About the Commentary: The Commentary addresses selected issues within the Code of Conduct to elaborate on their meaning, provide interpretive guidance, and suggest ways of adopting the Code of Conduct. It is intended primarily for implementers, policy administrators, aviation association management, and pilots who wish to explore the Code in greater depth, and will be updated from time to time. Please send your edits, errata, and comments to <PEB@secureav.com>. Terms of Use are available at <www.secureav.com/terms.pdf>.

COMMENTARY TO
AMCC V.b – *ENVIRONMENTAL ISSUES*

b. minimize the discharge of fuel, oil and other chemicals into the environment during refueling, preflight preparations, flight operations, and servicing,

"Now environmental responsibility is an integral part of pilot training."
Jack Haun, Embry-Riddle Aeronautical University[1]

"Environment is at the top of aviation's agenda."
International Air Transport Association[2]

SUMMARY CONTENTS

I. INTRODUCTION

The discharge of fuel, oil, and other chemicals used to operate and service GA aircraft can contaminate soil, surface and ground water, degrade air quality, compromise the health of humans and wildlife, violate the law, and threaten the vitality of aviation. This commentary to AMCC V.b addresses emissions of hazardous materials including fuel, oil, and other chemicals, both on the ground and in the air.[3] Recognizing the diverse equipment used in GA, this commentary considers reciprocating (including spark-ignited and diesel-powered) and small turbine-powered aircraft emissions,[4] as well as current and potential alternative fuels, diverse technologies, and practices to mitigate and better manage such emissions.

Scope – Aviation pollution is a complex problem[5] and mitigation measures are evolving, and will require an interdisciplinary approach. The disciplines that address mitigation include environmental and life sciences, aviation medicine and toxicology, meteorology, aircraft design, and engineering. Basic knowledge in each of these fields helps us better understand the issues, and improves the ability of the GA community to reduce pollution. Some recognized environmental health risks are presented for context and reference. An in-depth consideration of these disciplines, however, lies beyond the scope of this commentary,[6] as does a comprehensive evaluation of the potential health[7] and environmental effects of aviation pollutants.[8] The commentary recognizes our collective and individual responsibility as good environmental stewards—to improve the quality of our lives and those of future generations.[9] Moreover, "being environmentally friendly has always made business sense to aviation."[10]

The reader is advised that due to the intense worldwide interest in issues related to green house gas (GHG) emissions and due to the recent, rapid changes in the cost of conventional aviation fuels, many of the topics discussed in this commentary are rapidly changing. This is particularly true regarding regulations related to GHG emissions and developments in alternative fuels. The authors and reviewers of this material believe the discussions and background included here are accurate at the time of writing, and will serve as a useful foundation for understanding these rapidly changing and vital issues.

Proving Environmental Impact – Many pilots and scientists hold that the earth's self-cleaning capability is sufficient to remove pollutants,[11] and that climate change is not caused by human activity.[12] Scientists differ over the cause and impacts of the increase in the atmosphere's CO_2 concentration that has occurred with time. Some assert that increased atmospheric CO_2 is positive as it increases crop yields. Others suggest that CO_2 is not a harmful greenhouse gas,[13] and that global warming is occurring at a very slow rate if at all.[14]

On the other hand many pilots and scientists feel that pollution poses substantial environmental risks, including global warming. Although the effects of emissions (including aviation's contribution) may not be precisely understood, there is "an array of evidence"[15] concerning climate change and its possible sources,[16] and there is a developing body of scientific data quantifying aviation's environmental impact.[17]

Disputes over details reflect "the normal intellectual clash that takes place as science tests new approaches to old questions."[18] In any event, "[l]ogic requires that we listen to the science."[19] "You can't make environmental decisions based on emotion."[20] The United Nations' 1992 Rio Declaration states, "When there are threats of serious and irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."[21] "A wait-and-see policy may mean waiting until it is too late."[22] Even if uncertainties regarding environmental issues exist, this commentary assumes that exemplary, proactive action[23] by pilots and the GA community to develop their own well-considered judgments about and responses to environmental issues and practices is imperative,[24] and in their own self-interest.[25] In other words, GA needs to be ready to address changing environmental regulations despite the lack of scientific certainty. "We are all in this together. The environmental challenge is facing us all."[26]

GA Fleet and Fuel Consumption Metrics – The following fleet and fuel usage data illustrate the environmental impact of GA compared to other modes of transportation, and show a direct relationship between fuel consumption and emissions. Notwithstanding data limitations and variability, they suggest that GA fuel consumption and emissions are far less significant than those of the airlines and other modes of transportation.[27] For example, by volume, avgas consumption is less than 0.5 percent of automotive gasoline and less than 25 percent of automotive gasoline system evaporation.[28] Nonetheless, (1) negative public perception of GA as a polluter, (2) growth of GA aircraft (particularly the turbine sector – viewed by the public as consuming excessive fuel and harming the upper atmosphere), (3) airport expansion,[29] and (4) the continued use of avgas (a major lead polluter – discussed below) may outstrip anticipated environmental gains and contribute to further opposition to GA.[30]

GA Fleet – The FAA estimates that in 2008 there are 231,343 *active* GA aircraft in the US, 149,100 of which are fixed-wing piston-engine powered, and 19,816 are fixed-wing turbine-powered.[31] The FAA reports the US GA fleet is projected to increase to over 274,914 aircraft in 2020.[32]

GA Hours Flown – The FAA forecasts that in 2008 the US fleet will fly 29,702,000 hours.[33] Categorized by aircraft type, piston-engine fixed wing aircraft are forecast to log approximately 14,145,000 hours, turboprop fixed wing aircraft over 2,283,000 hours, turbojets more than 4,979,000 hours, and over 3,621,000 hours (piston and turbine combined) will be flown by rotorcraft.[34]

GA Fuel Consumption – Reversing a consistent upward fuel consumption trend for more than three decades, FAA data reflect a *3.9 percent decline* in avgas consumption, and a small (4.8 percent) increase in U.S. jet fuel consumption[35] for the period 2000-2005. For the period 2006-2007, U.S. avgas consumption declined 11 percent and jet fuel suffered a marginal decline.[36] The FAA forecasts 2008 US GA fuel consumption of 274.4 million gallons of avgas, and 1,552.5 million gallons of jet fuel – for a total GA fuel consumption of 1,827 million gallons.[37] By 2020, the FAA estimates GA consumption of avgas will rise to 301 million gallons and jet fuel will reach 3,699 million gallons.[38] GA jet fuel consumption has been forecasted to triple, in part due to the developing very light jet (VLJ) market.[39]

GA accounts for but a small fraction of total aviation fuel consumption, and a much smaller fraction of transportation's total fuel consumption.[40] While the above consumption data may seem inconsequential at first glance, the *public's misperception* of GA's contribution to environmental emissions (perhaps catalyzed by the projected overall growth of aviation fuel consumption[41]—not exclusive to GA) suggests that GA give due attention to emissions, fuel efficiency, fueling practices, and the related issues presented in this commentary.[42]

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II. FUELS

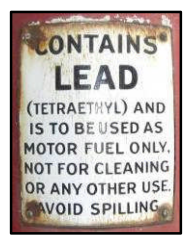
Until the 1920s, low-grade gasoline was the primary source of aviation fuel.[43] The demands of higher performance piston engines soon led to leaded gasoline eventually becoming the preferred fuel.[44] Tetra-ethyl lead additives uniquely increase gasoline octane[45] to improve detonation margins (diminish "knock") and burn more smoothly than low grade gasoline (see **A. AVIATION GASOLINE**, below). Following the development of gas turbine technology in the late 1930s, various formulations of kerosene have become the standard fuel for jet engines[46] (see **B. JET FUELS**, below).

Aviation fuels must work safely and effectively under harsh and varying engine conditions while satisfying increasingly rigorous environmental quality requirements. Consequently, such fuels undergo complex testing before they are certified for production and use. An overview of various aviation fuels, including their properties, requirements, and limitations is presented below.[47] Importantly, as discussed below, there is an "overriding" need for the development of one new single avgas specification.[48]

A. AVIATION GASOLINE

- 100LL (100 octane low lead) **–** The predominant fuel for gasoline-powered aviation engines is 100LL[49]—accounting for more than ninety seven percent of aviation gasoline sold.[50] Approximately thirty percent[51] of the certified piston-powered fleet—the high-performance/high compression fleet—require 100LL's high octane rating, and consumes approximately seventy percent of the US avgas inventory.[52] This disparity is explained by the fact that airplanes with more powerful engines require the detonation margins provided by tetraethyl lead, and those more powerful airplanes are those primary used for business and long-distance personal transportation.

  In addition to lead (discussed in the next paragraph), 100LL may contain various additives to reduce corrosion, ice, and oxidation.[53] Avgas's formulation makes it less volatile than automobile gasoline. 100LL is refined per the ASTM D910- *Standard Specification for Aviation Gasolines*.[54] Color: blue or clear.



  Avgas and Lead **–** Approximately 500 tons of lead are emitted into the atmosphere annually from avgas in the US.[55] Lead (tetra-ethyl lead, or TEL) is used in avgas as an octane booster to inhibit/prevent detonation.[56] 100LL may contain up to 2 ml (or 2.2 grams) of lead/US gallon, or 0.56 grams of lead/liter.[57] Lead is a hazardous substance,[58] and ethylene dibromide,[59] the primary additive used as a lead scavenger, creates toxic emissions that may be worse than lead.

  Lead is generally banned for use in motor vehicle fuels.[60] 100LL and 100/130 remain exempt from this ban, however, because of the lack of a suitable lead substitute for use in high compression piston engine aircraft. Various non-lead additives have been formulated to increase the octane ratings of avgas,[61] but such additives have failed to meet performance requirements (at least for high-compression piston engines), economy, and environmental requirements.[62] Earl

Lawrence, VP, EAA, and Secretary of the ASTM Aviation Fuels Subcommittee exclaimed: "There is nothing that replaces lead. Period. There is no magic solution."[63]

While leaded avgas will inevitably be phased out of use, a firm timetable is not set due to the challenges of finding a suitable unleaded replacement fuel.[64] Moreover, some claim a near-term ban on leaded avgas is unlikely[65] due to funding constraints, insufficient scientific data,[66] the elimination of most lead emissions (because of widespread use of unleaded gas in surface vehicles), and a lack of consensus among stakeholders.[67] Nonetheless, significant pressure is building for action, including a petition for stronger (and proposed new) air quality standards for lead.[68]

Lead's toxicity exacerbates transportation challenges.[69] "The economics of distributing a boutique fuel in small quantities yet requiring wide distribution of a hazardous substance means that it needs dedicated and costly distribution."[70] In any event, there is a widely recognized need for a single-fuel avgas solution.[71] For example, many FBOs find it uneconomical and impractical to sell more than one aviation grade of gasoline and assert that any revised product must satisfy the entire fleet.[72] Indeed, "for 2008 and beyond, the epic battle may be over the continued availability of 100LL avgas."[73]

"The epic battle may be over the continued availability of 100LL avgas."

A new specification that provides comparable octane of 100LL may need to be drafted. One view holds that the "most practical path forward to deal with aviation fuels is to take the 100LL formulation and just don't add the lead. So, you have . . . 91+ MON fuel (see 91/96UL, below), although 10 percent (perhaps no greater than 4-5 percent) of the fleet won't be able to run on it."[74] There is no consensus among industry experts on whether it will become necessary to ground that portion of the high-performance piston fleet unable to operate on the chosen replacement fuel. Some industry participants suggest that a larger percentage of the active GA fleet would be grounded without lead or a suitable alternative unleaded fuel, including "virtually all piston powered aircraft used for air taxi service and most of the piston powered fleet used for business transportation."[75] Still other experts urge varying solutions, such as a 95 unleaded fuel used with electronic ignition controls (see FADEC, below),[76] or other fuel formulations to serve as a general 100LL substitute. In any event, previous efforts to find a seamless avgas replacement have failed, and no single replacement fuel or technology promises to provide a complete solution.

Other Avgas Formulations – Although 100LL is the predominant avgas, other noteworthy formulations/specifications are presented below for context. Additional formulations that have been discontinued or lack production are listed in the endnotes.[77]

- 82UL – Intended for low-compression gasoline-powered engines.[78] Although 82UL (82 octane unleaded) is not a formal replacement for 80/87, 82UL is approved for use in aircraft holding an automotive gasoline FAA-issued Supplemental Type Certificate (STC), and that were certified to 80/87 grade or lower fuels.[79] Developed as a defensive mechanism in the early 1990s in case lead was entirely banned, 82UL became a *refiners' specification* (a production specification rather than one for reformulating and testing auto fuels). The specification seeks to ensure adequate controls over its autogas feedstock.[80] 82UL is not in production because manufacturers believe the market is too small and because the availability of MOGAS (see MOGAS below) may make 82UL commercially impractical. Color: purple.

- MOGAS (82 or 87 premium unleaded) – MOGAS (motor gasoline) contains 20-40 percent aromatics.[81] MOGAS conforms to the ASTM D-4814 standard.[82] STCs permit some GA aircraft to convert to and use MOGAS.[83] Nonetheless, controversy remains about its reliability,[84] and not all MOGAS satisfies the STCs.[85] For example, such STCs generally prohibit either the use of MOGAS blended with ethanol (see Ethanol, below), other oxygenates (such as MTBE[86]), or other specific fuel components in order to prevent engine damage.[87] Moreover, state legislation requiring auto gas to include a blend of ethanol may have the unintended effect of removing MOGAS as an available GA fuel sources.[88] Note that in 2008, approximately 51 percent of automobile gas contains ethanol.[89]

- 91/96UL – A 91 octane unleaded aviation grade fuel. Produced by Hjelmco Oil of Sweden,[90] this "well proven"[91] fuel has a relatively high octane number, low vapor pressure, good stability and solubility, and leaves no deposits. Produced and used nationwide in Sweden since 1991, it also burns cleaner and is less toxic than traditional leaded avgas. Hjelmco Oil asserts that this fuel conforms to current avgas standards[92] and is approved for many (medium compression) engines.[93] Additionally, 91/96UL has purportedly undergone some favorable experimental testing with high compression engines.[94] Nonetheless, 91/96UL is expensive to produce, not widely available, and does not work for all piston aircraft engines. Securing U.S. distribution channels may bolster this fuel's potential commercial viability. Color: none.[95]

- 91/98 – The 91/98 specification was removed in 1968 by ASTM D910 and then reintroduced in December 2001.[96] The EAA asserts that "while the reintroduction of 91/98 is not a complete solution to our inevitable loss of 100LL, it is one more important step in the effort to replace it."[97] 91/98 may contain up to 0.56 grams of lead per liter. Although the 91/98 specification is maintained, only a marginal amount of this fuel is produced. Color: brown.

- 91/98UL – Most of the current GA piston fleet could safely and effectively use this fuel.[98] 91/98UL can be produced and distributed through the current fuel transport infrastructure. Although not under production, 91/98UL is considered "another option on the shelf."[99] Nonetheless, some oil companies have expressed safety concerns due to anticipated confusion between 91/98 and 91/98UL and therefore will not produce the latter. Others fear that the market is insufficient to support more than one aviation gasoline.

- 100 – This fuel contains a maximum of 4 grams of lead/US gallon. Largely discontinued, it may still be available in Australia. 100 is sometimes known as 100/130. Color: green.

Unleaded formulations of avgas are under development. For example, ExxonMobil has developed a 100LL replacement[100] intended to "support high compression engines, except for the most severe cases. It contains an aromatic amine octane improver, the production of which needs commercial backing [if it is to be deployed] and may take five or more years to reach production."[101] Some industry observers think that this fuel is unlikely to be marketed by ExxonMobil because it is too great a departure from their traditional business. Other unleaded formulations are considered below (in **C. ALTERNATIVE FUELS**). Notwithstanding collaborative efforts, significant challenges to find a viable avgas replacement fuel remain as concluded by the Coordinating Research Council (CRC):

> Research results to date . . . have not identified a transparent replacement for the 100LL AVGAS product. Although full scale engine tests indicated some blends were capable of providing knock free operation in the test engine, these blends represented the use of specialty chemicals which require further evaluation with respect to environmental impact. . . .
>
> Although experimental blends of specialist components may achieve or exceed the 100LL specification of 99.6 MON minimum, such formulations are very different as compared to the current ASTM D 910 product and potentially compromise other important specifications. Depending upon engine power output and configuration, high performance aviation engines can require unleaded fuels in excess of 100 MON to achieve octane satisfaction. Leaded AVGAS 100LL or 91/98 offers greater octane satisfaction in full size engines when compared to unleaded products of similar laboratory MON.
>
> CRC test results are indicative of the *significant challenge* regarding a high octane unleaded AVGAS formulation and further serve as a reminder that aviation fuels represent specialized products optimized over many years to maximize performance and flight safety. . . .[102]

Difficulties finding a replacement for 100LL at comparable cost – even after nearly two decades of effort – have led industry to shift the burden back to aircraft and engine manufacturers.[103] These manufacturers are being urged to design (modify) their aircraft to operate on lower octane unleaded fuels.[104]

B. JET FUELS

Jet fuels are typically kerosene-based formulations that are heavier and less volatile than gasoline, and are also unleaded and colorless. The following are the most common grades of jet fuel.[105]

- Jet A – Jet A is the predominant aviation turbine fuel in the US. Jet A is similar to Jet A-1 (below) but with a higher freezing point (than Jet A-1) of -40°C. Jet A conforms to the ASTM specification 1655 (Jet A).[106]

- Jet A-1 – Kerosene-based, with a flash (ignition) point above 38°C (100°F) and a freeze point maximum of -47°C (lower than Jet A). Jet A-1 meets various national and international standards, including DefStan 91-91, ASTM specification D1655 (Jet A-1), and Canadian Standard CAN/CGSB-3.23.

- Jet B – A blend of kerosene and naphtha (a more volatile petroleum distillate normally blended into automotive gasoline), this fuel is used in very cold environments. Its flash point is much lower than Jet A-1. It meets ASTM D6615-06 *Standard Specification for Jet B Wide-Cut Aviation Turbine Fuel*,[107] and the Canadian Specification CAN/CGSB 3.23.

- JP-8 – The military equivalent of Jet A-1 with required antioxidant, corrosion inhibitor/lubricity improver, anti-icing, and anti-static additives, JP-8 conforms to the

U.S. Military Specification (MIL SPEC) MIL-DTL-83133E. JP-8 replaced JP-4 to improve handling safety and reduce environmental impact.[108]

Jet Fuel Use in Diesel Engines: Jet fuels (such as Jet A) have low temperature characteristics and consistent quality that are suitable for modern aviation diesel engine operation. One fuel expert observed, "Jet fuel has always been in the range of what diesels can accommodate—so to make aviation certified diesel engines [that operate on jet fuel] is a natural development."[109] However, there are limitations. A diesel engine's high-compression ignition requires a minimum cetane value[110] to cause detonation, and yet US jet fuel specifications neither require a set cetane number, nor address diesel engines. Jet fuel producers will not burden jet fuel specifications to accommodate diesel engines.[111] Also, motor diesel fuels are generally unsafe for aviation use.[112]

Fuel Properties – Some key fuel properties affect the viability of various aviation fuels, including:[113]

- Motor Octane – Octane is the main challenge in developing a replacement for 100LL. For unleaded octanes greater than 100, specialty chemical additives (such as aromatic amines) are generally required, each of which may significantly affect performance, cost, and emissions.
- Energy Density – Aircraft performance, particularly range, is partially dependent on the amount of BTUs that can be carried onboard. A high-energy content (per weight and volume) expands range. Each fuel's energy density varies. For example, ethanol's energy density is approximately 30 percent less than traditional hydrocarbons.
- Emissions – Each fuel's production and use causes specific emissions, and in varying volumes. Emissions are discussed below (see **IV. AIRBORNE EMISSIONS**, below).
- Toxicity – Each aviation fuel has varying levels of toxicity as a function of dose and chemical pathways of exposure to both the liquid and evaporative emissions (for example, by absorption in the lungs or skin) as well as exhaust emissions.[114] Toxicity also effects handing requirements – for example, leaded avgas requires special handing, storage, and dedicated infrastructure.

> ***Gasoline is just too good***
> **". . . But there's another reason why small private planes in some cases still use fifty-year-old gasoline engine designs instead of modern, vibration-free, brushless electric motors. It's the fuel. Gasoline is just too good. In terms of energy density, nothing comes close to it. . . . In substituting batteries for gasoline, 'you take a hundred-to-one hit,' says MacCready. "No other inexpensive harnessable energy source comes close to having the energy density of petroleum. If it did, we would have been using it long ago."**
> PAUL CIOTTI, MORE WITH LESS – PAUL MACCREADY AND THE DREAM OF EFFICIENT FLIGHT (Encounter Books 2002),

Thermal Stability – Different fuels have different freezing, boiling, and flashpoint temperatures. Low temperature characteristics are particularly important because some fuels may gum up or produce fuel system blockages in cold temperatures. For example, some bio-fuels tend to freeze at normal operating cruise temperatures.

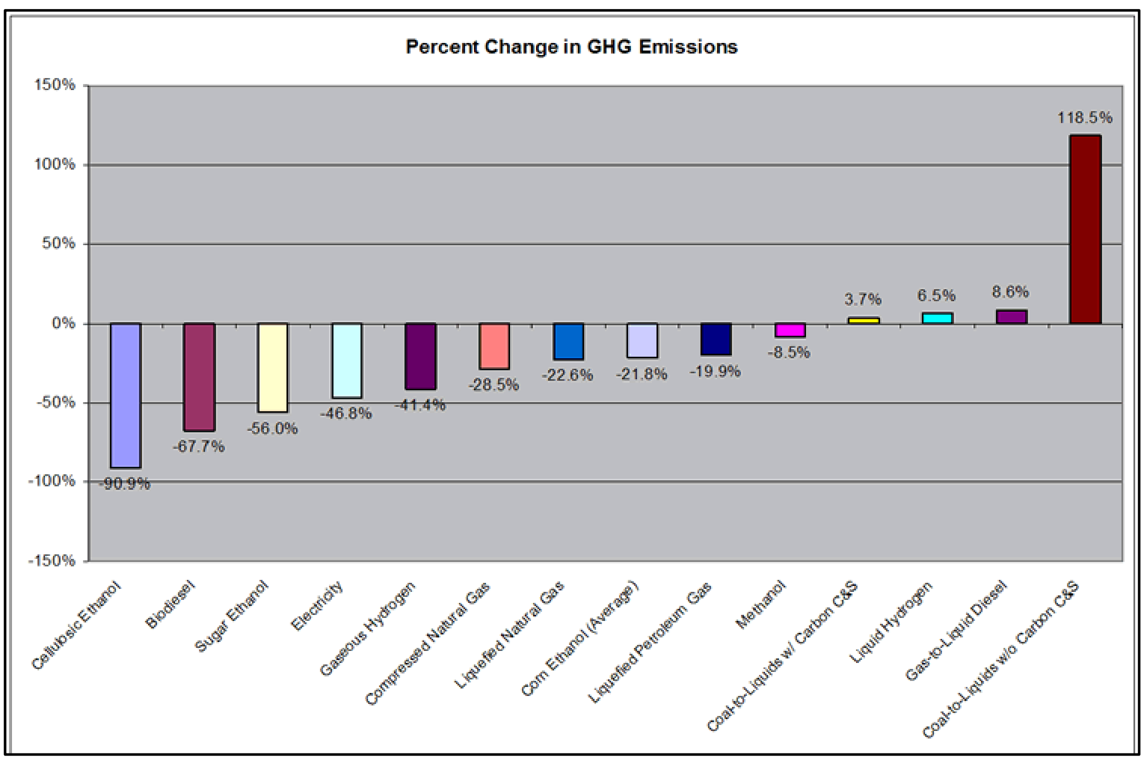
- Storage Stability – Aviation fuels must not deteriorate in storage (such as by loosing a specified octane or the effectiveness of additives) for a designated period of time.[115] Hydrogen and other cryogenically stored and high specific volume fuels may require significant design modifications, including, for example, insulation, high pressures, and heat exchangers.

- Volatility – Describes a fuel's ability to vaporize. Avgas and other light fuels have greater volatility than jet and diesel fuels.
- Lubricity – The lubricating qualities of a particular fuel.[116] For example, ethanol decreases avgas lubricity as a solvent.
- Materials Compatibility – The extent to which a fuel will swell, corrode, weaken, or otherwise damage fuel systems, including seals, pumps, and servos.

C. ALTERNATIVE FUELS

"Alternative fuel production is absolutely necessary if [commercial] aviation globally is going to reduce its footprint."[117] Alternative fuel production is also important to GA. A switch from 100LL to alternative fuels is even more related to the economics of 100LL production and transportation, which make it increasingly expensive in the U.S., Europe, and Australia, and increasingly unavailable at any price in other parts of the world. Alternative fuels are typically (although not always) nonpetroleum-based, and are intended to provide environmental, energy security,[118] and economic benefits.[119] Such fuels may be categorized as alcohols (such as ethanol), synthetics (such as those derived from coal and natural gas), bio-derived renewables (such as biodiesel),[120] and other alternative fuels such as hydrogen.[121]

Alternative fuels are in varying stages of development. Each alternative fuel formulation is necessarily a compromise among a complex set of properties and constraints which ultimately defines its relative suitability for use in aviation. In assessing the effectiveness of an alternative fuel, the *entire* fuel production cycle should be considered, including net environmental improvement or degradation.[122] In this regard, consider the following U.S. Environmental Protection Agency (US EPA) chart estimating the percent change in lifecycle[123] greenhouse gas emissions, relative to the displaced petroleum fuel, for a range of alternative and renewable fuels.[124]



Source: US EPA

The challenges of producing and deploying successful alternative fuels are extensive, complex, and, in many respects, not yet fully understood. These challenges are comprised of many factors including economic, public policy, environmental, production, transportation, and more.[125] One particularly vexing issue is that of recertification of engines/aircraft that use non-"drop in" (see "Drop-In" vs. Retrofit, below) alternative fuels. Aircraft will require both new fuels *and* (most likely) engine/system modifications. And yet, "[n]obody is there to recertify aircraft—this is 'the elephant in the room' . . . . Cessna won't spend a dime to recertify the fleet, and most of the [other] aircraft manufacturers don't exist anymore."[126] Plus, there are liability issues.[127] One thing is clear: there is no "home run" or quick fix that will sustainably provide the requisite environmental, energy security, and economic benefits. As put by the Chief Scientific and Technical Advisor, FAA Office of Environment & Energy, "Alternative fuels are not a panacea."[128] However, "they offer potentially the most attractive venue if we can get some things right with the renewables."[129]

Some alternative fuels relevant to aviation include:

- Ethanol – Ethanol[130] is an alcohol-based biofuel.[131] Ethanol burns cooler than 100LL thereby decreasing cylinder head and exhaust gas temperatures. Ethanol also has slightly better octane than 91/96UL. Aviation Grade Ethanol (AGE-85), the leading aviation ethanol formulation, is an unleaded blend of 85 percent ethanol and 15 percent light hydrocarbons (petroleum) and biodiesel fuel.[132] AGE-85 claims to produce cleaner combustion than traditional petroleum fuels, and prevent carburetor fuel line icing.[133]

  However, ethanol is rather energy-poor—with about two-thirds the energy density of 100LL[134]—which thus reduces aircraft range. Absent engine/aircraft retrofit or redesign, ethanol can increase the likelihood of vapor lock, deterioration of rubber seals and tubing, fuel system component corrosion, fuel metering inaccuracy, fuel phase separation[135] (allowing water into the engine), and various component failures.[136] Ethanol is the subject of extensive research and development.[137]

  Ethanol use in aircraft is forbidden in the absence of an appropriate STC.[138] STCs for AGE-85 are available for some low-compression aircraft engines.[139] Switching to ethanol-based fuel requires new fuel metering,[140] and once the conversion is made, avgas use must be discontinued permanently.[141] This creates problems for cross-country flight because of the product's spotty availability.[142] Earl Lawrence, VP, EAA asserts, "ethanol hasn't worked in airplanes. . . . any blend of ethanol into petroleum causes problems . . . they can't figure out how to certify it."[143] Cessna's engineering evaluation of ethanol concluded "that ethanol based fuels are not practical or safe alternatives to Grade 100LL Aviation gasoline."[144] The AOPA has stated, "Ethanol is not a suitable replacement fuel."[145]

  In North America, ethanol's primary feedstock of biomass is corn.[146] In the future, more energy dense[147] alternatives may prevail. Additionally, comparatively eco-friendly,[148] and economical alternatives feedstocks such as switchgrass,[149] and lignocellulose may substitute for corn (see below).[150]

  The impact of ethanol on the environment deserves close scrutiny.[151] One expert panel reports that the accelerating cultivation of crops to produce ethanol could hurt water quality and create water shortages.[152] Global food shortages—attributed in part to ethanol—have been described as "a crime against humanity,"[153] a "silent tsunami,[154] an object "of derision,"[155] and "the world's big story"—creating riots and political instability.[156] Revisions to government biofuels policies are clearly forthcoming.[157] Additionally, one study found that "corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years."[158] One noted venture capitalist asserts that "corn ethanol [and other food-based biofuels] have served a useful purpose and essentially are obsoleting themselves. We have eight or nine companies producing alternatives to corn ethanol that will be dramatically cheaper."[159]

Cellulosic Ethanol (CE) is a biofuel produced from lignocellulose–tightly linked sugar molecules–the most abundant naturally occurring organic molecule on Earth. The U.S. Department of Agriculture believes that one billion tons of it can be grown sustainably on available farmland.[160] Moreover, CE yields about 80 percent more energy than required to produce it. However, its composition is such that it is technically challenging to find effective and economical enzymes to break down lignocellulose so that it can be fermented into ethanol.[161] CE may also offer a better value proposition particularly recognizing that the price of ethanol continues to increase due to accelerating demand pressure on its primary feedstocks.[162]

- Synthetic Fuels – Synthetic fuel ("synfuel") is any liquid fuel obtained from coal, natural gas, or biomass.[163] The term can also refer to fuels derived from other solids such as oil shale,[164] tar sand, waste plastics, or from the fermentation of biomatter. It can also (less often) refer to gaseous fuels produced in a similar way.[165]

The leading synthetic fuel process, the Fischer-Tropsch process (F-T), produces liquid hydrocarbons (synthetic fuel) from reforming the feedstocks (coal, natural gas, etc.) through heat and catalytic reactions to syngas (carbon monoxide and hydrogen) followed by a conversion of the syngas into synthetic crude.[166] These liquids also provide high energy density (energy stored per unit volume) and thermal stability (avoiding coking at high temperature).

The CO_2 emissions from synthetic fuels produced by F-T in the absence of sequestration are higher than those of conventional jet fuel, when taking the entire fuel cycle into account, but generally produce significantly less particulate matter, smoke, nitrate, and sulfur. Studies suggest that F-T can be produced with significantly less CO_2 output than petroleum-based processes through appropriate carbon capture and storage (sequestration) technologies,[167] and that co-processing a small amount of biomass with coal may reduce the F-T carbon footprint by 20 percent.[168]

Syntroleum, an American synthetic fuels company, has produced over one million gallons of jet fuel from a F-T process using natural gas.[169] This fuel, using a 50/50 blend of synthetic and JP-8 fuel was tested in 2006 by the U.S. Department of Defense during a 7 hour flight of a B-52, subsequently in a transcontinental flight of a C-17,[170] and in a B-1B Lancer supersonic flight in March 2008.[171] Certification of the entire US Air Force fleet for synfuels is set for 2011.[172] Because coal-to-liquid (CTL) synfuels may offer the additional benefits of greater energy independence/ security,[173] the US Air Force has announced plans to build a CTL plant in central Montana.[174] CTL is claimed to be economically viable at 50-60 USD per barrel of crude oil.[175]

A commercial trial of gas-to-liquid (GTL) synfuel took place on Feb. 1, 2008 with an Airbus A380.[176] Such synfuels are claimed to become economically viable with oil prices as low as $35/barrel.[177] A protocol for acceptance of synthetic fuels under commercial specification was completed in December 2007, facilitating the operational use of F-T-based semi-synthetics in the near future.[178]

- Biofuels – Biofuels are renewable fuels derived from plants and animal fats (collectively, biomass). Biofuels blended with petroleum may offer substantially improved characteristics to satisfy aviation requirements. "The main advantage of using biofuels may be their potential to reduce overall life-cycle CO_2 impact."[179] Another advantage is improved energy security. The future of biofuels is also bolstered by favorable government policies.[180]

Biodiesel – Biodiesel fuels are produced from renewable resources. Biodiesel consists of mono-alkyl esters—long chain fatty acids (fatty acid methyl esters)[181] derived from vegetable oils, animal fats, or other nonpetroleum resources. Biodiesel contains no petroleum, but can be blended with petroleum diesel to create a biodiesel blend.[182] Biodiesel can be used in diesel engines with little or no modification as well as in some aircraft turbines (see below). Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics.

The leading formulation of biodiesel is designated as B100 (100 percent non-blended biodiesel), conforming to the ASTM D6751 standard.[183] Because of a lack of experience with biodiesel blends above B20 (20 percent biodiesel and 80 percent petroleum), B100 is standardized to be used exclusively as the blend stock (such as for B20) but not as a neat fuel. B20 is the predominant blended biodiesel. A voluntary quality control program (BQ9000) supports the production and distribution of biodiesel.[184] B100 is a clear liquid but may be produced in various colors.

The U.S. Department of Energy reports that B100 can eliminate 90 percent of conventional diesel's particulate matter and hydrocarbon emissions, and B20 can reduce such air toxics by 20-40 percent.[185] Biodiesel production from soybeans, for example, yields considerably more energy than ethanol from corn grain, and may have other technical and economic advantages.[186] Sugar cane as a biodiesel feedstock may offer up to six times the energy potential. Other biosources for biodiesel may include palm oil, Babassu nuts (from Brazilian palm trees), jatropha (a desert weed),[187] "giant reed,"[188] and algae.[189] Algae may offer a 60-80 percent reduction in CO_2 and has been described as "the most attractive lipid-based biofuel feedstock to pursue for aviation."[190] Although it is claimed that the technical challenges of algae production or bio-jet fuel have been overcome, the capital investment for algae production (potentially more than one trillion USD), and the landmass (the size of Belgium) to satisfy global aviation industry needs invariably present material obstacles.[191]

B100 has been demonstrated successfully by the flight of an L-29.[192] In February, 2008, Virgin Atlantic Airways tested a sustainable (purportedly B20) biofuel on a Boeing 747-400 flight.[193] Biodiesel-fueled transcontinental and global biodiesel-fueled jet flights are planned.[194] Continental Airlines, Boeing, and GE have announced plans for a biofuels demonstration flight before July 2009.[195]

B100-Fueled L-29 Flight

Biodiesel fuel faces challenges such as long-term storage stability, material compatibility, cold flow properties which create gelling in cold weather,[196] and environmental (predominantly land-use) concerns.[197] For example, "[S]cientists calculate that it would take 5.7 million sq. km. (equivalent area for the production of soybeans) – an area about the size of Europe – to produce enough biofuel to totally replace [world production of] jet fuel using soybeans."[198] Huge amounts of water are also required to produce biodiesel fuel.[199]

Biofuel Research and Development – Research and development on biofuels is extensive and continuing.[200] For example, one piston aviation fuel from Swift Enterprises that "closely emulates the ASTM D910 100LL specification is undergoing evaluation by the FAA Hughes Technical Center."[201] This fuel is characterized as a chemical reforming of oxygenates to form specified synthetic hydrocarbons producible from a broad range of bio-feedstocks.[202] Furthermore it claims to demonstrate a 15-20 percent greater volumetric energy density, a 30 degree lower freezing point than the 100LL specification, and reduced airborne emissions.[203] Swift asserts that its technology can formulate fuels economically into both reciprocating and turbine fuels.[204] The future results of the impartial third-party analysis of candidate fuels will be a significant contribution.

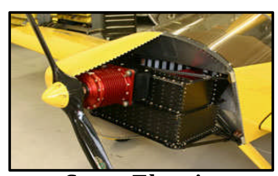
- Hydrogen – Hydrogen is comparatively poor when measured by the amount of energy that can be transported per unit of volume. Comparatively good as a function of energy per unit weight, hydrogen's primary emission from combustion is water vapor. A practical hydrogen combustion aircraft would require major infrastructure development, including power plants and fuel transportation/storage. Such aircraft are likely not feasible in the near-term.

- Methane – Methane, the most common natural gas compound, is an alternative fuel that may in the future be helpful in aviation but has failed to garner much attention and progress.[205] Methane is denser than hydrogen, and recent innovations may dramatically improve methane's storage density.[206] Nonetheless, significant further research and development are needed before the practical value of methane for aviation fuel can be accurately ascertained.


Pipistrel Taurus

- Non-combustible Alternatives – "Alternative fuels" surveyed in this commentary include non-combustible systems that generate electricity, and associated storage and propulsion technologies, including the following:

  - Electric Battery – Battery technology remains the major constraint in the development of battery powered aircraft, yet such technology is rapidly improving. High-discharge lithium-polymer batteries are some of the best candidates, and research and development seeks to mitigate their volatility, improve safe and rapid recharging, power output, and reduce weight. Self-launch battery powered electric gliders are commercially available,[207] as well as a battery powered weight-shift-control ultralight.[208] A promising electric battery powered aircraft was exhibited at AirVenture 2007,[209] and additional offerings are advancing or available.[210]


Sonex Electric-Powered Prototype

  Removable "swap-out" battery packs could potentially accommodate a segment of the recreational flying market that would tolerate battery swapping about every 45+ minutes (with safety reserves) – and the available energy of such batteries will invariably increase. Hybrid electric/piston aircraft are also under active development.[211] Super capacitors (or ultracapacitors), including hybrid battery-super capacitors which may dramatically reduce charging time and weight, among other benefits are also under development.[212] Nonetheless, "battery electric drive systems are not competitive with air breathing engines. Present battery powered GA aircraft demonstrations have been limited to flight times less than 40 minutes, at low subsonic speeds, while the air breathing propulsion which was removed to make room for the battery electric drive was capable of 250-300 minutes of continuous powered flight."[213]

Batteries are not without environmental cost. Among these are the impacts of electric power generation and charging (expenditure of fuels and emissions), and significant water use.[214] Batteries may create new risks upon impact in an accident, as well as hazardous or universal wastes.[215]

- Electric Motors – Electric battery, hydrogen fuel cell, and solar powered aircraft convert electricity to thrust via electric motor-driven propellers. Electric motor efficiency (in terms of general power density,[216] torque,[217] weight, reliability, controller sophistication, and cost) is progressing quickly.[218] Electric motors are efficient no matter their size, and without penalty at altitude (except that penalty associated with dissipating waste heat released by the motor).[219] Electric motor-propelled aircraft can also be viewed as accommodating a spectrum of fuels to the extent that electric power production (that charges batteries or powers electrolysis) can operate on coal, hydro, methane, and alternative fuels including solar, wind, and geothermal sources.


Electric Motor

The EAA has petitioned the FAA to accommodate electric-powered aircraft under LSA and ultralight regulations, asserting, "It is only a matter of time before aircraft powered by electric motors become the aviation industry standard."[220] Indeed, "there are no technology reasons that within five years, such aircraft can be completely electrical notwithstanding a tremendous amount of integration challenges."[221] Finally, the standards committee ASTM F-37 on Light Sport Aircraft has commenced standards development for aircraft electric motors.[222]

- Fuel Cells – The hydrogen-oxygen to water reaction can be harnessed to produce electricity without toxic emissions—emitting only water vapor.[223] Hydrogen fuel cell advantages include reduced air emissions,[224] quiet operation, and in the future, anticipated higher reliability, and higher energy density.[225] Technical challenges include the significant energy required to produce hydrogen, the high capital costs for components, the need to develop transportation and storage infrastructure,[226] and environmental threats caused by leaked hydrogen.[227]


Boeing Fuel Cell-Powered Plane

Successful manned flight testing of fuel-cell powered aircraft was undertaken in 2008.[228] Fuel cell tests have powered all phases of flight except takeoff and climb, when it is supplemented by a lithium-ion battery.[229] Nonetheless, the time line for wide-scale commercial implementation of fuel cells is uncertain—perhaps as much as "several decades"[230] or "maybe never."[231] Fuel cells also show particular promise and environmental benefits for auxiliary power unit (APU) replacement[232] and other aircraft subsystems. In the future, liquid hydrogen may also enable (by cooling) highly efficient and light-weight superconducting electric motors.[233]

- Solar – Unmanned solar-powered flight began in 1974 and manned flight in 1980.[234] Progressively more capable manned and unmanned experimental aircraft,[235] such as the Pathfinder,[236] are being developed. Around-the-world solar-powered and solar-hybrid global flights are planned.[237] Moreover, DARPA is funding the development of a solar-powered unmanned aircraft able to sustain high-altitude flight for at least five years.[238]

Alternative Fuel Practical Considerations – Beyond their basic properties, such as fuel density, emissions, and safety (see Fuel Properties, above), the commercial viability of alternative fuels depends upon various practical considerations, including the following:

- "Drop-In" vs. Retrofit – Drop-in fuels are direct-replacement fuels, requiring neither material modification to aircraft nor changes to operations and maintenance, and add no risks to power plant and airframe. Drop-in fuels have significant advantages in the short-term. "As soon as you're beyond drop-in fuels, you've just expanded the enormity of what you have to do in terms of moving to the next generation."[239]

- Transportation and Storage Infrastructure – Considerations include the availability of transport technology such as pipelines versus vehicles, and storage technology used in transport and at delivery sites such as airports. Special handling requirements of particular fuels impact the available infrastructure (for example, ethanol is hydroscopic, cannot be exposed to water, and may freeze in pipelines; TEL contaminates pipelines and thus cannot be co-mingled with unleaded fuels in transport infrastructure).[240]

- Capitalization – Capital costs for research and development, production, and operations. For example, a F-T coal-to-gas plant may cost more than one billion USD.

- Regulatory Compliance and Incentives – Regulatory rationales, objectives and burdens may include safety, environment, e.g., carbon and lead reduction, economics, or national/energy security.[241] Regulations may offer incentives for alternative fuel production or use.[242]

- Standardization – Developing and implementing technical standards for new fuels require time, money, and consensus building. Fuel standards are a prerequisite to certifying redesigned aircraft engines that use such fuels.

- Feedstock (Raw Materials) Costs – The availability, economic, and environmental costs of procuring or producing the raw materials used for fuel production.

Fuels and Emissions Initiatives – Diverse private and public fuel and emissions initiatives, including energy policy initiatives, are accelerating and relevant to GA. The following list, although not all-inclusive, identifies some such noteworthy initiatives.

- Clean Sky – *Clean Sky* is part of the European Union's Joint Technology Initiative, a seven-year collaboration between government and industry to improve the environment by bringing green technologies to market and advancing EU aeronautical industry competitiveness.[243] Although GA is not the focus of Clean Sky, it will invariably affect GA. Clean Sky's goals seek significant reductions in CO_2 and NO_x emissions, and advance green lifecycles for aviation products. Its initiatives include, for example, "CLEANENGINE" to optimize "modern clean [internal combustion] engines working with liquid biofuels."[244] Clean Sky has influenced aviation energy/environmental policy beyond the boundaries of the EU through participation in regional initiatives, such as the Atlantic Interoperability Initiative to Reduce Emissions (AIRE) which seeks to reduce greenhouse gas emissions from aircraft on a gate-to-gate basis.[245]

- National Plan for Aeronautics Research and Development and Related Infrastructure – This high-level plan guides U.S. aeronautics R&D and infrastructure through 2020.[246] Created by the National Science and Technology Council's Aeronautical Technology Subcommittee[247] in collaboration with federal agencies and diverse stakeholders, the plan includes both energy and environmental goals to help align R&D priorities:[248]

  - Goal 1 – Enable new aviation fuels derived from diverse and domestic resources to improve fuel supply security and price stability
  - Goal 2 – Advance development of technologies and operations to enable significant increases in the energy efficiency of the aviation system
  - Goal 3 – Advance development of technologies and operational procedures to decrease the significant environmental impacts of the aviation system.

  The program is billed as "the nation's first integrated plan" seeking to advance U.S. technological leadership in aeronautics,[249] and "includes efforts to improve the scientific understanding of the nature and impact of aviation emissions and thereby inform the development of more fuel-efficient aircraft, of alternative fuels that can reduce aircraft emissions, and of air traffic management technologies that further improve the efficiency of aviation operations."[250]

- The Commercial Aviation Alternative Fuels Initiative (CAAFI) – CAAFI is a US government-industry forum structured as a loose federation of stakeholders to explore the potential use of aviation alternative fuels.[251] Considered one of NextGen's (see below) environmental "five pillars."[252] CAAFI is developing a roadmap to securing a stable jet fuel supply, controlling fuel price volatility, enhancing energy security, incentivizing further research and analysis, undertaking a gap analysis, quantifying the ability to reduce environmental impact and improve aircraft operations.[253] The initiative "focuses the efforts of the U.S. Commercial Aviation supply chain to engage the emerging alternative fuels industry."[254] CAAFI's program is structured in four domains: certification and qualification, research and development, environment, and business and policy.[255] Among its various goals is to have available for certification a 50 percent Fischer-Tropsch synthetic kerosene fuel in 2008, 100 percent synthetic fuel in 2010, and other biofuels as early as 2013. Participating agencies include the U.S. Departments of Commerce, Transportation (including FAA), Defense, Energy, and NASA. CAAFI sits on the PARTNER Advisory Board (see FAA, below).[256] A related alternative fuels initiative with participation by AOPA, EAA, FAA, and GAMA is focused on advancing an aviation gasoline replacement (whereas CAAFI is focused on jet fuel).[257]

- Federal Aviation Administration – The FAA has various ongoing initiatives contributing to alternative fuels development, tightly coordinated with CAAFI (see CAAFI above).[258] The FAA's Office of Environment and Energy oversees the agency's alternative fuels program and "develops, recommends, and coordinates national aviation policy relating to environmental and energy matters, which includes noise and emissions."[259] Additionally, the FAA has various research and technical centers involved in alternative fuels research, including but not limited to the FAA William J. Hughes Technical Center. Characterized as "the nation's premier aviation research and development, and test and evaluation facility," the Technical Center includes the Propulsion and Fuels Systems Branch. This branch operates the Unleaded Fuel Research Program,[260] the work product of which has been significant, *inter alia*, to the Coordinating Research Council (CRC), and the American Society for Testing and Materials (ASTM - see below).

The FAA also funds emissions initiatives relevant to alternative fuel considerations, including the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER),[261] and a FAA/NASA/Transport Canada-sponsored Center of Excellence.[262] The FAA also partners with NASA on the Aviation Climate Change Research Initiative (ACCRI) as part of the NextGen initiative,[263] as well as an anticipated Continuous Low Emissions, Energy and Noise (CLEEN) program.[264] Additionally, the FAA participates in various regional initiatives that may contribute to fuel efficiency and solutions, such as the Asia and South Pacific Initiative to Reduce Emissions (ASPIRE) which "aspire[s] to increase efficiency [and] reduce fuel burn. Bottom line: we will ASPIRE to fly green"[265] by providing "a regional platform to showcase the region's leadership in global aviation emissions reductions to ensure that, as aviation grows, its environmental impacts are reduced over time."[266]

- The Next Generation Air Transportation System (NextGen) – NextGen is billed as "a wide ranging transformation of the entire national air transportation system . . . to meet future demands and avoid gridlock in the sky and in the airports . . . . This multi-agency initiative is led by the Joint Planning and Development Office"[267] (JPDO) which "is the central organization that coordinates the specialized efforts of the Departments of Transportation, FAA, NASA, Defense, Homeland Security, Commerce, and the White House Office of Science and Technology Policy."[268]

  NextGen includes an *Environmental Management Framework* recognizing that "the NextGen environmental challenge is to manage aviation's environmental impacts in a manner that limits or reduces their 'footprint' and enables the U.S. air transportation system to meet the nation's future transportation needs."[269] Thus, this framework seeks to ensure "*environmental protection that allows sustained aviation growth*."[270] "Environmental isn't just a piece of NEXTGen, it overlays and permeates everything we're doing."[271] Regarding fuel and emissions, "[t]he NextGen vision involves a significant reduction in flight time. Reduced flight times mean that aircraft engines operate less, burn less fuel, and [generate] fewer emissions."[272]

- National Aeronautics and Space Administration (NASA) – NASA is involved in many diverse research and development initiatives[273] which may benefit aviation fuels and emissions. A key participant in NextGen,[274] NASA undertakes fundamental research in aeronautics, aviation safety, and airspace systems and works in cooperation with airframe and power plant manufacturers. Among other initiatives,[275] NASA's Glenn Research Center includes a Combustion Branch, Propulsion Systems Division which "conducts fundamental and applied research aimed at advancing the technology for combustors, combustion processes and emission reduction of aeronautical gas turbine engines and space propulsion,"[276] and an Office of Power and Propulsion.[277] Glenn's Fundamental Aeronautics Subsonic Fixed Wing Project includes investigation of combustion behavior of both biofuels and F-T jet fuels. NASA research extends to long-term scientific and engineering initiatives to aid longer-term environmental improvements. Additionally, for example, NASA's Langley Research Center contributes to the Small Aircraft Transportation System (SATS) initiative including electric propulsion-enabled aircraft.[278] Nonetheless, NASA aeronautics research budget has been in decline over the past decade, reducing its ability to move its fundamental research to a level of maturity that facilitates commercial development and implementation.[279]

- U.S. Department of Defense (DoD) – Recognizing and responding to the national security implications of foreign oil and "peak oil", the DoD has taken a leadership role in developing alternative aviation fuels.[280] The Office of the Secretary of Defense (OSD) has initiated the OSD Assured Fuels Initiative "to catalyze commercial industry to produce clean fuels for the military from secure domestic resources using environmentally sensitive processes as a bridge to the future."[281] The initiative's goals include "Total Energy Development" (to accelerate industry production of alternative fuels), and "Joint Battlespace Use of Fuel of the Future" (to advance fuel specifications to enable a single fuel).[282] Additionally, the Defense Advanced Research Projects Agency's (DARPA) Advanced Technology Office (ATO) has initiated a biofuels program "to enable an affordable alternative to petroleum-derived JP-8."[283] Each of these initiatives should benefit aviation generally.

- US Department of Energy (DoE) – The DoE's mission includes advancement of "the national, economic, and energy security of the United States" and promotion of "scientific and technological innovation in support of that mission."[284] DoE's corresponding strategic goals include promotion of "America's energy security through reliable, clean, and affordable energy."[285] DoE's Energy Information Agency also collects, analyzes, and publishes critical energy and emissions statistics.[286] Among other initiatives, DoE includes a Biomass and Biofuels Program whose mission is to "[d]evelop and transform our renewable and abundant biomass resources into cost-competitive, high-performance biofuels, bioproducts, and biopower."[287]

- The Coordinating Research Council (CRC) – The CRC is a non-profit organization that directs, through committee action, engineering and environmental studies,[288] through public and private sector collaboration, on the interaction between transportation equipment and petroleum products.[289] The CRC's focal point for aviation gasoline is its Unleaded AVGAS Development Panel:

> formed with the objective of conducting research and testing that will facilitate development of the next generation aviation gasoline - a high octane unleaded aviation gasoline as an environmentally compatible, cost effective replacement for the current *ASTM D910 100LL* fuel. Consisting of representatives from the airframe manufacturers, engine manufacturers, fuel producers, FAA, AOPA, EAA, GAMA, and other interested parties, the CRC AVGAS Development Group acts as a steering committee, providing oversight and direction for research and testing.

> The CRC AVGAS Development Panel is committed to an interactive, collaborative process with the goal of ensuring the availability of the required technical information for the development of an aviation gasoline that meets the requirements of both the existing and future general aviation fleet. Safety, reliable operation, and *environmental awareness* are driving principles.[290]

The CRC also includes the CRC Aviation Engine Octane Rating Panel to develop "a method to consistently rate aircraft engine octane requirements under harsh repeatable conditions and to determine the general aviation fleet octane requirements."[291]

- ASTM Committee D02.J0 on Aviation Fuels – The Committee's formal scope is "the promotion of knowledge of aviation fuels and the development of specifications, test methods and other standards relevant to aviation fuels."[292] D02.J is the preeminent standards body on aviation fuels, ASTM Committee D02.J0[293] includes avgas, diesel, turbine, and alternative aviation fuels standardization.[294]

- Foundations – A few examples of the unique role played by foundations in aviation fuels and emissions include the following.

  - *The CAFE Foundation* (Comparative Aircraft Flight Efficiency)[295] in partnership with NASA, includes an annual General Aviation Technology Challenge (in part, to advance fuel efficiency), and a "Green Prize" for transportation seeking to promote "***all*** of the valuable measures of energy use; MPG, as well as speed and payload."[296] Among other initiatives, CAFE hosts the pioneering Electric Aircraft Symposium to advance electric powered aircraft,[297] and serves as a flight test agency for the Experimental Aircraft Association.

  - *The Lindbergh Foundation* "supports great innovations that foster the environment to keep the planet in balance,"[298] and has sponsored advanced combustion research and development.[299]

  - The *X Prize Foundation* characterizes itself as "the most radical approach to innovation yet."[300] The Foundation is an educational nonprofit prize institute whose mission is to create radical breakthroughs for the benefit of humanity.[301] Its *Biofuels Prize*[302] is recognized by the US Department of Transportation as promising to accelerate alternative fuels development.[303]

- Universities – Aviation fuels and emissions research are underway at academic institutions worldwide. To the extent that sustainable solutions to aviation's environmental challenges lie in *transformational technologies*,[304] basic and applied research are essential. A few notable or representative initiatives (presented in alphabetical order) include those at: Baylor University's Renewable Aviation Fuel Development Center,[305] Colorado State University's (CSU) Engines and Energy Conservation Laboratory,[306] Embry-Riddle Aeronautical University,[307] Georgia Institute of Technology's Center for Innovative Fuel Cell and Battery Technologies,[308] Imperial College, London's Center for Energy Policy and Technology,[309] Massachusetts Institute of Technology's Department of Aeronautics and Astronautics,[310] McGill University,[311] Missouri University of Science and Technology's Center of Excellence for Aerospace Particulate

Emissions Reduction Research,[312] Purdue University, College of Technology,[313] University of California Davis's Air Quality Research Center,[314] University of Dayton's Research Institute,[315] University of North Dakota's Energy and Environment Resource Center,[316] University of Stuttgart's[317] National Alternative Fuels Laboratory,[318] Princeton University's Aerospace Laboratory,[319] and Wichita State University's National Institute for Aviation Research.[320]

- Aircraft, Energy, and Power Plant Companies – Airframe, energy, and power plant[321] companies play a major—indeed intimate role — in initiatives to mitigate environmental emissions, improve fuel efficiency, and advance the state of relevant technologies. Their respective contributions are addressed throughout this commentary, and mentioned here as a matter of completeness.

- Industry Associations – Most of the major aviation industry associations have developed (at least) an interim response to fuel and emission challenges, such as by establishing or bolstering environmental committees, providing leadership in standards committees, collaborating with academia, industry, and government, developing member guidance and educational/training materials, promoting environmental stewardship by their constituents, or providing policy advocacy. Some of these associations include the: Aircraft Owners and Pilots Association,[322] Air Transport Association,[323] Air Transport Action group,[324] British Business and General Aviation Association,[325] European Business Aviation Association,[326] Experimental Aircraft Association,[327] General Aviation Manufacturers Association,[328] International Air Transport Association,[329] International Business Aviation Council,[330] National Air Transportation Association,[331] and National Business Aviation Association.[332]

- Capital Markets – With striking similarities to the legendary growth of Silicon Valley, the capital markets are aggressively developing new energy technologies. For example, in 2007, venture capital funded "clean tech" in the amount of 5.18 billion USD, representing a 44percent increase from 2006.[333]

D. FUELING PRACTICES

Studies indicate that 100 thousand or more gallons of aviation fuel are deliberately poured onto the ground annually during preflight fuel sampling[334]—"a procedure that's been used in aviation almost as long as aviation has been in existence."[335] Such dumped fuel results in lead, petroleum hydrocarbons, and other toxic residues permeating the soil and ground water,[336] evaporating hydrocarbons into the air, and deteriorating asphalt tarmacs. Petroleum hydrocarbons can be particularly damaging if discharged into rivers, streams, bays, and estuaries in ecologically sensitive coastal areas—the locale of many airports.[337]

"Slop" Tank

Pilots should exercise care to minimize discharge of fuel into the environment to avoid fuel contact with unprotected skin. Standard preflight procedures require sampling of the aircraft's fuel to confirm its grade and the absence of water and other contaminants. Absent contamination, fuel samples should be returned to the fuel tank in accordance with safe practices, and contaminated fuel should be placed in a "slop" tank.[338]

Many GA airports do not offer environmentally safe fuel collection containers,[339] and those offering collection points do not always place them in convenient locations. Additionally, the designs of many GA aircraft challenge environmentally responsible fueling practices[340] and thus require each pilot to make a personal commitment to responsible fueling practices. Handling fuel samples appropriately will mitigate the environmental impact of GA activities significantly.

