Aviation Emissions

Actions New York lawmakers could take to accelerate the transition to sustainable aviation

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Table of Contents

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Introduction

This white paper offers some thoughts as to how lawmakers could accelerate progress in reducing aviation emissions. The world's largest commercial airplane manufacturers, Airbus and Boeing, have steadily reduced the emissions from their commercial aircraft. For example, the Boeing 737 MAX, introduced in 2017, reduced fuel consumption and carbon dioxide emissions by 20% versus the previous generation 737, NG-737, which entered service in 1998. However, aviation emissions are rising, largely due to the success of low-cost airlines, such as Ryan Air in Europe and Southwest in the US, combined with the growth of the middle class in Asia.

Consumers in China, India, and other emerging market countries are flying in increasing numbers. The effect of an increased number of flights across the globe has overwhelmed the advances of the latest commercial jets. By [2020], global international aviation emissions are projected to be around 70% higher than in 2005. The International Civil Aviation Organization (ICAO) forecasts that by 2050 they could grow by a further 300%–700%.[1]

In view of rising aviation emissions, how could humankind first arrest the rate of emission increase and subsequently achieve a reduction?

[1] European Commission website, "Reducing Emissions from Aviation," https://ec.europa.eu/clima/policies/transport/aviation_en.

Airports

One source of emissions related to aviation is the airports themselves. Airport Ground Support Equipment (GSE) largely consists of vehicles with internal combustion engines (ICE) powered by gasoline or diesel fuel. If airports switched to electric vehicles (EVs), they would reduce both emissions and groundwater pollution. ICE vehicles require fuel, motor oil to lubricate moving parts, and transmission fluid. Older ICE vehicles also make use of power steering fluid. Inevitably, operators and maintenance technicians spill these four fluids, which leach into the ground. By contrast, EVs use fewer types and volumes of fluids.[2]

The time is right for airports to commit to using only zero-emission GSE. Moreover, airports are excellent applications for EVs. The equipment never, or rarely, leaves airport grounds, so an airport only needs a few charging stations. Some EV equipment used on a daily basis is available now, or will be soon.

- **Airplane tugs and tractors —** multiple manufacturers offer electric versions, including BYD, Eagle, Lektro, and Motok.
- **Baggage-handling tractors —** similarly, there are several EV choices.
- **Pickup trucks —** electric pickup trucks are about to hit the US market. Some of the production schedules described below will slip; nevertheless, businesses and consumers will be able to buy from multiple firms in 2021.
    - Bollinger Motors' B2; production starts in early 2021.
    - Ford's electric F-150 should start selling in 2021 or 2022. In July 2019, Ford released a video of an electric F-150 prototype.
    - GM partially revealed the GMC Hummer electric pickup in a 2020 Super Bowl commercial featuring LeBron James. GM plans a more detailed announcement on May 20 [2020?]. Production is likely to begin in 2021. In addition, GM may be considering electric versions of the Chevrolet Silverado/GMC Sierra pickup trucks.
    - Lordstown Motors' Endurance; production starts in late 2020.
    - Nikola's Badger, announced in February. Nikola plans to offer two versions, an all-electric version and an electric-hydrogen version. Production plans are unknown.
    - Rivian's R1T; production starts in late 2020. In 2019, Amazon invested $700 million in Rivian and Ford $500 million. In late 2019, Rivian raised another $1.3 billion, led by T.

[2] EVs do not require fuel, motor oil, or power-steering fluid. They usually have a single reduction gear instead of a transmission. A single reduction gear also requires oil for lubrication but much less than a transmission. Both EVs and ICE vehicles make use of hydraulic fluid for braking systems, and liquid cooling systems to cool battery packs and engines, respectively.

Rowe Price. Thus, Rivian is a well-funded startup. Amazon has ordered 100,000 electric vans, which it should start deploying in 2021.

  - Tesla's Cybertruck, unveiled in November 2021. Manufacturing is likely to begin in late 2021 or 2022.

- **Passenger buses —** Some airports deliver passengers to planes via buses, for example, Brussels Airport, or use buses to move passengers from one terminal to another, for example Los Angeles's LAX. Many EV buses are now on the market globally. In North America, manufacturers include BYD, GreenPower, New Flyer, Nova Bus (owned by Volvo), and Proterra. Brussels Airport is replacing its diesel buses with electric buses, using vehicles made by BYD.[3]

EV choices do not yet exist for some types of more specialized airport equipment, such as snow removal and deicing vehicles. In February, the Los Angeles Fire Department announced that it will become the first fire department in North America to deploy an electric fire engine, purchased from the Austrian-based manufacturer Rosenbauer. US suppliers in these market niches typically customize trucks from heavy-duty truck manufacturers, such as Paccar, or manufacturers of medium-duty trucks, such as Ford or GM.

Nearly all of the Class 7 and 8 truck manufacturers selling in North America have launched, or are about to launch, electric trucks.[4] Moreover, large European firms own most of the US big truck brands; thus, the US market is indirectly linked to the European market. Daimler (Germany) owns the US brands Freightliner and Western Star, and sells heavy-duty electric trucks in Europe. Volvo Group (Sweden) owns Mack and sells electric trucks in Europe. VW (Germany) has a 17% stake in the US's Navistar International, and is making electric trucks in Europe for its own brand and for its MAN subsidiary.

On April 24, 2019, Daimler announced that it will manufacture electric Freightliner trucks in Portland, Oregon, and expects to start production in 2021. China's BYD has been doing final assembly of medium- and heavy-duty electric trucks at its factory in Lancaster, California, since late 2016.

There are three US heavy-duty truck manufacturers: Paccar, the incumbent, and two challengers, Nikola Motors, and Tesla. Paccar owns the Peterbilt and Kenworth brands, and in Europe the Netherlands-based DAF brand, which is selling electric trucks. Nikola Motors has

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[3] "Brussels Airport introduces electric buses to serve its passengers," Brussels Airport Press Release, March 1, 2019, https://www.brusselsairport.be/pressroom/brussels-airport-introduces-electric-buses-to-serve-its-passengers.

[4] The US DOT puts trucks into classes by "Gross Vehicle Weight Rating" (GVWR), ranked from 1 to 8 (smallest to largest), where classes 1–2 are light duty, 3–6 medium duty, and 7–8 are heavy duty. These classes are antiquated because they refer to capability levels that modern vehicles have long surpassed.

designed several hydrogen-fueled heavy-duty trucks and hopes to start manufacturing in late 2022.[5] Tesla is also entering the heavy-duty truck market and will start manufacturing the Tesla Semi electric truck next year.

Unfortunately, in the medium-duty truck classes, US manufacturers are far behind the Europeans. Ford, for example, has released no information regarding possible EV versions of its Super Duty line, F-250 through F-750 trucks. Similarly, GM and FCA, a European–US company, are evidently not close to offering electric versions of their medium-duty commercial trucks.[6]

A case in point of a GSE specialist that does not yet offer EVs is the Oshkosh Corporation. Oshkosh is a leading supplier of firefighting and snow-removal equipment to airports around the world. Oshkosh uses diesel engines made by Cummins. Cummins sells diesel and natural gas engines to many vehicle manufacturers, including FCA, Nissan, Paccar, and others. However, Cummins recognizes that manufacturing diesel engines may become a stagnant market. Consequently, in 2017, Cummins acquired the electric drivetrain and battery pack manufacturer Brammo.

Thus, Oshkosh has the potential to offer to airports electric versions of its equipment. The situation is similar for other suppliers of airport GSE. Switzerland's Aebi Schmidt is a major supplier of GSE. Aebi Schmidt customizes trucks made by Daimler's Mercedes-Benz, Paccar's DAF, Volvo, VW, and others. Aebi Schmidt owns the US's M-B Companies, another supplier of GSE.

The San Francisco Airport (SFO) may be the US leader in reducing emissions. SFO's Five-Year Strategic Plan targets carbon neutrality across airport-controlled operations by 2021 and a 50% reduction in greenhouse gas (GHG) emissions from a 1990 baseline. SFO recently

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[5] In my opinion, hydrogen-fueled vehicles make little environmental sense in applications where battery EVs are technically feasible. Nikola Motors will use hydrogen in gaseous form. Hydrogen's lightness (it is the lightest of all elements) presents a disadvantage for its storage, transmission, and use in gaseous form. Industrial gas companies, such as Air Liquide, typically make hydrogen using natural gas a feedstock. A more environmentally benign method of producing hydrogen is via electrolysis, using water as a feedstock and electricity generated by a renewable source to do the electrolysis.

