FOOD MANUFACTURED IN FACTORIES VS. FOOD GROWN ON FARMS

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5. DENIAL AND A FAILURE TO SEE THE WHOLE PICTURE

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1. MANUFACTURD FOOD PROCESSES – BIOLOGICAL AND CHEMICAL

1.1 OVERVIEW

There are apparently two main approaches to these manufactured foods: biological and chemical. The biological approach includes ‘precision fermentation’ and cell-based meat, and the chemical approach (including ‘power to food’) typically starts with the electrolysis of water to obtain hydrogen which is used to make tryglycerides or other edible compounds.

1.2 PRECISION FERMENTATION (PF)

Precision fermentation is NOT one of the traditional (and natural) types of fermentation such as lactic-acid fermentation for making yogurt and sauerkraut, ethanol fermentation for making alcoholic beverages and bread, and acetic-acid fermentation for making vinegar and kombucha. Instead of just letting nature do its work, precision fermentation can involve some major manipulations of genetic sequences to result in specifically engineered animal or plant molecules being produced by microbes.

‘Now that food technologists have genome sequencing and gene editing at their disposal they are exploring a realm of “precision fermentation” in which microbes can be chosen, or engineered, for very specific purposes.’
https://geneticliteracyproject.org/2021/10/13/precision-fermentation-how-humans-are-harnessing-microbe-based-biochemistry-to-make-food-more-delicious/
“Through PF, scientists can program microbes to make specific, customized molecules to do whatever we want, including making food and other consumer products taste, feel and perform better. Scientists do this using precision biology to study and catalogue the proteins and other molecules in plants and animals, as well as the genetic information that codes for them. They then use this data – which is stored in massive, searchable databases – to copy, edit and paste relevant genetic sequences, and even brand-new sequences designed from scratch, into microbes. The microbes then act as highly efficient factories that consume specific inputs and spit out desired outputs (whether they are the exact same molecules that are found in plants and animals, modified or entirely new ones).”
https://rethinkdisruption.com/precision-fermentation-what-exactly-is-it/
“PF is the process that allows us to program micro-organisms to produce almost any complex organic molecule. These include the production of proteins (including enzymes and hormones), fats (including oils), and vitamins to precise specifications, abundantly, and ultimately at marginal costs approaching the cost of sugar… The cost of PF is being driven ever lower by a steep decline in the cost of precision biology. As a result, the cost of producing a single molecule by PF has fallen from $1m/kg in 2000 to about $100/kg today [2019]. We expect the cost to fall below $10/kg by 2025.” [page 18]
“Feedstock. Our analysis uses sugar (glucose) as the main feedstock, with efficiency trending from 3kgs of feedstock per 1kg of protein produced (a conversion ratio of 3:1) toward a ratio of less than 2:1 by 2030. There is also scope for other carbohydrates to
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be used for feedstock.” [page 65]
“Rethinking Food and Agriculture 2020-2030”
https://www.rethinkx.com/food-and-agriculture

1.3 ELECTRICITY TO FOOD

“A Swedish group from the Research Institutes of Sweden (RISE) is developing an electrochemical process that produces edible fats and free fatty acids using CO2, water, and energy. The process, called “Power to Food,” does not use biological processes like the majority of single-cell protein developers but instead uses a catalytic chemical process known as Fischer-Tropsch synthesis to ultimately isolate ethylene, synthesize fatty acid alcohols from the ethylene, and oxidize said fatty acid alcohols to free fatty acids… The researchers have one granted patent, which describes the method of production. At this time, the group has yet to establish a pilot production facility, and it estimates the costs for the edible fats to be up to three times higher than that of rapeseed oil.”
CASE STUDY: SWEDISH RESEARCHERS IDENTIFY FAT AS THE NEWEST OPPORTUNITY FOR CO_2-DERIVED INGREDIENTS
by Lux Research
web.archive dot org/web/20211101163202/https://www.luxresearchinc.com/blog/case-study-swedish-researchers-identify-fat-as-the-newest-opportunity-for-co-derived-ingredients

1.4 INTRACTABLE TECHNICAL CHALLENGES

This article is highly recommended (thanks Ruben):
https://thecounter.org/lab-grown-cultivated-meat-cost-at-scale/
from the article:

“..the document showed how addressing a series of technical and economic barriers could lower the production price from over $10,000 per pound today to about $2.50 per pound over the next nine years—an astonishing 4,000-fold reduction.”