GATS Jar

Environmentally sound fueling may include the following practices:[341]

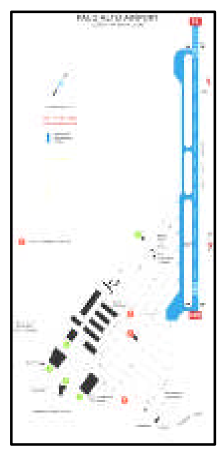
- Use a large fuel sample container, such as a Gasoline Analysis Test Separator ("GATS") jar or the equivalent to better ensure the removal of water and other residues from the tank (water attaches to the sides of fuel tanks due to internal surface tension; drawing larger samples may break the surface tension, allowing at least some of the water to be drained), and to encourage the return of samples to the tanks.[342] The importance of rigorous fuel sampling, to ensure delivery of the appropriate fuel (i.e., avgas vs. jet fuel) is underscored by a history of errors in fuel handling, storage, and distribution practices among a few distributors, airports, and FBOs. Moreover, "many avgas pumps and distribution facilities (particularly self-service pumps) are under-maintained" and are deteriorating.[343]

Fuel Inhalation Protection

- Do not overfill tanks. Overfilling leads to run-off from tank vents due to expansion in hot weather[344] and from parking and operating on acute angles. Consider that avgas is more volatile than jet fuel and that fuel systems in most small GA aircraft are vented to the atmosphere resulting in significant hydrocarbon evaporation.[345]
- Consider not refueling until you know the mission so as to avoid carrying unneeded fuel and improve fuel economy, reduce fuel run-off, and provide weight and balance flexibility on the next flight.[346]

Fuel/Chemical Protective Gloves

- Observe aircraft fueling to confirm that tanks are not overfilled, and that the correct fuel is loaded.
- Where practicable, attach a fuel recapture device to fuel tank vents in order to mitigate fuel venting drainage.
- Use environmentally sound portable gasoline containers for fueling both aircraft and ground support equipment.[347]
- Fuel in a well-vented area. Recognize the inhalation hazards.
- Wear appropriate protective gloves when sampling, fueling, or handling other toxic chemicals.[348] Because many types of gloves do not provide proper protection, exercise great care in choosing gloves because avgas and many other aviation-related chemicals are rapidly absorbed through the skin.[349]
- Clean up spilled fuel immediately, and dispose of absorbents lawfully.[350]
- Seek to use unleaded and alternative fuels[351] where approved,[352] available, and safe; promote their use.



Charted Fuel Dumping Facilities

- If a pilot's home airport does not have appropriate fuel collection containers ask the airport to provide such containers, or assist it in doing so.

E. LEGAL CONSEQUENCES FOR NONCOMPLIANCE

Beyond the health, safety, and ethical reasons to exercise environmentally sound fueling practices are serious legal consequences for polluting. Consider, for example, the high-profile case at Embry-Riddle Aeronautical University in Daytona Beach, Florida. The University was fined $24,999 by the Florida Department of Environmental Protection for violating the Florida Resource Recovery and Management Act[353] by failing "to implement a procedure to prevent the release of aviation fuel after inspecting for contaminants."[354] A Consent Order between the University and the government required Embry-Riddle to create fueling practices training materials, including a video.[355] The Embry-Riddle matter likely foreshadows a trend: new and more far-reaching measures with strong penalties for aviation-related pollution.[356] Legal consequences associated with improper disposal of lubricants, chemicals, and solid wastes are presented in Part III of this commentary, below.

Vero Beach Airport

F. FUEL EFFICIENCY: TECHNOLOGIES AND PRACTICES

Improving fuel efficiency contributes to environmental quality. Both technology and practice play essential roles in environmental quality. "The relationship between technology and our environment is one of the most important issues facing aviation and, in fact, all humankind," urged John King of the King Schools.[357] Moreover, "[i]f general aviation is to continue without restriction, there must be a concerted attempt to design future aircraft with fuel efficiency as an uppermost consideration."[358] "If we try to restrain emissions without a fundamentally new set of technologies, we will end up stifling economic growth . . .[359]

Aviation technologies and practices are evolving, and their applicability and benefits will vary as a function of equipment, mission, environment, and economics, among other factors. The diverse technologies and practices listed below (in alphabetical order) may improve fuel efficiency and thus environmental quality.[360]

- ***Technologies***

  - Advanced Avionics – Exploiting appropriate technologies will increasingly provide environmental benefits – for example, computer-based flight planning tools[361] (see Flight and Fuel Planning, below), use of more efficient terminal procedures (for example, RNAV IFR Terminal Transition Routes – "RITTRs"[362]), Reduced Vertical Separation Minimums (RVSM),[363] and more direct long distance RNAV routing. Other technologies being developed/ deployed for air transport (such as those within "NextGen"[364] and performance advisory systems[365]) should "trickle down" to the benefit of GA[366] (providing better efficiency and emissions), including ADS-B,[367] continuous descent arrivals (CDAs),[368] and Required Navigation Performance (RNP).[369]

  - Anti-Detonation Injection (ADI) – A technology used to provide Allied aircraft with superiority in WWII, ADI used with 100 octane and an intercooler can increase power and allow an engine requiring high octane to use a lower octane fuel. Petersen Aviation has STCs for the Beech Baron and Cessna 210 using ADI to accommodate 91 octane automotive gasoline. Peterson claims that ADI could be used to approve many 100LL fueled airplanes. Peterson asserts that "certification of this system on other high-compression engines is needed but the fact that STCs were issued over 20 years ago for both ADI and 91 octane is significant to the discussion. ADI is in fact the only technology that has been shown to prevent and/or stop detonation without any loss of power even down to an 87 MON gasoline."[370]

- Diesel Engines – Aviation diesels may increased range (up to 30 percent more efficient per volume of fuel – improved brake-specific fuel consumption[371]), among other environmental benefit (see ***Diesel Engines*** in Part IV, below).[372] Nevertheless, GA diesels require longer-term operational experience to ascertain their environmental impact and over-all dispatch reliability.[373]

- Engine Analyzers and Fuel Totalizers – These devices can ascertain lean-of-peak (LOP) exhaust gas temperatures for LOP operations of some engines (most effective with fuel-injected engines) which may reduce fuel burn by up to twenty-five percent.[374]

- FADEC – Full Authority Digital Engine Controls (FADEC) offer reduced pilot workload with regard to engine management, potentially greater fuel flexibility for reciprocating[375] and turbine power plants,[376] and possibly improved fuel economy.[377] For high-performance aircraft gasoline engines, FADEC may one day accommodate unleaded fuels.[378]

  General Aviation Modifications, Inc. (GAMI) has "demonstrated a high-performance piston engine [a 'conforming' 350 HP Lycoming engine] at full power and operating under hot day FAA certification conditions on unleaded avgas using currently developed electronic engine controls. However, operation with unleaded avgas may require use of richer mixtures during full-power operation and reduce the available horsepower during cruise operation with lean mixtures."[379] GAMI believes that if an aviation gasoline with a motor octane number (MON) in the range of 97-98 were available and operated with appropriate electronic ignition controls, most or all high-performance engines could be accommodated without material increase in fuel consumption or loss of power. Alternatively, a 95 MON unleaded fuel with electronic engine controls could (at least) "keep all of the engines in the fleet running," but would require richer mixtures during full-power operations and would limit the desirable and efficient Lean-of-Peak operations to power settings of 75 percent or less of rated power.[380] "These offsetting considerations could actually result in an overall environmental degradation as compared to the present use of TEL in the existing fuel, with more efficient engine operation."[381]

- Optimized Fuel-Injector Nozzles – Optimized cylinder-by-cylinder fuel injector nozzles (fuel-air mixture management) may improve fuel efficiency up to 20 percent.[382] One experimental project to develop *Direct Injector Fuel Nozzles* (where fuel is injected directly into the cylinders at the moment of desired ignition and burning, thereby providing a highly controlled, more precise burn)[383] may one day permit the use of diesel, Jet A, or other liquid or gaseous fuels in retrofitted reciprocating engines, as well as allow greater flexibility in new engine design.[384]

- Speed Modifications and Aerodynamically Clean Aircraft – While not a fuel device, such modifications deserve mention for drag reduction and resulting fuel economy.[385] Speed modifications may include lower-profile (and low-drag) antennas, flap and aileron seals, laminar flow control surfaces,[386] and winglets.[387] Propeller repitching (where safe and approved) may improve fuel savings. Clean airframes may save up to one-half percent in fuel consumption.[388]

- Tuned Exhaust and Induction Systems – By more efficiently removing exhaust gases from each cylinder and thereby improving fuel/air intake in the next intake stroke, tuned exhaust systems may improve horsepower, thereby providing fuel savings.[389]

- Turbocharging and Turbonormalizing – May help exploit the efficiencies of higher-altitude and density altitude flight (both thinner atmosphere and, when available, stronger tail winds) where missions are typically of longer duration (e.g., long range cross-country flights).[390]

As a practical matter, achieving significant improvements in aircraft energy efficiency requires the contribution of many diverse technologies touching almost every aspect of the aircraft – including basic airframe design. Increased power plant reliability coupled with skyrocketing fuel costs are driving a shift from twin to single engine GA aircraft—characterized as "a revolution in single engines."[391] Also, there may need to be compromises and tradeoffs between speed and fuel efficiency.[392]

➢ ***Practices –*** In addition to employing appropriate technologies, "there is, unarguably, a best method of operating a given aircraft which results in a maximum rate of return in airspeed (hence reduction in flying time) rather than in distance traveled, per unit of fuel consumed."[393] "The goal has always been proficiency, but it isn't just proficiency to be a better pilot, it's about honing your skills because it's the right thing to do. It's the patriotic thing to do. It's the greening of General Aviation."[394]

- Flight and Fuel Planning – Effective flight and fuel planning (see also Load Management, below) may include planning for the use of optimal altitudes to exploit favorable winds and engine performance, including lower power settings (provided headwinds are low).[395] Review of applicable performance tables to improve efficiency. Where practicable, VFR departures, prompt on-course headings upon departure, and choosing nearby alternates (weather permitting), may contribute to the reduction of emissions, as will avoiding turbulence. Also, use advanced flight planning software that suggests optimum altitude based on specific aircraft characteristics and forecast winds aloft. Consider the benefits of using a cruise descent (e.g., 300 to 500 fpm), where it fits into ATC requirements (see also CDA and RNP in ***Technologies***, above, this section).

- Ground Operations – Where practicable, obtain clearances before engine start, use single-engine taxi for multi-engine aircraft,[396] and promptly taxi away from ramps, hangars and other areas where personnel congregate to reduce their exposure to emissions. Preheat aircraft engines when practicable. Minimize fuel consumption and emissions by using ground-based electrical power (if available) to complete preflight inspection procedures, navigation instrument initialization and programming prior to APU or engine start. Lean aggressively during ground operations, and use low power settings. Taxi using the shortest route available.[397]

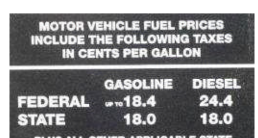
- Load Management – Balance the need for ample fuel with the cost of aviation fuel burn resulting from transporting excess fuel,[398] particularly in stable VFR conditions.[399] Transporting unnecessary baggage and charts may also contribute to inefficiencies.[400] Center of gravity (CG) affects fuel consumption, too.

Generally, a more aft-positioned CG (within an aircraft's permissible CG envelope) improves efficiency (although it also reduces aircraft stability about the pitch axis).

- Configuration – Includes power management, flap positioning, flight profile (including climb, cruise, descent, and approach), and air vent position.
  - Power Management – Understand the relative constraints and optimum climb techniques for your aircraft – loading, weather, and other factors will affect such performance. For turbine operations, where safe and approved, the US EPA is evaluating emissions reductions from derated take-offs.[401] "Rules of thumb" for fuel efficiency applicable to your airplane should be mastered.
  - "Decelerated Approach" – Subject to ATC, SOPs, and safety requirements, consider delay of gear and flap extension until 1,000 AGL.
  - Leaning – Lean aggressively (while maintaining safe operation),[402] and where practicable and authorized, consider lean-of-peak operations.[403]
  - Rental Charges – Rental arrangements are typically structured per wet hour (Hobbs) rather than structured to reward fuel conservation.[404]
  - Miscellaneous – Keep cowl flaps and air vents closed when not required.
- Engine Maintenance – Keep engines in optimal condition by adhering to the applicable maintenance regime.
- Airframe Maintenance – Keep airframes, including rigging, alignment of flaps, and seals, in optimal condition. Keep the aircraft exterior clean, polished, and free of dents and chipped paint, to minimize aerodynamic drag and deterioration. Keep tires properly inflated.
- Checklist: Environmental Items – Review and add appropriate environmental items to operational checklists.

G. INCENTIVES TO REDUCE EMISSIONS

Government, market, and "conscience-based" mechanisms and policies can influence fuel usage/economy, aircraft and engine design, pilot behavior,[405] and emissions. An efficient approach to reducing emissions of CO_2 involves giving businesses and households economic incentives for such reductions.[406] "Approaches using tax incentives, emissions trading or carbon offsets may all have a role to play . . . ."[407] Although not all are suitable, tested, or optimal for GA, the mechanisms and policies surveyed below may help navigate the developing landscape, and better arm the GA community to respond effectively to the challenging (and often contentious) debate accompanying such proposals.

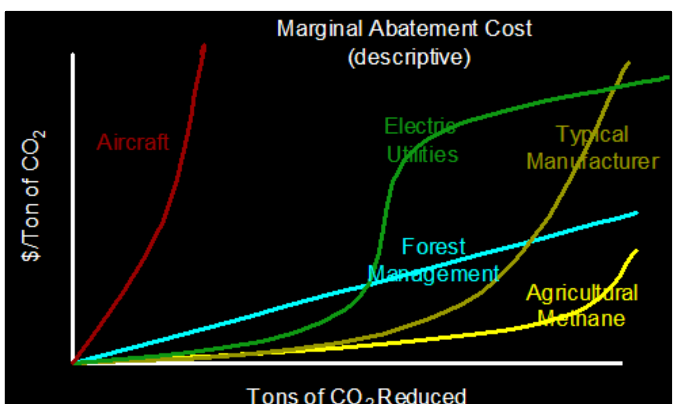


Cal. Fuel Pump Placard

- Fuel Taxes – The U.S. federal government levies an excise tax on both avgas and kerosene as a fixed fee per gallon.[408] Many states also tax aviation fuels.[409] Higher fuel tax increases are under consideration in many jurisdictions. Recognizing that the marketplace does not reflect fuel's entire environmental costs, some countries have implemented environmental taxes,[410] and some include a commensurate reduction in income tax.[411] The National Business Aviation Association asserts that a "tax on fuel use provides an incentive for general aviation users to purchase newer, cleaner, quieter and more fuel-efficient aircraft. Additionally, fuel taxes by their nature penalize operators that use congested airports which require more fuel use for increased taxi and air time."[412] Fuel taxes create lower administrative costs than offset schemes. Higher fuel prices also tend to reduce GA operations.[413] In any event, "tax incentives are certainly tricky,"[414] and demand the upmost scrutiny.

- Tax Credits and Refunds – Some tax credits promote and incentivize the production or use of alternative fuels,[415] and may increasingly fund alternative research, development, and fuel production.[416]
- Carbon Tax – A carbon tax may be levied to mitigate carbon emission production. A claimed benefit of this approach is "to provide clear, long-term price signals so companies can invest intelligently to lower carbon emissions."[417] Many analysts view a carbon tax as a "more economically efficient policy for reducing emissions than an inflexible cap."[418] Nonetheless, its imposition has been characterized as "political suicide."[419] Instead, carbon-offsetting approaches (see below) may be more viable.
- Tradable Fuel Rights – Some have proposed tradable fuel rights as an alternative to fuel taxes whereby government-distributed fueling rights could be used to apportion fuel or be traded with others for value.[420] Although not yet implemented, this proposal has generated considerable attention.
- Carbon Offsets – Carbon offsets incentivize the reduced use of fossil fuels and seek to mitigate the perceived environmental impact of carbon dioxide emissions[421] through compliance/regulatory (mandatory) schemes, or voluntary programs.[422] The size of carbon offsets is generally calculated to (at least) reduce or neutralize the subject emissions (see Calculating Carbon Offsets, below). Offset schemes generally fund environmentally clean or sustaining projects to compensate (in whole or in part) for a participating entity's emissions. From the perspective of the atmosphere (since it is globally well mixed), there is no difference (with the exception of *radiative forcing* effects,[423] discussed below) between: (a) CO_2 being added at one point while (an equivalent amount) is reduced or eliminated at another point, and (b) avoidance of the release in the first place.

  The economic basis of carbon offsetting uses the reality of *marginal abatement cost* to produce the greatest reduction in greenhouse gases (GHG) at the lowest cost to society and the GHG emitter.[424] For this reason, it is the fundamental component of schemes throughout the world that implement the Kyoto Protocol. The following figure demonstrates aircrafts' constrained cost effective options to reduce carbon and the corresponding comparative benefits of carbon offsets.[425]



Source: Carbon Neutral Airplane

Compliance/regulatory schemes provide for the "cap-and-trade" of emissions, typically by establishing a finite number of tradable emissions credits (the "cap") that are distributed by formula or public auction to emitters.[426] Emitters then conform to their permissible emissions level by direct reduction of emissions, purchase of additional emissions credits, or carbon offsets (the "trade").[427] Cap and trade mechanisms have been used previously (and successfully) to reduce sulfur dioxide and acid rain.

Voluntary carbon offset initiatives "may be considered as a cost-effective complement to technology transfer and other mechanisms to reduce fuel consumption and increase resource efficiency."[428] The benefits of voluntary schemes have been viewed as including: the possibility of broad participation, avoidance or mitigation of down-stream regulation,[429] preparation for future possible participation in regulated schemes, flexible innovation and experimentation, and corporate goodwill.[430] Moreover, unlike the longer-term results of research and development, carbon offsets provide an *immediate* reduction in carbon emissions.

Calculating Carbon Offsets – Various on-line "carbon calculators" are available to estimate the amount of carbon emissions generated from a specific flight and the corresponding offset cost.[431] These calculators use varying metrics[432] and are not largely GA-specific. Indeed, metrics for determining aviation carbon emissions and equivalent offsets are difficult to calculate accurately, due to the complex science involved (including, as an example, uncertainties about the effect of aviation on radiative forcing[433]), and the variability of air travel (such as equipment, weather, duration of flight, altitude, and loading).[434] Nonetheless, for example, one starting point is to calculate the generation of emissions from 100LL of 18.35 lbs. of CO_2 per gallon; and for Jet A, 21.1 lbs. of CO_2 per gallon.[435]

Criticism of Carbon Offsets – Some in the aviation community are critical of offsetting schemes because they see these as mechanisms that divert funds from the aviation community that could otherwise be used to fund aviation-specific emission-mitigation programs. For example, offsetting schemes could divert funds from GA-specific fuel, emissions, and engine research and development.[436]

Some critics in the environmentalist community argue that "consumers are simply buying their way out of having to make meaningful reductions in energy consumption."[437] Others assert that "offsets often encourage climate protection that would have happened regardless of the buying and selling of paper certificates [and that] one danger of largely symbolic deals is that they may divert attention and resources from more expensive and effective measures."[438] Some critics urge that "cutting carbon dioxide emissions will require real sacrifice closer to home, like driving less, flying less and putting restrictions on businesses"[439] rather than relying "too heavily on slight-of-hand accounting and huge donations to environmental projects abroad."[440] Despite available voluntary carbon offset standards,[441] accreditation and certification programs for bodies engaged in the reduction and removal of greenhouse gases,[442] and renewed oversight of "green advertising," the efficacy and accountability of offset schemes has been challenged.[443] Even schemes that claim they are *verified* projects and conforming "Clean Development Mechanisms" (CDM) under the Kyoto Treaty have not escaped criticism.[444] One study found that company announcement of voluntary scheme adoption had a negative impact on stock price and "point[ed] to the need for regulatory action on climate change,"[445] and other studies claim cap and trade would cost the US 4 million jobs by 2020.[446] Taxes generally have a lower administrative cost than offset schemes. Criticism of offsets also includes global warming skeptics – concerning both concentrations and projections of CO_2 as well as their impact.[447] Finally, the propriety of carbon offsets for a community as small as GA has been challenged as fundamentally flawed and unfair to the extent that the same metrics are used unjustifiably for GA as for air transport aircraft.[448]

Carbon Offset Initiatives – Aviation-centric carbon offset markets and products are evolving quickly to provide creative and varying offset products. As examples, consider offsets provided in connection with: the purchase of aircraft, current owners/operators, charter passengers,[449] fractional owners,[450] "jet card" passengers,[451] and even flight schools.[452] A few examples of carbon offset initiatives to GA pilots follow.

- The *Carbon Neutral Plane* program certifies that participating GA airplanes have compensated fully for their carbon dioxide emissions, by financially supporting verified projects aimed at reducing equivalent emissions from other energy uses via carbon offsetting.[453]
- Bombardier purchased carbon offsets for its fleet, and offers new owners the option of purchasing carbon-neutral aircraft.[454]
- The British Business and General Aviation Association (BBGA) provides a program whereby customers pay the operator an additional fee per liter of fuel consumed seeking to balance CO_2 emissions. Fees are passed to the World Land Trust[455] to implement environmentally worthy programs in developing countries. The BBGA plans to deploy this scheme into practice across Europe.[456]

While not carbon-offset mechanisms per se, voluntary initiatives such as the United Nations Global Compact[457] may promote and facilitate carbon offsetting by aircraft manufacturers, FBOs, and other aviation businesses. Finally, many airlines have undertaken voluntary carbon reduction programs,[458] or facilitate passengers' purchase of carbon offsets.[459]

Compliance/Regulatory Approaches – Whether initiated by intergovernmental accord, national law, or otherwise, compliance and regulatory approaches for cap and trade are, at present, accelerating. [460] The International Civil Aviation Organization (ICAO)[461] took an early lead in developing an "implementation framework for States to use in achieving emissions reductions, including . . . *positive economic incentives*, and *market-based measures*."[462] Although initially targeting the airlines, such schemes may impact GA business and corporate fleets, and eventually aircraft with under 6,000 lbs. of thrust.[463] Consider the following developments.

- European Parliament – The European Parliament gave preliminary approval for an open market carbon offset scheme for intra-European aircraft in 2011, and inter-European aircraft in 2012. The goal is to reduce future carbon emissions by 90 percent of the current average.[464] The European Emissions Trading Scheme (ETS) is "the largest multi-country, multi-sector Greenhouse Gas emission trading scheme world-wide."[465] The scope of the ETS (re: legacy carriers vs. start-up vs. regional carriers), and the extent to which carriers may purchase emission allowances outside of the aviation sector are still in play. Also, several nations have commenced litigation seeking to exclude their airlines from the ETS.[466] Criticism of the ETS has included assertions that "it is unilateral, extraterritorial and designed in a way to punish rather than to reward the aviation industry for its past and future commitment to emissions reductions. If implemented as currently contemplated . . . . it will achieve very little."[467] Unilateral action is widely considered impermissible by signatories to ICAO. Nonetheless, it is widely viewed that "some version of a cap-and-trade system is inevitable, and anyone who thinks otherwise is badly mistaken."[468]
- United States – The US has emphasized technological innovation rather than emissions caps as the best approach.[469] Nonetheless, the US is watching the European initiatives, recognizing that the federal government will invariably need to respond,[470] although the US response (and that of much of the international community) may take a "multi-path

approach comprising measures such as operational measures, market-based measures, voluntary measures, improvements in ATM and technological advances."[471] U.S. federal legislation to provide a national cap-and-trade plan is also under consideration.[472] The US Supreme Court's decision to compel the US EPA to assert jurisdiction over greenhouse gas emissions may also catalyze U.S. regulation.[473]

- Other Initiatives – Various national and regional aviation environmental initiatives may also advance alternative fuels and reduced emissions.[474]

➢ "Green Upgrades" – The AMCC appeals to every pilot's conscience to take personal responsibility for reducing the environmental footprint of GA. There is evidence that consumers, including pilots, are willing to adopt environmentally responsible practices, participate in environmental programs,[475] and make consumer purchase decisions with environmental considerations.[476] Such an ethical approach to flying may also provide incentive for voluntary carbon offsets.

➢ Market-Driven Fuel Price Hikes – Higher oil prices have been called "a perfect incentive to reduce our fuel burn and CO_2"[477] since they cause an "unrelenting economic imperative"[478] to reduce consumption, and have a demonstrated correlation to reduced fuel use and corresponding emissions reductions.[479]

➢ Green Marketing – Some aviation businesses are pursuing the potential marketing benefits of "being green" by promoting their efforts to reduce their greenhouse gas emissions. An example includes the frequent ads by Piaggio Avanti in the national press for their P.180 turboprop. Some aviation entities are following the example of firms such as Whole Foods and Lexus (hybrid cars and SUVs) in the belief that up-scale consumers will pay more for a product that displays environmental sensitivity.[480]

➢ User Fees – Notwithstanding their broader ominous impact, GA user fees may reduce emissions by curtailing GA flight operations.

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III. LUBRICANTS, CHEMICALS, AND SOLID WASTES

A. USE AND DISPOSAL OF MOTOR OIL

Used oil is a major source of water pollution.[481] The oil from one improperly disposed-of oil change can pollute a million gallons of fresh water.[482] Two hundred million gallons of used oil (from all sources, both aviation and non-aviation) are improperly disposed of annually.[483] Moreover, used oil from leaded avgas –burning aircraft contains lead.[484]

Used Oil Collection Site
French Valley Airport, CA

Many pilots replenish or change engine oil themselves. Do-it-yourself oil changes are sometimes completed at one's tie-down location absent formal environmental controls. As many as 60 percent of all "do-it-yourselfers"—including aviation and automotive—dispose of oil improperly![485] Perhaps aviators do better, but such data are not readily available. Still, even if the aviation segment of improper oil disposal is much smaller than for automotive, the environmental impact of used oil warrants heightened attention by all do-it-yourselfers.[486]

Used oil is recyclable into re-refined[487] fuels, lubricants, and raw material for diverse petrochemical products.[488] The US EPA presumes that used oil is to be recycled[489] and provides standards for the life-cycle management of used oil.[490] Corresponding state, regional, and local programs for recycling used oil are widespread, including at airports. However, the effectiveness of airport oil collection programs varies considerably. For example, some airport managements keep their oil collection facilities locked and require pilots to schedule access—which is limited to business hours.[491] Other managers provide unlimited access to oil receptacles distributed conveniently around the airport.[492]

RECYCLE USED OIL

Most piston-powered aircraft engines consume at least one quart of oil for each 8-10 hours of operation,[493] and replenishment of this oil is required for safe operation—generating tens of thousands of used oil bottles annually (in addition to the bottles generated from regular, periodic oil changes).[494] Consider, for example, that in California, plastic bottles from over 400 million quarts of oil are disposed of annually. Each "empty" quart container holds approximately one ounce of residual oil. Collectively, these account for 25,000 tons of plastic and over 3 million gallons of oil. Yet, there is no requirement for recycling these used oil bottles and the residual oil they contain. Some airports co-locate plastic-bag lined canisters (at oil collection locations) for used oil bottles.

Used Oil Collection Site

B. LUBRICATION PRACTICES

Environmentally sound oil (and used oil) practices[495] may include the following:

- Oil Level – To avoid crank case oil "blow out" do not top-off engine oil. Instead, know and maintain the stable level of oil required for safe engine operation.[496]

- Oil Capture – Ensure proper capture of used oil. Avoid dripping or leaking used oil during oil change.
- Used Oil Filters – Property dispose of used oil filters, and drain free flowing oil from used filters before disposal.[497]
- Oil Bottles – Recycle used oil bottles. If unable to recycle, reseal and place them in sealed and labeled plastic bags before disposal. Encourage FBOs to use bulk oil storage (rather than quart) containers to reduce oil waste.
- Used Oil – Recycle used oil responsibly, using authorized recycling facilities, and adhere to applicable recycling facility procedures.[498] If your home airport does not provide convenient access to oil receptacles, consider asking management to make such facilities available.

Petaluma Airport, CA

- *DIYers* – For "do it yourself" oil changes, learn and adhere to environmentally responsible procedures.[499]
- Spills – Maintain or identify the location of an available oil/chemical "spill kit";[500] clean up spilled oil/chemicals immediately, and dispose of absorbents lawfully and responsibly.
- Airport Recycling Programs – If your airport does not have a viable oil recycling program, consider helping to create such a program.
- Air/Oil Separators – While not a "practice", air/oil separators may reduce oil consumption and the emission of oil from the engine.

C. USE AND DISPOSAL OF OTHER CHEMICALS

Chemicals used widely in GA include those for repair, lubrication, cooling, stripping, deicing,[501] cleaning, and de-greasing. Some of these chemicals contain such toxic substances as methyl chloroform, propylene glycol, and chlorofluorocarbons,[502] which may, among other dangers, cause air and groundwater pollution,[503] and ozone layer depletion.[504] Because the extent of the actual risks of most chemicals is unknown and the US EPA's authority and capability to assess such risks is limited,[505] great diligence should be exercised with the purchase, transport, use, and disposal of all chemicals.

Chemical manufacturers and suppliers are required to make available Material Safety Data Sheets (MSDS) [506] for products they produce or distribute. Pilots who obtain chemicals from FBOs or other suppliers should ask for a copy of the MSDS (or obtain them online), or a description of the recommendations for storage and use, a list of hazards, disposal methods, and effective means of preventing exposure.

Pilots often work on their aircraft with neither knowledge of these risks, nor with adequate protection from chemicals, including from skin and eye contact (e.g., by use of protective goggles and gloves), and inhalation (e.g., by ensuring proper ventilation). Pilots should become familiar with the toxicity of chemicals they use, suggested protective measures, recommended antidotes/first-aide measures, and seek less toxic alternatives, where practicable. Flying with dangerous goods or hazardous materials is discussed in the Commentary to AMCC V.a.[507]

Environmentally sound chemical use and disposal practices may include the following:

- "Green" Chemicals – Where practicable, purchase and use environmentally sound chemicals for the cleaning, maintenance, and operation of your aircraft.[508]

- Wash Racks – Use an airport's "wash rack" for degreasing and cleaning, consistent with posted limitations.[509] Water trapped by wash rack drains should be filtered and recovered by the operating authority, ensuring any chemicals in the water are properly treated or disposed.

- De-Icing – Propylene glycol, while less toxic than its predecessor ethylene glycol,[510] is a hazardous waste. To reduce the environmental impact of de-icing fluids, the following methods have been recommended:
    1. Blocking or closing storm drain sewers during dry weather
    2. Conducting deicing operations in areas where fluids can easily be retained
    3. Installing lined detention basins or underground storage tanks
    4. Using mechanical vacuum sweepers or similar devices to capture runoff
    5. Installing aircraft wash racks[511]

- Disposal – Inquire about chemical disposal options with your FBO and airport management. If your airport lacks facilities for the safe disposal of harmful chemicals, take them to a community disposal facility, and consider volunteering to help develop responsible disposal options at your airport.

- Contaminated Rags – Contaminated rags or shop towels, such as those typically resulting from aircraft maintenance, may contain hazardous wastes and should be properly disposed of.[512]

- Spills – Clean up spilled fuel chemicals immediately, and dispose of absorbents lawfully.

D. UNIVERSAL WASTES

GA creates considerable widely generated, low-toxicity hazardous wastes[513] which are known as "universal wastes."[514] These include, but are not limited to, batteries,[515] and mercury devices (such as switches, and lights).[516] Consider that GA pilots expend a high quantity of batteries for flashlights, timers, backup transceivers, active noise reduction (ANR) headsets, emergency locator transmitters (ELTs), personal locator beacons (PLBs), portable navigation devices, flight computers, electronic flight books (EFBs), personal digital assistants (PDAs), back-up attitude indicators, and a growing number of other devices. Safe operating practices urge keeping a considerable supply of extra "fresh" batteries on hand. Safe aircraft maintenance practices, particularly for aircraft undertaking single-engine IFR operations, may include recommendations for the biennial replacement of lead-acid batteries.

While universal wastes are generally unregulated for individual household generators,[517] the US EPA encourages that these items be taken to collection sites for proper recycling or disposal.[518] In California, however, universal wastes must be properly managed through municipal collection or directly with a universal waste recycling processor.[519] Voluntary (and, where applicable, mandated) universal waste practices are encouraged herein. Such practices are an important step in mitigating GA's environmental impact.

E. STORM WATER DISCHARGE PRACTICES

Among other constraints, storm water discharge rules pertain at most airports. Such rules typically prohibit the discharge of pollutants, including hazardous waste, anti-freeze,[520] petroleum products, and wash water into the storm water or watercourses.[521] This may have the effect of prohibiting any flow of water at an airport except for that at designated wash racks, restaurants, and toilets. Become familiar with the location of storm water drains at your airport and avoid improper discharge into them. Inquire about local facilities and comply with disposal practices before servicing or cleaning your airplane at airports away from your home base.

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IV. AIRBORNE EMISSIONS

Airborne emissions from GA aircraft contribute to aviation-related air pollution, although such emissions play a comparatively minor role in reducing air quality.[522] The U.S. General Accountability Office (GAO) found that critical aviation pollutants account for less than .5 percent of total emissions in the U.S.[523] The General Aviation Manufacturers Association (GAMA) asserts that US "greenhouse gas emissions from GA are less than two tenths of one percent of overall emissions,"[524] and the IPCC pegs aviation's contribution to CO_2 at under 3 percent of anthropomorphic sources[525] U.S. transportation accounted for approximately twenty-seven percent, and aircraft approximately nine percent of the transportation sector's greenhouse gas emissions in 2003.[526] Of such aircraft emissions, GA contributed approximately seven percent[527] or less.[528] This represents well under one percent of transportation's greenhouse gas emissions.[529] Moreover, hydrocarbon emissions have decreased substantially since 1950.[530] Consider ICAO's assessment of small aircraft engines:

- Aviation accounts for under 1% of US air pollution
- Aviation accounts for 2.7% of US contribution to greenhouse gas emissions
- Global aircraft emissions cause approximately 3.5% of anthropomorphic warming

> The small commercial and general aviation segment has been growing rapidly in recent years and is likely to continue to do so. This segment's impact on the environment, however, is unlikely to be significant because of low NO_x emissions levels associated with the generally lower pressure ratio engines they employ and the decreasing percentage of the fleet's fuel burn they represent . . . . Furthermore, most of aircraft in this sector fly short missions with lower cruise altitudes and reduced potential for climatic impact. Significant improvements have been made in the idle emissions of small engines in recent years, so that CO, HC, and NO_x emissions from small regional and general aviation aircraft are often comparable, in terms of emissions per kilogram of fuel burned, to those from large engines.[531]

Nonetheless, airborne emissions from aviation "cannot be ignored."[532] The projected growth of aircraft[533] and air travel is expected to increase such emissions.[534] Moreover, decreasing emissions from non-aviation mobile sources could have the effect of increasing (and highlighting) aviation's relative contribution, with a corresponding potential regulatory focus on GA. As a practical matter, at least in the short-term, limited funding resources at the FAA, a lack of public concern communicated to the FAA,[535] and competing priorities of the EPA suggest that federal environmental regulation of airborne emissions by small GA is unlikely.[536]

When reading Part IV of this commentary, consider that most aviation environmental standards regulate higher-thrust commercial/transport aircraft engines rather than those built specifically for general aviation aircraft. Nonetheless, the general direction of emission standards is to become more stringent and inclusive – possibly regulating (or at least impacting design of) lower-thrust engines. Additionally, because of the increasing use of heavy fuels in GA (due to more turbine- and diesel-powered aircraft, and decreasing avgas availability), recent findings of heightened health hazards of certain emissions products (such as particulate matter), and broader climate change issues, including litigation,[537] it is helpful to understand how such regulations might most likely impact GA in the future.

A. CRITERIA POLLUTANTS

Harmful air pollutants emitted by aircraft include carbon, nitrogen, and sulfur compounds, particulate matter, water vapor (although its contribution may be quite minor), and various compounds containing carbon with chlorine, fluorine, bromine, and hydrogen.[538] Six pollutants are widely used as significant indicators of air quality—*Criteria Pollutants*. The following table introduces the *Criteria Pollutants*[539] in the context of aircraft emissions.

Carbon Monoxide (CO)	Colorless, odorless and poisonous gas resulting from incomplete burning of hydrocarbons, more than 3/4th of which are from transportation sources. Exposure impedes alertness, manual dexterity among other impacts, and may ultimately cause suffocation and death.
Lead (Pb)	Emitted by the combustion of avgas, lead is rapidly absorbed into the bloodstream and can cause many serious health effects including adverse effects on blood, the central nervous system, cardiovascular system, kidneys, and immune system.
Nitrogen Dioxide (NO_2)	Nitrogen oxides are highly reactive gases, contribute to O_3 formation, and the secondary formation of $PM_{2.5}$. Brownish and odorless,[540] NO_2 reduces respiratory function.
Ozone (O_3)	The primary ingredient of smog, O_3 results from hydrocarbons (volatile organic compounds) and oxides of nitrogen breaking down in the presence of heat and sunlight.[541] Causes or exacerbates pulmonary and respiratory problems; premature deaths.
Particulate Matter (PM)	A component of soot and smoke, and emitted from combustion of fuels. The classification of PM is generally bifurcated into $PM_{2.5}$ and PM_{10} – the aerodynamic diameter of the particles, each of which carries health hazards, including cancer, immunological and respiratory disease (including asthma and pneumonia), and premature mortality.
Sulfur Dioxide (SO_2)	Emitted by combustion of petroleum; less so with synfuels. A precursor to acid rain. Diminishes respiration and causes cardiovascular disease.

Criteria Pollutants

Maximum concentrations of criteria pollutants are established under the Clean Air Act by the US EPA in its *National Ambient Air Quality Standards* (NAAQS).[542] Areas failing to satisfy these standards are subject to classification as a *nonattainment area* – resulting in required remediation.[543] The US "EPA estimates that approximately 110 million people live in areas of the U.S. where the combined upper-bound lifetime cancer risk from all air toxics exceeds 10 in a million.[544]

"Engine emissions consist of (by mass) 70% CO_2, 30% H_2O, and less than 0.5% NOx, CO, SO_2, unburned hydrocarbons (UHC), and soot. For CO_2, H_2O, and essentially for SO_2, the amount emitted into the global atmosphere is proportional to fuel use, implying that about 90% of the emission occurs during non-LTO [landing & take-off cycle] operation."[545] Engine emissions standards appear to be gearing up to more completely mitigate the criteria pollutants, and, increasingly CO_2.

B. SEGMENTATION OF AIRBORNE EMISSIONS

Airborne emissions can be segmented roughly into (1) "local" emissions—those that materially affect ground level concentrations,[546] (2) those at and above 3,000 ft. (the "mixing level/height") which neither "mix" nor directly impact the local environment,[547] and (3) higher-altitude emissions (e.g., cruise level for jets) that may create contrails[548] and contribute to climactic change.[549] The latter category can be bifurcated for those emissions that are within the troposphere and stratosphere – many subsonic turbine aircraft operate in the upper troposphere and lower stratosphere.

➢ Ground/Local Emissions – The bulk of aircraft emissions (approximately 90 percent) occur at altitude, but approximately 10 percent of aircraft emissions are produced during ground operations or takeoff and landing. For hydrocarbons and CO, the split is closer to 30 percent ground level emissions and 70 percent at altitude.[550] Ground/local emissions may produce smog, and contain *hazardous air pollutants* (HAPs - discussed below). The impact of ground/local emissions from aircraft has been the subject of considerable study and increasingly, greater and more sophisticated monitoring and analysis.[551]

Thermal/Optical Carbon Analyzer

The following considers three pollutants that have drawn significant attention with regard to their impact at ground level: particulate matter, nitrogen oxides, and lead.

- Particulate Matter – Particulate Matter (PM) represents:

> a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. PM_{10} refers to particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers. Fine particles refer to those particles with an aerodynamic diameter less than or equal to a nominal 2.5 micrometers (also known as $PM_{2.5}$). The emission sources, formation processes, chemical composition, atmospheric residence times, transport distances and other parameters of fine and coarse particles are distinct. . . .
>
> Fine particles are directly emitted from combustion sources and are formed secondarily from gaseous precursors such as oxides of nitrogen (NO_X). Fine particles are generally composed of sulfate, nitrate, chloride, ammonium compounds, organic carbon, elemental carbon, and metals. Aircraft engines emit NO_X which reacts in the atmosphere to form secondary $PM_{2.5}$ (namely ammonium nitrate).[552]

Smoke/soot ("visible carbon") is produced by aircraft primarily during departure due to a high fuel-air ratio (see below) and low power (e.g., idle), both resulting in incomplete combustion.[553] One important study found that "[d]iesel particulate continues to dominate the risk from air toxics, and that the portion of air toxic risk attributable to diesel exhaust is increasing,"[554] and with possible implications for aviation diesels and turbines. It further found that "[d]iesel exhaust was the key driver for air toxics risk, accounting for an estimated 84% of the total."[555] The study concluded "that a continued focus on reduction of toxic emissions, particularly from diesel engines, is needed to reduce air toxics exposure"[556] "as early as practicable and as aggressively as feasible."[557] Assessment of the human health risks of PM are increasing: "the central estimate of the relative risk of premature death is 10 percent per 10 $\mu g/m^3$ increase in PM2.5 exposures."[558] Indeed, the "policy-making community needs improvements in the knowledge and modeling of particulate matter chemistry."[559]

- NO$_X$ – The environmental impact of NO$_X$ on ground and local emissions is extensive, and includes acidification,[560] eutrophication and nitrification,[561] plant damage from ozone, and impeded visibility.[562] NOx is getting emphasis in the aviation environmental community because of its significant contribution (although less than PM) to pollution and the comparative progress in having reduced CO, hydrocarbons, and smoke.[563] According to the US EPA, "[w]hile the current contribution of aircraft to nationwide NO$_X$ is less than one percent, their contribution on a local level, especially in areas containing or adjacent to airports can be much larger and is also expected to grow."[564]

- Lead – One recent study of airborne emissions undertaken at two southern-California GA airports used lead as a unique marker for piston-based aircraft engine emissions to better understanding the impact of leaded avgas-consuming aircraft on the local environment.[565] The study found lead levels in communities and near runways below federal and state standards, but elevated near runway sites.[566] The regulation of leaded avgas is considered above in Part II of this commentary.

➢ Tropospheric Emissions – The troposphere is an area ranging approximately between 9,000-40,000 ft. MSL, its boundaries varying by the level where a sharp reduction in temperature lapse rate occurs. Emissions with a potential impact on climate change have been the focus of both tropospheric and stratospheric studies.

➢ Stratospheric Emissions – The stratosphere is an area above the troposphere and below the mesophere, ranging from approximately 10-50 km above the surface, with temperature stratified (and higher) with altitude. Because the stratosphere is vertically stable, pollution does not vertically mix and purification by precipitation does not occur at such altitudes.[567] Thus, for example, contrail-based emissions at such altitudes present significant challenges.

Contrails result when water vapor, emitted in jet engine exhaust condenses into liquid droplets that immediately freeze in the cold ambient temperatures of the upper troposphere and stratosphere, effectively forming artificial cirrus clouds.[568] It is estimated that contrail cloud cover may quadruple—from 0-0.2 percent for the late 1990s, to 0-0.8 percent by 2050.[569] Contrails have a reflective property, reflecting some sunlight away from the earth's surface during the day. Conversely, its heat-trapping effect at night outweighs these reflective properties thereby causing a net heat-trapping effect. One study suggests that shifting flights from nighttime to daytime might mitigate the heat-trapping effect of contrails.[570] The introduction of very light jets (VLJs) that operate at higher-flight levels may focus increasing attention on GA's contribution to climate change. Nonetheless, "there are large uncertainties associated with the predicted climate impact of contrail and contrail cirrus, which could potentially be important."[571] And, the FAA's Chief Scientist and Technical Advisor notes that the impact of contrails are "amongst the most uncertain of pollutants."[572] "We don't know how to quantify it."[573]

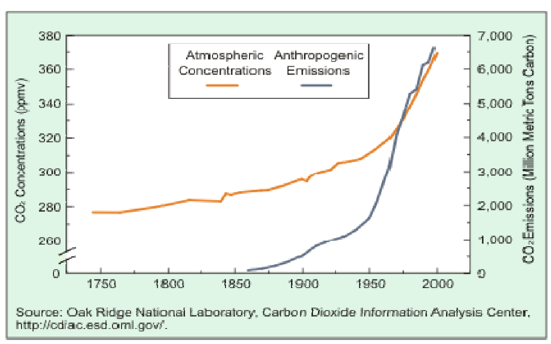


Table 2 - Trends in CO Emissions

The Ozone Layer – The ozone layer is a region in the lower stratosphere between 10 and 75 km altitude, with its maximum concentration between 20 and 25 km altitude, and contains approximately ninety percent of the earth's ozone (O_3). This unstable gas absorbs ultraviolet radiation and totally filters out lethal UVC radiation, as well as "excessive" levels of UVA—thus serving as a critical protective shield against harmful radiation.[574] Approximately ten percent of atmospheric ozone resides in the troposphere, and is mainly a byproduct of photochemical oxidation of carbon compounds, mostly from anthropomorphic sources. While stratospheric ozone has beneficial effects, tropospheric ozone is widely viewed as a primary source of smog and global warming.[575]

Chlorofluorocarbons (CFCs), halons (used for fire suppression),[576] and certain other chemicals pose dangers to the ozone layer. These chemicals are stable in the troposphere but undergo chemical reactions due to ultraviolet radiation in the stratosphere where they transform into ozone depleting chemicals. An index for the relative potential to deplete ozone has been established: the Ozone Depletion Potential (ODP).[577] Approximately 90 percent of the current CFCs in the upper atmosphere will remain for half a century – notwithstanding the 1990s ban of such chemicals under the Clean Air Act Amendments of 1990.

The Greenhouse Effect – Certain gases in the atmosphere absorb and then emit infrared radiation, and reflect such radiation to and from the Earth's surface.[578] Those gases that "trap" heat in this fashion are called "greenhouse gases." Historically, the Earth has maintained a balance between the solar radiation it absorbs, reflects, and emits. Since the advent of large-scale industrialization, many greenhouse gases have increased by about 25 percent, including what is thought to be the most important greenhouse gas, carbon dioxide.[579] The primary greenhouse gases are generally cited to include: water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3).[580]

- Radiative Forcing (RF) - *Radiative Forcing* has been employed in IPCC documents to denote "externally imposed perturbations in the radiative energy budget of the Earth's climate system [which may potentially] lead to changes in climate parameters,"[581] and defined more formally, as follows:

  > The radiative forcing of the surface-troposphere system due to the perturbation in or the introduction of an agent (say, a change in greenhouse gas concentrations) is the change in net (down minus up) irradiance (solar plus long-wave; in Wm^{-2}) at the tropopause AFTER allowing for stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropospheric temperatures and state held fixed at the unperturbed values.[582]

  "Increases in greenhouse gas concentrations during the past decade have lead to a positive Radiative Forcing, tending to warm the lower atmosphere in order to increase the terrestrial radiation and restore radiative balance."[583] RF "is a measure of the importance of aircraft-induced climate change other than that from the release of fossil carbon alone."[584]

- Climate "Multipliers" – To measure and assess the relative importance of a greenhouse gas to trap heat in the atmosphere during its lifetime, various metrics have been developed. For example, the IPCC introduced an index entitled the Global Warming Potential (GWP),[585] although its limitations (as is true for most attempts to simply very complex science) are significant.[586] Other metrics have also been developed to assess the non-CO_2 climate impacts of aviation. Nonetheless, "a suitable candidate for such "a multiplier requires further development, being fairly theoretical at present. The feasibility of arriving at operational methodologies for addressing the full climate impact of aviation depends not only on improving scientific understanding of non-CO_2 impacts, but also on the potential for measuring or calculating these impacts on individual flights."[587] Proposed RF multipliers vary considerably, but tend to range from about 1-3 and are trending under 2 times the CO_2 produced by aviation.

C. HAZARDOUS AIR POLLUTANTS (HAPS)

HAPS (or toxic air pollutants) cause or are suspected to cause serious health problems, including cancer. The US EPA maintains a list of 188 HAPs.[588] HAPs are emitted by both stationary and mobile sources – aircraft being one of the mobile sources. Testing has determined that aircraft exhaust produces "extremely low concentrations of HAPs,"[589] and "the measurement of aviation-based HAPs "in the exhaust of commercial and general aviation aircraft can be characterized as either *very limited or non-existent*."[590] The eleven most prevalent HAPs in aircraft exhaust are as follows:[591]

POLLUTANT	TOTAL EMISSIONS (TONS/YEAR)	RANKING	PERCENT OF TOTAL	CUMULATIVE PERCENT
Formaldehyde	6,408	1	42.3	42.3
Acetaldehyde	1,969	2	13.0	55.3
Benzene	1,184	3	7.8	63.1
Toluene	1,174	4	7.7	70.8
Acrolein	938	5	6.2	77.0
1,3-Butadiene	824	6	5.4	82.5
Xylene	702	7	4.6	87.1
Lead (in Avgas)	541	8	3.6	90.7
Naphthalene	454	9	3.0	93.7
Propionaldehyde	396	10	2.6	96.3
Ethylbenzene	211	11	1.4	97.7

Top GA Aircraft-related Hazardous Air Pollutants

"[S]peciation of HAPS [] emissions are poorly understood."[592] Further study, including advancements in environmental sciences are needed to better understand and assess the efficacy of their further regulation.[593] Among other issues, consider that one of the most vexing environmental policy challenges is to resolve the best/most effective time-frame for which the results of environmental remediation should to be achieved.[594] That is, by emphasizing particular emissions that have a lifecycle of, say, twenty five years, other emissions with a 50 or 100 year lifecycle may not necessarily be addressed effectively. Additionally, evaporative emissions deserve additional consideration.

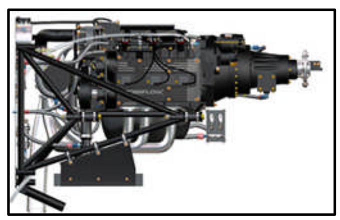
D. POWER PLANT DESIGN CONSIDERATIONS

Two engine types have dominated powered flight—reciprocating and turbine engines—and each has key features and advancements that impact their respective fuel consumption and airborne emissions. Aircraft engine emissions products (and quantity) vary as a function of fuel (composition and quantity) and engine type (e.g., reciprocating vs. turbine), power output, and flight profile, among other factors. As stated by the US General Accountability Office (GAO): "Better understanding of the nature and impact of aviation emissions can inform the development of lower-emitting alternative fuels . . . and more fuel-efficient aircraft engines."[595] Similarly, understanding the various types of aircraft engine attributes and their respective emission profiles underlies making informed decisions to improve emissions mitigation.

- ***Spark-Ignited Reciprocating Engines –*** "Conventional" aviation spark-ignited engines have designs that have not materially advanced for more than half a century.[596] These engines have served the GA community well but are technically dated, environmentally challenged, and cannot fully exploit available technology to achieve the most practicable fuel efficiencies and reduction in emissions.[597] Such engines can be characterized as air cooled (one engine manufacturer characterizes them as "inherent polluters"),[598] avgas burning, magneto-based ignition, large stroke, and low RPM. Such engines are primarily four stroke (Otto-cycle), and some are two stroke (*see* Light Sport and Ultralight Engines, below).

  "Advanced" spark-ignited engines offer diverse features to increase efficiency and reduce emissions. Some of the most significant features may include:

  - Liquid Cooled – Liquid cooled engines can operate in a much smaller range of temperatures (approximately 180-205° C versus -20-400° F and thereby can be engineered to much tighter tolerances—resulting in more efficient and cleaner combustion.[599] The tighter tolerances can better retain crankcase oil and produce less friction.
  - Electronic Ignition – Electronic ignition typically produces 60 kV versus 13-18 kV produced by magnetos.
  - Catalytic Converters – Conventional high-performance aircraft engines cannot tolerate backpressure on the exhaust (in addition to TEL) and therefore cannot exploit the environmental benefits of catalytic converters.[600]



Crossflow CF6-33

  - Avgas-Free Operation – Some advanced reciprocating engines can run on alternative fuels and diesel.[601]
  - Improved Power-to-Weight Ratio – Because water-cooled engines can operate at lower temperatures, lighter metals such as aluminum can possibly be used extensively with the effect of lowering engine weight.[602]
  - Higher Compression – The thermal efficiency of internal combustion engines increases with higher compression ratios.[603]
  - Thermal Efficiency – Thermal efficiency can be further raised by inter-cooled, recuperative engine concepts.

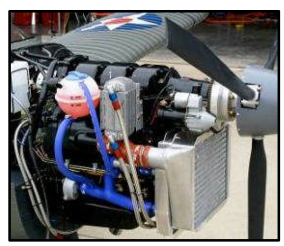
  Light Sport and Ultralight Engines – The light sport and ultralight sectors of GA use diverse engines. Rotax Aircraft Engines[604] is the dominant LSA engine manufacture but other companies are also present in the market,[605] and the classic Continental 0-200 is used on many LSAs. Typical two-stroke engines produce between 40-60 HP and the four-strokes produce between 50-100 HP. Two-cycle engines have the benefit of higher power-to-weight ratios but burn more fuel per HP and emit greater pollution.[606] Modern two-cycle technology can greatly reduce emissions but this technology has not been implemented in aircraft applications. In the past, four-stoke engine installations were rare but the recent shift towards heavier, faster and more sophisticated aircraft has made four-strokes the norm.[607]

Unlike traditional GA engines, purpose-built LSA engines are designed to run on unleaded auto gas but may operate on 100LL with enhanced maintenance. A typical LSA engine such as the four-stroke Rotax 912 has an installed weight of approximately 150 lbs. and produces 80 HP. The slightly bigger 912S produces 100 HP without weight gain. An LSA aircraft on the lighter side of the scale may burn only 3 GPH, a typical LSA (with a 912) may burn 3-5 GPH, and a "heavier" LSA flying at faster speeds may burn up to 6 GPH. Perhaps increasing fuel costs will catalyze improvements in LSA engine efficiency. Finally, diesel engine technology has undergone considerable development but has yet to gain a significant share of the market (see ***Diesel Engines***, below).

