A Circular Jet (Fuel)

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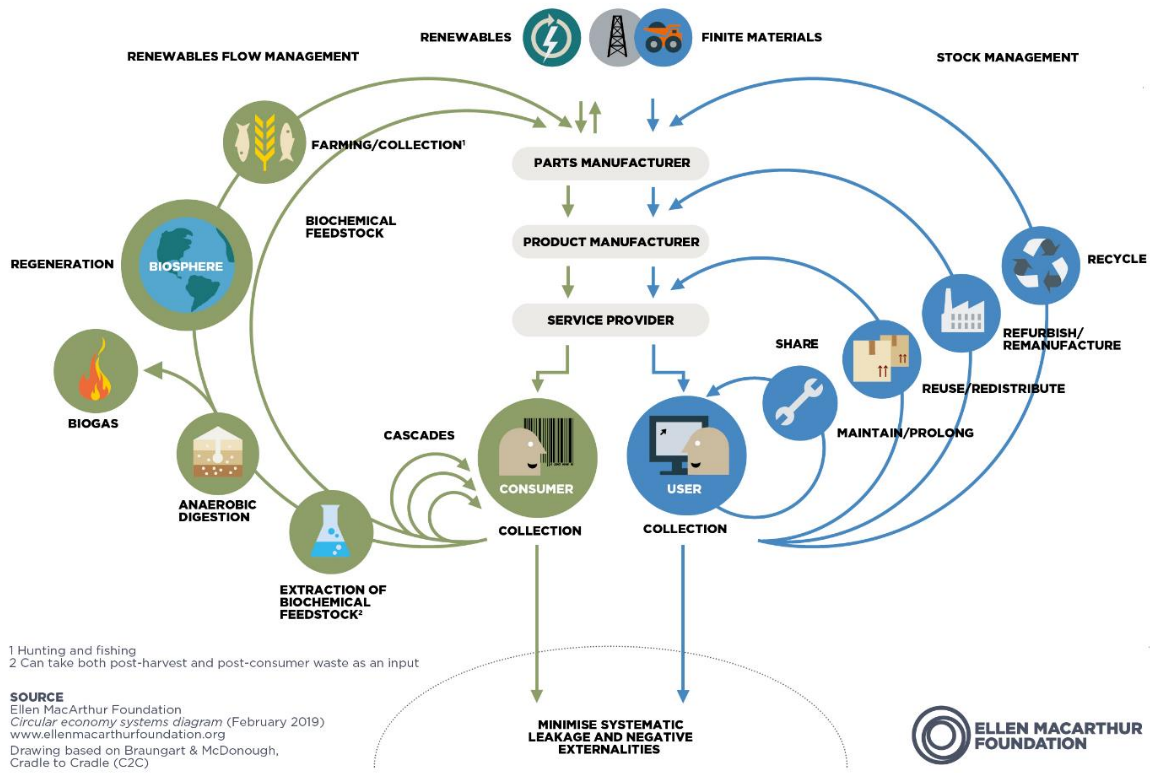
1. Introduction

This paper will explore three interrelated issues. The first is the circular economy model. This model has been proposed by the Ellen MacArthur Foundation (et al) and is represented by the chart below, and described by the text below that.



To solve big problems like climate change, waste, and pollution, we need a big idea.[1]

It's time to rethink how we design, make, and use the things we need, from the food we eat to the clothes we wear.

Together, we can create a better future for business, society and the natural world.

In our current economy, we take materials from the Earth, make products from them, and eventually throw them away as waste – the process is linear. In a circular economy, by contrast, we stop waste being produced in the first place.

The circular economy is based on three principles, driven by design:

- *Eliminate waste and pollution*
- *Circulate products and materials (at their highest value)*
- *Regenerate nature*

[1] Ellen Macarthur Foundation Home Page, https://ellenmacarthurfoundation.org/

The second issue was covered by a recent post that is described and linked below.

New Networks Compendium: *I started writing the "New NETWORKS" series almost two years ago. Thus, it didn't surprise me recently when, that there were major developments in negative emissions technology (NET). The first was a subject I wrote about over a year ago:*

XPRIZE officially launched the $100 Million XPRIZE Carbon Removal competition. In honor of the launch, XPRIZE founder Peter H. Diamandis sat down with Elon Musk, who is funding the competition through the Musk Foundation.