“…do these people have some secret sauce that I’ve never heard of?” Wood said. “And the reality is, no—they’re just doing fermentation. But what they’re saying is, ‘Oh, we’ll do it better than anyone else has ever, ever done”…

‘“David Humbird, the UC Berkeley-trained chemical engineer who spent over two years researching the report, found that the cell-culture process will be plagued by extreme, intractable technical challenges at food scale. In an extensive series of interviews with The Counter, he said it was “hard to find an angle that wasn’t a ludicrous dead end.”’

“Humbird likened the process of researching the report to encountering an impenetrable “Wall of No”—his term for the barriers in thermodynamics, cell metabolism, bioreactor design, ingredient costs, facility construction, and other factors that will need to be overcome before cultivated protein can be produced cheaply enough to displace traditional meat.”

"And it's a fractal no," he told me. "You see the big no, but every big no is made up of a hundred little nos."

https://thecounter.org/lab-grown-cultivated-meat-cost-at-scale/
That article is good journalism, in contrast with George Monbiot's "I watched scientists turning water into food" (with no examination of the process inputs including up to 75 kg of added chemicals/minerals required for each 100 kg of manufactured protein, as detailed further below).
https://www.monbiot.com/2020/01/10/saving-our-bacon/

2. FEEDSTOCKS AND ENERGY REQUIREMENTS (FIRST LOOK)

2.1 OVERVIEW

A summary of the feedstocks and energy requirements of factory food:

Precision fermentation costs in 2019 were about $100/kg, and costs were "expected" to fall below $10/kg by 2025. The primary feedstock is typically sugar, with around 3kg of feedstock per 1kg of protein produced, expected to fall below 2kg of feedstock by 2030. (I didn't find the energy costs of PF broken out from the total cost here.) PF can involve the manipulation of genetic sequences to result in specific animal or plant molecules being produced by microbes.

Power-to-Food uses electricity to obtain hydrogen from water, then uses the hydrogen to make ethylene, which is then used to synthesize fatty acid alcohols, which are then oxidized to free fatty acids, which can be esterified to produce triglycerides, which can be blended and processed into food products. The patent (link below) for the Swedish power-to-food process doesn't mention the amount of energy required per kg of triglycerides produced. Looking at just the electricity required for the initial step, electrolysis is typically only 75% efficient (25% loss of energy when going from electricity to hydrogen), and the generation of the electricity is typically only around 35% efficient (65% loss of energy when going from fuel to electricity), with additional losses for transmission and distribution of the electricity to the point of use. So already there can be a 75% (or higher) loss in energy content when going from fuel (for electrical generation) to the hydrogen (before the subsequent chemical processes to eventually obtain triglycerides).

Maths: $1-[(.75)x(.35)]=$ 74% loss of energy to obtain hydrogen from electricity generated from fuel (not including the transmission and distribution losses, nor the energy required to construct the power plant and obtain the fuel).

2.2 ELECTRICITY GENERATION INEFFICIENCIES

The electricity for making "food" (or powering electric cars) typically requires an energy input that's significantly higher than the kWh measured at the point of use. The generation efficiency is only around 35% (with 65% lost). Then there are transmission losses and distribution losses (which can amount to 5% or more). Not to mention the energy required to construct the power plant and obtain the fuel.

