TECHNOLOGY AND SUSTAINABILITY

Global Agrofuel Crops as Contested Sustainability
Part II: Eco-Efficient Techno-fixes?*

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Introduction

Biofuel crops have been widely attacked as unsustainable, especially for causing numerous harmful effects in the global South. These include competition for land use, land-grabbing, higher food prices, greater agrichemical usage, shifts to agro-industrial monocultures, loss of rural livelihoods, peasants' expulsion from land, and deforestation. Such harm arises from an agro-industrial system whose product is more appropriately called "agrofuel" because of the intensive, industrial way it is produced—"generally as monocultures, often covering thousands of hectares, most often in the global South" (Econexus et al. 2007, 6).

This agro-industrial system feeds expanding global markets, while always seeking or creating new opportunities. According to an expert report on biofuel production:

> [E]ven as cropland declined in Europe in recent years, changing technology and economics led cropland to expand into forest and grassland in Latin America. Higher prices triggered by biofuels will accelerate forest and grassland conversion there even if surplus croplands exist elsewhere. Most problematically, even with large increases in yields, cropland must probably consume hundreds of millions more hectares of grassland and forest to feed a rising world population and meat consumption, and biofuels will only add to the demand for land (Searchinger et al. 2008, 3).

Partly in response to such criticisms, biofuel promoters have advocated technoscientific research for more efficiently converting non-food renewable resources into biofuels. This technological innovation is meant to overcome sustainability problems of current biofuels. "After all, it's difficult to oppose a technology that's helping to save the planet," the journal *Nature Biotechnology* editorialized (2006, 725). Anticipating techno-fixes for sustainability, this beneficent expectation appeals to popular wishes for a painless, harmonious way to overcome society's dependence on oil. At the same time, promoters advocate state targets and financial incentives for currently available biofuels as a necessary stimulus for future solutions. Through a techno-fix lens, current harm is seen as incidental or contingent and so eventually avoidable or at least manageable.

This article will discuss the following questions:

- What causes the current harm from biofuels: inefficient production methods or political-economic drivers?
- What are meant to be solutions from future novel biofuels?
- How do their drivers and designs relate to the current causes of sustainability problems?
- How do beneficent expectations help to promote a specific agro-development pathway?

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Beneficent expectations for more efficient and therefore sustainable biofuels depend on doubtful assumptions—in particular, that inefficiency explains or drives the sustainability problems of current biofuels. On the contrary, in/efficiency always acquires its meaning from specific political-economic aims and so cannot explain difficulties or changes in resource usage. The term generally obscures various contexts and meanings: efficiency of what? for what purpose? For example, traditional multi-cropping often has greater efficiency for producing useful diverse organic matter and nutritional content, relative to agro-industrial systems for producing standard commodities. The latter systems may have more efficient input-output ratios for their specific purpose, but this depends on uniform inputs and imposes great environmental burdens. Greater efficiency has been a long-standing incentive and pretext to extend agro-industrial systems that enclose commons of many kinds.

As this article will argue: In the name of "sustainable biofuels," efforts towards future novel biofuels serve a common aim: to sustain the liquid fuel supply for an expanding transport sector, while gaining a commercial advantage through more flexible supply chains, whose profitability depends on more enclosures of human and natural resources. Agrofuel innovation trajectories have the same drivers as the current biofuel production causing sustainability problems and land-use competition.

Techno-fixes: Critical Perspectives

For analyzing biofuels innovation as a societal future, three critical concepts will be developed here: the biofuels market as a global integrated network, capital accumulation by dispossession, and techno-fixes as a performative device. A techno-fix can play a self-fulfilling role; it performs, facilitates, and naturalizes a specific development pathway, while pre-empting alternatives, regardless of whether or not its original expectations are fulfilled.

Biofuels can be understood as a global integrated network linking current markets with potential future ones. Industrial strategies integrate states and natural resources in networks of commodity flows. This integration enhances opportunities to identify, appropriate, and exploit resources as capital, i.e., as self-expanding value (Mol 2007). As a basis for capital accumulation, economic elites gain greater control over human and natural resources, thus dispossessing communities. Moreover, states have a weaker capacity or incentive to protect general livelihoods and environments (see Part I of this article, Levidow and Paul 2010).

Eco-efficient technological solutions often have been expected to avoid future harm by reducing pressure on natural resources. Low productivity is often blamed for food shortages, environmental destruction, and deforestation, as if these were essentially technical problems resulting from non-intensive land use practices. Yet the causal relation is often the reverse: technological development has facilitated efforts to intensify land use, sometimes to the point of large-scale deforestation (Hecht 2007, 67; also Angleson and Kaimowitz 2001).

The deforestation example illustrates an apparent paradox that has a long history. With each technological advance towards greater efficiency, optimistic expectations have conflated two different effects: as more efficient technology reduces resource usage per unit output, this improvement will lower overall resource usage. The latter prediction assumes that production serves a finite output, yet this has been repeatedly contradicted by economic growth.

For example, after James Watt's steam engine improved the efficiency of earlier designs, England's coal consumption greatly increased, especially as the steam engine provided cheaper energy to a wider range of industries. From that outcome, William Stanley Jevons put forward a general proposition that greater technological efficiency in using a resource tends to increase its usage:

> It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth… Nor is it difficult to see how this paradox arises… If the quantity of coal used in a blast furnace, for instance, be diminished in comparison with the yield, the profits of the trade will increase, new capital will be attracted, the price of pig-iron will fall, but the demand for it increase; and eventually the greater number of furnaces will more than make up for the diminished consumption of each (Jevons 1866, 140-141).

