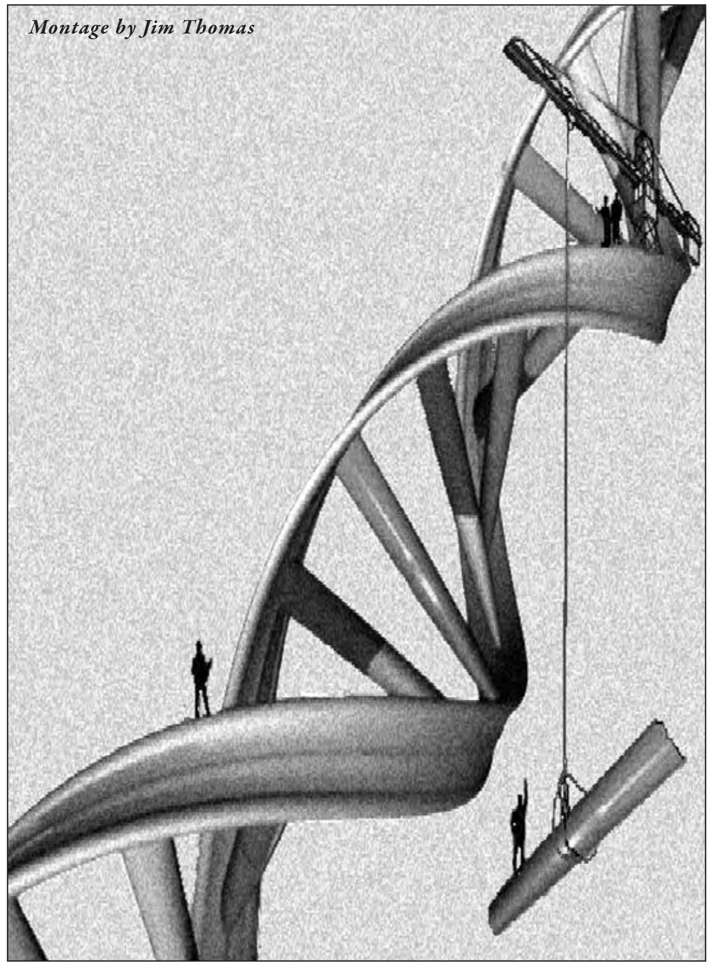
Biotechnology / Genetic Engineering

Both fermentation of plant sugars into alcohols and traditional plant breeding have been used for thousands of years. Now new genetic technologies have been introduced, which are driving much of the industrial excitement around biomass. These include new approaches to genetic engineering (recombinant DNA) to modify plants to express more cellulose or to more readily break down for fermentation or to grow in less favourable soils and climatic conditions. More recently, synthetic biology (see below) allows for the development of novel organisms that are either more efficient at harvesting sunlight or nitrogen or that can generate entirely novel enzymes (biologically active proteins). Such enzymes are used to carry out chemical reactions or to produce new compounds from plant material.



Nanotechnology

Nanotechnology refers to a suite of techniques that use and manipulate the unusual properties that substances exhibit when they are at the scale of atoms and molecules (roughly under 300 nm). There is increasing industrial interest in transforming nano-scale structures found in biomass for new industrial uses. Researchers are interested in nanocellulose as a new commodity, taking advantage of the long fibrous structure of cellulose to build new polymers, "smart" materials, nanosensors or even electronics. Research in nanobiotechnology aims to modify the nano-scale properties of living wood and other biomass feedstocks to alter their material or energy-producing properties.


Montage by Jim Thomas

Synthetic Biology – The Game Changer for Biomass

While the fast-growth areas for commercial biomass over the next few years are relatively low-tech – e.g., burning biomass for electricity production – in the longer term, synthetic biology promises to expand the commercial possibilities for biomass, which will accelerate the global biomass grab. Synthetic biology is an industry that creates 'designer organisms' to act as 'living factories.' The idea is that microorganisms in fermentation vats will transform biomass into a wide range of chemicals, plastics, fuels, pharmaceuticals and other high value compounds.

Synthetic biology refers to a set of 'extreme genetic engineering' techniques. These involve constructing novel genetic systems using engineering principles and synthetic DNA.[167] Synthetic biology differs from 'transgenic' techniques that 'cut and paste' naturally-occurring DNA sequences from one organism into another in order to change an organism's behaviour (for example, putting bacterial genes into corn or human genes into rice).[168]

"Over the next 20 years, synthetic genomics is going to become the standard for making anything. The chemical industry will depend on it. Hopefully, a large part of the energy industry will depend on it."
– J. Craig Venter, founder of Synthetic Genomics, Inc.[166]

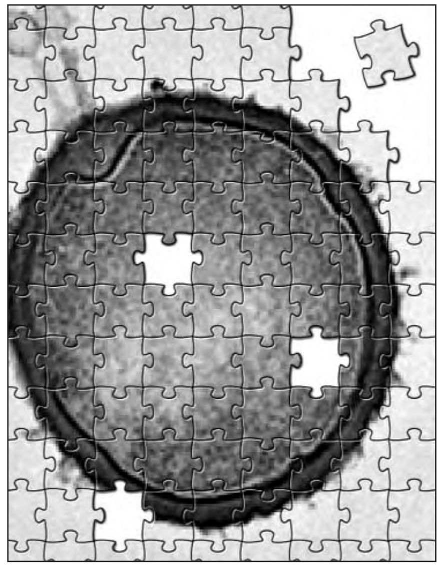
Instead, synthetic biologists build their DNA from scratch using a machine called a DNA synthesizer, which can 'print' the DNA to order. In this way, they are able to radically alter the information encoded in DNA, creating entirely new genetic instructions and jumpstarting a series of complex chemical reactions inside the cell, known as a metabolic pathway. In effect, the new, synthetic DNA strands 'hijack' the cell's machinery to produce substances not produced naturally.

In doing so, synthetic biologists claim to be becoming proficient at repurposing simple cells such as yeast and bacteria to behave like factories. In the past five years, synthetic biology has moved from being a "fringe" science – a hybrid of engineering and computer programming, rather separate from biology – to an area of intense industrial interest and investment.

Synthetic organism: machine-made life form; a living organism (usually yeast or bacteria) to which strands of DNA have been added that were constructed by a machine called a DNA synthesizer using the techniques of synthetic biology.

Synthetic Biology: Unpredictable, untested and poorly understood

> ***"If a synthetic microorganism is built by combining...genetic elements in a new way, it will lack a clear genetic pedigree and could have 'emergent properties' arising from the complex interactions of its constituent genes. Accordingly, the risks attending the accidental release of such an organism from the laboratory would be extremely difficult to assess in advance, including its possible spread into new ecological niches and the evolution of novel and potentially harmful characteristics."***
> – Jonathan B. Tucker and Raymond Zilinskas, "The Promise and Perils of Synthetic Biology"[169]



Montage: Jim Thomas, from an original photo by A.J. Can

To civil society observers, what is most striking about synthetic biology is not so much its claims to remake the parts of life, but how fast it is entering commercial use – without oversight. Synthetically-constructed organisms are already employed in the production of thousands of tonnes of biofuels and biobased chemicals, far in advance of research or debate about their safety and efficacy or about the assumptions underlying the techniques involved.

For example, synthetic biologists proceed on the assumption that DNA – a sugar-based molecule consisting of four types of chemical compounds organized in a unique sequence – forms a code that instructs a living organism how to grow, function and behave. By rewriting that code, synthetic biologists claim they are able to programme lifeforms much like programming a computer. These assumptions are based on a model of genetic systems that is over 50 years old, known as the "central dogma" of genetics. However, the accuracy of that dogma is becoming less and less certain.

New research in genetic science, particularly in the fields of developmental systems theory and epigenetics, question the prominence given to DNA code. Developmental systems theorists point out that all manner of complex elements both within and outside a living cell influence the way a living organism develops and this cannot be determined *a priori* by focusing solely on the DNA code.[170] Geneticists studying epigenetics (which looks at non-genetic factors in organism development) argue that subtler components, such as the organic chemicals that wrap around DNA (known as methyl groups), can have as large an effect on how an organism develops as does DNA. So too can environmental factors such as stress and weather.

Indeed synthetic biologists often report that their carefully designed DNA programs that work perfectly on a computer (in silico) don't work in living synthetically engineered organisms or have unexpected side effects on an organism's behaviour.[171]
It turns out biology is messy. Applying the standardization and rigour of engineering to the biological world is interesting theoretically, but it may not be relevant for living systems. "The engineers can come and rewire this and that. But biological systems are not simple," explains Eckard Wimmer, a synthetic biologist at the State University of New York at Stonybrook, "The engineers will find out that the bacteria are just laughing at them."[172] As synthetic biologist James Collins of Boston University admits, "If you have incomplete knowledge then it is highly possible that you are up for a few surprises."[173]

The likelihood of unexpected behaviours makes it all the more surprising that there is no methodology for testing the health or environmental safety implications of a new synthetic organism. The existing regulatory mechanisms for assessing the safety of 'conventional' genetically engineered organisms rely on a controversial idea known as 'substantial equivalence,'[174] which makes a best guess on how the mixture of inserted genes and recipient organism may behave. Yet substantial equivalence is wholly inappropriate for assessing synthetically constructed organisms: synthetic biologists are not simply moving discrete genetic sequences between species – they routinely insert constructed strings of DNA taken from many different organisms. They may also include sections of DNA that have never existed in nature before but were instead mutated using a lab technique called 'directed evolution' or designed using a computer programme and subsequently built from scratch by a DNA synthesis machine. For example, the synthetic yeast designed by Amyris Biotechnologies, which is about to be used commercially on a large scale in Brazil, has additional DNA constructed from 12 synthetic genes taken mostly from plants but all slightly altered to work in a particular microbe.[175] In the future such organisms may be constructed from hundreds of different sources. As a group of synthetic biologists noted in 2007, "how to evaluate such constructions for biological safety remains murky."[176]

Even ostensibly simpler synthetic organisms present "murky" prospects for safety evaluation. "Because of a lack of empirical evidence, the inventor of a synthetic microorganism could not predict the effects of its release on human health and the environment with any degree of confidence," say bioscientists Jonathan Tucker and Raymon Zilinskas of the Monterey Institute of International Studies. "Even if the source of all of the parts of a synthetic microorganism are known, and every new genetic circuit understood, it would be difficult to predict in advance whether the organism would have any unexpected 'emergent properties.'"[177] For example, even if the genetic sequences added to a synthetic organism are not considered to be pathogenic (disease-causing), there is still the possibility they could become pathogenic within the synthetic organism. Former U.S. environment regulator Michael Rodemeyer has noted in a review of synthetic biology safety issues that genetic engineering has led to unexpected health risks in the past, such as when an engineered mousepox virus that was expected to sterilize mice instead created a super-virulent strain of the mousepox.[178]

The ecological risks of synthetic biology are also significant in the case of either deliberate environmental release of synthetic organisms (e.g., crops and algae) or accidental escape from biorefineries. Since the species that are being commonly modified (such as algae, *E. coli* and yeast) are very common in the environment, there is a possibility of outcrossing with natural species and contamination of microbial communities in soil, seas and animals including humans. Microbes propagate and mutate quickly and also move through soil, waterways and other routes so it may be especially difficult to track escapes. Synthetic biologists contend that their lab-made creations are probably too weak to survive outside the optimised conditions in which they were developed; however, this assumption has been proven wrong before. When transgenic crops such as corn, cotton and soy were first approved for release in the 1990s, biotech companies assured regulators that they too would be too weak to outcross with conventional crops. Two decades later, much of the world's corn, canola and cotton crop have received low level contamination of engineered genes due to mixing of seed and cross pollination.

