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Aspen aviation and climate change

Executive Summary

Runaway climate change is eroding Aspen's economy, ecosystem, and experience. We've lost a month of winter. Less snow, wilder weather, more fires, and more summer weight restrictions are coming.

Aviation causes 7% of global climate change. Oil-fueled airplanes cause 97% of Aspen Airport's analyzed carbon emissions. Fortunately, aviation innovations can decouple flying from climate change better, cheaper, and faster than enabling bigger fossil-fueled planes to fly into Aspen.

First, climate-safe jet fuel

The County's targeted 30+% greenhouse-gas cut can happen on time (2030)—and severalfold more. First, strongly switch now to Sustainable Aviation Fuel. Aspen Airport sells it, but at the Fixed Base Operation's exorbitant private-monopoly prices. The next few months offer the County's only chance for decades, if not forever, to change the FBO monopoly and regain fair-pricing power, better serving the public interest in our community's public resource. (Our Ad #3 and Essay #3 explained how.)

Sustainable Aviation Fuel (SAF) has begun intense growth. Made now from waste fats, soon mainly from other non-food wastes, it's blended 30/70 with jet fuel here, 50/50 elsewhere, and probably 100/0 by 2030 (as United has tested). Most top airlines, including Aspen's, endorse SAF to save 75–80% of fossil carbon emissions now, rising to 99% later. Revenue-neutral County or state financial innovations could make Aspen a world leader in turning SAF into pilots' preferred choice.

Then climate-safe equipment, buildings, and planes

Electrifying fossil-fueled ground equipment and vehicles has begun. Local examples prove how new terminals and other buildings can cost-effectively and resiliently burn nothing and produce net renewable energy. Superefficient, electric, and hydrogen aircraft due later in this decade can complete the win. If they're late, existing airliners and backups burning SAF can reliably serve ASE for decades.

The Airport Advisory Board's sensible carbon-tracking recommendations need to fill five data gaps and resolve two puzzles: FBO pricing reform that drops fuel prices could boost sales, paradoxically reducing fuel now wasted when pilots tanker in cheaper fuel from other airports. And if private planes' emissions were counted per passenger as they are for airline service, they'd be seen as a far bigger part of the climate problem—and of its collaborative solution.

Deeper questions for better answers

Higher climate ambitions are realistic: ten Swedish airports are already net-zero-emission in all but their planes, which are quickly going electric. And our Airport could evolve more smoothly and smartly with a clear conversation about who, if anyone, wants to bring more people into town, why, and where they'll stay. If that's not the goal, let's stop assuming and enabling it. If it is the goal, let's understand exactly how it can deliver the Aspen experience undimmed, for all, for ever.

Climate change has been a long time coming[1], but it's now inexorable, obvious, and dangerous[2]. Only those who value ideology over observation would have failed to notice that Aspen's winter has shrunk by a month[3] and continues to shrink. Our local leaders are concerned and are responding. Pitkin County, and the City of Aspen with its Canary Initiative climate plan, have long led on many aspects of climate protection. The Aspen Skiing Company, with much of the winter sports industry, cofunds a substantial public lobbying campaign, Protect Our Winters, to combat this threat to its core interests. SkiCo has also helped enlist prominent spokespeople such as X Games athletes to amplify potent national climate-protection messages. And SkiCo continues to improve the energy efficiency of its new and existing buildings and operations. Such leadership is appropriate and essential. It is also a very small parts of diverse global efforts—top-down, bottom-up, middle-out, by business, civil society, and governments at all levels—to slow, stop, and reverse the climate change being caused daily by billions of choices all over the world.

The global climate emergency is a looming danger to Aspen's economy, and also to Aspen itself. "Global weirding"[4] is not confined to winter. The 1961 record of two days' relentless monsoon rains turning to 27″ of snow by Labor Day morning[5] showed what's possible, but only half of historic greenhouse-gas emissions has yet taken effect; the other half, slowed by the seas' heat absorption, is yet to manifest. Record drought is rapidly raising wildfire threats, exacerbated by forest death[6] from diseases and from insects no longer inactivated by low-and-long winter cold (once regularly below –30˚F, but now below –20˚F just once during 1997–2019). The coldest periods are becoming rapidly warmer and briefer: deep cold is disappearing. The winter half of the year is warming nearly twice as fast as the warmer half. March is warming 1F˚ per decade.

Wildfires could also dramatically degrade Aspen's water quality, adding debris and costly-to-abate toxins[7]. Faster runoff from deforested slopes could trigger flooding and landslides from heavy downpours or rapid snowmelts. Recent wildfire catastrophes in California (and subsequent conversion to different kinds of forest[8]) are a warning of potentially unstoppable drought- and wind-driven fire risk not just to outlying mountain homes but potentially even to downtown Aspen. The current debate about the Entrance to Aspen is rightly noting Commissioner Steve Child's concern that wildfire might disable the single Castle Creek Bridge road, cutting off Aspen from downvalley traffic for support or evacuation. Our community is at an early stage of understanding the complex interactions and feedbacks from, to, and within climate change[9], and how this basic shift in how our world works could threaten more than just Aspen's economy.

Climate change complicates aviation

Climate change could affect the Aspen-Pitkin County Airport in many ways. It could change the volume, composition, and seasonality of air traffic; alter wind and weather patterns important to aviation; change precipitation and hence runway traction; cut visibility in wildfire smoke; and increase the number of summer days when high temperatures plus thin mountain air exacerbate weight restrictions. The E175LR+EWT airplane officially proposed to replace SkyWest's current CRJ-700 airline fleet is especially sensitive to such hot-day restrictions, seemingly to an extent that threatens its summer commercial viability[10]. However, our Essay #4 showed why such replacement won't be needed for 2–3 more decades, while Essay #5 showed that long before then, and even in *this* decade, the CRJ-700s and E175s, as well as other fueled airplanes, are both likely to be replaced by rapidly emerging superefficient, electric, and hydrogen aircraft.

Aviation exacerbates climate change

Conversely, aviation contributes to causing climate change. Each kilogram of jet fuel burned emits 3.16 kg of heat-trapping carbon dioxide (CO_2). Aviation contributes ~2.4% of global CO_2 emissions (including from changing land-use)[11], so it's easily dismissed as minor. But that contribution to global heating is now thought to be only about half as big as the net heat-trapping effect of persistent contrails[12]—trails of high-altitude ice crystals frozen from jet-exhaust humidity condensing around exhaust soot particles (and perhaps sulfate particles from residual sulfur in jet fuel). These contrails cause more heating, mainly at night, than they reflect incoming solar energy. This is the largest of several non-CO_2 terms that "are currently warming the climate at approximately three times the rate [and with about eight times the uncertainty] of that associated with aviation CO_2 emissions alone[13]." Thus aviation's total effect is ~7% of global heating, not just its CO_2's commonly cited 2.4%. Contrails alone contribute over 0.6 GTCO_2-equivalent per year[14]—nearly twice as much as aviation's CO_2 emissions.

Fortunately, less than a tenth of all flights may be causing 80% of contrail warming. This offers opportunities to forecast high-contrail-risk conditions[15] and integrate them into routine flight planning. RMI and Breakthrough Energy have therefore formed a Contrail Impact Task Force[16] with airlines, airframe makers, and other aviation, tech, and academic partners. Sustainable Aviation Fuel (discussed below), besides reducing CO_2 emissions by ~80% on a lifecycle basis, may also reduce soot release and droplet nucleation[17], thus reducing persistent contrails.

Certain jet engines also emit far more soot than others, suggesting the potential for near-term technological mitigation by better matching planes (and perhaps fuels) to critical atmospheric zones and times. For example, in Japanese airspace, where 2.2% of flights contribute 80% of contrails' warming effect, "selectively diverting 1.7% of the fleet could reduce" that warming by "up to 59.3%...with only a 0.014% increase in total fuel consumption and CO_2 emissions", while better engine technology could also cut contrails' climate effects by 69%[18]. Such improvements also raise engine efficiency, cutting CO_2 as well: soot indicates incomplete combustion.

Atmospheric chemistry is very complex. For example, jets' rising emissions of nitrogen oxides cause a short-term increase in infrared-absorbing ozone, partly offset by long-term drops in ozone and methane and a slight decrease in stratospheric water vapor. The net climate effect of nitrogen oxide emissions is currently thought to be a warming about half as important as CO_2, or ~17% of the total net warming effect of aviation[19]—on top of their direct hazard to public health.