The above contest has now reached a major milestone which is covered in section 2. The second part of this post is on a report on Negative Emissions Technologies and Reliable Sequestration from the National Academies of Sciences, Engineering and Medicine, an organization that I respect greatly.

https://energycentral.com/c/ec/new-networks-compendium

Note the "…XPRIZE Carbon Removal" project name in the above description. In most cases, carbon removal is a two-step process: (1) capture the carbon dioxide (CO_2) from the atmosphere and (2) sequester the CO_2 for centuries to millennia. The idea that we can use the CO_2 from step 1 to manufacture useful products is not new, but in the case below, the product ends up producing more CO_2 that is released into the atmosphere. This is sort of OK, as long as we capture the CO_2 (and capture a bit more to allow for process leakage) and turn it back into the useful product (circular process).

Finally there is the third and real subject of this post, a sustainable aviation fuel.

2. Sustainable Aviation Fuel (SAF)

In the true circular economy, per the above figure, we attempt to "minimize systematic leakage." However, I am more interested in immediate results. There is a good chance at some point in the distant future we will power long-distance jet transports with ammonia. The combustion of ammonia only exhausts water vapor and nitrogen, and thus is largely benign (technically, water vapor is a greenhouse gas, but there is already so much of this circulating in our biosphere, I would guess that the additional amount from long-distance jet transports will have a negligible impact). However, until turbo-fan engines have been developed that can reliably burn ammonia, and we develop the ammonia fuel infrastructure, we will need a fuel today that will work sustainably as described above.

And then there are the economics. There have been many attempts at sustainable fuel (for all types of uses) that have failed because it was too expensive vs. the non-sustainable alternative. This is due to a combination of immature technology, insufficient incentives and lack of an appropriate price/penalty for emitting greenhouse gas.

2.1. Cheap flights now and Worldwide Disasters Later

It's a painful truth for people who fly: Airplanes are climate killers. Air travel is among the most carbon-polluting human activities. A round trip from New York City to London emits nearly 1000 kilograms of carbon dioxide (CO_2) per passenger, more than an average person in Burundi, Nicaragua, or 47 other countries emits in a year. Annually, airplanes *spew some 920 million tons of CO_2, accounting for roughly 3.5% of all greenhouse gas emissions worldwide.*[2]

2.2. Garbage to SAF

Derek Vardon is hoping a yellowish, foul-smelling liquid will help change that. The fluid is a collection of short, chainlike molecules called volatile fatty acids (VFAs) from decaying food waste, such as chicken primavera and Greek salads. (The same types of molecules give manure its stench.) In a process he and colleagues developed, the VFAs are vaporized, then percolate over a bed of white, marble-size pellets of zirconium oxide, which knit the VFAs into longer chains called ketones. After condensing into a sweet smelling, clear liquid, the ketones are piped to another reactor where gray platinum pellets link them together and strip off oxygen atoms to make kerosene, a.k.a. jet fuel.

Vardon, a chemist who spent most of the past decade at the National Renewable Energy Laboratory (NREL), is betting this food-to-fuel process and others that convert different forms of waste "biomass" into fuel represent the future of air travel, and the world's best hope for dramatically reducing the greenhouse gases it generates. In March 2021, he and his colleagues detailed the technology in the Proceedings of the National Academy of Sciences along with calculations revealing the resulting jet fuel could be nearly as cheap as the petroleum-based version. Because the carbon it contains originated in plants, which drew it from the atmosphere, the net emissions from bio-based jet fuel would only be a fraction of those from fossil fuel.

In October 2021, Vardon bet on his technology, leaving NREL to become chief technical officer of Alder Fuels, a startup aiming to produce sustainable aviation fuels (SAFs). Alder is hedging its bets by developing another process as well: using high temperatures to convert wood waste to jet fuel. "We have a limited window to impact climate change," Vardon says. "I had to ask myself, 'Do I want to write more papers or try to take this solution and get it into the marketplace?'"

2.3. United Airlines and SWA

In fall 2021, United Airlines committed to buying 5.7 billion liters of SAFs from Alder, the largest such aviation deal at that time. And Alder isn't alone. More than a dozen SAF startups have formed in recent years in the United States, China, Japan, Singapore, India, Finland, Sweden, Austria, and Canada. "The interest is global, and it is rapidly expanding," says James Spaeth, a biofuels expert with the U.S. Department of Energy's (DOE's) Bioenergy Technologies Office (BETO).