That outcome led Jevons to foresee future scarcities—a warning which was greeted by widespread ridicule (Perelman 2009). Nevertheless the Jevons paradox about greater resource usage has been repeatedly vindicated. The outcome seems paradoxical only if production is understood mainly as fulfilling human needs, or at least a finite demand. Rather, greater resource usage is a predictable consequence of financial incentives to supply expanding markets (Polimeni et al. 2009). Likewise economists have studied the rebound effect, whereby more efficient or higher-quality energy has often stimulated greater usage—sometimes even exceeding the efficiency gains, thus backfiring on the original aims or claims for resource conservation (Sorrell 2009).

A more fundamental feature is the private colonization of resources facilitating their greater usage. Technoscientific innovations have been celebrated for greater efficiency, yet this depends on plunder of human and natural resources, especially in the agricultural sector. Through such innovations, multinational corporations have a long history of colonizing "a multitude of new spaces that could not previously be colonized either because the technology or the legal rights were not available" (Paul and Steinbrecher 2003, 228-29). Land access can be obtained by formally withdrawing traditional land rights and/or bypassing them through violence.

More generally, capital accumulation has depended upon "the endless commodification of human and extra-human nature" (Moore 2010, 391). Further to Jevons' example of the steam engine, its success "was unthinkable without the vertical frontiers of coal mining and the horizontal frontiers of colonial and white-settler expansion in the long nineteenth century" (Moore 2010, 393). Cheap or nearly free raw materials have been supplied by cheap labor, which remains the ultimate source of surplus value. Capital-intensive technological innovation increases the organic composition of capital, i.e., the ratio of dead labor to living labor. This reduces the proportion of living labor, thus tendentially limiting surplus value. To overcome this limit, surplus value has generally expanded by appropriating more human and natural resources: "hence the centrality of the commodity frontier in modern world history, enabling the rapid mobilization, at low cost (and maximal coercion), of epoch-making ecological surpluses" (Moore 2010, 393).

Industrialization is popularly associated with technological innovation, as if this were the crucial driver.

> And yet every epoch-making innovation has also marked an audacious revolution in the organization of global space, and not merely in the technics of production….
>
> At the level of appearances, we are treated, then, to something of an optical illusion: a new stream of capital inputs leads one to think the Green Revolution in terms of capital-intensity. But insofar as this "revolutionary" project appropriated, *at little or no cost to capital*, quality land, access to water, and labor power, the value composition of yields was in fact very low, and therefore highly profitable. The revolutionary achievements were made through plunder as much as through productivity. This dialectic of productivity and plunder works so long as there are spaces that new technical regimes can plunder—cheap energy, fertile soil, rich mineral veins (Moore 2010, 405).

Thus a new "organization of global space" becomes essential for realizing the profitability of technological innovation.

From that perspective, more efficient technoscientific innovation depends upon and stimulates plunder. This remains an essential feature of capital accumulation by dispossession (Harvey 2003, 145). Conversely, greater resource usage is driven by greater efficiency, e.g., in extracting and processing raw materials. These causal relations operate in both directions: opportunities and imperatives for plunder can drive technoscientific innovation.

Wherever production serves the accumulation of capital, markets expand in search of maximum profits, while subordinating or redefining human needs accordingly. Efficiency always presupposes and reinforces particular forms of human activity. For example, public transport has greater efficiency and prospects for reducing greenhouse gas (GHG) emissions than private motor vehicles. But private transport better serves capital accumulation, e.g., through the broader automobile-industrialization complex (Foster 2000, 8). Indeed, technological innovation can reinforce and stimulate such accounts of human needs, while naturalizing them as a response to consumer demand.

In the neoliberal era, the extension of markets has been linked with the technological fix, which "relies on the coercive powers of competition." This "becomes so deeply embedded in entrepreneurial common sense, however, that it becomes a fetish belief that there is a technological fix for each and every problem," observes David Harvey (2005, 68). As a promissory device, a techno-fix performs, facilitates, and naturalizes a specific development pathway, while eluding accountability for its beneficent promises. Current efforts towards eco-efficient technology for future biofuels can be critically analyzed as a techno-fix in that performative sense.

Anticipating Eco-efficient Biofuels in a Bio-economy

Given the global conflict between biofuel markets versus environmental sustainability, solutions are being sought through technological innovation. Novel prospective biofuels are variously described as second-generation, next-generation, advanced, etc. Novel biofuels have been a prime symbol of the bio-based economy, which aims to substitute renewable raw materials for fossil fuels. Novel biofuels would use non-food parts of plants or non-food plants such as grasses or even algae. In the name of eco-efficiency, such innovations are being expected to use marginal land for growing non-food crops and to turn bio-waste into energy as a means to enhance sustainability. These solutions are meant to use resources that are now under-utilized or undervalued—e.g., post-harvest residues in agricultural fields and forests—using the rationale of putting the waste to productive use.

Towards such technological solutions, research seeks more efficient conversion pathways from novel biomaterials to cellulosic bioethanol and other industrial products. In 2007 the Organisation for Economic Co-operation and Development (OECD) published a report anticipating future success. Its scenario looks back from the year 2030:

> The early concerns in 2005 to 2015 regarding the limited availability of biomass and societal tension over crops for food versus fuel diminished as [the] biotech and seed development industry invested in new technologies that made available high-yield food crops adapted to grow in the changing climate, and dedicated energy crops much like Jatropha, Miscanthus, and Switchgrasses that were not suitable for eating yet grew on marginal lands. The introduction of more effective processing technologies and refineries that required less energy and provided maximum product increased the efficiency of "whole usage" crops and decreased the volume grown in the field (Murphy et al. 2007, 7).