Mitigating airplanes' contributions to climate change

Aviation adds about a billion tonnes of CO_2-equivalent to the atmosphere each year, and rapid growth in aviation has caused about half its cumulative global CO_2 emissions to occur in the past two decades. Further such growth could endanger social license to operate, so the industry is responding with a broad range of initiatives. The UN-sponsored International Civil Aviation Organization (ICAO), saying the global climate crisis is at "Code Red for Humanity," is calling on firms and nations to intensify their decoupling of aviation from climate[20]. On the other hand, while ICAO has established emissions reductions targets, IPCC says "only strategies to improve fuel efficiency and demand reductions have been pursued, and there has been minimal commitment to new technologies" [21]. The latest (2022) IPCC report continues to suffer from essentially the same flaw, as it has long done in many other areas of efficiency innovation.

The European Aviation Safety Agency EASA's 2022 *Environmental Report*[22] predicts that EU aviation could cut its 2050 CO_2 emissions by 69% compared with a frozen-technology business-as-usual scenario. Of those projected savings, 19% would come from improved technology and design, 8% from better operations and Air Traffic Management (called Air Traffic Control in the US), 5% from electric or hydrogen aircraft, and 37% from Sustainable Aviation Fuel. Our Essay #5 implies that the technology-and-design fraction may be understated as new and some existing vendors seek breakthrough competitive advantage. As mentioned in that Essay, the US is also introducing modest but useful aviation efficiency standards in 2023. Europe already did so in 2020 for new planes, and starting in 2028 for older models still in production.

The taxonomy of options is surprisingly rich. It does not include taxing jet fuel used in international travel—all tax-exempt under the 1944 Chicago Convention and dense thickets of treaties[23]. Aviation's climate-changing emissions can, however, be reduced by:

- Decreasing underlying long-distance travel demand, e.g. by preferring Zoom-sitting to jet-setting, or perhaps reduced *Wanderlust* or increased *flygskam* (flight shame);
- competing modes such as high-speed or ultralight rail if available (difficult in the US);
- more efficient routing such as point-to-point route architecture, direct GPS-guided free flight, continuous-descent and glide-maximizing approaches[24], potential wake energy retrieval when two aircraft cruise ~3 km apart, and other Air Traffic Control improvements: European planes in 2019 burned an average of 8.6–11.2% more fuel than they would have with ideal ATC, which policies are designed systematically to approach[25];
- filling more seats (already a highly developed part of airlines' yield management);
- "precision fueling" (whose adoption might earn on the order of a billion dollars a year for one big global airline by carrying more revenue passengers and cargo instead of thousands of pounds of transoceanic fuel beyond what safe and prudent practice requires[26]);
- eliminating "tankering" (carrying extra fuel to avoid buying it at the destination—as occurred on 21% of 2018 European flights, saving ~€265 million on fuel-price arbitrage but burning an extra 286,000 tonnes of fuel, or 0.54%, to haul that fuel around)[27];
- more widely using more-efficient existing airplanes, including such simple substitutions as Aspen-proven turboprops for ~70-seat regional jets, nominally saving ~45% of fuel[28];
- developing and adopting sooner still more efficient new planes, like the Transonic Truss-Braced-Wing (TTBW) Sustainable Flight Demonstrator project launched in January 2023 by NASA and Boeing to demonstrate 30% fuel savings in this decade, skipping a whole generation of airplanes[29];
- rapidly developing and adopting electric or hydrogen airplanes[30] (including electric Vertical Takeoff and Landing versions[31]), which our Essay #5 showed are likely to enter service a decade or two sooner than conventionally assumed; and meanwhile, importantly, powering existing conventional aircraft with
- Sustainable Aviation Fuel[32].

Sustainable Aviation Fuel (SAF)

SAF is the conventional, widely discussed, and most effective immediate pathway to far climate-safer aviation. The International Air Transport Association's technologically conservative decarbonization pathway to net-zero emissions by 2050 relies 65% on SAF. SAF can be synthesized by several pathways from a variety of feedstocks—ranging from municipal waste and used cooking oil to animal oils and fats, forestry and textile wastes, and fast-growing plants like algae. Some developers think carbon captured from the air may show promise as a SAF feedstock.

SAF's current price is currently about twice that of petroleum-based JetA. RMI and the World Economic Forum, with the Energy Transitions Commission and the Mission Possible Partnership, therefore created the Clean Skies for Tomorrow Coalition[33] to help ambitious stakeholders spur rapid SAF deployment, especially via a Sustainable Fuel Aviation Fuel credit (SAFc) program[34]. This financial innovation creates a high-quality carbon-credit certificate fungible for SAF. That unbundles SAF's current price disadvantage as a separately traded environmental commodity whose monetization can unburden operators already facing competitive challenges during recovery from the COVID-19 aviation slump. Where SAF isn't readily available, it can also be treated as a virtual fuel—physically supplied elsewhere instead and booked as an offset[35].

ICAO's Carbon Offsets and Reduction Scheme for International Aviation, CORSIA, in 2022 set a nonbinding net-zero carbon emissions goal for 2050. CORSIA's rules allow airlines to prioritize offsets to keep traffic growth carbon-neutral once they resume burning more fuel than in 2019. But unlike many other offsets, SAFc remains within the aviation industry's own value chain, making it easier to explain to customers and to capture regional air-quality and economic-development benefits. Carriers that unbundle SAF's environmental attributes from the fuel itself can also swap fuel traceably between their cargo and passenger operations. SAFc may further prove useful in marine shipping and, until overtaken by electrification, in heavy trucking. In 2023, RMI and Environmental Defense Fund announced a blockchain-enabled SAFc registry (using the efficient, fast, opensource tools developed by and with RMI's Energy Web Foundation initiative) to keep transactions transparent, traceable, and climate-effective[36].

SAF has been extensively tested in diverse aircraft up to and including an A380. (US military equivalents were extensively developed and deployed over the previous several decades.) SAF by 2021 had powered more than a quarter-million commercial flights—nearly all in a blend of up to 50% SAF with Jet A conventional aviation fuel, whose aromatic molecules are needed to keep older rubber gaskets and O-rings supple. Such blends are ASTM- and FAA-approved in the US and mandatory in Europe, where different kinds of SAF may in the medium term evolve to support different market segments. Industry committees are now examining a trajectory toward higher blends by fixing this temporary materials problem, and expect 100% SAF to be approvable by about 2030. United has already demonstrated 100% SAF on a Chicago-to-DC flight, and RollsRoyce's new UltraFan now entering testing combines 100%-SAF capability with 25% higher efficiency. (RollsRoyce also tested a hydrogen-powered jet engine a few months ago.)

Subject to the temporary 50% blending limit, SAF is a drop-in replacement for fossil-based jet fuel[37], globally certified under ICAO's CORSIA system. EASA expects SAF to supply 83% of Europe's aviation fuel in 2050. However, SAF costs ~2–4× more than the normal price of jet fuel, with the lower prices normal in dominant initial processes while the upper prices reflect less-mature processes now starting to scale using more-abundant feedstocks. Putin's War decreased or erased this initial SAF price disadvantage, but it is reemerging as world fuel prices re-equilibrate. The price gap is expected to shrink with scaling and innovation, though its trajectory remains uncertain, due to both tactical complexity and strategic competition.

SAF's price drop could slow or halt if rapid introduction of electric and hydrogen planes displaces SAF (perhaps slowing SAF's adoption in remaining fossil-fueled planes). Alternatively, superefficient planes would make SAF's higher price less important. But as long as fossil-fueled planes predominate, SAF is an important, large, and scalable part of aviation's near-term climate solution. Its production trajectory to at least 2030 looks broadly realistic[38]. Waste fats, oils, and greases can make ~5 billion gal/y of SAF or 3–4% of global jet fuel, then adding municipal solid waste and farm and forestry residues could reach nearly 90 billion gal/y or ~60%. Faster gains in aircraft efficiency and routing could meanwhile reduce projected fuel needs.

Bloomberg New Energy Finance is tracking 150 announced renewable-fuel projects with a total capacity of 16.2 billion gallons a year by 2030, currently set up for 10% SAF but increasable to 22% by 2030. That would be 3.6 billion gal/y, or half of global SAF demand under market forces with no new policies after August 2022. However, policy has an important role. Making road-vehicle biodiesel is currently ~$1.50/gal more profitable than making SAF, so the 2022 Inflation Reduction Act includes a SAF-specific tax credit rising from $1.25 to $1.75/gal with increasing emission savings. That should tip investment and production choices toward SAF, especially for newer processes about to be commercialized. If all projects planned for 2022–26 are built, they could produce over 2.5 billion gal/y of SAF by 2026, or 4 if they maximized SAF output, or 7.6 if all renewable diesel projects were adapted to maximize SAF production[39]. US federal policymakers on 23 September 2022 also launched the Sustainable Aviation Fuel Grand Challenge[40]. It aims to blend at least 3 billion gallons of SAF into US domestic jet fuel by 2030 (fitting current policies and announced airline targets), and 35 billion (100% of projected demand) by 2050.