However, efficiency losses from electrolysis and hydrogen compression range from 25% to over 40%. It is far more efficient to use the renewable electricity directly in EVs, rather than indirectly in hydrogen-fueled vehicles. Tesla is promising that its Semi will have a range of over 500 miles. If Tesla hits that mark, the only significant advantage a Nikola Motors truck may have versus the Semi would be a faster refueling time versus the Semi's charging time. However, that advantage will dissipate as charging technology continues to improve. Toyota is also a proponent of hydrogen trucks and is testing its fuel cell technology in a Kenworth T680 body at the Port of Los Angeles.

[6] However, the potential exists, given that Ford and GM are developing electric light-duty pickup trucks.

purchased six Proterra electric buses to replace diesel buses, and it joins seven other airports that have also purchased Proterra buses: Honolulu International Airport (HNL), John F. Kennedy International Airport (JFK), LaGuardia Airport (LGA), Newark Liberty International Airport (EWR), Raleigh-Durham International Airport (RDU), Sacramento International Airport (SMF), and Norman Y. Mineta San José International Airport (SJC). SFO's plan is to transition to 100% battery-electric buses.[7] More generally, the San Francisco Municipal Transportation Agency (SFMTA) has committed to purchasing only zero-emission buses starting in 2025, five years earlier than the New York's City's Metropolitan Transportation Agency (MTA).

Some airports have the potential to generate a considerable amount of renewable energy on-site. An urban airport, such as LaGuardia (LGA), has little land. By contrast, Denver International Airport (DIA), Dallas Fort Worth Airport (DFW), Orlando International Airport (MCO), and Dulles International Airport (IAD) have a considerable amount of open land. These facilities could generate a substantial amount of solar electricity. Per a National Renewable Energy Laboratory (NREL) study, the solar energy potential at US airports is nearly 117 gigawatts, equivalent to 117 large coal-fired power plants. The authors stated, "These calculations do not include small or military airfields, and thus, can be considered conservative."[8]

In 2015, the National Academy of Sciences sponsored a study investigating the economics of on-site generation of renewable energy at US airports. The study found that renewable energy can offer airports an important source of revenue. "Airports have particular characteristics that enhance the potential financial viability of onsite renewable energy. Land and buildings can provide cost effective physical locations for renewable energy facilities. The open landscape and geographic position of airports necessary for managing air traffic arrivals and departures also facilitates the capture of natural resources from the sun, wind, water, and earth that fuel renewable energy. Small rural airports may have surplus land available to site such facilities. Larger airports often have a level of electricity demand to support power consumption that positively affects project financials by avoiding the need to use the electrical grid. All of these attributes combined with improved renewable energy market conditions make airport renewable energy financially viable."[9]

Of course, over the last five years, the cost of renewable energy has declined dramatically, further strengthening this conclusion.

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[7] Mark Kane, "San Francisco Airport Purchases 6 Proterra Electric Buses," *InsideEVs*, April 26, 2019, https://insideevs.com/news/346184/san-francisco-airport-proterra-buses/.

[8] A. Kandt and R. Romero, "Implementing Solar Technologies at Airports," NREL, July 2014, page 1, www.nrel.gov/docs/fyosti/62349.pdf.

[9] National Academies of Sciences, Engineering, and Medicine 2015, *Renewable Energy as an Airport Revenue Source*, Washington, DC: The National Academies Press, page 6, https://doi.org/10.17226/2213.

In the US, local governments typically own airports. This situation presents government and airport officials opportunities to be more proactive in reducing emissions. **Airports should mandate EVs in requests for proposals for all types of GSE.**[10] The adoption of GSE EVs would substantially reduce airport operating and maintenance expenses, benefiting taxpayers over time. In addition, this campaign would have a secondary, beneficial effect: it would hasten the adoption of EVs by local governments. Most manufacturers of firefighting and snow-removal vehicles for airports also sell to governments. New York State has taken a small but significant step toward this objective; JFK's Terminal 5 has switched to electric-powered GSE.[11]

More broadly, **airports should adopt SFO's sustainability goals of zero net energy use, zero waste, and carbon neutrality, and investigate on-site generation of renewable energy.**

[10] The Ethisphere Institute named Oshkosh Corporation to the 2018 World's Most Ethical Company list for the third year in a row. If one airport expressed interest in an EV version of either snow-removal or firefighting equipment, then Oshkosh might consider making the investment needed to develop an EV version based on a combination of business and sustainability arguments.

[11] "Governor Cuomo Announces Major Airport Sustainability Milestone with Electrification of JetBlue's Terminal 5 at JFK Airport," press release September 26, 2019, on New York State Governor's website, https://www.governor.ny.gov/news/governor-cuomo-announces-major-airport-sustainability-milestone-electrification-jetblues.

Electric Aircraft

Background

In 2008, Tesla launched its first electric car, the two-seater Roadster. The Roadster was the first electric vehicle to use lithium-ion batteries and had a surprising range of 244 miles. By contrast, GM's EV1, also a two-seater, went into production a little over ten years earlier in 1996. It had a range of only 70–100 miles and used lead-acid or nickel-metal hydride batteries.

Tesla's 2020 Model S Long Range model, which can seat five adults and two children, has an EPA-rated range of 391 miles. Its Model X SUV has a range of 351 miles.[12] Tesla's more moderately priced 2020 Model 3 Long Range AWD model, which can seat five adults, has an EPA-rated range of 322 miles. On January 29, during Tesla's Q4 2019 earnings call, CEO Elon Musk said that the Model S is getting closer to achieving a 400-mile range as battery technology continues to improve.

Since 2008, Tesla and its lithium-ion cell partner Panasonic have been the market leader in making battery packs with the highest energy densities, a key factor in achieving EVs with long ranges. Tesla has substantially eliminated range as an EV disadvantage, given that the range of comparable gasoline-fueled ICE light vehicles typically is between 400 and 500 miles.

The other significant disadvantage of EVs versus ICE vehicles is that the time needed to charge an EV is longer than the time needed to refuel an ICE vehicle. Tesla leads the EV industry in this regard: it has deployed the world's most extensive charging network, the "Supercharger Network," with the fastest charging rates. Tesla first started installing its latest generation of superchargers, version three, during the summer of 2019. Supercharger V3 is capable of charging at a rate of 250kW. A study of 1,300 charges at Tesla's V3 supercharger station in Las Vegas demonstrated a median addition of 147 miles of range during 20 minutes of charging.[13]

This rate is not yet equivalent to the time needed to refuel an ICE vehicle, but it has substantially closed the gap. During most airline flights, when a plane arrives at and departs from an airport, it spends at least 45 minutes parked at a gate. Thus, charging technology appropriate for commercial aviation, in particular smaller aircraft, substantially exists today.

Tesla's example, combined with the rapid growth of the EV battery industry, influenced aircraft entrepreneurs and manufacturers. The private sector is now spending hundreds of millions of

[12] Tesla updated the ranges of the Model S and Model X in February.

[13] Teslanomics, "Tesla V3 Charging Explained!," YouTube, Summer 2019, 6:50 (minute: second), https://teslanomics.co/tesla-v3-charging-explained/.

dollars a year in research and development to advance electric aircraft. This wave of investment accelerated in 2017. The consultant Roland Berger determined that more electric aviation projects were announced that year than in all of the previous nine years combined.[14]

The number of aircraft development projects grew by about 30% in 2019, reaching 215. These efforts can be categorized in four market segments: urban air taxis (45%), general aviation (40%), and regional and large aircraft development projects (15% in total).[15] The companies funding projects range from industry giants, such as Airbus, Boeing, Embraer, and Hyundai, to slews of startups. Dag Falk-Petersen is the CEO of Avinor, the public operator of Norway's airports. He believes that Norway can make all short-haul flights, defined as flights lasting 1.5 hours or less, electrically powered by 2040.[16]

The benefits of electric aircraft will be transformative. They will eliminate jet fuel emissions, cut the cost of flying, and substantially reduce takeoff and landing noise at airports versus the noise generated by traditional aircraft.