In this bio-economy perspective, bio-energy will be linked with other industrial products through novel biorefineries. Continuing its future vision from 2030:

> In conjunction with the development of crops to produce non-food products was the development of processing plants to extract the desired products. Biorefineries developed, at first in the United States and followed by European Union countries, allowed for the efficient "total use" of crop inputs. Similar to petro-chemical refineries, these sophisticated processing plants had the flexibility of switching which products were extracted in response to market cues (e.g., price of energy)….
>
> For example, automotive MNCs bought up smaller biotechnology firms, fuel giants diversified and invested in agronomy and botany, and chemical monoliths purchased biotech and seed development firms creating new value chains and corners of industry (Murphy et al. 2007, 10).

In this biorefinery scenario, inputs and outputs can be flexibly adjusted according to market advantage, thus throwing suppliers into greater competition with each other. New investment is sought for the "integrated diversified biorefinery," which has multiple meanings—an agro-industrial model of renewable raw materials, an infrastructure for processing them into diverse products, vertical integration of resource flows within a single site, and horizontal integration of agriculture with the oil and transport industry. In this vision, various industries will undergo horizontal integration and concentration, thus optimizing the market value of resources.

Again speaking in retrospect from the year 2030, the OECD bio-economy report also foresees a political obstacle: "The development of rapidly growing GM trees with deep roots had been patented back in 2010, but had received limited use because of early public discomfort over [the] potential spread of the trees into natural stands" (Murphy et al. 2007, 17). In the 2030 future vision, proponents gain public support for genetically modified trees as a means to solve problems of land degradation—at the same time, helping to realize commercial gain on biotech patents.

Indeed, proprietary knowledge has become a major incentive for various industrial interests. They formulate biofuels research and development (R&D) agendas, lobby for public funds, and form international networks across industries as well as countries. Prospects for patents influence innovation pathways for biofuels and their sustainability potential. According to a 2008 report by the Institute for Agriculture and Trade Policy:

> Individual patents, joint ventures formed by patent portfolios and "strategic use" (anticompetitive use) of patents both guide biofuels investment and lock in at least royalties and licensing fees for the patent holder, if not necessarily profits for the biomass or biofuels producers. Hence, understanding patent policy, as well as individual patents on biomass for biofuels production, is crucial for strategizing how the biofuels technologies might aid or hinder sustainable development (Suppan 2008, 6).

Indeed, a drive for proprietary knowledge shapes research priorities. According to discussions in a trans-Atlantic research network:

> A significant challenge and opportunity that impacts scientists across the industrial and academic sectors with relevance to both fundamental research and scientific collaboration is Intellectual Property (IP). While not specifically a scientific challenge, it certainly is driven by and has a strong influence on science (E.C.-U.S. Task Force 2009, 17).

R&D priorities target patentable knowledge as embedded in biological artefacts, mainly GM plants and/or enzymes, as a means to realize the earlier commercial promises of biotechnology. Patents have been obtained or are expected for components at several stages—e.g., GM maize with higher starch content, GM crops or microbes producing microbial cellulase enzymes, non-food crops, etc. (Carolan 2009, 104). In those ways, a techno-fix for sustainability is linked with future value chains for proprietary knowledge. Such scenarios inform policies for expanding current conventional biofuels, along with R&D investment in novel biofuels, which could eventually supplement or replace conventional ones.

U.S. policies

In the name of energy independence, the U.S. government has been promoting corn bioethanol, whose domestic production has generated surpluses, which are then exported. This market expansion has been created by various policies—renewable fuel standards, tax credits, loans, ethanol-import tariffs, etc. Together these policies subsidize a bioethanol development which otherwise would be unprofitable, thus stimulating investment in infrastructure and commodity chains. Enormous land tracts and other resources are used to replace a small amount of fossil oil.

This policy is widely seen as unsustainable. Long-standing criticisms were acknowledged by a 2010 Congressional Budget Office report, which noted that corn bioethanol is a very costly way to reduce GHG emissions. Tax credits reduce the private costs of using fossil fuel to produce biofuels, whose environmental sustainability is thereby undermined. "Because the production of ethanol draws so much energy from coal and natural gas, it can be thought of as a method for converting natural gas or coal to a liquid fuel that can be used for transportation." However, the report suggests that future cellulosic fuels would provide a more cost-effective method (Congressional Budget Office 2010, 7). And GHG emissions could be assigned to the edible parts of the crop, rather than to the cellulosic components used for biofuels.

Alongside promoting current corn bioethanol, therefore, the U.S. government has also funded R&D for novel biofuels. From its mandate in the 2005 Energy Policy Act, the Department of Energy has funded several components and pathways, especially for cellulosic bioethanol, given the abundance of waste cellulose from agriculture. Research topics include genomics research that will improve biomass characteristics, biomass yield, or sustainability as well as novel microbial systems that can increase bioconversion efficiency and thus lower biofuel cost (U.S. Department of Energy n.d.). Such R&D gained a further boost from the Energy Independence and Security Act of 2007, which requires that 16 billion gallons of U.S. transportation fuel be cellulosic biofuel by 2022. This requirement was expected to stimulate cellulosic biofuel patents, especially for biodiesel (Kamis and Joshi 2008). To promote such innovation, in 2009 the U.S. government announced $800 million of economic stimulus funding for research into second-generation biofuels made from non-food crops such as grasses and algae, as well as $1.1 billion in new financing for commercial development, for example, for biorefineries and related infrastructure.

However, biofuel expansion will encounter resource limits. U.S. experts warn that biofuel production puts extra pressures on natural resources, especially water. For conventional biofuels, 4 gallons of water are needed to produce 1 gallon of ethanol—far more than the water needed for petroleum. Moreover, "In the longer term, the likely expansion of cellulosic biofuel production has the potential to further increase the demand for water resources in many parts of the United States," though this is difficult to predict, according to a report by the U.S. National Academy of Sciences (2007, 46, 19).