- ***Diesel Reciprocating Engines*** – A new generation of aviation diesel (compression ignition) engines has entered the GA marketplace, offering improved fuel efficiency—perhaps 30-40 percent greater efficiency (by volume of fuel) than avgas-based engines,[608] as well as reduced emissions.[609] Some modern diesels are markedly quieter, lighter, and smaller than conventional diesel power plants. Diesels are available increasingly in new aircraft (both certified and experimental),[610] and as retrofits (via STC) in the legacy fleet,[611] and are predicted to become the predominant small GA power plant.[612] Diesels also show great promise in the LSA market.[613] Nonetheless, there remains concern in the industry that aviation diesels may require extensive further development and testing in the field "with millions of hours of operations."[614]


SMA Diesel

Aviation diesels burn widely-available Jet A fuel which is projected to become increasingly cost competitive and more available than avgas[615] (see ***Jet Fuels***, above). Also, some diesels are certified to use kerosene and approved automotive diesel fuels.[616]


WAM-120 Diesel

However, one expert asserts that "available evidence suggests that in the real world, diesel engines configured for aircraft use will achieve brake-specific fuel consumption (BSFC)[617] in the 0.370 to 0.375 lbs/hr/hp range. This compares with well-established aircraft gasoline engines that already achieve 0.385 lbs/hr/hp BSFC efficiencies, before application of new engine technologies to those engines."[618] Thus, it is claimed, diesel engine efficiency gains may be illusory, especially considering the demonstrated (>35 percent) weight penalty versus aircraft with comparable horsepower gasoline engine.[619]

A well-designed and optimized diesel engine will be more efficient than its gasoline counterpart. However, to produce a lightweight structure for a diesel engine means running at lower than optimum compression ratio and probably timing to keep cylinder pressures down, hence allowing a lower weight structure. Thus, aircraft diesels will not match their ground-based counterparts in out-and-out specific fuel consumption, and may well be only a little better than their gasoline competition. And yet, diesels do provide additional environmental benefits:

- Diesel engines are almost as efficient off-load as they are on-load, so periods of idle / taxiing consume little fuel
- There is no requirement to run rich for climb etc. – the diesel will operate at near peak efficiency when fuel burn is fastest
- During the descent a diesel can be set to burn no fuel at all, and still be ready for a quick squirt of power for go-round
- The almost "flat" fuel consumption characteristics encourage flying at whatever speed is best for the airframe – as the engine will operate at near-enough the same efficiency over a broad range of speeds around the airframe optimum cruise speed

Notwithstanding their efficiencies over spark-ignited reciprocating engines, diesels are not without health and other environmental risks.[620] Diesel exhaust has been characterized widely as carcinogenic, mutagenic, and genotoxic.[621] The US EPA established a non-cancer diesel exhaust exposure standard of 5 µg/m (micrograms) for diesel particulate matter.[622] Debate continues regarding the quantification of carcinogenic risk from diesel exhaust, as well as the measurement techniques to identify diesel exhaust[623]—as characterized by one diesel aircraft engine manufacturer:

> Emissions are an emotive subject - there is a lot of conflicting data and lots of gaps in the data too that make it very difficult to be sure about things. Diesel engines do produce particulate (so do gasoline engines, just different quantities and sizes) but don't produce appreciable CO. Both types of engines produce CO_2 (harmless, but greenhouse gas), NO_x (not harmless), SOx (depending on fuel composition) as well as various hydrocarbons etc. Exhaust aftertreatment would be a nightmare on an aircraft engine (extra weight, cost, complexity) so engine-out emissions are the more important, and here gasoline engine's high levels of CO and NO_x are significant. Unburned fuel is also a significant pollutant, with, particularly, high-octane gasoline being worse for those in close proximity (some of the constituents in some fuels are highly carcinogenic) - however the general public are less at risk. All in all the data available can lead to a jolly good argument but no really firm conclusions, apart from the fact that burning fuel is bad.[624]

- ***Turbine Engines*** – Turbines are increasingly used in GA for both turboprop and turbofan aircraft, and are powering increasingly smaller airframes. Turboprops are gas turbine engines optimized to drive propellers whereas turbofans are optimized to produce thrust from exhaust gas. The developing Very Light Jet (VLJ) and Personal Jet (PJ) markets are contributing to the growth of the small-turbine sector.

Eclipse 400 Jet

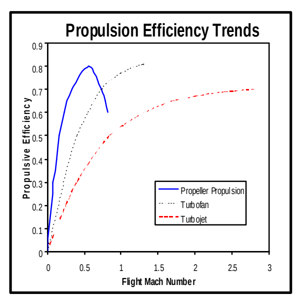
- Turbojets – Conventional, straight, or turbojets, are kerosene-burning engines which operate by compressing intake air (in a compressor[625]), combusting compressed air and fuel (in a combustion chamber), harnessing the resulting energy produced by the hot gas exhaust (in a turbine) to drive the compressor and to propel the aircraft through direct thrust.[626] Turbojets are inefficient, particularly at lower altitudes and speeds. These engines no longer service GA (except for antique aircraft) and commercial aircraft but are included in this commentary for completeness and historical context.

- Fanjets – Fanjets, or turbofans, operate like turbojets except that much of the air mass is directed through bypass ducts, diverting the airflow around rather than through the combustion chamber to exit the engine as cold air, contributing significantly to engine thrust. That is, fanjets provide a greater air-flow capacity at a given thrust level.[627] Low-bypass turbofans have bypass ratios of approximately 4-5 times that of the air directed to the combustion chamber, while high-bypass turbofans have bypass ratios of 9 or more.[628]

  Fanjets are both quieter and more fuel efficient than turbojets. ICAO maintains a comprehensive database of aircraft emission data for specific large turbines (most of which are larger than the vast number of GA aircraft)–the *Aircraft Engine Exhaust Emissions Data Bank*.[629]

- Turboprops – Turboprops are jet engines in which the exhaust gas energies are absorbed by a turbine that is mechanically connected to a propeller via a gearbox.[630] Approximately 85 percent of turboprop thrust comes from the propeller and the remainder from directed nozzle exhaust gases.[631] In general, turboprops operate more efficiently at lower speeds and altitudes, and jets at higher speeds and altitudes. Capacity to move large amounts of air at lower speeds gives turboprops comparative advantage in take-off and climb.[632] Turboprop speeds are limited due to a marked drop in propeller efficiency as the blade tips approach the speed of sound.[633] The comparative efficiency of turbojets, turbofans, and turboprops is presented in the figure entitled *Propulsion Efficiently Trends*.[634]

  The Pratt and Whitney PT-6 turboprop is the most deployed engine in aviation history,[635] installed on more than 100 aircraft models with 31,000 engines in service. Providing between 500-2,000 shp. A larger (and highly successful) P&W turboprop, the PW100, services larger aircraft. New turboprop modifications and designs benefit from the intensive and on-going research and development for larger turbofan engines.

  As the price of fuel increases, the efficiency of turboprops is garnering newfound recognition.[636] Moreover, new competition (such as General Electric's purchase of Walter Engines)[637] and increasing market pressure fuel economy are growing quickly.

Turbine Emissions – Complete combustion in a turbine is essential to mitigate pollution, however achieving optimal turbine emissions is a balancing act. Unburned fuel results in high levels of unburned hydrocarbons, carbon monoxide, and soot.[638] Ideal combustion produces carbon dioxide and water, among other products.[639] However, the more fuel-efficient an engine is, the hotter it typically runs. And, the hotter it runs, the greater the challenge in mitigating NO_x emissions since the temperature and time in the turbine's combustion chamber are the primary determinants of the production of NO_x.

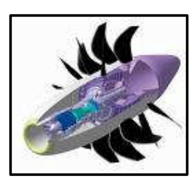
"[L]owering CO2 is a direct function of fuel efficiency. Newer aircraft engines operating at higher temperatures produce more power with less fuel and CO_2 and CO emissions, but may produce greater NO_x, particularly during the landing and takeoff cycle, when thrust settings are highest.

Engine designs that reduce combustion temperatures can also reduce NO_x emissions. Some design and performance criteria used for turbofans that affect their environmental impact include:[640]

- Bypass Ratio – The ratio of the mass flow rate of the cold (secondary) flow passing through the bypass duct into the mass flow rate of the hot (primary) flow passing through the gas generator.[641] Bypass ratios have increased with each new generation of turbine. The current generation of turbofans have bypass ratios of 7 to 9, and should increase to 16-18.[642] "While better fuel efficiency is typically achieved through higher bypass ratios, high-bypass engines are often challenged by lower noise requirements."[643]
- Combustors – The size, shape and number of combustors affects emissions. Moreover, use of multiple regions of the combustor depend on power demand.
- Pressure Ratio – Ratio of total pressure at the compressor exit and entry planes for takeoff conditions. Expressed as εc, this metric greatly reflects the extent of NOx emissions. Reduced compressor stages can reduce weight and improve efficiency.
- Turbine Entry Temperature (TET) – Temperature of the gas coming into turbine blades (represented as T_ρ,) effects both CO_2 and NO_x emissions. Increasing TET decreases amount of emission produced. TET is limited by the composition of the turbine blades.

Research and development to reduce turbine emissions includes diverse technologies, not all of which will benefit small turbines equally—at least not in the near-term. The following list highlights technologies that demonstrate the breadth and variety of both available and promising technologies that underlie improvements in turbine emissions.

- Advanced Materials – To accommodate higher temperatures and speeds. Lighter materials (such as composites and ceramics) improve heat transfer and endurance; and composites (such as for bypass nacelles) reduce weight and improve strength.
- Reduced Airfoil Count – Reducing the number of turbine blades can reduce engine weight.
- Geared Turbofans (GTF) – In GTS, the fan operates at a lower, more optimal speed as it is driven by a gearbox, independent of the low pressure compressor and turbine sections. This results in approximately 12 percent[644] and perhaps in the "upper teens to 20 percent"[645] better specific fuel consumption, and significant reduction of emissions, weight, and noise.[646] While first developed for high-thrust engines,[647] the technology is now advancing for regional jets



Open Rotor Turbine
Source: flightglobal.com

(14,000-17,000 lbs. thrust),[648] and will likely trickle down to smaller turbines.

- Open-Rotor/Unducted Fan Technology – In turbine engines with exposed fan/propeller (not enclosed in engine nacelles), fuel consumption and carbon emissions improvements are predicted to be as high as 25-30 percent compared to current turbofans.[649] Open-rotor research has taken on new urgency in response to increasing fuel costs.[650]

- Intercoolers and Heat Exchangers – Intercoolers and heat exchangers improve engine efficiency by reducing the effort required of the engine to flow compressed air through it. Workload is reduced by using cooled air, producing greater power for a given TET. Correspondingly, hotter air from heat exchangers (via recuperaters) recovers hot exhaust and directs it to the high pressure compressor intake to improve its efficiency.[651]

- Rich-Quench-Lean Combustors (RQL) – RQL quickly cools the gas mixture to reduce NO_x.[652] Such combustion decreases fuel-bound nitrogen conversion to NO_x through conversion into non-reactive N_2 in a fuel rich stage. Additional air is added to complete combustion in a quench stage. A lean stage provides sufficient time for complete combustion. Sometimes known as stoichiometric optimized combustion chambers.

The International Air Transport Association asserts that with the implementation of many of these technologies and practices, "Carbon neutral growth is a real possibility."[653]

E. SMALL TURBINE EMISSIONS

Small turbines, such as those powering VLJs and light turboprops, share certain technical constraints, such as in compressor efficiencies and maximum practical number of stages.[654] As a general principal, smaller turbines have greater challenges in achieving the same proportion of reductions in emissions as larger engines.[655] According to the US EPA:

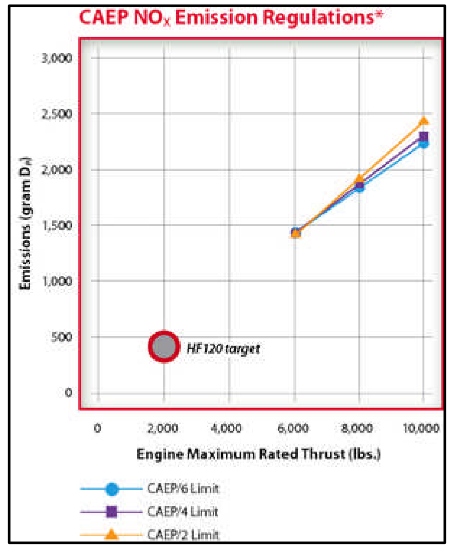
> Due to their physical size, it is difficult to apply the best NO_X reduction technology to low thrust or small engines. The difficulty increases progressively as size is reduced (from around 89 kN). For example, the relatively small combustor space and section height of these engines creates constraints on the use of low NO_X fuel staged combustor concepts which inherently require the availability of greater flow path cross-sectional area than conventional combustors. Also, fuel staged combustors need more fuel injectors, and this need is not compatible with the relatively lower total fuel flows of lower thrust engines. (Reductions in fuel flow per nozzle are difficult to attain without having clogging problems due to the small sizes of the fuel metering ports.) In addition, lower thrust engine combustors have an inherently greater line[a]r surface-to-combustion volume ratio, and this requires increased wall cooling air flow. Thus, less air will be available to obtain acceptable turbine inlet temperature distribution and for emissions control.[656]

Nonetheless, some of the newest small turbines offer novel combustion designs that reduce emissions,[657] including "combustors with optimized stoichiometry in the primary combustion zone, improved fuel/air mixing using efficient swirlers, and improved fuel spray quality using piloted air-blast and aerating fuel nozzles . . ."[658] Moreover, "[s]ignificant improvements have been made in the idle emissions of small engines in recent years, so that CO, HC, and NO_x emissions . . . are often comparable, in terms of emissions per kilogram of fuel burned, to those from large engines."[659]

As discussed below, the US EPA's (and ICAO's) NO_x emissions standards apply only to engines with a thrust or rated output of more than 26.7 kN[660] – an output greatly exceeding that of most GA engines. For example, the Eclipse 500 produces merely 4 kN (or 900 lbs) of thrust,[661] compared to a Boeing 737-800 which produces between 82 kN to 151 kN (18,000 to 34,000 lbs.) of thrust. The following figure of the HondaJet's emissions relative to CAEP NO_x standards is representative of how typical VLJ emissions are well-below regulatory requirements.

The US EPA emission regulations for turboprops are limited to smoke number standards. Such emission regulations "are relatively less severe than those applying to jets and can apparently be met using foreseeable extensions of current technology and methods. Engine weight and cost may be slightly increased, but power and physical envelope should be substantially unchanged."[662]

The following table shows the rated output of various GA turbofan and turboprop aircraft, each of which is well-below the aforementioned regulatory thresholds for both power and emissions. Because neither government/NGO nor engine manufacturers maintain (or make publically available) rigorous and complete emissions data for smaller engines (i.e., those below ICAO thresholds),[663] the table's emissions data is necessarily limited. Nonetheless, there are industry efforts "to fill this void of data."[664]



HondaJet's HF120 Emissions
Source: Honda

AIRCRAFT	ENGINE	RATED OUTPUT (PER ENGINE)	SMOKE NUMBER
TURBOPROPS			
Beechcraft King Air 200	Pratt & Whitney Canada PT6A-42	850 shp	TBD
Beechcraft King Air C90GT	Pratt & Whitney Canada PT6A-135A	550 shp	TBD
Cessna Citation Columbus	Pratt & Whitney, Pure Power PW810C[665]	10,000-15,000 lbs	TBD
EADS Socata TBM 850	Pratt & Whitney Canada PT6A-67B	850 shp	TBD
Epic Escape	Honeywell TPE331-10A	940 shp (1,000 shp)	TBD
Lancair Evolution	Pratt & Whitney Canada PT6-135A	550 shp	TBD
Hondajet	HF 120		TBD
Lancair IVP	Walter M601[666]	657 eshp	TBD
New Piper Meridian	Pratt & Whitney Canada PT6A-42A	500 shp (500 HP)	TBD
Pilatus PC-12	Pratt & Whitney Canada PT6A-67P	1,200 shp	TBD
TURBOFANS			
Bombardier Learjet 85	Pratt & Whitney Canada PW307B	6,000 lbs	TBD
Cessna Citation	Pratt & Whitney Canada JT15D	3,000 lbs -13 kN	TBD
Cessna CJ4	Williams FJ44-4A	3,400 lbs	TBD
Cessna Mustang	Pratt & Whitney Canada PW615F	6.49 kN	TBD
Cirrus Vision SJ50	Williams Int'l FJ33-4a-19 Fanjet	1,900 lbs	TBD
Dassault Falcon 7X	Pratt & Whitney Canada PW307[667]		TBD
Diamond D-Jet[668]	Williams FJ33-4A-19[669]	1,900 lbs - 10.6 kN	TBD
Eclipse 400[670]	Pratt & Whitney Canada PW615F	1,200 lbs	TBD
Eclipse 500[671]	Pratt & Whitney Canada PW610F[672]	4 kN	< 5
Embraer Phenom 100	Pratt & Whitney Canada PW 617F	1,615 lbs	TBD
Gulfstream G650	Rolls-Royce BR725[673]	16,000 lbs	TBD
HondaJet	HF120[674]	2,050 lbs	TBD

Small GA Turbine Rated Output and Smoke Numbers[675]

Apart from the formal regulatory emissions metrics discussed below, the public perception of GA's environmental impact may be portrayed in increasingly visceral and pedestrian terms. Consider, for example, the following "Prius" metrics used to contrast the Eclipse 500 and Gulfstream G450: the Eclipse 500 has a fuel efficiency of 6.64 MPG with CO_2 emissions of 1,208.6 lbs. for a 500 nm. flight, whereas a Gulfstream G450 has a fuel efficiency of 0.93 MPG with CO_2 emissions of 13,483.3 lbs. for a 500 nm flight. The comparison has been further characterized by suggesting that the Eclipse 500 expends the equivalent emissions of 7.35 Toyota Prius automobiles whereas the Gulfstream G450 expends the equivalent of 52.4 Priuses (based on Prius's 46 MPG and 19.564 lbs. of CO_2).[676] Similarly, the focus on fuel economy in an initial press release for the Eclipse 400 is noteworthy, "At an estimated 330 knots, the environmentally-friendly Eclipse 400 uses less than one pound of fuel per nautical mile—making it the world's most fuel-efficient jet aircraft."[677]

F. REGULATION OF GASEOUS EMISSIONS

The Commentary to AMCC V.a introduced the regulatory scheme for the control of environmental pollutants in aviation, and the regulation of carbon was introduced above.[678] In the United States, aircraft engine emission standards are set by the US EPA, as directed by the Clean Air Act (CAA),[679] and in consultation with the FAA.[680] In a 2005 rulemaking, EPA indicated that it interprets its authority under section 231 of the CAA to be somewhat similar to other provisions in title II of the CAA that require it to "identify a reasonable balance of specified emissions reduction, cost, safety, noise and other factors."[681]

The US EPA first regulated turbine, turboprop, and piston aircraft emissions in the early 1970s, but excluded GA aircraft from the regulations in 1978. These regulations were first established in 1973. [682] Citing as justification for new regulation, the US EPA stated, "the public health and welfare is endangered in several air quality control regions by violation of one or more of the national ambient air quality standards (NAAQS) for carbon monoxide, hydrocarbons, nitrogen oxides, and photochemical oxidants, and that the public welfare is likely to be endangered by smoke emissions [and] that aircraft and aircraft engines be subject to a program of control compatible with their significance as pollution sources."[683] Piston aircraft engine emissions were set as follows:[684]

Hydrocarbons:	0.00190 lbs/rated power/LTO cycle
CO:	0.042 lbs/rated power/LTO cycle
NO_x:	0.0015 lbs/rated power/LTO cycle

The US EPA also "concluded that sufficient evidence is already available in the form of measured emissions data on current [piston] aircraft to indicate that the proposed standards can be met by improved fuel management and will not require exhaust system reactors."[685] Venting, exhaust emission (including for smoke), and test procedures were then also set for turbines and turboprops.[686]

Exclusion of GA Aircraft – Following further study, in 1978 the US EPA proposed the withdrawal of piston, small turboprop, and small turbine engine emission standards,[687] which were finalized in 1980.[688] The EPA explained that its "decision to withdraw requirements for smaller aircraft engines was based primarily on the minimal air quality impacts of such engines,"[689] and that "the major air terminals overwhelm general aviation airports as air pollution problem areas."[690]

> Emissions impact studies at airports have shown that the most significant contribution to airport pollution is due to commercial turbine powered aircraft. At the major air terminals this contribution ranged from 80 to 99 percent of the total aircraft pollution burden. However, at smaller airports where non-commercial aircraft are flown, the total pollutants produced are not sufficient to justify the costs required to reduce them. Therefore it was concluded that the most cost effective control strategy for aircraft would be to control only those aircraft engines which cause the most significant pollution load, namely commercial aircraft engines.[691]

Later, US EPA regulations issued in 1982 withdrew HC, CO, and NO_x emissions standards for gas turbines used exclusively for GA.[692] The 1982 regulations also updated smoke numbers, including for turboprops producing more than 1,000 Kilowatts of shaft power.[693] In addition, the 1982 rulemaking deceased the stringency of the HC emission standards for newly manufactured (and previously certified) aircraft gas turbine engines, and these new standards were equivalent to the ICAO HC standards adopted in 1981. In 1997 the US EPA subsequently issued NO_X and CO emission standards for gas turbines equivalent to ICAO standards.[694] These standards were made more stringent in 2005 to conform to the then-current 2004 ICAO standards.

The gas turbine emission standards are limited to those with rated thrust greater than 26.7 kilonewtons (kN),[695] a level of thrust that includes mid-size and large GA jet aircraft (1 kilonewton = 224.808943 lbs. force). Also, such emission standards excluded (and continue to exclude) aircraft engines manufactured exclusively for GA,[696] although for competitive and manufacturing efficiency reasons, engine manufacturers generally build to the current or anticipated most stringent commercial standard. Aviation's contribution to particulate matter was later addressed in 2003.[697] (US EPA's current aircraft engine requirements apply to gas turbine engines that are mainly used by commercial aircraft, except in cases where GA aircraft sometimes use commercial engines. US EPA regulations do not apply to many engines used in business jets or to piston-engines used in aircraft that fall within the GA category.) As an aside, neither ICAO nor the US EPA has established fuel efficiency certification standards.

> Aircraft are required to meet the engine certification standards adopted by the Council of ICAO. These are contained in *Annex 16 — Environmental Protection, Volume II — Aircraft Engine Emissions* to the Convention on International Civil Aviation. These were originally designed to respond to concerns regarding air quality in the vicinity of airports. As a consequence, they establish limits for emissions of oxides of nitrogen (NO_x), carbon monoxide, unburned hydrocarbons, for a reference landing and take-off (LTO) cycle below 915 metres of altitude (3000 ft). There are also provisions regarding smoke and vented fuel.
>
> While these standards are based on an aircraft's LTO cycle, they also help to limit emissions at altitude. Of particular relevance is the standard for NO_x, a precursor for ozone, which at altitude is a greenhouse gas. The standard for NO_x was first adopted in 1981, then made more stringent in 1993, when ICAO reduced the permitted levels by 20 percent for newly certificated engines, with a production cut-off on 31 December 1999. In 1999, the Council further tightened the standard by about 16 percent on average for engines newly certificated from 31 December 2003. The latest review of medium- and long-term technology goals for NO_x [*Independent Experts NO_x Review and the Establishment of Medium and Long Term Technology Goals for NO_x* (Doc 9887)] will be published in 2008.[698]

ICAO has developed emissions limits for four power settings: idle, approach, climb, and take-off, and has created a corresponding "ICAO Cycle" and a comprehensive database of aircraft emission data for specific power plants–the *Aircraft Engine Exhaust Emissions Data Bank*[699] to assess emissions.[700] Non-ICAO turboprop emissions databanks have also been developed.[701] US EPA standards align with ICAO's engine certification standards.[702]

The 1998 CAEP/4 emission standard for NOx (for engines first produced after Dec. 31, 2008) for low thrust or small engines with a pressure ratio of 30 or less and with rated outputs or thrust levels between 26.7 and 89 kN, implemented a linear interpolation between the low range of the CAEP/3 standard and the high range of the CAEP/4 standard.[703]

Nonregulated GA turbine engines benefit collaterally from commercial/transport improved emissions specified in such standards.[704] Most GA aircraft (even though not regulated), can satisfy environmental requirements—not only because of their market-driven adoption of environmentally conforming engines, but also because most GA aircraft engines are small (and emit less pollutants and fall below emissions standards thresholds). The trend (of incremental increases in stringency of emissions requirements) and technologies (developed and implemented by engine manufacturers to achieve or surpass regulatory compliance)[705] incentivizes and makes feasible for GA manufacturers to continue to do better.

Future Regulation of Piston Aircraft – In concert with the US EPA's reconsideration of regulating (prohibiting) leaded aviation fuel (see Part II. Fuels, above), the re-regulation of CO, NOx, and unburned hydrocarbon emissions for GA piston aircraft remains a possibility. Piston engines have open-vented fuel systems which emit considerable evaporative emissions.[706] Moreover, as a practical matter, "air-cooled" aviation engines are largely cooled by fuel enrichment—an approach that emits considerable unburned hydrocarbons. In any event, although detailed consideration of emission standards is beyond the scope of this commentary, it is instructive for the reader to become appraised of current and developing aviation emission standards – both domestic and international.[707]

Smoke Number – A Smoke Number (SN) seeks "to reduce the visible smoke trails behind airplanes. Only the maximum smoke emission level is regulated, irrespective of the power level. Thus, while visible smoke has been reduced significantly in the last decades and the application of the SN can be deemed a success, there is currently no reliable means of developing an inventory of aircraft particle emissions."[708] Moreover, the SN has many recognized limitations,[709] and other related metrics have been developed that may offer additional insights.[710] The regulatory threshold for engine smoke emissions is a smoke number (SN) of 50.[711]

Phase of Flight Considerations – The phase of flight has marked impact on engine emissions. In the past, the primary concern about gaseous emissions was the impact on the local environments surrounding airports. This concern is "reflected in current certification requirements for civil aircraft engines where the emissions during the landing, during taxiing and during take-off (the LTO cycle) are regulated."[712]

The following table shows the emissions generated during each phase of a sample LTO cycle. This data is presented to highlight the relative emissions contributions during the LTO cycle in contrast to the cruise phase of flight (presented below).

Flight Phase	UHC	CO	NO_x
Takeoff	0.06	0.4	28.0
Climb Out	0.01	0.6	22.9
Approach	0.13	2.0	11.6
Taxi	1.92	21.9	4.8

LTO Cycle Data and Resulting Emissions (in g/kg of fuel)[713]

Because of the importance of flight profile (for example, cruise climb's impact on fuel consumption and resulting emissions), the role of both ATC and advanced navigation and control technologies (such as ADS-B[714] and RNP[715]) should be factored into the broader consideration of aviation emissions mitigation.

While emissions generated during the LTO cycle invariably (and immediately) impact the atmosphere around airports, emissions generated during cruise are indirect and longer term. This is because the amount of gas emitted during cruise is much larger than gaseous emissions of the typical LTO cycle, and because some emissions at cruise are claimed to be more damaging to the atmosphere.[716] The comparatively greater emissions at altitude (>3000) are highlighted in the following table.

Mode	Distance (NM)	No. of Flights	Fuel Burn (Kg)	CO (Kg)	HC (Kg)	NOx (Kg)	CO2 (Kg)	H20 (Kg)	SOx (Kg)
Ground	9.66E+07	12497827	1.52E+09	2.55E+07	3.49E+06	1.48E+07	4.80E+09	1.88E+09	1.22E+06
<=3000	2.37E+08	12497827	2.61E+09	1.16E+07	1.68E+06	4.15E+07	8.24E+09	3.23E+09	2.09E+06
>3000	6.59E+09	12497827	4.18E+10	9.52E+07	1.10E+07	5.36E+08	1.32E+11	5.17E+10	3.34E+07

Global Aviation Emissions Inventories for 2000 through 2004[717]

Cruise emissions are garnering increased attention as "investigations show that the recovery of nature and the influence on health is much less straightforward for these impacts."[718] ICAO standards addressing a reference emissions LTO cycle may not yet address emissions at cruise. ICAO and US Federal regulators are expected to give more attention to environmental issues (and regulation) for the cruise phase of flight.[719]

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V. SUMMARY

Fuel is an indispensable element of GA. Minimizing fuel and other chemical emissions is a vexing challenge, since aircraft have greater technical constraints than other modes of transportation. Certification and distribution of aviation fuels, and development of alternative fuels, are complex issues. The pilot community should become familiar with relevant fuel and emissions issues and play a role as a key stakeholder. In addition to helping prevent ground and water pollution, pilots should become familiar with and employ appropriate operating practices to improve fuel efficiency. The varieties and configurations of aviation power plants are increasing—and pilots should understand the environmental implications of such choices. The public is paying increased attention to the aviation sector as a polluter. The long-term health of GA requires proactive and responsible action to demonstrate that GA is doing its share to preserve the environment.

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CODE EXAMPLES:[720]

- "To ensure safest, security and regularity of civil aviation in Tanzania by providing effective oversight and efficient air navigation services *while protecting the environment* and safeguarding public interests." *Code of Conduct*, Tanzania Civil Aviation Authority[721]
- "Flying sites should be laid out and operated in an environmentally sustainable fashion by: Employing energy-saving measures, and encouraging the introduction of appropriate new technologies. Appropriate storing, handling and disposal of environmentally threatening substances (oil, petrol, paraffin, paints, chemicals and kitchen, campsite and toilet waste etc)." *Codes of Conduct*, Fédération Aéronautique Internationale[722]
- "[Air Traffic Management] will fully play its part in delivering a safe and efficient aviation system that meets the needs of society while minimising negative impacts on the local and global environment." *The CANSO Environmental Voluntary Code of Practice for Air Navigation Service Providers*, Civil Air Navigation Services Organisation[723]

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TABLE OF ABBREVIATIONS

ADS-B	Automatic Dependent Surveillance-Broadcast
AKI	Anti-Knock Index
AMCC	Aviators Model Code of Conduct
AOPA	Aircraft Owners and Pilots Association
ATC	Air Traffic Control
BSFC	Brake-Specific Fuel Consumption
CAA	US Clean Air Act
CAEP	ICAO Committee on Aviation Environmental Protection
CDA	Continuous Descent Approach
CDM	Clean Development Mechanism
CTL	Coal-to-Liquid
CRC	Coordinating Research Council
DoD	US Department of Defense
DoE	US Department of Energy
DoT	US Department of Transportation
EAA	Experimental Aircraft Association
ETS	Emissions Trading Scheme
F-T	Fischer-Troph Process
FADEC	Full Authority Digital Engine Controls
GAMA	General Aircraft Manufacturers Association
GAO	US General Accountability Office
GIACC	ICAO Group on International Aviation and Climate Change
GTL	Gas-to-Liquid
GWP	Global Warming Potential
HAPS	Hazardous Air Pollutants
HP	Horse Power
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
JPDO	Joint Policy Development Office
kN	KiloNewton
LTO	Landing and Takeoff Cycle
MON	Motor Octane Number
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NO_x	Nitrogen Oxides (NO and NO_2)
ODP	Ozone Depletion Potential
RF	Radiative Forcing
RNP	Required Navigation Performance
SFC	Specific Fuel Consumption
SHP	Shaft Horsepower
STC	Supplemental Type Certificate
TEL	Tetra-ethyl lead
UHC	Unburned Hydrocarbons
US EPA	United States Environmental Protection Agency

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[1] Fla. Dep't of Env'l Protection, *Aviation Environmental Responsibility* (instructional video on fueling practices required by the Consent Order - 2002), *available at* <http://paloaltoairport.aero/AER.mpeg>. *FDEP vs. Embry-Riddle Aeronautical University*, OGC File No. 02-0168, EPA ID No. FLD981745177 (FDEP, Central Dist. 2002) (Consent Order) (copy on file with author). *See* Editorial, *As Aviation Turns Green, It Must Lead or be Lead*, AVI. WEEK & SPACE TECH., Sept. 20/27, 2007, at p. 106, *available to subscribers at* <www.aviationweek.com/awst> ("Aviation has a choice: help shape the world's response or be shaped by what other do.").

[2] ICAO, Working Paper: *Towards A Carbon Neutral and Eventually Carbon Free Industry*, Assembly, 36th Sess., No. A36-OP/85, EX/33, Aug. 28, 2007, *available at* <http://www.icao.int/icao/en/assembl/a36/wp/wp085_en.pdf> (paper presented by the IATA). *See generally* ICAO, Working Papers in Item 17 - Environmental Protection, the 36th session, in Montreal, May 18-28, 2007, *available at* <http://www.icao.int/cgi/a36.pl?ai>.

[3] Because many agents/emissions may pollute air, ground, and water (and interact), there is some inherent overlap in the discussion.

[4] The GA turbine fleet growth deserves attention for its corresponding environmental impact. *See* General Aviation Manufacturers Association (GAMA), *infra* note 26.

[5] Steve Alterman, Pres., Cargo Airlines Ass'n, Presentation at the FAA Forecast Conference, *Panel 2 Environmental Challenges for Aviation-A Panel Discussion*, Mar. 10, 2008, in Wash., D.C. (video on file with author).

[6] For example, proof and assessment of the uncertainties of the climactic impact of greenhouse gases, and of natural resources, such as "peak oil" is beyond the scope of the commentary. *See* ICAO, *Workshop on the Impacts of Aviation on Climate Change*, A36-WP/309, EX/102, Sept. 22, 2007, *at* <http://www.icao.int/icao/en/assembl/a36/wp/wp309_en.pdf> (listing greenhouse gas-related uncertainties presented by Canada and the United States). *See infra The Greenhouse Effect* in IV. AIRBORNE EMISSIONS (introducing greenhouse gas considerations). For consideration of "peak oil," consider the following. "Global oil production is approaching an all-time peak before going into an irreversible decline, changing the world as we know it. . . . Even amongst the most optimistic experts the consensus is that the topping point and the risk of a permanent crisis will occur before the end of the next decade, while many industry analysts predict a global peak is imminent." Alex Kuhlman, *Peak Oil—and the Collapse of Commercial Aviation?*, AIRWAYS, July 2006, at p. 12, *available at* <www.airwaysmag.com>. *See* Peak Oil Info and Strategies, *at* <http://www.oildecline.com/> (defining and summarizing peak oil issues).

"Global oil discoveries peaked in 1964 and have been declining ever since, despite improved technologies. More than 95% of all recoverable oil has now been found, and approximately 90% of all known reserves are currently in production. There have been no significant discoveries of new oil since 2003." Kuhlman, *id*. at p. 14. *Cf.* Gary Duffy, *Brazil Announces New Oil Reserves*, BBC NEWS, Nov. 9, 2007, *at* <http://news.bbc.co.uk/2/hi/business/7086264.stm> (5-8 billion barrels of recoverable light oil); *A big oil discovery*, ECONOMIST.COM, Feb. 12, 2008, *at* <http://www.economist.com/daily/news/displaystory.cfm?story_id=10677726>; Paul Robertson, *Gulf Oil Discovery Could Have Far-Reaching Effect*, NPR, Sept. 10, 2006 (3-15 billion barrels of oil), *at* <www.npr.org/templates/story/story.php?storyId=6047189>.

"The future outlook for commercial aviation is dim. As oil prices continue to rise further, the world economy will be confronted with a major shock that will stunt economic growth and increase inflation. The chief economist of Morgan Stanley has predicted that we have a 90% chance of facing *economic Armageddon*," Kuhlman, *id*. at p. 16. "*The inescapable conclusion is that the scale and complexity of the problems that must be resolved to avert a permanent crisis are enormous and almost inconceivable.*" *Kuhlman*, *id*. at p. 19 (emphasis added). *Cf.* Robert C. Hendricks, Glenn Research Center, *Methane Hydrates: More Than a Viable Aviation Fuel Feedstock Option*, *AIAA-2007-4757*, Nov. 2007, at p. 2, *available at* <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20070038170_2007037800.pdf> ("There is re-emerging evidence that that oil is abiotic"- and citing D. Mendeleev, *L'origine du petrole*, REVUE SCIENTIFIQUE, 2e Ser., VIII, 1877, at pp. 409–416).

[7] *See, e.g.*, Lourdes Maurice, Ph.D., FAA Chief Scientist, FAA Office of Env't and Energy, *Impact of air pollution*, Presentation at ATA – *Overview of Aviation Air Quality and Climate Impacts*, Mar. 19, 2008, *available at* <http://www.airlines.org/NR/rdonlyres/51DF19E1-CF6F-43C8-8946-037E4AC5F73C/0/04MauriceWed1055.pdf> (identifying the following potential health concerns: premature mortality, hospital admissions, emergency room visits, asthma attacks, acute bronchitis, cancer, respiratory irritation, lost school/work days, restricted activity days).

[8] For example, we do not provide detailed proof of the climactic impact of greenhouse gases. However, this Commentary recognizes that:

> Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. This is an advance since the TAR's [Third Assessment Report's] conclusion that "most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations." Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns.

IPCC, *Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, S. Solomon, D. Qin, M. Manning, & Z. Chen et al. eds., Cambridge Univ. Press, Cambridge, UK and NY (2007), at p. 10, *available at* <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf>. *See* G8, *Declaration on Environment and Climate Change*, July 8, 2008, ¶ 22, *available at* <http://www.whitehouse.gov/news/releases/2008/07/20080708-3.html>, and <http://www.g8summit.go.jp/eng/doc/doc080709_02_en.htm> (in part, "reconfirm[ing] the significance of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) as providing the most comprehensive assessment of the science.").

See generally US EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006*, Public Review Draft, Feb. 22, 2008, *available at* <http://www.epa.gov/climatechange/emissions/downloads/08_CR.pdf> (In compliance with commitments under the UN Framework Convention on Climate Change; and stating that "Within the United States, fuel combustion accounted for 94.2% of [anthropogenically produced] CO_2 emissions in 2006." *id*. at ES-7).

[9] *See* US EPA, Nat'l Advisory Council for Environmental Policy and Technology, *Everyone's Business: Working Towards Sustainability Through Environmental Stewardship and Collaboration*, Mar. 2008, *available at* <http://www.epa.gov/ocem/nacept/reports/pdf/2008-0328-everyones-business-final.pdf> ("Stewardship is an ethic and practice of shared responsibility for environmental protection."). "This responsibility extends beyond the merely practical. In a world that is increasingly sensitive to these issues, the mere perception that a GA pilot is cavalier about the environmental impact of our activity (flying) has the potential to grievously damage the already fragile image of aviation in general, and GA in particular, that the lay public holds." Email from Michael Radomsky, Pres. Emeritus, Cirrus Owners and Pilots Ass'n, Feb. 6, 2008.

[10] GAMA, *2007 General Aviation Statistical Databook & Industry Outlook*, at p. 3, *available at* <http://www.gama.aero/events/air/dloads/2007GAMADatabookOutlook.pdf>. *See* Robert Nadeau, *The Economist Has No Clothes*, SCI. AM., Apr. 2008, at p. 42, *available at* <http://www.sciam.com/article.cfm?id=the-economist-has-no-clothes> (explaining that neoclassical economic theory that provides the underpinnings for today's markets are adaptations of obsolete 19th century physics, and that such theory impedes economic solutions to current environmental issues. "[T]his theory can no longer be regarded as useful even in pragmatic or utilitarian terms because it fails to meet what must now be viewed as a fundamental requirement of any economic theory—the extent to which this theory allows economic activities to be coordinated in environmentally responsible ways on a worldwide scale. Because neoclassical economics does not even acknowledge the costs of environmental problems and the limits to economic growth, it constitutes one of the greatest barriers to combating climate change

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and other threats to the planet. It is imperative that economists devise new theories that will take all the realities of our global system into account.").

[11] *See* G.J.J. RUIJGROK & D.M. VAN PAASSEN, ELEMENTS OF AIRCRAFT POLLUTION (Delft Univ. Press 2005), at pp. 112-114 (addressing the self-cleaning capability of the atmosphere – and explaining that the life span of most pollutants in the troposphere is generally under 10 days. However, "The effective lifetime of CO_2 in the atmosphere is believed to be in excess of 100 years," and pollution in the stratosphere can persist as long as 500 years. *id*. at p. 212); Prof. Dr. Martin Riese, ICG, *Atmosphere and Climate, Scientific Report 2004*, *at* <http://www.fz-juelich.de/scientific-report-2004/index.php?item=39&lang=en> (Summarizing its programme of investigation, and stating, "The self-cleaning capability of the atmosphere by means of chemical and physical processes is an elementary prerequisite for a sustainable development of the Earth system.").

[12] *See, e.g.*, *The Sun Also Sets*, INVESTOR'S BUSINESS DAILY, Feb. 7, 2008, *at* <http://ibdeditorial.com/IBDArticles.aspx?id=287279412587175> (solar activity fluctuation). *See generally* Andrews C. Revkin, *Skeptics on Human Climate Impact Seize on Cold Spell*, N.Y. TIMES, Mar. 12, 2008, at p. 14, *available at* <http://www.nytimes.com/2008/03/02/science/02cold.html?_r=1&oref=slogin>. *Cf*., S. Fred Singer, ed., *Nature, Not Human Activity, Rules the Climate; Summary for Policymakers of the Report of the Nongovernmental International Panel on Climate Change* (The Heartland Institute 2008), at p. 10, *available at* <http://www.heartland.org/pdf/2086111.pdf> (asserting that "The claim that man is the primary cause of the recent warming is not supported by science. The scientific evidence cited by the IPCC is largely contradicted by its observations and analysis").

[13] S. Fred Singer, *The Scientific Case Against the Global Climate Treaty; A Report from The Science and Environmental Policy Project* (Fairfax, VA 1999), *available at* <http://www.sepp.org/publications/GWbooklet/withfigures.html#CO2> ("The geologic record does not indicate that CO2 levels higher than the present level (of 350 ppm) would be 'dangerous.' In fact, some 500 million years ago the planet experienced CO2 levels as high as 15 times the present level: they have been declining ever since, reaching a secondary peak of about 1500 ppm some 200 million years ago… . . . If we cannot tell whether higher levels of carbon dioxide are better or worse than present or pre-industrial levels, there is little point to mounting elaborate schemes to control CO2 emissions.").

[14] Christopher Monckton, *Climate Sensitivity Reconsidered*, PHYSICS AND SOCIETY, Vol. 37, No. 3, at p. 6, *available at* <http://www.aps.org/units/fps/newsletters/200807/upload/july08.pdf> ("Since the phase-transition in mean global surface temperature late in 2001, a pronounced downtrend has set in. In the cold winter of 2007/8, record sea-ice extents were observed at both Poles. The January-to-January fall in temperature from 2007-2008 was the greatest since global records began in 1880.").

[15] The Nat'l Academies, Committee on Surface Temperature, *Surface Temperatures Reconstructions for the Last 2,000 Years* (The National Academies Press 2006), at p. 3, *available at* <http://www.nationalacademies.org/morenews/20060622.html>; and <http://books.nap.edu/openbook.php?record_id=11676&page=5>; US Dept. of Commerce, Nat'l Climatic Data Center, *Weather and Climate Extremes in a Changing Climate*. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands, A Report by the U.S. Climate Change Science Program and the Subcomm. on Global Change Research (Thomas R. Karl and Gerald A. Meehl et al. eds.), June 2008, *available at* <http://www.climatescience.gov/Library/sap/sap3-3/final-report/default.htm> (Certain aspects of observed increases in temperature extremes have been linked to human influences).

[16] *See generally* Intergovernmental Panel on Climate Change, *IPCC Fourth Assessment Report, Climate Change 2007: Synthesis Report, available at* <http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf> (including that "Anthropogenic warming over the last three decades has *likely* had a discernible influence at the global scale on observed changes in many physical and biological systems. {WGII 1.4, SPM}" *id*. at Topic 6); Nat'l Oceanic and Atmospheric Admin., *Carbon Dioxide, Methane Rise Sharply in 2007*, Apr. 23, 2008, *available at* <http://www.noaanews.noaa.gov/stories2008/20080423_methane.html> (CO_2 increased 2.4 PPM in 2007 –

now nearly 385 PPM compared to preindustrial levels of 280 PPM til 1850); Peter Backlund & Anthony Janetos et al., *The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States*, US Climate Change Science Program and the Subcommittee on Global Change Research, Final Report, Synthesis and Assessment Product 4.3, USDA, May 28, 2008, *at* <http://www.climatescience.gov/Library/sap/sap4-3/final-report/default.htm>. *But see* Zbigniew Jaworowski, M.D., Ph.D., D.Sc., *CO_2: The Greatest Scientific Scandal of Our Time*, EIR SCIENCE, Mar. 16, 2007, *available at* <http://www.warwickhughes.com/icecore/zjmar07.pdf> (asserting that preindustrial CO_2 levels were not lower).

[17] See diverse papers presented at the First Meeting of The Group on International Aviation and Climate Change (GIACC), ICAO Headquarters, Montréal, Canada, Feb. 25-27, 2008, *available at* <http://www.icao.int/env/meetings/GIACC.html>.

[18] Andrew C. Revkin, *Science Panel Backs Study on Warning Climate*, N.Y. TIMES, June 22, 2006, *available at* <http://www.nytimes.com/2006/06/22/science/22cnd-climate.html?_r=1&oref=slogin> (reflecting on the National Academies' study, *supra* note 15).

[19] Thomas Fuller and Peter Gelling *quoting* Stavros Dimas, Comm'r for Env't, European Union, *U.S. Stand On Quotas Deadlocks Climate Talks*, N.Y. TIMES, Dec. 12, 2007, at p. A12, *available at* <http://www.nytimes.com/2007/12/12/world/12climate.html?_r=1&oref=slogin>. Consider also that "A new international ranking of environmental performance puts the United States at the bottom of the Group of 8 industrialized Nationals and 39th among the 149 counties on the list." Felicity Barringer, *U.S. Given Poor Marks on the Environment*, N.Y. TIMES, Jan. 23, 2008, at p. A4, *available at* <http://www.nytimes.com/2008/01/23/washington/23enviro.html?_r=1&oref=slogin> (also quoting Daniel Esty, the study's author, "The U.S. continues to have a bottom-tier performance in greenhouse gas emissions." *id.*).

[20] Pete Bunce, Pres, GAMA, Presentation at the *Annual Industry Review and Market Briefing*, in Wash., D.C., Feb. 12, 2008, *available at* <http://www.aero-news.net/podcasts/casts/3/ann-special-feature-2008-02-27.mp3>.

[21] REPORT OF THE UNITED NATIONS CONFERENCE ON ENVIRONMENT AND DEVELOPMENT (in Rio de Janeiro, June 3-14, 1992), Annex I, RIO DECLARATION ON ENVIRONMENT AND DEVELOPMENT, A/CONF.151/26 (Vol. I), at Principle 15, Aug. 12, 1992, *available at* <http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm>. *See* PATANKER, *infra* note 84 at pp. 159-160 (presenting "acceptable risk," utilitarian, and virtue-based ethical considerations in environmental policy making); John Broome, *The Ethics of Climate Change*, SCI. AM., June 2008, at pp. 96-100, *available at* <http://www.sciam.com/article.cfm?id=the-ethics-of-climate-change> (presenting prioritarian ethical considerations). The propriety of the *precautionary principle* regarding climate change deserves consideration. *See* Kofi A. Annan, Opening Address, Global Humanitarian Forum, in Geneva, June 24, 2008, *webcast available at* <http://www2.ghf-ge.org/multimediacentre.cfm?tab=20&id=72> (climate change an all encompassing threat).

[22] Jules Charney, Chairman, Climate Research Board, Nat'l Academy of Sciences, *Carbon Dioxide and Climate: A Scientific Assessment* (1979), at p. vii.

[23] *See* Thomas L. Friedman, *It's Too Late for Later*, N.Y. TIMES, Dec. 16, 2007, at p. 10, *available at* <http://www.nytimes.com/2007/12/16/opinion/16friedman.html?_r=1&hp&oref=slogin> ("If there is one change in global consciousness that seems to have settled in over just the past couple of years, it is the notion that later is over." *id.* Also quoting Barnabus Sueba, Governor, Indonesian province of Papua, "Think big, start small, act now — before everything becomes too late." *id.*).

[24] "I think it is correct that we tend to overlook environmental issues in GA, but that does not make such disregard a good idea. What is common or popular in GA sometimes maps only poorly onto what is good for GA. I fear zealous outsiders justifying additional regulation by pointing out our adverse environmental impact, even if that impact exists primarily in their own eyes. 'Rich people and their private airplanes are

destroying my air and my peace!' (I don't know the numbers, but I can't imagine we have much impact in the grand scheme of pollution because we burn so little fuel compared to other fossil-fuel consumers. But, facts do not preclude polemics.) It's in our interest to engage the problems as a community, and I'll bet most pilots would be open to that engagement as long as it was *their idea*." Email from Bill Rhodes, Ph.D., June 16, 2006. Beyond an environmental integrity justification, accelerating petroleum costs may independently compel environmental stewardship. *See infra* Part II.G, Incentives to Reduce Emissions.

Jon Creyts et al., *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost,* McKinsey & Co., U.S. Greenhouse Gas Abatement Mapping Initiative, Exec. Report (Dec. 2007), at pp. xi and 71, *available at* <http://www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf> (The U.S. could abate as much as 28 percent of its greenhouse gas emissions at a fairly modest cost and with only small technology innovations, most from steps that would more than pay for themselves in lower energy bills and a "broad public education program around wasteful energy consumption could be mounted.").

[25] *Cf.* Anthony L. Velocci, Jr., Editor-in-Chief, AVI. WEEK & SPACE TECH., Jan 21, 2008, at p. 3, *available to subscribers at* <http://www.aviationweek.com/publication/awst/loggedin/AvnowStoryDisplay.do?fromChannel=awst&pubKey=awst&issueDate=2008-01-21&story=xml/awst_xml/2008/01/21/AW_01_21_2008_p03-25108.xml&headline=AW%26ST+Debuts+Analysis+Of+Carbon+Trading> ("No one can rationally argue that the greening of commercial aviation is anything other than beneficial for all stakeholders—not the least of whom are the operators themselves." Also describing global warming as the "economic equivalent of a tsunami" that "will slam into civil aviation within the next few years." *id.*). *See* Cornelia Dean, *Global-Warming Threat is Seen for Coastal Areas,* N.Y. TIMES, Mar. 12, 2008, at p. A21, *available at* <http://www.nytimes.com/2008/03/12/science/12coast.html?scp=1&sq=global-warming+threat+-+cornelia+dean&st=nyt> ("[A]irports in many large coastal cities are built in tidal areas, often on fill, making them 'particularly vulnerable'." The report, US Climate Change Science Program, *Coastal elevations and sensitivity to sea level rise*, Public Review Draft for Synthesis and Assessment Product 4.1, is available at <http://climatescience.gov/Library/sap/sap4-1/public-review-draft/>).

[26] Pete Bunce, Pres, GAMA, Presentation at the *Annual Industry Review and Market Briefing*, in Wash., D.C., Feb. 12, 2008. *See* Alice R. Thomas et al., Earthjustice, *Petition for Rulemaking Under the Clean Air Act to Reduce the Emission of Air Pollutants from Aircraft that Contribute to Global Climate Change*, Dec. 31, 2007, *available at* <http://www.earthjustice.org/library/legal_docs/petition-to-epa-on-aircraft-global-warming-emissions.pdf> (seeking findings and environmental rulemaking to mitigate aircraft emissions producing greenhouse gases).

[27] Consider that the entire aviation sector (including GA) contributes only 2-3 percent of greenhouse emissions. Intergovernmental Panel on Climate Change, Fourth Assessment Report, "Working Group 1: The Physical Science Basis," 2007, *available at* <www.ipcc.ch/>. One study found that piston aircraft emissions contributed "less than 1% share on total aviation fuel and CO_2." (Swiss) Federal Office of Civil Aviation (FOCA), *Aircraft Piston Engine Emissions Summary Report*, Reference 0 /3/33/33-05-003, June 2007, *available at* <http://www.bazl.admin.ch/fachleute/lufttechnik/entwicklung/00653/00764/index.html?lang=en>. *Cf.* Int'l Avi. Business Council, *IBAC Policy 30-5* (on Emissions), Jan. 15, 2004, *available at* <http://www.ibac.org/Library/policy2/30_5.htm> ("Notwithstanding the comparable size of the global business aviation turbine fleet to the airline fleet, the relative performance of business aviation aircraft is such that their typical engine emission products, combined with the significantly lower annual business aircraft utilization (typically, an order of a magnitude less than that for airline aircraft) results in a contribution to CO2 emissions that is extremely low, bordering on insignificant (i.e., of the order of 0.04% of global manmade emissions).").

[28] Lars. H. Hjelmberg, Exec. Dir., Hjelmco Oil AB, *Future fuels of aviation*, presented by Lennart Persson, at the IAOPA World Assembly, in Toronto 2006, *available at* <http://www.iaopa.org/flash/persson.pdf>; *See* Harry C. Zeisloft, *Aircraft Field Experience with Automotive Gasoline in the United States*, in FUTURE FUELS FOR GENERAL AVIATION, ASTM STP 1048 (K. H. Strauss and Cesar Gonzales, eds. 1989), at p. 19, *available at* <http://books.google.com/books?id=o5Bk81Nw8CkC&printsec=frontcover#PPA19> (avgas

less than ½ of 1 percent of gasoline market); David O'Reilly, CEO, Chevron, FORTUNE, *at* <http://money.cnn.com/video/ft/#/video/fortune/2007/11/28/fortune.csuite.chevron.renew.fortune> ("If you took every vehicle off the road of the world today, all the trucks, all the cars, *all the airplanes*, all the trains, you would reduce carbon emissions by [only] 14 percent.") (emphasis added).

[29] *See, e.g.*, FAA Admin'r Robert A. Sturgell, Presentation at the FAA Forecast Conference, Mar. 2008, in Wash., D.C., *available at* <http://www.aero-news.net/#d> ("From an operations standpoint, we predict that on average, every year from now to 2025, we're going to add the equivalent of JFK, LaGuardia, and Newark combined into the system."); Mike Boyd, The Boyd Group, Inc., *quoted in Midsize Airports Experiencing Rapid Growth*, PROPWASH, AERO-NEWS.NET, Mar. 27, 2008, *at* <www.aero-news.net> (midsize airports experiencing 400% increase in volume in past decade).

[30] *See* G. Bisignani, *Viewpoint: We Are Misunderstood and It's Our Own Fault*, AVI. WEEK AND SPACE TECH., Apr. 16, 2007, *available at* <www.aviationweek.com/awst> (presenting a viewpoint underscoring the importance of mitigating the future environmental impact of aviation because of such outstripped gains).

[31] FAA, FAA AEROSPACE FORECASTS FY 2007-2020, *Active General Aviation and Air Taxi Aircraft*, Table 27, *available at* <http://www.faa.gov/data_statistics/aviation/aerospace_forecasts/2007-2020/media/Web%20GA%2007%20Tab.xls>.

[32] FAA, FAA AEROSPACE FORECASTS FY 2007-2020, *Active General Aviation and Air Taxi Aircraft*, Table 27, *available at* <http://www.faa.gov/data_statistics/aviation/aerospace_forecasts/2007-2020/media/Web%20GA%2007%20Tab.xls>. Note, however, that these forecasts are likely to become obsolete due to rising fuel costs; and the FAA is developing new forecasts for release in 2009. Email from Lourdes Maurice, Ph.D., Chief Scientist, FAA Office of Environment and Energy, July 17, 2008.

[33] FAA, FAA AEROSPACE FORECASTS FY 2007-2020, *GA Aircraft Fuel Consumption*, Table 28, *available at* <http://www.faa.gov/data_statistics/aviation/aerospace_forecasts/2007-2020/media/Web%20GA%2007%20Tab.xls>.

[34] FAA, FAA AEROSPACE FORECASTS FY 2007-2020, *GA Aircraft Fuel Consumption*, Table 30, *available at* <http://www.faa.gov/data_statistics/aviation/aerospace_forecasts/2007-2020/media/Web%20GA%2007%20Tab.xls>.

[35] *Id*. (and only a 1% increase for the period 2006-20).

[36] Energy Info. Agency, *Prime Supplier Sales Volumes*, *available at* <http://tonto.eia.doe.gov/dnav/pet/pet_cons_prim_dcu_nus_m.htm>.

[37] FAA, FAA AEROSPACE FORECASTS FY 2007-2020, *GA Aircraft Fuel Consumption*, Table 30, *available at* <http://www.faa.gov/data_statistics/aviation/aerospace_forecasts/2007-2020/media/Web%20GA%2007%20Tab.xls> (further segmenting the 2008 forecast to include 155.3 million gallons for single engine pistons, 79.1 million gallons for multi-engine pistons, 168.1 million gallons for turboprops and 1,204.4 million gallons for turbojets).

[38] FAA AEROSPACE FORECAST FISCAL YEARS 2007-2020, at p. 41, *available at* <http://www.faa.gov/data_statistics/aviation/aerospace_forecasts/2007-2020/media/Web%20GA%2007%20Tab.xls> (Also, hours flown by turbine aircraft (including rotorcraft) are forecast to increase 6.1% yearly over the forecast period, versus 1.3% for piston-powered aircraft.). *See* FAA, *General Aviation and Air Taxi Activity and Avionics (GAATAA) Surveys CY2006*, Table 1.1, *available at* <http://www.faa.gov/data_statistics/aviation_data_statistics/general_aviation/CY2006/> (In 2005, GA piston-powered aircraft in the US consumed 322.8 million gallons (approximately 17% of total GA consumption), turboprops consumed approximately 182.8 million gallons (approximately 10 percent of GA consumption), turbojets burned about 1,138.2 million gallons (approximately 62 percent of total GA consumption), and helicopters and other aircraft accounted for nearly 201 million gallons of fuel consumed (approximately 11 percent of total GA consumption)).