United Airlines Ventures (UAV) and Oxy Low Carbon Ventures (OLCV) today announced a collaboration with Houston-based biotech firm Cemvita Factory to commercialize the production of sustainable aviation fuel (SAF) intended to be developed through a revolutionary new process using carbon dioxide (CO_2) and synthetic microbes. UAV also announced an equity investment in Cemvita Factory. OLCV, a subsidiary of Occidental (Oxy), is a founding investor in Cemvita Factory.[3]

[2] Robert F. Service, Science, "Can biofuels really fly?" June 24, 2022, p 1394, https://www.science.org/content/article/can-farm-and-food-waste-power-tomorrow-s-airplanes

[3] United Airlines, "Turning Carbon Dioxide into Sustainable Fuel," March 28, 2022, https://www.united.com/en/us/newsroom/announcements/united-and-oxy-low-carbon-ventures-announce-collaboration-with-biotech-firm-cemvita

United has invested in more SAF production than any other airline…

United and OLCV have previously worked together on new approaches to combat climate change. Together, UAV and OLCV will fund development work at Cemvita to convert carbon dioxide into hydrocarbons for SAF. If performance targets are achieved, UAV and OLCV plan to form a joint venture to commercialize the technology. This includes funding projects such as pilot and demo plants, engineering studies, financing construction and operating SAF plants.

"The use of SAF is a promising approach that we believe can significantly reduce global emissions from aviation and further decarbonization initiatives to combat climate change," said Richard Jackson, President, Operations, U.S. Onshore Resources and Carbon Management, Oxy. "We are eager to collaborate with United and Cemvita to accelerate SAF innovation to reach commercial scale."

Also the following article is about later commitments by United Airlines.

United and United Airlines Ventures (UAV) today announced an investment in Dimensional Energy for 300 million gallons of sustainable aviation fuel (SAF).[4]

Dimensional Energy's technology removes the need for fossil fuels, converting carbon dioxide and water into usable ingredients for the Fischer-Tropsch process – a nearly 100-year-old technology used to produce fuels from coal or methane. While facilities around the world continue to use Fischer-Tropsch to produce fossil fuels, Dimensional will be one of the first to use it to produce SAF…

Dimensional's technology can run on all forms of renewable energy. At the Tucson site, they are using electricity from the Arizona grid, which gets an increasing amount of power from local solar panels. Future plants are slated to use hydro-power, wind-power, and rapidly maturing concentrated solar, which utilizes heat from direct sunlight.

Today's announcement marks UAV's fourth SAF-related technology investment, but its first the pathway of power-to-liquids: which creates SAF synthetically without the constraints of feedstock growth that is prevalent in other biofuel pathways. Launched in 2021, UAV targets startups, upcoming technologies, and sustainability concepts that will complement United's goal of net zero emissions by 2050 – without relying on traditional carbon offsets. UAV's portfolio now includes SAF producers and other technologies including carbon capture, hydrogen-electric engines, electric regional aircraft, and urban air mobility.

Southwestern Airlines (SWA) is also investing in sustainable aviation fuel:

Southwest Airlines has announced an investment into SAFFiRE Renewables, a company formed by D3MAX as part of a Department of Energy (DOE)-backed project to develop and produce sustainable aviation fuel (SAF). Funded with a DOE grant matched by Southwest's investment, SAFFiRE is expected to utilize technology developed by the DOE's National Renewable Energy Laboratory (NREL) to convert corn stover, a widely

[4] Emily Holbrook, Environmental + Energy Leader, "United Signs Agreement for 300 Million Gallons of Sustainable Aviation Fuel," June 15, 2022, https://www.environmentalleader.com/2022/06/united-signs-agreement-for-300-million-gallons-of-sustainable-aviation-fuel/

available waste feedstock in the U.S., into renewable ethanol that then would be upgraded into SAF.[5]

In 2021, the DOE awarded D3MAX the only pilot-scale grant for SAF production, with a goal to scale technology that could commercialize SAF. According to NREL, this could produce significant quantities of cost-competitive SAF that could provide an 84% reduction in carbon intensity compared to conventional jet fuel on a lifecycle basis. Southwest's match of the DOE's grant supports phase one of the project, which is expected to include technology validation, preliminary design, and a business plan for a pilot plant.[6]

2.4. Other Information from DOE

The DOE has a good site on the subject fuel:

SAF made from renewable biomass and waste resources have the potential to deliver the performance of petroleum-based jet fuel but with a fraction of its carbon footprint, giving airlines solid footing for decoupling greenhouse gas (GHG) emissions from flight.[7]

The U.S. Department of Energy is working with the U.S. Department of Transportation, the U.S. Department of Agriculture, and other federal government agencies to develop a comprehensive strategy for scaling up new technologies to produce SAF on a commercial scale…

SAF is a biofuel used to power aircraft that has similar properties to conventional jet fuel but with a smaller carbon footprint. Depending on the feedstock and technologies used to produce it, SAF can reduce life cycle GHG emissions dramatically compared to conventional jet fuel. Some emerging SAF pathways even have a net-negative GHG footprint.