"Synthetic Biology will produce organisms with multiple traits from multiple organisms, and therefore it may be difficult to predict their properties."
– European Commission opinion on the ethics of synthetic biology[179]

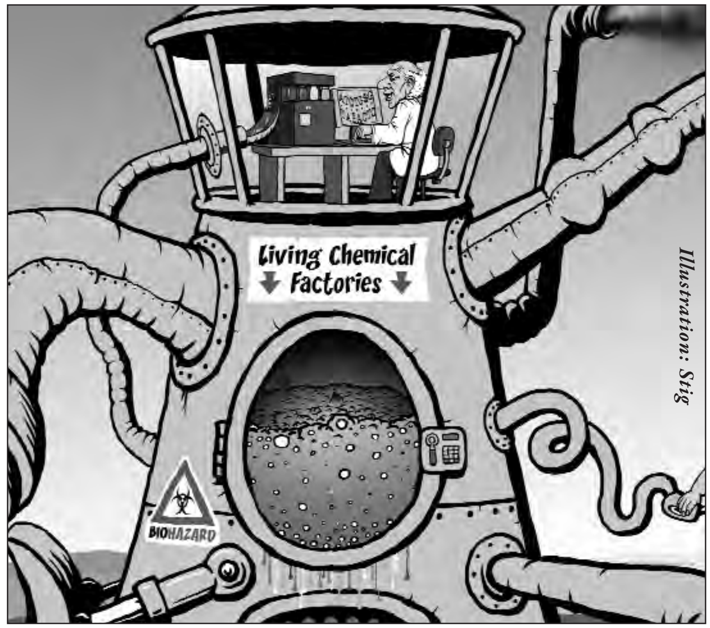


Illustration: Stig

Synthetic Organisms as Biofactories

Natural yeasts are already routinely harnessed by industry to behave as tiny bio-factories. For example, they transform cane sugar into ethanol or wheat into beer. However, by altering the yeast (or other microbes), the same sugar feedstock can be flexibly turned into novel products depending on how the yeast's genetic information has been "programmed." Billions of synthetic microbes contained in a single industrial vat can ingest sugar feedstocks and excrete hydrocarbon fuels with the properties of gasoline (instead of the ususal ethanol). The same microbes, if differently programmed, might excrete a polymer, a chemical to make synthetic rubber or a pharmaceutical product. In effect, the microbe has become a production platform for different chemical compounds. "Chemical engineers are good at integrating lots of pieces together to make a large scale chemical plant, and that is what we're doing in modern biological engineering. We're taking lots of little genetic pieces and putting them together to make a whole system," explains synthetic biology pioneer Jay Keasling of the U.S. Department of Energy's Joint BioEnergy Institute. "Really, we are designing the cell to be a chemical factory. We're building the modern chemical factories of the future."[180] Writer for *Grist*, David Roberts, articulates the synthetic biology vision more succinctly: "...genetically engineered microbes will eat sugar and crap oil."[181]

Synthetic Enzymes for Cellulose

Synthetic biologists are also creating the tools that will make cellulose an industrially accessible sugar. Enzyme companies such as DSM, Verenium, Genencor, Codexis and Novozymes develop synthetically altered microbes to produce powerful new enzymes (chemically reactive proteins) known as cellulases that break down the molecular tangle of lignocellulose into simpler cellulose sugar.[182] Until recently, energy-intensive processes involving high heat were needed to free up cellulose in biomass for further fermentation.

Other companies such as Mascoma and LS9 are attempting to build "one-pot bugs" that both break down biomass into available sugars and then ferment those sugars into fuels (in Mascoma's case that fuel is ethanol; for LS9 their synthetic *E. coli* can turn cellulose into a variety of chemicals, diesel fuel among them).[183] Christopher Voigt, a synthetic biologist at University of California—San Francisco has gone further to develop a 'feedstock flexible' method, dubbed Bio-MeX, in which synthetic microbes (containing 89 new genetic parts) can break down unprocessed switchgrass, corn stover, sugarcane bagasse or poplar woodchips and ferment them directly into a range of chemicals known as methyl halides. Methyl halides are typically used as agricultural fumigants but are also precursor molecules that can be converted to other chemicals and fuels such as gasoline.[184]

"A characteristic of the current industry is that if you build a corn-to-ethanol plant, corn is your only feedstock and ethanol is your only product," Voigt explains. "You can't switch on a dime. We have approached the feedstock and the product issue separately."[185]

Synthetic Plants – Changing the feedstocks

A handful of companies are also beginning to add synthetic DNA sequences to engineer plants to perform more efficiently as feedstocks for the bioeconomy. An example is Syngenta's alpha amylase maize (corn), which incorporates synthetic sequences engineered by Verenium (now owned by BP). These sequences cause the corn to produce an enzyme, which readily breaks down the corn's stalks into cellulose to produce cellulosic biofuels.[188] Agri-biotech company Agrivida has developed similar corn in conjunction with synthetic biologists from Codon Devices[189] (now defunct), while Chromatin Inc., in conjunction with Monsanto and Syngenta, is also using synthetic biology to 'reprogram' commodity crops such as corn, cotton and canola as more efficient biofuel feedstocks.[190]

Cellulose Crunchers and Fuel Fermenters on the Loose?

Much of the current commercial work in synthetic biology involves developing synthetic microbes that are able to digest cellulosic biomass into simpler sugars or to convert cellulose and other sugars into plastics, fuels and chemicals. Should such organisms escape the fermentation vat and be able to survive in the wild, there may be significant cause for concern. If escaped strains prove capable of breaking down cellulose and other sugars already found in the environment and ferment them into industrial products in situ, the results could prove an ecological and health hazard.

Such a scenario has precedent. In 1999, soil scientist Elaine Ingham of Oregon State University and graduate student Michael Holmes reported on experiments with a genetically engineered soil bacterium called *Klebsiella planticola*. A European biotech company had altered the bacteria to ferment cellulosic wheat straw into ethanol and was approaching its commercial use. Ingham and Holmes added the engineered bacteria to different soil samples and discovered that the bacteria fed on cellulosic residues in the soil to produce ethanol, which in turn poisoned and killed plants growing in the soil. At the time, the U.S. Environmental Protection Agency was considering allowing sludge residue from the use of engineered *Klebsiella planticola* to be added to fields.[186]

The case is relevant to the use of synthetic organisms in commercial biorefineries, which will also produce waste residues for disposal. Moreover, such biorefineries are not currently expected to put in place very stringent biosafety procedures, acting more as industrial brewing facilities than high-tech laboratories. Indeed evidence from the beer brewing industry that uses yeast for fermentation, just as existing commercial synthetic biology refineries do, suggests that escape of organisms may in fact prove quite common. According to brewing expert Hugh Dunn, a study involving six breweries investigated over three years discovered that commercial strains of cultured yeast do escape into the environment. Biodynamic vineyards have already raised concern that even non-engineered escaped strains could impact the flavour and character of their wines.[187]

Synthetic Bioelectricity?

Eventually, synthetic organisms grown in vats of biomass sugars may also be employed to produce electricity. In 2006, Yuri Gorby, then with U.S. Department of Energy's Pacific Northwest National Laboratory, showed that many strains of bacteria naturally produce small amounts of electricity conducted via natural nanowires.[191] Gorby now works on bacterial electricity at the Institute run by high profile synthetic biologist J. Craig Venter.[192] In 2008, a team of Harvard undergraduates built upon Gorby's work while competing in an international synthetic biology competition called iGEM (the international Genetically Engineered Machine Competition). The iGEM team developed what they called "Bactricity," synthetically altering the bacteria *Shewanella oneidensis* to assemble into wires and carry electricity. The researchers say such technology could be the basis of future bacterial fuel cells or sensors.[193]

Synthetic Biology's Grab on Livelihoods – Displacing commodities

To understand how synthetic biology's contribution to the biomass economy will affect Southern livelihoods, look to the business plan of Amyris Biotechnologies, founded by synthetic biology pioneer Jay Keasling. Amyris boasts that they are "now poised to commercialize pharmaceuticals and other high value, fine chemicals taken from the world's forests and oceans by making these compounds in synthetic microbes."[195] Amyris's highest profile project, funded to the tune of $42.5 million by the Bill & Melinda Gates Foundation, has been the re-engineering of industrial yeast to produce the precursor to artemisinin, a valuable anti-malarial compound usually sourced from the sweet wormwood bush, *Artemesia annua*, currently grown by thousands of small farmers in East Africa, South East Asia and South Asia.[196] Even supporters of the project admit that shifting artemisinin production from farmers' fields to proprietary vats of microbes owned and controlled by Amyris and their business partner, Sanofi Aventis, could impact the income and livelihoods of wormwood farmers.[197]

"We ought to be able to make any compound produced by a plant inside a microbe... We ought to have all these metabolic pathways. You need this drug: O.K., we pull this piece, this part, and this one off the shelf. You put them into a microbe, and two weeks later out comes your product."
– Jay Keasling, Amyris Biotechnologies[194]

Amyris Biotech is moving production of artemisinin out of the hands of farmers and into proprietary vats of synthetic microbes
Photo: Birgit Betzelt/action medeor

Indeed, a report by The Netherlands Royal Tropical Institute in 2006 highlighted the prospect of synthetic artemisinin as one of the major threats to artemesia growers.[198] Supporters of synthetic artemisinin contend that the global public health good of producing cheap artemisinin outweighs the loss of livelihoods for a few thousand farmers.[199]

The artemesia growers of Africa and Asia that may lose their markets are simply the canaries in the coalmine for a much larger displacement of livelihoods by synthetic biology companies and the new bioeconomy. Beyond medicinal compounds, synthetic biologists have their eyes on producing many of the bulk and strategic commodities that Southern nations now depend on for income:

Rubber – In 2007, ETC Group reported on attempts by Jay Keasling's lab to produce microbes that synthesize natural rubber,[200] a project that the U.S. Department of Agriculture hoped could help supplant the $2 billion worth of rubber imported by the USA from Southern countries. In September 2008, one of the world's largest car tire producers, Goodyear, announced a joint initiative with Genencor to scale up microbial production of isoprene, the chemical used to make synthetic tire rubber, using synthetic organisms that feed on biomass sugars.[201] The rubber was scheduled for commercial production by 2013. In their announcement, Goodyear made clear that the availability of synthetic isoprene would provide an alternative to natural rubber used for tires.[202]

It seems reasonable therefore that this product could impact the price of rubber and therefore the livelihoods of small-scale rubber producers and plantation workers. By March 2010 it was reported that Goodyear had already used Genencor's "bioisoprene" to make synthetic rubber, which it then used to make several prototype tires and was making its next decisions on building a pilot production plant.[203]

Flavourings – Glycyrrhizin is the sweet compound found in liquorice root that is 150-300 times sweeter than sucrose (table sugar) and is widely used as a natural sweetener as well as a traditional natural medicine. Liquorice root is in high demand, with supplies almost exclusively limited to wild indigenous species of the liquorice plant found in arid regions of China, the Middle and Near East. In 2009, researchers at the Japanese RIKEN Institute identified and synthesized all the genes responsible for producing glycyrrhizin.[204] According to researchers, it should now be possible to use synthetic biology to induce a soy plant or a microbe such as yeast to produce glycyrrhizin. If they are successful, it will be possible to move liquorice production away from the Far and Middle East to industrial soybean fields or even proprietary vats.

Soylent Green? – In October 2008, Synthetic Genomics, Inc., the private firm run by synthetic biologist J. Craig Venter, received an $8 million investment from Malaysian palm oil conglomerate The Genting Group to decode the oil palm genome.[205] While the cash injection was originally assumed to be geared toward altering oil palm for biofuel production, more recent pronouncements by Venter suggest a very different path. Speaking on U.S. television in 2010, Venter explained that his company was now trying to use synthetic algae to make food substances instead of harvesting plantations of oil palm. "You get 20 times the productivity theoretically out of algae growing in a much smaller space... Instead of getting fish oil from killing fish we can remake it in algae."[206] Venter isn't the only one looking for a biosynthetic replacement for palm oil. In September 2010, the world's largest purchaser of palm oil, food giant Unilever, announced a multimillion dollar investment in synthetic biology company Solazyme to develop algal oil that would replace palm oil in foods such as mayonnaises and ice creams as well as soaps and lotions. Unilever says they are currently three to seven years away from rolling out a new biosynthetic food ingredient but, they emphasize that, "This isn't just a niche application...This is something which we believe has tremendous capability." Solazyme claims they can engineer "oil profiles" of algae and devise replacements for different types of oil. While they say they can do this with natural strains, they are hoping that consumer opposition to genetically modified foods will die down to let them use synthetic biology.[207]

Nanocellulose – Shrinking biomass to grow new markets

By modifying the fibres of cellulose at the atomic scale, nanotechnologists are opening up new uses, and thus new markets, for industrial biomass:

Nanomaterials, energy and pharmaceuticals: While the poster child for nanomaterials, super strong carbon nanotubes (CNTs), are usually produced from graphite, it is also possible to produce CNTs from corn ethanol.[208] Meanwhile, nanotechnologists are becoming increasingly enamoured with a new class of nanostrctures known as cellulose nanocrystals (CNC). Derived from biomass, these CNCs can be added to plastics to make them 3000 times stronger, can de designed to deliver drugs and vaccines, and can be used as scaffolds to grow metallic nanowires and particles in order to create tiny sensors and new photovoltaic (solar electricity producing) materials.[209]

Body armour, medical devices and food: A form of nanocellulose produced from wood pulp by Swedish firm Innventia is simultaneously marketed as being as strong and light as Kevlar, able to prevent food spoilage when used in packaging, suitable for creating replacement human body parts in medical applications, and also edible as low calorie filler for processed foods. The first commercial plant for this biomass 'wonder material' is due to go into production in October 2010.[210]

Batteries: Nanotechnologists from Uppsala University in Sweden reported that coated cellulose fibres from hairy algae called *Cladophora* could make high quality paper batteries. The nanocellulose batteries could hold 50 to 200 percent more charge and be recharged many hundreds of times faster than conventional rechargeable batteries. "With the technique fully developed I believe that we may see applications that we cannot really dream of today," claims Maria Strømme one of the scientists who developed the battery. "Try to imagine what you can create when a battery can be integrated into wallpapers, textiles, consumer packaging, diagnostic devices, etc."[211]

Nanotechnology: tiny technology; nanotechnology involves engineering matter on the scale of atoms and molecules (~1-300 nanometers) in order to exploit novel properties exhibited at this scale.