[39] David Bond, *For Aviation's Greenhouse-Gas Emissions, It's Technology Versus Growth*, Avi. Week & Space Tech., Aug. 20/27, 2007, at p. 52, *available to subscribers at* <http://www.aviationweek.com/search/AvnowSearchResult.do?reference=xml/awst_xml/2007/08/20/AW_08_20_2007_p52-6563.xml&query=%2B%28Very%2BAND%2BLight%2BAND%2BJet%29>.

[40] FAA, FAA Aerospace Forecasts FY 2006-2017, *GA Aircraft Fuel Consumption*, Table 30, *available at* <http://www.faa.gov/data_statistics/aviation/aerospace_forecasts/2006-2017/media/Web%20GATAB-06.xls>. *See* Energy Information Agency, DoE, *Table F2: Aviation Gasoline and Jet Fuel Consumption, Price, and Expenditure Estimates by Sector, 2005*, *at* <http://www.eia.doe.gov/emeu/states/sep_fuel/html/fuel_av_jf.html>.

In any event, Giovanni Bisignani, Director General and CEO of the Int'l Air Transport Ass'n asserted that "fuel efficiency improved 70% in the last four decades and the IATA target is a further 25% by 2020." *Viewpoint*, Avi. Week & Space Tech., Oct. 22, 2007, at p. 58, *available to subscribers at* <www.aviationweek.com/awst>.

[41] David Esler, *Alternative Fuels for Jet Engines*, Business & Comm. Avi., Sept. 2007, at p. 82, *available at* <http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=bca&id=news/bca0907p3.xml> (also noting that the National Petroleum Council forecasts global demand for all energy to grow by as much as 60 percent by 2030). Esler also predicts that a global demand for Jet A fuel is expected to reach 7.6 million barrels per day compared to the 2007 rate of 6.8 million barrels – a demand growth of 2.3 percent. *id*.).

[42] Consider that the world uses 40,000 gallons of petroleum per second. Interview of David O'Reilly, CEO Chevron, Fortune, The Colvin Interview, Nov. 28, 2008, *at* <http://money.cnn.com/video/ft/#/video/fortune/2007/11/28/fortune.csuite.chevron.renew.fortune>.

See Prof. Ian A. Waitz, MIT, *Aviation Mobility, Economy and Environment – Evaluating Choices and Options*, Presentation at the 32nd Annual FAA Forecast Conference, in Wash., D.C., Mar. 15-16, 2007, *available at* <http://www.faa.gov/news/conferences_events/aviation_forecast_2007/agenda_presentation/media/4-%20Ian%20Waitz.pdf> ("Environment may be the dominant constraint on growth of the US air transportation system."). *Cf.* Barry Eccleston, *Aviation's Next Group Activity: Take Charge on Improving Environment*, Avi. Week & Space Tech., Jan. 14, 2008, at p. 62, *available to subscribers at* <http://www.aviationweek.com/search/AvnowSearchResult.do?reference=xml/awst_xml/2007/12/17/AW_12_17_2007_p42-20677.xml&searchAction=display_result> (in addressing commercial aviation, recognizing that "if no further action is taken, our sector's share [of CO_2 emissions] will increase 50% at a time when governments have agreed . . . to reduce emissions."). *But see* SBAC Aviation and Environmental Briefing Papers, *2. Engine Technology and Emissions*, Society of British Aerospace Companies, Mar. 4, 2008, *available at* <http://www.sbac.co.uk/community/dms/download.asp?txtFilePK=5263> (aviation fuel burn cut by 70% and NO_x cut by 50% in the past 50 years).

[43] Perhaps 58+ octane. *See* Dr. Kevin Kochersberger et al., *An Evaluation of the 1920 Wright Vertical Four Aircraft Engine*, AIAA-2001-2287, Am. Inst. of Aeronautics and Astronautics, 2001, at p. 5, *available at* <http://www.rit.edu/kgcoe/kittyhawk/tech_papers/aiaa-wright1910.pdf> (explaining that the octane number of the Wright Bros. fuel was unavailable in 1910 but ExxonMobil "provided a fuel blend for testing that closely resembles the original fuel."). "[P]rior to the 1918 fuel specifications, early aviation spark ignition engines operated on a gasoline fraction which could contain a fair proportion of 'kerosene' boiling range hydrocarbons. In other words, not kerosene as a whole, but just containing some of this material making the fuel of lower volatility and higher boiling point." Email from Alisdair Clark, BP Int'l LTD, Feb. 27, 2008. *See* Alexander R. Ogston, Exxon Int'l (ret.), *A short history of aviation gasoline development, 1903-1980*, Aeronautical J., Dec. 1981, at pp. 441-442 (includes an overview of Wright engine development and associated fuels) (copy on file with author).

[44] Discovered by General Motors on Dec. 9, 1921; commercialized in Ohio on Feb. 2, 1923. William Kovanik, Ph.D., *ETHYL – The 1920s Environmental Conflict Over Leaded Gasoline and Alternative Fuels*,

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Paper presented to the Am. Society for Environmental History, Mar. 26-30, 2003, *available at* <http://www.radford.edu/~wkovarik/papers/ethylconflict.html>. *See* Ogston, *supra* note 43, at p. 444 (characterizing the discovery "as the greatest single achievement in the development of gasoline fuels and without which the later development of 100 octane aviation gasoline would not have been possible.").

[45] *See* "Octane Rating," in *Wikipedia: The Free Encyclopedia*; *at* <http://en.wikipedia.org/wiki/Octane_rating>. *See also*, JOHN D. ANDERSON JR., THE AIRPLANE: A HISTORY OF ITS TECHNOLOGY (Am. Inst. of Aeronautics and Astronautics 2002), at p. 260:

> The power output of a reciprocating engine is dependent on the pressure ratio achieved during the compression stroke because the higher the pressure, the more efficient the combustion of the air-fuel mixture. If the pressure is too high, however, the combustion process, instead of being a well-behaved controlled burning mechanism, will instead be detonation that is less efficient and that can damage the pistons and cylinders—an audible phenomenon called "pinging" or "knocking. . . ."
>
> [In 1927] was the discovery of the effect of isooctane on knocking . . . . The octane rating of gasoline is the amount of isooctane present by volume. [It was discovered] that the more isooctane present in the fuel, the compression ratio could be made higher before knocking occurred. . . . [T]he Army adopted 100-octane fuel as the military standard in 1936. This fuel became the norm for the military during World War II; it was one of the factors that gave Allied airplanes during World War II a technical advantage.

The octane of an aviation gasoline is denoted by an octane or performance number. Some octane numbers are expressed as two values separated by a slash. For example, for "91/96UL" the first number (91) represents the octane when the engine is running lean, and the second number (96) is the octane when operated rich. In practice, the latter number is sometimes dropped.

Earl Lawrence cautions, "Octane number does not directly relate, as a measure of performance in a real airplane. For example, 110 unleaded octane will knock like crazy in a particular aircraft engine. Octane is not the most accurate reflection of engine performance. Sometime it works. A test is not a guarantee. From CRC testing, 91 unleaded vs. 91 leaded works totally different in an engine. [For testing unleaded fuel] we don't have a replacement test. We just put it in a plane and test it." Telephone Interview with Earl Lawrence, VP of Industry and Regulatory Affairs, EAA, Jan. 28, 2008.

[46] Following early experimentation with various fuels, the JP-1 standard was published in 1944 (AN-F-32). Between 1945-51, improved formulations (naphtha and kerosene – offering better freezing points) were specified in JP-2, JP-3, and JP-4. Various military jet fuel standards improved volatility, freezing point, specific gravity, sulphur, and aromatic limits. JP-8, as a formulation similar to Jet A was used in the late 1970s. BP, *The History of Jet Fuel*, *at* <www.bp.com/sectiongenericarticle.do?categoryId=4503664&contentId=57733>. *See generally* ASTM Jet Fuel D-1655 Specification, *available at* <www.aviationfuel.org/jetfuel/d1655_specs.asp> (for Jet A, Jet A-2, and Jet B).

[47] *See infra* text accompanying notes 113-116 (Fuel Properties); and text accompanying notes 117- 238 (**C. Alternative Fuels**). Airborne fuel emissions are considered in text accompanying notes 590-596 (Hazardous Air Pollutants).

[48] Telephone Interview with Earl Lawrence, VP of Industry and Regulatory Affairs, EAA, Jan. 28, 2008 (and urging the need for a single specification). *See* Andrew W. Cebula, Exec. VP, Gov't Affairs, AOPA, *Comment in response to EPA Docket No. OAR-2007-0294 Petition Requesting Rulemaking To Limit Lead Emission from General Aviation Aircraft; Request for Comments*, Mar. 17, 2008, *available at* <http://www.regulations.gov/fdmspublic/ContentViewer?objectId=09000064803fbb16&disposition=attachment&contentType=pdf> ("A suitable unleaded replacement fuel is one that can be used in all existing and new piston-powered general aviation aircraft.").

[49] *See* ASTM Int'l, Referenced Documents, *ASTM D910-07 Standard Specification for Aviation Gasolines*, *available at* <http://www.astm.org/cgi-

bin/SoftCart.exe/DATABASE.CART/REDLINE_PAGES/D910.htm?L+mystore+thjk5592>. *See* William R. Scott et al., *Aviation gasoline containing reduced amounts of tetraethyl lead*, July 27, 2004, *available at* <http://www.patentstorm.us/patents/6767372-description.html> (100LL formulations typically contain 75-92 vol % light alkylate, 5-18 vol % toluene, 3-20 vol % C_4 to C_5 paraffins and 2-4 ml/gallon TEL, plus additives such as dyes, scavenger, and antioxidants.).

[50] US EPA, *Petition Requesting Rulemaking To Limit Lead Emissions from General Aviation Aircraft; Request for Comments*, 72 Fed. Reg. 64,572 (Nov. 16, 2007), *available at* <http://www.epa.gov/EPA-AIR/2007/November/Day-16/a22456.htm>.

[51] *But see infra* text accompanying note 74 (Earl Lawrence, VP, Industry and Regulatory Affairs, EAA, urging that only 4-10 percent of such aircraft require 100LL).

[52] AOPA OnLine, *Regulatory Brief Avgas (100LL) Alternatives*, *at* <http://www.aopa.org/whatsnew/regulatory/regunlead.html>.

[53] *See* Chevron, *Aviation Fuels Technical Review*, 2006, at pp. 64-65, *available at* <http://www.chevronglobalaviation.com/docs/aviation_tech_review.pdf>.

[54] *Available at* <http://www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/REDLINE_PAGES/D910.htm?L+mystore+thjk5592>. Note that the suffix year for ASTM standards changes regularly, the latest being D910-07 (at the time of publication of this commentary).

[55] US EPA, *Review of the National Ambient Air Quality Standards for Lead: Policy Assessment of Scientific and Technical Information*, Office of Air Quality Planning and Standards Staff Paper, EPA-EPA-452/R-07-013, Nov. 2007, at p. 2-8, *available at* <http://www.epa.gov/ttn/naaqs/standards/pb/data/20071101_pb_staff.pdf> (citing US DoE, Energy Information Agency, Fuel production volume data, Nov. 2006, *at* <http://tonto.eia.doe.gov/dnav/pet/hist/mgaupus1A.htm>. US EPA, *Great Lakes Binational Toxics Strategy Report on Alkyl-lead: Sources, Regulations and Options* (June 2002), *available at* <http://www.epa.gov/bns/documents.html> (Leaded avgas accounts for 29% of lead air pollution in the US).

[56] Detonation is the uncontrolled burning of fuel in a piston-engine, which can be highly destructive to an engine.

[57] ASTM D 910, *supra* note 49.

[58] *See generally* US EPA, *Air Quality Criteria For Lead* (Final), Sept. 26, 2006, *available at* <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=158823>; Dept. of Health and Human Services, Agency for Toxic Substances and Disease Registry, *Lead Toxicity Cover Page*, *at* <http://www.atsdr.cdc.gov/csem/lead/pbcover_page2.html>.

[59] US EPA, *Technical Factsheet on: ETHYLENE DIBROMIDE (EDB)*, *at* <http://www.epa.gov/ogwdw/dwh/t-soc/edb.html>.

[60] Banned by the US EPA in highway vehicles after Dec. 1995. *See* US EPA, *Review of the National Ambient Air Quality Standards for Lead: Policy Assessment of Scientific and Technical Information*, Office of Air Quality Planning and Standards Staff Paper, EPA-452/R-07-013, Nov. 2007, at pp. 3-1 thru 4-39, *available at* <http://www.epa.gov/ttn/naaqs/standards/pb/data/20071101_pb_staff.pdf> (Policy-Relevant Assessment of Health Effects Evidence and Characterization of Health Risks).

[61] For example, MTBE (Methyl tertiary Butyl Ether), and ethanol. MANOJ S. PATANKER ET AL., SAFETY ETHICS (Ashgate 2005), at p. 176. Environmental Yukon, *High Lead in Used Oil From Piston Aircraft*, Yukon Gov't Website, *at* <http://www.environmentyukon.gov.yk.ca/monitoringenvironment/EnvironmentActandRegulations/peaoil.php>.

[62] Beyond fuel toxicity issues, environmental challenges may include carbon emissions. "The bottom line is that if you remove lead from avgas, you put more CO_2 in the atmosphere. So the question is, do you want to tolerate a trivial amount of lead or significantly more CO_2 emissions? It is really a political issue." Telephone Interview with George W. Braly, Chief Engineer, GAMI, Feb. 23, 2004.

[63] Telephone Interview with Earl Lawrence, VP of Industry and Regulatory Affairs, EAA, Jan. 28, 2008. *Cf*. Email from Lourdes Maurice, Ph.D., Chief Scientist, FAA Office of Environment and Energy, FAA, July 17, 2008 (". . . at some point it is very likely that GA will NOT be able to use lead – EAA needs to face that a solution is needed"). *See* Andrew W. Cebula, Exec. VP, Gov't Affairs, AOPA, *Comment in response to EPA Docket No. OAR*-2007-0294 *Petition Requesting Rulemaking To Limit Lead Emission from General Aviation Aircraft; Request for Comment*, Mar. 17, 2008, *available at* <http://www.regulations.gov/fdmspublic/ContentViewer?objectId=09000064803fbb16&disposition=attachment&contentType=pdf> ("Currently, there is no simple alternative for 100LL avgas. . . . Any change in the fuel used by general aviation aircraft must be compatible with all existing and new piston-powered aircraft.").

See David Atwood, FAA W.J. Hughs Technical Center, Propulsion and Fuel Systems Branch, *High-Octane And Mid-Octane Detonation Performance Of Leaded And Unleaded Fuels In Naturally Aspirated, Piston, Spark Ignition Aircraft Engines*, DOT/FAA/AR-TN07/5, Mar. 2007, at p. 12 (findings included that: "The 100 LL, 100/130 L, leaded aviation gasoline performed the same as the 104 amine fuel, having a 104 MON and a supercharge rich rating of >161, at the lower power cruise settings, but not as well at the higher climb and takeoff power settings. The 100 LL fuel performed the same as the 100/100 L fuel at the cruise power settings but performed significantly better at the higher power settings. For leaded hydrocarbon fuels, the supercharge rich rating has more significance at higher power settings. The 100 LL outperformed unleaded fuels of 100 MON even if they had a much higher supercharge rich rating.").

[64] Ben Visser, *What does the future hold for avgas?*, GEN. AVI. NEWS, Feb. 25, 2005, *available at* <http://generalaviationnews.com/main.asp?Search=1&ArticleID=10088&SectionID=3&SubSectionID=33&S=1>.

See Interview by Paul Bertorelli with Rhett Ross, CEO, TCM, AV. CONSUMER (Feb. 18, 2008), *at* <http://www.avweb.com/podcast/podcast/197170-1.html> ("I think [100LL] can't be viewed right now as sunset tech because we've got some 25,000 or some ungodly number of aircraft out there and you're not going to swap those over overnight.. I think gasoline is here for many years to come.").

[65] Earl Lawrence, VP of Industry and Regulatory Affairs, EAA, *EPA Seeks Comments Regarding Lead Emissions Petition* (Nov. 15, 2007), *at* <http://www.eaa.org/news/2007/2007-11-15_emissions.asp> ("The EPA has a lot of work to do before they would take any action on removing the lead in 100LL . . . [the US EPA is] in the process of setting the new airborne lead standard for the U.S. That will most likely not be done until early 2009."). "Don't expect anything whatsoever. EPA is concerned with aerial emissions. The EPA will see if there are any areas that exceed Pb limits and make it a containment area. It would only be restricting aircraft in that area. But evidence so far doesn't appear that there are significant elevated lead emissions aerial. . . . Consider that when EPA set Pb limits, there was so much lead in the environment that they didn't have a non-exposed [control group/environment]. Now, enough time has gone by, they can now find populations without elevated Pb." Telephone Interview with Earl Lawrence, Jan. 28, 2008.

"EAA's Earl Lawrence recently met with EPA officials to discuss this [Friends of the Earth] petition. EPA says that only two locations in the country, one having a lead smelter, exceeds the current EPA's standards for aerial lead pollution and that it would be years before sufficient data could be collected and analyzed to propose elimination of lead from avgas, should that be indicated by the data. Consequently, the Friends of the Earth petition is not expected to lead to the elimination of 100LL in the foreseeable future." EAA Website, *at* <http://www.eaa.org/news/2007/2007-12-20_or_avgas_paper.pdf>.

[66] For example, scientific data to support (and resolve) whether there are increases in lead exposure to at-risk populations or endangerment to public health proximate to airports remains in play. Also, updated lead National Ambient Air Quality Standards (NAAQS) and final rulemaking will not be completed until Oct. 15, 2008, *available at* <http://www.epa.gov/air/criteria.html> (Current NAAQS lead standard set at 1.5

$\mu g/m^3$ of air). *See* South Coast Air Quality Management District, *Enhanced Air Toxics Exposure Study for the South Coast Air Basin*, OAR-EMAD-03-08, Amd. 002, Application to the US EPA's Solicitation: "National Air Toxics Monitoring Program – Community Assessments," *available at* <www.epa.gov/ttn/amtic/files/ambient/airtox/fyo4la.pdf> (includes toxic monitoring near designated SoCal airports, including for lead. *id*. at p. 5) (The ambient monitoring portion of the study is completed; data analyzed, and is expected to be released in 2008).

Responding to this author's inquiry as to the existence of a study focused on the measurement of (any elevated level of) lead in the GA pilot community, the US EPA stated: "We have been searching for such studies and not found one. I have talked with a senior official at the Aircraft Owners and Pilots Association and he also was unaware of any such studies [related to the concentration of lead in the blood of pilots]. We are continuing to search and if we locate such a study we will let you know." Email from Marion Hoyer, Ph.D., Environmental Scientist, Office of Transp. and Air Quality, Nat'l Vehicle and Fuel Emissions Lab, US EPA (Jan. 11, 2008). Concerning studies addressing the potential for elevated ambient air lead near airports servicing general aviation aircraft, see for example, Environmental Protection Service, Ontario Region, Environmental Canada, *Airborne Particulate Matter, Lead and Manganese at Buttonville Airport, Final Report*, CPE Project 041-6710, May 2000, Prepared by Conor Pacific Environmental Technologies Inc. (copy on file with author) (Lead levels in airport air samples four times higher than background site, yet below applicable standards/guidelines); Illinois Environmental Protection Agency, Bureau of Air, *Chicago O'Hare Airport, Air Toxic Monitoring Program, June-December, 2000*, May 2002, *available at* <http://www.epa.state.il.us/air/ohare/ohare-toxic-report.pdf> (O'Hare Airport downwind concentrations of lead 87.5% higher but "still in the 'typical urban' range and lower than levels found in other large urban areas.").

"It is extremely difficult to predict the effect of multiple pollutant exposures in human populations; however, research continues . . . in developing appropriate regulatory programs to address complex exposure problems. . . . [Also,] many individuals have cumulative exposures that are significantly greater than risk thresholds—a true ethical challenge for occupational safety and health professionals and environmental health professionals alike." MANOJ S. PATANKER ET AL., SAFETY ETHICS (Ashgate 2005), at pp. 145, 147.

[67] *See* Commentary to AMCC V.a, at p. 4, *at* <www.secureav.com/Comment-AMCC-V.a-Environmental.pdf> (addressing environmental stakeholders).

[68] *See, e.g.*, US EPA, PETITION REQUESTING RULEMAKING TO LIMIT LEAD EMISSIONS FROM GENERAL AVI. AIRCRAFT; REQUEST FOR COMMENTS, Docket: EPA-HQ-OAR-2007-0294; FRL_0001, Nov. 16, 2007, *available at* <http://www.epa.gov/fedrgstr/EPA-AIR/2007/November/Day-16/a22456.htm>, *also available at* <http://www.foe.org/pdf/Aircraft_GHG_Petition.pdf> (Submitted by Friends of the Earth). *See also* Bluewater Network, Press Release, *Bluewater Network Files Petition To Get The Lead Out Of Aviation Fuel*, Oct. 11, 2006, *at* <http://www.foe.org/new/releases/october2006/epalead10112006.html>; Friends of the Earth, Press Release, *Call to Regulate Aircraft Carbon Emissions*, Dec. 5, 2007, *at* <http://action.foe.org/pressRelease.jsp?press_release_KEY=300>; Brent Plater, Visiting Ass't Prof. & Staff Att'y, *Environmental Law and Justice Clinic, Golden Gate U. School of Law, Comments on the EPA's Notice of Friends of the Earth's Petition for Rulemaking*, 72 Fed. Reg. 64,570 (Nov. 16, 2007), EPA-HQ-OAR-2007-0294-0091, Mar. 18, 2008, *available at* <http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&o=09000064803ff503> (claiming that US EPA's response was legally inadequate and implicating legal action should the EPA not respond within three months). *See* US EPA, Proposed Rule, *National Ambient Air Quality Standards for Lead*, EPA-HQ-2060-0735; FRL-RIN 2060-AN83, May 1, 2008, *available at* <http://www.epa.gov/air/lead/pdfs/20080501_proposal_fr.pdf> (proposing revision of the level to within the range of 0.10 to 0.30 $\mu g/m^3$, and soliciting comment on alternative levels up to 0.50 $\mu g/m^3$ and down below 0.10 $\mu g/m^3$).

[69] 100LL is transported intensively on barges in the US. Also, truckers and teamsters may refuse to handle leaded products. Environmental laws increasingly impede crossing state borders with lead, and transport

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and storage infrastructure costs for lead continue to climb. The required segregation of ethanol and avgas has further complicated rail transport logistics.

[70] Telephone Interview with Douglas C. Macnair, EAA VP Gov't Relations, Feb. 5, 2008.

[71] *See, e.g.*, Andrew W. Cebula, Exec. VP, Gov't Affairs, AOPA, *Comment in response to EPA Docket No. OAR-2007-0294 Petition Requesting Rulemaking To Limit Lead Emission from General Aviation Aircraft; Request for Comment*, Mar. 17, 2008, *available at* <http://www.regulations.gov/fdmspublic/ContentViewer?objectId=09000064803fbb16&disposition=attachment&contentType=pdf> ("For safety and supply reasons AOPA strongly supports a single fuel solution that can be used on new and existing aircraft."). Note that GAMA's Board of Directors voted in early 2008 to seek elimination of leaded fuels, drafting a policy statement to work with the GA community towards the goal of finding an unleaded alternative to avgas.

[72] This may be unattainable without lead. Email from Todd Petersen, Petersen Aviation, Inc., Feb. 28, 2008.

[73] Paul Bertorelli, *100LL: Time To Let It Go*, THE AVIATION CONSUMER, Jan. 2008, at p. 2, *available to subscribers at* <www.aviationconsumer.com/issues/38_1/editorial/5736-1.html>; Interview of Frank Thielert, Aero-TV (Jan. 16, 2008), *available at* <http://www.aero-tv.net/> ("I think in ten years time there will be no 100LL. . . . It will be a boutique product that will be very, very expensive." *id.*).

[74] Telephone Interview with Earl Lawrence, VP, Industry and Gov't Affairs, EAA, Jan 28, 2008 (further acknowledging that "People will be more likely willing to write off 4 percent of the population," and mentioned studies that have demonstrated that 100LL's octane is typically much higher than 100 MON, *id*.). *See* Andrew W. Cebula, Exec. VP, Gov't Affairs, AOPA, *Comment in response to EPA Docket No. OAR-2007-0294 Petition Requesting Rulemaking To Limit Lead Emission from General Aviation Aircraft; Request for Comments*, Mar. 17, 2008, *available at* <http://www.regulations.gov/fdmspublic/ContentViewer?objectId=09000064803fbb16&disposition=attachment&contentType=pdf> ("AOPA understands that for a small percentage of aircraft this may require engine and airframe modifications."). *See, e.g.*, Max Shauck et al., Baylor Institute for Air Science, Baylor Univ., Final Report DTFA03-01-C-00022, *Development of Ethanol and Avgas/Ethanol Blends as Alternative Fuels for General Aviation*, *available at* <www.baylor.edu/bias/index.php?id=5302>.

[75] Email From George Braly, Chief Engineer, GAMI, Feb. 26, 2008 (Among these would be all twin engine piston powered Cessna 400 series aircraft, the C-340 series aircraft and a large number of Cessna T-210 series aircraft. The entire fleet of Piper Navajo aircraft with turbochargers would also be grounded.). Separately, consider that almost one half of all Continental engines require 100 octane avgas, as well as any engine of 8½ to 1 compression or greater. *id.*

"Lowering the national ambient air quality standards for lead, without a suitable replacement fuel available, would negatively affect the $150 billion general aviation industry, threatening a nationwide transportation system that supports smaller communities, agriculture, firefighting, and medical emergency flights." "Reducing the amount of lead in avgas is not a simple process. The US EPA needs to consider the dramatic impact it could have on general aviation and the nation's economy if it were to make immediate changes in the lead standard." Andy Cebula, AOPA Exec. VP of Government Affairs, Testimony before the EPA, in Baltimore, MD, June 12, 2008, *quoted in* AOPA ONLINE, *Can GA get the lead out?*, *at* <http://www.aopa.org/advocacy/articles/2008/080612epa.html>.

[76] *Infra* text accompanying notes 375-381.

[77] The following noteworthy avgas formulations are either discontinued, lack production, are largely unavailable, or proposed.

- 80LL – Unavailable.
- 80/87 – Produced for use in low compression reciprocating aircraft engines, and contains up to 0.5 grams of lead/US gallon. Discontinued in 1992, and generally replaced by MOGAS. Many engines were originally certified for use of this fuel, perhaps as much as half of the GA fleet.

Color: red.

- 86UL – Not in production. *See* Product Code Conversion Table, *at* <http://www.google.com/search?q=cache:cC5TXxIE5XkJ:www.va.gov/ofinop/valociti/VAFleetDocs/ProductCodeConversionTable.doc+Product+Code+Conversion+Table&hl=en&ct=clnk&cd=3&gl=us>.
- 91 – Contains a maximum of 0.53 ml of lead/liter. Available in the Ukraine. Color: brown.
- 91/96 – Contains a maximum of 2 ml of lead/US gallon. Discontinued. Color: Blue.
- 95UL – Proposed as a replacement for 100LL (by Tim Roehl, GAMI President). This fuel would have at least a 97-98 octane at the refinery and, with ample margins, would be at least 95 octane at the pump.
- 100 – Contains up to 4 ml of lead/US gallon.
- 100/130 – Contains up to 4 grams of lead/US gallon, or 1.12 grams of lead/liter. Largely replaced by 100LL. Color: green.
- 108/135 – Discontinued.
- 115/145 – Contains up to 4.6 ml of lead/US gallon. Available by special order only. Used for some radial war birds. Color: purple.

See generally EAA, Avgas Grades, *at* <http://www.aviationfuel.org/avgas/grades.asp>, and Avgas Specifications, *at* <http://www.aviationfuel.org/avgas/avgas_specs.asp>. *See also* Lycoming, Service Instruction No. 1070N, *Specified Fuels* (June 14, 2006), *available at* <www.lycoming.textron.com/support/publications/service-instructions/pdfs/SI1070N.pdf>.

[78] *See* ASTM, *D6227-04a Standard Specification for Grade 82 Unleaded Aviation Gasoline*, *available at* <www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/REDLINE_PAGES/D6227.htm?L+mystore+qnaj8399>. Such unleaded avgas may be viable for up to 30 percent of the current users of 100LL. *See generally* Chevron, *Aviation Gasoline Specifications and Test Methods*, Aviation Fuels Technical Review (2000), *available at* <http://www.chevron.com>.

The FAA states:

> 82UL gasoline is only approved for use in airplanes incorporating supplemental type certificates (STC) approving the use of autogas with an aviation lean octane rating of 82 or less or an antiknock index of 87 or less. The minimum octane requirement unique to any airplane (and engine) approved for autogas is placarded. Aviation 82UL gasoline may not be used as a substitute fuel on airplanes requiring autogas with an aviation lean {motor method (MON)} octane rating greater than 82 or an antiknock index {(RON+MON)/2} greater than 87. Using this fuel on those higher performance engines originally approved for use with higher-octane fuels could result in engine detonation and associated destructive damage.

FAA, SAIB, CE-00-19R1, *Automobile Gasoline*, Apr. 5, 2000, *available at* <http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgSAIB.nsf/MainFrame?OpenFrameSet> (emphasis removed).

An ASTM participant observed: The ASTM specification for 82 was unleaded. There was great controversy regarding this fuel in ASTM. The only truly unleaded fuel from ASTM is 82UL – all other (avgas) specifications have not been designed to be unleaded. Telephone Interview with Anonymous, Jan. 21, 2008.

[79] *See* EAA, *at* <http://www.eaa.org/autofuel/autogas/approved.asp> (listing approved engine models).

[80] *See* ASTM D6227, *available at* <http://www.astm.org>.

[81] *See* Wikipedia, *Aromatic hydrocarbon*, *at* <http://en.wikipedia.org/wiki/Aromatic_hydrocarbons> (explaining aromatics).

[82] ASTM D-4818 - *Standard Specification for Automotive Spark-Ignition Engine Fuel*, *available at* <http://www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/REDLINE_PAGES/D4814.htm?E+mystore>.

[83] *E.g.*, EAA, *Automobile Fuel Program*, *at* <http://www.eaa.org/autofuel/>, and Petersen Aviation, Inc., *at* <www.autofuelstc.com> (sold at least 56,000 such STCs). *See generally* FAA, AC 91-33, *Use of Alternative Grades of Aviation Gasoline for Grade 80/87, and Use of Automotive Gasoline* (July 18, 1984), *available at* <http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/5abbef4b4ef9830c862569ba006f6e01/$FILE/AC91-33A.pdf>.

[84] FAA, SAIB, CE-07-06, *Alcohol (Ethanol or Methanol) Present in the Automobile Gasoline of any General Aviation Airplane* (Oct. 27, 2006), *available at* <http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgSAIB.nsf/dc7bd4f27e5f107486257221005f069d/6f3250f958b6a22286257259006d6dab/$FILE/CE-07-06.pdf>. *Cf.* "STCs are available for a number of what were originally 91/96 octane engines which allow the use of 91 octane mogas. There is no controversy over its reliability. It has been safely used for over twenty five years in thousands of airplanes. In the late 1980's MTBE and ETBE were approved for use with the STCs. Ethanol is not approved but these other oxygenates are." Email from Todd Petersen, Petersen Aviation, Inc,. Feb. 28, 2008. *See* ASTM, WK16902 *Specification for Ethyl Tertiary Butyl Ether (Etbe) For Blending With Aviationspark-Ignition Engine Fuel, available at* <www.astm.org/DATABASE.CART/WORKITEMS/WK16902.htm>.

[85] *See, e.g.*, European Aviation Safety Agency, *Type Certificate Data Sheet* (Nov. 2, 2006), *at* <http://www.easa.eu.int/doc/Certification/Design_Appro/Engines/TCDS-Superior%20O360%20series,%20issue%2001.pdf>.

[86] Ethyl-tertiary butyl ether. *See Memorandum from FAA, Mgr., Small Airplane Directorate, CE-100, et al, Approval of Ethyl-Tertiary-Butyl-Ether (ETBE) Oxygenate Additive for use in Autogas Supplemental Type Certificates (STCs)*, Dec. 1, 1993 (MTBE and ETBE approved by the FAA for use in autogas STCs.). *See, e.g.*, Wikipedia, *ETBE*, *at* <http://en.wikipedia.org/wiki/ETBE> (defining Ethyl tert-butyl ether). Although ETBE may work well technically, it faces political roadblocks and regulatory prohibitions, including because it is a known carcinogen.

See MANOJ S. PATANKER ET AL., SAFETY ETHICS (Ashgate 2005), at p. 147. (Following the elimination of TEL in automobile fuel, TEL was replaced by benzene, later found to be highly carcinogenic. MTBE served as a replacement for TEL which is now recognized as a serious water pollutant and is increasingly banned.) Separately, MTBE was found to be a highly sensitive and reliable marker/tracer for dumped/leaked gasoline.

[87] Textron Lycoming, Flyer-Key Reprints, *Do Not use Automotive Gasoline In Textron Lycoming Aircraft Engines That are Certified for Aviation Gasoline* (1995), at pp. 15-16, *available at* <www.textron-lycoming.com> (Lycoming identifies for following dangers of using mogas in its engines: reduction in safety, loss of octane, nonuniform quality, possible voidance of warranty or insurance, differences in additives (may contain highly corrosive auxiliary scavengers which cause rust and eventually can lead to exhaust valve failures, less desirable storage characteristics, higher vapor pressures precipitating vapor lock, varying methods to rate octane, and destructive detonation or pre-ignition.).

[88] For example, an Oregon law (House Bill 2210, §§ 17 and 18) mandates an 8-10% ethanol blend in all grades of gasoline sold in Oregon. HB 2210, *available at* <http://www.leg.state.or.us/07reg/measpdf/hb2200.dir/hb2210.en.pdf>. While not covering aircraft fuels, and thus not requiring an "exemption", the law contains no provision for Oregon pilots to secure ethanol-free fuel. *See* Randy Hansen, EAA et al., *Oregon Avgas—Where are we and where do we go from here?*, *available at* <http://www.eaa.org/news/2007/2007-12-20_or_avgas_paper.pdf>. *See* EAA, *Information paper - Oregon Avgas vs. Ethanol-Blended Autofuel*, *at* <www.eaa.org/news/2007/2007-12-

20_or_avgas_paper.pdf>; Anatomy of a Law in Oregon, *at* <www.stopeio.com/anatomy.html>; EAA, *EAA Members Responding to New Oregon Ethanol Law* (Nov. 29, 2007), *at* <www.eaa.org/news/2007/2007-11-29_ethanol.asp>.

See also US EPA, *Fuel Trends Report: Gasoline 1995 – 2005*, Exec. Summary (Jan. 2008), *available at* <http://epa.gov/otaq/regs/fuels/rfg/properf/420s08001.pdf> ("Concerns over groundwater contamination from MTBE resulted in various state laws banning or phasing out its use in gasoline. The Energy Policy Act of 2005 included a renewable content requirement for gasoline and eliminated the RFG [reformulated fuel standards] oxygen content requirement. RFG data for 2006, while not analyzed for this report, show that RFG suppliers continued to use oxygen in RFG even after the requirement was removed in May of 2006, and that *virtually all of this RFG was ethanol-oxygenated*. MTBE use in RFG is at near zero levels. EPA finalized Renewable Fuel Standard program regulations in April 2007 to implement the Energy Policy Act renewable content requirement. Like RFG, these regulations include new recordkeeping and reporting requirements designed to track the volume of renewable fuel, including ethanol."). *See also* US EPA, MTBE Home Page, *at* <http://www.epa.gov/otaq/consumer/fuels/mtbe/mtbe.htm>.

[89] This percentage may change in response to future legislation.

[90] Hjelmco Oil AB, *at* <www.hjelmco.com>.

[91] Telephone Interview with Earl Lawrence, VP of Industry and Regulatory Affairs, EAA, Jan. 28, 2008.

[92] However, there is debate within the standards committees about whether this fuel, as an *unleaded* fuel, conforms to ASTM D910, since D910 states the maximum lead content for each fuel but does not specify a minimum amount of lead.

[93] Lycoming, Service Instruction No. 1070N, *Specified Fuels* (June 14, 2006), *available at* <http://www.lycoming.textron.com> (approving 91/96UL for diverse Lycoming engines). Teledyne Continental approved 80/87 "for any TCM-AP engine originally certified for this fuel." Letter from J.G. (Jim) Wheelock, Mgr., Piston Engineering, Teledyne Continental Motors, Jan. 24, 1991 (letter on file with author) (also placing 80/87 ahead of 100LL in the order of preference of fuel usage for a newly overhauled engine certified for use of avgas 90/87). Rotax, Service Instruction, *Selection of Suitable Operating Fluids for Rotax Engine Type 912 and 914 (Series)*, Aug. 28, 2006, *available at* <www.rotax-owner.com/si_tb_info/serviceinfo/si912016914019.pdf>, and specified Russian radial engines per Approval From The Exec. Dir., Osrodek Badawczo-Rozwojowy Przemyslu Rafineryjnego w Plocku, Service Bulletin No. 129/S/2006 (Oct. 20, 2006) (for operation of the ASz621R and AI-14RA engine family in all configurations and versions) (copy on file with author).

Hjelmco also asserts that "The EASA approval of the Polish heavy radial which is 1050 HP (sits in the AN 2 biwing aircraft) automatically then covers the smaller radials of the ex. Soviet Union." Email from Lars Hjelmberg, Pres., Hjelmco Oil AB, Feb. 20, 2008. Collectively, these approvals provided support for Mr. Hjelmberg's assertion that his 80/87 fuel "carries engine manufacturer approvals for more than 90% of the entire world GA fleet." Email from Lars Hjelmberg, Feb. 15, 2008 (also stating "Our 91/96 UL meet the standard for AVGAS 80 UL of D910 but with the difference that 91/96 has higher octane numbers and the standard for AVGAS 80 UL says minimum octane numbers.").

[94] By GAMI in 2002. Engine testing was with a substantially modified 350 hp Lycoming TIO-540 engine.

[95] AVGAS 80UL in D910-81 was undyed. Dye denotes lead per international agreement. "In Sweden we thus have national legislation requiring transparent /undyed fuels if they are unleaded. As 80 UL is no longer in D910, the 91UL took its place as regards to having no dye." Email from Lars Hjelmberg, Feb. 20, 2008.

[96] Reintroduction in ASTM was undertaken by General Aviation Modifications, Inc. (GAMI).

[97] Earl Lawrence, VP, Industry and Regulatory Affairs, EAA NEWS, Dec. 10, 2001, *at* <http://www.eaa.org/media/pr/011207_lawrence.pdf>.

[98] The precise percentage of the fleet that can safety do so is in play, as discussed in this commentary.

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[99] Telephone Interview with Douglas C. Macnair, EAA VP Gov't Relations, Feb. 5, 2008.

[100] Roger G. Gaughan, *Unleaded aviation gasoline*, U. S. Patent 5,470,358, Nov. 25, 1995, and USPTO Application #**:** 20060225340, Oct. 12, 2006, *available at* <http://www.patentstorm.us/patents/5470358.html> (Aromatic amines effective in increasing the motor octane number of aviation; a MON of at least 98).

[101] Telephone Interview with Earl Lawrence, VP, EAA, Jan. 28, 2008 (noting that ExxonMobil modified a molecule in one of the amines–with low temperature modification and is undergoing cancer studies with rats). Some industry observers suggest that "ExxonMobil management 'aren't going anywhere with it.' They thought they could not deliver it for less than $ 15 Gal. Can you get an amine to work -- yes? Does it satisfy certification of 100LL (it is actually 104/108 octane). So, if you had enough amine maybe, but it is hazardous and cancer causing. Europe has already said they are not touching it. They think it will go to $15 gal and then that is when they will offer the fix. Because that is what the distribution guys are telling us." Telephone Interview with Anonymous, Aviation fuel standards expert, Jan. 21, 2008.

[102] CRC, *Exec. Summary, CRC Research Results, Unleaded High Octane Aviation Gasoline*, Apr. 24, 2008, at p. 9 (emphasis added) (copy on file with author).

[103] As a historical note, this is reminiscent of early automotive fuel issues. "The burden falls upon the engine, it must adapt itself to less volatile fuel, and it must be made to burn the fuel with less waste. . . . Automotive engineers must turn their thoughts away from questions of speed and weight . . . and comfort and endurance and focus on averting the calamity." *The Declining Supply of Motor Fuel*, SCI. AM., Mar. 8, 1919, at p. 220.

[104] Manufacturers of high compression reciprocating engines have been put on notice (perhaps admonished) that it is "unconscionable" for them to manufacturer aircraft knowing that they may not have a fuel supply within ten years. Telephone Interview with Douglas C. Macnair, EAA VP Gov't Relations, Feb. 5, 2008.

See Textron Lycoming, Press Release, *Lycoming Engines Announces IO/O-360 Automotive Gas Approval Program*, June 2, 2008 (unleaded automotive gasoline approval program – 93 AKI automotive gasoline conforming to either Euro Norm EN228 or ASTM D4814), *available at* <http://www.lycoming.textron.com/news-and-events/press-releases/release-06-02-08.jsp>.

[105] Other fuels (specific to diesels) include: Diesel No. 1 (C8-C19), Diesel No. 2 (C9-C21), and Diesel No. 4 (C25+), *further described at* <http://www.afcee.brooks.af.mil/PRO-ACT/fact/petfuels.asp>.

[106] ASTM D1655-07e1 *Standard Specification for Aviation Turbine Fuels*, *at* <www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/REDLINE_PAGES/D1655.htm?E+mystore>. *See* ExxonMobil Aviation, *Product Descriptions*, *at* <http://www.exxonmobilaviation.com/AviationGlobal/ProductsServices/product_descriptions.asp> (summarizing aviation fuel specifications).

[107] *Available at* <http://www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/REDLINE_PAGES/D6615.htm?E+mystore>.

[108] *See generally* USAF, PROACT Fact Sheet, *at* <http://www.afcee.brooks.af.mil/PRO-ACT/fact/petfuels.asp#4>. Additionally, JP-8+100 – This is JP-8 fuel with improved heat sink/thermal stability performance by the inclusion of an additional additive package.

[109] Interview with Anonymous, Aviation fuels producer, Jan. 21, 2008.

[110] Or, *hexadecane*, an alkane hydrocarbon that is also a shorthand measurement for detonation (ignition delay) in diesel fuel, *at* <http://en.wikipedia.org/wiki/Cetane>. *See* Wikipedia, *Cetane number*, *at* <http://en.wikipedia.org/wiki/Cetane_number>. Diesel engines are addressed in **Part IV. AIRBORNE EMISSIONS**, below.

[111] Nonetheless, producers are surveying what current levels of cetane are used and its affect on detonation. Note that the ASTM Biodiesel standard, Specification D6751, provides for a cetane number of 47 whereas conventional diesel fuel requires a minimum cetane number of 40.

[112] *See, e.g.*, Ben Vissar, *Jet A vs. #2 diesel: Which is better?*, GEN. AVI. NEWS, Apr. 22, 2005, *available at* <www.generalaviationnews.com> (For example, diesel fuel's freezing point is approximately0°C at sea level, cleanliness requirements vary, and engine manufacturers may not have approved it.); Robert Goyer, *Skyhawk With a Bang,* FLYING, Apr. 2008, at p. 67 (Cessna chose not to certify its 172TD (turbo diesel) for diesel fuel and instead certified it only for Jet A even though the engine is certified to use diesel fuel in other applications. "[T]he ever-changing spec of automotive diesel . . . convinced Cessna that the safer route would be to stick with old reliable jet-A . . ." *id.*).

[113] *See, e.g.*, FAA, *Fuel Properties, Effect on Aircraft and Infrastructure*, Aviation Rulemaking Advisory Committee, *available at* <http://www.fire.tc.faa.gov/pdf/TG67.pdf>.

[114] *See, e.g.*, Agency for Toxic Substances and Disease Registry, Public Health Service, US DHHS, *Toxicological Profile for Jet Fuels JP-5 and JP-8*, Aug. 1998, *available at* <http://www.atsdr.cdc.gov/toxprofiles/tp121-p.pdf>, and health effects, *at* <http://www.atsdr.cdc.gov/toxprofiles/tp121-c2.pdf>. *See also* U.S. Oil and Refining Co., Jet A, *available at* <http://www.usor.com/pdfs/msds/fuels/Jet_Fuel_MSDS.pdf> (various Material Safety Data Sheets (MSDS) for aviation fuels toxicity noting tumors, central nervous system, and respiratory risks).

[115] *See, e.g.*, Coordinating Research Council, *Jet Fuel Storage Stability*, CRC-327, 4/58, *available at* <http://www.crcao.com/reports/aviafuel/storstab.htm>.

[116] *At* <www.biodiesel.org/pdf_files/fuelfactsheets/Lubricity.PDF> (lubricity of diesel).

[117] Dan Elwell, Ass't Admin'r for Avi. Policy, Planning and Env't, FAA, Presentation at the FAA Forecast Conference, *Panel 2 Environmental Challenges for Aviation-A Panel Discussion,* in Wash., D.C., Mar. 10, 2008.

[118] Energy security refers to sufficient confidence that supply will not be interrupted (or made cost prohibitive) by foreign political action. *See* GovTrack.us, H.R. 6--110th Congress (2007): ENERGY INDEPENDENCE AND SECURITY ACT OF 2007, *GovTrack*.us, *at* <www.govtrack.us/congress/bill.xpd?bill=h110-6&tab=summary> (addressing energy security). *But see* Jad Mouawad, *Promise of Biofuel Clouded by Weather Risks*, N.Y. TIMES, July 1, 2008, at pp. A1, A15 (crop failure issues create energy security issue in use of biofuels).

[119] *See* DoE, Alternative Fuels & Advanced Vehicles Data Center, *at* <www.eere.energy.gov/afdc/>.

[120] Alternative fuels can be viewed in four classes: Fischer-Tropsch fuels (synthesized largely from fossil fuels), biodiesel (e.g., derived from fatty acid methyl esters), hydrogenated bio-oils, and alcohols (such as ethanol). Tim Held, General Electric Aviation, *quoted in* BUSINESS & COMM. AVI., Sept. 2007, at p. 88, *available to subscribers at* <www.aviationweek.com/awst>.

[121] Oren Hadaller, *Alternative Aircraft Fuels*, in ASTM STANDARDIZATION NEWS (Apr. 2007), *at* <www.astm.org/cgi-bin/SoftCart.exe/SNEWS/APRIL_2007/hadaller_apr07.html?E+mystore>.

[122] Elisabeth Rosenthal, *Europe, Cutting Biofuel Subsidies, Redirects Aid to Stress Greenest Options*, N.Y. TIMES, Jan. 22, 2008, at p. C3 ("There is increasing evidence that the total emissions and environmental damage from producing many 'clean' biofuels often outweigh their lower emissions when compared with fossil fuels."). *See* Air Transport Ass'n, *ATA Alternative Fuels Principles Document*, *at* <www.airlines.org>.

[123] "**Life cycle assessment** (also known as life cycle analysis or cradle-to-grave analysis) is the assessment of the environmental impact of a given product or service throughout its lifespan, including all phases: raw material production, manufacture, distribution, product use and disposal and all intervening transportation steps." World Resources Institute / World Business Council on Sustainable Development, Greenhouse Gas Protocol Initiative, *Questionnaire on Supply Chain and Life Cycle GHG Emissions Accounting*, Nov. 2007, *available at* <www.ghgprotocol.org/files/ghg-protocol-life-cycle-supply-chain-questionnaire.doc>.

[124] US EPA, *at* <http://www.epa.gov/otaq/renewablefuels/420f07035.htm> ("The fuels are compared on an energy equivalent or BTU basis. Thus, for instance, for every BTU of gasoline which is replaced by corn

ethanol, the total lifecycle greenhouse gas emissions that would have been produced from that BTU of gasoline would be reduced by 21.8 percent. These emissions account not only for CO2, but also methane and nitrous oxide.").

[125] *See, e.g.*, Laura Carlsen, *The Agrofuels Trap*, American Program, Center for Int'l Policy, Sept. 11, 2007, *at* <http://americas.irc-online.org/am/4535/> ("Studies contradict each other on whether net energy generation is positive or negative, whether greenhouse gas emissions and pollution increase or decrease, and how costs and energy efficiency sort out." *id.*) Also consider that petroleum fuels contain a wide range of chemicals with beneficial properties (such as lubricity) which may be difficult to substitute.

[126] Telephone Interview with Douglas C. Macnair, EAA VP Gov't Relations, Feb. 5, 2008. *See infra* note 608 (noting Cessna's diesel initiatives. Separately, consider Cessna's challenges in seeking certification of a diesel-powered C172 in light of Thielert's bankruptcy in light of its earlier assertion that there may not be a 100LL option for the Skyhawk after 2009).

[127] "Any company with the resources it takes to recertify airplanes will be reluctant to do so given the huge amount of liability they must absorb. If they have enough money to do this type of work then they will be characterized as 'deep pockets' and hence a target of lawsuits the first time there's a fatal accident." Email From Todd L. Peterson, Petersen Aviation, Inc., Feb. 28, 2008.

[128] Lourdes Maurice, Ph.D., Chief Scientist, FAA Office of Environment and Energy, FAA, *Alternative Aviation Fuels, Aviation and the Environment*, Presentation to ICAO at Transport Canada, Sept. 20, 2006, *available at* <http://www.icao.int/icao/en/env/WorkshopFuelEmissions/Presentations/Maurice.pdf>.

[129] Interview with Lourdes Maurice, Ph.D., Chief Scientist, FAA Office of Environment and Energy, in San Diego, Cal., Mar. 14, 2008.

[130] Ethanol is also known as ethyl or grain alcohol: C_2H_5OH. *See* Renewable Fuels Association, *at* <http://www.ethanolrfa.org>.

[131] A biofuel is liquid, gaseous, or solid fuel derived from biomass. Ethanol can be produced by biomass containing starch, sugar, or cellulose. *See The case for Ethanol*, Baylor Univ., Institute for Air Science, Alternative Aviation Fuel Research, *at* <http://www.baylor.edu/bias/index.php?id=4556>. Biomass is organic matter available on a renewable or recurring basis and derived from forest, agricultural residues, food and yard wastes, or crops grown solely for energy production, among other such sources. *See* OR Act 2007 (2007 HB 2210-B), *available at* <http://www.leg.state.or.us/07reg/measpdf/hb2200.dir/hb2210.en.pdf>.

[132] AGE-85: Aviation Grade Ethanol – A project funded by the South Dakota Corn Utilization Council, *at* <http://www.age85.org/>. *See* Age85, *Aviation Grade Ethanol 85 (Age-85) Technical Briefing*, *available at* <http://www.age85.org/Attachments/Technical%20Briefing.ppt#259,4,Slide 4> ("a reciprocating-engine aviation fuel that contains about 85 volume percent (vol%) ethanol and about 15 vol% "pentane isomerate" (an oil refinery product comprising about 35% isopentane), in addition to small amounts of soy methyl ester lubricant and a fatty acid-based corrosion inhibitor. Variation in fuel ethanol content from a minimum of 80% to a maximum of 90 vol% may be needed to meet fuel volatility requirements based on seasonal considerations and/or refinery-specific pentane isomerate vapor pressure."). *See also* Cesar Gonzolaz & Richard Jesik, Cessna Aircraft Co., *Evaluation of Ethanol Based Aviation Spark-Ignition Engine Fuel*, Cessna Engineering Report, July 2002, Table 2, at p. 4 (copy of file with author) (presenting an AGE-85 specification in accordance with the S. Dakota Univ. Age-85 specification).

[133] AGE-85: *Aviation Grade Ethanol*, at <http://www.age85.org/>. Note that such ice prevention happens because water does not readily separate from Ethanol fuels, which itself presents a potential safety hazard from Ethanol use in airplanes.

[134] Gonzolaz, *supra* note 132, ¶ 10.2.2, at p. 70 ("Under identical EGT mixture management procedures, the AGE-85 fuel required 37% higher volumetric fuel flows than the baseline 100LL Avgas at identical maximum power levels, 30% at maximum cruise and 33% at low cruise power conditions.").

[135] David Korotney, US EPA, *Water Phase Separation in Oxygenated Gasoline*, Memo (Feb. 27, 1996), *available at* <http://www.epa.gov/otaq/regs/fuels/rfg/waterphs.pdf>.

[136] Gonzolaz, *supra* note 132, ¶¶ 10.7-10.9, at pp. 68-69 ("Component failures with AGE-85 fuel proved to be of a more severe nature than with other fuels" including fuel pump, strainer, and fuel bladder deterioration. Also, gum deposits were "45 times worse than the limits established by the ADTM D 910 Avgas Specification" and accelerated storage deterioration.).

[137] *See, e.g.*, Baylor Univ., Alternative Aviation Fuel Research, *at* <http://www.baylor.edu/bias/index.php?id=111> (developing ethanol and ETBE for piston aircraft, and blends of biodiesel and Jet A for turbines); Univ. North Dakota, Energy & Environmental Research Center (EERC), *at* <http://www.undeerc.org/centersofexcellence/nafl.aspx>.

[138] FAA, SAIB, No. CE-07-06, *Alcohol (ethanol or methanol) present in the automobile gasoline on any General Aviation airplane* (Oct. 27, 2006), *available at* <http://www.aviationfuel.org/saibs/10_27_06%20-%20CE-07-06.pdf>.

[139] *See, e.g.*, Embraer's Ipanema, an ethanol-burning crop duster, *at* <http://en.wikipedia.org/wiki/Embraer_EMB_202_Ipanema> (using a modified 320 hp Lycoming reciprocating engine); AGE-85, South Dakota State Univ., *at* <http://www.engineering.sdstate.edu/~ethanol/>.

[140] Telephone Interview with Earl Lawrence, VP of Industry and Regulatory Affairs, EAA, Jan. 28, 2008. ("It would cost more than the value of the aircraft to modify the fleet." *id*.).

[141] CASA, *Airworthiness Bulletin 28-003*, Issue 1, Jan. 4, 2007, *available at* <http://www.casa.gov.au/airworth/awb/28/003.pdf>.

Ethanol STCs generally provide for anodized aluminum that contacts the fuel, ensuring that rubber parts in the fuel system are ethanol-safe, and modifying the fuel injector unit to reflect ethanol's lower BTU output. Aviation gas has at least 18,700 BTUs and is nominally rated at 20,000 BTUs per pound. *See* Dale De Remer, Ph.D., Aircraft Systems For Pilots (Jeppesen Sanderson 1996), at p. 89 (providing an overview of the specification of avgas).

[142] *But see* Antonio Regaldo, *Ethanol Maker Buys Exxon's Brazil Outlets*, Wall St. J., Apr. 25, 2008, at p. B4 (Brazil's major ethanol producer purchases ExxonMobil's 1,500 Esso chain of gas stations in Brazil).

[143] Telephone Interview with Earl Lawrence, VP of Industry and Regulatory Affairs, EAA, Jan. 28, 2008.

[144] Cesar Gonzolaz and Richard Jesik, Cessna Aircraft Co., *Evaluation of Ethanol Based Aviation Spark-Ignition Engine Fuel*, Cessna Engineering Report, July 2002, ¶ 10.3, at p. 70 (copy on file with author).

[145] Andrew W. Cebula, Exec. VP, Gov't Affairs, AOPA, *Comment in response to EPA Docket No. OAR-2007-0294 Petition Requesting Rulemaking To Limit Lead Emission from General Aviation Aircraft; Request for Comment*, Mar. 17, 2008 (caps removed), *available at* <http://www.regulations.gov/fdmspublic/ContentViewer?objectId=09000064803fbb16&disposition=attachment&contentType=pdf>.