Likewise, according to another expert study, bioethanol production needs enormous quantities of water. To displace just one-quarter of U.S. gasoline usage:

> Even cellulosic ethanol would require 146 gallons of water per gallon and 35 percent of the [U.S.] cropland. "Our appetite for transportation fuels is too gargantuan," said Jerald L. Schnoor, lead author on the National Academy of Sciences report. "We can't grow our way out of it" (Geis 2010, 15-16).

Despite those environmental limits, the Union of Concerned Scientists (UCS) advocates R&D investment and tax incentives for developing cellulosic biofuels. Its report highlights the sustainability benefits:

> Diverse and sustainable sources of biomass including prairie grasses from the Great Plains, wood waste from our forests, and nonrecyclable garbage from our cities can generate clean biofuels and provide new economic prospects….
>
> These grasses can grow with much lower inputs of pesticides and fertilizer than most food crops, thus reducing water pollution and global warming emissions; and they can grow under conditions not suitable for food crops, thereby avoiding the displacement of food production (Martin 2010, 41).

At the same time, the UCS warns that novel biofuels could extend the current harm from conventional biofuels, especially by depleting water and soil:

> As cellulosic biofuels production grows to a scale of billions of gallons a year, demand for feedstocks like energy crops will start to compete with food and feed production for scarce agricultural resources (i.e., fertile land, water, and nutrients) (Martin 2010, 7).

Thus beneficent expectations depend on optimistic assumptions about measures to manage natural resources, especially water.

Cellulosic biofuel production poses more environmental problems beyond water usage. When former President George W. Bush highlighted the United States' "oil addiction" in his 2006 State of the Union speech, he also mentioned switchgrass as a solution beyond corn bioethanol. This prospect stimulated warnings from NGOs and scientists: switchgrass normally helps to sequester carbon, preserve soil fertility, and conserve wildlife on set-aside land, so these benefits would be undermined or lost by large-scale harvesting for biofuels. As another biomass source being targeted for fuel, crop residues are otherwise tilled back into the soil after harvest as a necessary means to maintain soil health as well as to avoid soil erosion in "no till" cultivation; so their usage for biofuels would likewise undermine such benefits (Tokar 2010). These examples indicate resource limits that contradict any techno-fix for sustainable agrofuels.

E.U. Policies

Like the U.S.A., the European Union gives a prominent role to novel biofuels. At the 2000 Lisbon summit of the E.U. Council, representing the member states, Ministers committed the E.U. to become "the most competitive and dynamic, knowledge-based economy in the world, capable of sustainable growth with more and better jobs" within a decade (European Council 2000). Extending that perspective, E.U. policy seeks to develop and maintain a competitive advantage for biofuel innovation in global markets.

Second-generation biofuels are expected to "boost innovation and maintain Europe's competitive position in the renewable energy sector," according to the Commission of the European Communities (2007). In its view:

> By actively embracing the global trend towards biofuels and by ensuring their sustainable production, the E.U. can exploit and export its experience and knowledge, while engaging in research to ensure that we remain in the vanguard of technical developments. (Commission of the European Communities 2006a, 6)
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> In parallel, long-term market-based policy mechanisms could help achieve economies of scale and stimulate investment in "second generation" technologies which could be more cost effective (Commission of the European Communities 2006b, 27).

As another rationale for biofuels, Europe is expected to increase its use of transport fuel. If dependent on fossil fuel, transport becomes less secure:

> The sector is forecast to grow more rapidly than any other up to 2020 and beyond. And the sector is crucial to the functioning of the whole economy. The importance and the vulnerability of the transport sector require that action is taken rapidly to reduce its malign contribution to sustainability and the insecurity of Europe's energy supply (Directorate General for Energy 2009, 1).

That account naturalizes the increase in E.U.-wide transport as an objective force that must be accommodated: "there is a particular need for greenhouse gas savings in transport because its annual emissions are expected to grow by 77 million tonnes between 2005 and 2020—three times as much as any other sector." Consequently, the European Commission argues, "the only practical means" to gain energy security is biofuels, along with efficiency measures in transport (Commission of the European Communities 2007, 2, 7).

More recently, biofuel innovation has been given an additional role—to address problems of agri-environmental sustainability. According to a research network funded by the European Commission:

> At a time when the expansion of first-generation biofuels derived from food crops is causing concern and in some sectors of the public active opposition related to questions of sustainability and competition with food, more emphasis has to be placed on second-generation biofuels (Coombs 2007, 17).

More flexible biomass sources and processing methods are expected to avoid the current harm from agrofuels. An industry consortium declares that further research will successfully develop "sustainable and competitive biofuels in the E.U." by "[i]ncreasing yield per hectare and developing efficient supply logistics both for dedicated crops and residues" (EBTP 2008, ii). Such optimistic expectations provide a rationale for E.U. biofuel targets as essential incentives for the investment that will bring next-generation biofuels, in turn solving problems created by the first generation.

Numerous politicians have promoted future novel biofuels as a solution. Recognizing the sustainability problems of conventional biofuels, a European Parliament rapporteur proposed strict criteria regarding negative side effects, especially adverse macro-effects that displace livelihoods and wider environmental resources. She also proposed a deadline for phasing out first-generation in favor of second-generation fuels (Corbey 2007). Within the European Commission's unit which assists developing countries, a similar remedy was foreseen: "The use of technology must improve production efficiency and social and environmental performance in all stages of the biofuel value chain" (EuropeAid 2009, 5).