What Is Switching?

Switch 1: Switching Power – Burning biomass for heat and bioelectricity

At present, the International Energy Agency (IEA) reports that 10.1% of global primary energy comes from biomass, mostly wood, dung and straw burned for traditional cooking and heating. However, they predict this amount could increase to 25% by 2030,[212] a massive upswing reflecting the new commercial race to burn biomass to generate electricity.

Low Hanging Fruit

In a few short years, the electricity industry has embraced biomass burning as a strategy to not only cut costs but also to capture carbon credits and meet renewable energy targets. Biomass power plants now exist in over 50 countries around the world and supply a growing share of electricity. Globally, an estimated 54 GW of biomass power capacity was in place by the end of 2009.[213] In many ways, burning biomass is the low hanging fruit of the renewable energy world. It requires little or no new technology and can be easily implemented in existing industrial facilities by switching feedstock from mineral oils to vegetable oils, or from coal to wood pellets (compacted sawdust). As such, national and regional authorities often target biomass burning as a simple 'transitional' form of supposedly renewable energy. In particular, the practice of co-firing wood in existing coal power plants is becoming widely practiced. This is done simply by mixing biomass with coal in the burning chambers of power plants that in turn drive steam turbines.

Biomass Burning in the USA

The United States generates over one third of all biomass electricity – making it the largest producer of biomass power in the world.[214] As of October 2010, the grassroots group Energy Justice Network had mapped over 540 industrial power facilities burning biomass in the U.S., with a further 146 slated to be built.[215] Eighty biomass power plants connected to the electrical grid in 20 U.S. states currently generate about 10GW of power,[216] which is half of all U.S. "renewable energy" in an industry worth $1 billion.[217] Since 2000, biomass generation on the electrical grid has risen 25% to about 2,500 megawatts, according to the Biomass Power Association.[218]

Biomass Power in the South

According to REN21 (Renewable Energy Policy Network for the 21st century), biomass power has also grown significantly in the global South, particularly in the BRICS countries (Brazil, India, China and South Africa). Other countries with bioelectricity production include Costa Rica, Mexico, Tanzania, Thailand, and Uruguay. China's share of biomass power in 2009 was 3.2 GW and the country plans to produce up to 30 GW by 2020. India is aiming for 1.7 GW of capacity by 2012. Brazil has over 4.8 GW of biomass electricity, almost entirely produced from sugarcane bagasse at sugar mills.[219]

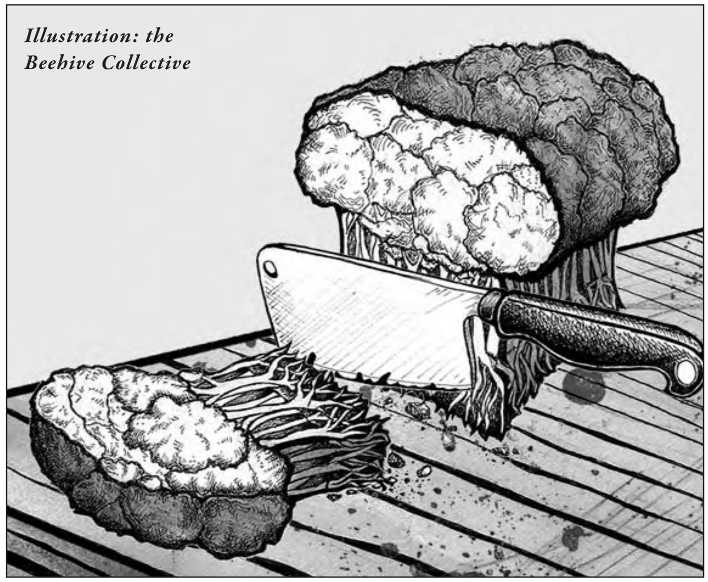


Illustration: the Beehive Collective

Counting the Costs of Biomass Electricity I: Gobbling fields and forests

The most straightforward impact of new biomass power facilities is the increased requirements for biomass, chiefly wood, required 24 hours a day to keep the turbines turning. According to a report on biomass availability prepared by the Massachusetts Department of Environmental Resources, 13,000 tonnes of green biomass are required to generate one megawatt of biomass power for one year.[220] As U.S. activist Josh Schlossberg puts it, these facilities are "gaping mouths waiting for a constant supply of forest."[221]

The world's largest wood-burning biomass power station, the Prenergy plant at Port Talbot in Wales (currently under construction), aims to import over 3 billion tons of woodchips from the U.S., Canada, South America and Eastern Europe. According to watchdog Biofuelwatch, the land area needed to grow this much biomass could be as large as one half-million hectares – ensuring the deforestation of an area three times the size of Liechtenstein every year.[222]

Counting the Costs of Biomass Electricity II: Threatening human health

> ***"I saw very strong and significant associations between tonsillitis, frequent cough, pseudo-croup, exercise-induced wheeze, food allergies and wood smoke exposure in our school children. I think that wood smoke is one of the most harmful air pollutants we have on Earth."***
> – Gerd Oberfeld, M.D., epidemiologist, Public Health Office – Unit for Environmental Health, Salzburg, Austria[223]

Burning biomass may be 'natural' but it is still a major health hazard to communities that live close to large-scale facilities.

- A 1997 estimate by the World Health Organization put the number of premature deaths due to wood smoke inhalation, mostly from indoor cooking fires, at between 2.7 and 3 million people.[224] The prime cause of these deaths appears to be the effects of fine and ultrafine particles that reach deep into the lungs.
- The U.S. EPA estimates that lifetime risk from cancer is 12 times higher from inhaling wood smoke than from an equal volume of second-hand cigarette smoke.[225] According to one EPA calculation, burning just two cords of wood (around one quarter of one tonne) produces the same amount of mutagenic particles as driving 13 gasoline-powered cars 10,000 miles each at 20 miles/gallon.[226]
- Children living in communities where wood smoke is prevalent exhibit decreases in lung capacity and increases in asthma attacks, frequency and severity of general respiratory illness, emergency room visits and school absences.[227] Air-borne wood dust (uncombusted) can also cause respiratory, eye and skin irritation.
- Wood smoke contains over 200 chemicals and compound groups, some of which are toxic in their own right.[228] According to the public interest group Clean Air Revival, wood burning is the third largest source of dioxin in the United States, recognized as one of the most toxic compounds known to exist.[229]

Incineration in Disguise

While woodchips and oils are presented as the clean, green face of biopower, the industry's dirty little secret is hidden behind the acronym MSW, or Municipal Solid Waste. Facilities that are permitted to burn wood are often allowed to mix some percentage of municipal solid waste, up to 30% in some U.S. states, and often get paid to do so, making garbage-burning an attractive option. Globally, over 12 GW of so-called biomass power is currently produced by burning garbage.[230] Dioxins, furans, heavy metals including mercury and lead, polycyclic aromatic hydrocarbons (PAHs), ultrafine particulate matter, carbon monoxide, sulphur dioxide, nitrogen oxides and a range of other dangerous toxins have been spewing from incineration facilities all over the world for years. Now, along with a host of new technologies like pyrolysis, gasification and plasma arc incineration, incinerators are getting a green makeover as biomass power facilities, relabeled as "Waste to Energy," or "Waste Conversion" technologies. These "incinerators in disguise" claim to simultaneously resolve problems of "too much waste," and "not enough renewable energy," thus reducing the take of biomass from the natural world.

Switch 2: Liquid BioFuels: Liquefying biomass for transport

> ***"Whoever produces abundant biofuels could end up making more than just big bucks—they will make history...The companies, the countries, that succeed in this will be the economic winners of the next age to the same extent that the oil-rich nations are today."***
> – J. Craig Venter, Founder, Synthetic Genomics, Inc.[231]

The production of liquid transport fuels made from biomass is the glossy (and well-heeled) poster child for the new biomass economy. From the short lived corn ethanol boom of 2006-2008 to the new wave of venture capital and big oil companies sinking billions of dollars into biofuel startups, the biofuels industry is still regarded as a massive new source of revenue in an age of peak oil and carbon pricing. Although predictions from 2006 that biofuels would make up 30% of all transport fuel by 2030[232] now look overblown, nonetheless the sector is still growing rapidly – buoyed by government mandates, 'clean energy' stimulus funds and heavy investment by Big Oil. Recent attention on the BP Deepwater Horizon oil spill seems to also be giving new life to the idea that non-fossil liquid fuel may be a panacea for environmental problems.[233]

Scoring an F – Failures of first generation biofuels

The 'first' or 'failed' generation of biofuels refers to either fermented alcohols – almost entirely ethanol from corn and sugarcane – or to refined biodiesel from oil crops (soy, rapeseed, sunflower, mustard) and tree oils (palm, jatropha). The first generation came with three significant blocks to success:

- **Competition with food and forest protection**
  In 2008, an internal World Bank report (later made public) revealed that up to 75% of the increase in food prices during that year's food crisis, was due to the biofuels policies of Europe and the U.S., which prompted a massive switch away from wheat planting to rapeseed growing coupled with major diversion of corn and soy into ethanol and biodiesel production.[234] Previous modeling by the conservative IFPRI (International Food Policy Research Institute) had estimated that 30 percent of the overall increase in grain prices during the 2008 food price crisis could be pinned on biofuels. Nevertheless IFPRI calculated that if a global moratorium on biofuel production were put in place in 2007, prices of key food crops would have dropped significantly – by 20 percent for maize, 14 percent for cassava, 11 percent for sugar, and 8 percent for wheat by 2010.[235]

  Biodiesel crops (soy, sunflower, canola) also use up water, nutrients and prime agricultural land or, in the case of plantation crops such as palm oil, are implicated in the clearance of rainforest lands, impacting endangered species and the rights of forest dwellers.[236]
- **Poor energy balance**
  Ethanol in particular is a poor fuel that produces less energy when combusted than gasoline. This negatively affects the so called 'energy balance' for first generation biofuels. Energy economists have calculated that once the energy costs of agricultural inputs are factored in, corn ethanol production requires 29 percent more fossil energy than the fuel produced. Biodiesel from soybean plants requires 27 percent more fossil energy than the fuel produced, and sunflower biodiesel requires 118 percent more fossil energy than the fuel produced.[237]
- **Requires special engines and/or distribution lines**
  Pumping neat ethanol into existing engines can corrode engine parts and requires adjustments in the flow of air and fuel. As a result, ethanol requires separate handling and therefore costly storage tanks and distribution mechanisms. (Biodiesel more easily adapts to existing engines and fuel systems.)

While these failings of first generation biofuels are widely known, OECD governments continue to maintain subsidies and fuel mandates for ethanol and biodiesel. Biofuel boosters argue that such biofuel mandates must stay in place to enable the smooth transition to what they claim is a less problematic (but so far still theoretical) next generation.

"Survivors" of Generation F – Sugar and Jatropha

Even after the collapse of initial biofuel hype, there are at least two 'first generation' biofuels that continue to receive enthusiastic support:

Cane sugar – In Brazil, cane sugar has been transformed into fuel ethanol on an industrial scale for three decades. Since 2008, over 50% of fuel sold in the country for cars and other light vehicles was ethanol and the country looks set to produce a record 27 billion litres of ethanol in 2010.[238] The Brazilian ethanol industry claims that their cane sugar has a far better energy balance than corn ethanol and that additional sugar can be grown sustainably without competing with food production. In February 2010 Royal Dutch Shell signed an agreement with sugar giant Cosan to form a joint venture worth $12 billion producing ethanol from Brazilian sugar cane. This investment represents the single largest commitment to biofuels that any oil company has made to date.[239]

Cutting cane in Brazil Photo: John McQuaid

Continued overleaf

"Survivors" of Generation F – Sugar and Jatropha Continued:

These 'green' claims of Brazilian sugar fuel are hotly contested. Estimates point to a doubling of the current 8.89 million hectares of Brazilian sugarcane plantations by 2020.[240] This is largely at the expense of ecologically sensitive regions such as the fragile and highly biodiverse Cerrado watershed, known as the 'father of water' since it is home to the three largest river basins in South America, including the Amazon. Ethanol expansion is driving Amazon destruction as new sugar plantations push soy growing and cattle-raising deeper into Amazonian territory. Along with being water hungry, crop cane sugar requires intensive application of agrochemicals and the large scale burning of fields. According to a recent study, this burning combined with fertilizer use and other inputs annually releases close to 150 million tons of carbon dioxide[241] into the atmosphere, contributing to Brazil's standing as the seventh largest emitter of greenhouse gases in the world.[242] The social costs run high too. The expanding agro-frontier is driving landlessness and a rapidly growing population of urban poor in Brazil's larger cities. Meanwhile sugarcane is harvested by Brazil's army of a half million migrant workers – a significant proportion of whom endure indebted slave labour conditions, respiratory health problems and early death from exhaustion.[243]

Jatropha – Jatropha is a family of tropical bushes, some of which produce inedible oil-rich nuts that are pressed to provide oils for biodiesel. Companies such as D1 Oils (owned by BP) and Daimler are now backing the massive expansion of jatropha in Africa, South America and Asia, hailing it as a wonder crop. They laud jatropha's ability to grow on so-called marginal lands, in poor soils, and even in semi-arid conditions. Communities across Africa and Asia have reacted to land grabs associated with new jatropha plantations, many of which are displacing food production and taking lands where poor people subsist. While jatropha can indeed survive in some low water conditions, in order to thrive and produce useful quantities of oil it requires significant water. One recent study on the water footprint of biofuel crops concludes that a single litre of jatropha biodiesel requires an astonishing 20,000 litres of water to grow – far outstripping canola, corn, soybeans, sugarcane or any other commonly used biofuel crop.[244] Other problems seen with jatropha include the toxicity of the seeds to humans, concerns about its invasiveness, and reports that jatropha is not, after all, pest resistant as claimed.[245]

Generation NeXt: Switching fuels and feedstocks

After being largely blindsided by the problems associated with the first wave of biofuels, industry along with OECD governments are now pumping a tremendous amount of money into what is being called the 'next generation' of biofuels. The high level of commitment hints at a political desperation to rescue the significant monies and commitment already invested in the field.