Producing SAF from common lipid and biomass feedstocks—about 95% of current SAF, likely to stay over 80% until 2030—cuts the fossil CO_2 released by a total of about 75–80%, conventionally expressed for neat SAF rather than a blend and using CORSIA methodology. Chemical-synthesis routes can raise this figure of merit to ~85–94%, and power-to-liquid routes using green electricity can achieve ~99%[41]. As SAF scales, these more climate-effective versions are likely to dominate, with some market complexities because all processes co-produce biodiesel or similar road fuels plus some lighter ones. Several watchdog organizations are also tracking SAF production to detect and deter potentially abusive feedstocks such as palm oil, especially in the near term when feedstock categories include some that may raise ethical issues. Fortunately, the SAF industry is being careful not to compete with food supplies—a conflict readily avoided[42].

SAF has the further advantage of lower sulfur content, and often contains far fewer soot-forming aromatic molecules than fossil jet fuel's roughly one-fifth (hence the SAF gasket issue), so as mentioned above, SAF reduces formation of persistent contrails, boosting its climate benefits.

SAF adoption and pricing

Initial SAF deployment is under one-thousandth of world jet-fuel use, and was under 0.05% in Europe in late 2022, but it is rapidly growing and widely supported by industry[43] and policymakers. The EU proposes to mandate at least 2% SAF in 2025, ramping aggressively to 63% in 2050. At the World Economic Forum's 2021 Sustainable Development Impact Summit, an impressive list of more than 100 countries, companies, and other stakeholders released a joint Ambition Statement to power global aviation with 10% SAF by 2030[44]. By mid-2022, 38 of the world's 66 top airlines—including United, American, and Delta—had committed to net-zero emissions by or before 2050, as have 242 European airports. Many airlines are signing multi-year SAF purchase contracts that elicit and help finance new capacity. Delta and American have announced especially strong decarbonization goals under the Science Based Targets initiative. Their European rivals will need to start paying for their CO_2 emissions starting in 2026, and the EU is considering adding a tax on aviation kerosene for the first time.

Aspen's current FBO operator, Atlantic Aviation, since April 2021 has offered SAF procured and trucked in from Los Angeles by the respected industrywide fuel provider Avfuel. Atlantic maintains a continuous SAF supply at its four Colorado FBOs (Aspen, Telluride/Montrose, Steamboat Springs/Hayden, and "Aspen/Rifle") and across California. On 7 February 2023, airnav.com reported a full-service ASE SAF price of $11.74/gal, vs. $10.54 for Jet A—both quite high for structural reasons discussed in our Essay #3. For comparison, the same database on the same day showed Atlantic's LAX FBO as selling Jet A for $9.08 and SAF for $10.08, while other FBOs within 20 miles of LAX sold SAF for $7.86[45]–$10.97, averaging $9.28.

Atlantic also reported using all-renewable biodiesel for its ground support equipment at LAX[46], and from 22 November 2022, using biodiesel-fueled Avfuel trucks to deliver SAF to all four of its Colorado FBOs for a ~30% blend with Jet A. Atlantic's airport-terminal ads reportedly stating that all its Aspen aviation fuel is sustainable reflect its carbon offsets for all General Aviation fuel and, unusually, all commercial aviation fuel sold at ASE[47].

We suggest the AAB and advisors assess whether Aspen Airport could encourage a dramatic shift to SAF by:

- adopting the SAFc financial innovations,
- raising the local 30% blending fraction to the normal 50% and then to 100% as quickly as standards permit, and
- optionally but importantly if feasible, at least equalizing SAF's price with Jet A's by a differential tax or fee on fossil-based jet fuel (perhaps expressed as a climate impact charge) *coupled with a rebate to SAF*. This may be feasible on a local or state level, and could be revenue-neutral to the buyer and seller and neutral or favorable to the County. It would become easier if the FBO structural reforms proposed in our Essay #3 restored the County's power to influence or control aviation fuel prices to be fair and reasonable in the public interest.

Local-government and Aspen Airport efforts to abate climate change

Pitkin County's longstanding concern about climate change has driven many of its policies and priorities, with many commendable outcomes. The City of Aspen is similar engaged. Yet other priorities remain to be fulfilled. For example, on 31 October 2022, ASE's FBO operator of the past 15 years, Atlantic Aviation, gave CORE $0.5 million to start research on abating ~9,000 tonne/y of methane from the Coal Basin mines above Redstone. Those vast methane emissions cause more climate harm than emissions from all "buildings, transportation, aviation and waste in Pitkin County combined[48]." Atlantic Aviation said it intends to "continue to support the project" after the initial research phase[49]. This welcome effort has been hanging fire for decades, and could probably have progressed faster if prioritized with earlier public support and attention within a fully comprehensive climate strategy. Its implementation may also create local carbon-offset opportunities.

Assessing and abating the biggest fossil CO_2 emissions ascribed to activities within Pitkin County are caused by buildings, road vehicles, and Aspen Airport. Here we discuss just the Airport among these opportunities for major reduction.

Direct "Scope 1" emissions must of course be supplemented by "Scope 2" emissions to include those from fossil-fueled power plants providing electricity to Airport facilities and equipment. Very helpfully, Holy Cross Energy, the exceptional Rural Electric Cooperative that powers the Airport and most customers in the County, expects to raise the renewable fraction of its electricity deliveries from 39% to 100% by 2030. The City of Aspen's municipal electric system is already a 100%-renewable pioneer. Both providers have a strong interest in resilient supply.

It's relatively easy to estimate how much CO_2 (and other greenhouse gas such as NO_x) is emitted by the Airport's collective buildings, ground equipment (such as tugs, pushback tractors, Aircraft Ground Power Units, snowplows, de-icers, fuel tankers, emergency vehicles, etc.), runway and ramp lighting, other exterior lighting, fuel pumps, and Airport-operated road vehicles. These emissions are practical and generally profitable to abate by a mixture of efficient operation, efficient design, electrification, and fuel-switching. A variety of existing, proposed, and potential policies and efforts can help speed these shifts, importantly facilitated by CORE and other public, private, and nonprofit entities.

On the Airport's airside, some progress has already been made with specialized vehicles and equipment, whose energy use can be tracked. A 2021 Aspen Chamber press release[50] reports that "70% of the ground support equipment at the Atlantic Aviation FBO at ASE is electric and operates on renewable technology[51]. This percentage will continue to be increased over time as Atlantic Aviation evaluates the integration of Electric Powered Units that facilitate power to aircraft while being serviced," saving fuel, noise, pollution, and emissions. No doubt the Airport Advisory Board will be exploring this opportunity, tracking progress, and seeking data and speeding action on SkyWest-owned ground equipment supporting ASE's commercial operations.

Since a new Passenger Terminal, FBO terminal, and other construction are all being proposed, it's worth noting that most if not all new buildings in our Valley should be net-zero-energy or better, so they produce each year at least as much energy as they use. (The Passenger Terminal project has that declared intent.) Perhaps less familiar is that, as Amory Lovins's Old Snowmass house / office / research center showed to ~200,000 visitors since 1983), making buildings so efficient that they need little or no space-heating or -cooling *need add little if any extra construction cost* if they're properly designed and built. That building's 80 passive-solar banana crops are optional, and it needn't look like it does to work like it does. RMI's net-positive, no-mechanicals, passive-solar Innovation Center in downtown Basalt is another good example of superefficient integrative design, providing superior comfort, esthetics, and 100-year planned durability with good economics. Though new public- and private-sector buildings in our Valley show improving energy efficiency, some dramatically, many seem to get stuck in incremental improvements that raise construction cost, rather than more than paying for their efficiency gains by shrinking or eliminating mechanical equipment.

Superefficient *and integratively designed*[52] buildings' design lessons should prove adaptable to the new Terminals and other structures—especially if the design professionals are paid for what they save, not what they spend, using Performance-Based Design Fees[53] and Integrated Project Delivery[54]. Such arrangements brought in RMI's unusual Basalt building slightly ahead of schedule and budget. In 2015 it was the most efficient commercial structure in North America's coldest climate zone, using about one-sixth to one-ninth the normal amount of gross energy and negative net energy.

Ensuring that buildings' built-in solar power works with or without the grid, and integrating rooftop solar power with groundmount solar power as the Airport evolves into an energy hub producing solar electricity and probably hydrogen, can also contribute importantly to our community's energy resilience—a topic of deep concern since Aspen came within one minute of losing power in the Lake Christine wildfire over 2018's July 4th weekend.