“However over the next 30 years, the losses associated with the conversion of primary energy (conventional fuels and renewables) into electricity are due to remain flat at around 2/3 of the input energy.”
https://www.future-energy-partners.com/post/energy-losses-in-power-generation

2.3 HYDROGEN PRODUCTION – THE INEFFICIENCY OF ELECTROLYSIS

“A kilogram of hydrogen holds 39.4 kWh of energy, but typically costs around 52.5 kWh of energy to create via current commercial electrolyzers.”
https://newatlas.com/energy/hysata-efficient-hydrogen-electrolysis/

2.4 PROCESS DETAILS FROM THE PATENT

“[054] A third aspect relates to a method for the production of edible organic substances, said method comprising the steps electrolysis of water to produce hydrogen and oxygen, capture or recovery of carbon dioxide, conversion of said carbon dioxide to carbon monoxide, subjecting said hydrogen and carbon monoxide to a Fischer-Tropsch synthesis to produce a mixture of olefins, optionally increasing the proportion of ethylene by coupling of methane to form ethylene, and/or converting, for example cracking higher olefins to form ethylene, isolating ethylene, synthesizing alpha-olefins or fatty acid alcohols from said ethylene, and oxidizing said alpha-olefins or fatty acid alcohols to free fatty acids…

Example 5. Food production
[0101] Substances produced via the described processes are administered directly, or as formulations/mixtures, to humans. Free fatty acids play an important role in the aroma and flavour of many dairy products, such as milk, butter and cheese. Synthetic free fatty acids can thus be used to produced non-dairy substitutes for such products…
[0102] Fats can be processed into stable emulsions by vigorously mixing fat, water and one or more emulsifiers, and optionally adding flavouring, food dyes, vitamins and other additives well-known to persons skilled in the art of food processing. Examples of products obtainable from the synthetic fats disclosed herein include but are not limited to non-dairy milk and cream substitutes, non-dairy cheese, spreads, and ice-cream. The synthetic fats can also be incorporated into cereal or legume-based products, such as snacks, ready meals, baked goods etc.
[0103] As the substances are identical to nutritional substances found in conventional food, they will contribute to the human metabolism. For humans, maintaining the body temperature is a main energy sink and the substances produced according to the concept, methods and processes disclosed herein can be used as a fundamental energy supply for this purpose and thereby complement a diversified diet. A unique feature of this concept is that the energy gained by the human body this way is indirectly produced by electricity…”

Patent: Concept for the production of food with reduced environmental impact
https://patents.google.com/patent/WO2020035528A1/en

2.5 ELECTRICITY TO FOOD — RECIPE

The “recipe” for a Power-to-Food example that uses hydrogen-oxidizing bacteria requires
0.14 kg of Sulfur
and
0.16 kg of Ammonia
per kg of biomass output that has 60% protein content.

https://link.springer.com/article/10.1007/s11367-020-01771-3/tables/1
Table 1 Energy and material flows of processes of the base situation per 1 kg of produced biomass
From: A life cycle environmental sustainability analysis of microbial protein production via power-to-food approaches
The “recipe” also requires 0.14 kg of mineral phosphate per 1 kg of biomass output having 60% protein content.

Rearranging some data from Table 1 to make it easier to grasp the implications:
Manufacturing 100 kg of Power-to-Food protein requires approximately 74 kg of chemicals/minerals, plus 30 kg of CO2, plus 2,940 kWh of energy.
(This accounts for the 60% protein content of the biomass output, but doesn’t include energy losses during the generation of the required electricity)
Required chemicals/minerals:
Phosphate – 23.3 kg
Sulfur – 23.3 kg
Ammonia – 26.7 kg
Other chemicals – 0.6 kg
Total chemicals/minerals – 73.9 kg per 100 kg of protein

2.6 COMPARISON TO SOYBEANS

How does this compare to soybeans produced on a farm? A soybean crop producing 100 kg of soybeans requires 28 kg of chemical/mineral uptake, and those soybeans contain 40% protein and 19% oil.

Thus, 100 kg of protein from soybeans requires 28/.4 = 70 kg of chemical/mineral uptake.
However, in addition to that 100 kg of protein, there is 47 kg of oil that’s produced with no additional chemical/mineral uptake.

Note that this is uptake, not application. The largest component this uptake is nitrogen, and “a significant part of the N uptake can be derived from BNF [Biological Nitrogen Fixation].”

"Soybean is a very energy-rich grain legume containing 40 percent protein and 19 percent oil in the seeds….