To overcome the problems of generation F, the 'next generation' approach employs new feedstocks (particularly cellulose and algae) and attempts to produce more energy-rich liquids using improved transformation technologies (particularly synthetic biology). The second-generation elixir that the bio-alchemists are now trying to brew is ideally a liquid whose feedstocks will not affect the food supply, will pack the same energy punch as gasoline (or better), and that can be pumped into existing fuel tanks over existing delivery lines.

At least 200 companies are reportedly attempting to realize this vision of the 'perfect biofuel[246] – each working on single pieces of the 'next generation' puzzle. Some of these companies are already moving to commercial production but only in small quantities (see Annex). Most are struggling with scale-up issues.

Ethanol Plant Photo: Aaron Brown

Biorefinery: industrial facility for processing biomass. Like oil refineries, bio refineries are factories that break biomass into constituent parts and then 'refine' them using chemical and biological techniques (including fermentation) to produce industrial compounds such as chemicals and fuels as well as heat and power.

Cellulosic Fuels

> ***"The fuel of the future is going to come from fruit like that sumac out by the road, or from apples, weeds, sawdust—almost anything."***
> – Henry Ford in The New York Times, 1925[247]

Remember those 180 billion tonnes of cellulose sugar produced annually in woody branches, leaves, grasses and algae worldwide? To an industry that needs sugar to make fuels, that cellulosic bonanza appears to be the perfect non-food feedstock. U.S. legislation from 2005 that called for the production of 100 million gallons of cellulosic ethanol by 2010 had to be dramatically downsized in February 2010 to a mere 6.5 million.[248] The same legislation calls for U.S. cars to consume 4.3 billion gallons of cellulosic ethanol by 2015 – another target also unlikely to be met.

There are two approaches to making cellulose-based fuels: thermochemical and biological.

Thermochemical production of cellulosic fuels

Chemists have known how to turn biomass into fuels since the 1930s when the Fischer-Tropsch process to turn coal into liquid was commercialized by the wartime German government. This process superheats either coal (or biomass) into gas that is chemically transformed to fuel:

Following at least $320 million of investment, of which the U.S. government and state of Georgia account for half, **Range Fuels** of Colorado USA has opened its first large scale commercial plant (in Georgia), which is producing 4 million gallons of cellulosic methanol annually – not the billion gallons of ethanol they originally promised.[249]

BlueFire Ethanol of California uses strong acids to break down lignocellulose into available sugars for fermenting. BlueFire's first bio-refinery will transform presorted landfill waste to produce approximately 3.9 million gallons of fuel-grade ethanol per year. A second plant aims to produce 19 million gallons of ethanol per year from woody biomass.[250]

Biological Production of Cellulosic Fuels

The other main approach for creating cellulosic biofuels is to apply powerful enzymes, called cellulases, to break down cellulose into more available sugars for subsequent fermentation to ethanol and other alcohols. Natural, genetically engineered and synthetic microbes are all being developed to break down cellulose and ferment it.

- **BP** created a $45 million joint venture with **Verenium** (formerly Diversa) in 2009 to create cellulosic ethanol through the use of Verenium's synthetic enzymes.[251] In July 2010, BP paid a further $98 million to buy their biofuel business including two production facilities.[252]
- **Iogen Corporation** uses enzymes from genetically modified *Trichoderma reesei* (responsible for "jungle rot") to break down plant material at its Ottawa-based demonstration plant, which already produces 170,000 gallons per year of cellulosic ethanol. As part of a 50:50 joint venture with **Shell**, Iogen is planning what it calls the "world's first commercial-scale cellulosic ethanol plant" in Saskatchewan, Canada.[253]
- **Mascoma** has re-engineered yeast and bacterial microbes to not only break down cellulose for ethanol production but also to carry out the fermentation into cellulosic ethanol in a streamlined 'one pot' procedure. It has partnerships with **General Motors**,[254] **Marathon Oil**,[255] and ethanol company **Royal Nedalco**[256] and is building a commercial production facility in Michigan. Through a partnership with **Stellenbosch Biomass Technologies**, Mascoma is also moving its technology into South Africa.[257]
- **Coskata**, which has partnerships with **General Motors** and **Total Oil**,[258] have bred natural microbes that, in concert with a gasification process, can transform feedstocks such as woodchips or old tires into cellulosic ethanol.
- **DuPont** has partnered with biotech company **Genencor** to create **DuPont Danisco Cellulosic Ethanol LLC**, a $140 million project to use **Genencor's** synthetic enzyme technology.[259] Their Tennessee demonstration plant currently turns a couple of thousand tonnes of corncobs into ethanol. Commercial production is expected by 2013.
- **POET**, which claims to be the world's largest ethanol producer, will use commercial enzymes from **Novozymes** to turn corn cobs into an annual 25 million gallons of ethanol when their biorefinery becomes operational in late 2011 or early 2012.[260]
- **Verdezyne**, a California-based synthetic biology company, is developing yeast that can turn switchgrass, hemp, corn and wood into ethanol.[261] The company has agreements with **Novozymes**, **Genencor** and **Syngenta**.[262]
- In February 2008, forestry giant **Weyerhaeuser** formed a joint venture with **Chevron** called **Catchlight Energy** to produce cellulosic ethanol from wood. Very few details been disclosed since making their initial announcement.[263]
- U.S.-based company **Qteros** has 'enhanced' a naturally occurring bacterium called the Q microbe to transform lignocellulosic biomass into sugar for ethanol and chemicals. Its current backers include **BP** and Soros Fund. Qtero is hoping to license its Q microbe in Brazil and India for turning sugarcane bagasse into ethanol.[264]

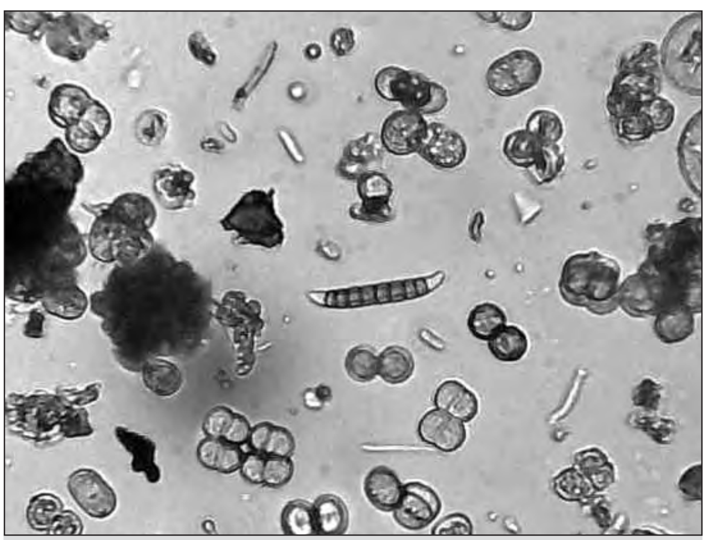
Beyond Alcohol to Hydrocarbons – Biogasoline, butanol, isopentanol, hexadecane, farnesene

Whether it's made from woodchips, cornstalks or algae, the biggest problem in the marketplace for cellulosic ethanol is that it is still ethanol, an energy-poor fuel requiring engine modifications and separate delivery infrastructure. As synthetic biologist and biofuel entrepreneur Jay Keasling likes to say, "Ethanol is for drinking, not driving."[265] A number of companies are now dispensing with ethanol and other such alcohols and working instead to mass-produce hydrocarbons resembling diesel or gasoline that can be refined in traditional oil refineries or pumped straight into ordinary car engines.

Thermochemical approaches

1. German biofuel company **Choren** opened the first commercial 'biomass-to- liquid' refinery to annually turn 68,000 tonnes of wood into 18 million litres of hydrocarbon diesel fuel. Choren's partners include Shell, Daimler and Volkswagen.[266]
2. **Dynamotive Corporation** of Vancouver, Canada, subjects agricultural and forest-derived biomass to 'fast pyrolysis' (burning without oxygen), which yields a hydrocarbon oil. Dynamotive's lead demonstration plant in Ontario, Canada, however, closed down and went into receivership in July 2010.[267]

Photo: Yersinia Pestis



Algae: pond scum and seaweeds; the term refers to a wide and diverse variety of photosynthetic plant-like organisms that grow in water, ranging from single-celled cyanobacteria to larger kelps and seaweeds.

Synthetic biology approaches

3. **LS9** has developed proprietary synthetic microbes that ferment sugars and even cellulose into hydrocarbon fuels indistinguishable from gasoline, diesel and jet fuel. Following $25 million investment by **Chevron**, a new biorefinery in Florida is expected to produce 50,000 to 100,000 gallons of its 'UltraClean' diesel by 2011 and to sell commercially by 2013.[268]
4. **Gevo**, another U.S. synthetic biology company, has developed microbes that transform agricultural sugars into isobutanol, an energy-rich alcohol fuel that can run in gasoline engines. The company has agreements with **Cargill** and investments from **Total Oil** and **Virgin Group**.[269]
5. **Amyris Biotechnologies** has developed synthetically modified yeast to ferment cane sugar into hydrocarbon diesel, gasoline and jet fuel equivalents based on the chemical farnesene. Led by a former BP director, Amyris has numerous partnerships, including with **Shell**, **Total**, **Votorantim**, **Crystalsev**, **Mercedes**, the **U.S. Department of Defense**, **Bunge**, **Cosan** and others. Its Brazilian biorefinery will begin selling "no compromise" biodiesel in 2011. It is also collaborating with **Procter & Gamble** to make chemical products.[270]

Beyond Cellulose: Algal Biofuels

> ***"If humanity were to plow a portion of the Sahara Desert, irrigate it with saltwater from the Mediterranean, then grow biomass such as algae, we could replace all the fossil carbon fuel that our species currently uses and provide food for a growing global population at low cost."***
> – Dennis Bushnell, chief scientist at NASA's Langley Research Center[271]

For dedicated biofuel believers, the development of fuels from algae (cyanobacteria, or common pond scum) represents the ultimate in sustainable biomass sourcing. The UK Carbon Trust forecasts that by 2030 algae-based biofuels could replace more than 70 billion litres of fossil fuels used every year for road transport and aviation.[272]

Algae is proposed to be grown in four possible systems:

Open ponds located in deserts or other high sunlight regions are the preferred method for cultivating algae. Wastewater or freshwater can be moved through the ponds using moving paddles.

Algae ponds for fuel production Photo: Agrilife Inc.

Photobioreactors are systems that enclose algae in glass tubes or transparent plastic bags while pumping water, CO_2 and nutrients through those containers. They can potentially be used in urban locations.

Closed vats derive energy from sugar instead of sunlight. Algae can be grown in large vats and tricked into making hydrogen instead of oils.

Open sea cultivation of algae is still very speculative and raises risks that strains will escape and cause ecological damage. Some companies such as Blue Marble propose harvesting wild algae from ocean dead zones.[273] Meanwhile researchers at NASA's Algae OMEGA Project propose growing floating farms of freshwater algae in closed bags at sea so that escaped strains don't persist in the marine environment.[274]

Claims in favor of algae

- Algae produce a hydrocarbon oil that can be pressed and refined for use as biodiesel or refined into gasoline, plastics and chemicals.
- Algae also produce cellulose, which can be recovered for transformation into cellulosic fuel or bioelectricity.
- Algae can be tricked into producing hydrogen.
- Algae are more efficient at transforming sunlight to biomass than other green plants.
- Algae grow quickly and easily in nutrient rich waters; algae are abundant and renewable.
- Algae are not a major food source.
- Algae can absorb atmospheric or industrial carbon dioxide.
- Algae can be grown in wastewater or saltwater (depending on algal strains), thus avoiding stressing freshwater resources.
- Algae-growing avoids agricultural lands and instead takes place in deserts, marginal lands, at sea, and even in urban environments.