Electric plane manufacturers

Easy Jet, Europe's second-largest carrier by passenger volume, hopes to put in service by 2030 a 180-passenger electric aircraft under development by Wright Electric. Easy Jet anticipates a range of about 500 km (310 miles), which would allow Easy Jet to use it from London to Amsterdam, Europe's second busiest route.[17]

In the US, similar routes include New York LGA–Boston (185 miles), New York JFK–Washington DC DCA (214 miles), New York JFK–Buffalo (301 miles), Chicago ORD–Detroit (234 miles), Chicago ORD–St. Louis (261 miles), Dallas DFW–Houston IAH (224 miles), Seattle–Portland (129 miles), Los Angeles LAX–San Diego (109 miles), Los Angeles LAX–Las Vegas (236 miles), and many others. Of course, if a breakthrough in battery technology occurs, offering a major increase in energy density, then electric planes would be able to service even longer routes.

A more immediate example of electric aircraft adoption is that of Canada's Harbour Air, which recently announced that it will convert its entire fleet of seaplanes into an all-electric commercial fleet. Harbour Air flies mostly six-passenger de Havilland DHC-2 Beavers and will

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[14] Peggy Hollinger, "How the promise of electric power could transform aviation," *Financial Times*, September 18, 2018, https://www.ft.com/content/0a58d62e-aeb9-11e8-8d14-6f049d06439c.

[15] "Electrically propelled aircraft developments exceed 200 for the first time," Roland Berger website, January 15, 2020, https://www.rolandberger.com/en/Point-of-View/Electric-propulsion-is-finally-on-the-map.html.

[16] "Norway aims for all short-haul flights 100% electric by 2040," *The Local Norway*, January 18, 2018, thelocal.no/20180118/norway-aims-for-all-short-haul-flights-100-percent-electric-by-2040.

[17] Sarah Young, "Easy Jet expects to be flying electric planes by 2030," *Reuters,* October 29, 2018, https://www.reuters.com/article/us-easyjet-ceo-electric-idUSKCN1N31PS.

retrofit these planes with electric propulsion technology supplied by Redmond, Washington-based MagniX.

Harbour Air is North America's largest seaplane airline. It carries more than 500,000 passengers on 30,000 commercial flights annually between hubs like Seattle and Vancouver. Harbour first tested an electrified de Havilland seaplane in December 2019. The airline has committed to a fully electric fleet of float planes by 2022.

Roei Ganzarski, CEO of MagniX, stated that in 2018, 75% of worldwide airline flights were 1,000 miles or less in range.[18] Thus, short-haul flights within the Wright Electric airplane's projected range of 310 miles may account for up to 25% of commercial aviation emissions. Wright Electric is developing a 737-class electric airplane that it anticipates will enter service in 2030. Per its CEO, Jeffrey Engler, "Wright believes all short flights of up to 1,000 miles can be hybrid or electric by 2040, which would dramatically reduce emissions in aviation."[19]

The potential for emission reduction in the New York City metropolitan area may be even better. Embraer is a world leader in manufacturing regional commercial jets. In a 2018 speech, Embraer CEO Cesar de Souza e Silva stated that one third of the flights in and out of LaGuardia Airport occur on Embraer aircraft.[20]

In 2018, the FAA certified the first electric airplane, Pipistrel's Alpha Electro. Pipistrel is focusing on flight schools. Close behind is Bye Aerospace, which is also targeting flight schools. The FAA may certify Bye's eFlyer later this year. Bye has over one thousand orders for its two and four seaters, including a 60-plane order from Norway's OSM Aviation Academy. Per Bye Aerospace's website:

> According to industry sources, 80% of new student pilots drop out of training. The number one objection is cost. The answer: 20,000 new flight trainers are needed. The clean, all-electric Sun Flyer (recently renamed eFlyer) trainer is ideal as it dramatically reduces the ops-cost for flight training while replacing a small, obsolete training fleet of 10,000 conventional aircraft that averages nearly 50 years old.[21]

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[18] Betsy Lillian, "Harbour Air to Transition to Electric Seaplanes," *NGT News*, April 8, 2019, https://ngtnews.com/harbour-air-to-transition-to-electric-seaplanes.

[19] Stephanie Goulet, Assistant Chief of Staff, Wright Electric, "Sierra Club article mentioning Wright Electric," email message to Wayne Arden, February. 28, 2020.

[20] Paulo Cesar de Souza e Silva, Embraer CEO, "EmbraerX — The Next Generation of Flight," speech given at Uber Elevate Summit, Los Angeles, May 8, 2018, https://www.youtube.com/watch?v=fEhQPZs3f7E.

[21] Home page of Bye Aerospace website, "Growth," https://www.byeaerospace.com/.

The list below includes many of the leading companies pursuing electric or hybrid-electric planes that have been in the press. In general, these companies are in the design and prototyping phase, and must raise additional funding to advance to the manufacturing phase.

- **Ampaire** (Los Angeles, CA) — Ampaire is completing its electric propulsion technology, which it will use to retrofit existing propeller aircraft. In June 2019, Ampaire's hybrid-electric Cessna 337 Skymaster made its first test flight. Ampaire has signed letters of intent with over a dozen regional airlines around the world that fly routes accessible by electric aircraft. In particular, Ampaire is working with Mokulele Airlines in Hawaii, which primarily flies the nine-passenger Cessna 208EX Grand Caravan.
- **Bye Aerospace** (Englewood, CO) — Bye's eFlyers, mentioned above, use Rolls Royce motors. Bye is a startup and has been developing electric planes since 2010.
- **Airbus and Rolls Royce** (Europe) — These two companies are working together to test all-electric and hybrid-electric propulsion systems originally developed by Siemens. The partnership bases the plane, called E-Fan X, on a modified 100-seat BAe146 regional aircraft. They are aiming for the first flight of a prototype by 2021. The earliest a commercial aircraft could enter service is 2030. In 2019, Siemens sold its eAircraft business unit to Rolls Royce.
- **Embraer** (São Paulo, Brazil) — In August 2019, Embraer unveiled its fixed-wing, single-engine, demonstrator electric aircraft, based on Embraer's EMB-203 Ipanema crop duster. Another Brazilian company, WEG, is supplying the motor and controller. First flight is expected in 2020.
- **Eviation Aircraft** (Kadima–Tzoran, Israel) — Eviation's Alice Commuter is an all-electric aircraft designed to take two pilots and nine passengers up to 650 miles at a cruising speed of 240 knots (275 miles per hour). Eviation expects to introduce the plane commercially in late 2022. Eviation is using motors manufactured by MagniX and Rolls Royce. Eviation Aircraft's first commercial customer is Cape Air, a Massachusetts-based regional airline with flights in the US and Caribbean. Cape Air has a fleet of 94 aircraft, carrying over 500,000 passengers a year.
- **MagniX Technologies** (Redmond, WA) — MagniX is an Australian–US company focused on electric propulsion systems for aircraft, mentioned above. MagniX competes with Rolls Royce.
- **Magnus Aircraft** (Pogány, Hungary) — Similar to Pipistrel, Magnus Aircraft is developing an electric two-seater aircraft for flight schools and general aviation — the eFusion, an electric version of its Fusion aircraft.
- **Pipistrel** (Ajdovscina, Slovenia) — Pipistrel, mentioned above, was the first aircraft manufacturer to certify an all-electric aircraft. In addition, Pipistrel is working with Uber on an eVTOL aircraft.
- **Rolls Royce** (London, UK) — Rolls Royce, in collaboration with two other UK-based firms, YASA and Electroflight, is developing the ACCEL (Accelerating the Electrification of Flight) prototype. Rolls Royce is using energy-dense battery packs in an attempt to set a speed

record for an electric plane, greater than 300 mph, and a range of 200 miles, allowing flight between London and Paris. The ACCEL team will attempt its record-setting run during the spring of 2020. The UK government is partially funding this project.

- **VoltAero** (Médis, France) — VoltAero is developing a hybrid-electric airplane series called Cassio, using motors designed by Safran. Production versions are expected to fly three and a half to five hours, achieving speeds over 370 kph (230 mph). VoltAero plans to build four- and nine-seat versions of Cassio; they hope to start delivering airplanes in 2022.
- **Wright Electric** (Albany, NY) — Wright, mentioned above, is developing all-electric airplanes, targeting the lower end of the single-aisle commercial aircraft market, such as the Airbus 320 and Boeing 737 families. Wright Electric has begun the propulsion development program for its 186-seat aircraft, aiming to test the motor on the ground in 2021 and flight tests in 2023. It expects to complete development of the Wright 1 aircraft and enter it into service in 2030. Earlier this year, Wright Electric relocated its headquarters to Albany to take advantage of "extraordinary local engineering talent."[22]
- **Zunum Aero** (Kirkland, WA) — Zunum Aero is a hybrid-electric aviation startup backed by Boeing, Jet Blue, and the State of Washington Clean Energy Fund. The company estimates a $2 trillion to $3 trillion market for regional hybrid-electric aircraft over the next 10 to 20 years in the corporate jet and regional commercial aircraft market segments. The firm will start with a nine- to twelve-seat hybrid-electric aircraft and increase the size and capabilities over time as electric propulsion systems mature. Zunum has signed a deal with JetSuite for up to 100 planes and is targeting a flight range of up to 1,000 miles. Zunum hopes to deliver its first plane in the early 2020s. However, it is struggling from cash-flow problems; the company laid off most of its staff in November.