SAFs lower carbon intensity makes it an important solution for reducing aviation GHGs, which make up 9%–12% of U.S. transportation GHG emissions, according to the U.S. Environmental Protection Agency.

An estimated 1 billion dry tons of biomass can be collected sustainably each year in the United States, enough to produce 50–60 billion gallons of low-carbon biofuels. These resources include:

- *Corn grain*
- *Oil seeds*
- *Algae*
- *Other fats, oils, and greases*
- *Agricultural residues*
- *Forestry residues*
- *Wood mill waste*

[5] Emily Holbrook, Energy + Environmental Leader, "Southwest Airlines Invests in DOE-Supported Sustainable Fuel Project," June 2, 2022, https://www.environmentalleader.com/2022/06/southwest-airlines-invests-in-doe-supported-sustainable-fuel-project/
[6] D3MAX Homepage, https://www.d3maxllc.com/home
[7] Energy Efficiency & Renewable Energy, "Sustainable Aviation Fuels," https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuels

- *Municipal solid waste streams*
- *Wet wastes (manures, wastewater treatment sludge)*
- *Dedicated energy crops.*

This vast resource contains enough feedstock to meet the projected fuel demand of the U.S. aviation industry, additional volumes of drop-in low carbon fuels for use in other modes of transportation, and produce high-value products and renewable chemicals….

2.5. Past Failures and a Future Long Road

For now, SAF producers create just 100 million liters of fuel per year for an industry that consumed more than 360 billion liters in 2019, before the pandemic cut that in about half. By 2030, the market for SAFs may grow by 70-fold, to nearly $15.7 billion, according to Markets and Markets.[2]

There is a shadow over the effort: the failed attempt, more than a decade ago, by a handful of companies to turn agricultural wastes into vehicle fuels. But this go around, success may be more likely, in part because companies are trying many approaches, and in part because airlines desperate to find ways to reduce their carbon footprint have few alternatives. Cars can run on batteries, but planes will likely always require liquid fuels, which carry much more energy in a given volume. "Nobody is going to be flying a battery-powered jet to Australia anytime soon," says Eric McAfee, CEO of Aemetis, a startup that turns wood waste and kitchen grease into biofuel.

Slowly and haltingly, the transition has already begun. In addition to United, more than a dozen airlines around the globe have committed to collectively buying some 21 billion liters of SAFs in coming years. SAFs were first mixed with fossil fuel–derived kerosene for an airline flight in 2008, and thousands of jetliners have burned such mixtures since then. But it was only in December 2021 that a United Airlines flight from Chicago to Washington, D.C., became the first passenger flight to fly on 100% SAFs.

Biofuels' first turn in the spotlight was a partial flop. Nearly every motorist has pumped some biofuel into their tank. In the United States that was ethanol made from corn kernels. Corn ethanol now supplies some 59 billion liters a year in the United States alone, but growing and harvesting the corn requires heavy use of fertilizer and other energy intensive inputs, making its climate benefit marginal at best. "Cellulosic ethanol" made from corn stalks, forest debris, and other waste carbon was supposed to change that.

Billions of dollars went into the effort after Congress instituted the renewable fuels standard in 2005 to create a market for ethanol and other vehicle biofuels. A massive chemical plant that opened in 2014 in Emmetsburg, Iowa, in the middle of corn fields stretching toward the horizon, is one monument to its failure. The $275 million plant, dubbed Project Liberty, converted farm waste including decaying corn stalks and cobs into ethanol for blending into gasoline. The technology worked, but Project Liberty shut down in 2020, and in 2021, the Emmetsburg plant's owners shifted to producing hand sanitizer. Other cellulosic plants also went belly up within a few years. According to the Environmental Protection Agency (EPA), fewer than 1 million liters of cellulosic ethanol were produced in the United States last year.

The recipe for cellulosic ethanol seemed like a winner. Start with farm and forest waste that is so abundant it is essentially free, use microbial enzymes to convert it to sugars, *let yeast ferment the sugar, and you've got a fuel you can sell. The climate case was equally compelling. Compared with fossil fuels, corn-derived ethanol reduces CO_2 emissions by 20% to 40%; ethanol made from waste biomass cuts emissions by 90%. For world leaders to have any shot of meeting their climate goals, such fuel is "just an absolute necessity," says Lee Lynd, an energy engineer at Dartmouth. "In the future, the need for energy from biomass is greater than all the wind and solar combined."*

But a viable way to make cellulosic ethanol at scale proved elusive. Most biomass contains a lot of water, making it heavy and expensive to truck to processing plants. The corn harvest only lasts about 1 month per year; stalks and other debris must be stored for the rest of the year to feed the bio-refinery, further driving up costs. The biomass-degrading enzymes aren't cheap. And the spear-like corn stalks and other woody biomass often jammed machines designed to grind it up. "The chemical industry is built on handling liquids and gases," says Bruce Dale, a biofuels engineer at Michigan State University. "It's much harder with solids."