Arguments against algae as a fuel source

Far from a panacea, algae-based biofuels have many of the same problems as other biofuels:

- **Scale up** – In over 40 years of experimentation with algae for biofuels, no company has succeeded in producing commercial quantities to rival petroleum fuels of either algal oil or algal biomass. It is widely expected that to do so is going to require genetic engineering of some form.
- **Land** – Because most algae production requires sunlight as an energy source, algal ponds must remain shallow to let light through to reach the organisms. As a result production is spread thinly over extremely large areas of land, impacting ecosystems, land rights and customary use, especially in desert regions. Renewables expert Saul Griffiths has recently calculated that even if an algae strain can be made four times as efficient at harvesting sunlight for energy, it would still be necessary to fill one Olympic-size swimming pool of algae every second for the next twenty five years,[275] which would offset only 3 percent of global energy consumption.
- **Energy and water balanc**e – Depending on the production system, growing algae can prove energy intensive. Largely this is due to the fact that cultivating algae in open ponds or closed bioreactors requires continuous fertilizer use. In a recent life-cycle assessment of algal biofuels published in the journal Environmental Science and Technology, researchers concluded that algae production consumes more water and energy than other biofuel feedstocks like corn, canola, and switchgrass, and also has higher greenhouse gas emissions.[276] Fertilizer production, in particular, is highly energy intensive. Moreover, production and continuous operation of photobioreactors, water pumps and mixing equipment, as well as harvesting and extracting technology, add to overall energy use. "Given what we know about algae production pilot projects over the past 10 to 15 years, we've found that algae's environmental footprint is larger than other terrestrial crops," said Andres Clarens, of the University of Virginia's Civil and Environmental Department and lead author of the study.[277] The authors suggested that companies could use nutrient-rich waste water to reduce fertilizer inputs.
- **Peak fertilizer and food competition** – The energy cost associated with high fertilizer use is not the only major drag on algal biofuel expansion. Global stocks of fertilizer-grade phosphate are estimated to have dwindled to only 8000 million tonnes. One commentator has noted that if we switched oil production to algae we would only have enough phosphate fertilizer to last 37 years.[278] Given the impending scarcity of this key mineral, stocks of phosphate directed to biofuel production are directly competing with fertilizing food crops – a classic food vs. fuel dilemma.

- **Invasiveness and genetic engineering risks** – The notion of moving cyanobacteria into large-scale open-air production has many ecologists alarmed, since algae reproduce extremely fast, doubling mass daily. Wild algal strains are already responsible for some of the worst acts of ecological invasion, from the vast deoxygenated 'dead zones' found in coastal areas and caused by fertilizer runoff, to blooms of blue-green algae that suffocate freshwater ecosystems and threaten human health. Genetically engineering cyanobacteria increases the ecological risks since not only will altering the genetic code likely bring unanticipated side effects, but also the aim of such engineering is to breed strains of 'superalgae' that can harvest more solar energy than natural strains. At a 2010 meeting of U.S. President Barack Obama's new bioethics commission, Allison A. Snow, an ecologist at Ohio State University, testified that a "worst-case hypothetical scenario" would be that algae engineered to be extremely hardy might escape into the environment, displace other species and cause algal overgrowths that deprive waters of oxygen, killing fish.[279]
- **Geoengineering and the climate** – Algae are central to regulating life on Earth, responsible for between 73% and 87% of the net global production of oxygen by fixing atmospheric carbon dioxide.[280] Re-engineering algae's biology, or altering global algal stocks on any large scale, therefore, may directly impact the global oxygen cycle, carbon cycle, nitrogen cycle and ozone production – potentially in unpredictable and harmful ways. Proposals to farm algae in coastal and open ocean areas raise the same ecological, climate and justice concerns as geoengineering plans to seed oceans with iron or urea to provoke plankton blooms (ocean fertilization).

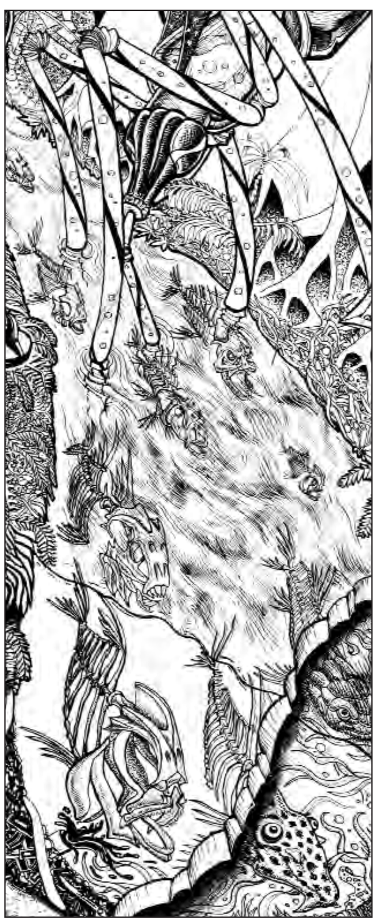


Illustration: the Beehive Collective

The New Algal Crowd

While no company is yet marketing commercially viable quantities of algae-derived biofuel, market research group Global Information reckons that more than 100 companies worldwide are attempting to make fuel and other chemicals out of it. In the USA at least, these companies are generously supported by over $70 million of U.S. government and state funding. Global Information claims that the algal fuel market is worth $271 million in 2010 and could be worth more than $1.6 billion by 2015.[281]

Those to watch include:

Synthetic Genomics, Inc. – a high profile synthetic biology company founded by gene mogul J. Craig Venter – has a $600 million joint venture with **ExxonMobil** to develop highly efficient algal strains and scale them up to commercial production. ExxonMobil claims this is currently one of their largest technology research projects.[282] In 2010 they opened a demonstration greenhouse in San Diego, California and are developing a much larger test facility at an undisclosed location to be announced in 2011.[283] In May 2010 Venter told the U.S. Congress that Synthetic Genomics is looking at building facilities as large as the city of San Francisco.[284] Venter's other backers include **BP**, the Malaysian **Genting Group, Novartis** and **Life Technologies Corporation**, as well as several individuals.

Sapphire Energy claims that by 2011 they will be producing one million barrels of algal diesel and jet fuel annually, and 100 million by 2018. They have raised $100 million from prominent investors, including **Bill Gates**,[285] plus a further $100 million in federal financing to build a 300-acre demonstration site in the New Mexico desert. Sapphire is working with both natural and synthetic strains of algae. Their directors include former **Monsanto** CEO Robert Shapiro and also a former executive director of **BP**.[286]

Transalgae, a U.S. company based in Israel, claims that it intends to be "the Monsanto of algae seed."[287] It is developing genetically modified algae for fuel and animal feed in collaboration with **Endicott Biofuels** of Texas, USA and also **Raanan**, Israel's largest fish feed producer. Transalgae's first generation of transgenic algae is now being field tested at a 400MW natural gas power station in Ashdod, Israel in collaboration with the **Israeli Electric Company**. The company has told press that it has added a switchable terminator gene into its algae so that the algae will theoretically 'self-destruct' within six hours;[288] however, its patents suggest a much weaker mechanism that merely makes the algae less hardy in the wild.[289]

Solazyme, based in San Francisco, USA, applies synthetic biology to produce algal biodiesel in closed vats where the algae feed on sugar instead of carbon dioxide. It has a joint venture with oil giant **Chevron** to scale up production of its algal fuel by 2013 and also agreements with **Unilever** to develop algal oil alternatives for palm oil. After delivering 20,000 tonnes of algal diesel to the **U.S. Navy** in September 2010, the company announced a second naval contract for a further 150,000 gallons.[290] Solazyme also has agreements with grain trader **Bunge** to grow algae on sugarcane bagasse as well as investments from Sir Richard Branson of the **Virgin Group** and major Japanese food-ingredient company **San-Ei Gen**.[291]

Joule Biotechnologies, a spin-off from Massachusetts Institute of Technology in Boston, USA claims to have developed a highly engineered synthetic cyanobacteria (blue-green algae) that secrete alkanes, a chemical usually refined from petroleum. Joule's current product secretes ethanol directly into the water in which its organism grows but according to the company, "Different variants can also make polymers and other high-value chemicals that are ordinarily derived from petroleum."[292] Joule is constructing a commercial plant to begin operations in 2012 with a predicted yield of 15,000 gallons of diesel per acre.

Algenol, from Florida USA, is partnering with **Dow Chemical** to build an algal biorefinery in Texas. Algenol's hybrid algae strains produce ethanol in bioreactors. Other partners include the **U.S. Environmental Protection Agency** and **Valero Energy Corporation**, a leading ethanol producer.[293]

Cellana is a joint venture between **Royal Dutch Shell** and **HR BioPetroleum** to select and grow natural algae strains for biofuels and animal feeds. They have research agreements with several universities internationally and operate a small experimental facility in Hawaii, USA that cultivates ocean algae in closed and open systems.[294]

Petrochemistry: making materials from petroleum; a branch of industrial chemistry that transforms crude oil (petroleum) and natural gas into useful products and raw materials. Petrochemistry begins by 'cracking' complex petroleum molecules into simpler molecules and then recombining them.

Switch 3: Switching Chemicals – Bioplastic and biobased chemicals

The shift by the $3 trillion global chemical industry[295] toward sugar and biomass feedstocks has probably received the least critical attention from civil society and grassroots movements and yet is the most marked – especially in the area of bio-based plastics and fine chemicals. Making chemicals rather than transport fuels out of biomass is attractive because the markets are smaller and therefore easier to break into and the prices for chemical products are on average two to four times higher. Indeed venture capital investors are increasingly advising second-generation biofuel companies to branch out into chemicals (and also foods) as a secondary or even primary revenue stream.

The global chemical industry accounts for about 10 percent of petroleum use[296] and many of the thousands of synthetic chemicals currently incorporated into everyday products are based on cracking and refining petroleum into ever more elaborate hydrocarbon molecules. Yet the chemical industry has always derived some portion of its carbon feedstock from sugar and is well structured to switch back to carbohydrates. In the early 20th century the first commercial plastics and many everyday chemicals were based on biomass, including celluloid and rayon. In his history of 'the carbohydrate economy' economist David Morris reports that as late as 1945 the largest British chemical manufacturer ICI still maintained three production divisions – one based on coal, one based on petroleum and the third based on molasses.[297]

Already a handful of high value chemicals are bio-based including lysine (used widely for animal feed), glutamic acid (used for food flavourings such as monosodium glutamate) and soy-based dyes and inks, which now supply over 90 percent of U.S. newspaper production and 25 percent of commercial printers.[298] However, as developments in synthetic biology make it possible to process and refine plant sugars within cells instead of inside chemical factories, so more synthetic organisms are being fashioned to secrete chemicals that would previously have been refined from fossil sources. Now bio-based production is being applied across all sectors of the chemical industry including scents and flavourings, pharmaceuticals, bulk chemicals, fine and specialty chemicals as well as polymers (plastics). While biobased chemicals, especially bioplastics, are touted as green and clean, some are indistinguishable from their petro-cousins when it comes to biodegradability and toxicity.

Bio-based Building Blocks

In particular, synthetic biologists and chemists are attempting to manufacture what they call 'platform chemicals' from a sugar or biomass feedstock. These are key building block chemicals that can in turn be refined into hundreds of other useful chemicals currently being produced in commercial refineries. Commercial petrochemistry already takes this approach, cracking petroleum into essential building blocks such as ethylene, butadiene, propylene and xylene and flexible intermediates such as ammonia, acetic acid, carbolic acid and butylene for refinement into thousands more. By targeting these key platform chemicals or choosing new ones, chemists developing biobased substances are able to convert tens or hundreds of chemicals at one time from fossil carbon to plant carbon. Examples of bio-based platform chemicals now coming to market include:

Isoprenoids or terpenoids are a class of naturally occurring compounds including rubber, taxol, neem, artemisinin and cannabinoids. Some of these have been produced in synthetic yeast by **Amyris Biotechnologies, Inc**. Amyris has focused on one isoprenoid called **farnesene** (which produces the acrid smell in apples), which they claim can be further refined into "a wide range of products varying from specialty chemical applications such as detergents, cosmetics, perfumes and industrial lubricants, to transportation fuels such as diesel."[299] Amyris, whose synthetic yeast currently munch on Brazilian cane sugar have an agreement with **Procter &Gamble**[300] to turn farnesene into cosmetics and household products. They have a further agreement with **M&G Finanziaria**, the worlds' largest supplier of plastic for packaging bottles to use bio-based farnesene in production of PET plastic.[301] **Genencor** has also engineered synthetic E. coli to produce isoprene used for rubber production. In 2008 they partnered with global tire manufacturer **Goodyear, Inc.** to produce industrial quantities of tire rubber. They claim their 'bioisoprene' replaces the seven gallons of crude oil currently required to make one synthetic rubber tire.[302]

1,3-Propanediol is a building block chemical that can be used for plastics, composites, adhesives, laminates, coatings and as a solvent in antifreeze and wood paint. Although usually produced from ethylene oxide (a petroleum derivative), it has now been produced by **Genencor** in synthetic yeast as **Bio-PDO**, a precursor for **DuPont**'s bioplastic Sorona. DuPont, in partnership with **Tate & Lyle**, currently produces 45,000 tonnes per year of Bio PDO at its plant in Loudon, Tennessee, USA annually consuming 152,000 tonnes of corn (covering an area of about 40,000 acres – roughly the size of Liechtenstein).[303] In June 2010, **DuPont** announced a 35% expansion of production.[304] French bio-based products company, **METabolic EXplorer** also makes Bio-PDO, converted from glycerol, a plant oil. The company estimates the global PDO market will reach 1.3 billion Euros by 2020.[305]