Such optimistic expectations are shared by some critics of the E.U. targets for renewable energy for transport fuels. After the targets were criticized by the Scientific Committee of the European Environment Agency (2008), its executive director stated that in retrospect, the committee's "modelling framework assumed much faster progress on the introduction of second-generation technology and environmentally friendly crops than seems likely on the basis of current trends" (McGlade 2008, 54). This comment casts doubt on the speedy progress of novel biofuels, though not on their beneficent potential.

Amidst the debate over harmful effects of biofuels, a U.K. Parliamentary committee published a report criticizing biofuels and government targets, but it also supported "the development of more efficient biofuel technologies that might have a sustainable role in [the] future" (Environmental Audit Committee 2008, 2). The Gallagher Review of the Indirect Effects of Biofuels Production criticized current biofuels for their "negative indirect effects," but added: "[b]y avoiding direct competition with feedstock for food, feedstock for advanced technologies avoids direct food price increases" (Renewable Fuels Agency 2008, 47)—as if such technologies already existed.

Likewise, a public consultation exercise encouraged such expectations by equating input-output efficiency with sustainability:

> In the future we may be able to use algae, trees, the inedible "woody" parts of plants, and agricultural waste to produce biofuel. In addition, scientists are working to increase the yield of biofuel crops and improve the production process, in order to maximize the energy output of land and reduce net greenhouse gas emissions (Nuffield Council for Bioethics 2009).

In those ways, future expectations for greater efficiency are equated with environmental improvements, in turn justifying statutory targets that effectively promote conventional biofuels. A beneficent techno-fix is promised and expected, even by some critics of current conventional biofuels. This optimistic expectation reinforces a view of current harm as temporary or contingent—e.g., as negative impacts, negative indirect effects or negative side-effects—and therefore as avoidable by future improvements. This expectation is extended to the global South as a necessary source of biomass to expand E.U. consumption.

All the above aims and expectations converged in a political decision to formalize E.U.-wide targets for the year 2020. Under the 2009 Renewable Energy Directive, 20 percent of all energy must come from renewable sources (including biomass, bioliquids and biogas). Likewise, 10 percent of total transport fuel must come from renewable energy—meaning mainly liquid fuels in practice. Sustainability criteria define which biofuels qualify for the targets: greenhouse gas savings must rise from 35 percent to 50 percent in 2017 for existing production and to 60 percent for new installations in 2017 (EC, 2009). In practice, those criteria could be fulfilled only by Brazilian bioethanol or by second-generation biofuels, if they materialize in time.

To fulfil the E.U. targets for renewable transport fuel, however, member states on average expect 92 percent of the 10 percent target to come from conventional biofuels, according to their Renewable Energy Action Plans through 2020 (Bowyer 2010). So they will need much greater imports of conventional biofuels from the global South. Meanwhile techno-fix expectations for future improvements serve to justify the current targets that stimulate such imports.

Given the inherent demand for land and water, some NGOs maintain a cautious view about whether second-generation agrofuels can overcome the current sustainability problems. An Oxfam report asks skeptically:

> So will second-generation biofuels have fewer adverse impacts on poverty and the environment? Although yields are likely to be higher, many second-generation technologies may still pose similar problems because they will depend on large-scale monocultures that threaten biodiversity, food production, or land rights. Just because a second-generation biofuel does not use food as a feedstock, it does not necessarily mean that it does not threaten food security: it may still compete with food for land, water, and other agricultural inputs (Bailey 2008, 18).

Indeed, higher productivity could increase financial incentives to feed the growing demand for land and water. If current unsustainability problems arise from those market pressures, then more efficient production methods could aggravate the problems.

Diversifying Production from Agro-industrial Oil Wells

An agrofuels market provides an opportunity to expand industrial agriculture on a global scale, facilitated by technological innovation. Claims for sustainability emphasize an input-output efficiency in resource usage for producing various commodities for a global market. This coincides with an agro-industrial vision of the future bio-economy.

Funded by the European Commission, an international research network develops research agendas around the biorefinery concept. Since 2006 it has aimed to design new generations of bio-based products derived from plant raw materials that will reach the market place ten to fifteen years later (EPOBIO 2006). Its bio-economy vision changes the role of agriculture, which becomes analogous to oil wells:

> It was noted by DOE and E.U. that both the U.S. and E.U. have a common goal: Agriculture in the 21st century will become the oil wells of the future—providing fuels, chemicals and products for a global community (BioMat Net 2006).

As a primary means to extract and recompose valuable substances for a biorefinery, "Biotechnology has the potential greatly to improve the production efficiency and the composition of crops and make feedstocks that better fit industrial needs" (EPOBIO 2006, 8).

The "diversified biorefinery" takes biotechnology beyond first-generation GM crops to more novel ones. Since the 1980s genetic modification techniques have targeted four major crops—corn, soybeans, oilseed rape (canola) and cotton; the first three have been grown increasingly for animal feed. Now industry can use these crops to produce fuel, while also using the residue to produce animal feed and other industrial co-products. Even without GM crops as feedstock, biorefineries are being designed to diversify inputs and outputs, especially through novel enzymes and processing methods. According to a promotional account, future by-products will become inputs for more energy production:

> [T]he integrated diversified biorefinery—an integrated cluster of industries, using a variety of different technologies to produce chemicals, materials, biofuels and power from biomass raw materials agriculture—will be a key element in the future. And although the current renewable feedstocks are typically wood, starch and sugar, in future more complex by-products such as straw and even agricultural residues and households waste could be converted into a wide range of end products, including biofuels (EuropaBio 2007, 6).