See Paul Krugman, *Grains Gone Wild*, N.Y. Times, Apr. 7, 2008, at p. A25, *available at* <http://www.nytimes.com/2008/04/07/opinion/07krugman.html?_r=1&hp&oref=slogin> ("Where the effects of bad policy are clearest, however, is in the rise of demon ethanol and other biofuels. The subsidized conversion of crops into fuel was supposed to promote energy independence and help limit global warming. But this promise was, as Time magazine bluntly put it, a "scam." This is especially true of corn ethanol: even on optimistic estimates, producing a gallon of ethanol from corn uses most of the energy the gallon contains. But it turns out that even seemingly "good" biofuel policies, like Brazil's use of ethanol from sugar cane, accelerate the pace of climate change by promoting deforestation.").

[146] *See generally* Michael Pollan, Omnivore's Dilemma (Penguin Books 2006).

[147] *See, e.g.*, Steven Ashley, *Fueling Alternatives*, SCI. AM., Jan. 2008, at p. 45, *available at* <http://www.sciam.com/article.cfm?id=sciam-50-fueling-alternatives> (describing a way to extract synthetic fuel from sugar "Called 2, 5-dimethylfuran, or simply DMF, the fuel posses the energy density equivalent to that of gasoline. It is also insoluble in water and stable in storage." *id*.).

[148] *But see* Searchinger, *infra* note 158 (claiming that biofuels from switchgrass, if grown on U.S. corn lands, increase emissions by 50%). Another study found that grassland clearance releases 93 times the amount of greenhouse gases saved. Joseph Fargione, *Land Clearing and the Biofuel Carbon Debt*, SCIENCE, Published Online Feb. 7, 2008, *available at* <www.sciencemag.org/cgi/content/abstract/1152747>.

[149] The Proceedings of the National Academy of Sciences believes that with appropriate biorefineries, switchgrass would yield 540 percent more energy than used to produce it versus no greater than 25 percent from corn-based ethanol. SCI. AM, Mar. 2008, at p. 30. *See* David Biello, *Grass Makes Better Ethanol than Corn Does*, SCI. AM, Jan. 8, 2008, *available at* <http://www.sciam.com/article.cfm?id=grass-makes-better-ethanol-than-corn>.

[150] Wikipedia, *at* <http://en.wikipedia.org/wiki/Cellulosic_ethanol> ("Lignocellulose is composed mainly of cellulose, hemicellulose and lignin. Corn stover, switchgrass, miscanthus and woodchip are some of the more popular cellulosic materials for ethanol production. Cellulosic ethanol is chemically identical to ethanol from other sources, such as corn starch or sugar, but has the advantage that the lignocellulose raw material is highly abundant and diverse. However, it differs in that it requires a greater amount of processing to make the sugar monomers available to the microorganisms that are typically used to produce ethanol by fermentation.").

Sugar cane has also garnered attention as a particularly energy dense alternative, but not a viable option for extensive US production. *See* Edward Smeets, at al., *Sustainability of Brazilian bio-ethanol*, Report NWS-E-2006-110, Utrecht University, Copernicus Institute (Aug. 2006), *available at* <http://www.bioenergytrade.org/downloads/sustainabilityofbrazilianbioethanol.pdf> (sugar cane is the primary source of ethanol in Brazil); Milton Maciel, *quoted in* THE OIL DRUM, Oct. 11, 2006, *at* <http://www.theoildrum.com/story/2006/10/10/171011/86> ("Sugar cane ethanol from Brazil is NOT a realistic target or a comparable model for USA ethanol from corn.").

[151] Thomas D. Durbin et al., *Effects of Ethanol and Volatility Parameters on Exhaust Emissions,* Final Report, CRC Project No. E-67, Coordinating Research Council, Inc. (Jan. 30, 2006), *available at* <http://www.crcao.com/>.

See generally James Canter, *Europe May Ban Imports of Some Biofuel Crops*, N.Y. TIMES, Jan. 15, 2007, *available at* <http://www.nytimes.com/2008/01/15/business/worldbusiness/15biofuel.html?_r=1&ref=business&oref=slogin> (Most current ethanol production creates fertilizer pollution, water resource burden, and competition with food sources and agriculturally productive land.); Sasha Lilley, *Green Fuel's Dirty Secret*, CorpWatch, June 1, 2006, *at* <http://www.corpwatch.org/article.php?id=13646>; *UN warns on food price inflation*, BBC NEWS, Mar. 6, 2008, *at* <http://news.bbc.co.uk/2/hi/in_depth/7281686.stm> (citing biofuel production as contributing factor to high food prices and noting that some food prices rose 40% in 2007).

[152] The National Academies, National Research Council, NEWS, *Increase in Ethanol Production From Corn Could Significantly Impact Water Quality and Availability if New Practices and Techniques Are Not Employed*, Oct. 10, 2007, *available at* <http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=12039>.

Corn ethanol production may also create soil erosion and run-off. Consider that Air New Zealand is exploring "second-generation" biofuel – a term that implicates fuels that neither compete with water or fresh water resources nor requires deforestation. "Candidate fuels must be renewable, sustainable and manufacturable in quantity at a profit." Michael Mecham, *Better Biofuels*, AV. WEEK & SPACE TECH., Oct. 8, 2007, at p. 45, *available to subscribers at* <www.aviationweek.com/awst>.

[153] Jean Ziegler, UN Special Rapporteur for the Right to Food, *quoted in* Steven Erlinger, *U.N. Panel Urges Changes to Feed Poor While Saving Environment*, N.Y. TIMES, Apr., 16, 2008, at p. A6, *available at* <http://biz.yahoo.com/nytimes/080416/1194765742622.html?.v=3>.

[154] Josette Sheeran, Exec. Dir., World Food Program, N.Y. TIMES, Apr. 23, 2008, at p. A9, *available at* <http://www.nytimes.com/2008/04/23/world/europe/23fbriefs-WORLDFOODCRI_BRF.html?scp=2&sq=Josette+sheeran&st=nyt>. *See* Josh Gerstein, *Food Crisis Eclipsing Climate Change*, N.Y. SUN, Apr. 25, 2008, *available at* <http://www2.nysun.com/article/75292> (Stating that an estimated thirty percent of the US corn crop is devoted to fuel rather than food).

[155] H. Josef Hebert, *Ethanol commitment scrutinized so soon?*, S.J. MERCURY NEWS, May 7, 2008, at p. 3C, *available at* <http://www.mercurynews.com/politics/ci_9179018>.

[156] Jeffrey Sachs, Dir., Earth Institute, Columbia Univ., *quoted in* CNN, *Riots, instability spread as food prices skyrocket*, Apr. 14, 2008, *at* <http://www.cnn.com/2008/WORLD/americas/04/14/world.food.crisis/index.html>. *See* Food and Agriculture Organization of the United Nations, *High-Level Conference On World Food Security: The Challenges Of Climate Change And Bioenergy*, HLC/08/INF/1, Apr. 2008, at p. 7, *available at* <http://www.fao.org/fileadmin/user_upload/foodclimate/HLCdocs/HLC08-inf-1-E.pdf> ("*Biofuels and agricultural commodities:* The emerging biofuels market is a new and significant source of demand for some agricultural commodities such as sugar, maize, cassava, oilseeds and palm oil. The increase in demand for these commodities has been one of the leading factors behind the increase in their prices in world markets which, in turn, has led to higher food prices."). *Cf.* Renewable Fuels Ass'n, *at* <http://www.ethanolrfa.org/> (refuting "food vs. fuel").

[157] Andrew Martin, *Fuel Choices, Food Crises and Finger-Pointing*, N.Y. TIMES, Apr. 15, 2008, at p. 1, *available at* <http://www.nytimes.com/2008/04/15/business/worldbusiness/15food.html?ei=5065&en=9e715f242c497f48&ex=1208923200&partner=MYWAY&pagewanted=print>. *See* C. Ford Runge & Benjamin Senauer, *How Biofuels Could Starve the Poor*, FOREIGN AFFAIRS, May/June 2007, *available at* <http://www.foreignaffairs.org/20070501faessay86305/c-ford-runge-benjamin-senauer/how-biofuels-could-starve-the-poor.html>.

[158] Timothy Searchinger et al., *Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change*, SCIENCE, Published Online, Feb. 7, 2008, *at* <www.sciencemag.org/cgi/content/abstract/1151861>. *Cf. The Case for Ethanol*, Baylor Univ., *at* <http://www.baylor.edu/bias/index.php?id=4556> ("The use of ethanol significantly reduces the CO2 burden when compared to the use of any fossil fuel. This is because ethanol is a biomass fuel, and most of the CO2 emitted to the atmosphere by its combustion is sequestered by the plants used to produce it. Only the fraction of fossil fuels used in the production of the ethanol adds to the CO2 burden (it is possible to eliminate this fraction by using renewable fuels in the entire cycle of ethanol production)."). *But see E3 Biofuels*, *at* <http://www.e3biofuels.com/> (presenting a "closed loop" system to diminish ethanol production emissions).

[159] *On the Record: Vinod Khosla*, Interview by Al Saracevic et al., S.F. CHRONICLE, May 11, 2008, in the SFGATE, *at* <http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2008/05/11/BUD010IHPC.DTL>

[160] US DoE, *Biomass as Feedstock for A Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, Apr. 2005, *available at* <http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf>.

[161] Evan Ratliff, *The Plant that will save America*, WIRED, Oct. 2007, at p. 160, *available at* <http://www.wired.com/science/planetearth/magazine/15-10/ff_plant>. *See* Andrew Pollack, *Through Genetics, Tapping a Tree's Potential as a Source of Energy*, N.Y. TIMES, Nov. 20, 2007, at p. D3, *available at* <www.nyt.com> (explaining research to reduce the amount of lignin, a chemical in plants that provides trees with structural stiffness and pest resistance, to turn cellulose into simple sugars that can be processed

into ethanol – with a cost savings of $ 0.10 per gallon. Also, claiming that transgenic trees will be on the market within 5-10 years.).

[162] Also, from prohibition of other oxygenators. Matthew L. Wald, *Federal Recipe for Gasoline Helped Drive Up the Price*, N.Y. TIMES, May 6, 2006, at p. A10, *available at* <http://www.nytimes.com/2006/05/06/washington/06fuel.html?_r=1&oref=slogin>. *See also* zFACTS.com, *at* <http://zfacts.com/p/436.html> (stating that it increased $1.30 per gallon from 2005 to 2006). *Cf. On the Record: Vinod Khosla*, *supra* note 159 ("I have no question that in 10 years, there's no way oil will be able to compete with biofuels. Even in five years. Now it will take a long time to scale biofuels, but I'm the only one in the world forecasting oil dropping in price to $35 a barrel by 2030. I'll put it on the record: Oil will not be able to compete with cellulosic biofuels.").

[163] Wikipedia, *Synthetic fuel*, *at* <http://en.wikipedia.org/wiki/Synthetic_fuel> ("Synthetic fuel or synfuel is any liquid fuel obtained from coal, natural gas, or biomass. It can sometimes refer to fuels derived from other solids such as oil shale, tar sand, waste plastics, or from the fermentation of biomatter." *id.*); Wikipedia, *Biomass*, *at* <http://en.wikipedia.org/wiki/Biomass> ("refers to living and recently dead biological material that can be used as fuel or for industrial production.").

[164] *See* U.S. Dept. of the Interior, Bureau of Land Mgt., *Oil Shale and Tar Sands*, *at* <http://www.blm.gov/wo/st/en/prog/energy/oilshale_2.html> (surveying these resources, estimating US oil shale reserves of the equivalent of 1.23 trillion barrels of oil, and referencing key provisions of the Energy Policy Act of 2005).

[165] *See, e.g.*, Michael A. Aimone, U.S. Air Force Ass't Deputy Chief of Staff for Logistics, *quoted in* Thom Shanker, *Military Plans Tests in Search for an Alternative to Oil-Based Fuel*, N.Y. TIMES, May 14, 2006, at p. 14, *available at* <http://www.nytimes.com/2006/05/14/us/14fuel.html?_r=2&adxnnl=1&oref=slogin&adxnnlx=1203948314-yG/R0EcaDREe/RZq+PQG4A> (recognizing that "Energy is a national security issue").

[166] F-T Archive, *at* <http://www.fischer-tropsch.org/>. *See* W. Rose & Hans O. Pfannkuch, *Unconventional Ideas about Unconventional Gas,* Society of Petroleum Engineers Unconventional Gas Recovery Symposium, in Pittsburgh, Pa., May 16-18, 1982, *available at* <http://www.spe.org/elibinfo/eLibrary_Papers/spe/1982/82UGR/00010836/00010836.htm>.

The two basic approaches to convert CTL are direct and indirect liquefaction. Direct liquefaction involves breaking coal down in a solvent at elevated temperature and pressure, followed by interaction with hydrogen gas and a catalyst. Indirect liquefaction (the F-T process) involves first gasifying coal and then making synthetic fuels from the "syngas". Indirect liquefaction is the leading approach and produces environmentally compatible zero-sulfur liquid fuels that are cleaner than required under today's emissions laws and regulations. Nat'l Mining Ass'n, *Liquid Fuels from U.S. Coal*, *available at* <http://www.nma.org/pdf/liquid_coal_fuels_100505.pdf>. *See Fischer Tropsch Catalyst Test on Coal-Derived Synthesis Gas,* Syntrolium Corp., White Paper, Nov. 2007, *available at* <http://www.syntroleum.com/pdf/White%20Paper%20Text%20Eastman.pdf>.

[167] *See* F. Jeffrey Martin and William I. Kubic, Jr., Los Alamos Nat'l Laboratory, *Green Freedom – A Concept for Producing Carbon-Neutral Synthetic Fuels and Chemicals*, Nov. 2007, *at* <http://www.lanl.gov/news/newsbulletin/pdf/Green_Freedom_Overview.pdf>. *See also* Richard L. Altman, Exec. Dir, CAAFI, *Alternative Fuels in Commercial Aviation – The Need, the Approach, Progress*, Alternative Fuels Roadmap – Level 2 – Aggregates Team Process/Products, Presentation at the 32nd Annual FAA Forecasting Conference, in Wash., D.C., Mar. 16, 2007, *available at* <www.faa.gov/news/conferences_events/aviation_forecast_2007/agenda_presentation/media/9-%20Rich%20Altman.pdf>, Marian Blakey, FAA Admin'r, *An Affirmative Obligation*, Speech, June 19, 2007, *available at* <http://www.faa.gov/news/speeches/news_story.cfm?newsId=8988>.

[168] David Gray et al., *Increasing Security and Reducing Carbon Emissions of the U.S. Transportation Sector: A Transformational Role for Coal with Biomass*, Nat'l Energy Technology Laboratory, DOE/NETL-2007/1298, Aug. 24, 2007, at pp. 62-63, *available at* <http://www.netl.doe.gov/energy-

analyses/pubs/NETL-AF%20CBTL%20Study%20Final%202007%20Aug%2024.pdf>. *See generally* Alternative Fuel Research Addressing Nation's Energy Independence, Glenn Research Center, *at* <http://www.nasa.gov/centers/glenn/news/AF/2007/Feb07_AltFuel.html> (summarizing Glenn's F-T research initiative). *Cf.* Telephone Interview with Mark Rumizen, Reciprocating Engines/Fuels Specialist, ANE-110, FAA, Mar. 5, 2008 (characterizing the environmental impact of using alternative fuels as "negligible" and underscoring that any fuel "must be chemically identical or it won't work.").

[169] Syntroleum, Press Release, *Syntroleum Signs Contract to Deliver Renewable Alternative Jet Fuel to U.S. Department of Defense*, July 9, 2007, *available at* <www.syntroleum.com/pr_individualpressrelease.aspx?NewsID=1023522>.

[170] Roger Drinnon, *C-17 uses synthetic fuel blend on transcontinental flight*, AIR FORCE LINK**,** *at* <http://www.af.mil/news/story.asp?id=123079891> ("The Air Force is taking a leadership role in testing and certifying the use of synthetic fuel in aircraft." Sec'y, USAF, Michael W. Wynne, *id*.).

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[174] Matthew Brown, Asso. Press, *Air Force to Wall Street: Invest in coal conversion*, USA TODAY, Feb. 22, 2008, *at* <http://www.usatoday.com/money/industries/energy/2008-03-22-airforcecoal_N.htm>; *Big Sky Depot*, AVI. WEEK & SPACE TECH., Mar. 31, 2008, at p. 13 (plans production of up to 22,000 barrels per day on leased land at Malmstron AFB).

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[179] Nat'l Science and Technology Council, *Nat'l Plan for Aeronautics Research and Development and Related Infrastructure* (Dec. 2007), at p. 27, *available at* <http://www.aeronautics.nasa.gov/releases/aero_rd_plan_final_21_dec_2007.pdf> ("Lifecycle" refers to the emissions created in producing the fuel as well as expending it.).

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[183] ASTM, *Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels, available at* <http://www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/REDLINE_PAGES/D6751.htm?E+mystore>.

[184] The National Biodiesel Accreditation Commission, BQ 9000, *at* <http://www.bq-9000.org/>.

[185] US DoE, *BIODIESEL Handing and Use Guidelines*, DOE/GO-102006-2358, 3rd ed., Sept. 2006, at p. 5, *available at* <http://www.nrel.gov/docs/fy06osti/40555.pdf>. Diesel emissions are addressed in Part IV. Airborne Emissions, below.

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[188] Elisabeth Rosenthal, *New Trend in Biofuels Carries New Risks*, N.Y. TIMES, May 21, 2008, at p. A6, *available at* <http://www.nytimes.com/2008/05/21/science/earth/21biofuels.html?_r=1&ref=science&oref=slogin> (reporting that most second-generation crops identified for biofuel production have been labeled by scientists as invasive species). *See* UN Environment Programme – World Conservation Monitoring Centre, *at* <http://www.unep-wcmc.org/>.

[189] *See* Nat'l Renewable Energy Laboratory - Air Force Office of Scientific Research, *Workshop on Algal Oil for Jet Fuel Production*, Feb. 2008, *available at* <http://www.nrel.gov/biomass/algal_oil_workshop.html>; *On a Wing And . . . Pond Scum?*, AERO-NEWS.NET (July 17, 2007), *at* <http://www.aero-news.net/news/commair.cfm?ContentBlockID=1ba9ef37-2a16-41dc-a0cb-7bbd4be2c5ad&Dynamic=1> ("New Zealand's Independent Financial Review reports

Boeing and Air New Zealand are secretly working with Aquaflow Bionomic Corporation, a Blenheim-based biofuel developer, to come up with an environmentally friendly aviation fuel made from wild algae."). *See also*, Ariz. State U., *Researchers Evaluate Algae Jet Fuel*, Aug. 21, 2007, *at* <http://asunews.asu.edu/20070821_algae> (DARPA-funded research with UOP, a Honeywell company for JP-8 algae-based biofuel –"the oil yield of algae is projected to be at least 100 times that of soybean per acre of land on an annual basis."); Miles O'Brien, *Fuel from scum*, CNN, Feb. 1, 2008, *video at* <www.cnn.com/video/#/video/tech/2008/02/01/solutions.fuel.from.scum.cnn>; <http://www.valcent.net/i/misc/Vertigro/index.html>. Note: The 2007 Energy Security and Independence Act of 2007, PL: 110-140. includes language promoting the use of algae for biofuels.

[190] David L. Daggett, Boeing et al., *Alternative Fuels for use in Commercial Aircraft*, Boeing Co. (2007), at p. 7, *available at* <http://www.boeing.com/commercial/environment/pdf/alt_fuels.pdf>; Eric E. Jarvis, Ph.D., National Renewable Energy Laboratory, National Bioenergy Center, *Aquatic Species Program (ASP): Lessons Learned*, NREL-AFOSR Joint Workshop on Algal Oil for Jet Fuel Production, Feb. 2008, *available at* <http://www.nrel.gov/biomass/pdfs/jarvis.pdf>.

[191] Gunther Matschnigg, Sr. VP of Safety, Operations and Infrastructure, IATA et al., *IATA 2007 Report on Alternative Fuel* (Mar. 1998), *available at* <www.iata.org>, *and at* <http://www.iata.org/NR/rdonlyres/329E1C20-1A46-4E02-9F68-BAD5C9080F31/60972/ReportonAlternativeFuels.pdf>. *See* James Ott, *Algae Advances*, AVI. WEEK & SPACE TECH., Mar. 17, 2008, *available at* <http://www.aviationnow.com/search/AvnowSearchResult.do?reference=xml/awst_xml/2008/03/17/AW_03_17_2008_p66-35819.xml&query=algae>.

[192] David Biello, *Biodiesel Takes to the Sky*, SCI. AM. (Nov. 30, 2007), *at* <http://www.sciam.com/article.cfm?id=biodiesel-takes-to-the-sky> (describing the 37 minute flight on Oct. 2, 2007); Greenflight Int'l, Press Release, *World's First Jet Flight Powered Entirely On Renewable Biodiesel Fuel* (Oct. 5, 2007), *at* <http://www.greenflightinternational.com/pr.htm>.

[193] *Biofuel, Party from Nuts, Is tested on an Airline Flight*, N.Y. TIMES, Feb. 25, 2008, at p. C7, *available at* <www.nytimes.com/2008/02/25/business/25virgin.html?ref=business>, and Virgin Atlantic media, *at* <http://www.digitalnewsagency.com/story/view/739-virgin-atlantic-becomes-the-worlds-first-airline/video> (25% babassu nut and coconut oil blend with Jet-A running one unmodified GE turbine for a flight from London to Amsterdam). *Cf. Biofuel aircraft not viable for at least five years*, TIMES ONLINE, Feb. 25, 2008, *at* <http://www.timesonline.co.uk/tol/news/environment/article3430055.ece> (claiming that the Virgin flight used only 5% biofuel).

Additionally, Branson stated, "Two years ago, people said that was impossible. They said it would freeze at 20,000 feet." *id*. Nonetheless, one expert commented, "You can take a current bio material, run it through a hydrocracker, and make it impossible to know it was bio. But fatty acids have temperature constraints – you cannot have wax crystals [in jet fuel] – so you have to do other processing. That really is the other issue – very simple issue. It must have the right balance. It is really processing steps and cost – [and will be] the big deal for years." Telephone Interview with Anonymous aviation fuels standards expert, Jan. 21, 2008.

The Virgin Atlantic flight came 10 months earlier than Virgin–or project partners Boeing and GE Aviation–had planned. Al Yoon, *Virgin Atlantic 747 to test biofuel in early 2008*, REUTERS, Oct. 15, 2007, *available at* <www.reuters.com/article/technologyNews/idUSN1535208020071015>; *see* UPI, *Virgin Atlantic to Test Biofuel*, Feb. 6, 2008, *at* <http://www.upi.com/NewsTrack/Top_News/2008/02/06/virgin_atlantic_to_test_jet_biofuel/1281/>.

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[195] Continental, Press Release, *Continental Airlines, Boeing and GE Aviation Announce Plans for Sustainable Biofuels Flight Demonstration*, Mar. 13, 2008, *available at* <http://www.continental.com/web/en-US/apps/vendors/default.aspx?i=PRNEWS> (using a Boeing 737 and CFM56-7B engines).

[196] US DoE, *BIODIESEL Handing and Use Guidelines*, DOE/GO-102006-2358, 3rd ed., Sept. 2006, at p. 9, *available at* <http://www.nrel.gov/docs/fy06osti/40555.pdf> (B100 begins to cloud at between 35-56º F; additives can reduce its pour point as much as 30º F. *id*. at p. 20).

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[197] Timothy Searchinger et al., *Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change*, SCIENCE, Feb. 7, 2008, at pp. 1,238-1,240, *available at* <http://www.sciencemag.org/cgi/content/abstract/319/5867/1238?maxtoshow=&HITS=10&hits=10&RESULTFORMAT=&andorexacttitleabs=and&fulltext=Searchinger+&andorexactfulltext=and&searchid=1&FIRSTINDEX=0&resourcetype=HWCIT> (finding that prior analysis "have failed to count the carbon emissions that occur as farmers worldwide respond to higher prices and convert forest and grassland to new cropland to replace the grain (or cropland) diverted to biofuels."); Organization for Economic Co-operation and Development (OECD), *Economic Assessment of Biofuel Support Policies*, 2008 *available at* <http://www.oecd.org/dataoecd/19/62/41007840.pdf> (Government support of biofuel costly, marginally reducing greenhouse gases and improving energy security, impacts world crop prices significantly).

[198] Michael A. Taverna, *Coming Clean*, AVI. WEEK & SPACE TECH., June 11, 2007, at p. 48, *available to subscribers at* <www.aviationweek.com/awst>. *See* David Nielson, Boeing, *Commercial Aircraft Alternative Fuels*, Presentation to the Transport. Resource Bd. (2007), *at* <http://www.trbav030.org/pdf2007/TRB07_alt_fuel.pdf> (Boeing states that a 16% bio-Jet fuel blend to satisfy the US fleet would require 2.04 billion gallons, requiring 34 million acres of land – about 10% of the entire crop land in the US, or about 78% of current soybean production!).

[199] Rachelle Hill & Dr. Tamin Younous, *The Water Cooler – The interwined tale of energy and water*, Virginia Tech, Virginia Water Resources Research Center, *at* <www.vwrrc.vt.edu/watercooler.html> (biodiesel production requires up to 75,000 gal of water per million BTUs, and "biodiesel and ethanol production are in conflict with protecting water resources." *id*.).

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[201] Swift Enterprises, Ltd., *Swift Renewable Fuels*, Presentation to the CRC Aviation Gasoline Group, Apr. 28, 2008 (copy of presentation slides on file with author).

[202] Telephone Interview with Jon Ziulkowski, Principal Investigator & Chief Pilot, Swift Enterprises, Ltd., May 9, 2008.

[203] Swift Enterprises, Ltd., Press Release, *Designer Aviation Fuel May Provide Cleaner, Greener, Cheaper Alternative*, May 5, 2008, *available at* <http://www.businesswire.com/portal/site/google/?ndmViewId=news_view&newsId=20080505005358&newsLang=en>. *See generally* Swift Enterprises Website, *at* <http://www.swiftenterprises.com/>.

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[205] E. Dendy Sloan, Jr., *Fundamental principles and applications of natural gas hydrates*, NATURE, Nov. 20, 2003, at p. 354, *available at* <http://www.gas-hydrate.org.cn/permafrost/perm_11.pdf>. *See generally* Robert C. Hendricks, Glenn Research Center, *Methane Hydrates: More Than a Viable Aviation Fuel Feedstock Option*, AIAA-2007-4757, Nov. 2007, *available at* <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20070038170_2007037800.pdf>.

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208 Electric Aircraft Corp., *at* <www.electraflyer.com> (presenting the Electraflyer-C).

209 Sonex Video, *at* <http://www.youtube.com/watch?v=P8Pb_psj1A8>. *See* Sonex Aircraft Press Release, *Sonex Aircraft, LLC and AeroConversions Unveil E-Flight Initiative for Sport Aircraft Alternative Energy Research & Development*, July 24, 2007, *at* <http://www.sonexaircraft.com/press/releases/pr_072407.html> (stating that its electric motor is planned to be over 90% efficient and capable of flying over one hour). *See* Randy Hansen, EAA, *Petition for exemption from Federal Aviation Regulations, Parts 1 (definition of Light-Sport Aircraft) and 103.1 (Ultralight Vehicle), to permit the development of electric motors and their required battery packs as a viable alternative to fossil-fuel-powered reciprocating aircraft engines*, FAA-2008-0501, Apr. 24, 2008 ("E-Motor Petition"), *available at* <www.regulation.com>, and <http://tinyurl.com/58vpet> (EAA has sought regulatory exemption to permit LSA and ultralight use of electric motors and ASTM E-motor standard).

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211 Ron Gremban, Tech. Lead, The Cal. Cars Initiative, *Hybridizing Light Aircraft*, Presentation at the Cafe Foundation's Electric Aircraft Symposium, in San Francisco, Apr. 26, 2008, *available at* <http://cafefoundation.org/v2/pdf_pav_electricaircraft/2008/ron.gremban.hybridizing.light.aircraft.pdf>.

212 *See, e.g.*, MIT, Laboratory for Electromagnetics and Electronic Systems, *Carbon Nanotube Enhanced Ultracapacitors*, *at* <http://lees.mit.edu/lees/ultracapacitors.htm>.

213 Email from David J. Bents, Glenn Research Center, NASA, July 17, 2008.

214 Carey W. King & Michael E. Webber, *The Water Intensity of the Plugged-In Automotive Economy*, ENVIRON. SCI. TECH, Feb. 20, 2008, *available at* <http://pubs.acs.org/cgi-bin/sample.cgi/esthag/2008/42/i12/html/es0716195.html> (more than three times the water consumed and over seventeen times water withdrawn than used by petroleum – "widespread shift to grid-based transportation would be substantial enough to warrant consideration for relevant public policy decision-making." *id*.).

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219 D.J. Bents, et al., *Propulsion System for Very High Altitude Subsonic Unmanned Aircraft*, SAE Transactions 1998, Proc. SAE Aerospace Power Systems, NASA TM 1998 206636, in Williamsburg Va.,

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Apr. 21-23, 1998; Email from David Bents, July 21, 2008 ("It becomes a much harder problem at high altitude because of the air density lapse . . . air density is reduced 50 percent for every 15 knots of altitude . . . so although OAT is dropping as you climb, the air mass available to dissipate heat to is dropping even faster. That means you have to have bigger inlets and ducts, more heat exchanger surface area etc.").

[220] E-Motor Petition, *supra* note 209, at p. 6 (Also asserting that it expects to see type-certified recreational and GA aircraft within 5 to 10 years. *id.* at p. 8).

[221] Interview with Earl Laurence, VP Industry and Gov't Affairs, EAA, in Marysville, Cal, June 7, 2008 (also noting that since most recreational aircraft "sit around so much," they can be charged for the duration by windmill or solar cells.").

[222] ASTM F37, *at* <http://www.astm.org/COMMIT/COMMITTEE/F37.htm> (developing, in part, an international standard for electric-motors, and possibly electric controllers).

[223] *See* Horizon Fuel Cell, *at* <http://www.horizonfuelcell.com/aerospace.htm> (describing a record-breaking hydrogen cell powered UAV flight of 310 miles).

[224] Martin G. Schultz et al., *Air Pollution and Climate-Forcing Impacts of a Global Hydrogen Economy*, SCIENCE, Oct. 24, 2003 (claiming a 50% reduction in anthropogenic emissions of NO_x), *available at* <http://www.sciencemag.org/cgi/reprint/302/5645/624.pdf>.

[225] Email from David J. Bents, Ph.D., Glenn Research Center, Mar. 27, 2008 ("The biggest technical challenge is power density and energy density – neither are competitive with 'conventional' air breathing aeropropulsion."); James Dunn, Adv. Tech. Products, *Fuel Cell Electric Aircraft –Energy Challenge*, Presentation at the Electric Aircraft Symposium, CAFE Foundation, in San Francisco, Cal., May 23, 2007, *at* <http://cafefoundation.org/v2/pav_eas_2008.php> (claiming an energy density of "2-3X battery density").

[226] Herbert W. Cooper, *Fuel Cells, the Hydrogen Economy and You*, CHEMICAL ENGINEERING PROGRESS, Nov. 2007, at p. 34, *available to members at* <www.aiche.org/cep>. Cooper's article is based upon a corresponding paper, *available at* <www.dynalytics.com>. *See generally* Fuel Cells, *at* <http://www.fuelcells.org/>.

[227] Ryunosuke Kikuchi, *Penetration of hydrogen-based energy system and its potential for causing global environmental change: Scoping risk analysis based on life cycle thinking*, SCIENCEDIRECT (Sept. 2005), *at* <http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V9G-4H5MYBC-2&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=e4aef578475fb12a360304ca7a01fb64> (stating possibility of escaping (vaporizing) hydrogen could contribute to depletion of stratospheric ozone, and cause temperature and hydrides cycle change).

[228] Boeing, New Release, *Boeing Successfully Flies Fuel-Cell Powered Airplane*, Apr. 3, 2008, *available at* <http://www.boeing.com/news/releases/2008/q2/080403a_nr.html>, and <http://video.boeing.com:8080/asx_external/events/fuel_cell_powered_airplane_56.asx> (video of first flight); Liz Moscrop, *Across the Pond #3: Fuel-Cell Planes and More VLJs*, AVWEB, Apr. 25, 2007, *at* <http://www.avweb.com/news/acrossthepond/across_the_pond_fuel_cell_194954-1.html>. *See* Robert Wall, *Energy Exploration*, AVI. WEEK & SPACE TECH., Apr. 28, 2008, at p. 45 (describing various future commercial aircraft applications to include: running galley or inflight entertainment systems, taxiing of aircraft, lavatory water, and fuel-inerting systems).

[229] *Id.* [Boeing]

[230] Cooper, *supra* note 226, at p. 34. *See* David L. Daggett et al., Boeing Commercial Airplane et al. *Alternative Fuels for use in Commercial Aircraft*, Boeing Co. (2007), at p. 1, *available at* <http://www.boeing.com/commercial/environment/pdf/alt_fuels.pdf> ("50-plus year horizon"). *Cf.* Romeo Giulio, Prof. of Airplane Design and Aerospace Structures, Turin Polytechnic Univ., *quoted in First fuel-cell powered, manned aircraft to be designed in EU*, WHAT'S NEW IN SCIENCE AND TECH., July 5, 2007, *at* <http://www.whatsnextnetwork.com/technology/index.php/2007/06/05/first_fuel_cell_powered_manned_ai

rcraft> ("Hydrogen and fuel cell power technologies have now reached the point where they can be exploited to initiate a new era of propulsion systems for light aircraft and small commuter aircraft."); Blake A. Moffitt, Thomas H. Bradley et al., *Design Space Exploration of Small-Scale PEM Fuel Cell Long Endurance Aircraft*, 6th Am. Inst. of Aeronautics and Astronautics Aviation Technology, Integration and Operations Conf., Sept. 25-27, 2006, in Witchita, Kan., *at* <http://www.prism.gatech.edu/~gtg406v/ATIO_v3.4.2pdf.pdf>.

[231] Email from David J. Bents, Ph.D., Glenn Research Center, Mar. 27, 2008.

[232] John Botti, CTO, EADS, *quoted in* Robert Wall, *Sketching the A30X*, AVI. WEEK & SPACE TECH., Feb. 4, 2008, at p. 40, *available to subscribers at* <www.aviationweek.com/awst> (characterizing fuel cell APUs as "a very strong contender"); Airbus Letter, *Emissions Free Power for Civil Aircraft*, Jan./Feb. 2008, at p. 2, *at* <http://www-org.airbus.com/store/mm_repository/press_kits/att00005531/media_object_file_AirbusLetter_JanFeb08_EN.pdf> (Airbus and Michelin completed fuel cell test in A320 used to generate 20 kW electricity and operate hydraulic pump); *see* Glenn Research Center, Propulsion Systems Division, Combustion Branch, *Hydrocarbon Reformer*, *at* <http://www.grc.nasa.gov/WWW/combustion/zReformer.htm> (transforming Jet A fuel into syngas for aircraft fuel cell APU application).

[233] *Future Aviation*, ASIAN AIRLINE AND AEROSPACE, July 2007, *available at* <http://www.adprconsult.com.my/Articles/AAA_Jul07_CoverStory.pdf>.

[234] *See* NASA, *Solar-powered Gossamer Penguin in flight*, *at* <http://www.dfrc.nasa.gov/Gallery/Photo/Albatross/HTML/ECN-13413.html>.

[235] NASA, *Solar-Powered Research and Dryden*, *at* <http://www.nasa.gov/centers/dryden/news/FactSheets/FS-054-DFRC.html>; and <http://www.solarimpulse.com/en/challenge/index.php?idContent=18&idIndex=7> (presenting a brief history of solar-powered aviation).

[236] *See generally* NASA, *NASA Pathfinder Solar-Powered Aircraft*, *at* <http://www.nasa.gov/centers/dryden/news/FactSheets/FS-034-DFRC.html>.

[237] SolarImpulse, *at* <http://www.solarimpulse.com/en/index.php>; Lisa Airplanes, *at* <http://lisa-airplanes.com/uk/innovation/electric-flight.php> (trans-oceanic solar-hybrid powered). *See* Trina Solar Ltd., *Trina Solar to Provide Photovoltaic Cells for Hy-Bird: The First Airplane to Fly Around the World Using Only Renewable Energies*, July 14, 2008, *at* <http://www.trinasolar.com/front/en/news.php?newid=73> (cooperative agreement with Lisa Airplanes to supply solar cells to power fuel cell and electric engine).

[238] DARPA, Tactical Tech. Office, *at* <http://www.darpa.mil/ucar/programs/vulture.htm > (describing the Vulture program).

[239] David Esler, *Alternative Fuels for Jet Engines*, AVI. WEEK & SPACE TECH., *quoting* Tim Held, GE, Sept. 17, 2007, *available at* <http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=bca&id=news/bca0907p3.xml>.

[240] Telephone Interview with Owen Busch, VP Supply, AvFuel, June 12, 2008 (The avgas supply chain is composed of disparate parts that require coordination; distribution points are fragmented and multimodal – if interruption, there is variability of supply. Capacity constraints (e.g., shortages during the summer of 2007) resulted from rail limitations).

[241] *See* Commentary to AMCC V.a (on environmental regulation), *at* <http://www.secureav.com/Comment-AMCC-V.a-Environmental.pdf>; *see infra* text accompanying notes 680-721 (describing gaseous emissions regulations).

[242] *See infra* text accompanying notes 406-481 (describing such incentives).

[243] European Commission, Joint Technology Initiative (Clean Sky), *at* <http://ec.europa.eu/research/transport/info/jti_en.html> (promulgated by the Advisory Council for

Aeronautical Research, and includes the goal of moving technologies closer to market). *See* Advisory Council for Aeronautics Research in Europe (ACARE), *The Challenge of the Environment*, *available at* <http://www.acare4europe.org/docs/es-volume1-2/volume2-03-environment.pdf>; and Chris Kjelgaard, *Europe Launches New Aviation Research Program*, SPACE.COM, Oct. 19, 2007, *at* <http://www.space.com/businesstechnology/071019-european-aviation-research-projects.htm>.

[244] *At* <http://ec.europa.eu/research/transport/projects/article_5114_en.html>. *See* Robert Wall et al., *Europe Pushes Green Technology Research Forward*, Feb. 8, 2008, *at* <http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=comm&id=news/CLEAN02088.xml>. *But see* James Canter, *Europeans Reconsier Biofuel Goal*, N.Y. TIMES, July 8, 2008, at p. C1, *available* at <http://www.nytimes.com/2008/07/08/business/worldbusiness/08fuel.html?ref=business> (describing "a major about-face").

[245] *See Transatlantic Plan to Cut Aircraft Emissions Lifts Off*, ENVIRONMENTAL NEWS SERVICE, June 18, 2007, *at* <http://www.ens-newswire.com/ens/jun2007/2007-06-18-04.asp>; FAA Managers Ass'n, *Clean AIRE and Green*, MANAGING THE SKIES, Sept./Oct. 2007, at p. 6, *available at* <http://www.faama.org/files/mts_issues/MTS0907.pdf> (AIRE described as "the First Large-Scale Green Initiative Joining Players from Both Sides of the Atlantic," which "fits in with the cooperation protocol signed by the Commission and the FAA to coordinate two major programs on air traffic control infrastructure modernization, Single European Sky ATM Research (SESAR) in Europe and NextGen in the US." *id*.). *See* EU, Air Transport Portal of the European Commission, *at* <http://ec.europa.eu/transport/air_portal/traffic_management/environment/aire_en.htm>, and EU, *EU Commission and FAA Launch Transatlantic Action Plan to Cut Emissions*, June 18, 2007, *at* <http://www.eurunion.org/news/press/2007/2007071.htm> (describing AIRE); SESAR – European Consortium – The "operational" part to the legislative packages of the Single European Sky (proposing a new approach to reform the ATM structure in Europe), *at* <http://sesar-consortium.aero/phase1.php>; and EC, Single European Sky ATM Research, *at* <http://ec.europa.eu/transport/air_portal/sesame/index_en.htm>.

[246] National Plan for Aeronautics Research and Development and Related Infrastructure [Hereinafter *Plan*], *available at* <http://www.aeronautics.nasa.gov/releases/aero_rd_plan_final_21_dec_2007.pdf>. *See* NASA, Press Release, *President Bush Approves National Plan For Aeronautics Research And Development And Related Infrastructure*, Dec. 21, 2007, *available at* <http://www.aeronautics.nasa.gov/releases/12_21_07_release.htm>.

See Exec. Order No. 13419, *National Aeronautics Research and Development* (Dec. 20, 2006), *available at* <http://www.aeronautics.nasa.gov/releases/exec_order_for_aero_policy_dec_2006.pdf>; Nat'l Science and Tech. Council, Office of Science and Tech Policy, *National Aeronautics Research and Development Policy*, Dec. 2006, *available at* <http://www.ostp.gov/pdf/nationalaeronauticsrdpolicy06.pdf> (preceded the current policy, above).

[247] Co-chaired by the Office of Science and Technology Policy <http://www.ostp.gov/>, and NASA.

[248] *Plan supra* note 246, at pp. 28-30. *See* NASA, *Fact Sheet for National Plan for Aeronautics Research and Development and Related Infrastructure, Description of the Plan* (Dec. 2007), *available at* <http://www.aeronautics.nasa.gov/releases/aero_rd_plan_press_fact_sheet_21_dec_2007.pdf>. *See* Editorial, *U.S. Should Follow Europe's Clean Sky Example*, Editorial, AVI. WEEK & SPACE TECH., Feb. 4, 2008, at p. 58, *available to subscribers at* <www.aviationweek.com/awst> (suggesting that the US aerospace industry should seek an American version of the EU's Clean Sky initiative for both environmental and competitive reasons).

[249] *Plan*, *supra* note 246, at p. 1.

[250] Gerald L. Dillingham, Ph.D., Dir. Physical Infrastructure Issues, US GAO, Testimony Before the Subcommittee on Aviation, Committee on Transportation and Infrastructure, US House of Representatives, *Aviation and the Environment*, GAO-08-706T, May 6, 2008, at p. 14, *available at* <http://www.gao.gov/new.items/d08706t.pdf> (further explaining that "Improving the scientific

understanding of aviation emissions can help guide the development of approaches to reducing emissions by improving aircraft manufacturers' and operators' and policy makers' ability to assess the environmental benefits and costs of alternative policy measures." *id.*).

[251] Members include the Aerospace Industries Ass'n (AIA), ATA, FAA, and Airports Council Int'l-N. America (ACI-NA). *See* FAA, *CAFFI Fact Sheet*, Jan. 3, 2008, *at* <http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=10112>.

[252] The "five pillars" template reflects the US view of how to manage and reduce carbon emissions:

- Perform the necessary science to determine what needs to be solved;
- Accelerate improvements of existing operations procedures through agreements like AIRE;
- Accelerate the introduction of better emissions reducing technology;
- Quicken the US's Commercial Aviation Alternative Fuel Initiative;
- Implement market based measures to reduce pollution, like emissions trading.

Carl Burleson, Dir., FAA Office of Env't and Energy, *quoted in* Cathleen Cummins Mifsud, *Cleen AIRE and Green Skies Ahead?*, MANAGING THE SKIES, FAAMA, Sept./Oct. 2007, *available at* <http://www.faama.org/files/mts_issues/MTS0907.pdf>.

[253] Adopted May 24, 2006 by AIA/ATA/FAA-sponsored workshop with DoE, DoD, and NASA stakeholders, *at* <http://www.faa.gov/news/conferences_events/aviation_forecast_2007/agenda_presentation/media/9-%20Rich%20Altman.pdf>. *See* <http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=9433> (mentioning CAAFI's intended contribution to the FAA's broader environmental strategy), <http://www.faa.gov/news/conferences_events/aviation_forecast_2007/agenda_presentation/media/9-%20Rich%20Altman.pdf>, and <http://www.faa.gov/news/speeches/news_story.cfm?newsId=8988>.

[254] CAAFI, *Brochure, available at* <http://web.mit.edu/aeroastro/partner/caafi/caafi-descrip.pdf>.

[255] CAAFI *Brochure, id*. *See* Richard Altman, CAAFI, *Alternative Aviation Fuels Alphabet Soup, A Primer* (Jan. 21, 2007), *available at* <http://www.trbav030.org/pdf2007/TRB07_Altman-CAAFI.pdf>; Richard Altman, *Overview of Alternative Fuels and CAAFI*, Aviation and the Environment: A Primer for North American Stakeholders, *available at* <http://www.airlines.org/NR/rdonlyres/CA5FDDE7-1A65-4DD4-8A1C-4935EB6A48C9/0/13AltmanThurs845.pdf>.

[256] PARTNER Website, *CAAFI joins PARTER Board*, Jan. 14, 2008, *at* <http://web.mit.edu/aeroastro/partner/news/caafi-board.html>.

[257] Interview with Earl Lawrence, VP Regulatory Affairs, EAA, in Marysville, Cal. June 7, 2008.

[258] Telephone Interview with Curtis A. Holscraw, Mgr., Emissions Division, Office of Energy and Env't, FAA, Mar. 5, 2008 (speaking of FAA's initiatives for alternative fuels, "That's it [CAAFI] for FAA." *id.*).

[259] FAA, Aviation Policy, Planning & Env't**,** *at* <http://www.faa.gov/about/office_org/headquarters_offices/aep/>.

[260] FAA, William J. Hughes Technical Center, Unleaded Fuel Research Program, within the Airport and Aircraft Safety Research and Development Division, Airworthiness Assurance Research and Development Branch, *available at* <http://www.tc.faa.gov/its/cmd/visitors/data/AAR-430/unleaded.pdf>.

[261] *See* Mohan Gupta, Ph.D., Office of Env't & Energy, FAA, *PARTNER Research on Air Quality and Health Impacts due to Aviation-Related Air Pollutants*, Presentation at the ANERS 2007 Meeting, in La Baule, France, June 25, 20007, *available at* <http://www.faa.gov/about/office_org/headquarters_offices/aep/models/history/media/ANERS_health_impact.pdf>, <http://web.mit.edu/aeroastro/partner/>, and <http://web.mit.edu/aeroastro/partner/projects/project17.html> (Project 17, Alternative Fuels); PARTNER, *Emissions Characteristics of Alternative Aviation Fuels, at* <http://web.mit.edu/aeroastro/partner/projects/project20.html>; ICAO, CAEP, *Partnership For Air Transportation Noise And Emissions Reduction (Partner) Center Of Excellence Research Activities And*

International Collaboration, Information Paper, CAEP/7-IP/27, Jan. 24, 2007, *available at* <http://web.mit.edu/aeroastro/partner/reports/caep7/caep7-ip027-partneractivities.pdf> ("The group conducts basic research and engineering development to reduce uncertainties associated with aviation's environmental impact and prototype solutions to mitigate these impacts."). *See generally* Ian Waitz & Jessica Townsend et al., *Report to the United States Congress: Aviation and the Environment*, Dec. 2004, *available at* <http://web.mit.edu/aeroastro/partner/reports/congrept_aviation_envirn.pdf>. GAO: FAA Centers of Excellence are FAA partnerships with universities and affiliated industry associations and businesses throughout the country that conduct aviation research in a number of areas, including advanced materials, aircraft noise, and aircraft emissions. PARTNER is a cooperative research organization that includes 10 collaborating universities and approximately 50 advisory board members who represent aerospace manufacturers, airlines, airports, state and local governments, and professional and community groups.

262 *At* <http://web.mit.edu/aeroastro/partner/index.html>.

263 Dan Elwell, Ass't Admin'r for Avi. Policy, Planning and Env't, *A Primer for North American Stakeholders Administration*, Presentation at Aviation and the Environment*:* Mar. 19, 2008 ("Addressing environmental challenges is at the heart of the NextGen plan." *id*.).

264 Dan Elwell, Ass't Admin'r for Avi Policy, Planning, and Env't FAA, Before the House Transportation and Infrastructure Committee, Subcommittee on Aviation on Aviation Emissions, May 6, 2008, *available at* <http://www.faa.gov/news/testimony/news_story.cfm?newsId=10217> (in part, "focused on accelerating the maturation of lower energy, emissions.").

265 Bobby Sturgell, FAA Acting Admin'r, *ASPIRE To Green*, Presentation at the Aviation Leadership Summit, 2008 Singapore Air Show, Feb. 18, 2008, *available at* <www.faa.gov/news/speeches/news_story.cfm?newsId=10169>.

266 New Zealand Airlines, Press Release, *Airways New Zealand signs with US and Australia to reduce aircraft emissions*, Feb. 22, 2008, *available at* <http://www.airways.co.nz/about_Airways/_media/media_emissions2008.asp>.

267 FAA, Fact Sheet, *NextGen*, Feb. 14, 2007, *at* <http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=8145>. *See* JPDO Website, *at* <http://www.jpdo.gov/>.

268 Joint Planning and Development Office (JPDO), *at* <http://www.jpdo.gov/nextgen.asp>.

269 *See* FAA, JPDO, *Concept of Operations for the Next Generation Air Transportation System*, Ver. 2.0, at p. 7-1, June 13, 2007, *available at* <http://www.jpdo.gov/library/NextGen_v2.0.pdf>.

270 *Id.* [NextGen ConOps]

271 Dan Elwell, Ass't Admin'r for Avi. Policy, Planning and Env't, FAA, *Panel 2 Environmental Challenges for Aviation-A Panel Discussion*, Presentation at the FAA Forecast Conference, Mar. 10, 2008, in Wash., D.C., *available at* <http://www.faa.gov/news/conferences_events/aviation_forecast_2008/agenda_presentation/>.

272 JPDO, *NextGen in Brief*, at p. 7, *available at* <http://www.jpdo.gov/library/In_Brief_2006.pdf>.

273 Stephen A. Merrill, Aeronautics Innovation: NASA's Challenges and Opportunities, *at* <http://cafefoundation.org/v2/pdf_pav_tech/PAV.SATS.demographs/PAV.NRC.Report.NASA.Aero.pdf>.

274 NASA, *NASA and the Next Generation Air Transportation System*, June 26, 2007, *available at* <http://www.aeronautics.nasa.gov/docs/nextgen_whitepaper_06_26_07.pdf>.

275 Michael T. Tong & Scott M. Jones, NASA, Glenn Research Center, *An Updated Assessment of NASA Ultra-Efficient Engine Technologies*, ISABE-2005-1163 (2005), *available at* <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080002273_2008000933.pdf>.

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[276] *See generally* Glenn Research Center, Combustion Branch, Propulsion Systems Division, *at* <http://www.grc.nasa.gov/WWW/combustion/>; <http://www.nasa.gov/centers/glenn/research/power.html> (Power and Propulsion Office); Dan Bulzan, NASA Glenn Research Center, *Combustion*, Fundamental Aeronautics 2007 Annual Meeting, in New Orleans, La (Oct. 31, 2007), *available at* <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080003894_2008003839.pdf> (presenting an overview of emissions-related research).

[277] *At* <http://www.nasa.gov/centers/glenn/about/fs10grc.html>, and <http://www-psao.grc.nasa.gov/>.

[278] *See, e.g.*, Mark D. Moore, NASA Langley Research Center, *Electric Propulsion Enabled Advanced Air Vehicles*, Presentation at the Cafe Foundation Electric Aircraft Symposium, Apr. 26, 2008, *available at* <http://cafefoundation.org/v2/pdf_pav_electricaircraft/2008/mark.moore.eas2008.pdf>.

[279] Gerald L. Dillingham, Ph.D., Dir. Physical Infrastructure Issues, US GAO, Testimony Before the Subcommittee on Aviation, Committee on Transportation and Infrastructure, US House of Representatives, *Aviation and the Environment*, GAO-08-706T, May 6, 2008, at p. 23, *available at* <http://www.gao.gov/new.items/d08706t.pdf>.

[280] *See, e.g.*, Roger Drinnon, *C-17 uses synthetic fuel blend on transcontinental flight*, AIR FORCE LINK, *at* **<**http://www.af.mil/news/story.asp?id=123079891**>** ("The Air Force is taking a leadership role in testing and certifying the use of synthetic fuel in aircraft," Michael W. Wynne, Sec'y, USAF, *id*.).

Peak oil is a forecast date at which maximum worldwide oil production reaches its peak, with reduction in readily accessible sources of raw crude and increasing exploitation, production and transportation costs leading to a decline in total petroleum-products production afterward. *See* Int'l Energy Agency, *Medium Term Oil Market Report*, July 2008, *at* <http://www.iea.org/w/bookshop/add.aspx?id=402> (global oil supply failing to meet rising demand); Clifford Krauss, *Oil Demand to Grow Despite Prices, Report Says*, N.Y. TIMES, July 2, 2008, at p. C4, *available at* <http://www.nytimes.com/2008/07/02/business/02oil.html>.

[281] Dr. Theodore K. Barna, Ass't Dep'y Under Sec'y of Defense, Advanced Systems and Concepts, *OSD Assured Fuels Initiative* (2006), *at* <http://www.trbav030.org/pdf2006/265_Harrison.pdf>.

[282] *id*. at p. 19.

[283] DARPA Strategic Technology Office, *Biofuels* (July 5, 2006), *at* <http://www.darpa.mil/sto/solicitations/BioFuels/>.

[284] DoE, *About DOE*, *at* <http://www.energy.gov/about/index.htm>.

[285] DoE, *id*.

[286] Energy Information Agency, DoE, *at* <http://www.eia.doe.gov/environment.html>.

[287] *See* Neil Rossmeissl, US DoE and Jay Keller, Sandia Nat'l Lab, U.S. DoE, Biomass and Biofuels Program, Presentation at the Cafe Foundation's Electric Aircraft Symposium, Apr. 26, 2008, *at* <http://cafefoundation.org/v2/pdf_pav_electricaircraft/2008/jay.keller.usdoe.pdf>.

[288] *See, e.g.*, CRC, Atmospheric Impacts, *at* <http://www.crcao.com/publications/atmosphereImpacts/index.html> (listing CRC environmental studies).

[289] CRC Website, *at* <www.crcao.com>.

[290] CRC, Unleaded AVGAS Development Group, *Mission Statement*, *available at* <www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&o=090000648027c336> (emphasis added); Clifford A. Moses, Fuels and Lubricants Tech. Dept., SW Research Institute, *Development of the Protocol for Acceptance of Synthetic Fuels Under Commercial Specification*, Final Report, Dec. 2007, prepared for Coordinating Research Council, *available at* <http://www.crcao.com/>.

[291] CRC, *Exec Summary, CRC Research Results, Unleaded High Octane Aviation Gasoline*, Apr. 24, 2008, at p. 3 (copy on file with author) (also providing a general update of CRC avgas developments).

[292] Adopted June 1969 by ASTM, *at* <http://www.astm.org/COMMIT/SCOPES/D02.htm>.

[293] *At* <http://www.astm.org/COMMIT/COMMITTEE/D02.htm>.

[294] *See* ASTM, Technical Committee D02.J0 on Aviation Fuels, *at* <http://www.astm.org/cgi-bin/SoftCart.exe/COMMIT/SUBCOMMIT/D02J0.htm?L+mystore+wqty1066+1201032458>; <http://www.astm.org/cgi-bin/SoftCart.exe/COMMIT/SUBCOMMIT/D02J0.htm?L+mystore+hqji8033+1204943690>, ASTM, *Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels, available at* <http://www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/REDLINE_PAGES/D6751.htm?E+mystore>.

[295] Cafe Foundation, *at* <http://www.cafefoundation.org/v2/aboutcafe_home.php>.

[296] *At* <http://cafefoundation.org/v2/pav_gatchallenge.php>; and <http://cafefoundation.org/v2/pav_gatchallenge_rules.php#greenprize> (Challenge details).

[297] *At* <http://cafefoundation.org/v2/pav_eas_2008.php>. Some of the recent developments noted at the conference included: feasibility and benefits of hybrid aircraft, wingtip propellers/wind turbines; nano-filament Li-ion battery (potentially offering a 10X improvement in specific energy and cost), and ultracapacitors. Email from Brian Seeley et al., Apr. 27, 2008.

[298] *At* <http://lindberghfoundation.org/media-resources/media-press-kit/foundation-backgrounder.html>; and <http://www.lindberghfoundation.org/contribute/contribute/participate-aviation-green-investment-program.html> (presenting its Aviation Green Investment Program).

[299] *See infra* text accompanying notes 382-384 (describing direct injector fuel nozzles research and development).

[300] Automotive X Prize Website, *at* <http://auto.xprize.org/>.

[301] X Prize Foundation Website, Press Releases, *at* <http://auto.xprize.org/auto/press-releases/rss>.