The companies targeting short-haul commercial jet flights commonly served by the Airbus A320 family or Boeing 737 planes, such as the Airbus–Rolls Royce partnership and Wright Electric, will take the longest to bring their planes to market.

Electric vertical take-off and landing aircraft manufacturers

In parallel with electric plane development, companies are pursuing electric VTOL (eVTOL) and hybrid eVTOL aircraft. Similar to the case of electric planes, these companies are largely in the design and prototyping phase. The startups and smaller companies, unlike established firms, such as Airbus, Bell, Boeing, and Embraer, will need to raise additional funding to advance to the manufacturing phase. The firms' engineering design choices and the projected flight ranges of their aircraft vary considerably.

[22] "Wright Electric Begins Engine Development Program for 186 Seat Electric Aircraft," press release on Wright Electric website, January 30, 2020, https://drive.google.com/drive/folders/1-HXsRRHNU9D_ApVT407nxNXJYieK0Esv.

By comparison, a typical helicopter used for downtown to airport trips, tourist excursions, or corporate and offshore transport is a Bell 407 light utility helicopter, which seats seven people (six passengers). A normal flight time is two and a half hours. Its maximum speed is 140 knots (161 miles per hour), maximum range is 337 nautical miles (388 miles), and maximum flight time is four hours.

Some eVTOL firms are attempting to create a new class of aircraft, "air taxis," which are small aircraft that consumers could use for commuting or short trips instead of cars.

Here are a number of the leading firms developing electric or hybrid-electric VTOL aircraft:

- **Airbus** (Marignane, France) — Airbus Helicopters is developing a multi-passenger, autonomously piloted eVTOL designed for urban air mobility using motors designed by Rolls Royce (formerly Siemens) and batteries developed by Airbus's Defense and Space arm. The City Airbus will carry up to four passengers and cruise at a speed of 75 mph. The current model has a flight time of 15 minutes. Airbus's prototype conducted its first flight in May 2019. Airbus hopes to introduce the City Airbus commercially by 2023. The City Airbus could replace traditional helicopters for short-haul flights, such as from downtown to an airport or seaport.
- **Airbus Acubed** — Acubed is the Silicon Valley innovation center of Airbus. Acubed developed the Vahana, a single passenger eVTOL aircraft with a range of 31 miles (50 km).
- **Airspace Experience Technologies** (Detroit, MI) — ASX was founded in 2018 and is a subsidiary of the Detroit Aircraft Corporation, founded in 2011. ASX's eVTOL concept, MOBi-One, employs six propellers on a tilt-wing design. It will carry five passengers, either autonomously or pilot-assisted, at speeds up to 150 mph for a distance of 65 miles. ASX has been testing a subscale prototype since 2018. In February, the company signed a cooperation agreement regarding the development of eVTOL aircraft with Spirit AeroSystems. Spirit designs and builds aerostructures for commercial and defense customers; its 2019 revenues were $7.9 billion.
- **Bell Helicopter** (Ft. Worth, TX) — Bell, a subsidiary of Textron, is developing the Nexus Air Taxi, a VTOL aircraft. Bell showcased its latest prototype at the 2020 Consumer Electronics Show in January. The Nexus 4EX can carry four to five passengers up to 60 miles (95 kilometers) at a cruise speed of about 150 mph (240 km/h). While intended to be an electric aircraft, it has been designed to be propulsion agnostic, and a hybrid version would extend that range to beyond 150 miles. Bell is behind the V-22 Osprey and V-280 Valor tiltrotors as well as decades of military and civilian helicopters. Bell has experienced partners. Safran, a French jet engine specialist, is designing the hybrid propulsion system. Thales, also a French company, is designing the flight-control computers. Bell anticipates flight testing in 2023.
- **Beta Technologies** (Burlington, VT) — Beta came out of stealth mode in early 2019. Beta unveiled its latest eVTOL prototype, the Alia, in November. The Alia is projected to have a

range of up to 250 miles (400 kilometers) on a single charge. That range is sufficient for the transportation of human organs for launch customer United Therapeutics. United Therapeutics CEO Martine Rothblatt was a founder of SiriusXM and is a lead funder of Beta Technologies. Beta is targeting production in 2024. Beta conducts testing at Plattsburgh International Airport.

- **Boeing's Aurora Flight Sciences** (Manassas, VA) — Boeing acquired Aurora in November 2017. Aurora is a leader in manufacturing unmanned aircraft. Aurora's autonomous Passenger Air Vehicle (PAV) completed its first flight on January 23, 2019. PAV has a range of 50 miles and is designed to transport 500 pounds, either people or cargo. Aurora is developing both two- and four-passenger variants with cargo options. Earlier this year, the Defense Advanced Research Projects Agency (DARPA) awarded Aurora a VTOL contract to develop an unmanned VTOL experimental plane. The program aims to increase top speeds in VTOL aircraft without sacrificing range and efficiency.
- **EHang Holdings** (Guangzhou, China) — EHang is a developer of autonomous and passenger eVTOL aircraft. In 2016, EHang unveiled its first Autonomous Aerial Vehicle (AAV). To date, EHang has safely conducted over two thousand trial flights in Austria, China, the Netherlands, Qatar, the UAE, and the US. As of December 2019, EHang had delivered 38 aircraft to customers. In addition, EHang went public in December, issuing an IPO on Nasdaq (symbol EH).
- **Embraer** (São Paulo, Brazil) — Embraer is the world's third largest producer of civil aircraft after Boeing and Airbus. Embraer has focused its EmbraerX initiative on urban mobility — improving transportation in large cities that suffer from traffic congestion. The first EmbraerX concept is a five-person (one pilot, four passengers) eVTOL aircraft. In addition, Embraer is working with partner Elroy Air on an autonomous aerial cargo aircraft called Chaparral, designed to carry 300 pounds up to 300 miles. Embraer has written a white paper about Urban Air Mobility (UAM): Flight Plan 2030.
- **Hyundai** (Seoul, Korea) — In October, Hyundai announced the formation of a new division, the UAM Division, naming a former NASA aeronautics engineer, Dr. Jaiwon Shin, as its head.
- **Impossible Aerospace** (Santa Clara, CA) — Impossible is focusing on drones for first responders. Its US-1 drone has a flight time of up to 78 minutes with a standard payload versus the typical 30 minutes. A drone with this extent of performance could replace traditional helicopters for many tasks, such as surveying crime scenes, power lines, and railroad tracks, searching for lost hikers, or reporting on local traffic conditions. The founder and CEO, Spencer Gore, stated, "A drone can provide about half of the utility of a helicopter

at less than one percent of the price. It can even be more useful than a helicopter, because a drone can fly lower and get in closer to evaluate dangerous situations."[23]