Although rarely mentioned, novel traits for agrofuel crops may also be stacked alongside familiar genetically modified agronomic traits, such as GM herbicide tolerance and insect resistance. By allowing farmers to kill all other plants, herbicide tolerance facilitates low-till or no-till cultivation techniques, which can be operated by minimal staff using big machines for profitable economies of scale. Such chemical-intensive systems encourage the development of resistance in insect pests and weeds, already a widespread and growing problem. To avoid this problem, biotech companies develop and stack more resistance traits in their key crops—which can supply the food, feed, and/or fuel markets.

This innovation agenda links major agricultural industries—e.g., seed, fertilizer, pesticide, commodities and biotechnology—with the energy sector, including the oil, power, and automotive industries. The industry seeks a flexible horizontal integration, diversifying biomass sources and its potential uses (http://www.bio-economy.net). Their research agendas are promoted by various technology platforms, as invited and funded by the European Commission. In particular the European Biofuels Technology Platform advocates the following research aims (EBTP 2008, SRA-24):

- Maximization of yield and crop resistance to biotic and abiotic factors (pests, diseases, water scarcity, rising temperatures, etc.).
- Initiate innovative cropping systems to allow efficient, bulk material production for food, feed, fiber and fuel (4F agricultural systems).
- Exploitation of marginal land options.

The Biofuels Technology Platform develops strategies to optimize valuable products from novel inputs. It requests funds to "[d]evelop new trees and other plant species chosen as energy and/or fiber sources, including plantations connected to biorefineries." For advanced biofuels, a biorefinery needs: "Ability to process a wide range of sustainable feedstocks while ensuring energy and carbon efficient process and selectivity towards higher added value products," e.g., specialty chemicals from novel inputs (EBTP 2008, SRA-23).

Through the closed-loop concept, wastes must be continually turned into raw materials for the next stage: "It will be necessary to optimize closed-loop cycles and biorefinery concepts for the use of wastes and residues in order to develop advanced biomass conversion technology" (EBTP 2010, 7, 16). These novel value chains would depend on significant changes in inputs, processing methods, and outputs. A successful biorefinery eventually would depend on R&D&D—research and development and demonstration plants—with government subsidies.

More modest, recent research has focused on GM crops. These can be illustrated by two examples—linking feed with fuel and changing the structure of plant cells—each facilitating market flexibility in a diversified biorefinery.

Linking feed with fuel

Agrofuel systems can offer several industrial outputs. With some crops (e.g., canola and soy), the oil extraction leaves a cake (or meal) residue that is fed to animals as a co-product of fuel. Sugarcane processing leaves bagasse, which can be fermented and then produce energy to drive the processing factories. The corn crop in the U.S. illustrates such a pairing: the starch from the corn is used for ethanol, while the residue is used for animal feed. Corn syrup and other products are made from the stillage left over from ethanol production, so more could be available (Renewable Fuels Agency 2008).

Multiple co-products could give agro-industry the market flexibility and eco-efficient image that it seeks. An industry vision for the year 2030 foresees that:

> Integrated biorefineries co-producing chemicals, biofuels and other forms of energy will be in full operation. The biorefineries will be characterized, at manufacturing scale, by an efficient integration of various steps, from handling and processing of biomass, fermentation in bioreactors, chemical processing, and final recovery and purification of the product (Biofrac 2006, 16).

Cheaper animal feeds are welcomed as a co-product by a unit of the European Commission, interested to support farmers' incomes:

> The cattle production would benefit from the availability of dried distiller grain (DDG), the by-product of bioethanol production from cereals, at very competitive prices… Pork and poultry production would equally benefit from cheaper protein feeds partly from bioethanol but more importantly from the biodiesel production (Directorate General for Agriculture and Rural Development 2007, 6).

Wherever biomass can be used more efficiently, what would otherwise be considered waste material becomes a raw material for another process or product. For example, "The increased demand for biofuels may put huge amounts of waste protein on the market that cannot be absorbed by feed production, enabling the development of a protein-based bioplastics industry" (Plants for the Future Technology Platform 2007, 32). In this circular logic of efficient recycling, more waste is welcomed as an opportunity for its commercial use by another process.

Such an integrated industrial system appears to be an attractive way to supply growing markets, especially in the global South. By inducing consumer demand for meat and poultry, this system massively increases the market for animal feed. In addition to long-established markets in the developed economies, such markets are rapidly expanding elsewhere, especially in China and India. When experts predict a great rise in future markets for meat (FAO 2009, 1), this is cited as an imperative for technoscientific innovation and integrated production systems to increase efficiency. Market demand is naturalized as somehow external to production, which simply accommodates the demand and thereby serves the public good.

Agribusiness corporations—Monsanto, Syngenta, Cargill, and Archer Daniels Midland—have been cooperating to control the production, processing, and movement of feed commodities around the world. They now have the opportunity to exploit the same agricultural biomass for fuel as well as feed. Such feed-energy integration can stimulate the extension of agro-industrial monocultures across wider geographical areas. This system complements the economies of scale, standardized products, and the infrastructure that the same companies already control.

Research for GM agrofuel crops has sought to integrate the production of fuel with animal feed. With that aim, Monsanto (2006, 10) developed Mavera, a GM corn variety. Its novel composition offered two advantages: a high starch content to enhance ethanol production; and high lysine to provide an amino acid essential for protein and muscle production in mammals, thus enhancing the crop's value for animal feed.

Renessen, a joint venture between Cargill and Monsanto, began building installations to treat the residue of Mavera corn left over from ethanol production and turn it into animal feed (Kaskey 2006). One pilot plant milled only Mavera corn, so that farmers had to buy Mavera seed in order to sell their crop there (Shattuck 2008). This GM corn has been approved in several countries—Japan, South Korea, Canada, Australia and New Zealand—and for cultivation in the U.S. But its risk assessment was criticized by the E.U.'s biosafety experts, so the application was withdrawn, and the product was abandoned for commercial use anywhere (Bioscience Resource Project 2009; Organic Consumers 2009). A related innovation is Extrax™ technology to split corn into several products—starch for ethanol production, oil for biodiesel, and a nutrient-rich meal that can replace corn in animal feed (Fraley 2009).