[302] *At* <http://www.xprize.org/future-x-prizes/energy-and-environment>.

[303] DoT, Volpe Center, *B—NEXTGEN Alternative Fuel Development Roadmap*, *at* <http://www2.fbo.gov/spg/DOT/RITA/VNTSC/DTRT57-08-R-20016/SynopsisP.html>. Other alternative energy prizes may be funded by the US Federal government. *See, e.g.*, DoT, *U.S. Transportation Secretary Peters Announces New Near and Longer Term Measures to Help Aviation Industry Struggling with High Fuel Costs*, DOT 96-08, July 10, 2008 <http://www.dot.gov/affairs/dot9608.htm> (FAA participation/funding of an X Prize competition for renewable alternative jet fuel); Brian Knowlton, *McCain seeks new energy approach*, INT'L HERALD TRIBUNE, June 24, 2008 (proposing creation of 300 million dollar prize to developer of breakthrough car battery technology).

[304] Roger Pielke, Jr. & Tom Wigley et al., *Commentary, Dangerous Assumptions*, NATURE, Apr. 2, 2008, *available for fee at* <http://www.nature.com/nature/journal/v452/n7187/full/452531a.html> (asserting that technical challenges are greater than anticipated). Nobuo Tanaka, Exec. Dir., Int'l Energy Agency, Press Release, *Now or Never - IEA Energy Technology Perspectives 2008 shows pathways to sustained economic growth based on clean and affordable energy technology*, June 6, 2008, *at* <http://www.iea.org/Textbase/press/pressdetail.asp?PRESS_REL_ID=263> ("technological transition on an unprecedented scale" required).

[305] *At* <http://www.baylor.edu/bias/index.php?id=111> (ethanol and other aviation alternative fuel).

[306] *At* <http://www.colostate.edu/features/clean-energy.aspx>.

[307] *At* <http://www.erau.edu/er/newsmedia/newsreleases/2008/biofuel.html> (aviation biofuel research within the Aviation Maintenance Department, College of Aviation; and a design project (analytical study)

by the Aerospace Engineering students-Propulsion Track–gas turbine engine design modified to optimize its operation when using biofuel.).

308 *At* <http://www.fcbt.gatech.edu/>.

309 *At* <http://www3.imperial.ac.uk/icept/ourresearchactivities>.

310 *At* <http://web.mit.edu/aeroastro/index.html>.

311 *At* <http://www.mcgill.ca/> (includes collaboration with Pratt & Whitney, Canada).

312 *At* <http://coe.mst.edu/>.

313 *See, e.g.*, <http://news.uns.purdue.edu/x/2008a/080623T-StanleyBiofuel.html>.

314 *At* <http://airquality.ucdavis.edu/pages/events/2007/aviation_presentations/index.html>; Univ. Cal., Davis, Flying Green Program, *at* <http://airquality.ucdavis.edu/pages/events/2008/flying_presentations/index.html>.

315 *At* <http://www.udri.udayton.edu/NR/exeres/E6E10C8B-08CB-4756-8A85-1CACD0426763.htm>.

316 *At* <http://www.undeerc.org/>. "The EERC's present activities for DARPA are focused on producing a drop-in compatible jet fuel that complies with the physical characteristics defined in the military specification MIL-DTL-83133E. . . . To date, we have been successful in producing a 100% bio-derived jet fuel from processing crop oil such that the resulting fuel meets the critical military specifications of JP-8 (Mil-DTL-83133E) as determined by the Air Force Research Laboratory at Wright-Paterson Air Force Base." Email from Chad Wocken, Research Mgr., EERC, Mar. 25, 2008. Additionally, EERC is developing and commercializing a "drop in" renewable jet fuel compatible with petroleum-derived Jet A-1 and/or JP-8; and now designing a 2-million-gallon-per-year renewable oil refinery capable of producing jet fuel, diesel fuel, gasoline, and naphtha, and securing a site and financing for building and operating the refinery. Email from Ted Aulich, Sr. Research Mgr., EERC, July 14, 2008.

317 (developing the EU's first hydrogen-powered aircraft).

318 Univ. of N. Dakota, Energy & Environmental Research Center, *at* <http://www.undeerc.org/centersofexcellence/nafl.aspx>.

319 Fuels and Combustion Research Laboratory, *at* <http://engine.princeton.edu/>, and <http://www.princeton.edu/~combust/database/other.html>; Hilary Parker, *Green skies: Engineer's work may reduce jet travel's role in global warming*, NEWS AT PRINCETON, Sept. 13, 2008, *at* <http://www.princeton.edu/main/news/archive/S18/96/92S56/index.xml> (describing the Next Generation Jet Fuel Project).

320 *At* <http://www.niar.wichita.edu/>.

321 For example, Pratt & Whitney's Biofuel Research Project, Press Release, *Pratt & Whitney Canada Leads Groundbreaking Biofuels Research Project*, July 13, 2008, *at* <http://www.pwc.ca/en/0_0/0_0_8/0_0_8_1_1_1.asp?id_news=496> (four-year project to assess biofuels, study their effect on engine component, develop appropriate technologies and design changes to accommodate them, and conduct tests comparing current jet fuels with biofuels); Telephone Interview with Sam Sampath, Ph.D., Mgr. & Sr. Fellow, Pratt & Whitney Canada, July 11, 2008 (underscoring that "biofuels, by definition, will improve [turbine] carbon footprint"); Pratt & Whitney's "Green Engine Program," Pratt & Whitney Canada Corp., *Imagine the Power* (undated brochure) ("designing engines with the environment in mind") (copy on file with author); Jayant Sabnis, Chief Engineer, Systems Analysis & Aerodynamics, P&W, *Green Engine Developments for Next Generation Aircraft*, Presentation at the UC Davis Symposium, *Aviation Noise and Air Quality*, in San Francisco, Cal. (2007), *available at* <http://airquality.ucdavis.edu/pages/events/2007/aviation_presentations/Sabnis.pdf>; Pratt & Whitney Canada, *Green, 2007, Making Blue Skies Greener* (copy on file with author) ("P&WC is investing $1.5 billion Cdn in research and development over the next five years to create its next generation of green engine technologies, with support from the Canadian government and through partnerships with leading

Canadian universities and research centres.") Pratt & Whitney, Press Release, *Pratt & Whitney Canada Brings Greener Engines to Market*, June 17, 2007, *available at* <http://www.pwc.ca/en/0_0/0_0_8/0_0_8_1_2_2.asp?id_news=45>; CFM, Press Release, *CFM Unveils New LEAP-X Engine*, July 13, 2008, *available at* <http://www.cfm56.com/press/news/cfm+unveils+new+leap-x+engine/441> (highlighting Ceramic Matrix Composite (CMC) technology and engine announcement); CFM, *CFM Successfully Tests Ester-Based Biofuel On Cfm56-7b Engine*, June 15, 2007, *at* <http://www.cfm56.com/index.php?level2=blog_viewpost&t=395> (CFM's joint venture between GE and Snecma - a division of the French aerospace company SAFRAN Group; James M. Guyette, Pres. & CEO, Rolls-Royce N. Am., Press Release, *Rolls-Royce wins $2.6BN Trent 1000 order from Virgin Atlantic and launches joint environment initiative*, Mar. 3, 2008, *available at* <http://www.rolls-royce.com/media/showPR.jsp?PR_ID=40618> ("We share a common agenda to address environmental issues, and the new environmental partnership will help speed up research and development into reducing carbon emissions."); Rolls-Royce, *Rolls Royce and the environment*, *at* <http://www.rolls-royce.com/rolls-royce-environment/faq.html> (describing a range of environmental initiaitaves); Lycoming, Advanced Technology Center, *at* <http://www.lycoming.textron.com/company/advanced-technology-center.jsp>.

[322] "The AOPA does not have a 'stated policy position' on aviation [environmental matters], but has a goal to have such a policy by the end of 2008." Telephone Interview with Melissa Rudinger, VP, Regulatory Affairs, AOPA, Mar. 7, 2008. Nonetheless, the AOPA has a long history of advocacy that includes environmental matters. *See, e.g.*, *supra* note 48 (Andrew Cebula's comment on behalf of the AOPA regarding TEL). Note that the Int'l AOPA (IAOPA) issued an "Environmentally Friendly Fuels" resolution, No. 23/6 (June 2008), *available at* <http://www.iaopa.org/policies-and-positions/resolutions.html> (providing "that although general aviation aircraft engine exhaust emissions on atmospheric pollution are minimal, IAOPA strongly supports the enhanced production of aviation gasoline and jet fuel containing environmentally friendly materials of biological origin that will meet aviation fuel standards."). The AOPA views environmental issues as one ot the two "next big challenges for both general aviation and for airports." Warren D. Morningstar, *Airports a tip priority, Boyer tells execs, quoting*, Phil Boyer, Pres., AOPA, AOPAOnline, July 14, 2008, *at* <http://www.aopa.org/advocacy/articles/2008/080717aaae.html>

[323] Air Transport Association, *at* <http://www.airlines.org/government/environment/> (presenting the ATA's environmental affairs). *See* James C. May, Pres. & CEO, Air Transport Ass'n, *The Commercial Airlines' Climate Change Commitment*, Statement before the House Select Committee on Energy Independence and Global Warming, Apr. 2, 2008, at p. 5, *available at* <http://globalwarming.house.gov/tools/assets/files/0467.pdf> ("ATA carriers have made a commitment to achieve an additional 30 percent systemwide fuel efficiency improvement through 2025, on top of prior improvements. That equates to an additional 1.2 billion metric tons of CO_2 saved – roughly equivalent to taking over 13 million cars off the road each year."); ATA, Press Release, *ATA Names Nancy Young as VP, Environmental Affairs*, June 26, 2007, *at* <http://www.airlines.org/news/releases/2007/news_06-26-2007.htm>.

[324] Air Transport Action Group (ATAG), *at* <http://www.atag.org/content/default.asp>. *See* <http://www.enviro.aero/Home.aspx> ("The only global industry association that brings together organizations and companies throughout the air transport chain . . . addressing the environmental challenges facing the industry." *id.*).

[325] (BBGA), *at* <http://www.bbga.aero/news.html> (describing BBGA's environmental initiatives).

[326] (EBAA), *at* <http://www.ebaa.org/content/dsp_page/pagec/currentissues> (proposing, *inter alia*, an exemption for business aviation from the EU's ETS based on its low level of emissions (<3% of aviation emissions) and small size; proposing a voluntary offset scheme, and the block purchase of emissions credits).

[327] The EAA has taken a leadership role in alternative fuels policy and standards development. *See, e.g.*, Earl Lawrence, VP, EAA, *An Update on Advocacy Issues*, EAA SPORT AVIATION, May 2008, at p. 21.

[328] GAMA, *at* <http://www.gama.aero/home.php> GAMA has authorized an "Environmental Committee" to focus on a broad range of environmental issues. *See* GAMA, Environment Committee, *at* <http://www.gama.aero/committees/committeeHome.php?commID=35>.

[329] (IATA), Environment Webpage, *at* <http://iata.org/whatwedo/environment> (IATA maintains an Environmental Committee, *at* <http://iata.org/workgroups/env.htm>, and an Alternative Fuels Project).

[330] (IBAC), *at* <www.ibac.org> (The IBAC has an Environmental Issues Work Group (EIWG). The IBAC claims that business aircraft are responsible for 0.04% of global man made emissions. IBAC Emissions Policy 30-5, Jan. 15, 2004, *at* <www.ibac.org/Library/policy2/30_5.htm>).

[331] (NATA), *at* <http://www.nata.aero/>. NATA has also established an environmental committee pursuing a "Climate Initiative" which includes carbon offsets and best management practices. *See generally* James K. Coyne, Pres., NATA, Statement of the Nat'l Air Transp. Ass'n before the Subcommittee on Aviation, Committee on Transportation and Infrastructure, U.S. House of Representatives, Hearing *on Aviation and the Environment: Emissions*, May 6, 2008, *available at* <http://www.aviationairportdevelopmentlaw.com/Coyne%20Written%20Comments.pdf>.

[332] *At* <www.nbaa.org>.

[333] Bryan Walsh, *Why Green is the New Red, White and Blue*, TIME, Apr. 28, 2008, at p. 46, *available at* <http://www.time.com/time/specials/2007/article/0,28804,1730759_1731383_1731363,00.html>. *See generally* Cleentech, *at* <www.cleantech.com>.

[334] FDEP & Embry-Riddle Aeronautical Univ., *Preflight Fuel Dumping* (brochure on file with author); Myles Accessories, *Detrimental Impact Study Of Aircraft Fuel Sampling and Year 2000 Followup Addendum* (1989, 2000), *at* <http://www.reidhillview.com/Lead_4_times_car_fuel.htm> (providing multiple derivations to support an average of 2,345,272 Gal. per year); Weslay Stagg, *quoted in* Dale Smith, *Busted! Pre-Flight Fuel Dumping Under Fire*, AVI. MAINTENANCE, June 2002, at p. 24.

Cf. James B. Burrows, Jr., *Private Analysis of the FAA's General Aviation and Taxi Activity Survey CY2000 Embry Riddle's Fuel Dumping Data* (2003) (copy on file with author) (analysis concluding: "Clearly the 3 million gallons a year number is based on a single analysis of one set of data and three highly suspect assumptions. When you make adjustments to correct for these assumptions you end up with a volume of disposed fuel that is a factor of 3.6 times less and [another data set] 22 times less. Clearly the true amount of fuel disposed of on the ground from preflight operations is way less then the commonly quoted 3 million gallon number." *id*.).

The National Academy of Sciences reports that: "[n]early 85 percent of the 29 million gallons of petroleum that enter North American ocean waters each year as a result of human activities comes from land-based runoff, polluted rivers, [and] *airplanes*." Nat'l Research Council of the Nat'l Academies, *Oil in the Sea III, Inputs, Fates, Effects* (2002) (emphasis added), *available at* <http://books.nap.edu/books/0309084385/html/R1.html#pagetop>.

[335] Jack Haun, ERAU, *Aviation Environmental Responsibility*, *supra* note 1 (aviation instructional video).

[336] A noninclusive list of aviation-based groundwater-polluting items includes: used oil, parts, washer fluid, sump fuel or waste fuel, non-empty aerosol cans, stripped paint residue, expired oxygen generators, alodine waste (brushes, wipes, swabs), any liquid in contact with chlorinated solvents used to clean parts, used oil filters, batteries and battery acid, used shop towels, hydraulic fluid, turbine wash residue, expired chemicals. DoT, Research and Special Programs Administration, Office of Hazardous Materials Safety, *available at* <http://hazmat.dot.gov/>.

[337] Some pilots and others assert that fuel discharges are not a material problem, pointing to a study concerning leaking underground fuel tanks that observes that microorganisms break down harmful chemicals. *See* David W. Rice et al., *Recommendations To Improve the Cleanup Process for California's Leaking Underground Fuel Tanks* (LUFTs) (UCRL-AR-121762 – report submitted to the Cal. State Water Resources Control Board (SWRCB), Underground Storage Tank (UST) Program) (Oct. 16, 1995), *available at* <http://www-erd.llnl.gov/library/121762.pdf>. Notwithstanding, considerable fuel from the

tarmac is carried by sewers and other mechanisms *that do not discharge underground*. And "the very high amount of lead in aviation gasoline easily kills microorganisms so there is no breakdown of harmful chemicals." Email from Lars Hjelmberg, Exec. Dir., Hjelmco Oil (Apr. 13, 2003).

[338] Some pilots urge that for small slop tanks, the combination of fuel and water can simply be allowed to evaporate. However, this practice releases hydrocarbons into the air. For larger slop tanks, more sophisticated remediation systems are required. Lars Hjelmberg describes fuel sumping equipment appropriate for small GA airports that uses a stainless steel drum with a funnel pipe and cap, a funnel separating water and dirt from the fuel, and a hand-driven fuel pump for the removal of clean fuel from the drum. Drainage fuel is filtered through the filter-funnel into the drum (which is closed when not in use). Periodically, fuel is returned to the main fuel farm using the hand pump or some other approved method. Email from Lars Hjelmberg, Exec. Dir., Hjelmco Oil (Oct. 19, 2002).

See generally DALE DE REMER, PH.D., AIRCRAFT SYSTEMS FOR PILOTS (Jeppesen Sanderson 1996), at pp. 91-94 (providing an overview of fuel contamination).

[339] Nevertheless, some airport communities have implemented responsive programs. *See, e.g.*, the Ventura County's Airport *Used Oil Collection Program*, *available at* <http://portal.countyofventura.org/portal/page?_pageid=827,1102055&_dad=portal&_schema=PORTAL&_calledfrom=2>. Some airport associations have taken initiatives to improve responsible fuel sampling. *See, e.g.*, Palo Alto Airport Ass'n, *GATS Jar Project*, *at* <http://www.paloaltoairport.aero/gats.htm>.

[340] Since it involves "operational issues," this is an airplane certification issue. Manufacturers should not design aircraft that impede environmentally safe fuel sampling. *For example:*

- New Piper Saratoga airplanes contain a fuel "strainer sump quick drain" that requires depressing a lever aft of the copilot seat to drain fuel ported from the aircraft's belly, which, as a practical matter, challenges environmentally safe fuel sampling.
- Mooney Aircraft have a gascolator fuel drain under the aircraft. To drain the fuel, one pulls on a lever located between the pilot and co-pilot seat. The drain is below the belly pan.
- Older Cessna 172s and 152s have a fuel sump drain lever by the dip stick under the engine cowl (below the front of the nose cowl), checking the fuel requires one to reach both the lever and the drain tube – a distance of forty or more inches.

High wing aircraft that require the pilot to use a ladder to sample and recycle sampled fuel back into its tanks also discourage good fuel practices. Also, manufacturers that supply small fuel sampling containers may promote undesirable behavior (encouraging pilots to spill or discard the samples on the ground). Such containers are not as effective as larger containers anyway, since they cannot hold a complete set of pre-flight fuel samples.

[341] *See* DALE DEREMER, PH.D., AIRCRAFT SYSTEMS FOR PILOTS (Jeppesen Sanderson 1996), at Ch. 6 (presenting an overview of good fuel sampling practices); FAA, AC 150/5230-4A, *Aircraft Fuel Storage, Handling, and Dispensing on Airports*, June 18, 2004, *available at* <www.faa.gov>, *also available at* <http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/165e9c832474d05886256edd006ceb58/$FILE/150-5230-4A.pdf>.

[342] Pilots are more likely to return larger samples to the tank if only to save on fuel costs, and less likely to pour larger samples on the ground because the perceived environmental impact is greater than with small samples. *See* Aviation Specialists, *at* <https://airsport.com/aviagear/merchant.ihtml?pid=84&lastcatid=75&step=4> (manufacturer of the GATS Jar).

[343] Guidance for jet fuel quality control at airports is covered by the Air Transport Ass'n *de facto* standard ATA-103. Relevant guidance from ATA-103 is not typically enforced, and there is not comparable GA guidance. "The [GA] industry has not pushed it [developing and adhering to fuel quality guidance]." Telephone Interview with Mickey Kellum, ExxonMobil Fuels Marketing Co., Jan. 15, 2008 (Kellum also mentioned the comparative superiority of jet fuel tank storage, "floating suction" in contrast to avgas tank

storage the latter of which "takes suction right off the bottom of the tank." He further observed that [FBO] customers tend to view water absorption units as "fail safe" *id.*). *See* Air Transport Ass'n, *ATA 103* (2006), *at* <http://www.airlines.org/products/pubs/product-detail.htm?Product=9>. *See generally* Core, Jet Fuel Storage Fuel Safety Practices, *at* <www.core-es.com/newsletter/aviationcodes.htm> and <www.hsac.org/RPs/2004-02.pdf> (suggested standard practices for jet fuel handing). *But see ATA Spec 103*, AIRPORT BUSINESS MAG. (Apr. 2001), *at* <http://www.airportbusiness.com> (presenting ATA 103 limitations, including that it "doesn't cover general or corporate aviation," but recognizing that it is "an important part of regular safety and maintenance procedures").

[344] This is particularly important when fueling during the early morning or evening, since daytime temperature increases will tend to result in discharged fuel. In addition, fumes from fuel run-off increase the risk of a hangar fire. Electrical equipment in hangars is not typically designed to prevent fuel vapor explosions.

[345] *Cf.* FAA, Airworthiness Standards, 33 C.F.R. § 67, *available at* <http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=6d56ea087534cb74ba589933f625314c&rgn=div5&view=text&node=14:1.0.1.3.16&idno=14> (fuel systems); FAA AC 34-1B, *Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes* (June 27, 2003), *at* <http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/e41add77de4b2080862570a6005b36ed/$FILE/AC34-1B.pdf>; US EPA, 40 C.F.R. § 87 [47 Fed. Reg. 58,462-58,472], *Control of Air Pollution From Aircraft and Aircraft Engines; Emission Standards and Test Procedures* (Dec. 30, 1982), at § 87.11 ("No fuel venting emissions shall be discharged into the atmosphere from any new or in-use aircraft gas turbine engine subject to this subpart."). *See* Bruce C. Jordan, *An Assessment of The Potential Air Quality Impact of General Aviation Aircraft Emissions*, US EPA, Office of Air Quality Planning and Standards, OMSAPC-78-1, June 17, 1977, at p. 35 (copy on file with author) ("evaporation losses during refueling may be significant").

Most GA aircraft have open-vented fuel systems. This means that the fuel tanks are vented to the atmosphere using a pipe originating from the top of the tank, to a "snifter valve" (anti-siphon valve) at the pipe's highest point, then out the bottom of the airframe or wing. Often, if the tank is filled to capacity, and the fuel expands as it warms while sitting on a hot ramp, fuel is forced out the vent tube. If the anti-siphon valve malfunctions, fuel may continue to siphon overboard, especially with flexible bladder-type tanks. The collapse of the flexible bladder keeps the fuel level at or above the venting point, causing fuel to continue to siphon until the tanks are nearly empty.

Anti-siphon valves are particularly susceptible to insect damage. Insects can crawl into the small spaces around these valves and die there from toxic fumes. Eventually, their bodies clog the valve by physically obstructing the valve. For example, Mud Dauber wasps often construct mud nests on or near the valves then abandon the hardened mud when fumes are detected. The result is the loss of considerable fuel which stains the tarmac, implicating the aircraft owner as the polluter. Solutions to this problem may include: (1) refraining from topping off the tanks until just prior to departure, and (2) ensuring the anti-siphon valves are inspected regularly for contamination and proper function. Pilots should learn how to check these valves, and check them periodically.

Closed fuel systems are not vented to the atmosphere. Instead, they are pressurized by some means. A pressurized-closed fuel system prevents vaporization at higher altitudes.

[346] However, that fueling procedures must conform to the requirements in the applicable aircraft Pilots Operating Handbook (POH).

[347] "Ground support equipment" may include piston-powered aircraft tows, pre-heaters, electrical generators, and HVAC units. Consider that the US EPA has proposed a standard to limit hydrocarbon emissions that evaporate from or permeate through gas cans starting with containers manufactured in 2009. It is expected that the new cans will be built with a simple and inexpensive inner coating and other minor modifications to comply with the proposed standards. EPA, *Control of Hazardous Air Pollutants from Mobile Sources*, Proposed Rule, 40 Fed. Reg. 15,804 (May 29, 2006), *available at*

<http://www.epa.gov/otaq/regs/toxics/420f06021.htm#gascan>. *See generally* US EPA, *Outdoor Air-Transportation: Gas Cans – Additional Information*, *at* <http://www.epa.gov/air/community/details/gascan_addl_info.html#activity3>.

[348] PVA- and nitrile-based gloves are recommended for their ability to prevent fuel absorption. Int'l Occupational Safety and Health Info. Centre Website, *at* <http://www.ilo.org/public/english/protection/safework/cis/products/safetytm/solann.htm> (such gloves should be at least 11 mil. thick). *See* Int'l Labour Org., *at* <http://www.ilo.org/public/english/protection/safework/cis/products/icsc/dtasht/_icsc14/icsc1400.htm> (describing dangers and handling of gasoline – including use of protective gloves).

[349] *See, e.g.*, US Army Petroleum Center, *Information Paper*, Subject: Fuel Ethanol (E85) AMSTA-LC-CJPL (71O), Apr. 24, 2001, *at* <http://usapc.army.mil> ("Protective gloves should be worn while handling E85 [ethanol] *or any petroleum product*." (emphasis added)).

[350] *See, e.g.*, Gov't of New Brunswick, Green Smart, *Handling Small Petroleum Spills, at* <http://www.gnb.ca/0009/0011-e.pdf>.

[351] *See supra* ***Alternative Fuels***, text accompanying notes 117-242.

[352] *See, e.g.*, Lycoming, *Service Instruction 1070N, Specified Fuels* (June 14, 2006), *available at* <http://www.lycoming.com/support/publications/service-instructions/pdfs/SI1070N.pdf> (listing approved engines for 91UL fuel).

[353] § 403; FLA. ADMIN. CODE, r. 62-710 and r. 62-730 (authorizing fines up to $10,000 per violation for dumping fuel); and 40 C.F.R. §§ 260 - 266, 268 and 279. *See* FLA. STAT ANN. ch. 403.727. *Violations, defenses, penalties, and remedies, available at* <http://www.flsenate.gov/Statutes/index.cfm?App_mode=Display_Statute&Search_String=&URL=Ch0403/Sec727.HTM>.

[354] The FDEP's *Hazardous Waste Inspection Report* (Aug. 20, 2001) complaintant's *Summary of Potential Noncompliance Items and Recommended Corrective Actions* stated:

> a. 40 C.F.R. 265.31 Maintaining and Operating a Facility
>
> Embry Riddle Aeronautical University, failed to minimize the possibility of fire, explosion, or any unplanned sudden or non-sudden release of hazardous waste to air, soil, or surface water which could threaten human health and the environment. Specifically, Embry-Riddle Aeronautical University failed to implement a procedure to prevent the release of aviation fuel after inspecting for contaminants.

[355] The Consent Order included a requirement that "6. Respondent must ensure that all employees and students are thoroughly familiar with proper waste handling and emergency procedures, relevant to their responsibilities during normal facility operations and emergencies." *FDEP vs. Embry-Riddle Aeronautical University*, OGC File No. 02-0168, EPA ID No. FLD981745177 (FDEP, Central Dist. 2002) (copy on file with author). A fueling practices video production by the University, entitled *Aviation Environmental Responsibility*, is available at <http://paloaltoairport.aero/AER.mpeg>.

[356] Consider, for example, the Aeronautica Civil de Venezuela (Venezuelan Civil Aeronautics Law) which states:

> Principle of Environment Preservation, Article 6: The environment will enjoy special protection regarding the effects that development of aeronautical activities may produce. Regulations dictate that the Aeronautical Protection and Maintenance Authority will be oriented to the adaptation and performance of the ruling judicial code and those methods and regulations recommended by specialized local and international organizations.
>
> The no compliance to this disposition will result in sanctions as stated in the present law and on those special laws that rule the matter.

Venezuelan Aeronautical Law, *available at* <http://www.gobiernoenlinea.ve/docMgr/sharedfiles/LeyAeronauticaCivil.pdf >. Note: "The last sentence of the Venezuelan Law pertains to the laws and regulation dictated by the Venezuelan Environment and Renewable Resources Ministry - something like the EPA in the US but with far more reach - and other international agencies. Later on, the same law states in its Article 146: 'Who in contravention with that already established in the technical regulation, pollutes an aerodrome or airport environment or surrounding areas, by any means or during the practice of any aeronautical activity or in connection with it, will be punished with three to five years of imprisonment'." Email from Tony Alvarez, Oct. 18, 2006.

[357] John King, King Schools, *Letter to the Editor*, BUS. & COMM. AVI., Jan. 2008, at p. 9, *available to subscribers at* <www.aviationweek.com/awst>.

[358] B.H. Carlson, U. Naval Academy, *Fuel Efficiency of Small Aircraft*, AIAA-80-1847, Paper presented at the AIAA Aircraft Systems Meeting, in Anaheim, Cal. (1980), at p. 1, *available at* <http://cafefoundation.org/v2/pdf_pav_tech/PAV.MPG.engines/AIAA.1980.1847.B.H.Carson.pdf> ("An objective observation is that aircraft are designed with a basic mismatch between the aerodynamics of the airframe and the amount of power required to realize its most efficient use, and that as a result, aircraft are operated in a wasteful fashion." *id*.).

[359] Andrew C. Revkin, *A Shift in the Debate Over Global Warming*, N.Y. TIMES, Apr. 6, 2008, at p. WK 3, *available at* <www.nytimes.com/2008/04/06/weekinreview/06revkin.html?_r=1&ref=environment&oref=slogin>.

[360] *See* Jeanne Yu, Dir. Environ. Performance, Boeing Comm. Airplanes, *Commitment to a Better Future*, Mar. 2007, *available at* <http://www.faa.gov/news/conferences_events/aviation_forecast_2007/agenda_presentation/media/7-%20Jeanne%20Yu.pdf> (Saving one pound of fuel means not emitting 3.1 lbs. of CO_2. Yu also parses environmental performance as follows: engine, aerodynamics, structures and materials, systems, air traffic management, and engine/airframe integration.). Note that the listed technologies are largely focused on reciprocating engines.

[361] *See* Airbus, *Getting to Grips with Fuel Economy* (July 2004), *available at* <http://www.iata.org/NR/ContentConnector/CS2000/Siteinterface/sites/whatwedo/file/Airbus_Fuel_Economy_Material.pdf> (surveying "significant operating variables that affect fuel economy"). *See generally* ICAO, Asia/Pacific Office, ICAO Special Implementation Project (Sip), Workshop On The Development Of Business Case For The Implementation Of Cns/Atm Systems, *Environmental Benefits Of Cns/Atm Systems*, SIP/2007-WP21 (Bangkok, July 23-27, 2007), *available at* <http://www.bangkok.icao.int/meetings/2007/sip_cnsatm/wp21.pdf> (surveying approaches and methods for calculating emissions).

[362] RITTRs expedite movement of IFR overflight traffic around or through certain congested terminal airspace via IFR-approved RNAV (initially GPS) equipment without reliance on terrestrial navigational aides or ATC. *Establishment of Area Navigation Instrument Flight Rules Terminal Transition Routes (RITTR)*, Charlotte, NC, Final Rule, 70 Fed. Reg. 34,649 (June 15, 2005) (effective Sept. 1, 2005), *available at* <http://www.lion.com/Reference_Library/FederalRegister/2005/June15/05-11760.pdf>. RITTRs provide more direct routing and thus less fuel burn. Telephone Interview with Paul Gallant, Airspace and Rules, Office of System Operations and Safety, FAA (Nov. 28, 2005).

[363] *See* FAA, *RVSM*, *at* <http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/enroute/rvsm/> (a domestic fleet fuel savings of 2 percent is estimated), Daniel K. Elwell, Ass't Admin'r, Office of Avi. Policy, Planning & Env't, FAA, *Statement before the Select Comm. On Energy Independence and Global Warming*, Hearing on Avi. Emissions, Apr. 2, 2008, at p. 4, *available at* <http://globalwarming.house.gov/tools/assets/files/0466.pdf> (3 million tons of CO_2 annually).

[364] FAA, *Concept of Operations for the Next Generation Air Transportation System, v2.0*, Joint Planning and Development Office (June 2007), *available at* <http://www.jpdo.gov/library/NextGen_v2.0.pdf>;

NextGen, Webpage, *at* <http://www.faa.gov/regulations_policies/reauthorization/>; Lourdes Maurice, Ph.D., Chief Scientist, FAA Office of Env't and Energy, Presentation at Women in Aviation, in San Diego, Mar. 14, 2008 ("Environment is at the heart of the [NextGen] plan.").

See Bruce Bunce, Pres. and CEO, GAMA, Press Release, *GAMA Calls for Focus on Air Traffic Modernization*, GAMA NEWS 08-4, Feb. 12, 2008, *at* <www.gama.aero/mediaCenter/pr.php?id=162> ("Achieving the Next Generation Air Transportation System (NextGen) objectives goes well beyond simply reducing congestion and air traffic delays," said Bunce. "It will bring tangible environmental benefits as well." *id*.). *See also* US DoT, *Fiscal Year 2009 Budget in Brief*, *available at* <http://www.dot.gov/bib2009/htm/EnvSte.html> (funding CLEAN – Continuous Low Energy, Emissions, and Noise Program with 10 million USD to "accelerate the introduction of quieter and cleaner technology in commercial fleets, and to initiate a NextGen Environmental Management System" *id*.).

[365] *E.g*, Applied Aeronautical Systems, Inc., Pilots Performance Advisory System, *at* <http://www.avionco.com/pdfs/aasi.pdf> (suggesting a 2-5% fuel burn savings).

[366] Ed McKenna, *Technology Lightens*, AVIONICS, Dec. 2007, at pp. 32-35, *available at* <www.avionicsmagazine.com>.

[367] Automatic Dependent Surveillance Broadcast system (ADS-B) allows pilots and ATC to view and control aircraft more precisely over a far larger area of the Earth's surface. Such precision and control can result in more flight patterns, thereby reducing fuel consumption and emissions while maximizing flight effectiveness. *See generally* ADS Technologies, Inc., *at* <http://www.ads-b.com/home.htm>; David Esler, *ADS-B's Impact on Business Aviation*, BUSINESS & COMM. AVI., Nov. 2007, at pp. 68-80 (recognizing enhanced operational efficiency and fuel savings), *available to subscribers at* <www.aviationweek.com/awst>.

[368] *See* Capt. Karen Lee, UPS Dir. Ops., *NextGen CDA's Solutions for Aviation Environmental Challenges – A Brave New World!*, Presentation at the 32nd FAA Aviation Forecast Conference, in Wash, D.C., Mar. 16, 2007, *available at* <http://www.faa.gov/news/conferences_events/aviation_forecast_2007/agenda_presentation/media/6-%20Karen%20Lee.pdf> (reporting 34% reduction in NOx below 3000 ft. and 250-465 lbs. less fuel burn/flight); David Hughes, *ATM Is No 'Silver Bullet,"* AVI. WEEK & SPACE TECH., Aug. 20/27, 2007, at p. 66, *available to subscribers at* <www.aviationweek.com/awst> (claiming that CDAs can save 10% of fuel used in descent); Wayne Rosenkrans, *ASD-B On Board*, AEROSAFETYWORLD, Nov. 2007, at p. 45, *available at* <http://www.flightsafety.org/asw/nov07/asw_nov07_p44-47.pdf> (describing "near-idle" power setting descent from the flight levels to the runway); UK, Dept. of Transport, *Arrivals Code of Practice*, at ¶ 42, *available at* <http://www.dft.gov.uk/pgr/aviation/environmentalissues/arrivalscodeofpractice/arrivalscodeofpractice> (CDAs can provide "valuable reduction in the amount of carbon dioxide and combustion by-products produced by each arrival." *id*.).

[369] *See* FAA, AC 90-101, *Approval Guidance for RNP Procedures with SAAARAC* (Dec. 15, 2005), *available at* <www.faa.gov>, *also available at* <http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/821aca6a248d6aea862570ed00536340/$FILE/AC90-101.pdf>. Capt. David Carbaugh, *Good for Business*, AEROSAFETYWORLD, Dec. 2007, at p. 12, *available at* <http://www.flightsafety.org/asw/dec07/asw_dec07_p11-15.pdf> (RPN-based fuel savings over a large fleet called "astonishing").

Advanced avionics for air traffic management (ATM) also make a compelling environmental proposition. It is widely believed that ATM globally could eliminate the claimed 12 percent inefficiency via technology integration and such that "halving ATM inefficiency by 2012 could save 35 million tonnes of CO2." George Marsh, *Europe's Green Pursuit*, AVIONICS, Mar. 2008, at p. 31, *available at* <http://www.avionics-digital.com/avionics/200803/?sub_id=DHUh7cKpJl1eF&folio=26>.

[370] Email from Todd Petersen, Feb. 28, 2008. *See* Email from Dave Atwood, FAA W.J. Hughs Technical Center, Propulsion and Fuel Systems Branch, Mar. 3, 2008 ("I have read and heard great things about water - alcohol injection in its ability to greatly reduce engine octane requirement. We have yet to test anything at our facility but may get a chance as we move into the next phase away from fuels and toward engine modifications. This could be very promising technology."). Note that all warbirds are certified for 91 octane fuel.

[371] BSFC is the weight of the fuel burned per hour to produce a given amount of brake horsepower in a reciprocating engine – expressed in lbs burned/hr.

[372] For example, the DeltaHawk® is designed to BSFC (brake specific fuel consumption) of .37 lb/hp/hr versus current avgas-powered aviation engine book BSFC of .59 lb/hp/hr at 75%, *at* <http://www.deltahawkengines.com/Brochure_Oshkosh_2003.shtml>.

[373] Paul Bertorelli, *Thielert Diesel Reliability: Mixed at Best . . . ,*" AVI. CONSUMER (Dec. 2007), *available to subscribers at* <www.aviationconsumer.com/issues/37_12/industrynews/5729-1.html>; Paul Bertorelli, *Flight Fuel Efficiency: Is Diesel Really Better?,* AVI. CONSUMER (Apr. 2008), *available to subscribers at* <http://www.aviationconsumer.com/issues/38_4/industrynews/5772-1.html>.

[374] *Cf.* Email from Thomas Turner, June 1, 2008 ("I teach a lot of LOP and don't think the savings are quite that impressive—instead, the savings are probably closer to 15% in most cases for an equivalent MP/RPM combination. Also consider the power loss with LOP vs. ROP [rich of peak] cruise settings—although fuel flow is reduced, time en route is increased. A Beech Baron, for instance, loses about 10 to 15 KTAS off high-power cruise if mixture is changed from 75F ROP to about 20F LOP. On longer flights the total fuel savings are less impressive than a simple comparison of the GPH suggests.").

[375] Email from Tom Ehresman, Mar. 1, 2008 (asserting that the reliability of FADEC in diesels will likely be comparable to gasoline engine FADEC systems).

[376] *See, e.g*., Aerosance, PowerLink FADEC, *available at* <www.fadec.com/overview.html>, and GAMI, PRISM (Pressure Reactive Intelligent Spark Management), *at* <www.gami.com/prism.html>. *See also* Rhett Ross, CEO, TCM, Interview by Paul Bertorelli, AV. CONSUMER, Feb. 18, 2008, *at* <http://www.avweb.com/podcast/podcast/197170-1.html> (FADEC "affords the potential to extend maintenance intervals, it affords the potential to make 100 hr and annual inspections much easier. . . . And it affords the potential to extend the TBO on engines." *id.*).

Peter A. Bedell, *Controlling tomorrow's powerplants*, AOPA PILOT, June 2000, *available at* <www.aopa.org/pilot/features/future0006.html> (surveying FADEC products); Liberty Aircraft, FADEC, *at* <http://www.libertyaircraft.com/airplane-liberty-xl2/7-engine.php>. *See* Fred George, *How They Work: Turbine Engine Fuel Controls,* BUS. & COMM. AVI., Nov. 2007, at pp. 38-41 (describing development of three progressively sophisticated and capable turbine engine fuel controls: hydromechanical fuel control units, supervisory electronic engine controls, and most recently, FADEC).

[377] Aerosance, PowerLink FADEC, System Overview, *at* <http://www.fadec.com/overview.asp> (claiming up to 15% reduced fuel consumption).

[378] Bryan Lewis, Pres., Teledyne Continental Motors, *quoted in* THE SOUTHERN AVIATOR, *PowerLink™ FADEC System Installations Emerge*, July 30, 2003, *at* <www.southern-aviator.com/editorial/articledetail.lasso?-token.key=7606&-token.src=press&-nothing> ("PowerLink FADEC has the potential to provide long-term answers allowing the use of lower octane, unleaded fuels." *id.*); Rhett Ross, CEO, TCM, Interview by Paul Bertorelli, AV. CONSUMER, Feb. 18, 2008, *audiocast at* <http://www.avweb.com/podcast/podcast/197170-1.html> ("I think long term [FADEC] definitely will help [accommodate use of unleaded grade avgas]." "Roughly a 96 octane or trying to go to the mid or high-grade auto fuels like the 90-91 grades." "We are looking at how do we deal if we're forced down to an autogas grade in the 87/97 - 91/93 octane rating – and the variabilities you find in autogas." *id.*).

Cf. George Braly, Chief Engineer, GAMI, *Comment in response to EPA Docket No. OAR-2007-0294 Petition Requesting Rulemaking To Limit Lead Emission from General Aviation Aircraft; Request for*

Comment, Mar. 17, 2008, *available at* <http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&o=09000064803fc92b> ("If the industry were to move to a base unleaded fuel formulation that would consistently measure in the 98 MON range, then the fuel could be enhanced with minimal additional amounts of lead. These levels would be smaller levels than the existing 100LL fuels, but the fuel would still contain some amounts of lead. then the fuel could be enhanced with minimal additional amounts of lead.").

Telephone Interview with Bill Brogden, Teledyne Continental Motors, Feb. 29, 2008 (The use of unleaded and lower octane fuel with FADEC "is an issue that we do need to address and address formally.").

[379] Telephone Interview with Braly, *supra* note 62.

[380] However, the production of a 97-98 MON unleaded fuel faces challenges, such as providing adequate margins to ensure minimum octane in the fuel delivered downstream at the pump and into the aircraft fuel tank. Petroleum manufacturers would need confidence that they could guarantee this fuel's octane. Also, it would be somewhat more expensive fuel to manufacture. However the costs may be offset by reduced transportation expenses as a result of elimination of the TEL. Braly, *id*. *Cf*. Email from Lars Hjelmco, Pres., Hjelmco Oil AB, Feb. 15, 2008 ("We have both 95 MON UL fuels and 99+ MON fuels easy to produce and at no higher cost than current AVGAS and include CO2 neutral components.").

[381] Braly, *id*.

[382] For example, GAMIjectors, *available at* General Aviation Modifications, Inc., *at* <http://www.gami.com>.

[383] Tom Ehresman, *Spark Ignited Direct Injection Nozzle White Paper* (undated) (copy on file by author); Tom Ehresman, *Creating a Direct Injection Igniter Fuel Nozzle to Eliminate Use of Leaded Fuels in Existing High Power Density Aircraft Piston Engines*, Lindbergh Foundation, Funded Grant Projects: 2007, *at* <http://www.lindberghfoundation.org/grants/2007-funded-grants/ehresman-thomas.html>; Textron, News Release, *Inventor Tom Ehresman Awarded Lycoming Engines and the Lindbergh Foundation Grant to Focus on Eliminating Leaded Aviation Fuel* (July 25, 2007), *at* <http://phx.corporate-ir.net/phoenix.zhtml?c=110047&p=irol-newsArticle&ID=1035088&highlight>.

[384] Email from Tom Ehresman, Mar. 1, 2008.

[385] *See, e.g.*, LoPresti Speed Merchants, *at* <http://www.speedmods.com/lsm-mods.htm>, and Knots2U, Ltd., *at* <http://www.knots2u.com/> (offering various speed modifications for GA aircraft).

[386] *See generally* Fred George, *Piaggio Aero P180 Avanti II*, BUSINESS & COMM. AVI., Sept. 2007, at pp. 116-125 (describing the extensive development and use of laminar flow and other drag-reduction technologies and techniques).

[387] By reducing induced drag, winglets have produced fuel economies of up to 4-5 percent. Boeing, AERO No. 17, *at* <http://www.boeing.com/commercial/aeromagazine/aero_17/winglet_story.html>. Winglets also create a forward force on the aircraft. NASA, Langley Research Center, C-17 Fact Sheet, *at* <http://www.nasa.gov/centers/langley/news/factsheets/C-17.html>. Winglets reduce "spanwise flow" – "the higher pressure air underneath the wing [] trying to get to the lower pressure above. As it flows around the end of the wing and over the top we can see that it would flow outward on the bottom of the wing and inward at the top. The wing moves on and this flow circulates behind it, creating vortices." Ross Detwiler, *Aerodynamics to Go the Distance*, BUSINESS & COMM. AVI., Jan. 2008, at p. 51.

[388] Pierre Sparaco, *Go Green, Now*, Avi. WEEK & SPACE TECH., June 23, 2008, at 67.

[389] *See* Power Flow Systems, Inc., *at* <http://www.powerflowsystems.com/faqs.php#q12> (referencing fuel savings of 1.12 to 1.9 gallons per hour).

[390] *Are You Wasting Avgas?*, AVI. CONSUMER, Nov. 2005, at pp. 12, 32, *available at* <http://www.aviationconsumer.com/issues/35_11/misc/5497-1.html>. *See generally* ICAO Circular 303 – *Operational Opportunities to Minimize Fuel Use & Reduce Emissions* (Feb. 2004), *at* <http://www.icao.int/envclq/clq07/Presentations/McDonald.pdf>.

[391] Vern Raburn, CEO, Eclipse Aviation, *The New Eclipse 400*, Presentation, June 5, 2008, Aero-News Network, *at* <http://www.aero-news.net/images/content/commav/2008/AeroTV-Eclipse-ECJ-0308d_tn.jpg> ("Economy is going to become a byword in aviation—fuel economy.").

[392] Interview of Brian Seeley, Pres., CAFE Foundation, *Fuel Economy: We're Getting Serious Now*, AvWeb Audio News, Mar. 25, 2008, *available at* <http://www.avweb.com/podcast/podcast/197454-1.html> ("I think we're going to see a move toward aircraft that use less fuel, have smaller engines, and the trade off of very high horsepower high speed aircraft toward slower aircraft that have smaller engines and get better fuel economy, whether that be with avgas or biofuel."). Interview of Marc Cook, Editor, Kitplanes, by AvWeb Audio, *id.* ("We are moving in that general direction" (from speed to MPG as a primary consideration)). *Cf.* Vern Raburn, FAA, Presentation at the FAA Forecast Conference, *Panel 2 Environmental Challenges for Aviation-A Panel Discussion*, Mar. 10, 2008, in Wash., D.C. ("Just smaller is better" – "You burn a pound of Jet A, you produce 2.62 pounds of CO_2.").

[393] B.H. Carlson, U. Naval Academy, *Fuel Efficiency of Small Aircraft*, AIAA-80-1847, paper presented at the AIAA Aircraft Systems Meeting, in Anaheim, Cal. 1980), at p. 7, *available at* <http://cafefoundation.org/v2/pdf_pav_tech/PAV.MPG.engines/AIAA.1980.1847.B.H.Carson.pdf> (urging manufacturers to include supplemental operational data for optimal cruise performance).

[394] Jeff Van West, *Making it a Low-Cal ILS*, IFR, Jan. 2008, at p. 2. *See generally* IATA, *Guidance Materials and Best Practices for Fuel and Environmental Management*, Dec. 2004, *available at* <http://www.britflight.com/wingfiles/systems/fuelactionplan.pdf>.

[395] Scott McCartney, *Sparing Fliers Even Higher Airfares*, Wall St. J., June 6, 2006, at p. D4 (United Airlines has lowered cruise speed on some flights to achieve fuel savings.); *Like Motorists, Airlines Are Reducing Their Speed to Save Fuel Costs*, N.Y. Times, May 2, 2008, at p. C3, *available at* <http://www.nytimes.com/2008/05/02/business/02air.html> (including Southwest, Northwest, JetBlue, and American Airlines).

[396] Provided ample time is available for engine warm-up, airport conditions (such as weather and ramp grade) provide for safety, and aircraft engine procedures do not prohibit it. Also, lack of support and fire services should be considered.

[397] Do not interpret these recommendations to suggest ground operations should be rushed, that important safety checks (like engine run-up) be skipped/abbreviated, or that aircraft configuration or predeparture checks should be done while taxiing to the detriment of positional awareness, taxi safety and runway incursion avoidance. Safety remains more important than minute reductions in environmental impact.

[398] Managing fuel load requires, among other factors, that the pilot have confidence in the amount of fuel loaded, and the fuel flow of the aircraft.

[399] Of course, this suggestion must be tempered by safety considerations. Pilots should carry more fuel than required by legal minimums, particularly on cross-country flights and when anticipating flight in instrument meteorological conditions (IMC).

[400] Even airlines have reduced the number of magazines carried onboard. Scott McCartney, *Sparing Fliers Even Higher Airfares*, Wall St. J., June 6, 2006, at p. D4 (Alaska Airlines removed five magazines from each plane – saving $10,000 in fuel/yr).

[401] US EPA, *Procedures for Emission Inventory Preparation*, Vol. IV.: Mobile Sources, EPA420-R-92-009, Dec. 1992, at § 5.3.2.2, p. 192, *available at* <http://www.epa.gov/otaq/invntory/r92009.pdf> (A take-off using less than full power —sometimes of 90% or less—as a function of the worst-case operating conditions.). *See* Remy Gutierrez, Boeing, *Noise and Emissions Impacts of De-rated Engine Thrust*, Mar. 2008, *at* <http://airquality.ucdavis.edu/pages/events/2008/flying_presentations/GUTIERREZ.pdf> (contributing to lower NOx).

[402] *See, e.g.*, GAMI, *GAMI's Lean Test*, *available at* <www.gami.com/gamileannew.html>. *See also* Thomas P. Turner, *Leading Edge #17: Having a Say in Fuel Costs*, AvWeb, Apr. 28, 2008, *at*

<http://www.avweb.com/news/leadingedge/leading_edge_17_having_a_say_in_fuel_costs_197668-1.html>.

[403] Telephone Interview with Andrew DeMond, Pres., iFly, Apr. 15, 2008 ("We see really good fuel burn levels [using lean-of-peak operations] – a few gallons less per hour."). However, some FBOs with a mixed fleet (a fleet not fully engineered to accommodate LOP operations) may tend to discourage LOP operations due to risks of improper LOP procedures and non-uniform LOP training.

[404] "As a matter of customer service, and customer ease of use, rental arrangements are typically structured per "wet hour" (Hobbs). This allows the aircraft to be re-fueled as needed (not over-filled) by appropriately trained personnel with adequate safety equipment. The wet rate also promotes safer engine operation because wet-rate pricing does not incentivize renters to over-lean with high power settings. Moreover, with dry-rate schemes, most pilots will fuel the plane to the top, because any other system (fill to tabs, fill to 2 inches below the top, etc.) leaves some pilots feeling like they got the short end of the stick. So a post-flight accounting for a pilot's fuel usage results in overloaded aircraft with excessive fuel leaking onto the tarmac. Consequently, although the wet hour arrangement is thought to discourage fuel conservation, its benefits outweigh its down-side." Email from Josh Smith, Gen. Mgr., West Valley Flying Club, Feb. 12, 2008.

[405] *See* Paul C. Stern, *Toward a Coherent Theory of Environmentally Significant Behavior*, J. OF SOCIAL ISSUES, Fall 2000, *available at* <http://findarticles.com/p/articles/mi_m0341/is_3_56/ai_69391495> ("public policies can change the behaviors of many people and organizations at once"). *But see* Michael Fitzgerald, *Home Brew for the Car, Not the Beer Cup*, N.Y. TIMES, Apr. 27, 2008, at p. BU 5, *available at* <http://www.nytimes.com/2008/04/27/technology/27proto.html> ("There are plenty of consumers who want to reduce their carbon footprint and are willing to make an upfront investment to do it – consider the success of the Prius.").

[406] US Cong. Budget Office, *Preface, Policy Options for Reducing* CO_2 *Emissions*, Feb. 2008, *available at* <http://www.cbo.gov/ftpdocs/89xx/doc8934/toc.htm>.

[407] Daniel K. Elwell, Ass't Admin'r, Office of Avi. Policy, Planning & Env't, FAA, *Statement before the Select Comm. on Energy Independence and Global Warming*, Hearing on Avi. Emissions, Apr. 2, 2008, at p. 8, *available at* <http://globalwarming.house.gov/tools/assets/files/0466.pdf>.

[408] All grades of avgas (specified in ASTM D910 or military specification MIL-G-5572) are taxed by the U.S. at the rate of $ 0.194 per gallon, and kerosene at the rate of $ 0.244 per gallon. U.S. Internal Revenue Service, Fuel Taxes, *available at* <http://www.irs.gov/publications/p510/ch01.html#d0e2009>. *See generally* Wikipedia, *Aviation Fuel Taxes, at* <http://en.wikipedia.org/wiki/Fuel_tax#US_Aviation_Fuel_Taxes_.28Federal_Excise_Tax.29>. *Cf.* FAA, Current Aviation Excise Tax Structure pursuant to the Taxpayer Relief Act of 1997, *available at* <http://www.faa.gov/about/office_org/headquarters_offices/aep/aatf/media/Simplified_Tax_Table.xls> (updated 2/7/07 - stated avgas rate at 0.193/gal and jet fuel at 0.218/gal). Such taxes help fund the Airport and Airway Trust Fund, established pursuant to the Airport and Airways Revenue Act of 1970, 49 USC § 1742(a), later repealed and reestablished under the Tax Equity and Fiscal Responsibility Act of 1982, PL 97-248, Sept. 3, 1982, and other legislation. FAA, Airport and Airway Trust Fund, *at* <http://www.faa.gov/airports_airtraffic/trust_fund/>. See various versions of the *Airport and Airway Trust Fund Financing Bill of 2007*, HR 3539, US House of Representatives, *available at* <http://www.govtrack.us/congress/bill.xpd?bill=h110-3539> (proposing increases of avgas taxes from more than 19 to more than 24 cents per gallon, and jet fuel from more than 21 to more than 30 cents per gallon).

[409] For example, a $ 0.06 per gallon fuel tax in Wisconsin. Wis. Dept. of Revenue, *General Aviation Fuel Tax Information*, Apr. 2006, *available at* <www.dor.state.wi.us/pubs/mf-108.pdf>. California imposes an excise tax on jet fuel at $ 0.02 per gallon (21.9 cents /gal for noncommercial aviation jet fuel), and gasoline (incl. avgas) and diesel fuel at $ 0.18 per gallon. Cal. Energy Commission, *Transport Fuel Tax Rates for 2006*, *at* <http://www.energy.ca.gov/gasoline/fuel_tax_rates.html>. *See* Cal. Reg. 1101, *Motor Vehicle Fuel Tax Regulations*, *available at* <http://www.boe.ca.gov/sptaxprog/pdf/reg1101.pdf> (California

includes aviation gasoline as motor vehicle gasoline for tax purposes); AOPA, *Fuel Tax Refunds*, *at* <www.aopa.org/members/files/topics/fuel_refunds.html>.

[410] *See, e.g.*, David Morris, VP, Institute for Local Self-Reliance, *Green Taxes*, *at* <http://www.ilsr.org/ecotax/greentax.html>, Monica Prasad, *On Carbon, Tax and Don't Spend*, N.Y. Times, Mar. 25, 2008, *available at* <http://www.nytimes.com/2008/03/25/opinion/25prasad.html?em&ex=1206590400&en=c527510ca0d8803f&ei=5087%0A>.

[411] *See, e.g.*, Earth Policy Institute, *Selected Examples of Explicit Environmental Tax Reform Packages*, *available at* <http://www.earth-policy.org/Updates/Update14_data.htm>.

[412] NBAA, *The Fuel Tax – The Most Effective Payment System For General Aviation*, *at* <http://web.nbaa.org/public/govt/issues/fueltax.ph>. *Cf.* Telephone Interview with Henry Ogrodzinski, Pres. & CEO, Nat'l Ass'n of State Aviation Officials (NASAO), Feb. 28, 2008 ("Philosophically, NBAA isn't wrong. In most states though, you get a more straight forward view of "look, we need the money for the infrastructure. I don't know of any state that uses fuel taxes as an incentive or disincentive for flying. I don't know if the public policy of those taxes goes beyond maintaining and building infrastructure.").

[413] *See infra* text accompanying notes 478-480 (addressing impact of higher fuel prices).

[414] Lourdes Maurice, Ph.D., Chief Scientist, FAA Office of Env't and Energy, Presentation at Women in Aviation, in San Diego (Mar. 14, 2008).

[415] *See* US DoE, Energy Efficiency and Renewable Energy, Alternative Fuels & Advanced Vehicles Data Center, *State Incentives and Laws*, *at* <http://www.eere.energy.gov/afdc/progs/in_matrx.php> (cataloging incentives encouraging alternative fuel use and fuel conservation); IRS, *Fuel Tax Credits and Refunds*, Pub. 378, No. 46455F, Apr. 2005, *available at* <http://web.nbaa.org/public/ops/taxes/irsforms/p378_200504.pdf> (providing tax credits for alcohol and biodiesel fuel mixture production). *See also* The American Jobs Creation Act of 2004, PL 108-357 (biodiesel tax incentives); Volumetric Ethanol Excise Tax Credit, Energy Policy Act of 2005, *at* <http://www.eere.energy.gov/afdc/progs/view_ind_mtx.php/in/TAX/US/0> (tax credits for alternative fuel infrastructure – up to 30%).