- **Jaunt Air Mobility** (Glassboro, NJ) — Jaunt is a start-up developing an eVTOL aircraft that has attributes of both a helicopter and a fixed wing plane. Jaunt projects that its four-passenger aircraft will achieve FAA certification in 2023 and be on the market in 2025.
- **Joby Aviation** (Santa Cruz, CA) — Joby is developing an eVTOL aircraft that will transport five people at speeds of 200 mph as far as 150 miles. Joby investors include Intel, Jet Blue, and Toyota. In January, Joby raised $590 million in Series C funding led by Toyota.
- **Karem Aircraft** (Lake Forest, CA) — Abe Karem founded his firm in 2004, which specializes in tiltrotor aircraft technology. Uber added Karem as a partner in 2018 because of its Butterfly concept. The Butterfly's four rotors are larger than typical eVTOL rotors. Consequently, they turn more slowly and are quieter and more efficient than those of competitors. Unlike Bell, Karem does not have experience building an entire aircraft.
- **Kitty Hawk** (Mountain View, CA) — Google co-founder Larry Page funded this startup. Kitty Hawk has developed Cora, a two-person eVTOL air taxi with a range of 62 miles that stays aloft for an hour. Kitty Hawk is testing its aircraft in New Zealand. In 2019, Kitty Hawk formed a joint venture with Boeing and Wisk Aero to commercialize Cora.
- **Lillium Jet** (Munich, Germany) — Lillium Jet is developing a five-person eVTOL aircraft with an intended range of 300 km (185 miles). China's Tencent and Twitter's Ev Williams are investors. Lillium's prototype first flew in 2017. The company has raised a total of $340 million in funding as of March and hopes to put the Lillium Jet into service by 2025.
- **Opener** (Palo Alto, CA) — Opener is developing BlackFly, a single-person eVTOL aircraft capable of landing on grass, asphalt, snow, or ice. It can travel up to 40 miles at a speed of 72 mph. One of Opener's investors is Google co-founder Larry Page. The BlackFly does not require a pilot's license to fly, as the US has classified it as an ultralight aircraft; it could eventually cost about the same as an SUV.
- **Tier 1 Engineering** (Santa Ana, CA) — On December 10, 2018, Tier 1 Engineering set a Guinness World Record for the farthest distance traveled by an electric helicopter. Tier 1's modified Robinson R44 four-seat helicopter traveled 30 nautical miles (35 miles) at an average speed of 80 knots (92 mph). Tier 1 has a contract with Lung Biotechnology PBC to produce an electrically powered, semi-autonomous rotorcraft for organ delivery. Lung Biotechnology PBC is a subsidiary of United Therapeutics Corporation (Silver Spring, MD).
- **Uber** (San Francisco, CA) — Uber states that Dallas and Los Angeles will be the first cities to offer Uber Elevate Air Flights, with the goal of beginning demonstrator flights in 2020 and commercial operations in 2023. Uber is working with eight Elevate vehicle partners: Boeing's

[23] Laura Kolodny, Andrew Evers, Jeniece Pettitt, "This engineer lived in an RV in Tesla's parking lot — now he's on a quest to build electric planes," *CNBC,* April 1, 2019, https://www.cnbc.com/2019/03/29/impossible-aerospace-ceo-spencer-gores-quest-to-make-planes-electric.html.

Aurora Flight Sciences, Bell, EmbraerX, Hyundai, Jaunt Air Mobility, Joby Aviation, Karem Aircraft, and Pipistrel.[24]

- **Volocopter** (Bruchsal, Germany) — Volocopter is developing an 18-rotor electric helicopter and first demonstrated a prototype in 2011, the year it was founded. The current version, the two-person VoloCity, features a maximum range of 35 km (22 miles) and airspeeds of up to 110 kph (68 mph), supporting flight times as long as 30 minutes. Investors include Daimler and Intel. In 2019, Volocopter raised €50 million ($55 million) to commercialize the VoloCity; the lead investor was the Chinese automaker Zhejiang Geely. The VoloCity will be built under contract by the German sailplane manufacturer DG Flugzeugbau. Volocopter has a multi-year partnership with the transit authority of Dubai to test its air taxis. Dubai's goal is to launch a commercial pilot program in the early 2020s.
- **XTI Aircraft** (Englewood, CO) — XTI, founded in 2009, is developing the Trifan 600, a hybrid eVTOL aircraft. The TriFan 600 will carry a pilot plus five passengers. XTI is targeting a maximum cruise speed of 300 knots (345 mph) and a range of 1,200 nautical miles (1,381 miles), equivalent to a flight from New York to Dallas. In May 2019, XTI successfully completed the first test flights of its 65% scale prototype. In July, XTI selected GE's Catalyst turbine engine for XTI's series hybrid propulsion system. XTI is targeting the business jet market segment and has an 81-order backlog, representing a half billion dollars in potential revenue. XTI is raising up to $30 million in a Series B (pre-production) round of funding.

Electric aircraft market

Beta Technologies' Rothblatt expressed well the potential of electric aviation: "We've seen 7% improvements in energy density every year for the past several decades," she said. "We need 300 watt-hours per kilogram in order to reach a range of 250 nautical miles (288 miles), which is what I'm asking for, and it's a no-brainer to see that we'll be there in just a few years."[25]

Beta engineer Kyle Clark described three key advantages of electric aircraft. The biggest is reliability: "With many fewer moving parts running at much lower temperatures, electric motors will go for three to ten times longer before requiring an overhaul," he said. Another is efficiency. Internal combustion aircraft operate at between 20% and 30% efficiency, while electric motors reach 90% to 99% efficiency, meaning they can be operated far more economically without emitting any pollution from the aircraft itself.

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[24] Uber website, "Uber Elevate vehicle partners," https://www.uber.com/us/en/elevate/partners/.

[25] Eric Adams, "Beta Technologies, A Vermont Air Taxi Start-up, Might Be About to Change the Aviation World," *The Drive,* January 11, 2019, https://www.thedrive.com/tech/25914/beta-technologies-a-vermont-e-vtol-air-taxi-start-up-might-be-about-to-change-the-aviation-world.

Finally, there is a clear performance advantage. “Electric motors put out a constant torque across all speeds,” Clark said. “This enables them to be used in a distributed propulsion configuration where the flight controller can demand and expect instantaneous thrust adjustments at any power level.” The result: ultra-precise control no matter the speed or attitude. In fact, eVTOL aircraft could safely cut power completely — such as to avoid a collision — go into freefall, then restart and recover before hitting the ground.[26]

Kobe Bryant’s tragic death in a helicopter accident on January 26, 2020 is a reminder that flying in helicopters is not as safe as in commercial airplanes. In March 2018, a sightseeing helicopter suffered an engine malfunction and plunged into the East River, killing five passengers. In general, helicopters have several single points of failure, including the main rotor, its mast, and the engine that rotates the mast. By contrast, most eVTOL designs incorporate distributed electric propulsion, i.e., multiple electric motors and rotors. An eVTOL aircraft will survive the failure of one or more motors or rotors.

In the New York metropolitan area, flight training schools include Long Island’s MacArthur Airport (Ronkonkoma) and Republic Airport (East Farmingdale), and Westchester County Airport. In northern New Jersey, flight schools are located in Essex County Airport, Monmouth County Airport, and Teterboro Airport (Bergen County). If electric airplanes gain significant market share in flight schools and in general aviation over the next few years, these sales would increase the probability of success in the segment that accounts for most of the emissions — commercial aviation.

Impossible Aerospace and Tier 1 Engineering are pursuing one of the most compelling eVTOL opportunities that could greatly improve emergency healthcare just a few years from now — the delivery of organs and patients to trauma centers. Consider this headline: “Air Ambulances Are Flying More Patients Than Ever, and Leaving Massive Bills Behind.”[27] This Bloomberg article explains that air ambulances, unlike their counterparts on the ground, have few restrictions on what they can charge for services.

Air Methods is a for-profit air ambulance company owned by a private equity firm. Per the GAO, its average charge increased from $13,000 in 2007 to $49,800 in 2016. Electric VTOL aircraft will significantly reduce the operating costs of air ambulances. Even more importantly, autonomous eVTOL aircraft should allow hospital systems to operate air ambulance services themselves, cutting out avaricious intermediaries, such as Air Methods.

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[26] Ibid.

[27] John Tozzi, “Air Ambulances Are Flying More People Than Ever, and Leaving Massive Bills Behind,” *Bloomberg*, June 11, 2018, https://www.bloombergquint.com/business/private-equity-backed-air-ambulances-leave-behind-massive-bills.