Estimating Airport CO_2 emissions

The volunteer Airport Advisory Board is blessed to include Rick Heede, a leading authority on greenhouse gas assessment. He and AAB Chair Jacque Francis (who leads the Keeling Curve Prize climate-innovation competition) proposed on 13 December 2022, and the Board of County Commissioners approved on 8 February 2023, a process for tracking ASE's climate-harming emissions[55]. The AAB's analysis reveals[56] that *about 97% of total 2019–20 Aspen Airport CO_2 emissions come from airplanes* (based on fuel sold), 1.5% from County-owned buildings on Airport land, and 0.5% from county and tenant ground support equipment. Thus electrifying all the equipment and making the buildings superefficient, passive-solar, etc., is worthwhile but small. The climate payoff is overwhelmingly in aviation, which ASE can only encourage.

CO_2 emissions by road vehicles owned by third parties and partly associated with the airport, such as shuttle vans, buses, rental cars, private cars, and employee commuting, are relatively small and can be hard to attribute between different purposes and activities, so their emissions have been removed from the Airport's Baseline inventory and will no longer be estimated. (This departs from some recommended practices but is understandable and probably justified.) However, some Commissioners think contract renewals with car-rental firms and others may offer opportunities to obtain better data. The Baseline inventory also doesn't yet include FBO or FAA Tower emissions, but is planned to.

The AAB's sensible approach includes asking the County to require the FBO, which provides all aviation fuel at the Airport, to track and report its fossil and SAF aviation fuel sales. The results would be posted at www.aspenairport.com and updated every three years for comparison with the 2019/20-average Baseline. As part of that increased transparency, we also encourage the County to require the FBO, under the post-September 2023 new contract arrangements discussed in our Essay #3, to track and report General Aviation (GA) deplanements and emplanements just as the airlines do. Knowing how many people arrive and depart by GA—a mystery described at the start of our Essay #3—would yield sounder public policy and support more efficient and effective private-sector planning and better guest experience.

Policy puzzles

The AAB's proposed method of estimating airplanes' fuel use from on-airport fuel sales (both commercial and GA, currently aggregated) seems broadly reasonable, because aviation fuel is conventionally attributed to the departure airport no matter where the plane is going or who owns, operates, or occupies it. This convention is recommended by the National Academies[57], adopted by the Intergovernmental Panel on Climate Change (IPCC), and followed almost universally by practitioners. It allows consistent estimates that count each airplane's fuel combustion once and only once. The AAB recommends widely used accounting conventions for calculating emissions from those aviation-fuel sales, and emphasizes that "transparency of calculations and results is paramount." But like any other convention that might be chosen, tracking our Airport's climate-protection progress by measuring its aviation fuel sales is fraught with ambiguity.

If aviation fuel sales decrease because fewer people choose to fly or they fill more empty seats, or if commercial or private operators choose airplanes that burn less or no fossil fuel, or if operators substitute SAF for fossil fuel in existing planes, that's all climate progress. However, if aviators buy fuel elsewhere to fly in *and out* of Aspen Airport to avoid its high fuel prices, that doesn't result in lower CO_2 emissions—quite the contrary, because such tankering (as mentioned above) uses *extra* fuel to carry the fuel being flown in for later use, rather than delivered by efficient (and renewably fuelable) diesel tank trucks.

As our Essay #3 showed, the current FBO operator's private monopoly charges exceptionally high prices for aviation fuel sold at ASE. The same operator also reinforces that price regime by leveraging its FBO operations in the region, and reportedly in some instances by linking fuel pricing to sales of other services. If the County chooses in the coming months to continue that private monopoly structure, it will lock in the extra emissions caused by tankering. But if the County instead, as Essay #3 proposed, changes the FBO's business structure to introduce fair and reasonable fuel pricing, then the 2019/20 inferred-emissions Baseline will need to be reset, because lower fuel prices imply higher fuel purchases, yet this will decrease emissions. Why?

Ordinarily, buying more fuel at Aspen Airport would be interpreted as retrogressing on climate goals, but to the extent it comes from reduced tankering, that's actually climate progress. We encourage the AAB and County to inquire urgently into the current extent of tankering, which we understand prevails among most if not all of ASE's main operators: they have no desire to come to Aspen to buy fuel. We also encourage the AAB to prepare for Baseline revision if the FBO regime changes, prices drop, sales rise, and tankering falls. Those would all be good things, should be recognized as climate progress, and shouldn't mask or dilute later improvements.

Another puzzle is how ASE Vision and County analyses so far compute and compare the fuel efficiency of aircraft. The data presented to ASE Vision and underlying the County's policies compare CO_2 emissions per Landing and Takeoff Cycle (LTO) *not per aircraft but per* *passenger* (assuming every seat is filled, so the actual metric is per *potential* passenger)[58]. Emissions per aircraft can be computed by adjusting for the nominal number of seats per aircraft, but this information was not presented. We have encouraged its inclusion in future analyses[59].

The per-passenger metric's rationale is that fewer LTOs will be needed to bring the same number of passengers to and from Aspen. On this "passenger-normalized" basis, as interpreted by County consultant Kimley-Horn in August 2019, an existing 70-seat CRJ-700 was said to emit 35.62 g of CO_2 per passenger per LTO (based on ICAO standard mission assumptions), a 76-seat Embraer E-175LR with Extended Wingtips 26.96, and a non-ASE-compliant (115′ wingspan) 140-seat A220-300 14.33. However, *per aircraft*, their respective emissions would be 2,493 for the CRJ-700, 2,049 for the E-175LR, and 2,006 for the A220-300—advantages of 18–20% *vs.* the CRJ-700, not 24–60%, and far short of the County's ≥30% reduction goal.

Such comparisons are also very sensitive to load factor (percentage of seats filled), which at ASE is typically around 70% but rises to ~100% at peak periods and falls much lower in off-season. Load factors may shift markedly if aircraft types or schedules change. Year-to-year variations in average load factor over the past decade often exceeded emission intensity differences between aircraft types. More fundamentally, whether to normalize emissions per passenger depends on one's assumptions about whether switching to aircraft with more seats would actually result in fewer flights, or would instead be used to bring in more people.

Critics might reasonably infer that the County and its consultants presented only per-passenger emissions to favor the bigger planes that the County hopes to allow. Yet curiously, although ~83% of ASE operations are not airline flights but General Aviation (as discussed in our Essay #3), as far as we know *the County never applies this per-passenger metric to General Aviation.* If it did, then General Aviation's fraction of ASE's aviation emissions would be very much larger, because GA airplanes generally have an order of magnitude *fewer seats* than SkyWest's airplanes serving the airlines.

Also of note, BOCC Resolution 105-2020 at p 8 requires negotiations with "airlines and FAA to achieve agreements with the county that ASE will be served by aircraft with…greenhouse gas and other emissions that are significantly lower than the CRJ-700…." This is framed in terms of emissions per *aircraft*, not per passenger. (It could not reasonably be interpreted as meaning per-passenger because it also requires "seat limitation of no more than 100–120 passengers," making the number of passengers highly uncertain.) Leaving aside that the County lacks authority and the airlines lack motivation for such an agreement, this provision hardly seems meaningful, and may not be realizable using the aircraft officially proposed.

Data gaps

Our Essay #3 identified at least five important kinds of missing information worth reviewing here. Lately ~83% of Aspen Airport's landings and takeoffs are General Aviation rather than commercial (airline) planes, but very little is publicly known about those GA planes and their occupants. The FBO knows more but is apparently reluctant to share that information.

First, no data are available on how many people fly into Aspen on GA planes. In principle, this could be roughly inferred from Line 19 ("Persons aboard") of mandatorily filed Flight Plans. Some uncertainty is inevitable because of deviations from plan without filing an amendment (such as unplanned stops to emplane or deplane passengers), incomplete filings, and uncertainties about crew count; but even approximate data would be much better than none. Many Aspen and Pitkin County ski- and resort-industry actors would love to know how many people come to and leave from Aspen by what modes, including mixtures of air with ground transport. It would also help to ask Eagle/Vail Airport car-rental and shuttle providers roughly how many people fly into EGE but then drive to ASE—reportedly a surprisingly large number.

No data seem to be available on the extent of fuel tankering by current aviation operators to avoid the very high aviation fuel prices allowed and encouraged by the current FBO private monopoly structure. This must be understood to make the Baseline meaningful.

No data are available on how many seats are in ASE-landing GA planes, though this could be easily computed by combining type characteristics with operational statistics (the County knows the distribution of operations among the main aircraft types). As an initial indicator, our essay #3 documents in Ref. 5 that a 2017 FAA study assumed that 40% of itinerant US GA flights carry overnight passengers and that each such flight averaged 2.84 passengers (Essay #3, Ref. 1, notes that in 2018, ~79% of ASE operations were itinerant, 21% local); also that the average European private jet carries 4.7 passengers, but 41% of flights carry none (e.g. because they're drop-and-go, or deliver something other than people, such as pets[60] or special food items).