Succinic acid is a naturally occurring by-product of sugar fermentation that is a close chemical cousin to **maleic anhydride** – a petroleum-derived chemical used as a common feedstock for food and pharmaceutical products, surfactants, de-icers, coolants, detergents, plastics, pesticides, clothing fibres, and biodegradable solvents. Since it is possible to transform succinic acid into maleic anhydride, a number of firms are now competing to produce large quantities of succinic acid, chasing a market that could be worth $2.5 billion per year.[306] Those developing bio-based succinic acid include **DSM** and **Mitsubishi Chemicals**. **BASF** and **Purac** are developing a succinic acid plant in Spain and a 2000 tonne per year plant is already operational in Pomacle, France, using mutant E. coli bacteria to produce succinic acid from wheat sugars. The plant is run by **Bioamber** – a joint venture of U.S. biotech company **DNP** and **ARD** (France's Agro-industrie Recherches et Developpements).[307] In 2010 U.S.-based synthetic biology company **Myriant** received a $50 million grant from the **U.S. Department of Energy** to build a 14,000 tonne bio-succinic acid plant in Louisiana.[308]

Ethylene is the gaseous raw material used in the manufacture of plastics including **polyethylene** (PE), **polyester**, **polyvinyl chloride** (PVC) and **polystyrene**, as well as fibres and other organic chemicals. Usually made from naptha or natural gas, ethylene can also be made as a byproduct of ethanol production. Indeed in the 1980s Brazilian companies produced 160,000 tonnes of PVC and polyethylene (PE) from ethanol until world oil prices fell and the plants were closed down. In 2008 three separate chemical companies, **Braskem**, **Solavay** and **Dow Chemical**, all announced they would restart production of bio-based PVC and PE in Brazil and Argentina from sugarcane amounting to 860,000 tonnes per year.[309]

Other companies to watch that are using chemistry and synthetic biology to create bio-based chemicals and plastics include:

ADM/ Metabolix, **BASF**, **Blue Marble**, **Cargill Natureworks**, **Codexis**, **Draths Corporation**, **DSM**, **DuPont**, **Genomatica**, **LS9**, **OPX Biotechnologies**, **Segetis**, **Solazyme**, **Qteros** and **Zeachem**.

The Future is (Bio)Plastic?

"There's a great future in plastics. Think about it." That was the advice whispered in Dustin Hoffman's ear in the 1967 film "The Graduate." Fifty years later, the one area of the plastics industry whose future still looks bright is bioplastics. According to insiders, the bioplastics industry could be worth $20 billion by 2020.[310] Current worldwide use of bioplastics amounts to just over one half-million metric tonnes in 2010, which could fill the Empire State Building five times over. While use is expected to rise to 3.2 million metric tonnes by 2015,[311] this is still only a sliver of the 200 million tonnes of plastic resin produced every year[312] (although some analysts say that it is technically feasible to switch up to 90% of plastics to bio-based feedstocks).[313]

For the plastics industry going green is as much about the market opportunity to improve their image as hedging against rising oil prices. Consumers often assume (and the plastics industry would like them to believe) that bioplastics automatically meet a gold standard in environmental protection, a break from the toxic legacy of vinyl, bisphenol A (BPA) and polystyrene products now filling up the world's landfills and oceans. Despite attempts to market themselves as 'earthy' and 'close to nature,' bioplastics producers are largely the same polluting agribusiness and chemical corporations: **Cargill** and **ADM** – which sew up most of the world's grain trade between them – are also two of the biggest players in bioplastics, controlling the Natureworks and Mirel lines, respectively. **DuPont**, **DSM**, **BASF** and **Dow Chemical** – four of the world's largest chemical companies – are also key players.

Plastic bottles Photo: Shea Bazarian

Do Bioplastics Biodegrade?

Some bioplastics – such as ADM's Mirel bioplastic and those made by Plantic – do break down in the environment or in home composters, while other bioplastics, even some marketed as compostable, may prove difficult to break down except over a long time. This is particularly true for biobased plastics that replicate existing petroleum-derived chemicals. **DuPont**'s Sorona for example makes no claims to break down in the environment nor does **Braskem**'s bio-based Poly Vinyl Chloride (PVC) and Polyethylene. The leading bioplastic, **Cargill**'s polylactic acid (PLA) sold under the brand 'Natureworks' is one so-called 'compostable' plastic that does not break down in home composters, or in the environment, but needs to be hauled away to industrial high-heat composters.

Nor is it clear how fully the biodegradable bioplastics break down. Close studies of so-called degradable plastics have shown that some only break down to smaller, less visible plastic particles, which are more easily ingested by animals. Indeed, small plastic fragments of this type may also be better able to attract and concentrate pollutants such as DDT and PCB. As one plastics industry insider has observed "designing degradable plastics without ensuring that the degraded fragments are completely assimilated by the microbial populations in the disposal infrastructure in a short time period has the potential to harm the environment more that if it was not made to degrade."[314]

Can Bioplastics be Recycled?

Theoretically bioplastics can be recycled, but, in reality, there are few if any recycling facilities that will separate out new bio-polymers from other plastics. Cargill Natureworks, for example, insists that PLA can in theory be recycled. In reality, this plastic is likely to be confused with Polyethylene Terepthalate (PET) used for plastic bottles and so can actually hamper recycling efforts by contaminating existing recycling streams. In October 2004 a group of recyclers and recycling advocates issued a joint call for Natureworks to stop selling PLA for bottle applications until key questions related to recycling PLA were addressed. In January 2005 the company put in place a moratorium on selling "additional" PLA for bottle production, but began selling PLA for bottles again, claiming that the levels of PLA in the recycling stream were too low to be considered a contaminant. Bioplastics in packaging in North America are supposed to carry the number 7 "chasing arrow symbol," though industry protocols stipulate that the symbol must be inconspicuous enough that it doesn't affect consumers' buying decisions.[315]

Are Bioplastics Toxic?

One of the reasons that campaigners against toxic chemicals are actively encouraging the development of the bioplastic sector is that it is possible to invent new polymers from starch and sugar that break down more easily in the environment or human body without toxic byproducts. However, as chemists and synthetic biologists get better at creating chemicals identical to petroleum-derived building blocks, we are beginning to see the same old toxic chemicals produced from a different (plant-based) source of carbon. **Solvay**'s bio-based PVC is a clear example. PVC has come under sustained attack from environmental health campaigners for its use of phthalates, a hormone-disrupting plasticizer, and for the production of highly toxic dioxins in the making, recycling and disposal of PVC. Like petroleum based PVC, producing bio-based PVC still requires chlorine in the production. As one research group commissioned by the European Bioplastics Association was forced to admit, "The use of bio-based ethylene is therefore unlikely to reduce the environmental impact of PVC with respect to its toxicity potential."[316]

Are Bioplastics Sourced Sustainably?

If you search the Internet for clues about the origin of bioplastics, you could be forgiven for thinking that today's plastics industry has become a market gardening enterprise. There's **ADM**'s Mirel, for example, a "bioplastic" made from corn or cane sugar, yet whose website sports photos of pond grasses. Or **Sphere Inc.**, Europe's leading biofilm producer whose homepage is adorned with tulips even though their plastics are made from potatoes. Sorona, **DuPont**'s flagship bioplastic, is promoted by images of grassy hillsides, while **Cargill**'s "Natureworks" website displays a montage of tree leaves. In truth, both Natureworks and Sorona derive mainly from industrial genetically modified corn drenched in pesticides and in the case of Sorona, transformed by vats of synthetic organisms – no tree leaves or grass in sight. Corn-based bioplastics raise the same concerns as first generation biofuels in terms of competing with food.

According to Bob Findlen of the **Metabolix/ADM's joint venture**, bioplastic company **Telles**, "If the bioplastics industry grows to be 10% of the traditional plastics industry, then around 100 billion pounds of starch will be necessary, and there is no question that that will have an effect on agricultural commodities."[317]

If it is unacceptable to turn food into fuel at a time of extreme hunger, it should be doubly unacceptable to turn food into plastic bags.

If it is unacceptable to turn food into fuel at a time of extreme hunger, it should be doubly unacceptable to turn food into plastic bags.

As with biofuels, bioplastics manufacturers are attempting to move out of the firing line in the food vs. fuel battlefield by shifting feedstocks. Brazilian cane sugar is particularly in their sights. **Dow Chemical**, the world's largest polyethylene producer, has partnered with Brazilian sugar giant **Crystalsev** and in 2011 will start producing sugarcane-derived polyethylene (the most widely used of all plastics) from a manufacturing plant with a capacity of 317,000 tonnes per year.[318] The plant will consume 7.2 million tonnes of sugarcane per year requiring at least 1000 square km of land.[319] In October 2010 Brazil's largest petrochemicals firm, **Braskem**, opened a $278 million factory designed to produce an annual 181,000 tonnes of polyethylene from sugarcane ethanol. Braskem has already secured contracts to provide products to **Johnson & Johnson**, **Proctor & Gamble**, cosmetics company **Shiseido** and the **Toyota Group**.[320] Meanwhile **Coca-Cola** is making one third of its new so-called "Plant Bottle" out of biobased PET from Brazilian sugarcane – a move that received the enthusiastic endorsement of WWF World Wide Fund For Nature, whose CEO declared it "yet another great example of their leadership on environmental issues."[321]

As already noted, Brazilian sugarcane plantations have attracted fierce criticism for their social and environmental impact. Meanwhile even plastics made from the humble potato such as Stanelco's 'Bioplast' also raise production concerns. U.S.-based watchdog Environmental Working Group regards potatoes as having one of the highest pesticide residue limits on any food.[322]

GM Crops, Synthetic Biology and Nanotechnology

The links between genetic engineering and bioplastics are everywhere. In March 2010, the first genetically modified crop to gain approval in Europe in over a decade was a high-starch GM potato from **BASF** aimed squarely at the bioplastics market.[323] Meanwhile corn, the chief feedstock for bioplastics, is almost universally sourced from GMO harvests. In fact, only three major bioplastics producers, Italy's **Novamont**, Germany's **Pyramid Bioplastics** and **EarthCycle** of Canada, tout their product as non-GMO although **Cargill**'s Natureworks offers a bizarre scheme where purchasers can "offset" the use of GMOs in their product by paying Cargill to buy a specified quantity of non-GMO corn. Genetic engineering is also being applied to create a next-generation bioplastic in which the plastic is produced directly in the plant itself. Boston-based **Metabolix Inc.** has used synthetic biology to engineer a switchgrass variety that produces polyhydroxybutyrate (PHB) bioplastic in 3.7% of its leaf tissue. Metabolix says that the leaves will need to produce 5% of PHB to be commercially viable. The synthetically engineered switchgrass is already in greenhouse trials.[324] The risk of contamination of the food supply by "plastic crops" is an obvious environmental and health concern. Meanwhile, the same engineered gene sequences are incorporated into synthetic microbes that transform corn into 50,000 tonnes of Mirel bioplastic at a facility in Iowa (USA) in a joint venture between **Metabolix** and **ADM**. **DuPont**'s Sorona bioplastic is similarly produced by yeast containing synthetic DNA and Amyris Biotechnologies is also using synthetic yeast to turn sugarcane into PET bottles via its collaboration with M&G, the world's largest plastic bottle maker.

Bioplastics: corporate-owned, competing with food, non-biodegradable, bolstering industrial agriculture and leading us deeper into genetic engineering, synthetic biology and nanotechnology. It's hard to get excited about the supposedly green future the bioplastics industry is selling.

Nanotechnology too figures prominently in the brave new world of bioplastics. Worried that bio-based polymers might have poor barrier properties (that is, they might leak air or liquid), bioplastic companies are adding nanoparticles to their plastics to improve them. For example, **Cereplast**, which produces bioplastic cutlery, drinking straws, plates and cups uses nanoparticles to improve the heat resistance of PLA plastic.[325]

Can Bioplastics Be Done Right?

Bioplastics: corporate-owned, competing with food, non-biodegradable, bolstering industrial agriculture and leading us deeper into genetic engineering, synthetic biology and nanotechnology. It's hard to get excited about the supposedly green future the bioplastics industry is selling. However, there are attempts to put bioplastics back on course. One such step is the Sustainable Biomaterials Collaborative (SBC) – a network of 14 civil society groups and 'ethical businesses' working to define a truly sustainable bioplastic. One of its founders, Tom Lent of The Healthy Building Network, explains that SBC started because "the promise of bioplastics was not being realized." His SBC colleague, Brenda Platt of the Institute for Local Self-Reliance acknowledges that at present the term "sustainable plastic" is more oxymoron than fact, but is optimistic about changing that. "No doubt we have a long way to go but we've been quite active and I believe are already making a difference," she says.[326] The SBC has issued lengthy "Sustainable Bioplastic Guidelines" available online, based on 12 principles ranging from avoiding GM crops, pesticides and nanomaterials to supporting farmer livelihoods. The principles, however, do not address global justice implications, competition with food, land rights or corporate ownership and concentration. The use of synthetic organisms in biorefineries is also considered acceptable by the SBC.[327]

Conclusions: Earth Grab!