[416] *E.g.*, OR Act, (Effective Jan. 1, 2008), *available at* <http://www.leg.state.or.us/07reg/measpdf/hb2200.dir/hb2210.en.pdf>. *See* <http://www.deq.mt.gov/Energy/bioenergy/Biodiesel_Production_Educ_Presentations/21Taxes_Mont_BIODIESEL_V_Olson_Nov2007.pdf> (Montana Biodiesel Production Incentive 15-70-601, Apr. 28, 2005 - ten cents/gallon tax incentive payable to biodiesel producers for increases in annual production for the first three years of production).

[417] David G. Victor & Danny Cullenward, *Making Carbon Markets Work*, Sci. Am., Dec. 2007, at pp. 70-77, *available at* <http://www.sciam.com/article.cfm?id=making-carbon-markets-work>. *See* Matthew L. Wald, *For Carbon Emissions, A Goal of Less Than Zero*, N.Y. Times, Mar. 26, 2008, at p. H7, *available at* <http://www.nytimes.com/2008/03/26/business/businessspecial2/26negative.html> (explaining that the response to global warming may require "carbon negative" rather than only carbon neutral – and that tax incentives may be needed to achieve it).

[418] US Cong. Budget Office, *Policy Options for Reducing CO_2 Emissions*, Feb. 2008, at ch. 2, *available at* <http://www.cbo.gov/ftpdocs/89xx/doc8934/toc.htm>.

[419] Editors, *Enough Hot Air Already*, Sci. Am., Dec. 2007, at p. 40, *available at* <http://www.sciam.com/article.cfm?id=enough-hot-air-already>. Perhaps a particularly heinous result would be a double taxation resulting from the imposition of both carbon taxes and carbon trading schemes. *See* Nancy Young, VP, Env't Affairs, Air Transport Ass'n, FAA, Presentation at the FAA Forecast Conference, *Panel 2 Environmental Challenges for Aviation-A Panel Discussion*, Mar. 10, 2008, in Wash., D.C. ("We are very concerned about [legislative] proposals that take money out of aviation. If you take

money out, then you take away our ability to make tech improvements. If you tax us/charge us and send our money to ExxonMobil, we'll have less money to do that.").

[420] *See* Martin Feldstein, *Tradeable Gasoline Rights*, WALL ST. J., June 5, 2006, at p. A10, *available at* <http://www.nber.org/feldstein/wsj060506.html> (proposing a system of tradable gasoline rights that would rely on market price for the TGRs. Unlike a gasoline tax which "lowers everyone's real income," the TGR "creates winners as well as losers." TGRs would "create an incentive to economize on gasoline [and provides] both an economic and a political advantage."). Prof. Feldstein believes that TGRs are viable for GA although he has "not thought through an explicit schedule." Email from Martin Feldstein, Harvard Univ. (June 5, 2006). The details of a tradable fuel rights program in the United States are not yet well-defined.

[421] Carbon and other environmental emissions are presented in Section IV (Airborne Emissions) of this Commentary to AMCC V.b.

[422] *See* ICAO, Environmental Unit, *Collected Voluntary Activities Against Global Warming* (Feb. 2007), *available at* <http://www.icao.int/icao/en/env/info_collected.pdf> (listing diverse voluntary efforts to reduce carbon emissions). *See also* ICAO, *Report on Voluntary Emissions Trading for Aviation*, Preliminary Ed. – Apr. 15, 2007, at p. 7, *available at* <http://www.icao.int/env/vets_report.pdf> (acknowledging that "[v]arious interpretations exist as to what is meant by voluntary emissions trading and specifically what is meant by the term *voluntary* and that in practice, voluntary mechanisms are generally combined with incentives").

[423] *Radiative forcing* is presented in *The Greenhouse Effect* in Part IV of this Commentary to AMCC V.b, in the text accompanying notes 583-586.

[424] *See* Development Brief No. 45, *The cost of air pollution abatement*, The World Bank, Jan. 1995, *available at* <http://www.worldbank.org/html/dec/Publications/Briefs/DB45.html> ("The highest abatement costs for a pollutant are often 10 times greater-and sometimes 100 times greater-than the lowest costs . . . these results suggest an important lesson. . . . Optimal regulation would attain the desired reduction in pollution while equalizing the marginal cost of abatement across sectors.").

[425] Telephone Interview with Jeffrey G. Witwer, Ph.D., President, Carbon Neutral Airplane, Apr. 1, 2008 ("Aircraft are already so efficient. Even an old Continental engine has a BSF consumption which is quiet low . . . so the marginal cost of offsetting aircraft is always less expensive by paying someone else to do it. It's just the cheapest way by far to do it.").

[426] *See generally* US EPA, *Cap-and-Trade Resources*, *at* <http://www.epa.gov/airmarkets/resource/cap-trade-resource.html>; US EPA, *Clean Air Markets*, *at* <http://www.epa.gov/airmarkets/index.html> (explaining cap and trade as "a market based policy tool for protecting human health and the environment"), ICAO, Air Transport Bureau, Environmental Unit, *Emissions Trading System*, *at* <http://www.icao.int/icao/en/env/EmissionsTrading.htm>; US Cong. Budget Office, *The Implications of Design Decisions for the Performance of Cap-and-Trade Programs*, June, 2001, *available at* <http://www.cbo.gov/doc.cfm?index=2876&type=0&sequence=3> (considering, *inter alia*, allocation allowances and the efficacy of ceilings).

[427] *See* Environmental Economics, *ECON 101: Carbon Tax vs. Cap-and-Trade*, *at* <http://www.env-econ.net/carbon_tax_vs_capandtrade.html> (distinguishing carbon tax and cap-and-trade policies); Jane Hupe, Chief, Environmental Unit, ICAO, citing CAEP/5, Economic Analysis of cost-effectiveness of Potential Market-based Options for Reduction of CO2 Emissions from Aviation, Jan. 2005, *available at* <http://www.icao.int/env/meetings/Giacc/ICAOCAEP.pdf> ("Open emissions trading was found to be the most economically efficient approach, as compared with taxes and charges and voluntary measures for meeting the specified targets and the only viable one capable of meeting the most stringent (Kyoto Protocol) emission reduction targets."). *Cf.* Andrew C. Revkin, *A Shift in the Debate Over Global Warming*, N.Y. TIMES, Apr. 6, 2008, *available at* <http://www.nytimes.com/2008/04/06/weekinreview/06revkin.html?ex=1365134400&en=83072b90ebe2935f&ei=5088&partner=rssnyt&emc=rss> ("…whatever benefits the cap approach yields, it will be too little

and come too late." *id.*); Tess Taylor, *A Clear Sense of Emission*, N.Y. TIMES MAG., Apr. 20, 2008, at p. 51, *available at* <http://www.nytimes.com/2008/04/20/magazine/20Act-t.html?pagewanted=1> (characterizing CO_2 equivalents as possibly "the most complicated currency on world markets today.").

See, e.g., The Chicago Climate Exchange, *at* <http://www.chicagoclimatex.com/> (North America's first and only voluntary, but legally binding, emissions-trading market). The cost of offsets has varied from about 3 cents, down to 2 cents, and is currently about 6 cents. The conversions factors work out such that the cost in cents per gallon, is roughly the same as cost in dollars per metric tons.). Taylor, *id.* at p. 51 (carbon trading a 30 billion market in 2008 – trading approximately 1.7 billion tons of CO_2).

[428] ICAO, *Report on Voluntary Emissions Trading for Aviation*, Preliminary Ed. – Apr. 15, 2007, at p. 7, *available at* <http://www.icao.int/env/vets_report.pdf>.

[429] Consider, for example, that the US EPA has issued an *Advanced Notice of Proposed Rule Making for Greenhouse Gases* under the Clean Air Act, *at* <http://www.epa.gov/regulations/documents/ail-epa-mar2008-20080415-corrected.pdf> (which includes aviation sources).

[430] *See* Anja Kollmuss, SEI-US & Helge Zink, Tricorona et al., *Making Sense of the Voluntary Carbon Market: A Comparison of Carbon Offset Standards*, WWF Germany, Mar. 2008, at pp. iv-v, *available at* <http://www.sei-us.org/wwf_offset_standards_execsum.pdf>.

[431] *See, e.g.*, US EPA, *Personal Emissions Calculator*, *at* <http://www.epa.gov/climatechange/emissions/ind_calculator.html>; and Sustainable Travel Int'l, *at* <http://www.sustainabletravelinternational.org/documents/op_carboncalcs.html>; Anja Kollmus et al., *Voluntary Offsets For Air-Travel Carbon Emissions: Evaluations and Recommendations of Thirteen Offset Companies*, Dec. 2006, *at* <http://www.geo.ucl.ac.be/Pacte/Rapport-ONG-compensationsCO2.pdf> (providing a survey of carbon offset companies and their calculators).

[432] See, for example, the following:

Advance Parking	*At* <http://www.cheap-parking.net/flight-carbon-emissions.php#form>
Carbon Fund	"CO_2 emissions in air travel vary by length of flight--ranging from .24 kg CO_2 per passenger mile for short flights down to .18 kg CO_2 per passenger mile for long flights. Our new calculator (as of April 2007) allows the user to take the issue of radiative forcing into account." *At* <http://www.carbonfund.org/site/pages/carbon_calculators/category/Assumptions/>
Climate Care	Dr. Christian N. Jardine, *Calculating the Environmental Impact of Aviation Emissions* (June 2005), *available at* <http://www.climatecare.org/media/documents/pdf/Aviation_Emissions_&_Offsets.pdf>
Climate Friendly	*At* <https://climatefriendly.com/flight>. Using an airt ravel GHG multiplier of 2.7, and implementing tools to calculate GHG provided by the Greenhouse Gas Protocol Initiative, *at* <http://www.ghgprotocol.org/calculation-tools/all-tools>
Conservation International	.0099 Tons of CO_2 per private jet flight mile. *At* <http://www.conservation.org/act/live_green/carboncalc/Pages/methodology.aspx>
EPA	Greenhouse Gas Equivalencies Calculator, *at* <http://www.epa.gov/cleanenergy/energy-resources/calculator.html> (provides a tool to help put emissions in perspective)
ICAO	*At* <http://www2.icao.int/public/cfmapps/carbonoffset/carbon_calculator.cfm>
Sustainable Travel Int'l	*At* <www.sustainabletravelinternational.org/offset_customers/op_carboncalcs_4.html>

433 Estimates are wide-ranging, but generally between 2 and 4 times that of CO_2 alone. IPCC, *IPCC Special Report-Aviation and the Global Atmosphere, Summary for Policymakers* (1999), § 4.4 at p. 7, *available at* <http://www.ipcc.ch/pub/av(E).pdf>.

434 *At* <http://www.climatecare.org/> (*ClimateCare*, now part of J.P. Morgan, has developed (arguably) supportable metrics for calculating aviation carbon emissions and offsets).

435 Susan Trumbore, U. of Cal. Irvine, *What is the weight ratio of CO2 released to fuel burned?*, SCI. AM., Feb. 12, 2008, *available at* <http://www.sciam.com/article.cfm?id=experts-weight-ratio-co2-fuel> (explaining the science resulting in a roughly 3 to 1 ratio of CO_2 produced per octane molecule burned).

436 "It is my experience . . . that environmental critics of offsetting do not like offsetting because they want to achieve ancillary changes to society through climate change concerns, e.g., development of solar energy, grounding of private jets (see www.planestupid.com), promotion of electric cars, etc. and offsetting does not directly achieve these other goals. Because I think offsetting is so essential to the future of GA, I am very cautious about repeating what I think are ill-informed and disingenuous criticisms of it." Email from Jeffrey G. Witwer, Ph.D., Pres., Carbon Neutral Plane, Apr. 1, 2008.

437 Eilene Zimmerman, *Undoing Your Daily Damage to the Earth, for a Price*, N.Y. TIMES, Nov. 11, 2007, at p. 5, *available at* <http://www.nytimes.com/2007/11/11/business/yourmoney/11carbon.html?_r=1&adxnnl=1&oref=slogin&adxnnlx=1197051057-ghiK2DKe+JOpnrpoqTUPiQ>. Others suggest that offsetting is better than doing nothing.

438 *Another Inconvenient Truth*, BUSINESSWEEK, Mar. 26, 2007, *available at* <http://www.businessweek.com/magazine/content/07_13/b4027057.htm>.

439 Elisabeth Rosenthal, *Lofty Pledge to Cut Emissions Comes With Caveat in Norway*, N.Y. TIMES, Mar. 22, at p. 1, *available at* <http://www.nytimes.com/2008/03/22/world/europe/22norway.html?ex=1363924800&en=396a7f4a207c20a4&ei=5088&partner=rssnyt&emc=rss>.

440 Rosenthal, *id*.

441 Voluntary Carbon Standard, World Business Council for Sustainable Development, *at* <http://www.v-c-s.org/about.htm>; Voluntary Carbon Standard, 2007, *at* <http://www.v-c-s.org/docs/VCS%202007.pdf>; The Gold Standard, *at* <www.v-c-s.org> ("ensures that carbon offsets that businesses and consumers buy can be trusted and have real environmental benefits." *id*.). *See* Carbon Fund, *at* <www.Carbonfund.org>, LiveNeutral, *at* <http://www.liveneutral.org/>, and Sustainable Travel Int'l, *at* <Sustainable Travel International>.

442 *See, e.g.*, Green-e Climate, Press Release, *Green-e Climate Begins Certification of Retail Carbon Offset Products*, Feb. 13, 2008, *at* <http://www.resource-solutions.org/where/pressreleases/2008/021308.htm>; American National Standards Institute (ANSI) *at* <http://www.ansi.org/conformity_assessment/accreditation_programs/greenhouse_gas.aspx?menuid=4> (presenting a new pilot accreditation program for the Greenhouse Gas validation/verification bodies – to operate per ISO 14065:2007). Applicable Standards/Protocols include:

- ISO 14064-1:2006 *Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals*
- ISO 14064-2:2006 *Greenhouse gases – Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements*
- The Climate Registry (TCR) Verification Protocol (currently under revision; final text expected prior to ANSI assessments of the applicant's program)

[443] *See* Louise Story, *F.T.C. Asks if Carbon-Offset Money Is Winding Up True Green*, N.Y. TIMES, Jan. 9, 2008, at p. C1, *available at* <http://www.nytimes.com/2008/01/09/business/09offsets.html?_r=1&ref=business&oref=slogin> (questioning where carbon-offset money is being used, Federal Trade Commission plans to investigate, and wide-spread acknowledgement of a need for greater scrutiny); FTC Chairman Deborah Platt Majoras, *Statement – Carbon Offset Workshop Opening Remarks*, Jan. 8, 2008, *available at* <http://www.ftc.gov/speeches/majoras/080108carbonow.pdf> (asserting that carbon offsets have "a heightened potential for deception"); Valerie Gibbons, *Brown calls on feds for carbon offset standards*, LEGALNEWSLINE.COM, Mar. 19, 2008, *available at* <http://www.legalnewsline.com/news/209421-brown-calls-on-feds-for-carbon-offset-standards> (Cal. Att'y Gen. Jerry Brown warnings of rampant fraud and abuse and calling on the US government to regulate carbon offsets.).

[444] UN, The KYOTO PROTOCOL TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (1998), *available at* <http://unfccc.int/resource/docs/convkp/kpeng.pdf>; and *UN Framework Convention on Climate Change Handbook* (2006), *available at* <http://unfccc.int/resource/docs/publications/handbook.pdf>. Clean Development Mechanisms provide "(b) Real, measurable, and long-term benefits related to the mitigation of climate change; and (c) Reductions in emissions that are additional to any that would occur in the absence of the certified project activity." *Id*. at Art. 12 (B) & (C). *See* UNFCC, Clean Development Mechanisms, *at* <http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php>; Commentary to AMCC V.a., *at* <http://www.secureav.com/Comment-AMCC-V.a-Environmental.pdf> (introducing the Kyoto Treaty).

[445] Claudia H. Deutsch, *Saving the Plant?, Not With My Money*, N.Y. TIMES, Mar. 26, 2008, at p. H2 (companies lost 0.9 percent of their market value after joining an industry environmental association or announcing environmental goals). Consider that "the market hasn't rushed to reward firms that are preparing for a future of Kyoto targets and carbon taxes." Gabriel Sherman, *Green on the Outside*, WIRED, April 2008, at p. 126, *available at* <http://www.wired.com/techbiz/it/magazine/16-04/bz_green>.

[446] Nat'l Ass'n of Mfgrs., *at* <http://www.nam.org/s_nam/sec.asp?CID=202493&DID=23620>. *But see* Nathaniel Koehane, Ph.D. & Peter Goldmark, Environmental Defense Fund, *What Will it Cost to Protect Ourselves from Global Warming?*, 2008, *at* <http://www.edf.org/documents/7815_climate_economy.pdf> ("In present-value terms, the median projected impact of climate policy on U.S. GDP is less than one-half of one percent for the period 2010-2030, and under three-quarters of one percent through the middle of the century." *id* at iv). *See* Int'l Monetary Fund, *Climate Change, the Environment and the Work of the IMF*, *at* <http://www.imf.org/external/np/exr/facts/enviro.htm> (includes links to IMF economic and policy papers on climate change).

[447] *See generally* Letter from 100 Scientists to Ban Ki-Moon, Sec'y Gen., United Nations (Dec. 13, 2007), *available at* <http://www.middlebury.net/op-ed/un-signatories.html> (urging that anthropomorphic global warming is unfounded, that the IPCC cease development of responsive and economically destructive restrictions, and that it is "irrational" to apply the "*precautionary principle*, because many scientists recognize that both climatic coolings and warmings are realistic possibilities over the medium-term future."). *See also* Proceedings of The 2008 Int'l Conf. on Climate Change, Mar. 2-4, 2008, in NYC, *available at* <http://www.heartland.org/NewYork08/proceedings.cfm>; S. Fred Singer, ed., *Nature, Not Human Activity, Rules the Climate, Summary for Policymakers of the Report of the Nongovernmental Int'l Panel on Climate Change*, 2008, the Heartland Inst., *available at* <http://heartland.temp.siteexecutive.com/pdf/22835.pdf>; *Editorial: The Great Global Warming Hoax?*, The Middlebury Community Network, *at* <http://www.middlebury.net/op-ed/global-warming-01.html>; Alfred Schack, Der industrielle Warmeubergang [The industrial heat transfer] (Verlag Stahleisen m.b.H., Dusseldorf, 1. Auage 1929, 8. Auage 1983), *quoted in* S, Fred Singer, *Global Warming - Scientific Controversies in Climate Variability*, Int'l Seminar at The Royal Institute of Tech. (KTH), in Stockholm, Sweden, Sept. 11-12, 2006, *available at* <http://gamma.physchem.kth.se/~climate/> (urging that water vapor is responsible for most absorption of the infrared radiation in the Earth's atmosphere; that the wavelength of the radiation absorbed by carbon dioxide is only a fraction of the entire infrared spectrum,

and that it does not change considerably by raising its partial pressure); Gerhard Gerlich & Ralf D. Tscheuschner, *Falsification Of The Atmospheric CO_2 Greenhouse Effects Within The Frame of Physics*, ver. 3.0, arXiv:0707.1161v3 [physics.ao-ph], Sept. 9, 2007, at p. 94, *available at* <http://arxiv.org/PS_cache/arxiv/pdf/0707/0707.1161v3.pdf> (denying an atmospheric greenhouse effect, in particular a CO_2-greenhouse effect in theoretical physics and engineering thermodynamics; and that it is thus "illegitimate to deduce predictions which provide a consulting solution for economics and intergovernmental policy." *id*.).

[448] Telephone Interview with Frank Hofmann, IAOPA Rep. to ICAO, May 1, 2008. Moreover, Kyoto Treaty CO_2 caps don't consider industry growth rates. *Cf.* Testimony by James C. May, Pres. & CEO, Air Transport Ass'n, Apr. 2, 2008, at p. 5, *available at* <http://globalwarming.house.gov/tools/assets/files/0467.pdf> ("Commercial jets are five to six times more fuel efficient than corporate jets. The math is simple: carrying 200 people and cargo across the country in a single plane burns a lot less fuel than 33 separate corporate jets, each flying six people.").

[449] Green Mountain Energy, Press Release, *Cerulean Jet First Private Charter Service to Offset Its Carbon Emissions*, Apr. 10, 2007, *at* <http://www.greenmountainenergy.com/>, and <http://www.greenmountainenergy.com/news/current_pr/2007/4_10_07.shtml> (*Green Mountain Energy Company* providing carbon offsets to GA, such as to Cerulean Jet, a major charter service). *See* Cerulean Jets, *at* <http://www.ceruleanjet.com/>.

[450] For example, *TerraPass* provides offsets to fractional owners, such as AvantAir. *See* Avantair, Press Release, *Fractional Operator Avantair Goes Green With TerraPass*, Aug. 15, 2007, *at* <http://phx.corporate-ir.net/phoenix.zhtml?c=207263&p=irol-newsArticle&ID=1040577&highlight=> (Avantair, a Florida-based fractional operator of the Avanti P.180 turboprop aircraft, provides each of its 300 fractional owners with carbon offsets for the next 5 hours of their aircraft use.).

[451] *At* <http://www.ecosecurities.com/> (*EuroSecurities* providing carbon-offsets to Netjets); Netjets, Press Release, *NetJets Europe Announces Comprehensive New Climate Initiative*, Sept. 13, 2008, *at* <http://www.netjetseurope.com/climate/>, and <http://www.prnewswire.co.uk/cgi/news/release?id=207113>:

> NetJets Europe is working with EcoSecurities . . . . The company is investing in Verified Emissions Reductions (pre-registration offsets) from Kyoto-level CDM registered projects to offset the carbon emissions of both the company and its clients. Particular care has been taken to ensure that the offset projects undertaken are genuinely additional under the definition introduced in Article 12.5 of the Kyoto Protocol. Only projects which achieve CO_2 reductions that would not have happened without carbon financing are certified under the Kyoto Clean Development Mechanism (CDM).
>
> At the heart of the emissions neutralizing initiative is a decision to include carbon offsetting in NetJets pricing as of October 1, 2007. All new clients and all existing customers who renew their contracts will purchase carbon credits that neutralise all the carbon emissions associated with their aircraft usage. Existing customers will also be encouraged to sign-up to the program and offset their flying immediately.

[452] *See, e.g.*, Angel City Flyers, Long Beach, Cal., *at* <http://www.angelcityflyers.com> (participating in Carbon Neutral, and claiming "that it is one of the most environmentally friendly flight schools in the nation").

[453] Carbon Neutral Plane, *at* <http://www.carbonneutralplane.com>.

[454] Bombardier, MARKETWIRE (Sept. 18, 2007), *at* <http://www.marketwire.com/mw/release.do?id=771070> (purchasing one-year's carbon offsets; "[N]ew aircraft buyers will have the option to take part in a carbon offset program managed by UK-based Climate Care. The cost to offset one year's average carbon emissions from the aircraft will be included in the aircraft purchase price. The funds will be invested through Climate Care in green energy projects to reduce an equivalent amount of carbon . . . Bombardier is enrolling its demonstration fleet and PartsExpress

aircraft in the Climate Care carbon offset program, an annual investment in excess of approximately $250,000 US.”). *See* Climate Care, *at* <http://www.climatecare.org/>.

[455] *At* <http://www.worldlandtrust.org/>.

[456] *See* BUSINESS AND COMM. AVI., *Intelligence*, Apr. 2007, *available at* <www.aviationweek.com/bca>.

[457] *At* <http://www.unglobalcompact.org/AboutTheGC/TheTenPrinciples/environment.html> (presenting the Compact’s environmental provisions). The Global Compact, FAQ, *at* <http://www.unglobalcompact.org/AboutTheGC/faq.html> (“The Global Compact is not a code of conduct. Rather, it offers a policy framework for organizing and developing corporate sustainability strategies while offering a platform - based on universal principles - to encourage innovative initiatives and partnerships with civil society, governments and other stakeholders.”).

[458] All Nippon Airways, Press Release, *ANA Reveals Ecology Plan 2008-2011 – becomes first airline to set own absolute CO2 reduction targets*, May 22, 2008, *available at* <http://www.ana.co.jp/eng/aboutana/corporate/csr/index.html> (implementing an “Ecology Plan” to reduce CO emissions consistent with Kyoto level reductions).

[459] For example, Air New Zealand (offsets via TrustPower and funds a three-year tree planting program), British Airways, Cathay Pacific (FLY *greener* carbon offset programme), Continental, Delta (via donations to the Conservation Fund), KLM (CO_2 Zero Program), Qantas, SAS, and Virgin Atlantic Airlines.

[460] *See* Leila Abboud, *Carbon King – Economist Strikes Gold in Climate-Change* Fight, Mar. 13, 2008, *available at* <http://online.wsj.com/article_email/SB120535230851631199-lMyQjAxMDI4MDA1MTMwNTEyWj.html> (carbon permits nearly doubled [in 2007] to about $60 billion US; the Chicago Climate Exchange transacts about ninety percent of trading on carbon exchanges). *See generally* EPA, Clean Air Markets, *at* <http://www.epa.gov/airmarkets/>.

[461] ICAO Website, *at* <http://www.icao.int/icao/en/env/aee.htm>, and ICAO, Assembly Resolutions in force (as of 8 October 2004), Doc. 9848, *at* <http://www.icao.int/icao/en/env/A35-5.pdf>. ICAO is a specialized agency of the United Nations that seeks to “ensure the safe and orderly development of international civil aviation.” ICAO arose out of the Chicago Convention on International Civil Aviation (Dec. 7, 1944), *available at* <http://www.mcgill.ca/files/iasl/chicago1944a.pdf>. *See* 15 U.N.T.A. 295, ICAO Doc. 7300/6th ed. (1980). The Chicago Convention’s preamble includes a commitment to “public safety,” [Chicago Convention, Art. 37(b)] and is “conscious of the adverse environmental impacts that may be related to aircraft activity . . . and on the quality of the human environment.” ICAO Resolution A22.12, 22nd Sess. (Sep./Oct. 1977), *available at* <http://www.icao.org>.

Relevant ICAO initiatives include those through its Committee on Aviation Environmental Protection (CAEP). CAEP was established by ICAO in 1983, superseding the Committee on Aircraft Noise (CAN), and the Committee on Aircraft Engine Emissions (CAEE). *See* ICAO, A35-7: *Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection*, in Assembly resolutions in force, Oct. 8, 2004, Appendix H: Environmental impact of civil aviation on the atmosphere, *available at* <http://www.icao.int/icao/en/env/a33-7.htm#h>.

Other initiatives include though through the United Nations Framework Convention on Climate Change (UNFCCC), *available at* <http://unfccc.int/not_assigned/b/items/1417.php>. UNFCCC’s “ultimate objective,” in part, is “to achieve . . . stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.” *Id. at* Art. 2, *available at* <http://unfccc.int/essential_background/convention/background/items/1353.php>.

Other nongovernmental organizations (NGOs) have also played a profound role in international environmental standards and regulation, including the Intergovernmental Panel on Climate Change (IPCC – formed in 1998), *available at* <http://www.ipcc.ch/>, and the World Meteorological Organization (WMO), *available at* <http://www.wmo.ch/>. The IPCC's and WMO's scientific report on greenhouse gasses in 1990 served as the catalyst for The UN Framework Convention (1992) which focused on implementing the Kyoto Protocol (the first formal binding legislation under the Convention), *available at* <http://unfccc.int/resource/docs/convkp/conveng.pdf>. *See* the *Kyoto Protocol to the UNFCCC*, *available at* <http://unfccc.int/resource/docs/convkp/kpeng.html>; Dr. Kotaite, *quoted in* ICAO, News Release, *International Civil Aviation Day Calls for the Greening of Aviation* (Nov. 30, 2005), *available at* <http://www.icao.int/cgi/goto_m.pl?/icao/en/search_icao.html> (The entry into force of the Kyoto Protocol to the [UNFCCC] on 16 February 2005 gave new impetus to ICAO's work in addressing greenhouse gas emissions and reinforced ICAO's leadership role on aviation and climate change. Specifically, the Protocol calls on industrialized countries of the world to work through ICAO to pursue the limitation of greenhouse gas emissions from international civil aviation,").

[462] ICAO, Press Release, *Sharp Focus on Safety and Environmental Protection in 2007*, PIO 14/07, Dec. 28, 2007, *available at* <http://www.icao.int/icao/en/nr/2007/pio200714_e.pdf> (emphasis added) (The ICAO "Assembly agreed to a programme of action to address the issue of aircraft emissions more effectively. A resolution adopted by consensus called on the ICAO Council to form a new 'Group on International Aviation and Climate Change,' [hereinafter GIACC] composed of senior government officials. Its purpose is to develop an aggressive Programme of Action on International Aviation and Climate Change.").

[463] ICAO and EPA standards use the equivalent of 6,000 of thrust as a regulatory threshold. Among the many fears of such regulation is that GA would not be treated fairly because the same "yardstick" would be used for both GA and the airlines. Also, consider that GA tends to fly lower and does not comparably get preferred routing by ATC. It has been suggested that GA should instead be compared to automobile use (using a miles per gallon standard), perhaps with emphasis on trips such as between Las Vegas and Los Angeles (where considerable mountainous terrain demonstrates the relative efficiency of flight).

[464] Matthew Wald & James Kanter, *Plan to Cut Jet Pollution is Approved in Europe*, N.Y. TIMES, Nov. 14, 2007, at p. C3, *available at* <http://www.nytimes.com/2007/11/14/business/worldbusiness/14emissions.html?_r=1&oref=slogin >. *See* DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community, *available at* <http://eur-lex.europa.eu/LexUriServ/site/en/com/2006/com2006_0818en01.pdf>.

[465] European Commission, Emission Trading Scheme (EU ETS), *at* <http://ec.europa.eu/environment/climat/emission.htm>.

[466] Robert Wall, *quoting* Giovani Bisignani, in *Curbing Carbon*, AVI. WEEK AND SPACE TECH., Jan. 7, 2008, at p. 21, *available to subscribers at* <www.aviationweek.com/awst>.

[467] Testimony of Thomas S. Windmuller, Sr. VP, Int'l Air Transport Ass'n, Before the Select Committee on Energy Independence and Global Warming, *From the Wright Brothers to the Right Solutions: Curbing Soaring Aviation Emissions*, US House of Representatives, Apr. 2, 2008, at p. 5, *available at* <http://globalwarming.house.gov/tools/assets/files/0470.pdf> (further claiming it violates the Chicago Convention, is a tax, and suffers inconsistency). *See* Jeffrey S. Sachs, *Keys to Climate Protection*, SCI. AM., Apr. 2008, at p. 40, *available at* <http://www.sciam.com/article.cfm?id=technological-keys-to-climate-protection-extended> (Asserting that "Europe's carbon-trading system may or may not have modestly reduced emissions, but it has not shown much capacity to generate large-scale research nor to develop, demonstrate and deploy breakthrough technologies. At the margin, a trading system might marginally influence the choices between coal and gas plants or provoke a bit more adoption of solar and wind power, but it will not lead to the necessary fundamental overhaul of energy systems." *id.*).

[468] Editorial, *Potential Cost of Cap and Tax*, AVI WEEK & SPACE TECH., June 9, 2008, at p. 66.

[469] *See* NextGen, *Environmental Management Framework*, *available at* <http://www.faa.gov/about/office_org/headquarters_offices/ato/publications/nextgenplan/0608/solution_set

s/sse/index.cfm?print=go> (OI-6019 Mitigate Impacts of Aviation on Climate). *Cf.* GAMI, *2007 General Aviation Statistical Databook & Industry Outlook*, at p. 3, *available at* <www.gama.aero/events/air/dloads/2007GAMADatabookOutlook.pdf> ("GAMA supports ICAO development of science-based standards and practices in order to reduce carbon emissions."). *But see* Rick Piltz, Dir., Climate Science Watch et al., *NextGen Air Transportation System Progress Reports Ignore Climate Change*, July 2007, *available at* <http://www.climatesciencewatch.org/index.php/csw/details/qnn_interview/> ("Under the current administration, the leadership of . . . NextGen appears to be engaging in a deliberate effort to disconnect aviation planning from the global warming problem.").

[470] *See* Peter Liese, EU Lawmaker, *quoted in Proponents of EU Carbon Caps Await US Presidential Election*, AERO-NEWS NETWORK, May 8, 2008, *available at* <http://www.aero-news.net/index.cfm?ContentBlockID=b98dedea-5196-4e51-a883-674bfda95f52> ("Until a few months ago, it was very unrealistic that other major players would link to our [EU] scheme, but times have changed.").

[471] ICAO, GIACC, First Meeting, Summary of Discussion – Day 3, Agenda Item 3: *Planning of actions and policy elements to be developed by group*, GIACC/1-SD/3, Feb. 8, 2008, at p. 3, in Montreal, Can., *available at* <http://www.icao.int/env/meetings/Giacc/sd3_en.pdf>.

[472] John M. Broder, *Panel Passes Bill to Limit Greenhouse Gas Emissions*, N.Y. TIMES, Dec. 6, 2007, at p. A29, *available at* <http://www.nytimes.com/2007/12/06/washington/06energy.html?_r=1&oref=slogin> (passed by the Senate Environmental and Public Works Committee - seeking a roughly 70 percent reduction from 2005 levels by 2050 in CO_2 and other greenhouse gases.). *See* Rep. Edward Markey, Chairman, Select Committee on Energy Independence and Global Warming, Letter to US EPA Admin'r Stephen Johnson, Jan. 8, 2008, *available at* <http://globalwarming.house.gov/mediacenter/pressreleases?id=0153> (asserting that "[t]he EPA has a clear role to play in protecting Americans from the worst impacts of heat-trapping emissions that cause global warming."). *See* Andrew Ross Sorkin, *On an Island Paradise, Seeking Global Warming's Silver Lining*, N.Y. TIMES, Mar. 22, 2008, at pp. B1, B7, *available at* <http://www.nytimes.com/2008/03/22/business/worldbusiness/22deal.html?scp=1&sq=andrew+sorkin+-+on+an+island+paradise&st=nyt> (stating that Tony Blair predicts that the US will soon adopt a cap and trade system and asserting skepticism that the EU's cap and trade system "will work unless it's part of a global deal." *id.* at B7); Vicki Arroyo, Dir. of Policy Analysis, Pew Center on Global Climate Change, *Climate Change Policy Overview*, Presentation at the ATA, *Aviation and the Environment: A Primer for North American Stakeholders*, Mar. 20, 2008, at p. 19, *available at* <http://www.airlines.org/NR/rdonlyres/AF534BE6-F179-4B3A-BF65-C318905DA56E/0/LUNCHArroyoThurs1200.pdf> (stating that in 2007, there were over 110 climate-related-hearings, around 150 bills mentioning climate change, and the US EPA was directed and funded to draft a rule for green house gas registry in all sectors).

See, e.g., US Senate S.2191, the Lieberman-Warner Climate Security Act of 2007, *available at* <http://www.govtrack.us/congress/bill.xpd?bill=s110-2191> (seeking to cut carbon to 2005 levels by 2012 and 70% below 2005 levels by 2050); Sheryl Gay Stolberg, *Bush Calls for U.S. to Halt Rise in Gas Emissions by 2025*, N.Y. TIMES, Apr. 17, 2008, at p. 19, *available at* <http://www.nytimes.com/2008/04/17/washington/17bush.html?ex=1366171200&en=2c6f0ceebd8a06e5&ei=5124&partner=permalink&exprod=permalink> (quoting Pres. George W. Bush, "It is now time for the U.S. to look beyond 2012 and take the next step . . . . The wrong way is to raise taxes, duplicate mandates, or demand sudden and drastic emissions cuts that have no chance of being realized and every change of hurting our economy.").

[473] Consider that the U.S. Supreme Court reversed a Federal Appellate Court's decision to prohibit the US EPA's regulation of carbon emissions under the Clean Air Act. *Massachusetts et al. v. Environmental Protection Agency et al.*, 549 U.S. __, 127 S.Ct. 1438, 415 F.3d 50 (Apr. 2, 2007), reversed and remanded, *available at* <http://www.law.cornell.edu/supct/html/05-1120.ZO.html> (holding, in part, that "§202(a)(1) of the Clean Air Act authorizes EPA to regulate greenhouse gas emissions from new motor vehicles in the

event that it forms a 'judgment' that such emissions contribute to climate change" and that EPA's failure to regulate was "arbitrary [and] capricious." *id.*); US EPA, Advanced Notice of Proposed Rulemaking, *Regulating Greenhouse Gas Emissions under the Clean Air Act*, July 11, 2008, *available at* <http://www.epa.gov/epahome/pdf/anpr20080711.pdf> (responding to the aforementioned Sup. Ct. decision but failing to take affirmative action).

[474] For example, Canadian offsets, *at* <http://www.airlines.org/NR/rdonlyres/96D813C7-558E-4DD3-A487-21404075B63A/0/23ManzoThurs315.pdf>; Japan Carbon Offsets Forum, *at* <http://www.j-cof.org/e/index.html>.

[475] *See* Christine Larson, *A New Way to Ask, 'How Green Is My Conscience?'*, N.Y. TIMES, June 25, 2006, at p. 6, *available at* <http://www.nytimes.com/2006/06/25/business/yourmoney/25green.html?ex=1151899200&en=fb58f43bc6dad75b&ei=5070&emc=eta1>. *Cf.* Renee Martin-Nagle, VP & General Counsel, AirBus N. America Holdings, Inc., Presentation at Women in Aviation, in San Diego (Mar. 14, 2008) ("Both Airbus and Boeing feel a deep responsibility" for environmental stewardship.); Boeing, *Environmental and Climate Change Policies*, *at* <http://www.boeing.com/aboutus/environment/policies.html> ("Work together with our stakeholders on activities that promote environmental protection.").

Email from Bill Rhodes, Ph.D., July 1, 2006 ("[Carbon-offset] programs must consider cultural issues, and, rather than "repairing damage" (as is the focus of TerraPass), a "second-order" approach might be favorable."). *See generally* Commentary to AMCC VII.e, *at* <http://www.secureav.com/Comment-AMCC-VII.e-Ethics.pdf> (on ethics). *But see* Steven Pinker, *The Moral Instinct*, N.Y. TIMES MAG., Jan. 13, 2008, at p. 58, *available at* <http://www.nytimes.com/2008/01/13/magazine/13Psychology-t.html?_r=1&ref=todayspaper&oref=slogin> ("Though voluntary conservation may be one wedge in an effective carbon-reduction pie, the other wedges will have to be *morally boring*, like carbon tax and new energy technologies, or even taboo, like nuclear power and deliberate manipulation of the ocean and atmosphere.") (emphasis added). British Business and General Aviation Ass'n, *BBGA Environmental*, Headline News, accessed July 20, 2008, *at* <http://www.bbga.aero/headline-news.php> ("As a sector we realise we have to go further; politically and morally we need to minimise our impact on the environment"); Julian Sinclair, *quoted in* Leah Koenig, *The Green Issue*, N.Y. TIMES, Apr. 20, 2008, at p. 68, *available at* <http://www.nytimes.com/2008/04/20/magazine/20Live-a-t.html?_r=1&pagewanted=3&oref=slogin> (Observing a growing theologically based environmental movement. Religion has been "in the behavior-changing business for 3,000 years." *id.*). *See, e.g.*, Evangelical Environmental Network, *at* <http://www.creationcare.org/>, and the Jewish Climate Initiative, *at* <http://www.jewishclimateinitiative.org/home/index.php>.

[476] Integrated carbon offsets and insurance products have also been developed. For example, ClimateSure has consolidated carbon offsets in its travel insurance product. *At* <http://www.climatesure.co.uk/insurance-cover.html> ("When you buy a policy, Climatesure will calculate the CO2 you produce by flying overseas* and pay for it to be 'offset' by Climate Care, a leading carbon offset company. This payment is part of the price, and doesn't cost you any extra. Climate Care offsets your CO2 emissions through funding sustainable energy projects, which will reduce CO2 emissions by the same amount as your activities produce." *At* <http://www.climatesure.co.uk/how-it-works.html>). *See* <http://www.carbonfund.org/site/pages/businesses/category/Allstate%20Green%20Agency%20Program/> (CarbonFund.org teams with Allstate for reforestation and other projects).

[477] Testimony of Thomas S. Windmuller, Sr. VP, Int'l Air Transport Ass'n, Before the Select Committee on Energy Independence and Global Warming, *From the Wright Brothers to the Right Solutions: Curbing Soaring Aviation Emissions*, US House of Representatives, Apr. 2, 2008, at p. 7, *available at* <http://globalwarming.house.gov/tools/assets/files/0470.pdf>.

[478] Testimony of James C. May, Pres. and CEO, Air Transport Ass'n, Apr. 2, 2008, at p. 6, *available at* <http://globalwarming.house.gov/tools/assets/files/0467.pdf>.

[479] *See, e.g.*, Daniel K. Elwell, Ass't Admin'r, Office of Avi. Policy, Planning & Env't., FAA, *Statement before the Select Comm. On Energy Independence and Global Warming*, Hearing on Avi. Emissions, Apr.

2, 2008, at p. 4, *available at* <http://globalwarming.house.gov/tools/assets/files/0466.pdf> (also referencing a 2001 finding by ICAO's Committee on Aviation Environmental Protection that fuel prices eliminate the need for CO_2 emissions standards), Ed McKenna, *Technology Lightens*, AVIONICS, Dec. 2007, at p. 33, *available at* <www.avionicsmagazine.com> (describing higher fuel costs as "motivational"); US EPA, *US Greenhouase Gas Inventory Report**,** Inventory Of U.S. Greenhouse Gas Emissions And Sinks: 1990-2006*, USEPA #430-R-08-005, Apr. 2008, at p. ES-4, *available at* <http://www.epa.gov/climatechange/emissions/downloads/08_ES.pdf> ("restraint on fuel consumption caused by rising fuel prices, primarily in the transportation sector"); and AOPA, *AOPA supports move to lower gas prices*, AOPA Online, July 10, 2008, *at* <http://www.aopa.org/advocacy/articles/2008/080710oil.html>(reporting that ¾ths of its members have "scaled back their flight time" due to high avgas prices); S.O.S.*NOW* (Stop Oil Speculation Now), *at* <http://www.stopoilspeculationnow.com/> (urging, in part, reform of commodities trading in oil).

[480] *See supra* note 406 (concerning behavior).

[481] US EPA, Used Oil Management Program, *at* <http://www.epa.gov/epaoswer/hazwaste/usedoil/index.htm>. *See* US EPA, *Nonpoint Source Pollution: The Nation's Largest Water Quality Problem*, EPA841-F-96-004A, *at* <http://www.epa.gov/nps/facts/point1.htm> (Oil as a contributing nonpoint source pollutant).

[482] US EPA, Used Oil Management Program, *id*. *See* US EPA, *Collecting Used Oil for Recycling/Reuse, Tips for Consumers Who Change Their Own Motor Oil and Filters*, EPA 530F-94-008 (Mar. 1994), *available at* <http://www.epa.gov/epaoswer/non-hw/recycle/recy-oil.pdf>.

[483] US EPA, Municipal Solid Waste, Oil, *at* <http://www.epa.gov/epaoswer/non-hw/muncpl/oil.htm>. *See* Utah Dep't of Environmental Quality, Used Oil Section, *at* <http://www.usedoil.utah.gov/UsedOilSection.htm>. A specific break-out for improper disposal of oil in the aviation sector was not identified.

[484] Todd Peterson, *Aviation Oil Lead Content Analysis*, Report # EPA 1-2008, Jan. 2, 2008, *available at* <www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&o=09000064803a128f>. Also, consider the toxicity of oil additives and synthetic oils.

[485] Rufus Browning, Public Research Institute, San Francisco State Univ., *DIYers—Who Are the Best Targets?* (May 4, 2005), *available at* <http://www.ciwmb.ca.gov/HHW/Events/AnnualConf/2005/April28/Session4/DIYers/DIYTarget.pdf>.

In Pennsylvania, for example, do-it-yourself oil changers dispose of 11 million gallons per year; approximately 14% (1.5 million gallons) of this oil is recycled; and the remaining 9.5 million gallons are improperly dumped. Penn. Dept. of Environmental Protection, *Used Oil, Recycled Used Motor Oil - When you do-it-yourself, do it right, available at* <http://www.depweb.state.pa.us/landrecwaste/cwp/view.asp?a=1239&Q=463396>.

[486] Furthermore, consider that "your high-users of aircraft (such as rental organizations, shared management groups, part 135 and 121 operators), and high use maintenance shops are licensed and inspected regularly by fire, water, and local hazmat officials–most of which use bulk oil (not bottled), hence require less plastic storage and bottle disposal. Additionally such high-users are required to dispose of the used oil, filters, oily rags . . ., etc., through a very expensive (albeit effective) recovery process. Consequently, high-volume users of engine oil and supplies can be compared to auto service centers that dispose of the oil using environmentally safe processes. Indeed, GA's imprint on the environment is miniscule in comparison to that of automobiles, energy, and industry sectors." Email from Josh Smith, Gen. Mgr., West Valley Flying Club, May 12, 2008.

[487] *See Cal., The Facts About Re-Refined Oil, available at* <http://www.ciwmb.ca.gov/Publications/UsedOil/33297014.doc> (explaining that used oil undergoes extensive re-refining "to remove contaminants to produce a good-as-new base oil."). *See also* Cal. Integrated Waste Board, *at* <http://www.ciwmb.ca.gov/UsedOil/Rerefined/>.

[488] Separately, the biodegradability of lubricants has been the focus of an ASTM standards-making group. *See* ASTM, Committee D02.12 on Environmental Standards for Lubricants, *at* <http://www.astm.org/cgi-bin/SoftCart.exe/COMMIT/SUBCOMMIT/D0212.htm?L+mystore+lxmq0500+1131297416>.

[489] Unless a used oil handler disposes of used oil, or sends it for disposal. 40 CFR 279.10(a), *available at* <http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=076d86b286941392dfcf95f60856b82d&rgn=div8&view=text&node=40:26.0.1.1.8.2.47.1&idno=40>. *See generally* US EPA, Oil Management Program, *at* <http://www.epa.gov/epaoswer/hazwaste/usedoil/#pubs>.

[490] 40 C.F.R. Part 279, pursuant to the Solid Waste Disposal Act (§§ 1006, 2002(a), 3001-3007, 3010, 3014, and 7004, as amended (42 U.S.C. §§ 6905, 6912(a), 6921 through 6927, 6930, 6934, and 6974), *available at* <http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=b976066d6eff2d44127a9730db5ea374&rgn=div5&view=text&node=40:26.0.1.1.8&idno=40>; US EPA, Hazardous Waste Management System; Identification and Listing of Hazardous Waste; Recycled Used Oil Management Standards, Final Rule, 57 Fed. Reg. 41,566 (Sept. 10, 1992), *available at* <http://www.epa.gov/epaoswer/hazwaste/usedoil/fr/fr091092.txt> (EPA determined (consistent with RCRA § 3014) that recycled used oil need not be listed as a hazardous waste since EPA's used oil management standards are adequately protective of human health and the environment – to be listed as 40 CFR 279).

[491] One airport manager stated that its oil collection facilities are kept locked to prevent exotic chemicals (*e.g.*, solvents and other chemicals other than used oil) from contaminating the collection tanks and to ensure that the contents are accounted for. Oil recovery companies test/analyze the contents of the oil collection tank before agreeing to take custody of it. One airport manager explained that a single incident where a solvent had been improperly dumped in the oil collection tank cost the airport over $1,700. (Anonymous).

[492] Telephone Interview with John Frymyer, Whitman Airport Manager (Nov. 29, 2005); Telephone Interview with Mike Gloss, Petaluma Airport Manager (Nov. 29, 2005).

The concentrations of lead in used oil from aircraft engines that burn 100LL fuels are typically above 1000 ppm. As this is above the EPA regulatory level identifying a solid waste as "hazardous waste," this used oil must be managed as "hazardous waste" if disposed. There is, however, an exemption in the hazardous waste regulations for "used oil" that is recycled. [40 CFR 261.6(a)(4)]. Most often used oil is recycled by being burned as a fuel substitute. When recycled in this manner, the lead concentration in the used oil must be below 100 ppm. [40 CFR 279.11]. Some used oil recyclers may accept off-specification used oil and mix it with automotive and/or diesel engine oil to achieve the specification, whereas others recyclers may not. When arranging for a shipment of used oil from 100LL-fueled engines, you should always tell the recycler in advance that the used oil may be "off-specification." By doing so, you will avoid the possibility of the recycler rejecting the shipment, and possibly holding you financially liable for shipping an "unusable" load of used oil. Another option that has worked for many used oil generators is to burn the off-specification used oil onsite in a space heater (or furnace) to heat the shop or hanger. [40 CFR 279.20(b)(3)]. This option is prohibited in some states, so you are advised to check your local and state laws prior to setting up a used oil program, especially for used oil from 100LL-fueled engines. Email from Ben Visser, Aviation fuels and lubricants expert and columnist for GENERAL AVIATION NEWS, July 21, 2008, and Charles Corcoran, Office of Policy, Dept. of Toxic Substances Control, State of California, July 21, 2008. Nonetheless, such burning of lead-contaminated used oil raises ethical and health issues that deserve consideration.

[493] Oil leaves an engine through evaporation at high temperatures, leaks, and blow-by past the piston rings during operation. Bill Coleman, *The Facts about Engine Oil*, SW AVIATOR ONLINE, *available at* <http://www.swaviator.com/html/issueja02/Hangar7802.html>. "Typical oil consumption for a large turbocharged engine such as the –AE2A may vary between 3-10 hours per quart depending on the time in service." Textron Lycoming, *Operating Recommendations for TIO-540-AE2A Engine in New Piper Aircraft Malibu Mirage* (2000), *available at*

<http://www.lycoming.textron.com/support/troubleshooting/resources/SSP400.pdf>. Continental cited ¾ qts. consumption per hr. of operation for its 550 engines. Telephone Interview with Teledyne Continental Customer Service Representative (Nov. 28, 2005).

[494] The FAA estimates that GA piston aircraft flew 20,900,000 hours in 2002. This translates into 2,090,000 quarts of oil for replenishment (at the conservative rate of 1 qt. per each 10 hours of operation) – and may represent over 2 million quart bottles of waste annually from GA. GAMA, General Aviation Statistical Databook 2002, *citing* FAA, *U.S. Flight Hours by Type and Aircraft, available at* <http://www.gama.aero/dloads/2004StatisticalDatabook.pdf>. This may represent over 15,625 US gal. (representing approximately 1 oz. unrecovered residual oil in each quart bottle).

[495] On May 10, 2007, the US EPA's Oil Program office issued a statement that a facility must prepare or amend and implement its Spill Prevention, Control, and Countermeasure (SPCC) Plan no later than July 1, 2009. The US EPA proposed further revisions to the SPCC rule in Oct. 2007, *at* <http://www.epa.gov/emergencies/content/spcc/spcc_oct07.htm>. *See* US EPA, *at* <http://epa.gov/oilspill/>.

[496] For oil changes, instruct your FBO to replace only the stable amount of oil. Consider, for example, that a Lycoming TIO-540 series engine has an oil capacity of 12 quarts and yet a minimum safe quantity of 2¾ quarts. New Piper, Saratoga II TC Info. Manual, § 8-11 (1997). A "stable" amount of oil for this engine is typically 8-10 quarts.

[497] For example, California requires that "The drained filters must be accumulated, stored, and transferred in a rain-proof container that is capable of containing any oil that may separate from the filters." Cal. Code Regs. § 66266.130. *See, e.g.*, Los Angeles County, Certified Unified Program Agency, Health Hazardous Materials Division, Fact Sheet 02-04-HW, *Management of Used Oil Filters* (Oct. 2002), *available at* <http://fire.lacounty.gov/HealthHazMat/PDFs/MgmtUsedOilFilters.pdf>. *See generally* Oil Stopper, *Quick Facts about Hot Topics, at* <http://www.oilstopper.info/quick_facts.html>.

Gasoline fuel filters also require careful labeling and disposal. *See, e.g.*, 22 Cal. Code Regs. § 66266.130(c)(3), and Cal. Heath & Safety Code § 22250.22(b)(1), *referenced at* <http://www.calguard.ca.gov/caev/Documents/CA_TeamG/POL.doc>.

[498] Bob Cerullo, *Waste Oil At Your Disposal*, Motor, Jan. 2000, *at* <http://findarticles.com/p/articles/mi_qa3828/is_200001/ai_n8893427>.

[499] Earth 911, *Do-It-Yourself (DIY) Oil Changing Tips - Handle Your Oil Like A Pro, at* <http://www.earth911.org/master.asp?s=lib&a=oil/doityourself.asp>.

[500] *See* <http://oilspillproducts.com/spillkits.htm> (providing oil spill kits suitable for personal GA use).

[501] *See* FAA, AC 150/5300-14A, *Design of Aircraft Deicing Facilities* (Sept. 19, 2007), *available at* <http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/FBA78D44CD44A12086257364006879D6?OpenDocument> ("Since deicing/anti-icing fluids are chemical products with environmental consequences, deicing facilities shall have runoff mitigating structures."). *See generally* US EPA, Airport Deicing Effluent Guidelines, *at* <http://www.epa.gov/guide/airport/index.html>; Alaska Proposed Deicing Regulation (Oct. 21, 2007), *at* <http://www.adn.com/money/industries/aviation/story/9396702p-9310029c.html> (proposed revisions to the Alaska Oil and Other Hazardous Substances Pollution Control regulations in 18 AAC 75).

[502] Carole Blackshaw, Aviation Law & Regulation 251 (Krieger Publ'g Co. 1992).

[503] *See* FAA, AC 150/5320-15, *Change 1 to Management of Airport Industrial Waste* (Apr. 22, 1997), *available at* <http://www.aopa.org/members/files/ac/ac150-5320151.pdf>.

[504] *See infra* text accompanying notes 576-577 (considering the ozone layer), and text accompanying notes 578-579 (ozone depleting compounds).

[505] US GAO, Chemical Regulation, *Options Exist to Improve EPA's Ability to Assess Health Risks and Manage Its Chemical Review Program*, Report No. GAO-05-458 (June 2005), *available at*

<http://www.gao.gov/new.items/d05458.pdf>; Michael P. Wilson, School of Public Health, UC Berkeley, *quoted in* Susan Moran, *A Turn to Alternative Chemicals*, N.Y. TIMES, Mar. 26, 2008, at p. H2, *available at* <http://www.nytimes.com/2008/03/26/business/businessspecial2/26chemical.html?_r=1&oref=slogin> (describing toxic chemical oversight as "a major regulatory and market failure," and stating that 62,000 chemicals were grandfathered in before the Toxic Substances Control Act), *available at* <http://www.access.gpo.gov/uscode/title15/chapter53_.html>). *See Better Living Through Chemurgy*, THE ECONOMIST, June 28, 2008, at pp. 71-72, *available at* <http://www.economist.com/business/displaystory.cfm?story_id=11632861> (Technologies coupled with meteoric oil prices have catalyzed new initiatives to use agricultural feedstock (that is, renewable alternatives from diverse chemicals and products) in substitution for petroleum. A branch of applied chemistry *chemurgy* may produce a whole new class of chemicals with corresponding new or novel toxic and polluting properties.).

See Nat'l Science and Tech. Council, *National Plan for Aeronautics Research and Development and Related Infrastructure* (Dec. 2007), at p. 52, *available at* <http://www.aeronautics.nasa.gov/releases/aero_rd_plan_final_21_dec_2007.pdf> (long-term (>10 yrs) US goal to "[e]nable environmentally improved aircraft materials and handling of fuel and de-icing fluids."). *Cf.* EU Reg. 1907/2006 on the Registration Evaluation and Authorisation of CHemicals – *REACH in brief*, Euro. Comm., Environmental Directorate General, Feb. 2007, *at* <http://ecb.jrc.it/DOCUMENTS/REACH/REACH_in_brief_0207.pdf> (explaining the new framework for chemical substances); EU, REACH Website, *at* <http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm> (requiring inventory of substances, gap analysis, registration, risk management, disclosure, transparency).