Nutrient requirements

Total nutrient uptake by the plants per tonne of grain production can be taken as follows (IFA, 1992):

– macronutrients (kg): N 146, P_2O_5 25, K_2O 53, MgO 22, CaO 28 and S 5;

– micronutrients (g): Fe 476, Zn 104, Mn 123, Cu 41, B 55 and Mo 13.

Under conditions favourable for N fixation, a significant part of the N uptake can be derived from BNF [Biological Nitrogen Fixation]."

Plant Nutrition for Food Security, FAO, 2006

Chapter 8, Nutrient management guidelines for some major field crops

(page 246)

https://www.fao.org/3/a0443e/a0443e04.pdf

2.7 UP TO 90 KWH REQUIRED PER KG OF PROTEIN?

As detailed in the study linked below, another type of Power-to-Food process creates protein by supplying the hydrogen to H_2-oxidizing bacteria. This process also uses Ammonia (from Haber-Bosch), Phosphorus (from mineral phosphate), Sulfur (from oil refinery), and CO_2 (from direct air capture).

Adding up the reported energy inputs (in kWh per kg of biomass produced):

Direct air capture – 4.48 kWh

Bioreactor – 9.86 kWh

Post process – 3.30 kWh

Total energy input (per kg of biomass produced) = 17.64 kWh

Total energy input (per kg of protein produced) = 17.64/0.60 = 29.4 kWh

(assumes 60% protein content for the biomass from C. necator bacteria)

This 29.4 kWh per kg of protein does not include the embodied energy for the ammonia and mineral inputs. More important, it also doesn't account for the energy losses during the generation of the electricity (which could effectively triple the energy required per kg of protein, for the typical power plant generation efficiency of around 35%, resulting in a total fuel energy input of around 90 kWh per kg of protein).

Data obtained from

A life cycle environmental sustainability analysis of microbial protein production via power-to-food approaches

https://link.springer.com/article/10.1007/s11367-020-01771-3

3. RESULTS OF A MAJOR STUDY (PNAS, 2021)

3.1 RENEWABLE ENERGY INPUT PER ONE KG PROTEIN = 58 KWH (MORE IF NON-RENEWABLE)

Considering the energy requirements of manufacturing "single-cell protein" from microbes (using hydrogen made with electrolysis), numbers from a major study (linked below) suggest that about 58 kWh of energy input is required per kg of protein produced (not including the energy required to make the manufacturing equipment and facility). This scenario assumes that 100% of the electricity input comes from photovoltaic panels, with no hidden generation losses requiring more energy input (as there would be when generating the electricity from natural gas, coal, or oil).

3.2 COMPARISON TO ENERGY INPUT REQUIRED FOR ONE KG OF SOYBEANS

Soybeans grown on farms in the US, on the other hand, on average require less than 1 kWh of energy input per kg of protein content (including fuels and the energy equivalents for fertilizers, minerals, herbicides, etc.), according to another study. And besides the kilogram of protein, these soybeans also contain oil and other nutrients, at no extra energy cost (beyond the 1 kWh input) for these additional foodstuffs which coexist in soybeans.

58 kWh vs. 1 kWh of energy input. The difference is of course largely due to the sun automatically providing energy directly to the plants for free.

3.3 DETAILS: SOYBEANS REQUIRE LESS THAN 1 KWH ENERGY INPUT PER KG OF PROTEIN

“The farm input data from 19 major soybean-growing states were averaged weighted by harvested acreage to derive energy used for soybean agriculture (table 2).”
Table 2. Soybean agriculture system inputs, weighted averages of 19 major soybean-growing states, 2006

Looking at all the inputs in Table 2, diesel and gasoline comprise more than half of the total “Life-Cycle Energy Equivalent”, and the next highest is herbicide.

Pradhan, Anup & Shrestha, Dev & McAloon, Andrew & Yee, Winnie & Haas, M.J. & J.A, Duffield. (2011). Energy Life-Cycle Assessment of Soybean Biodiesel Revisited. Transactions of the ASABE (American Society of Agricultural and Biological Engineers). 54. 1031-1039. 10.13031/2013.37088.
https://www.researchgate.net/publication/233955304_Energy_Life-Cycle_Assessment_of_Soybean_Biodiesel_Revisited

3.4 2021 STUDY OVERVIEW

A research article published last year by the National Academy of Sciences (USA) is the updated source of data I used to calculate the energy requirements of manufacturing food from microbes. This article is geared toward showing how “Photovoltaic-driven microbial protein production can use land and sunlight more efficiently than conventional crops” (the article title).