No data are available on the emissions of ASE-operating GA aircraft (though again these could be inferred from operational statistics and type characteristics). Yet *their fraction of ASE's aviation emissions would probably be an order of magnitude larger on a per-passenger than a per-aircraft basis*[61]. That is, whatever is the GA fraction of emissions from ASE aviation, it's probably far larger if counted the same way the County counts emissions for commercial airplanes. This obvious but apparently overlooked fact makes the County's virtually complete emphasis on commercial rather than all airplanes' CO_2 abatement even less justifiable and productive. It also increases the importance of the AAB Safety Task Force's interest in collaborating with GA trade organizations, which should share an interest not only in safety but also in fuel economy and emissions. Let's dig a bit deeper on why this is important.

No data seem to be available on the split in ASE aviation fuel sales between GA and commercial operations—the first step in starting to understand these sectors' relative importance in emissions and their abatement potential. It's unclear why this number is secret: the County seems (we infer) to defer to asserted competitive confidentiality even though the data are held by a private monopolist with no local competitor[62]. We think the County could insist on getting this information, could legitimately publish it, and should. The operator's cost and price structures would not thereby be revealed, though they can be roughly estimated from available data breadcrumbs.

Meanwhile, a local expert has told Aspen Fly Right that the ASE fuel-sales split in a recent 12-month period averaged about 59% GA and 41% commercial. If that were correct, then since the average commercial plane was two-thirds full (46 passengers), General Aviation's inferred emissions share of ASE aircraft emissions *per passenger* would be not 59% but *97%* if the average GA plane carried 2 passengers, 94% with 4, 91% with 6, 88% with 8, 85% with 10, etc., converging to 59% with an implausible 46 (that is, if GA and commercial planes had the same average number of passengers)[63]. Thus on any reasonable assumptions, *probably over 80% and plausibly perhaps 90+% of* total *Aspen Airport CO_2 emissions per passenger appear to be coming from General Aviation.* The County's virtually 100% focus on abating emissions *from commercial aircraft* thus seems especially misdirected. Conversely, the dynamism of the GA industry may increase its share of the opportunity for aviation innovation to make GA a vital part of ASE's climate solutions.

These five "no data are available" items strongly suggest the importance of promptly determining and publishing their value by AAB or consultant analysis, perhaps using suitable statistical sampling methods if a database is big and unwieldy. Without this information, the County cannot make sound decisions or provide transparent governance, nor can citizens perform their civic duty to learn, scrutinize, understand, assess, and inform.

Level of climate ambition

The Board of County Commissioners' Resolution 105-2020 (16 December 2020) set at p 5 a goal of reducing Airport greenhouse gas emissions" (i.e. CO_2-equivalent emissions) by at least 30% "as soon as possible, but no later than 2030". With ~97% of inferred Airport CO_2 coming from airplanes, that clearly implies major use of SAF or changes in aircraft or probably both, as well as a suite of operational improvements including more sophisticated ramp procedures[64].

EASA's 2022 Environmental Report[65] says that for European airport emissions fully within the airport's control, i.e. for buildings and ground equipment but *not* for airplanes, "More than 90 airports are already set to achieve net zero CO_2 emissions by 2030, with 10 airports managed by Swedavia [in Sweden's[66] severe winter climate] having already achieved this target." More than 500 European airports have committed to do so by 2050 at latest. This suggests it would be realistic and appropriate for the County to adopt more-ambitious non-airplane emission targets.

Aspen Airport might get some useful advice on certain implementation details from the Airport Carbon Accreditation Council of the Airports Council International—a global operation since 2014, including 24 member airports in North America, all at the initial tier of six levels of potential achievement[67]. By the standards described here, this program is not ambitious—it excludes airplane changes, assumed be outside airports' influence—but it links ASE with helpful global experience. Swedavia may be a more helpful direct mentor and partner[68].

Most importantly though not immediately, as our Essay #5 documented, it now seems likely that superefficient, electric, or hydrogen[69] airplanes of suitable range and capacity, offering ~80–100% CO_2 reductions—on the order of three times the County's goal—will enter commercial service on a similar timescale (2030), but without needing to invest ~$200+ million to expand the airside for bigger planes. This would indicate and require a realignment of County policies and decision processes, as this series of Essays explores.

What kind of community do we aspire to sustain and become?

That realignment would also benefit from renewing and deepening the ASE Vision conversation about community character and values. That Working Group, after all, voted 5–0[70] that it wouldn't be right "to proceed with airside development for the foreseeable future unless we have a better understanding of what a much larger airport will mean for the character of the community."

It would clear the air, literally and figuratively, to have a better understanding of who, if anyone, wants to bring more people into Aspen, why, and where those visitors would stay. Those people and organizations who hold this goal should identify themselves and explain their reasoning.

Newcomers to our community who expect it to offer the same travel options they had where they came from, such as nonstop flights to the East Coast, could be helped to adapt to their now being in a different place with different goals, options, and opportunities. Or, if they wait a bit, they could still get their wish from superefficient planes (think bigger Celera-style point-to-point offerings described in Essay #5), probably within a decade or so, but without putting important community values at risk from bigger and potentially dirtier and noisier airplanes.

Old-timers too should reflect on what the adopted target of 0.8% annual growth in Aspen air traffic actually implies, who benefits, who loses, and who decides. To be sure, the Safety Task Force's 26 January 2023 technical meeting revealed important potential innovations starting to emerge in the more-efficient use of Aspen's scarce airspace. If successful, these might safely permit both more and safer flights. This in turn may allow direct flights to more (and farther) places, increasing choice and convenience while reducing emissions—not only via inherently clean aircraft but also by not needing two flight segments to achieve the purpose of one.

Yet arithmetic is inexorable: seemingly sedate 0.8%/y growth means a 50% increase in 51 years and a doubling, a 100% increase, in 87 years. Should a child born here today look forward to an Aspen with twice as many airplane-arriving guests as those to whom our community now struggles to deliver a consistently wonderful experience? Are Aspenites twice as happy and well-off as we were 30 years ago, when Aspen Airport had half[71] as many air-carrier operations as it did in 2022? Does our community really need (as Airport planning assumes), does it want, and can it gracefully accommodate growth in winter emplanements *nearly six times faster*[72] *than their actual average growth over the past three decades*? Says who? Why?

These are difficult and perhaps uncomfortable questions, but they are at the root of the thinking we all need to do together to keep our Airport a key source of our well-being and progress—and to sustain the hospitable physical climate on which our safety, health, and prosperity all depend.

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[1] Amory Lovins's first professional paper on climate change was in 1968, and his 1976 *Foreign Affairs* paper correctly called its timing. Prof. Carroll Wilson's 1972 SCEP and 1971 SMIC studies from MIT Press reflect most of the fundamentals of climate change as it is now, far more elaborately, understood.

[2] Intergovernmental Panel on Climate Change, https://www.ipcc.ch; Aspen Global Change Institute, "A User Guide to Climate Change Portals," https://www.agci.org/projects/climate-portal-guide.