Biomass contradictions: Advocates who insist that a mix of biomass feedstocks and new technologies will provide the solution to our energy, food and environmental crises should consider getting realistic or at least reconciling their own rhetoric. Overwhelmingly, uncritical support for the biomass vision is coming from the same agencies and think-tanks that have also repeatedly told us that, by 2050, world population could increase by 50% and food demand by almost 100%. They warn (correctly) that climate change will, at the very least, make harvests erratic and, at worst, cut industrial food production anywhere from 20-50% and they proscribe (wrongly) that we need to use more chemicals on our fields to rescue marginal lands and endangered habitats from crop production. Yet, at the same time, these policymakers are saying that still experimental technologies will not only make everything alright, but will make it OK to impose monumental new demands on our soils and water in the name of replacing fossil carbon with living biomass.

Illustration: the Beehive Collective

Bioeconomy bubble? Having failed to predict the collapse of the dot com bubble, the sub-prime mortgage bubble, the food price spike and the collapse of the banking system – all in one decade – OECD states now tout a new "Green Economy" as the "next big thing" that will rescue their industries. In doing so they are creating a new mythology around the notion that living biomass can be harnessed for a new industrial revolution that will maintain current levels of production and consumption without harming the planet. This kinder, gentler economic colonialism needs the global South's soil and water. It is being made to look like a technological gift that will let Africa, Asia and Latin America profit from climate change. In the process, the bioeconomy could destabilize commodity markets – and concentrate OECD power – based on a resource that may collapse from overuse.

Gambling on synthetic biology: The absurdity becomes existential when we consider the techno-fix being proposed. Synthetic biology claims to be able to redesign DNA to build novel species, potentially with characteristics never before seen in nature. Presuming this is even possible, we are being asked to believe that these experimental organisms will provide no threat to either our economy or ecosystems.

If contained in biorefineries – despite the proliferation of production sites and the quantities involved – we are told there is little danger of environmental contamination and that these new biofactories can be fed sustainably. Those with similar hubris told us that nuclear power would be safe and too cheap to monitor; that the chemical age would end hunger and disease; that biotechnology would end hunger and disease, too – and not contaminate; and – only recently – that climate change is probably a figment of our imagination.

In other words, gamble with Gaia (and the grandkids) using experimental life forms on the back of untested hypotheses. More than a biomass grab or a Land Grab, this is an Earth Grab.

Recommendations: Towards Global Governance

Immediate:

1. **Civil Society:** Civil society and, especially, social movements – who are or will be affected by the new bioeconomy – need to come together. This spans indigenous communities and famers fighting agribusiness expansion in the food sovereignty movement and those concerned with forest protection, climate justice, toxic chemicals, marine conservation, desert protection, water rights and much more. We urgently need a cross-movement conversation and a grand coalition to analyze, address and confront the New Biomassters.
2. **Mandates, Targets and Subsidies:** National governments must revisit their support for biofuels, industrial biotechnology and the wider bioeconomy in light of likely impacts on the South, biodiversity, and other international development commitments. Existing mandates, targets and subsidies for biofuels, biobased production and bio-electricity production should be dropped in favour of targets to reduce overall production and consumption. Government research monies should switch to evaluating the ecological and societal costs of the bioeconomy, especially next generation biofuels such as algae, cellulosic and hydrocarbon fuels and synthetic biology

3. **Legal Definitions:** Biomass use is not "carbon neutral" and rarely 'renewable' from an ecosystem perspective and should not be presented as such. Carbon accounting rules, both at national and international levels, must be revised to reflect the true biodiversity- and carbon-cost of biomass removal, processing and use, including emissions from land use change and reflecting the time taken to resequester. The cost to communities that already rely on that plantlife must also be made transparent and calculated.
4. **Climate Change:** The UN Framework Convention on Climate Change (UNFCCC) should reverse its institutional support and financing for bioenergy and commodification of biomass. The UNFCCC should revise the Kyoto Protocol's carbon accounting rules to reflect the fact that industrial biomass strategies are not carbon neutral (see 3 above). Action must also be taken to remove biomass from the approved methodologies under the Clean Development Mechanism, REDD+ proposals and the Climate Technology Initiative's PFAN programme. New biomass technologies and new uses of biomass should not be eligible for financial support via any climate change mechanisms or any future biodiversity mechanisms for innovative financial mobilization.
5. **Biodiversity:** The UN Convention on Biological Diversity should be commended for its early consideration of synthetic biology and the biomass economy and must take a lead role in exploring the potential implications for biological diversity. In the spirit of the precautionary principle, the CBD should proceed with a de facto moratorium on the environmental release and commercial use of novel lifeforms constructed via synthetic biology pending further study and transparent and precautionary governance arrangements.
6. **Food, Forestry, Water and Agriculture:** The UN Food and Agriculture Organization (FAO) and, especially, the Commission on Genetic Resources for Food and Agriculture and the Governing Body for the International Treaty on Plant Genetic Resources for Food and Agriculture should study the implications of synthetic biology and the accelerating grab on biomass for food security for crops, livestock, aquatic species and forests. Together with UNCTAD (UN Conference on Trade and Development), FAO should also examine implications for commodity markets and monopoly.
7. **Human rights:** The Special procedures of the UN Human Rights Council, including the special rapporteurs on the right to food, the right to water, Indigenous Peoples Rights, as well as the Special Representative of the Secretary General on transnational corporations and human rights, and the independent expert on extreme poverty, should undertake a joint investigation into the implications of synthetic biology and the new bioeconomy for the full enjoyment of human rights, particularly for those individuals, communities and countries whose lands will be affected by the search for new sources of biomass.
8. **Ownership:** The World Intellectual Property Organization (WIPO) should undertake an immediate investigation of the scope and implications of recent patents and patent applications involving synthetic biology based on *ordre public* concerns.
9. **The "Green Economy:"** Governments must carefully consider the proposed role and potential implications of the Green Economy as it is being presented for the Rio+20 Summit in Brazil in 2012. The preparatory process leading to Rio+20 should encourage a full global public debate on all of the socioeconomic, environmental and ethical issues related to biomass use, synthetic biology, and the governance of new and emerging technologies in general.
10. **Environmental Governance:** The UN System's Environment Management Group (EMG) should undertake a major study of the implications of the new bioeconomy particularly for livelihoods, biodiversity and the rights of affected communities. The study must engage all governments and the widest range of concerned parties, especially indigenous peoples and forest and farming communities.

Next:

11. **Technological Governance:** Recognizing that the new tools of biomass transformation such as synthetic biology are just part of a suite of powerful new technologies at the nano-scale that have vast applications for the economy and the environment, governments meeting at Rio+20 should adopt a negotiating process that will lead to a legally-binding International Treaty for the Evaluation of New Technologies (ICENT). This treaty should allow for the monitoring of major new technologies by governments and all affected people.

Annex: Table of Next-Generation Biofuel Companies

Company	Location	Feedstock(s) / Envisioned Feedstock(s)	Product(s) / Future Products	Partners and Investors
Abengoa Bioenergy	bioenergy facilities in Spain, Brazil and USA	cereals including wheat/wheat straw, corn stover	cellulosic ethanol	CIEMAT (Spain), University of Lund, NREL (USA), Auburn University
AE Biofuels	Montana, USA	switchgrass, grass seed, grass straw, corn stalks, bagasse, corn, sugarcane	cellulosic ethanol	
AlgaeLink N.V.	Yerseke, The Netherlands	algae	biocrude	KLM (project to produce jet fuel from algae)
Algafuel	Lisbon, Portugal	algae	biocrude	INETI (Portugal's National Institute of Energy, Technology and Innovation)
Algasol Renewables	Baleares, Spain	algae	biocrude	
Algenol Biofuels	Florida, USA and Mexico	algae	cellulosic ethanol	BioFields, Dow Chemical Company, Valero Energy, Linde Gas, Georgia Tech, Florida Gulf Coast University
Amyris Biotechnologies, Inc. (Amyris Brasil S.A. and Amyris Fuels, LLC)	Sao Paulo, Brazil, California, USA	fermentable sugars, sugarcane	hydrocarbons (farnesene)	Crystalsev, Santelisa Vale, Votarantim, Total, Mercedes Benz, Proctor & Gamble, U.S. Dept of Defense, Bunge, Cosan, M&G Finanziaria
Aurora Algae	California, USA, Perth, Australia	algae	biocrude	Noventi Ventures, Gabriel Venture Partners
BBI BioVentures LLC	Colorado, USA	existing waste stream feedstocks that require little /no pretreatment (in development)	cellulosic ethanol	Fagen, Inc.
BFT Bionic Fuel Technologies AG	Gross-Gerau, Germany	straw pellets	hydrocarbons: diesel, heating oil	OFT Aarhus (Denmark)

Company	Location	Feedstock(s) / Envisioned Feedstock(s)	Product(s) / Future Products	Partners and Investors
BioFuel Systems SL	Alicante, Spain	algae	biocrude	
BioGasol	Ballerup, Denmark	various grasses, garden waste, straw, corn fibres	ethanol, biogas, methane hydrogen	Siemens, Alfa Laval, Grundfos, Aalborg University, Ostkraft, Tate & Lyle, Agro Tech AS, NNE Pharmaplan
BioMCN	Delfzijl, Netherlands	crude glycerine	methanol	Waterland, Econcern, Teijin, NOM
BioMex, Inc.	California, USA	wood chips, switchgrass	methyl halides, biogasoline	
BlueFire Ethanol	California, USA and Izumi, Japan	wood chips	cellulosic ethanol	
Borregaard Industries, LTD	Sarpsborg, Norway	sulphite spent liquor from spruce wood pulping	cellulose, lignin, bioethanol	
BP Biofuels	Louisiana, California, Texas, USA; Brazil	miscanthus	cellulosic ethanol	In 2010, BP Biofuels acquired Verenium's biofuels business, Galaxy Biofuels LLC and Vercipia Biofuels; has joint venture with DuPont (see Butamax)
Butamax Advanced Biofuels	Delaware, USA	grasses, corn stalks	biobutanol	Joint venture: BP Biofuels and DuPont; Kingston Research Ltd (Hull, UK) is also BP-DuPont joint venture making biobutanol
Carbona, Inc.	Finland and USA	forest residues	Fischer-Tropsch fuels	GTI (Gas Technology Institute), UPM-Kymmene (pulp & paper mills)
Catchlight Energy	Washington, USA	timber supplemented with perennial grasses, residues	cellulosic ethanol	Joint venture: Chevron and Weyerhaeuser
Cellana	Hawaii, USA	algae	biofuels and animal feed	Joint venture: Royal Dutch Shell and HR BioPetroleum; various US universities + Bodø University College, Norway

Company	Location	Feedstock(s) / Envisioned Feedstock(s)	Product(s) / Future Products	Partners and Investors
Chemrec AB	Pitea, Sweden	pulp and paper mill by-products	bioDME (dimethyl ether)	Volvo, Haldor Topsøe, Preem, Total, Delphi, ETC
CHOREN Technologies GmbH	Freiberg, Germany	dry wood chips and forest residues	biomass-to-liquid synthetic fuel	Shell, Daimler, Volkswagen
Colusa Biomass Energy Corporation	California, USA	rice straw, rice hulls, corn stover and cobs, wheat straw and husks, wood chips and sawdust	cellulosic ethanol, silica/sodium oxide, lignin	
Coskata, Inc.	Pennsylvania, Florida, Illinois, USA	agricultural and forest residues, wood chips, bagasse, municipal solid waste	cellulosic ethanol	GM, Globespan Capital Partners, Blackstone Group, Sumitomo, Arancia Industrial, Khosla Ventures, Total
CTU (Clean Technology Universe)	Winterthur, Switzerland; demonstration plant in Güssing, Austria	wood, corn, grass, whole crop silage	synthetic gas	Vienna University of Technology, Paul Scherrer Institute (Switzerland), Repotec (Austria)
Cutec-Institut GmbH	Clausthal-Zellerfeld, Germany	straw, wood, dried silage, organic residues	Fischer-Tropsch fuels	
DuPont Danisco Cellulosic Ethanol, LLC (DDCE)	Tennessee, USA	corn stover, cobs and fibre, switchgrass	cellulosic ethanol	Genera Energy (University of Tennessee)
Dynamic Fuels, LLC	Louisiana, USA	animal fats, used cooking greases	diesel, jet fuel	50-50 joint venture: Syntroleum Corporation and Tyson
ECN (Energy Research Centre of the Netherlands)	Alkmaar and Petten, Netherlands	wood chips	SNG (synthetic / substitute natural gas)	HVC
Enerkem	commercial plants in Alberta and Quebec, Canada and Mississippi, USA	municipal waste, forest and agricultural residues	ethanol and bioethanol	Braemar Energy Ventures, US Department of Energy, Natural Resources Canada, GreenField Ethanol, Inc.