In the article, a comparison is made between two hypothetical one-hectare plots of land (Fig. 4). One of the hectares is covered with photovoltaic panels for supplying energy for the microbial protein production. The other hectare is used for a crop of soybeans.

When the hectare of PV panels operates year-round in a location with as much sunshine as the Imperial Valley (Southern California), the resulting energy can cover the production of 15 tons of protein per year. The hectare used for growing soybeans provides 1.1 tons of protein per year. This leads to the conclusion about using land and sunlight more efficiently (which is not too surprising considering that the PV panels are collecting energy every day of the year, while the soybean crop occupies the plot for only part of the year and at varying stages of growth).

3.5 ENERGY AND LAND REQUIREMENTS

I did not find where the article actually discloses (or admits) the grand total energy requirements (per kilogram produced) of the microbial protein production process. The energy requirement (per kilogram produced) for the electrolyzed hydrogen input seems to be missing from the report and supplemental materials. I obtained this energy requirement indirectly by using what relevant data was provided (namely the irradiance of 2,000 kWh/m2 and equation [1] in Methods).

So, if the estimates in the article are correct, then for situations where arable land is scarce while photovoltaic energy is plentiful, a microbial process could maximize the amount of protein produced on a given amount of land. However, in situations where there is enough arable land to produce adequate amounts of food, while energy supplies are already stretched, then it seems ill-advised to devote PV production to do something the sun is already doing for free (considering that the farming of soybeans requires less than 1 kWh per kilogram of protein, while the hydrogen-fed microbe process requires 58 kWh/kg as mentioned above).

3.6 VARIATION USING SUGAR BEETS

The research article also examines another scenario using a different type of microbial process. In this scenario, most (94%) of a hectare is used to grow sugar beets which subsequently provide sugar to feed some protein-producing microbes. The remaining portion (6%) of the hectare plot is covered with PV panels to provide the energy required for this process. The resulting protein is 2.7 tons per year (compared to the previously mentioned 1.1 tons of protein resulting from growing a hectare of soybeans).

The energy requirement (per kg of protein) for this sugar-beet scenario is also not disclosed, but I did some calculations based on the 610 m2 of PV panels powering this process, and found that 20 kWh were required for each kilogram of microbial protein (compared to less than 1 kWh required for farmed soybeans containing a kilogram of protein).
[Note: I am willing to provide details of my calculations if there are any specific questions about them.]

3.7 LAND COVERED BY PHOTOVOLTAIC ARRAYS OR CROPS?

Again, my conclusion here is that if energy supplies are already stretched, and there’s enough arable land, then it seems ill-advised to devote PV production to do something the sun is already doing for free. The energy advantages of growing soybeans (less than 1/20th of the energy input required per kg of protein, compared to the sugar-fed microbial process) seem more compelling than the spatial advantages of the microbial protein production (around 2.5 times the protein produced per year with a one-hectare plot of land). In other words, getting 2.5 times the protein output per hectare doesn’t seem worth 20 times the required energy input per kg of protein.

3.8 LINK TO THE RESEARCH ARTICLE (2021)

“Photovoltaic-driven microbial protein production can use land and sunlight more efficiently than conventional crops”
Dorian Leger, Silvio Matassa, Alon Shepon, Ron Milo, and Arren Bar-Even
June 21, 2021
118 (26) e2015025118
doi(dot)org/10.1073/pnas.2015025118
https://www.pnas.org/doi/full/10.1073/pnas.2015025118

3.9 ONE FOOD FACTORY REQUIRES 4,000 HECTARES OF SOLAR PANELS?

The research article and supporting material seem to have some significant flaws. I’ll mention a couple.

Some of the assumptions have a wide range, such as the annual capacity of the microbial protein production facility (25,000 tons for the low value, and 108,000 tons for the high value).