The electric aviation market is a nascent market, equivalent to the EV market in 2008 when Tesla started selling its first EV, the Roadster. In addition, aviation is heavily regulated. Regulators will move slowly in approving new electric aircraft and related techniques. **New York State could act as a catalyst by helping electric aircraft gain acceptance in the market, improving safety, reducing the cost of transportation, creating jobs, and lessening emissions.** In addition, the lower operating costs of electric aircraft versus traditional aircraft will give regional airlines new options to improve service on existing routes to smaller communities or to bring service to new communities. New York State could take the following actions:

- Require all publicly owned airports to purchase only zero-emission GSE starting in 2022 and to fully deploy them by 2030.
- Fund a study to analyze the potential for on-site electricity generation using renewable energy at all New Yok State airports.
- Fund assistance to hospitals to replace helicopters with eVTOL aircraft, which will dramatically lower the cost of transporting both organs and severely injured patients to hospitals.
- Fund grants or low-cost loans to flight-training schools and flying clubs to buy electric airplanes, defraying the initial higher purchase price versus conventional airplanes. The buyers representing these two market segments could jump-start zero-emission aviation in New York State. In addition, the quieter attributes of electric aircraft versus traditional aircraft will be much appreciated by constituents who live in neighborhoods adjacent to airports.
- Fund tax credits for consumers to stimulate the purchase of electric aircraft, similar to state and national tax credits promoting EV adoption.[28]
- Require sightseeing helicopters and airport transportation helicopters to fully implement fault-tolerant multi-rotor (eVTOL) aircraft by no later than 2030.
- Engage with aircraft manufacturing companies active in New York State, such as Beta Technologies and Wright Electric, to further explore efforts to create jobs in this rapidly growing industry.

By 2030 or a few years afterward, the potential exists for all commercial flights within New York State, including diagonally across the state from New York City to Buffalo (301 miles), to be flown using zero-emission aircraft.

[28] Admittedly, an airplane is a luxury good. However, a moderate tax credit, a form of economic nudge, would serve a greater good by helping to establish the market for zero-emission aircraft.

Sustainable Aviation Fuel

Background

Barring an unforeseen technological breakthrough in battery energy density, twenty years from now people will still be flying from New York to Tokyo in an Airbus 350 or a Boeing 777X. Medium to long-distance commercial flights will still require liquid fuel. Thus, the only way to reduce the emissions of these flights is to replace jet fuel (a type of kerosene) with an equivalent renewable fuel.

If a renewable fuel is made from biomass that is a waste material, then the lifecycle GHG emissions of substituting the biofuel for petroleum-based aviation fuel can result in a significant reduction in emissions. Most renewable fuels are biofuels in that they use some form of biomass as an input. (Hydrogen, if produced via renewable processes, would be an example of a renewable fuel that is not a biofuel.) The term sustainable aviation fuel (SAF) is granted to aviation biofuel that has been certified for use in jet aircraft by a credible independent third party.

On behalf of the Air Force, Boeing developed an experimental liquid-fueled hydrogen unmanned aircraft called the Phantom Eye, which could carry a payload of 450 pounds. Boeing conducted test flights of the aircraft from 2011 to 2014, but the Air Force did not fund further development. It would require decades of research, development, testing, and certification efforts before Boeing or Airbus would deploy a commercial airliner using hydrogen as a fuel.

Hydrogen is one of the world's most flammable substances. Per the National Fire Protection Association (NFPA) 704 rating, hydrogen is rated four, the highest and most dangerous. By contrast, the fuel commercial airlines use, Jet A, which is pure kerosene, is rated two. A Pacific Northwest National Laboratory website states that under optimal combustion conditions, hydrogen's minimum ignition energy is ten times lower than that of other common fuels, i.e., it is an order of magnitude more flammable.[29]

In addition, a liquid-hydrogen fueled aircraft would suffer from a range problem. Liquid hydrogen has only one fourth the energy density by volume of kerosene, although combustion of hydrogen is more efficient than kerosene. It is doubtful that a commercial aircraft fueled by liquid hydrogen could make a 14-hour non-stop flight from, say, Los Angeles to Sydney. Over the next 20 years, hydrogen is not a viable choice as a replacement for kerosene in large commercial aircraft. The only option that can be adopted in the near term is biofuel.

[29] Hydrogen Tools website, Pacific Northwest National Laboratory, "Hydrogen Compared with Other Fuels," Figure 4, Minimum Ignition Energy, https://h2tools.org/bestpractices/hydrogen-compared-other-fuels.

The first flight to use biofuel occurred over ten years ago. In 2018, Virgin Atlantic flew a 747 from Orlando to London using a 5% blend of biofuel. In spite of this milestone, airlines today do not yet use biofuel in significant quantities. Biofuel companies have struggled to both produce biofuel in industrial quantities and make it price-competitive with traditional jet fuel.[30] Per a report recently published by the International Energy Agency (IEA), the cost premium of a 15% blend of commercial aviation biofuel per passenger from London to Berlin is $2, from London to New York is $10, and from London to Sydney is $31.[31] More broadly, the biofuel industry's reputation as a whole is somewhat tarnished. A number of prominent startups declared bankruptcy over the last few years, including Range Fuels (2011), Kior (2014), and Solazyme (2017).

Nevertheless, there are some recent signs that this situation may be changing. Qantas announced in 2017 that, starting in 2020, it will purchase over eight million gallons of biofuel a year from SG Preston. Qantas will blend the renewable jet fuel, made from non-food plant oil, with traditional jet fuel in a 50%–50% mixture and use it for flights between Los Angeles and Australia. Jet Blue announced in 2016 that it will purchase 33 million gallons of blended jet fuel a year, also buying from SG Preston, starting in 2019. That blend will consist of 30% biofuel.

SG Preston's production capacity in South Point, Ohio, of 120 million gallons per year of renewable jet and diesel fuel may be the largest annual production volume of any US producer,[32] but this amount is a tiny fraction of the aviation fuel that commercial airlines consume globally. Statistica estimates that airlines consumed 96 billion gallons of fuel in 2019, up from 70 billion gallons ten years earlier.[33] According to the IEA, only five airports have regular biofuel distribution today: Bergen, Brisbane, Los Angeles, Oslo, and Stockholm.[34]

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[30] I have some insight into these challenges. Eleven years ago, I consulted for Carbon Recycling Inc (CRI). CRI was the first firm to recycle carbon dioxide in industrial quantities, using the carbon dioxide exhaust of a geothermal power plant and water as feedstocks to make renewable methanol. CRI's challenge was then, and is now, to make the price of renewable methanol competitive with standard methanol, which is derived from natural gas.

CRI's "Vucanol" is a renewable fuel but not a biofuel, as the production process requires no biomass. More recently, Bill Gates-backed Carbon Engineering and Climeworks have garnered publicity for developing plants that recycle carbon. The technical issues of recycling carbon are formidable, but these companies face an even greater hurdle of realizing a viable business model.

[31] Pharoah Le Feuvre, IEA Energy Analyst, "Commentary: Are Aviation Biofuels Ready for Take-off?" IEA website, March 18, 2019, https://www.iea.org/newsroom/news/2019/march/are-aviation-biofuels-ready-for-take-off.html.

[32] It is unclear if SG Preston could devote the entire volume of the plant to only renewable jet fuel.

[33] Statistica website, "Total fuel consumption of commercial airlines between 2005 and 2025," https://www.statista.com/statistics/655057/fuel-consumption-of-airlines-worldwide/.

[34] "Commentary: Are aviation biofuels ready for take-off?," Pharoah Le Feuvre.

Sustainable aviation fuel producers

A number of US companies make aviation biofuels. They include:

- **Fulcrum BioEnergy** (Pleasanton, CA) — Cathay Pacific, Endeavor Air, and United have signed offtake agreements for biofuel; Fulcrum has signed a feedstock supply agreement with Waste Connections and Waste Management, which is also an investor. Fulcrum is building a plant east of Reno, Nevada, and expects to start production in 2020. Fulcrum accepts household garbage that would otherwise go to a landfill, processes it, thereby removing inapplicable elements, and then refines aviation fuel using the Fischer-Tropsch process, a well-understood chemical process first developed in 1925. Fulcrum predicts that its Nevada plant will consume 175,000 tons of garbage a year, resulting in 10.5 million gallons of aviation fuel. United is expected to purchase up to 10 million gallons of aviation fuel from Fulcrum over the next two years.
- **Gevo** (Englewood, CO) — Air Alaska has been a customer for demonstration flights; production of aviation fuel is low. Gevo's fermentation technology can be applied to the production of ethanol or isobutanol. Per Gevo's March 2020 10-Q filing with the SEC, its Luverne, MN, production facility has a production capacity of 1.5 million gallons per year of isobutanol, which can be further refined into aviation fuel. However, Gevo focuses on market segments such as renewable diesel in addition to aviation fuel. In 2019, Gevo signed fuel supply agreements with Air Total, Delta, and Scandinavian Airlines. These agreements depend on the successful expansion of production facilities. Gevo was founded in 2005 but has never experienced a profitable year.
- **Honeywell UOP** (Morris Plains, NJ) — Honeywell UOP specializes in developing refining technology, which it then licenses to other firms.
- **LanzaTech** (Skokie, IL) — LanzaTech was founded in 2008 and produces low-carbon fuels made from industrial gases that otherwise would be emitted, or syngas generated by any biomass resource, such as municipal solid waste and agricultural waste. LanzaTech leverages anaerobic bacteria fermentation technology originally developed by the DOE's Pacific Northwest National Lab (PNNL). LanzaTech has partnered with Virgin Atlantic and signed an offtake agreement with ANA in June 2019.