Dale and others argue that companies, backed by grants from DOE, were too quick to try to scale up. Each step up in scale brings new challenges, such as getting farmers to agree to harvest crop wastes, rather than just crops. "The DOE declared victory way too soon" in trying to commercialize the technology, says Daniel Sperling, who directs the Institute of Transportation Studies at the University of California (UC), Davis. "As a result, R&D in the field just disappeared."

2.6. More Hope for the Future

SAF backers hope to prevent a repeat. In October 2021, President Joe Biden's administration outlined a Grand Challenge to produce 11.4 billion liters of SAFs annually by 2030 and enough to meet 100% of aviation fuel demand by 2050, projected to be about 160 billion liters. As part of that effort, BETO[8] announced nearly $65 million for 22 projects to develop new biomass feedstocks and SAF technologies. Unlike cellulosic ethanol, which relied on a single basic recipe, the idea is to nurture multiple pathways, hoping some will succeed.

Some may not, SAF backers concede. "I am hopeful this technology will get over the finish line," says Daniel Sanchez, a bioenergy expert at UC Berkeley. "But what isn't clear is how many projects will fail first."

McAfee[9] is betting Aemetis won't be among them. He's building a large chemical facility in the middle of Northern California's almond orchard country. Almond farmers typically replace their trees every 15 to 25 years. That creates more than 2 million tons of agricultural waste per year. Farmers used to burn it, but the practice is being phased out to improve the region's air quality. Aemetis has now contracted to buy much of that waste at $20 per ton and will use a high-temperature process called gasification to extract hydrogen from it. The waste CO_2 from the process will be captured and sequestered underground, McAfee says.

See the earlier post described and linked below:

NUTS: This paper is about woody biomass, why, when and how we should use this for energy production. Oh yes, and it is also about everything nuts.

https://www.energycentral.com/c/cp/nuts

[8] U.S. Department of Energy's (DOE's) Bioenergy Technologies Office

[9] Eric McAfee, CEO of Aemetis, a startup that turns wood waste and kitchen grease into biofuel

The company will use the hydrogen to chemically treat vegetable oils and animal fats. This "hydro-treatment" breaks the oil molecules—typically hydrocarbons with three or more branches—into chains with just a single branch. A second reaction, called hydro-isomerization, then rearranges these chains into the mix of hydrocarbons that make up standard jet fuel, also known as Jet A.

Other routes to making SAFs are springing up as well. LanzaJet is converting municipal garbage, wood waste, and waste industrial gases to ethanol and then upgrading that to jet fuel. First water molecules are stripped from the ethanol, turning it into ethylene. Multiple ethylene molecules are then spliced together to make short hydrocarbons called olefins. Another reaction with hydrogen turns the olefins into an array of hydrocarbons, including kerosene, which is refined into fuel in a final step.

Colorado-based Gevo is converting corn stalks and other agricultural wastes to a different alcohol, isobutanol, which the company then chemically upgrades to aviation fuel. And Canada-based Enerkem is partnering with Shell to use heat and steam to convert municipal garbage and other feedstocks into syngas—a mix of hydrogen and CO_2 *that it then purifies and converts into SAFs using a century-old process called Fischer-Tropsch technology.*

All of these pathways have already been tested and approved for making jet fuel that can be blended into Jet A by the American Society for Testing and Materials, the standards agency responsible for aviation fuel blends. The variety of waste feedstocks they rely on is a strength, engineers say, allowing companies to take advantage of whatever local waste is cheapest.

The diversity of feedstocks should also help SAF producers meet the demand from airlines. According to Vardon, wet wastes, including food leftovers, could provide raw material for up to 15 billion liters of SAFs per year. Another 19 billion liters could come from treating fats, oils, and greases with hydrogen. And likely billions more from converting municipal garbage and farm waste to fuel. The market for aviation fuels is so large, "all technically and economically viable pathways to produce chemicals and fuels from waste carbon will be needed," Laurel Harmon, a chemist who is LanzaTech's vice president of government relations, told a U.S. House of Representatives committee looking into SAFs.