The listed capital cost for a facility ranges from 60 million to 351 million USD, and the cost of the PV “solar farm” for powering the process isn’t included in the capital cost estimates. So I did some calculations to estimate the required capital cost of a “solar farm” which could power such facilities, starting with the low end of the ranges (a facility costing 60 million USD and producing 25,000 tons of biomass per year:

Since 1 hectare of PV is required for 15 tons protein per year (figure 4), divide the 15 tons of protein by .55 which gives
27 tons of biomass produced per hectare of PV panels (assuming 55% protein content of the biomass, if I recall correctly);
then divide 25,000 tons (the total biomass production of the facility) by 27 tons (produced per hectare of PV panels)
to result in 925 hectares of PV panels required to power the smaller facility.

925 hectares of PV panels for the smallest production facility! Some online sources estimate that a “solar farm” costs about 1 million USD per hectare, in which case the PV system for the smaller facility would cost 925 million USD (in addition to the 60 million USD facility cost).

Doing similar calculations for the larger facility size, producing 108,000 tons of biomass per year, results in 4,000 hectares (!) of PV panels required to power the process, costing roughly 4 billion USD just for the required PV system (not including the cost of the land itself), in addition to the 351 million USD cost of the manufacturing facility.

3.10 FACILITY LIFESPAN

According to that study, the lifespan of the microbial protein production facility equipment is 25 years. Assumptions and projections that are made to financially justify the construction of such a facility, such as the expected cost of inputs, may no longer apply when it’s time for replacement, leading to the facility becoming yet another shuttered factory. Such technology is not much of a “rescue”, and its precarious existence (if it ever gets off the ground) is a poor reason to shut down farms.

3.11 HUGE INITIAL CAPITAL COSTS, UNREALISTIC ASSUMPTIONS

Even if the PV-powered microbial protein production is feasible in practice at such a large scale, which remains to be seen, a major impediment is the huge capital cost (where a facility cost in the hundreds of million dollars is dwarfed by the cost of the PV “solar farm” required to power it).

The research article promoting this PV-powered scheme effectively dodges the issue (of the huge capital cost for the PV energy source) by assuming that enough PV energy (or other renewable source of electricity) will somehow be available during the entire 25-year life of the facility, at a cost of only 5-10 cents per kWh!

I previously mentioned how the expected favorable costs of some inputs may no longer apply when it’s time for replacement after 25 years, but here the expected cost of renewable energy has already been exceeded after only one year beyond the publication of the article.

from the article’s Supplementary Information:
“The main capital investments for equipment and infrastructures included the fermentation and post-processing steps of SCP plants producing between 25,000 and 108,000 ton-dw-biomass [per year]…. considering a range of $0.05 to $0.10 [per] kWh for renewable energy, and applying these to the energy demand of SCP production…”
https://www.pnas.org/doi/suppl/10.1073/pnas.2015025118/suppl_file/pnas.2015025118.sapp.pdf

3.12 A REALISTIC ASSUMPTION

To the credit of the paper I quoted above, they didn’t use the theoretical output of PV panels (as some other studies have done); instead they derived their PV efficiency numbers from real-world performance data for “solar farms” operating around the world.

“To obtain a more realistic view of solar farm efficiency, we used available data from >600 utility-scale sites (Dataset S1A). As explained in Methods, we found that ηpv ranges between 4.1% and 5.6% (30th to 70th percentiles), considerably lower than the solar cell efficiency.”
https://www.pnas.org/doi/full/10.1073/pnas.2015025118

3.13 UNSAFE FOR HUMAN CONSUMPTION?

‘Fun fact’ about the factory food (which Simon Fairlie calls studge) – the output from the bioreactor can be used as animal feed but it’s unsuitable for humans to eat until some additional steps are done to remove the nucleic acids (according to the paper I quoted earlier).