These R&D priorities seek more efficient co-production of standard non-food commodities. Although that aim is technically feasible, other efforts remain more speculative, e.g., changing the plant structure.

Changing plant structure

For next-generation biofuels, researchers are trying to design plant varieties that break down more easily for more efficient conversion into biofuel. They are also trying to change the crop composition and/or the energy-extraction process so that industry can extract fuel from whole plants, not just their fruits or seeds. At the same time they promise that the seeds will remain available for food or fuel uses.

One such project, a European-Brazilian joint venture, seeks more efficient ways to process sugarcane waste into bioenergy as a more sustainable way to use renewable resources. But more efficient energy conversion creates extra commercial incentives: "This will make sugar cane monocultures for agrofuel more financially attractive," as critics point out (Corporate Europe Observatory 2009, 6).

Trees have also been targeted for agrofuel research (Petermann 2008). Compared to annual field crops, trees require lower maintenance and fewer inputs, thus promising a double advantage for industry. They also contain more carbohydrates—the raw material for agrofuels. Lignin is a complex polymer that binds with the more abundant cellulose; together they comprise some 85 percent of the cell walls of trees.

From that standpoint, lignin becomes an undesirable polymer because it limits the digestibility of cell wall material, as noted in a workshop report. To solve this commercial problem, GM techniques are being used in efforts to alter, remove, reduce, or break down the lignin, as well as to alter metabolic processes: This aims at "improving the efficiency and reducing the cost of a key generic process in biorefining" (EPOBIO 2006, 27, 21). However, if GM trees or plants have less lignin, they could become more vulnerable to disease and pests, especially if planted in monocultures.

Beyond easier breakdown of cell walls, research seeks to develop value-added lignin-based compounds for extracting valuable substances (Plants for the Future Technology Platform 2007). It envisages "a tailor-made platform to maximize cell wall utility in biorefineries." The tailor metaphor, implying customization especially for end users, is extended further: "This larger-scale research effort was considered essential to achieve the foundation for designing *in planta* strategies to engineer bespoke cell walls optimized for integrated biorefinery systems" (EPOBIO 2006, 21).

Implementing the "oil well" metaphor, biological characteristics are being redesigned for more efficient processing into more diverse, valuable products. Non-food biomass is described as waste, decomposable into energy and other high-value products, by analogy to crude oil being cracked into different products in a traditional refinery. Thus research agendas are guided by a vision of agriculture as a factory for global commodity markets.

If such technological advance is successful, it may provide greater incentives to remove organic material, especially from forests. As an NGO report warns, "to maintain the carbon storage, the accumulation of organic material in forests should increase. However, this is not compatible with the present bio-energy goals for forests and with the increased intensive harvesting of biomass in forests" (Global Forest Coalition 2010, 3). Such designs are linked with eco-efficiency expectations for an "integrated, diversified biorefinery." According to a critic, "this is the antithesis of the 'relocalize and scale down' production models that grassroots activists view as key" (Smolker 2013, 523). This antithesis highlights contending agendas for a wider bio-economy (Levidow 2011).

Conclusion: Techno-fix for What Problem?

Agrofuels generate sustainability problems that are widely characterized as negative side effects, as if they were contingent and remediable. According to proponents, a policy commitment to current biofuels is necessary in order to stimulate next-generation biofuels. Even some biofuels critics anticipate sustainability improvements from technological innovations. How do their drivers and designs relate to the current causes of sustainability problems?

In efforts towards next-generation biofuels, R&D seeks greater productive efficiency in converting renewable raw materials into substitutes for fossil fuels. Prospective innovations are being expected to avoid the sustainability problems of current biofuels. Such a techno-fix rests on many assumptions—e.g., regarding land use, its availability, benign markets, resource usage, waste, etc. These assumptions are contradicted by recent experience of similar problems, as summarized in Table 1 (and analyzed in Part I of this article). Most acute in the global South, environmental sustainability problems and land-use competition result from industrial monocultural systems that produce commodities for global markets. Even if non-food crops or components are chosen, agrofuel developments seek the most fertile, well-watered land rather than marginal land, a term that conceals land uses for local needs (Franco et al. 2010; Cotula et al. 2008).

Table 1:

Novel biofuels for sustainable production?
Optimistic assumptions versus experience