[3] C. Lutz ("Degrees of warming in Aspen," Aspen Journalism, 22 Dec 2019, https://www.aspendailynews.com/news/degrees-of-warming-in-aspen/article_d089629e-2453-11ea-a00a-3ffdea573610.html, reports frost-free days per year fell by a total of 31 days during 1980–2018.
[4] This term is from L. Hunter Lovins.
[5] *Id.*
[6] Western Slope Conservation Center, "Beetle Kill & Aspen Decline," https://westernslopeconservation.org/beetle-kill-aspen-decline/; US Forest Service updates at https://www.fs.usda.gov/main/r2/forest-grasslandhealth.
[7] T. Petach, "Water quality impacts under the worsening wildfire regime," Aspen Global Change Institute, Nov 2022, https://www.agci.org/research-reviews/water-quality-impacts-under-the-worsening-wildfire-regime.
[8] E. Jack-Scott, "After the megafires: What's left and what's next," Aspen Global Change Institute, Sep 2021, https://www.agci.org/research-reviews/after-the-megafires-whats-left-and-whats-next.
[9] Aspen Global Change Institute, "Learning from the Land," strategic plan for the Roaring Fork Observation Network 2022–32, https://www.agci.org/wp-content/uploads/imported-files/2022/08/iRON-Strategic-Plan-(1).pdf.
[10] Lean Engineering, *Airspace Impact and Aircraft Feasibility Assessment Update*, 25 Aug 2018 report (filename suggests 26 Aug draft) to Aspen Pitkin County Airport https://aspenairport.wpenginepowered.com/wp-content/uploads/2020/09/ASE_Airspace-and-Aicraft-Feasibility-Draft_082618-1.pdf [*sic*] analyzes these restrictions in §8.8.2 starting on p 83. For example, in the typical weather analyzed, estimated maximum load factor for the E175-LR+EWT flying ASE-ORD would fall below 60% for five hours a day in June, nine in July, and seven in August; below 90% ASE-DEN for five hours in June and nine in July and August; below 80% ASE-DFW for ten hours in June, 15 in July, 13 in August, and nine in September; and below 80% ASE-LAX for three hours in May, 15 in June, 16 in July and August, 13 in September, and three in October; and so on. Many of the less favorable cases call into question whether this aircraft could be seriously considered a viable commercial candidate. All summer or longer would experience frequent and highly disruptive offloads and flight cancellations. Moreover, Lean Engineering's assessment relies on old weather data (discussed on pp 12–33) and would be very sensitive to the increased temperatures and associated challenges to be expected from the general summer warming trend.
[11] IPCC, AR6, WG III, §10.5, p 1086 (mentioning that about two-thirds of these 2018 emissions were from international flights), https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf.
[12] A good lay introduction by J. Fredenburgh, "Clouds created by aircraft have a bigger impact than the emissions they emit," is at http:///www.imperial.ac.uk/news/242017/clouds-created-aircraft-have-bigger-impact/.
[13] D. Lee *et al.*, "The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018," *Atmospheric Environment* **244**:117834, 1 Jan 2021, https://doi.org/10.1016/j.atmosenv.2020.117834/.
[14] A. Klauber, N. Harvey, & K. Wight, "The Low-Carbon Jet Fuel market Is Cleared for Take-Off," RMI, 22 Oct 2020, https://rmi.org/the-low-carbon-jet-fuel-market-is-cleared-for-take-off/.
[15] Called ice supersaturated regions or ISSRs. These occur where the air is cold but humid at certain times and altitudes (often in a thin slice): R. Teoh *et al.*, "Aviation contrail effects in the North Atlantic from 2016 to 2021," *Atmos. Chem. Phys.* **22**:10929–10935 (2022), https://doi.org/10.5194/acp-22-10919-2022.
[16] J. Cathcart & A. Chen, "Contrail Mitigation: A Collaborative Approach in the Face of Uncertainty," 21 Nov 2022, RMI, https://rmi.org/contrail-mitigation-a-collaborative-approach-in-the-face-of-uncertainty/; RMI, "Airlines Unite with Tech Sector and Academia to Tackle Climate Challenge of Aviation Contrails," 21 Nov 2022, https://rmi.org/press-release/airlines-unite-with-tech-sector-and-academia-to-tackle-climate-challenge-of-aviation-contrails/.
[17] C. Voigt *et al.*, "Cleaner burning aviation fuels can reduce contrail cloudiness," *Commns. Earth & Envt.* **2**:114 (2021), https://doi.org/10.1038/s43247-021-00174-y.
[18] R. Teoh *et al.*, "Mitigating the Climate Forcing of Aircraft Contrails by Small-Scale Diversions and Technology Adoption," *Environ. Sci. Technol.* **54**(5):2941–2950, 2020, https://pubs.acs.org/doi/10.1021/acs.est.9b05608.
[19] Ref. 17.
[20] ICAO, Aviation & Environmental Outlook, July 2022, https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ENVReport2022_Art5.pdf.
[21] Intergovernmental Panel on Climate Change (IPCC), AR6, WG III, *Climate Change 2022: Mitigation of Climate Change*, Technical Summary, p 99, https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf. Unfortunately, the analysis of technology options on p 1087 is seriously deficient, cites only one 2017–18 reference (five times—the authoritative but quite outdated ICAO expert-group report #10127 published in 2019 at http://www.icscc.org.cn/upload/file/20200603/20200603140731_33885.pdf), and ignores timely review critiques offering evidence supported by peer-reviewed literature. IPCC therefore wrongly concludes that "the literature does not support the idea that there are large improvements to be made in the energy efficiency of aviation that keep pace

with the projected growth in air transport." This information-lag issue has persisted for at least three IPCC cycles across virtually the whole range of end-use efficiency opportunities in all sectors. The discussion of alternative powertrains and fuels (pp 1087–1089) is also badly outdated. The entire aviation analysis on pp 1086–1093 is nonetheless worth reading as a summary of conventional wisdom around 2015–18—now being rapidly overtaken by events before the AR6 synthesis report is published in 2023.

[22] https://www.easa.europa.eu/eco/sites/default/files/2022-09/220723_EASA%20EAER%202022.pdf.

[23] International Air Transport Association, "Tax Exemption on Jet Fuel," https://www.iata.org/contentassets/ebdba50e57194019930d72722413edd4/iata-position---tax-exemption-on-jet-fuel.pdf, expresses the views one would expect. However, some countries do tax other jet fuel, and the EU in 2021 proposed to tax intra-EU aviation fuel as part of its Fit for 55 strategy: https://www.transportenvironment.org/wp-content/uploads/2021/07/2010_01_Briefing_domestic_fuel_taxation_briefing.pdf.

[24] Optimized Profile Descent is now allowed at 64 US airports, of which 11 were added in 2022: "Your next flight might land a lot smoother and quieter than you're used to as new rules that save fuel expand to more airports," 7 Feb 2023, *Business Insider*, https://blinks.bloomberg.com/news/stories/RPQ977CGBL6O (subscriber product).

[25] EASA, *European Aviation Environmental Report 2022*, https://www.easa.europa.eu/eco/sites/default/files/2022-09/220723_EASA%20EAER%202022.pdf, at p 12. The metrics and improvement plans at pp 83–97 are impressive.

[26] Based on a rough estimate by a very senior longhaul pilot who routinely achieves his share of such outcomes by overcoming complex institutional barriers to paying careful attention how much fuel is really needed—and thereby not only increasing profits but also avoiding the ~1/3–1 pound of fuel needed to carry each pound across the Pacific. The European Union Aviation Safety Agency (EASA) in 2022 revised its regulation about contingency fuel reserves to align safe fuel planning and management with environmental goals, offering three increasingly sophisticated tiers of effort. EASA estimated that this could save up to 1 million tonnes of EU operators' fuel annually or ~1% of European flight emissions: summary at https://blog.openairlines.com/easa-fuel-policy-why-should-airlines-implement-a-fuel-monitoring-system, 19 Dec 2022, whose references include the original 25 Mar 2022 EASA release at https://www.easa.europa.eu/en/newsroom-and-events/press-releases/easa-publishes-new-fuelenergy-rules-positive-environmental describing Decision 2022/005/R. The savings accrue mainly on longhaul flights (>4,000 km), which in 2020 were 6.2% of EU flights, carried 10% of total seats and over 40% of seat-km, and emitted half of CO_2: https://www.eurocontrol.int/publication/eurocontrol-data-snapshot-co2-emissions-flight-distance.

[27] Ref. 25, at p 10.

[28] B. Corliss, "Outlook 2023: Turboprops: Embraer and De Havilland look to future, leaving market to ATR," 9 Jan 2023, https://leehamnews.com/2023/01/09/turboprops-embraer-and-de-havilland-look-to-future-leaving-market-to-atr/. (Savings naturally depend on mission and many other parameters.) As noted in our Essay #4, Pitkin County and its consultants adamantly reject the excellent Dash-8/Q400, in production until 2021 and in successful Aspen service until 2016, because main US airlines no longer use it, although it flourishes in the other 95% of the global market and is more fuel-efficient than the E-175 (B. Fehrm, "Carbon footprint: Regional jet versus turboprop, how large is the difference?," 27 Jan 2022, https://leehamnews.com/2022/01/27/carbon-footprint-regional-jet-versus-turboprop-how-large-is-the-difference/#more-38364). Fehrm concludes, consistent with our Essay #4's analysis, that "With new, more comfortable turboprops in the works, the drive for sustainability could see a return of the turboprop to the US market." As our Essay #5 notes, electrified and hydrogen turboprop adaptations are also being developed.