  The DOE is in the negotiation stage with LanzaTech for a $14 million investment in a demonstration-scale integrated biorefinery at LanzaTech's Freedom Pines site in Soperton, GA.[35] LanzaTech formed a joint venture with Shoujang Group, a Chinese iron and steel producer, to build a plant in Caofeidian, China. The plant has produced over nine million gallons of ethanol from recycled steel emissions in its first year of operation.

[35] "LanzaTech advances on alcohol-to-jet scale ups in the United States and Japan," *Bioenergy International*, November23, 2019, https://bioenergyinternational.com/opinion-commentary/lanzatech-advances-on-alcohol-to-jet-scale-ups-in-the-united-states-and-japan.

- **Red Rock Biofuels** (Fort Collins, CO) — Red Rock was founded in 2011. Via a proprietary integration of existing technologies, Red Rock makes the Fischer-Tropsch process economic at biomass scale, using forest and sawmill residues as feedstocks. In July 2018, Red Rock began construction of a $320 million plant in Lakeview, OR, with a capacity of 15 million gallons of jet fuel per year. Red Rock is targeting the spring of 2020 for production start. Red Rock customers include FedEx and Southwest.
- **S.G. Preston** (Philadelphia, PA) — S.G. Preston was founded in 2012. As described earlier, it produces aviation biofuel in significant quantities. Jet Blue and Qantas are customers.
- **World Energy** (Boston, MA) — In March 2018, World Energy, a biodiesel producer, acquired AltAir Paramount. AltAir licensed Honeywell's Renewable Jet Fuel process technology that uses nonedible animal oils and fats as a feedstock to produce aviation fuel. In this case, AltAir used carinata seeds as a feedstock, a non-edible mustard seed. AltAir's Paramount, CA, plant, near LAX, had a capacity of 45 million gallons. Later in 2018, World Energy announced that it plans to invest $350 million to achieve a production capacity of 150 million gallons of biojet fuel per year. Customers include Lufthansa and United.

The largest US producer of advanced biofuels is Renewable Energy Group (REG), which reported revenues for 2019 of $2.4 billion. REG has a production capacity of 505 million gallons per year of advanced biofuels, predominantly biodiesel and renewable diesel, an order of magnitude more than the next largest US producer of aviation biofuel.

Sustainable aviation fuel market

At current course and speed, the replacement or blending of traditional jet fuel with biofuel will happen gradually. Only over the last few years have companies produced aviation biofuel in quantities of over a million gallons per year. As the pioneers expand their businesses, bigger companies like REG will acquire them or jump into the market themselves. Better access to capital should facilitate more investment in production facilities and improved economies of scale.

Neste is a major European supplier of petroleum and renewable fuels, with 2019 revenues of €15.8 billion ($17.2 billion). Renewable products accounted for 83% of the company's operating profit versus 18% generated by its traditional (petroleum) oil refining and distribution business. In 2019, Neste production capacity for renewable products was 3.1 million metric tons, up 20% from 2018's total.[36] Over the last several years, Neste has increased its focus on sustainable

[36] In 2019, Neste produced 3.09 million metric tons of renewable products, including renewable diesel, jet fuel, propane, and renewable solvents and raw materials for bioplastics. This figure is roughly equivalent to 959 million gallons per year, using the weight of a gallon of diesel fuel (3.2245 kilograms) as a proxy to convert from weight to volume. Neste Oyj, 2019 Annual Report, page 109, https://www.neste.com/corporate-info/news-inspiration/material-uploads/annual-reports.

aviation fuel (SAF). In 2019, Neste announced that KLM has purchased SAF produced by Neste for flights departing from Amsterdam's Schiphol Airport. The fuel is derived from used cooking oil and reduces emissions by up to 80% compared to traditional kerosene jet fuel. President and CEO Peter Vanacker wrote in Neste's 2019 annual report:

> In our Renewable Aviation business, we have moved from feasibility to execution and ramped up our capacity to produce up to 100,000 tons of renewable jet fuel. With further production expansion on the way, we will have the capacity to produce over 1 million tons of renewable jet fuel globally by 2022. In 2019, we also started collaboration with companies such as Air BP, Lufthansa, and KLM to support these industry players in reducing aviation-related emissions.[37]

The environmental benefits of aviation biofuel vary, depending on how it is made. In a 2016 report, the DOE's National Renewable Energy Lab (NREL) identified four pathways that aviation biofuel companies could leverage to make jet fuel: alcohol-to-jet (ATJ), gas-to-jet (GTJ), oil-to-jet (OTJ), and sugar-to-jet (STJ). Gevo is pursuing ATJ, LanzaTech and Red Rock are pursuing GTJ, and AltAir, Honeywell UOP, Neste, and S.G. Preston are pursing OTJ.

In the report's conclusion, NREL stated that the GHG emissions of the OTJ pathway are less than 50% of those of conventional jet fuel. The emission reduction of the GTJ pathway is even better; emissions can be less than 25% of those of conventional jet fuel. NREL did not specify a total figure for the ATJ pathway, since it lacked information about the final process of transforming alcohols into jet fuels. This pathway is the least environmentally beneficial of the four approaches, likely resulting in at least 50% of the emissions of conventional jet fuel.[38] No companies appear to be presently working on STJ processes for aviation biofuel.

LanzaTech in particular is worth keeping an eye on. It uses carbon emissions from heavy industry as a feedstock to make fuel, emissions that otherwise would be released into the atmosphere. The question is, can LanzaTech scale production in a cost-effective manner?

New York State could spur the adoption of aviation biofuel by urging more airlines to use biofuel and ensuring that airports make it available in significant quantities. The government should partner with international airlines and US airlines that use airports in New York as hubs: American, Delta, and Jet Blue.[39] In addition, the government should consider incentives to encourage instate production of aviation biofuel.

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[37] Neste Oyj, 2019 Annual Report, CEO's Review, page 5.

[38] Liaw Batan, Mary Biddy, Jennifer Markam, Eric Tan, Ling Tao, Wei-Chang Wang, and Yanan Zhang, "Review of Biojet Fuel Conversion Technologies," National Renewable Energy Laboratory, Technical Report, NREL/TP-5100-66291, July 2016, page 64, https://www.nrel.gov/docs/fy16osti/66291.pdf.

[39] Jet Blue's headquarters is in Long Island City, Queens, New York City.

Depending on the process, production of aviation biofuel in New York State could help cities better manage municipal waste or help farmers dispose of agricultural waste.

Carbon Offset and Reduction Scheme for International Aviation

In October 2016, the UN's International Civil Aviation Organization (ICAO) committed to regulate emission growth from international aviation starting in 2020 via CORSIA (the Carbon Offset and Reduction Scheme for International Aviation). CORSIA is a market-based system that gives the aviation sector the ability to offset growth in carbon emissions. CORSIA has three phases: the pilot phase (2021–2023), the first phase (2023–2027), and the mandatory second phase (2027–2035). The second phase will include all state signatories of ICAO except those least developed and small island countries that account for less than 0.5% of global air traffic.

The US committed to participating in the voluntary phases of CORSIA during the Obama administration. However, CORSIA only applies to international flights. Europe's ETS (European Trading Scheme[40]) applies only to intra-Europe flights. (ETS is a cap-and-trade system that puts a market price on European GHG emissions, including those from commercial aviation.) By contrast, the US has no national mechanism, via either a tax or a market-based system that prices GHG emissions. Moreover, the US has no regional mechanism that prices aviation emissions.

The US's ongoing support for CORSIA is unclear. Per a November 2019 *Politico* article, "The Trump administration has participated in the ICAO conversations and officially supports CORSIA, but the FAA has conditioned CORSIA implementation 'on a high level of participation by other countries, particularly countries with significant aviation activity'."[41]

One reason why European airports have been more proactive in promoting biofuel than US airports may be the influence of ETS. European airlines, especially those that have a high proportion of their flights within the EU, have a financial motivation to minimize emissions. A second reason, at least in Sweden, is the rise of "flygskam" (flying shame), a word coined around 2017. Climate activist Greta Thunberg underscored this new consumer movement by sailing roundtrip, rather than flying, from Plymouth, England, to New York to give her speech to the UN General Assembly in September.