	Assumptions	**Experience**
GHG savings	GHG savings may be undermined by using edible crops (or edible components)—but can be optimized by using non-edible material.	GHG savings are already being undermined for reasons beyond the use of edible components for biofuels.
Land use	Competition for land use results from low productivity—and so could be avoided by higher-yield crops, a broader geographical range, more efficient energy-extraction, etc.	Land-use competition arises from agro-industrial monoculture systems feeding global markets. Greater efficiency increases financial incentives for a shift to such systems.
Markets & demand	Greater productivity and efficiency can alleviate competition between diverse uses of biomass—food, feed, fuel—assuming that markets respect food needs.	Biofuel crop expansion feeds global markets, whose greater demands readily consume any extra production or yield, especially given global links between feed and fuel markets.
Resource use efficiency	Integrated diversified biorefineries can use biomass inputs more efficiently by deriving many industrial products, e.g., animal feed co-products which substitute for production elsewhere.	More efficient resource use increases financial incentives to supply ever-expanding global markets with limitless demand for fuel and feed, thus displacing local needs for land use.
Marginal land	Non-food crops, or crops designed for stress tolerance (e.g., arid, saline, or degraded land), would extend the geographical range to marginal land. Cultivation there avoids conflict with food needs.	Agro-industrial biofuel production has already invaded marginal land that was previously used for cultivation, grazing or other local needs. Such land is deceptively called marginal, meaning that it had not added value to global markets.
Waste biomass	GM techniques can alter plants or microorganisms to more efficiently break down plant residues into biofuel, thus recycling waste biomass (which has no other use).	So-called waste biomass is essential for forest health and biodiversity (via rotting wood), soil fertility, moisture retention and nutrients. If removed in large quantities, then this biomass would have to be replaced by chemical fertilizers, whose usage causes direct and indirect harm.
Agronomy	GM agronomic traits (herbicide and insect tolerance) help to increase yield by better controlling weeds and pests, while minimizing agrochemical inputs.	Any higher yield from current GM crops depends upon agrochemical inputs—e.g., fertilizers, aerial herbicide sprays—thus polluting soil and water, while generating new pests.
Livelihoods	Through greater efficiency, novel biofuels will help to enhance rural employment, especially by enabling more exports from the global South.	Greater productivity strengthens financial incentives to grab more land, while also disciplining, exploiting, or removing labor within agro-industrial production methods.

Current R&D priorities complement the agro-industrial production model. R&D seeks to break down biomass into simpler, more homogeneous components that can be re-composed into diverse outputs. Crop research seeks genetic changes that can enhance compositional characteristics and facilitate bioenergy extraction. An integrated diversified biorefinery is being designed for more flexibly processing diverse biomass sources into various industrial products according to market prices at any time. Designs seek high added-value products, in addition to a standard fuel and co-products such as animal feed. In these ways, agriculture potentially becomes future oil wells.

This agenda links many aims—increasing crop yield, integrating energy with feed production, enhancing energy extraction, broadening the geographical range to marginal land, and processing bio-waste material. These resources are seen as lacking societal uses, equated with calculable value chains. Conversely, biofuel innovation defines more land as marginal—likewise more resources as waste—and thus available for agro-industrial systems.

In those ways, technoscientific innovation is largely driven by the same political-economic forces causing the current sustainability problems and land-use conflicts over agrofuels. Private interests increasingly converge in driving the horizontal integration of R&D as well as production systems. Sustainability is understood as an input-output efficiency for global value chains. Seen as an engineering task, greater efficiency has become an incentive and pretext to extend agro-industrial systems that enclose commons of many kinds.

Hypothetically, production systems could use technological innovation to minimize resource usage within finite limits. But governments have little incentive or capacity to impose such limits; instead, they generally help an emerging agro-energy-industrial complex to expand labor exploitation, global transport and commodity markets. Indeed, as a key rationale for biofuels, governments foresee even greater demand for transport fuel, which in turn results from neoliberal policies throwing people worldwide into greater competition with each other. In this political-economic context, novel biofuels sustain the expansion of global value chains, whose market value can be appropriated mainly at the upper, capital-intensive end of the chain.

If technically successful, novel biofuels would provide greater financial incentives for extending agro-industrial monocultures. Agrofuel production will use more natural resources, both renewable and non-renewable, thus extending the Jevons paradox. In the global North, environmental regulations may set limits on land degradation, but they will not be able to avoid greater pressure on water supplies.

Extending agro-industrial monocultures has more severe consequences in the global South. This would aggravate the political-economic pressures that have already dispossessed or subordinated local small-scale producers; it would also continue to take over water supplies and the most fertile land. Moreover, GM seeds and agrochemicals displace farmers' knowledge, thus undermining their control over their own local resources.

Such technoscientific developments receive public funds through R&D budgets that link public and private sectors. Moreover, agrofuel developments have become candidates for carbon credits under the Clean Development Mechanism of the Kyoto Protocol (Grupo de Reflexion Rural et al. 2009). This rewards and legitimizes further agro-industrial development, e.g., using oil palm effluent to provide energy to oil palm mills, or using pig slurry to generate biogas, while apparently avoiding waste through recycling. In this Green neo-Keynesianism, a green economy discourse legitimizes specific economic actors as benefactors of humanity (Houtart and Bawtree 2010, 168-69).

As these agendas illustrate, "responses to the energy crisis follow a typical capital accumulation script—that is, attempting to overcome barriers to profitability by extending the realm of value creation, even as this intensifies capitalism's contradictions" (McMichael 2009, 1). Each barrier becomes an extra challenge for technological innovation and re-organization of global space for resource extraction. R&D agendas target patentable knowledge as embedded in bio-artefacts such as novel crops, enzymes, and biomass processing techniques.

Within a bio-economy perspective, future novel biofuels will benignly increase the productivity of non-food renewable resources. Implicitly, this expects to avoid the Jevons Paradox or rebound effect, even to supersede labor productivity as a source of wealth (Birch et al., 2010). However, future novel biofuels cannot supersede the earlier pattern of capital-intensive innovations. Their eventual profitability still depends upon exploiting cheap labor and natural resources, while also extending commodity frontiers, as in previous agri-technological innovations (Moore 2010).

Regardless of whether or when more efficient innovations materialize, techno-fix expectations already play a significant political role. They justify the continued expansion of energy use, especially transport fuel, while avoiding responsibility for the harmful consequences. These expectations perform, facilitate, and extend an agro-industrial development pathway linking food production more closely with energy markets. Optimistic expectations reinforce several assumptions: that agro-industrial monocultures are essential for societal progress; that sustainability problems are contingent side-effects that can be avoided or solved by greater efficiency; and that a techno-fix can avoid the need for drastic reductions in energy use. These assumptions facilitate resource depletion and enclosures—in the name of future sustainable biofuels.

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