“For the production of human food, the food downstream processing includes two additional steps to reject nucleic acids, bead-milling and microfiltration”
“The removal of nucleic acids is crucial when SCP serves as a human food since in too high of concentrations, their catabolism leads to an accumulation of uric acid, which cannot be easily degraded and can form gout (20). Unlike humans, all farm animals possess the enzyme uricase, which precludes this effect, therefore making nucleic acid removal unnecessary for feed production.”
https://www.pnas.org/doi/full/10.1073/pnas.2015025118

4. SOYBEANS VS. MICROBES

4.1 OVERVIEW

Let’s compare microbial protein studge (at the factory gate) directly with soybeans (at the farm gate).
To make the comparison more interesting, we’ll use theoretical ideal-world numbers for the microbial protein (upper limit, thermodynamic constraints on the processes), compared to real-world data from soybean farmers.

4.2 REAL-WORLD SOYBEAN INPUTS (LIFE CYCLE ENERGY EQUIVALENTS)

Table 2. Soybean agriculture system inputs, weighted averages of 19 major soybean-growing states, 2006 (source: ERS, 2009a; NASS, 2007; NASS, 2010).
https://www.researchgate.net/publication/233955304_Energy_Life-Cycle_Assessment_of_Soybean_Biodiesel_Revisited
Inventory [item], Quantity Used (per ha); Life-Cycle Energy Equivalent (MJ/ha)
Diesel 33.3 L; 1417.6
Gasoline 12.8 L; 515.7
LP gas 2.0 L; 52.7
Natural gas 4.1 m3; 161.4
Nitrogen 3.3 kg; 168.2
Phosphorus 12.1 kg; 111.2
Potassium 22.4 kg; 133.4
Lime 463.7 kg; 57.9
Seeds 68.9 kg; 324.4
Herbicide 1.6 kg; 507.7
Insecticide 0.04 kg; 13.2
Electricity 17.1 kWh; 127.1
Total 3590.5 MJ/ha

3590.5 MJ/ha = 998 kWh per hectare of soybeans
“Total Life-cycle energy input in soybean agriculture was 3590.5 MJ/ha”
“The weighted average yield equaled 2906.7 kg/ha (43.2 bu/ac) in 2006.”

So, one hectare yields 2907 kg of soybeans
which required 3590 MJ of energy.
3590/2907 = 1.23 MJ/kg of soybeans

Conversion 1 MJ = 0.278 kWh
1.23(0.278) = 0.34 kWh/kg of soybeans

Protein content of soybeans (from the internet):
“Whole soybeans typically contain 38 to 42 percent crude protein and 16 to 20 percent fat (dry matter basis).”

At 40% protein, to obtain 1 kg of protein for soybeans, we need 1/.4 = 2.5 kg of soybeans
At 18% fat, that 2.5 kg of soybeans will also contain 2.5(.18) = 0.45 kg of fat
To grow these 2.5 kg of soybeans requires 2.5(.34 kWh/kg) = 0.85 kWh of energy

So, to obtain 1 kg of protein, plus 0.45 kg of fat, from soybeans requires 0.85 kWh.
Thus, the energy requirement of 0.85 kWh/kg of protein from soybeans (with a “bonus” 0.45 kg of fat included in the deal).

We’ve established that 0.85 kWh of total-life-cycle energy inputs will produce soybeans containing 1 kg of protein (plus about a half kilogram of fat), based on real-world data from soybean growers.

4.3 THEORETICAL IDEAL-WORLD MICROBIAL PROTEIN ENERGY REQUIREMENT

How does the microbial protein (studge) compare? Let’s look at the upper-limit constraints on the microbial performance, which result in the absolute lowest energy inputs (per kg of product) that are theoretically possible for these processes (in an ideal world):

“Here we present a molecular-scale model that sets an upper limit on the performance of any organism performing electromicrobial protein production. We show that [genetically] engineered microbes that fix CO2 and N2 using reducing equivalents produced by H2-oxidation or extracellular electron uptake could produce amino acids with energy inputs as low as 64 MJ [per] kg”
“Thermodynamic Constraints on Electromicrobial Protein Production”
https://www.biorxiv.org/content/10.1101/2021.11.22.469619v1.full
So, “energy inputs as low as 64 MJ/kg”
converts to a minimum of 64(.278) = 17.8 kWh/kg
for microbial protein.