[29] NASA Release 23-008, 18 Jan 2023, "NASA Issues Award for Greener, More Fuel-Efficient Airliner of Future," https://www.nasa.gov/press-release/nasa-issues-award-for-greener-more-fuel-efficient-airliner-of-future. NASA is investing $425 million of Space Act funding, Boeing and partners ~$725 million, aiming at 2028 testing for early-2030s service at Mach 0.80. The Transonic Truss-Braced Wing design's 30% fuel saving is compared with today's *most* fuel-efficient single-aisle aircraft, not with the fleet, and continues the line of development in the SUGAR prototypes shown in our Essay #5. The wings will fold nearly in half to avoid reconfiguring airports (https://simpleflying.com/boeing-ttbw/), reportedly using a 170′ wingspan like Boeing's 2019 design (https://www.boeing.com/features/2019/01/spreading-our-wings-01-19.page); the final design's folded wingspan is not yet known, but might conceivably fit Aspen's current 95′ limit if one published report from 14 Dec 2020 is correct (https://mentourpilot.com/boeing-ttbw-a-persistent-idea-maturing/). In any event, the TTBW design would have to compete with, among others, the ~8× fuel saving available with short wings and extensively laminar flow (Essay #5), and likely to be available sooner in ASE-relevant size and range, albeit at lower airspeed.

[30] According to Ref. 25, p 62, hydrogen airplanes could use fuel cells, reducing climate impact ~75–90% (they emit more water than jet fuel or SAF combustion but no particulates to nucleate persistent contrails), or gas turbines (~50–75% and emitting NO_x). Battery-electric airplanes would emit nothing, and their climate impact could be zero (other than the energy embodied in their materials) if they use renewable electricity, which will dominate in many markets by the time there could be many electric planes in service. Hybrid-electric designs would have climate

impacts between those of fossil-fueled or SAF-fueled and battery-electric planes. Superefficient planes' impacts would depend on their powertrain and be reduced in rough proportion to their efficiency gain.
[31] The Vertical Flight Society's site https://eVTOLnews provides extensive data and news on many hundreds of models since 2017, plus extensive technical and industry resources. As of 5 Feb 2023, its eVTOL Aircraft directory https://evtol.news/aircraft listed and described 256 models with vectored thrust, 139 lift+cruise designs, 106 hoverbikes or personal flying devices, 225 wingless, and 52 electric rotorcraft, for a total of 778 designs, obviously not all commercial and with production intent. In 2022, Leehamnews.com's "Bjorn's Corner" series published an extensive set of 25 eVTOL commentaries; they reflect deep aeronautical knowledge and contain many useful insights and critiques, but tend toward a conservative view of mass, composite-structure manufacturing techniques, and some other key technical parameters. We'll soon know who's right, with Archer and United announcing eVTOL shuttle service from downtown Manhattan to Newark Airport for ~$100 as early as 2025, the Paris vertiport test site aiming for 2024 first commercial service, and other early releases likely. Bloomberg New Energy Finance counted $3.63b raised in 80 private-market deals in 2022 by low-carbon aviation technology firms, including $2.39b for urban air mobility firms, mostly air taxi developers: T. Kawahara, "Air Taxi, E-Fuel Startups Raised Most Aviation Tech Funds," 13 Jan 2023, https://www.bnef.com/shorts/15481 (subscriber product).
[32] World Economic Forum and McKinsey & Company, "Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation," Nov 2020, https://www3.weforum.org/docs/WEF_Clean_Skies_Tomorrow_SAF_Analytics_2020.pdf; Resolution A41-21 passed Oct 2022, https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A41-21_Climate_change.pdf; "ICAO advocates for decarbonization of aviation at COP 27," 7 Nov 2022, https://www.icao.int/Newsroom/Pages/ICAO-advocates-for-decarbonization-of-aviation-at-COP-27.aspx, stating that "The introduction of radical, disruptive, and in many cases revolutionary innovations in technologies and operations is now required to deliver the overall decarbonization needed to keep global temperatures in check." Oddly, though, the Long-Term Global Aspiration Goal of net-zero-carbon global aviation by 2050 would reduce emissions to 203 $MtCO_2$/y from 2050 while assuming *no* improvement in aircraft technology *after* 2050: https://www.icao.int/environmental-protection/pages/SAF.aspx/. Further valuable references from the Energy Transitions Commission are at https://www.energy-transitions.org/sector/transport/aviation/.
[33] World Economic Forum (with PwC Netherlands and RMI), "Powering Sustainable Aviation Through Consumer Demand: The Clean Skies for Tomorrow Sustainable Aviation Fuel Certificate (SAFc) Framework," 2022, https://www.weforum.org/reports/powering-sustainable-aviation-through-consumer-demand-the-clean-skies-for-tomorrow-sustainable-aviation-fuel-certificate-safc-framework.
[34] Ref. 14.
[35] This "book-and-claim" option is offered by Atlantic Aviation at ASE, San Jose, Orlandop: https://www.4air.aero/press/atlantic-aviation-teams-with-4air-for-100-saf-book-claim-at-nbaa-bace., 4 Oct 2022.
[36] RMI, "SAFc Registry," 2023, https://rmi.org/saba/safc-registry/.
[37] Jet fuel is a class of kerosene fuels, heavier than gasoline but lighter (more hydrogen-rich) than diesel fuel. It comes in various flavors—different freezing points and flashpoints, civil or military—and contains more than 2,000 different kinds of hydrocarbon molecules, so it is classified by performance, not by exact composition. Its carbon was absorbed from the ancient atmosphere into primeval plants that were transformed by heat and pressure into petroleum over geological time. In contrast, the carbon in SAF came from the atmosphere very recently, so cycling it from and back into the atmosphere is "on current account" rather than adding carbon that hasn't been in the atmosphere for many millions of years. Most SAF is made from currently grown biological materials or wastes. Emergent processes seek to make SAF by capturing carbon from the atmosphere and combining it with hydrogen, which can be produced with or without releasing greenhouse gases—ideally as "green hydrogen" split from water using renewable electricity.
[38] Ref. 25, pp 73–80.
[39] D. Robinson & J. Patterson, "2022 Sustainable Aviation Fuel Outlook: Picking Up Pace," Bloomberg New Energy Finance, https://www.bnef.com/insights/29527/view, 15 Aug 2022 (subscriber product).
[40] J. Patterson, "US Sustainable Aviation Fuel Grand Challenge Aptly Named," Bloomberg New Energy Finance, 3 Oct 2022 (subscriber product).
[41] Ref. 32. All feedstocks and routes reduce fossil-fuel CO_2 emissions by less than 100% due to fossil fuels still used for process heat, power, or building the equipment, or sometimes from land-use and other complexities of lifecycle analysis. A simple process comparison is B. Fehrm, "Bjorn's Corner: Sustainable Air Transport. Part 54. Sustainable Aviation Fuel Production," 20 Jan 2023, https://leehamnews.com/2023/01/20/bjorns-corner-sustainable-air-transport-part-54-sustainable-aviation-fuel-production/. More details start at p 70 of Ref. 25. The EU's Renewable

Energy Directive (2018, Article 29) requires ≥65% lower CO_2 emissions from SAF made in facilities started after 2021, or ≥70% for renewable fuels of nonbiological origin. The CORSIA standard is ≥10%, plus other conditions.

[42] However, United's holding company, low-carbon ethanol producer Green Plains Inc. (which has nearly 1 billion gal/y of current capacity), and energy infrastructure firm Tallgrass Energy Partners LP have invested up to $50M in Blue Blade Energy for corn-ethanol-to-SAF production. This could fit well into the industry's diversifying process and feedstock portfolio. The low-carbon credentials of this feedstock will doubtless receive due scrutiny. Of course, a large US corn ethanol industry already exists (with varying and debated attributes), and electric cars could free up its gasoline blending to make SAF instead for airplanes.

[43] World Economic Forum, "What 6 aviation executives say about an EU sustainable aviation fuel blending mandate," 16 Jul 2021, https://www.weforum.org/agenda/2021/07/what-6-executives-europe-aviation-sector-say-eu-sustainable-fuel-saf-blending-mandate-refueleu/.

[44] Clean Skies for Tomorrow, "10% Sustainable Aviation Fuel by 2030," https://www3.weforum.org/docs/WEF_EMBARGOED_CST_Ambition_Statement_for_Signatories.pdf.

[45] At Burbank's Bob Hope Airport (KBUR) from Million Air Burbank, compared with Jet A for $6.81/gal. Atlantic's KBUR FBO station sold Jet A for $8.71 and reportedly didn't offer SAF. The lowest reported price on 7 Feb 2023 was L.A. County Aviation's public FBO at Whiteman Airport (WHP), 19 miles north of LAX, selling Jet A for $5.88: https://www.airnav.com/fuel/local.html. In Nov 2022, leading SAF producer NESTE delivered a half-million gallons (1,500 tonnes) of SAF to LAX's multi-airline fuel distributor LAXFUEL: https://www.neste.us/releases-and-news/renewable-solutions/neste-delivers-more-500000-gallons-sustainable-aviation-fuel-los-angeles-international-airport, 22 Nov 2022. Subscribers to PLATTS' database can compare retail with wholesale SAF prices.