Company	Location	Feedstock(s) / Envisioned Feedstock(s)	Product(s) / Future Products	Partners and Investors
Envergent Technologies	Illinois, USA	forest and agricultural residues	upgraded pyrolysis oil to act as gasoline, diesel, jet fuel	Joint venture: Ensyn and UOP (Honeywell)
EtanolPiloten (Ethanol Pilot Plant)	Örnsköldsvik, Sweden	forest residues	cellulosic ethanol	Umeå University, Luleå University of Technology and the Swedish University of Agricultural Sciences
Flambeau River Biofuels, LLC	Wisconsin, USA	bark, sawdust, wood, and forest residues	electrical power, steam and heat, diesel fuel, wax	US Department of Energy
Frontier Renewable Resources, LLC	Michigan, USA	wood chips	ethanol, lignin	Subsidiary of Mascoma
Fulcrum BioEnergy	California, USA	municipal solid waste	cellulosic ethanol	US Renewables Group and Rustic Canyon Partners
Gevo	California, USA	corn	bio-isobutanol,	Cargill, Total, Virgin Group, Lanxess
Green Star Products, Inc.	California, USA, Naboomspruit, South Africa	algae	biodiesel	De Beers Fuel Ltd.
Gulf Coast Energy, Inc.	Florida, USA	wood chips	ethanol	
HR Biopetroleum	Hawaii, USA	algae	biodiesel	Royal Dutch Shell (see Cellana)
IMECAL	Valencia, Spain	citric waste (peel, seeds and pulp)	bio-ethanol	CIEMAT, Ford Spain and AVEN
Inbicon (subsidiary of DONG Energy)	Kalundborg, Denmark	wheat straw, wood pellets	ethanol	Genencor (Danisco), Novozymes and Statoil
Iogen	Idaho, USA, Ontario and Saskatchewan, Canada	wheat straw, barley straw, corn stover, switchgrass, rice straw	cellulosic ethanol	Royal Dutch Shell, Petro-Canada and Goldman Sachs
Joule Biotechnologies	Massachusetts, USA	algae converts sunlight and CO_2	diesel	
Karlsruhe Institute of Technology (KIT)	Karlsruhe, Germany	straw	synthetic gas	Lurgi GmbH

Company	Location	Feedstock(s) / Envisioned Feedstock(s)	Product(s) / Future Products	Partners and Investors
KL Energy Corporation	Wyoming, USA	wood (Ponderosa pine), sugarcane bagasse	cellulosic ethanol	Petrobras America, Inc.
LanzaTech New Zealand Ltd.	Auckland, New Zealand (plants in China, New Zealand, USA)	industrial waste gases	ethanol	Henan Coal and Chemical Industrial Corporation, Boasteel (China), Qiming Ventures, Softbank China Venture Capital, Khosla Ventures, K1W1
Lignol Energy Corporation	British Columbia, Canada and Colorado, USA	wood and agricultural residues	ethanol, lignin	US Department of Energy, Novozymes, Kingspan Group PLC
LS9	California and Florida, USA	sugarcane syrup, wood chips, agricultural residues, and sorghum	biogasoline, biodiesel	Chevron, Procter & Gamble, Khosla Ventures
Mascoma	New Hampshire and New York, USA	wood chips, switch-grass, agricultural residues	ethanol, lignin	Flagship Ventures, General Motors, Khosla Ventures, Atlas Venture, General Catalyst Partners, Kleiner Perkins Caufield & Byers, VantagePoint Venture Partners, Marathon Oil
M&G (Gruppo Mossi & Ghisolfi) / Chemtex	Rivalta, Italy	corn stover, straw, husk, woody biomass	cellulosic ethanol	
M-real Hallein AG	Hallein, Austria	sulphite spent liquor (SSL) from spruce wood pulping	cellulosic ethanol	
Neste Oil	Porvoo, Finland; Rotterdam, The Netherlands; Tuas, Singapore	palm oil, rapeseed oil and animal fat	biodiesel	Singapore Economic Development Board
NSE Biofuels Oy	Varkaus, Parvoo and Imatra, Finland	forest residues	Fischer-Tropsch fuels	joint venture: Neste Oil and Stora Enso, JV; Foster Wheeler, Technical Research Centre of Finland (VTT), Finland's Ministry for Industry

Company	Location	Feedstock(s) / Envisioned Feedstock(s)	Product(s) / Future Products	Partners and Investors
Pacific Ethanol	Oregon, USA	wheat straw, corn stover, poplar residues	ethanol, biogas, lignin	BioGasol, LLC, US Department of Energy's (DOE) Joint Bioenergy Institute (Lawrence Berkeley National Laboratory and Sandia National Laboratories)
PetroAlgae	Florida, USA	algae	biocrude	Asesorias e Inversiones Quilicura (Chile), EcoFrontier (Korea), Foster Wheeler (USA)
Petrosun	Arizona, USA	algae	oil, ethanol	
POET	South Dakota, USA	corn cobs	cellulosic ethanol	Novozymes
Procethol 2G Consortium	Marne, France	various biomass sources	cellulosic ethanol	Consortium members: Agro industrie Recherches et Développements (ARD), Confédération Générale des Betteraviers (CGB), Champagne Céréales, Crédit Agricole du Nord-Est, Institut Français du Pétrole (IFP), Institut National de la Recherche Agronomique (INRA), Lesaffre, Office National des Forêts (ONF), Tereos, Total and Unigrains
Qteros, Inc.	Massachusetts, USA	municipal waste,	cellulosic ethanol	Camros Capital, LLC, BP, Soros Fund, Long River Ventures, Valero Energy Corporation, Venrock Associates, Battery Ventures
Queensland University of Technology	Brisbane, Australia	sugarcane bagasse	cellulosic ethanol	Mackay Sugar Ltd., Sugar Research Ltd., Viridian pty Ltd., Hexion
Range Fuels	Colorado and Georgia, USA	Georgia pine, hardwoods and Colorado beetle kill pine	cellulosic ethanol, methanol	Khosla Ventures, US Departments of Energy and Agriculture, Passport Capital, BlueMountain, Leaf Clean Energy Company, Morgan Stanley, PCG Clean Energy & Technology Fund, Georgia
Sapphire Energy	Arizona, USA	algae	biocrude	ARCH, Wellcome Trust, Cascade Investment (Bill Gates), Venrock Associates

Company	Location	Feedstock(s) / Envisioned Feedstock(s)	Product(s) / Future Products	Partners and Investors
SEKAB Industrial Development AB	Örnsköldsvik, Sweden	wood chips and sugarcane bagasse	cellulosic ethanol	
SGC Energia	Portugal, Austria and New Mexico, USA	algae		Global Green Solutions, Oxford Catalysts Group PLC
Syngenta Centre for Sugarcane Biofuels Development	Brisbane, Australia	sugarcane bagasse	cellulosic ethanol	Queensland University of Technology (QUT), Farmacule Bioindustries, the Queensland Government, Federal Government and Syngenta
Synthetic Genomics, Inc.	California and Maryland, USA	algae, sugar	biocrude, biogasoline, jet fuel	ExxonMobil, BP, Genting Group, Life Technologies, Novartis, Draper Fisher Juvetson, Meteor Group, Biotechonomy, Plenus, Asiatic Centre for Genome Technology
Solazyme	California, USA	algae	biodisel, biogasoline, jet fuel	Chevron, Unilever, US Navy, Bunge, Virgin Group, San El Gen, Harris & Harris Group, Braemar Energy Ventures, Lightspeed Venture Partners, VantagePoint Venture Partners, Roda Group
Solix Biofuels	Colorado, USA	algae	biocrude	Los Alamos National Laboratory, Valero Energy Corp., Hazen Research
Southern Research Institute	North Carolina, USA	North Carolina pine	oils, lignin, fermentable sugars	HCL CleanTech (Israel)
SunDrop Fuels	Colorado, USA	rice straw, wheat straw, miscanthus, sorghum, switchgrass, wood	gasoline, diesel, aviation fuels	Kleiner Perkins Caufield & Byers and Oak Investment Partners

Company	Location	Feedstock(s) / Envisioned Feedstock(s)	Product(s) / Future Products	Partners and Investors
SynGest, Inc.	Iowa, USA	corn stover	bio-ammonia	Iowa Power Fund and Iowa Office of Energy Independence
Technical University of Denmark (DTU)	Copenhagen, Denmark	wheat straw, corn fibre	ethanol, biogas, lignin	BioSystems, Cambi A/S, Novozymes
Tembec Chemical Group	Quebec, Canada	spent sulphite liquor feedstock (pulp mill by-product)	cellulosic ethanol	
Terrabon, Inc.	Texas, USA	municipal solid waste, sewage sludge, manure, agricultural residues	ethanol, mixed alcohols, various chemicals	Texas A&M University, Valero Energy Corp.
TetraVitae Bioscience	Illinois, USA	cellulosic feedstocks	biobutanol	
TMO Renewables, Ltd.	Surrey, UK	initially corn, then diverse cellulosic feedstocks	cellulosic ethanol	Fiberight, LLC
TransAlgae, Ltd.	Texas, USA and Ashdod, Israel	algae	fish meal, oil	Raanan, Endicott Biofuels, Israeli Electric Company
United States Envirofuels, LLC	Florida, USA	sweet sorghum, sugarcane	cellulosic ethanol	
Verenium Corporation	Massachusetts, USA	(in July 2010, BP bought Verenium's cellulosic biofuel business, but Verenium continues to sell enzymes to biofuel producers)	enzymes	BASF, Bunge, Cargill, Danisco
Verdezyne, Inc.	California, USA	switchgrass, hemp, corn stover, wood	cellulosic ethanol	Novozymes, Genencor, Syngenta, Lallemand Ethanol Technology, OVP Venture Partners, Monitor Ventures, Tech Coast Angels and Life Science Angels

Company	Location	Feedstock(s) / Envisioned Feedstock(s)	Product(s) / Future Products	Partners and Investors
Vienna University of Technology	Güssing, Austria	syngas from gasifier	Fischer-Tropsch fuels	Repotec GmbH, Biomasse Kraftwerk Güssing
Virent Energy Systems	Wisconsin, USA	sugars and starches	gasoline, jet fuel, diesel	Shell, Cargill
Weyland AS	Blomsterdalen, Norway	coniferous wood, sawdust, rice straw, corn cobs and bagasse	cellulosic ethanol	The Norwegian Research Council, Fana Stein & Gjenvinning AS, Sarsia Seed, Bergen University College
Xethanol Corporation	Florida, USA	citrus peels	cellulosic ethanol	Renewable Spirits, LLC
ZeaChem Inc.	Oregon, Colorado, USA	trees, sugarcane	cellulosic ethanol, various chemicals	GreenWood Resources, US Department of Energy, Stark Venture Investors, Cargill, Honda, Advantage Capital

Endnotes

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ETC Group

Action Group on Erosion, Technology & Concentration

ETC Group is an international civil society organization. We address the global socioeconomic and ecological issues surrounding new technologies with special concern for their impact on indigenous peoples, rural communities and biodiversity. We investigate ecological erosion (including the erosion of cultures and human rights), the development of new technologies and we monitor global governance issues including corporate concentration and trade in technologies.
We operate at the global political level and have consultative status with several UN agencies and treaties.
We work closely with other civil society organizations and social movements, especially in Africa, Asia and Latin America. We have offices in Canada, USA, Mexico and Philippines.

Other ETC Group publications on synthetic biology are available online:
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BANG!

In 2008, ETC Group and its partners convened an international meeting of civil society activists in Montpellier France under the title, BANG – signifying the convergence of technologies at the nano-scale – specifically, Bits, Atoms, Neurons and Genes. At the meeting, ETC Group agreed to prepare a series of background documents on major new technologies, which could assist our partners and governments in the global South in understanding these developments and responding to them. This report is one of the studies.

The full set is:

Communiqué # 103 – Geopiracy : The Case Against Geoengineering

Communiqué # 104 – The New Biomassters: Synthetic Biology and the Next Assault on Biodiversity and Livelihoods.

Communiqué # 105 – The Big Downturn? Nanogeopolitics 2010

ETC Group has also completed a book, BANG, describing the impact of technological convergence over the next 25 years. While the book is not science fiction, it uses fiction to describe four different scenarios for the next quarter-century. "BANG" has been published in German by Oekom with the title "Next BANG".

ETC Group aims to publish all these reports in English, French and Spanish.

The New Biomassters

Synthetic Biology and the Next Assault on Biodiversity and Livelihoods

Global energy, forestry, agribusiness, chemical, nanotech and biotech companies are collaborating to construct a 'New Bioeconomy' using techniques such as Synthetic Biology to transform living 'biomass' into fuels, chemicals and power. However what is sold as a 'green' switch from fossil fuels to plant-based production is in fact a red-hot resource grab on the lands, livelihoods, knowledge and resources of peoples in the global South.

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