4.4 COMPARISON RESULTS

At this point, it’s unclear whether this 17.8 kWh/kg applies to the actual protein product suitable for human consumption (after milling and microfiltration to remove the harmful nucleic acids from the mix, and all the other processing, which requires additional energy).

For the purpose of this comparison, let’s be generous and assume the 17.8 kWh/kg of microbial protein includes the energy to make it safe for human consumption, and all the other processing energy requirements. This gives us:

Microbial protein production requires an ideal-world minimum of 17.8 kWh/kg of protein.
vs.
Soybean farming requires a real-world 0.85 kWh/kg of protein (with a “bonus” 0.45 kg of fat included in the deal).

17.8 is more than 20 times 0.85
This means that the energy requirement of microbial protein production, at its theoretical absolute best, is more than 20 times the actual real-world energy input for farming soybeans, per kilogram of protein produced.

4.5 SOYBEANS GIVE MUCH MORE FOOD FOR MUCH LESS ENERGY INPUT

Besides the advantage of requiring less than 1/20th of the energy inputs to produce protein, soybean farming provides fats and other nutrients not included in the microbial protein process.

In other words, at the theoretical limits for microbial protein production, how much food can be produced with 1 kWh of energy inputs?
Soybean farming provides 1176 grams of protein, plus 529 grams of fat, plus other nutrients.
Microbial protein production provides less than 56 grams of protein, with no fat, and no other nutrients.

4.6. SOYBEANS COMPARED TO REAL-WORLD MICROBIAL PROTEIN PRODUCTION

For real-world conditions, the 2021 study indicates that 58 kWh of renewable energy is required to manufacture one kg of protein (as shown above), instead of the 17.8 kWh/kg estimated to be the absolute theoretical limit.

58 kWh/kg (for microbial protein) is more than 68 times the 0.85 kWh/kg for soybeans.
This means that the real-world energy requirement of microbial protein production is more than 68 times the real-world total life-cycle energy input for farming soybeans, per kilogram of protein produced.

Thus, for real-world conditions, how much food can be produced with 1 kWh of energy inputs?
Soybean farming provides 1176 grams of protein, plus 529 grams of fat, plus other nutrients.
Microbial protein production provides only around 17 grams of protein, with no fat, and no other nutrients.

4.7 ONE KG PROTEIN = 100 KG STEEL?

To put this 58 kWh/kg (for microbial protein) into perspective, steelmaking using electricity as the energy source requires roughly 500 kWh/tonne, or about half of a kWh per kg of steel (with an electric arc furnace which melts scrap at 1,520 °C, or 2,768 °F).

In other words, manufacturing one kilogram of protein requires the same amount of energy as making more than 100 kg of steel.

“To produce a ton of steel in an electric arc furnace requires approximately 400 kilowatt-hours (1.44 gigajoules) per short ton or about 440 kWh (1.6 GJ) per tonne; the theoretical minimum amount of energy required to melt a tonne of scrap steel is 300 kWh (1.09 GJ) (melting point 1,520 °C (2,768 °F)).”
https://en.wikipedia.org/wiki/Electric_arc_furnace

5. DENIAL AND A FAILURE TO SEE THE WHOLE PICTURE

George Monbiot has written this about denial:
“We’re all responding to the same impulses, but we’re all being tripped up by denial. Denial, and a failure to see the whole picture, are our enemies.” [Our Crushing Dilemmas, 5th May 2011]

I’d say there’s a lot of denial involving the energy consumption implications of ecomodern ‘rescues’ like the factory food schemes. Not to mention the failures to ‘see the whole picture’ regarding our energy-constrained world.

In addition to the benefits of requiring much less energy, farms are arguably more resilient than manufactured food systems, due to less complexity (less things that could go wrong) and less concentration (less eggs in one basket). Foods manufactured by complex industrial processes seem much more vulnerable to supply-chain disruptions and energy supply issues.

In many ways, there is no real contest between self-assembling sun-powered food generators (plants) vs. ‘food’ manufacturing processes (precision fermentation, power to food, etc.) requiring major amounts of energy inputs and capital expenditures.