[46] Atlantic Aviation, "Atlantic Aviation Introduces Sustainable Aviation Fuel at ASE on Earth Day," 22 Apr 2021, https://www.atlanticaviation.com/news/atlantic-aviation-introduces-sustainable-aviation-fuel-at-ase-on-earth-day.

[47] Atlantic Aviation, "Atlantic Aviation Offers Consistent Supply of Sustainable Aviation Fuel at all Colorado Locations," 22 Nov 2022, https://www.atlanticaviation.com/news/atlantic-aviation-offers-consistent-supply-of-sustainable-aviation-fuel-at-all-colorado-locations. The offset went into effect 1 Dec 2021 and was announced by the Aspen Chamber at https://aspenchamber.org/blog/atlantic-aviations-new-carbon-offset-program-aspen-fbo.

[48] See https://aspencore.org/coal-basin-climate-project/.

[49] M. Webber, "Coal Basin project receives big donation," 31 Oct 2022, https://www.aspendailynews.com/news/coal-basin-project-receives-big-donation/article_9f8ab318-58c7-11ed-b36e-ef41f10f786f.html.

[50] Ref. 47, second citation.

[51] The last phrase appears to refer to the FBO operator's contract with Holy Cross Energy for all-renewable electricity supply under its PuRE Power Mix program.

[52] A.B. Lovins, "How big is the energy efficiency resource?," *Env. Res. Ltrs.* **13**(9), 090401, https://doi.org/10.1088/1748-9326/aad965, summarized in a half-hour seminar at https://youtu.be/Na3qhrMHWuY. Lovins teaches this design method at Stanford University.

[53] C. Eley, "Energy Performance Contracting for New Buildings," RMI, 2004, http://eley.com/sites/default/files/pdfs/energy_performance_contracting_for_new_buildings_rmi_ef.pdf.

[54] https://rmi.org/our-work/buildings/scaling-zero-net-carbon/rmi-innovation-center/design-process/.

[55] R. Heede & J. Francis, "Memorandum on ASE Climate Emission Baseline & Inventory Updates," 13 Dec 2022.

[56] S. Condon, "Pitkin County faces challenge reducing airport emissions," *Aspen Daily News*, 8 Feb 2023, p 1, https://www.aspendailynews.com/news/pitkin-county-faces-challenge-reducing-airport-emissions/article_a799c84c-a763-11ed-9ec3-bf1bcddda09a.html.

[57] National Academies and Transportation Research Board, *Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories*, 2009, https://doi.org/10.17226/14225, at p 17.

[58] Using here the "Commercial Aircraft Data" table presented to the fourth meeting of the ASE Vision Technical Working Group, https://aspenairport.wpenginepowered.com/wp-content/uploads/2020/09/Meeting-4-Aircraft-Data-and-Characteristics-PDF.pdf. The several variants all appear to be presented only per-passenger.

[59] In the discussion following Amory Lovins's 19 Oct 2022 brief for Jacobsen | Daniels and the Airport Director, cited in our Essay #4, Ref. 32.

[60] Such as petairways.com, happytailstravel.com, petjets.co, doggonetaxi.com, flypets.com, bluecollarpettransport.com, airpetsinternational.com, airanimal.com, etc.

[61] Our essay #3's Ref. 5 notes some of the complexities and uncertainties of such comparisons, including the increasing importance of "sub-charter" carriers offering semi-scheduled services in aircraft with more seats than typical GA models.

[62] Indeed, the operator's control of several nearby FBOs bolsters its ASE monopoly pricing power by making pilots fly farther and have less choice when seeking cheaper fuel elsewhere.
[63] A simple way to estimate the GA fuel share is to divide the ~41% commercial fuel share by 46 passengers, then compare the result with 59% divided by the assumed average number of GA passengers. If the two datapoints three paragraphs earlier are any guide, the GA share of inferred ASE aviation emissions *per passenger* could exceed 90%.
[64] These should include serious consideration of the kinds of scheduled staging of ground operations between door closure and takeoff (at least for commercial planes) routinely used at many European airports. We have connected the Safety Task Force with a local corporate pilot with long experience of those orderly procedures, which can save fuel, emissions, time, money, and ramp staff time.
[65] Ref. 25, p 105. The Airports chapter, pp 99–111, contains many potentially helpful ideas for Aspen.
[66] Sweden's aviation industry has agreed to end fossil-fuel reliance by 2030 and ensure that by 2045 no flight departing a Swedish airport will use fossil fuel. Two Swedish airports have already installed rechargers for initial electric airplanes. So have three French airports. Edmonton Airport and others are planning hydrogen provision.
[67] At https://www.airportcarbonaccreditation.org.
[68] Swedavia's vision is at https://www.swedavia.com/about-swedavia/our-environmental-responsibility/. References are linked at https://www.swedavia.com/arlanda/environment/. A useful summary and context for these efforts is at https://centreforaviation.com/analysis/reports/swedavia-is-the-first-airport-group-to-achieve-net-zero-co2-emissions-558309. Broadly, Swedavia's ambition for 2030 is over three times as stringent as Pitkin County's. There is much to be learned from its experience.
[69] Consistent with our Essay #5, ZeroAvia promises hydrogen-fuel-cell-powered commercial service from Rotterdam to The Hague by 2025 (https://www.flightglobal.com/air-transport/zeroavia-plans-commercial-flights-from-rotterdam-by-2025/151959.article, 7 Feb 2023).
[70] With one abstention and eight absences: "Additional document based on review of the technical committee report through the lens of the CCWG [Community Character Working Group] report," 27 Dec 2019, https://aspenairport.wpenginepowered.com/wp-content/uploads/2020/09/Meeting-Additional-Document-from-the-CCWG-review-ing-the-TWG-report-through-the-lens-of-the-CCWG-reportPDF.doc. This document was addressed to the overarching Airport Vision Committee, which appears to have ignored it. Instead, the Vision Committee proceeded on the basis of the 24 Sep 2019 recommendations as summarized by the ASE Vision process's three leaders (https://aspenairport.wpenginepowered.comwp-content/uploads/2020/09/12.5.19/Compiled-AAG-Reports-PDF.pdf), prepared before the Technical Working Group report was available for review. The adopted document was said to be approved by all members present at a CCWG meeting 24 Sep 2019; those members are not numbered or listed. The adopted summary's relevant airside recommendations are to "Encourage use of next generation regional aircraft…as close as possible to those we have now that are more consistent with community character" (~76-seat, not larger planes), "Avoid the unintended consequences of a new class of generation aviation aircraft," "Incentivize and accommodate aviation innovation (clean emissions)," and "Decrease General Aviation operations" while reducing their impacts, partly via a slot reservation system by plane registration. The group felt "hampered by the absence of baseline data" (air quality, noise, traffic,…), so it recommended prioritizing terminal planning, fast-tracking baseline data collection, and to "Proceed with airside improvements *only after* the community has determined a baseline…, discussed…impacts…,…and confirm[ed] targets." The following page (6) is reserved for a "Community Character Working Group addendum forthcoming," which does not seem to be posted but might be the 27 Dec 2019 report. The subsequent Continua diagrams show a strong group sentiment for sustaining or shrinking current overall operations, with decreased GA operations favored 10:1 over slight growth. The vote for reduced local air pollution/"exhaust" fell entirely in the strictest of three categories, and 8–3 at its most stringent end. It is hard to reconcile entirely some of these recommendations with current County policy.
[71] I.e. 5,456 air-carrier operations in 1990 *vs.* 11,006 in 2022 per FAA OPSNET report generated 7 Feb 2023: https://aspm.faa.gov/opsnet/sys/opsnet-server-x.asp. This comparison doesn't show the number of people carried; doesn't include itinerant GA operations, which shrank from 25,715 in 1990 to 18,644 in 2022, or itinerant air taxi operations, which grew from 8,229 in 1990 to 15,058 in 2022; and doesn't adjust for the 2004 addition of TRACON operations, which reportedly often track ASE or regional overflights that don't involve an ASE landing or takeoff. These data are thus only impressionistic and indicative. More-detailed data on commercial passenger flows are probably available from the Bureau of Transportation Statistics but would be complex to retrieve.
[72] More precisely, the 5.7 ratio of the official 0.8%/y target to 0.14%/y—the average exponential rate yielding the 4.2% total increase in winter emplanements between 1993/4 (155,792) and 2021/2 (162,358). (Raw data kindly provided by Bill Tomcich, personal communication, 7 Feb 2023; interpretation by Amory Lovins.) Of course, this comparison doesn't include the unknown number of visitors arriving by GA or surface—the former not meaningfully included in County data or policy either.