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[40] A number of exchanges offer futures or spot trading on European emission contracts, including the US exchanges: the Chicago Mercantile Exchange, the Intercontinental Exchange, and Nasdaq. Dr. Richard Sandor pioneered emission trading when he founded and launched the Chicago Climate Exchange and the European Climate Exchange in 2003. The Intercontinental Exchange acquired both exchanges in 2010. It subsequently shut down the Chicago Climate Exchange when the US Clean Energy and Security Act, which passed in the House of Representatives in June 2009, stalled in the Senate.

[41] Kelsey Tamborrino, "What do global aviation emissions look like under Trump?," *Politico,* November 25, 2019, https://www.politico.com/newsletters/morning-energy/2019/11/25/what-do-global-aviation-emissions-look-like-under-trump-782994.

Robin Hayes, CEO of JetBlue Airways, told industry analysts during a conference call recently that it is only a matter of time before Americans follow the lead of their Swedish counterparts to find more environmentally friendly alternatives to commercial air travel. "This presents a clear and present danger, if we don't get on top of it," he said. "We've seen that in other geographies and we should not assume that those sentiments won't come to the US."[42]

Swedish state-owned railway operator SJ reported an 11% rise in 2019 passenger traffic, saying that concerns over the environmental impact of air travel have contributed to the increase.[43]

A 2019 survey by Swedish Radio showed that climate change is the most important political topic for young people today. In response, SAS has teamed up with Swedish fuel company Preem to increase production of biofuel in Sweden as it seeks to use biofuel corresponding to all its domestic fuel consumption by 2030.[44] Preem is the largest fuel company in Sweden; it refines and sells gasoline, diesel, heating oil, and renewable fuels.

US Emissions Trading

As stated above, the US does not have a nationwide system that prices the GHG emissions of electrical power plants, heavy industry, and aviation, unlike Europe. However, North America has two different regional GHG pricing systems, the Regional Greenhouse Gas Initiative (RGGI) and the Western Climate Initiative (WCI). RGGI members include all northeastern states plus New York, New Jersey, Delaware, and Maryland.

WCI consists of California, Nova Scotia, and Quebec. Having two inconsistent systems lessens the effectiveness of each system and lessens the likelihood that other states and Canadian provinces will join as members.

WCI is a more comprehensive initiative than RGGI. RGGI applies to carbon dioxide emitted by fossil-fuel electrical power plants. By contrast, WCI applies to all major GHGs (of which carbon dioxide is one) emitted by power plants, industrial sources, and distributors of fuel used in ground transportation, including gasoline, diesel fuel, liquefied petroleum gas, and natural gas.

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[42] Hugo Martin, "Travel by plane and you might get 'flight shamed.' This worries airlines," *The Los Angeles Times*, February 17, 2020, https://www.latimes.com/business/story/2020-02-07/flight-shaming-airlines-climate-change-greta-thunberg.

[43] Tommy Lund and Jaagda Darlak, "Sweden's rail travel jumps with some help from 'flight shaming'," *Reuters*, February 13, 2020, https://uk.reuters.com/article/uk-railway-sweden/swedens-rail-travel-jumps-with-some-help-from-flight-shaming-idUKKBN2071J7.

[44] Hanna Hoikkala and Niklas Magnuson, "As 'Flying Shame' Grips Sweden, SAS Ups Stakes in Climate Battle," *Bloomberg*, April 14, 2019, https://www.bloomberg.com/news/articles/2019-04-14/as-flying-shame-grips-sweden-sas-ups-stakes-in-climate-battle.

These emissions represent about 80% of the total.[45] As a result, California earns far more revenue from WCI than New York State does from RGGI. In FY 2020–2021, New York State expects to realize $118 million in revenues that it will spend on programs to mitigate climate change.[46] By contrast, California realized $3.2 billion in FY 2018–2019 auction revenues that it will spend on programs to mitigate climate change.[47] Correcting for California's larger population, California earns over thirteen times more in cap-and-trade revenue per capita than New York does.

[45] 2020 Annual Report to the Legislature on California Climate Investments Using Cap-and-Trade Auction Proceeds, California Air Resources Board, March 2020, page 2, https://ww3.arb.ca.gov/cc/capandtrade/auctionproceeds/2020_cci_annual_report.pdf.

[46] New York State's Regional Greenhouse Gas Initiative Investment plan, 2019 Operating Plan, Final Report, October 2019, page 7, https://www.nyserda.ny.gov/-/media/Files/EE/RGGI/2019-RGGI-Operating-Plan.pdf.

[47] California Air Resources Board, California Cap-and-Trade Program, Summary of Proceeds to California and Consigning Entities, last updated March 2020, https://ww3.arb.ca.gov/cc/capandtrade/auction/proceeds_summary.pdf.

Summary — actions New York State could take

To halt the rise of aviation emissions, governments and industry must pursue simultaneously the use of electric aircraft for shorter distances and conventional aircraft, fueled by biofuel, for longer distances. The implementation of CORSIA may be a positive influence in both cases.

New York State should consider a multi-faceted initiative to accelerate progress in the aviation sector. The actions suggested below would both reduce emissions and stimulate job growth. New York State should:

Airports

- Require all publicly owned airports in New York State to purchase only zero-emission GSE starting in 2022 and to fully implement them by 2030.
- Fund a study to analyze the potential for on-site electricity generation using renewable energy at all New York State airports.
- Adopt the SFO sustainability goals: that airports achieve zero net energy use, zero waste, and carbon neutrality, no later than 2025.[48]

Hospitals

- Fund assistance to hospitals to replace helicopters with eVTOL aircraft, which will dramatically lower the cost of transporting both organs and severely injured patients to hospitals.

Businesses and consumers

- Fund state grants or low-cost loans to flight-training schools and flying clubs to buy electric airplanes, defraying the initial higher purchase price versus conventional airplanes. The buyers representing these two market segments could jump-start zero-emission aviation in New York State. In addition, the quieter attributes of electric aircraft versus traditional aircraft will be much appreciated by constituents who live in neighborhoods adjacent to airports.
- Enact tax credits or sales tax forgiveness for consumers to stimulate the purchase of electric aircraft, similar to state and national tax credits promoting EV adoption.
- Require sightseeing helicopters and airport transportation helicopters to fully implement fault-tolerant multi-rotor (eVTOL) aircraft by 2030.
- Engage with aircraft manufacturing companies active in New York State, such as Beta Technologies and Wright Electric, to further explore efforts to create jobs in this rapidly growing industry.

[48] SFO is trying to achieve these objectives by 2021: SFO website, "Your Gateway to Green Travel," https://www.flysfo.com/environment/your-gateway-green-travel, accessed March 2020.

Aircraft and airlines

- Develop a program to reduce aviation emissions by motivating airlines to switch to electric aircraft for local and regional flights as soon as they are available.
- Develop a program to reduce aviation emissions in cities by motivating airport transportation companies, local governments, hospitals, news organizations, and tourist sightseeing companies to switch from traditional helicopters to eVTOL aircraft as soon as they are available.

Sustainable aviation fuel

- Develop a program to motivate more airlines to use SAF and ensure that airports make it available in sufficient quantities. The government should partner with US airlines that use airports in New York as hubs, American, Delta, and Jet Blue, and also international airlines.
- Offer incentives to encourage instate production of SAF.

National policy

- Advocate for the merger of RGGI and WCI into a common system. As New York State is the most populous RGGI member, the governor in a position to make this merger happen is Governor Cuomo.
- Advocate for the pricing of emissions nationally by either a tax or a market-based approach. A national system should apply to all significant commercial sources of GHG gas emissions, including power plants, industrial sources, and the three modes of transportation: ground transportation, aviation, and water transportation via boats and ships. WCI could be incrementally expanded and implemented in the US and a number of Canadian provinces.
- Advocate for the US to continue to participate in the CORSIA initiative.

International policy

CORSIA is a UN initiative and the UN, of course, is headquartered in New York City. Thus, New York State and New York City both have an opportunity and a responsibility to lead in the adoption of sustainable aviation practices: to achieve net-zero emissions at airports, to accelerate the use of zero-emission aircraft, and to work with domestic and international air carriers to adopt SAF for medium- and long-distance flights.