[506] Each product with harmful chemicals is accompanied by a Material Data Safety Sheet (MSDS), or each MSDS is available on-line. *See, e.g.*, U.S. Dep't of Labor, Occupational Safety & Health Administration, *Hazardous Communications: Foundation of Workplace Chemical Safety Programs*, *at* <http://www.osha.gov/SLTC/hazardcommunications/index.html>; the *MSDS FAQ*, *at* <http://www.ilpi.com/msds/faq/parta.html#whatis>. *See generally* CDR Jay Dudley MC, USN, *Aviation Toxicology*, U.S. Army School of Aviation Medicine, Presentation, *at* <http://www.usarmyaviation.com/pubs/Aeromed/av_tox.ppt> (providing a survey of physiological hazards from aviation chemicals). The Chemical Abstract Services (CAS), *at* <http://www.cas.org/> (provides an extensive chemical/scientific data base relevant to chemical safety).

[507] At p. 5, *at* <http://www.secureav.com/Comment-AMCC-V.a-Environmental.pdf>.

[508] *See* FAA, AC 43-205, *Guidance for Selecting Chemical Agents and Processes for Depainting and General Cleaning of Aircraft and Aviation Products* (Sept. 25, 1998), *available at* <http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/8a26d5587e43ce69862569b600737e07/$FILE/ATTPDGFY/ac43-205.pdf>.

[509] Determine and adhere to any limitations on a wash rack's permissible use of chemicals. Also, although many GA airports provide a "wash rack" to mitigate environmental impact from aircraft degreasing and washing, much of this maintenance is often done at environmentally unprotected tie-down or hangar locations. *See* ICAO, *Airport Planning Manual*, Doc. 9184 – AN 902.P.2 (date), *at* 13.2 (addressing water contamination by airport waste disposal and drainage systems), *available at* <http://www.icao.org>.

[510] Centers for Disease Control, *at* <http://www.atsdr.cdc.gov/tfacts96.html>.

[511] *Substitution And Recycling Of Aircraft Deicing Products*, THE JOINT SERVICE P2 OPPORTUNITY HANDBOOK, at Sect. 6-1-7, *available at* <http://p2library.nfesc.navy.mil/P2_Opportunity_Handbook/>. *See generally* Joint Service Pollution Prevention and Sustainability Technical Library, *at* <http://p2library.nfesc.navy.mil/index.htm>.

[512] *See* US EPA, Hazardous Waste, *at* <http://www.epa.gov/epaoswer/osw/hazwaste.htm#hazwaste> (defining hazardous waste); Carmen R. Wieher, *Hazardous Waste Curriculum for Aviation Maintenance*,

Fla. Dept. of Envtl. Prot., *available at* <http://www.dep.state.fl.us/waste/quick_topics/publications/shw/hazardous/aviationmaintcurriculum.pdf>.

[513] US EPA, *at* <http://www.epa.gov/epaoswer/osw/hazwaste.htm#hazwaste> (stating that these wastes have one or more of four properties: toxicity, reactivity, ignitability, and corrosivity).

[514] *See* US EPA, *Universal Waste*, *at* <http://www.epa.gov/epaoswer/hazwaste/id/univwast/index.htm>; US EPA, *Universal Waste Rule*, 40 C.F.R. Part 9 et al., May 11, 1995, *available at* <http://www.epa.gov/EPA-WASTE/1995/May/Day-11/pr-223.html> ("These wastes share several characteristics: – They are frequently generated in a wide variety of settings other than the industrial settings usually associated with hazardous wastes; – They are generated by a vast community, the size of which poses implementation difficulties for both those who are regulated and the regulatory agencies charged with implementing the hazardous waste program; and – They may be present in significant volumes in non-hazardous waste management systems.").

[515] This includes nickel-cadmium, most alkaline, carbon-zinc, and lead-acid batteries.

[516] *See* US EPA, Mercury-Containing Equipment, *at* <http://www.epa.gov/epaoswer/hazwaste/id/univwast/mercury.htm>. *See generally* United Nations Environment Programme - Chemicals, Mercury Programme, *at* <http://www.chem.unep.ch/MERCURY/> (providing diverse scientific and policy materials, and links about mercury).

[517] US EPA, *Universal Waste Rule* (Hazardous Waste Management System, 60 Fed. Reg. 25,491 (May 11, 1995), *available at* <http://www.epa.gov/docs/fedrgstr/EPA-WASTE/1995/May/Day-11/pr-223.html> (For example, EPA proposal to maintain the current exemption from hazardous waste regulations for lead-acid batteries under subpart G, part 266). *Cf.* CAL. CODE REGS., Ch. 23 of Div. 4.5, Title 22 C.C.R. or H.S.C. § 25201.16. *See* Cal. Universal Waste Regulations, *available at* <http://www.dtsc.ca.gov/LawsRegulationsPolicies/UWR/index.html>; Mercury-Containing and Rechargeable Battery Management Act, 110 Stat. 1329 (May 13, 1996), *available at* <http://www.epa.gov/epaoswer/hazwaste/state/policy/pl104.pdf>. *See generally* US EPA, Mercury Website, *at* <http://www.epa.gov/mercury/>.

[518] National programs involving tens of thousands of participating locations have eased the challenges of responsible disposal, such as via the Rechargeable Battery Recycling Corp., *at* <www.call2recycle.org>.

[519] Cal. EPA, *Managing Universal Waste in California*, Fact Sheet, June 2003, *available at* <http://www.dtsc.ca.gov/HazardousWaste/EWaste/upload/HWM_FS_UWR.pdf>.

[520] *See* US EPA, *Source Water Protection Practices Bulletin, Managing Aircraft and Airfield Deicing Operations to Prevent Contamination of Drinking Water* (Aug. 2002), *available at* <http://cfpub.epa.gov/safewater/sourcewater>.

[521] For example: "It shall be unlawful to discharge, or cause, allow or permit to be discharged into any part of the storm water system or watercourses any sewage, industrial wastes, hazardous waste, anti-freeze, petroleum or petroleum products, coal tar, chemicals, detergents, solvents, paints, contaminated or chlorinated swimming pool water, pesticides, herbicides, fertilizers, soil sediments, washwater, cans, bottles, refuse, animal wastes, cement powder, concrete waste, broken concrete, construction-site waste or debris, motor or other vehicles or parts thereof, or any material that may be deleterious to aquatic life." County of Santa Clara Ordinance Code, Ch. II. *Discharges to Storm Water System*, § B11 1/2-4 (Ord. No. NS-517.74, § 1, 10-17-06), Discharge prohibition, *available at* <http://www.sccgov.org/scc_ordinance/31202001.HTM>. *See generally* US EPA *Stormwater Regulations*, *available at* <http://cfpub.epa.gov/npdes/regresult.cfm?program_id=6&view=all&type=1>.

[522] FAA, *Select Resource Materials and Annotated Bibliography on the Topic of Hazardous Air Pollutants (HAPs) Associated with Aircraft, Airports, and Aviation*, Prepared by URS Corp. for FAA, Office of Env't and Energy (July 1, 2003), *available at* <http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/HAPs_rpt.pdf>.

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523 GAO, *Aviation and the Environment, Strategic Framework Needed to Address Challenges Posed by Aircraft Emissions*, Report to Congress, Report GAO-03-252 (Feb. 2003), at p. 1, *available at* <http://www.gao.gov/new.items/d03252.pdf>; EPA, *Regulatory Announcement: New Emission Standards for New Commercial Aircraft Engines*, *at* <http://www.epa.gov/otaq/regs/nonroad/aviation/420f05015.htm>.

524 GAMA, *2007 General Aviation Statistical Databook & Industry Outlook*, at p. 3, *available at* <http://www.gama.aero/events/air/dloads/2007GAMADatabookOutlook.pdf>.

525 IPCC, *IPCC Special Report-Aviation and the Global Atmosphere, Summary for Policymakers* (1999), § 4.1, *available at* <http://www.ipcc.ch/ipccreports/sres/aviation/006.htm#spm41>.

526 US EPA, *Greenhouse Gas Emissions from the U.S. Transportation Sector 1990-2003* (Mar. 2006), at § 5.1, *available at* <http://www.epa.gov/oms/climate/420r06003.pdf>. *Ed.* – the precise percentage of aviation's contribution to CO_2 emissions is a matter of debate.

527 US EPA, *id.*

528 The NBAA asserts less than 0.6 percent.

529 *See, e.g.*, Sir Nicholas Stern, *Stern Review on the Economics of Climate Change*, Oct. 2006, *available at* <http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm> (approximately 0.016% of total emissions).

530 Renee Martin-Nagle, VP and General Counsel, AirBus N. America Holdings, Inc., Presentation at Women in Aviation, in San Diego, Cal. (Mar. 14, 2008) (claiming a 50% reduction).

531 IPCC, *Aviation and the Global Atmosphere*, 1999, at Ch. 7.9, *available at* <http://www.grida.no/Climate/ipcc/aviation/112.htm>.

532 Lourdes Maurice, Ph.D., Chief Scientist, FAA Office of Env't and Energy, *Aviation and the Environment: Problems and Strategic Solutions,* Presentation at Women in Aviation, in San Diego, Mar. 14, 2008 ("getting toward carbon neutrality is where we need to go.").

533 Renee Martin-Nagle, VP and General Counsel, AirBus N. America Holdings, Inc., Presentation at Women in Aviation, in San Diego, Cal. (Mar. 14, 2008) (asserting that the fleet will grow from 16,800 in 2006, to 34,430 by 2020 – citing the Airbus Global Market Forecast).

534 FAA, Office of Env't and Energy, *Aviation & Emissions - A Primer* (Jan. 2005), at p. 4, *available at* <http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/AEPRIMER.pdf> (aviation creates under .4% of NO_x emissions and piston powered aircraft are, by implication, a small fraction of that; nonetheless, greenhouse gas emissions from aircraft are projected to increase 60 percent by 2025. *id.* at pp. 5, 10). Nonetheless, the injection of NO_x into the upper atmosphere is problematic because NO_x concentrations at altitude are negligible. At altitude, the lifetime of NOx is 10 times that at ground level.).

FAA, *Background Materials on Air Quality:* FAA Order 1050.1DCHNG4, *Policies and Procedures for Considering Environmental Impacts* (1999), *see* FAA Order 5050.4A, *Airport Environmental Handbook* (Oct. 8, 1985), *available at* <http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/airquality_handbook/> (Air quality guidelines and assessment for new airports, new or extended runways -- contains expanded information on ARP procedures to meet the Council on Environmental Quality's (CEQ) NEPA implementing regulations as they relate to ARP's administration of the Airport Improvement Program); FAA, *Air Quality Handbook*, *available at* <http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/airquality_handbook/index.cfm?print=go> (includes instructions on preparing emission inventories and conducting atmospheric dispersion modeling).

[535] Telephone Interview with Curtis Holsclaw, Mgr., Aviation Policy, Planning and Env't, FAA (May 17, 2006) ("Someone needs to tell us this is an issue [for GA]." *id*.).

[536] The regulation of airborne emissions is introduced in the Commentary to AMCC V.a, *available at* <http://www.secureav.com/Comment-AMCC-V.a-Environmental.pdf>.

[537] *See* Stepan Faris, *Conspiracy Theory*, ATLANTIC, June 2008, *available at* <www.theatlantic.com/doc/200806/conspiracy> (federal lawsuits against 24 oil, coal, and electric companies claiming responsibility for global warming and conspiracy to cover-up anthropomorphic threat. Also suit by Union of Concerned Scientists against ExxonMobile claiming ExxonMobil established "front" groups akin to the tobacco industry's strategy to promote writers to exaggerate scientific uncertainties of smoking hazards to health); Matthew L. Wald, *George Judge Cites Carbon Dioxide in Denying Coal Plant Permit*, N.Y. TIMES, July 1, 2008, at p. C4 (Sup.Ct., Fulton County, GA, by the Sierra Club and Friends of the Chattahoochee relying on U.S. Sup. Ct. decision permiting regulation of CO_2); Kofi A. Annan, Opening Address, Global Humanitarian Forum, in Geneva, Switz., June 24, 2008, *at* <http://www2.ghf-ge.org/multimediacentre.cfm?tab=20&id=72> (asserting, "We must have climate justice."); and Alice R. Thomas et al., Earthjustice, *Petition for Rulemaking Under the Clean Air Act to Reduce the Emission of Air Pollutants from Aircraft that Contribute to Global Climate Change*, Dec. 31, 2007, *available at* <http://www.earthjustice.org/library/legal_docs/petition-to-epa-on-aircraft-global-warming-emissions.pdf> (seeking findings and environmental rulemaking to mitigate aircraft emissions producing greenhouse gases).

[538] RUIJGROK, *supra* note 11, at p. 149.

[539] US EPA, *Criteria Pollutants*, *at* <http://www.epa.gov/oar/oaqps/greenbk/o3co.html>; US EPA, National Ambient Air Quality Standards (NAAQS), *available at* <http://www.epa.gov/air/criteria.html>

[540] *See* US EPA, *NOx: What is it? Where does it come from?, at* <http://www.epa.gov/air/urbanair/nox/what.html>. *See* US EPA, *Health and Environmental Impacts of NOx*, *at* <http://www.epa.gov/air/urbanair/nox/hlth.html>; US EPA, *Integrated Science Assesment for Oxides of Nitrogen – Health Criteria (Final Report)*, July 11, 2008, *available at* <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=194645>.

[541] *See* 73 Fed. Reg. 16,436 (Mar. 27, 2008) (lowering ozone concentrations from 0.08 PPM to 0.075 PPM in an eight-hour period). The ozone NAAQS is an 8-hour standard which is met when the fourth highest daily maximum 8-hour average ozone concentration measured over a 3-year period is less than or equal to 0.084 parts per million (PPM). The former 1-hour ozone standard was revoked in June 2005. US EPA, *National Ambient Air Quality Standards for Ozone*; Final Rule, 62 Fed. Reg. 38,855 (July 18, 1997), *available at* <http://www.epa.gov/fedrgstr/EPA-AIR/1997/July/Day-18/a18580.htm>. US EPA, *Final Rule to Implement the 8-Hour Ozone National Ambient Air Quality Standard – Phase 1*, Final Rule, 69 Fed. Reg. 23,951 (Apr. 30, 2004), *available at* <http://www.epa.gov/fedrgstr/EPA-AIR/2004/April/Day-30/a9153.htm>. *See generally* US EPA, *Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final), at* <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=149923>.

[542] US EPA, NAAQS, *available at* <http://www.epa.gov/air/criteria.html>.

[543] 40 C.F.R. § 81, Protection of Environment – Designation of Areas for Air Quality Planning Purposes, *available at* <http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=d1db0aff7b575f1a10494bb6cd8deadf&tpl=/ecfrbrowse/Title40/40cfr81_main_02.tpl>.

[544] US EPA, *Summary of Results for the 1999 National-Scale Assessment*, Technology Transfer Network, *at* < http://www.epa.gov/ttn/atw/nata1999/risksum.html>. A cancer risk of 10 in a million is considered a key threshold.

[545] ICAO, CAEP Information Paper, *infra* note 564 at p. A3.

[546] FAA, Office of Env't and Energy, Roger L. Wayson et al., *Consideration of Air Quality Impacts by Airplane Operations at or Above 3000 feet AGL*, Final Report, FAA-AEE-00-01, DTS-34 (Sept. 2000), at p. 11, *available at*

<http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/catex.pdf> (explaining that the "mixing heights" to determine effect on a local area are "less than the minimum altitude of airplane operations being evaluated, *even at the smaller GA airports*." *id*. at p. 3 (emphasis added). Above the mixing height, "pollutants that are released generally do not mix with ground level emissions and do not have an effect on ground level concentrations in the local area. Accordingly, if airplane operations occur above the mixing height, they will have negligible effect on ground level concentrations." *id*.).

547 The mixing height is variable as a function of season and meteorological conditions.

548 Contrails result from high-altitude water vapor that collects on condensation nuclei (tiny particles) that crystallizes, forming streaks of frozen water vapor. US EPA, *Aircraft Contrails Factsheet*, EPA 430-F-00-005 (Sept. 2000), *available at* <http://www.epa.gov/otaq/regs/nonroad/aviation/contrails.pdf>. The environmental impact of contrails remains under study. The introduction of very light jets (VLJs) and "personal jets" that operate at higher-flight levels may bring new attention of "small GA's" contribution to climate change.

549 Additionally, some emissions may "have an impact on atmospheric composition." U.N., Intergovernmental Panel on Climate Change, *IPCC Special Report-Aviation and the Global Atmosphere, Summary for Policymakers* (1999), at § 2, *available at* <http://www.ipcc.ch/pdf/special-reports/spm/av-en.pdf> ("These gases and particles alter the concentration of atmospheric greenhouse gases, including carbon dioxide (CO_2), ozone (O_3), and methane (CH_4); trigger formation of condensation trails (contrails); and may increase cirrus cloudiness—all of which contribute to climate change." *id*.). Greenhouse gases absorb thermal radiation from earth's surface and have a blanketing effect on it.

550 FAA, Office of Env't and Energy, *Aviation & Emissions - A Primer* (Jan. 2005), at p. 2, *available at* <http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/AEPRIMER.pdf>.

551 *See, e.g.*, South Coast Air Quality Management District, *Multiple Air Toxics Exposure Study in the South Coast Air Basin, (MATES-III)*, Draft for Public Review (Jan. 2008), at p. 6-1 [hereinafter Mates-III], *available at* <http://www.aqmd.gov/prdas/matesIII/draft/ch6.pdf>, and <http://www.aqmd.gov/prdas/matesIII/matesIII.html>. *See* ICAO, *Resolutions Adopted by the Assembly*, 36th Sess., in Montreal, Sept. 18-20, 2007, at p. 15, *available at* <http://www.icao.int/icao/en/env/A36_Res22_Prov.pdf> ("the impacts of aviation emissions of NOx (nitrogen oxides), PM (particulate matter), and other gaseous emissions [on local air quality] need to be further assessed and understood").

552 US EPA, *Control of Air Pollution From Aircraft and Aircraft Engines; Emission Standards and Test Procedures*, Nov. 17, 2005, *at* <http://www.epa.gov/fedrgstr/EPA-AIR/2005/November/Day-17/a22704.htm>. *See generally* US EPA, Particulate Matter, *at* <http://www.epa.gov/air/particlepollution/index.html>.

553 RUIJGROK, *supra* note 11 at p. 289.

554 MATES-III, *supra* note 552, at p. EA-6.

555 *Id*. at p. 6.1.

556 *Id*. at p. 6.1.

557 *See, e.g.*, *id*. at p. 6-1.

558 Hien T. Tran, Ph.D. et al., *Methodology for Estimating Premature Deaths Associated with Long-term Exposures to Fine Airborne Particulate Matter in California*, Cal. EPA, May 22, 2008, at p. 32, *available at* <http://www.arb.ca.gov/research/health/pm-mort/pm-mortdraft.pdf> (with 3-20 percent confidence interval. *id*. at p. 32. Moreover, "[t]reating diesel PM and ambient PM as equally toxic and using the new PM2.5-mortality function, staff estimate that statewide, public exposures to diesel PM can be associated with about 3,900 deaths, with uncertainty ranging from 1,200 to 7,100." *id*. at p. 39). *See* US EPA, *at* <http://www.epa.gov/ord/researchaccomplishments/particulate_matter.html>, Prof. Lynda Lisabeth et al., *Ambient Air Pollution and Risk of Ischemic Stroke and TIA*, ANNALS OF NEUROLOGY, July 2008, *available*

at <http://www.interscience.wiley.com> (finding that exposure to PM increases the risks of stroke). *See infra* notes 622-625 (health risks of diesel emissions). *See generally*, US EPA, PM Research, *at* <http://www.epa.gov/pmresearch/pm_research_accomplishments/> (providing a survey of current research and findings on PM).

559 Christopher J. Sequeira, Candidate for Master's Degrees in Aeronautics and Astronautics and the Technology and Policy Program at the Massachusetts Institute of Technology, *Relationship Between Emissions-Related Aviation Regulations and Human Health*, Presented at the 10th PARTNER Advisory Board Meeting, in Ottawa, Ont., Mar. 15, 2008, at p. 17, *available at* <http://web.mit.edu/aeroastro/partner/reports/hartman/sequeira-08.pdf>.

560 Acidification is the unnaturally high level of acid in precipitation and in the Earth's surface generally (i.e., soil, oceans, and groundwater). It is caused by nitrogen oxides (NO_x), sulfur dioxide (SO_2), and ammonia (NH_3) – all of which are emissions produced from burning fossil fuels. *See* US EPA, Acid Rain, *at* <http://www.epa.gov/acidrain/index.html>. Acidification decimates fish populations by making lakes, rivers, ponds, and oceans uninhabitable. It also destroys property and is detrimental to human health. *See* Nat'l Science and Technology Council, *National Acid Precipitation Assessment: Report to Congress*, (2005), *available at* <http://www.esrl.noaa.gov/csd/AQRS/reports/napapreport05.pdf>. *See generally* US EPA, *Control of Air Pollution From Aircraft and Aircraft Engines; Emission Standards and Test Procedures*, 70 Fed. Reg. 69,665, 69,672-3 (Nov. 17, 2005), *available at* <http://www.epa.gov/fedrgstr/EPA-AIR/2005/November/Day-17/a22704.pdf>.

561 USGS, Toxic Substances Hydrology Program, *Eutrophication*, *at* <http://toxics.usgs.gov/definitions/eutrophication.html> ("a process whereby water bodies, such as lakes, estuaries, or slow-moving streams receive excess nutrients that stimulate excessive plant growth").

562 *See* NRC, PROTECTING VISIBILITY IN NATIONAL PARKS AND WILDERNESS AREAS, Nat'l Academy of Sciences Committee on Haze in Nat'l Parks and Wilderness Areas (Nat'l Academy Press, Wash, D.C. 1993), *available at* <http://www.nap.edu/books/0309048443/html>.

563 ICAO, CAEP, *Science Update: Effects of Aircraft Emissions on Climate and Local Air Quality*, Information Paper, CAEP/7-IP/8, Oct. 27, 2006 ("CAEP Science Update"), at p. A-2, *available at* <http://www.tc.gc.ca/civilaviation/International/ICAO/committee/pdf/information/CAEP7_IP08.pdf>.

564 EPA, *at* <http://www.epa.gov/fedrgstr/EPA-AIR/2005/November/Day-17/a22704.htm>.

565 By the South Coast Air Quality Management District, SoCal, *available at* <http://www.aqmd.gov/>.

566 Philip M. Fine, Ph.D., Atmospheric Measurements Mgr., South Coast Air Quality Management District, *AQMD Airport Monitoring Studies*, Slide Presentation, Jan. 21, 2008 (describing monitoring in communities around GA airports 2005-2007) (copy on file with author).

Another airport ground-based emissions monitoring initiative–at Santa Monica Airport–highlights the political fallout from some such studies, having been characterized by the AOPA as "potentially crippling." Phil Boyer, Pres., AOPA, *Special Notice to Members* (May 30, 2006) (responding to Cal. legislative initiative AB 2501 seeking to require the Santa Monica Airport to undertake 24/7 emissions monitoring notwithstanding prior studies finding no evidence of elevated rates of mortality; and the AOPA claiming the initiative's purpose is to restrict GA). *See* Kevin Herrera, *LA zeroes in on airport*, SANTA MONICA DAILY PRESS, May 20, 2006, *available at* <http://www.smdp.com/article/articles/1363/1/LA-zeroes-in-on-airport/print/1363>.

567 RUIJGROK, *supra* note 11 at p. 114.

568 EPA, *Aircraft Contrails Factsheet*, EPA 430-F-00-005 (Sept. 2000), *available at* <http://www.epa.gov/otaq/regs/nonroad/aviation/contrails.pdf>. *See generally* RUIJGROK, *supra* note 11 at p. 309.

569 RUIJGROK, *supra* note 11 at p. 311.

570 Nicola Stuber, et al, *The importance of the diurnal and annual cycle of air traffic for contrail radiative forcing*, NATURE (July 2006), at pp. 864-867, *available at* <http://www.nature.com/nature/journal/v441/n7095/full/nature04877.html>; <http://ncas.nerc.ac.uk/meetings/past/aviation_impacts/talks/forster.pdf>.

571 ICAO, CAEP, *Science Update: Effects Of Aircraft Emissions On Climate And Local Air Quality*, in Montreal, Feb. 5-16, 2007, at p. A-11, *at* <http://www.tc.gc.ca/civilaviation/International/ICAO/committee/pdf/information/CAEP7_IP08.pdf>.

572 Email from Lourdes Maurice, Ph.D., FAA Office of Env't and Energy, July 15, 2008.

573 Lourdes Maurice, Ph.D., Presentation at Women in Aviation, in San Diego, Cal., Mar. 14, 2008.

574 RUIJGROK, *supra* note 11 at p. 128, 145 (UVC is one of three bands of ultraviolet radiation: UVA 320-400 nm [<3.2 x 10^{-7} - 4.0 x 10^{-7}], UVB 280-320 nm [<2.8 x 10^{-7} – 3.2 x 10^{-7}], and UVC 100-280 nm [<2.8 x 10^{-7}]. The depletion of the stratospheric ozone layer may cause pilots proportionally more harm than any other class because of pilots flying at higher altitudes. [Gamma radiation [<10^{-14} - 10^{-10}], the most energetic and destructive (to life forms) of all types of radiation, is also partially absorbed by the ozone layer).

575 RUIJGROK, *supra* note 11 at pp. 157-162.

576 Alternative fire suppression chemicals/systems have been developed. For example, Eclipse's PhostrEx fire suppression system using a non-halon agent. *See* Eclipse Aviation, *at* <www.eclipseaviation.com>.

577 *See, e.g.*, European Environmental Agency, *at* <http://glossary.eea.europa.eu/EEAGlossary/O/ozone_depletion_potential>.

578 These gases have internal modes that absorb energy in the same infrared wavelengths as emitted by the surface of the Earth, and in doing so, reflect heat.

579 *But see supra* notes 444, et seq. (regarding CO_2).

580 RUIJGROK, *supra* note 11 at p. 143. *See* US EPA, *California v. Johnson*, Petition for Rule Making Seeking the Regulation of Greenhouse Gas Emissions from Aircraft, *available at* <http://cdn.sfgate.com/gate/pictures/2007/12/05/ga_aircraftpet6.pdf> (characterizing greenhouse gases to include: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbonsm, and sulfer hexaflouride.).

581 IPCC, *Climate Change 2001: Working Group 1: The Scientific Basis*, § 6.1.1, *Definition*, Contribution of Working Group I to the Third Assessment Report of the IPCC, *available at* <http://www.grida.no/climate/ipcc_tar/wg1/214.htm#611>.

582 *Id*. *Cf.* IPCC, Glossary (1995), *available at* <http://www.ipcc.ch/pdf/glossary/ipcc-glossary.pdf>, and IPCC, Glossary, Annex 1, at p. 951, *available at* <http://www.ipcc.ch/pdf/glossary/ar4-wg1.pdf>; Joyce E. Penner et al., *Aviation and the Global Atmosphere*, IPCC, 1999, § 6.2.1, *available at* <http://www.grida.no/climate/ipcc/aviation/070.htm>; P. Forster & V. Ramaswamy et al., *Changes in Atmospheric Constituents and in Radiative Forcing*, in *Climate Change 2007: Mitigation*, Contribution of Working Group III to the Fourth Assessment Report of the IPCC, 2007, S. Solomon et al. eds., Cambridge Univ. Press., § 2, at pp. 129-234, *available at* <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf>. Estimates are wide-ranging, but generally RF is considered between 2 and 4 times that of CO_2 alone. IPCC, *IPCC Special Report-Aviation and the Global Atmosphere, Summary for Policymakers* (1999), § 4.8, *available at* <http://www.ipcc.ch/ipccreports/sres/aviation/007.htm>.

583 RUIJGROK, *supra* note 11 at p. 140. *See generally* Susan Solomon & Dahe Qin et al., IPCC, *A report accepted by Working Group I of the Intergovernmental Panel on Climate Change but not approved in detail* (1977), TS.2.5, *available at* <http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_TS.pdf> ("Net Global Radiative Forcing, Global Warming Potentials and Patterns of Forcing"); ICAO, CAEP Information Report, *supra* note 564, at p. A-6 (Table: Instantaneous RF from cumulative emissions of the historical fleet for 1992 and 2000).

[584] IPCC, *IPCC Special Report-Aviation and the Global Atmosphere, Summary for Policymakers* (1999), at § 6.2.3, *at* <http://www.ipcc.ch/ipccreports/sres/aviation/071.htm>.

[585] IPCC, *at* <http://www.ipcc.ch/>. RUIJGROK, *supra* note 11 at p. 144 (noting dispute in the scientific community regarding the accuracy of the GWP because of these gasses purported indirect influence on atmospheric warming and dependent on many variables, including location, season, and altitude. *id*. at p. 168). *See* Commentary to AMCC V.a (introducing the IPCC).

[586] IPCC, *Aviation and the Global Atmosphere, Special Reports*, Sect. 6.6.2, *available at* <http://www.ipcc.ch/ipccreports/sres/aviation/071.htm> ("GWP has provided a convenient measure for policymakers to compare the relative climate impacts of two different emissions. However, the basic definition of GWP has flaws that make its use questionable, in particular, for aircraft emissions. For example, impacts such as contrails may not be directly related to emissions of a particular greenhouse gas. Also, indirect RF from O3 produced by NO_x emissions is not linearly proportional to the amount of NOx emitted but depends also on location and season. Essentially, the buildup and radiative impact of short-lived gases and aerosols will depend on the location and even the timing of their emissions. Furthermore, the GWP does not account for an evolving atmosphere wherein the RF from a 1-ppm increase in CO_2 is larger today than in 2050 and the efficiency of NOx at producing tropospheric O3 depends on concurrent pollution of the troposphere.

In summary, GWPs were meant to compare emissions of long-lived, well-mixed gases such as CO_2, CH4, N2O, and hydrofluorocarbons (HFC) for the current atmosphere; they are not adequate to describe the climate impacts of aviation.").

[587] Kahn Ribeiro, S. S. Kobayashi et al., *Transport and its Infrastructure*, in *Climate Change 2007: Mitigation*, Contribution of WG III to the Fourth Assessment Report of the IPCC, 2007, B. Metz et al. eds., Cambridge Univ. Press., § 5.5.2.1., at p. 376, *available at* <http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter5.pdf> (characterizing it as "A major difficulty in developing a mitigation policy").

[588] US EPA, The Clean Air Act Amendments of 1990, List of Hazardous Air Pollutants, *at* <http://www.epa.gov/ttn/atw/orig189.html>.

[589] URS Corp., *Select Resource Materials and Annotated Bibliography on the Topic of Hazardous Air Pollutants (HAPs) Associated with Aircraft, Airports, and Aviation*, Prepared for FAA, Office of Env't and Energy (July 1, 2003), at p. ES-4, *available at* <http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/HAPs_rpt.pdf>. *See generally* US EPA, *Environmental Indicators: Ozone Depletion*, *at* <http://www.epa.gov/Ozone/science/indicat/>.

[590] URS Corp., *id*. at ES-6 (emphasis added).

[591] URS Corp., *id*. at p. ES-2 (The URS-EPA's table includes 29 HAPs. This table to the Commentary to AMCC V.b presents ethylbenzene as its 11th HAP, which is a TEL reactant and critical component of leaded avgas). *See* US EPA, Air Toxics Website, *at* <http://www.epa.gov/ttn/atw/188polls.html> (presenting the original list of HAPs); US EPA, Summary of Results for the 1999 National-Scale [Air Toxics] Assessment, *at* <http://www.epa.gov/ttn/atw/nata1999/risksum.html>.

[592] ICAO, CAEP *Information Paper supra* note 564, at p. A-3.

[593] *See, e.g.*, Carl Burleson, Dir., FAA Office of Env't and Energy, *Key Environmental Goals and Objectives*, Integrated Product Teams, Next Generation Air Transportation System Institute, *available at* <http://www.ncat.com/pdf/Needs%20Statement-Environment-Round%202.pdf>.

Toxic Assessment rather than CAA coverage: Neither airports nor aircraft are specifically included among the sources identified in the Clean Air Act (CAA) § 112, nor do they meet the definitions of the covered source types. Rather, they are characterized under the National Air Toxics Program (NATP) as an example of complex facilities that produce aggregates of pollutants, including HAPs, from multiple source types. FAA guidelines pertaining to air quality do not specifically address HAPs.

As part of the NATP, the US EPA initiated the National Air Toxics Assessment (NATA) to collect and evaluate information on ambient levels of HAPs, including the near- and long-term patterns and trends; develop tools and techniques for conducting emission inventories and dispersion modeling of HAPs; and identify the primary areas of air pollutant concerns (or "risks") to human and natural environments. *See* <http://www.epa.gov/ttn/atw/nata/>. Similarly, the EPA initiated the Integrated Urban Air Toxics Strategy (IUATS) – a complex and multifaceted approach to assessing HAPs and their sources. *See* US EPA, *Air Toxics Strategy: Overview*, *at* <http://www.epa.gov/ttn/atw/urban/urbanpg.html>.

[594] Lourdes Maurice, Ph.D., Chief Scientist, FAA Office of Env't and Energy, Presentation at Women in Aviation, in San Diego, Cal., Mar. 14, 2008.

[595] Gerald L. Dillingham, Ph.D., Dir. Physical Infrastructure Issues, US GAO, Testimony Before the Subcommittee on Aviation, Committee on Transportation and Infrastructure, US House of Rep., *Aviation and the Environment*, GAO-08-706T, May 6, 2008, at p. 4, *available at* <http://www.gao.gov/new.items/d08706t.pdf>.

[596] Consider the following three aviation engines, each of which is a leading engine in its respective class:

- Textron-Lycoming IO-540 – A version of one of the manufacturer's main post- World War II era GA engines. The Lycoming IO-540 is a six-cylinder, horizontally opposed direct drive engine of 540 cubic inch displacement, equipped with carburetors (referred to as "O-540") or turbochargers (known as "TIO-540"). Generally these engines produce 260 to 315 horsepower. They are installed on many Aero Commanders, Piper Navajos, Chieftans, Aztecs, Saratogas, Comanches, and Aerostars. *See* Textron Lycoming, *at* <http://www.lycoming.textron.com/company/our-history.jsp>, and <http://www.prime-mover.org/Engines/Lycoming/Lyc_Cert_list.html>.
- Continental IO-520 and IO-550 – Developed in the 1960's as turbocharged and fuel injected engines, these engines are the primary competition to the Textron-Lycoming IO-540 series. *See* TCM, *at* <http://www.tcmlink.com>.
- Textron-Lycoming 360 – An air-cooled, carbureted, four-cylinder horizontally opposed piston aircraft engine – a version of one of the manufacturer's main post-World War II era GA engines successfully installed in thousands of aircraft including Cessna 172s, Piper Cherokees/Archers, Grumman Tigers, and many home-built aircraft. *See* <www.lycoming.textron.com/company/our-history.jsp>; and <www.prime-mover.org/Engines/Lycoming/Lyc_Cert_list.html>.

[597] Keep in mind that conventional aircraft piston engines have served the community well and have commendable efficiencies.

[598] Interview with Jorge Alonso, Pres. & CEO, Crossflow Aero Corp., in Orilla, Ontario (June 22, 2006).

[599] *See* Crossflow Aero Corp., *Engine Cooling System*, *available at* <http://www.crossflow.com/tech_info/cooling_system/cooling_system.html>; Steven W. Ells, *Three to go*, AOPA PILOT, July 2006, at p. 134, *available at* <http://www.aopa.org/pilot> ("There's some prejudice in the field—by both technicians and pilots—against liquid cooling, but it's proven to be an effective method of controlling cylinder head temperatures (CHTs)."). *See also* Bombardier, *at* <http://machinedesign.com/ContentItem/61999/TheflyingVsarecoming.aspx>.

[600] And (emissions) effective muffler systems. A "three-way" catalytic converter converts engine emissions of nitrogen oxides (NO_x), carbon monoxide (CO) and unburned hydrocarbons from fuel (C_xH_y) into water (H_2O), carbon dioxide (CO_2), and nitrogen (N_2). RUIJGROK, *supra* note 11 at pp. 16-17.

[601] *See* <http://www.eere.energy.gov/de/pdfs/ares_program.pdf>. *But see* Textron Lycoming, Press Release, *Lycoming Engines Announces IO/O-360 Automotive Gas Approval Program*, June 2, 2008, (unleaded automotive gasoline approval program – 3 AKI automotive gasoline conforming to either Euro Norm EN228 or ASTM D4814), *available at* <http://www.lycoming.textron.com/news-and-events/press-releases/release-06-02-08.jsp>.

[602] For example, the Bombardier V220 and V300T aircraft engines, *at* <http://www.brp.com/NR/rdonlyres/3B0CFB18-5606-43F8-A09D-D05E2F8E7523/0/englbackgrounder_v220v300tlogo.pdf>, and <http://www.brp.com/en-CA/Innovation/Technology/V220.V300T.Aircraft.Engines.htm>, and the Crossflow six cylinder engines weigh less than 460 lbs., and the four cylinder engines weigh under 360 lbs. However, the comparative weight of a water-cooled engine should include the weight of a radiator, coolant, and cooling pump. Moreover, air cooled engines are generally aluminum, except for the crankshaft.

[603] For example, 10.8-to-1 for the 220-hp engine, and 9-to-1 for the 300-hp engine.

[604] *Rotax*, *at* <http://www.rotax-aircraft-engines.com/>.

[605] These companies include: Jibaru, *at* <http://www.jabiru.net.au/>, and Ecofly, *see* TODAY'S PILOT, July 2004, *at* <http://www.ecofly.de/Assets/Todays_pilot_07_04.pdf>.

[606] Two-stroke engines are responsible for about 32% of mobile source emissions. historically two-cycle engines dump 20-30% of their fuel unburned. The US EPA asserts that two-cycle engines emit 30 times the hydrocarbons (benzene, butadiene, and polycyclic aromatic HC) and 40 times the PM of four-cycles.

[607] Concerning reliability, because of the highly varied quality of maintenance in the field, it is difficult to establish if two-cycles engines are less reliable than the four-cycles, but the typical failure mode of a two-cycle is much more sudden than that of a four-cycle. This may contribute to the common belief that four-cycles are much more reliable. Regardless, the four-cycles have many qualities that make them attractive despite their price and weight penalties.

[608] Matthew L. Wald, *Diesel a Savior in Squeeze on Energy? Obstacles Exist*, N.Y. TIMES, May 29, 2006, at p. A13, *available at* <http://www.nytimes.com/2006/05/29/us/29diesel.html?_r=1&oref=login> (stating that one gallon of diesel fuel produces 128,000 BTU versus 115,000 for gasoline, and diesel engines offer a better pre-combustion air-fuel mixture). Email from Phil Franklin, Wilksch Airmotive Ltd (WAM), Apr. 21, 2008 ("We have seen significant (10-30%) operational fuel consumption improvements when aircraft have been fitted with WAM diesels of existing avgas burning engines.").

[609] *Cf.* US EPA, *at* <http://www.epa.gov/otaq/highway-diesel/index.htm>.

[610] For example, until its bandruptcy, the Thielert diesel was offered in the Diamond Aircraft Industries' DA42 Twin Star, *see* Diamond, *at* <http://www.diamondair.com/aircraft/da42_private/index.html>; as well as in the Cessna Skyhawk 172S and TD (turbo diesel Thielert Centurion 2.0 litre engine with FADEC, turbocharged, 155 hp at 2,300 rpm, liquid cooled engine, with a fuel consumption of 30 percent less than the gasoline-powered version). Thielert's bankruptcy demonstrates the aviation diesel industry's immaturity and, the "drama at Thielert may well be that the engine simply was certified too soon." *Frank Thielert knows a lot about diesel engines, less about GA conditions of customer service, and not enough about managing a public company*, DIESEL AIR NEWSLETTER, Apr. 27, 2008, *at* <http://www.dieselair.com/>. Note that TCM plans for a 300 HP diesel to be certified by 2009-10.

[611] Thielert claims to have been awarded more than 110 international certifications. STCs cover nearly the entire Cessna 172 product range. SMA (Société de Motorisations Aéronautique) has obtained an STC for the Cessna 182 [230 HP SR305] and is near completion of an STC for the Piper PA 28. Cessna Aircraft announced plans to offer diesel-powered single-engine piston airplanes in its 2009 model year and was well along with test flights of a Thielert-equipped Skyhawk before abruptly suspending development in response to Thielert's bankrupty.

[612] Andre Teissier-duCros, Publisher, *The progression of aero diesel production and availability will coincide with a mutation of the world market of piston-engined airplanes*, DIESEL AIR NEWSLETTER, Dec. 15, 2007, *at* <http://www.dieselair.com/>. *See* Rhett Ross, CEO, TCM, Interview by Paul Bertorelli, AV. CONSUMER, Feb. 18, 2008, *at* <http://www.avweb.com/podcast/podcast/197170-1.html> (TCM "kicking off a major aerospace-specific [diesel] engine design" with the goal of type-certification in late 2009 to early 2010). *See* Austro Engine, Jet A1 Piston Engines, *at* <http://www.austroengine.at/produkte/jet-a1-piston-engines/> (Diamond Aircraft equipped with the Austro Engines AE 300).

613 A Wilsch WAM 120-equipped Thorpedo from IndUS Aviation. A three-cylinder, 120-horsepower engine burning 3 gal. hour of Jet-A. *See* <www.indusav.com>, and <http://www.indusav.com/indusav/newsdetails.php?sid=58> (first ASTM standards-compliant diesel LSA).

614 Interview with Earl Lawrence, VP, Industry and Regulatory Affairs, EAA, in Marysville, Cal. (June 7, 2008) (also acknowledging that the small volume of engines in GA are not a significant incentive to fund such rigorous testing regimes).

615 Diane Doers, *quoted in* David Kowalsky, *The Future of Diesel?*, PIPERS, June 2006, at p. 49 ("There are parts of the world where general aviation fleets are effectively grounded because they cannot buy avgas. And if it's available, the cost is 3 to 5 times what U.S. pilots pay.").

616 For example, the Thielert Centurion 2.0 engine, *at* <http://www.centurion-engines.com/>.

617 *See* Wikipedia, *Brake specific fuel consumption*, *at* <http://en.wikipedia.org/wiki/Brake_specific_fuel_consumption> (explaining BSFC).

618 Email from George Braly, Chief Engineer, GAMI, Feb. 26, 2008 (also noting that, "for example, an available 350 Hp diesel aircraft engine has an all up installed wet weight that is more than 225 lbs heavier than the approximately 500 pound weight of a popular 350 Hp gasoline powered aircraft engine."). *Cf.* "Diesel engines have been around since the '20's, built specifically for aviation. Events of WWII and the need to rapidly manufacture and deploy aircraft and engines necessitated the production of already well-researched gasoline engines. Using data from the past and new technology, manufacturers such as Thielert have been able to manufacture engines of comparable weight and power with bsfc's at .36 and lower. The main advantage of diesels is their fuel efficiency at takeoff and climb as well as their good cruise efficiency. Even takeoff and climb stays in the .3 bsfc range whereas gasoline engines, even with fadec, are at .4 or .5 ranges in takeoff and climb for cooling. Reliability of Thielerts is mainly affected by the fadec and will likely be comparable to gasoline engine FADEC systems. Continentals recent announcement of development of a 300-350 HP diesel or 'heavy fuel' engine for about the same weight and power as the IO-550 are interesting and timely." Email from Todd Petersen, Petersen Aviation, Inc., Mar. 1, 2008.

Aviation diesel engine's SFC similarity to that of existing avgas-burning engines has been explained as follows:

- the diesel engine's higher compression ratio (CR) will help give a more efficient cycle
- a high-compression gasoline engine is not far behind because the effect of CR is very small above 12:1
- the diesel engine's higher air:fuel ratio will also help give a more efficient cycle
- lean-burn gasoline engines are about equivalent to the high air:fuel ratio of a diesel
- the unthrottled diesel cycle (obviously) does not suffer throttle losses ever
- at WOT a gasoline engine has no throttle loss
- good turbocharging will significantly improve an engine – because a diesel does not suffer knock it can run at much higher boost pressures, where the turbo's contribution to fuel economy is that much greater
- at high altitude a gasoline engine can also accept high boost pressure ratios because of the thin cold air

Email from Phil Franklin, Wilksch Airmotive Ltd (WAM), Apr. 21, 2008.

619 Braly, *id*. [Feb. 26, 2008]; *see* George Braly, *Comment in response to EPA Docket No. OAR-2007-0294 Petition Requesting Rulemaking To Limit Lead Emission from General Aviation Aircraft; Request for Comment*, Mar. 17, 2008, *available at*

<http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&o=09000064803fc92b> (listing diesel engine disadvantages). Additionally, consider that diesel fuel weights more than avgas.

620 *See, e.g.*, Environmental Defense, *Scorecard – Diesel Emissions*, *at* <http://www.scorecard.org/env-releases/def/hap_diesel.html> (overview of risks from diesel fuels – including that "cancer risks from diesel emissions are about ten times higher than the cancer risks from all other hazardous air pollutants combined." *id*.); US EPA, National Center for Environmental Assessment, Office of Research and Development, *Health Assessment Document for Diesel Engine Exhaust, Quality*, US EPA/600/8-90/057F (2002), *available at* <http://oaspub.epa.gov/eims/eimscomm.getfile?p_download_id=36319> ("assessment concludes that long-term (i.e., chronic) inhalation exposure is likely to pose a lung cancer hazard to humans, as well as damage the lung in other ways depending on exposure. Short-term (i.e., acute) exposures can cause irritation and inflammatory symptoms of a transient nature, these being highly variable across the population. . . . evidence for exacerbation of existing allergies and asthma symptoms is emerging."); South Coast Air Quality Management District, *Multiple Air Toxics Exposure Study in the South Coast Air Basin (MATES-III)*, Draft for Public Review (Jan. 2008), at § 6.3, at p. 6-1, *available at* <http://www.aqmd.gov/prdas/matesIII/draft/ch6.pdf>, and <http://www.aqmd.gov/prdas/matesIII/matesIII.html> (Finding that "[d]iesel exhaust was the key driver for air toxics risk, accounting for an estimated 84% of the total."). *See generally* US EPA, *National Clean Diesel Campaign*, *at* <http://www.epa.gov/cleandiesel/publications.htm#caaac-apr06>, and <http://www.epa.gov/otaq/highway-diesel/index.htm> (summarizing initiatives to improve diesel emissions); *supra* text accompanying notes 553-560 (describing PM).

621 *See* MANOJ S. PATANKER ET AL., SAFETY ETHICS (Ashgate 2005), at p. 168.

622 US EPA, *Clean Trucks, Buses, and Diesel Fuel Proposed Rule*, *at* <http://www.epa.gov/otaq/regs/hd2007/dsl-nprm.htm>. *See supra* note 68 (May 1, 2008 US EPA petition to further tighten lead standards). *See also* Claus Wahl, Theo Rindisbacher, et al, *Microphysical and Chemical Properties of Nanoparticles Emitted by Flight Engines*, Sept. 13, 2005, *available at* <http://hjelmco.com/upl/files/2419.pdf> (Avgas-powered reciprocating engines found to emit nanoparticles of soot and lead bromide, at least during rich mixture conditions).

623 PATANKER, *supra* note 66 at p. 167 ("It is my contention, and that of many others, that in the absence of a point estimate or a plausible range of estimated unit cancer risks(s), which reflect the conservative and non-conservative risk estimates for this pollutant, it remains uncertain how appropriate health-protective policy can be adopted and an effective informed debate can occur." *id*.).

624 Email from Phil Franklin, Wilksch Airmotive Ltd (WAM), Apr. 21, 2008.

625 There are two types of compressors used in turbine engines – centrifugal and axial flow. Axial flow compressors are more efficient producing higher compression ratios, and are the predominant type used in GA turbines.

626 *See* NASA, *Beginner's Guide to Propulsion*, *at* <http://www.grc.nasa.gov/WWW/K-12/airplane/bgp.html>, and NASA, *Turbine Animation*, *at* <http://www.grc.nasa.gov/WWW/K-12/airplane/Animation/turbtyp/ettm.html>.

627 NASA, *Quest for Performance: The Evolution of Modern Aircraft*, Ch. 10, *available at* <http://www.hq.nasa.gov/office/pao/History/SP-468/ch10-3.htm>.

628 US EPA, *Control of Air Pollution from Aircraft and Aircraft Engines*, May 8, 1997, at p. 7, *available at* <http://epa.gov/otaq/regs/nonroad/aviation/airrsd.pdf>.

629 ICAO, Committee on Aviation Environmental Protection (CAEP), Engine Emissions Databank, *at* <http://www.caa.co.uk/default.aspx?categoryid=702&pagetype=90> (but limited to jet engines producing rated output greater than 26.7 kN).

630 *See* NASA, *Turboprop Engine*, *at* <http://www.grc.nasa.gov/WWW/K-12/airplane/aturbp.html> (simulation).

[631] Raffi Babikian, Stephen P. Lukachko & Ian A. Waitz, MIT, *The Historical Fuel Efficiency Characteristics of Regional Aircraft from Technological, Operational, and Cost Perspectives* (undated), at p. 8, *available at* <http://web.mit.edu/aeroastro/people/waitz/publications/Babikian.pdf>.

[632] *Id*.

[633] RUIJGROK, *supra* note 11 at p. 268.

[634] Based upon a chart in RUIJGROK, *supra* note 11 at p. 269.

[635] *At* <http://www.utc.com/profile/facts/history.htm>.

[636] *Turboprops fly back in favour as greener and cheaper options*, TIMESONLINE, Apr. 21, 2008, *at* <http://business.timesonline.co.uk/tol/business/industry_sectors/transport/article3745007.ece>.

[637] *See* General Electric, Press Release, *General Electric Company To Acquire Walter Engines* (Aug. 27, 2007), *available at* <http://www.genewscenter.com/content/Detail.asp?ReleaseID=2666&NewsAreaID=2>; Stephen Singer, Asso. Press, *GE Aviation buys Czech turboprop engine maker*, FORBES.COM, July 3, 2008, *at* <http://www.forbes.com/feeds/ap/2008/07/03/ap5182828.html>. The Walter M601 engine is used on more than 30 aircraft types. GE's purchase invokes direct competition with Pratt & Whitney.

[638] RUIJGROK, *supra* note 11 at p. 283 ("Complete combustion of a hydrocarbon fuel given by CxHy [means] no dissociation, so that all fuel carbon C is found in CO_2 and all fuel hydrogen H is found in H_2. The necessary condition for obtaining complete combustion is that the air-fuel ratio is stoichiometric, i.e., the quality of oxidizer air is just the amount required to completely burn a quantity of fuel CxHy." *id*.). NOx formation varies exponentially with the stoichiometric flame temperature. *id*. at p. 300. Higher combustion temperatures (increasingly designed into newer engines) create greater thermal efficiency and yet greater thermal NO_x formation. *id*. at p. 301.

See V. Ramanathan & G. Carmichael, *Global and regional climate changes due to black carbon*, NATURE GEOSCIENCE, Mar. 23, 2008, at pp. 221-227, *available for fee at* <http://www.nature.com/ngeo/journal/v1/n4/full/ngeo156.html> (citing black carbon, or soot, as the "dominant absorber of visible solar radiation in the atmosphere" caused by fossil fuel combustion).

[639] RUIJGROK, *supra* note 11 at p. 289.

[640] RUIJGROK, *supra* note 11 at p. 239.

[641] RUIJGROK, *supra* note 11 at p. 79.

[642] Charlotte Adams, *Green Engines*, AVIATION MAINTENANCE, May 2008, *available at* <http://www.avtoday.com/am/categories/commercial/21556.html>.

[643] Rick Kennedy, GE Aero Engines, *quoted in* David Esler, *A New Engine Class Emerges: The '10Ks'*, BUSINESS & COMM. AVI., Aug. 2007, at p. 48.

[644] Guy Norris, *Testing Times*, AVI. WEEK & SPACE TECH., Dec. 10, 2007, at p. 48, *available to subscribers at* <www.aviationweek.com/awst>; Pratt & Whitney, Press Release, *Pratt & Whitney Announces New Geared Turbofan Technology Partnership*, July 18, 2006, *available at* <http://www.pw.utc.com/vgn-ext-templating/v/index.jsp?vgnextoid=2e35288d1c83c010VgnVCM1000000881000aRCRD&prid=281905a2072de010VgnVCM100000c45a529f>.

[645] Bob Saia, VP Production, Pratt & Whitney, *quoted in* Guy Norris, *Composite Question*, AVI. WEEK & SPACE TECH., Mar. 31, 2008, at p. 48, *available to subscribers at* <www.aviationweek.com/awst>.

[646] Pratt & Whitney, Press Release, *Pratt & Whitney's Geared Turbofan™ Demonstrator Engine Achieves Full Power*, Dec. 4, 2007, *available at* <http://www.pw.utc.com/vgn-ext-templating/v/index.jsp?vgnextoid=2e35288d1c83c010VgnVCM1000000881000aRCRD&prid=eacceb66a66a6110VgnVCM100000c45a529f>. Paul Adams, Sr. VP of Engineering, Pratt & Whitney, *quoted in* Michael Mecham, *Group Talents*, AVI. WEEK & SPACE TECH., May 12, 2008, at p. 61 (anticipating a 1%

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per year reduction in SFC "for the rest of the decade."). *See* MTU Aero Engines, *Clare – Clean Air Engines*, *at* <http://www.mtu.de/en/technologies/claire/index.html> (targeting significant reductions in fuel burn).

[647] *See* Pratt & Whitney, Press Release, *Airbus to Flight Test Pratt & Whitney Geared Turbofan Engine*, Apr. 21, 2008, *available at* <http://www.pw.utc.com/vgn-ext-templating/v/index.jsp?vgnextoid=2e35288d1c83c010VgnVCM1000000881000aRCRD&prid=eacceb66a66a6110VgnVCM100000c45a529f____>.

[648] Pratt & Whitney, Press Release, *Pratt & Whitney Launches Geared Turbofan Engine with Mitsubishi Regional Jet*, Oct. 9, 2007, *available at* <http://www.pw.utc.com/vgn-ext-templating/v/index.jsp?vgnextoid=2e35288d1c83c010VgnVCM1000000881000aRCRD&prid=5148df489cb65110VgnVCM100000c45a529f____> (14,700-17,000 lbs. thrust).

[649] SBAC Aviation and Environmental Briefing Papers, *3. Open Rotor Engines*, Society of British Aerospace Companies, Apr. 3, 2008, *available at* <http://www.sbac.co.uk/community/news/download.asp?a=4738>; Robert Wall & Michael Mecham, *Open for Business*, AVI. WEEK & SPACE TECH., Feb. 25, 2008, *available at* <http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=comm&id=news/aw022508p3.xml> (considering the Leap56 research initiative by GE and Snecma to develop open-rotor and counter-rotating fan technologies). *Cf.* Douglas Barrie et al., *Open Question*, AVI. WEEK & SPACE TECH., Oct. 22, 2007, at p. 26, *available at* <http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=comm&id=news/aw102207p2.xml> (suggesting that actual fuel-burn improvement of open rotors may be 10% or less, rather than the target 15%, in part, due to extra weight; and that geared turbofans may be more competitive).

[650] Guy Norris, *Open Warfare*, AVI. WEEK & SPACE TECH., May 12, 2008 (GE collaborating with NASA to revive unducted fan technology studies).

[651] Guy Norris, *HEART of the MATTER*, AVI. WEEK & SPACE TECH., May 12, 2008, at p. 48.

[652] RUIJGROK, *supra* note 11 at p. 307.

[653] IATA, *Destination Zero, The Journey Towards . . . CO_2-free flight, video at* <http://iata.org/iata/video/homePage/destinationzero.asx>.

[654] Centrifugal compressors (vs. axial compressors) are more efficient on engines producing under 12,000 lbs. of thrust, and offer better protection against FOD and bird strikes.

[655] *Flying by the Numbers, Emission Control*, PRIVATE AIR, Mar./Apr. 2008, at p. 168, *available at* <www.privateairdaily.com>.

[656] US EPA, *Control of Air Pollution From Aircraft and Aircraft Engines; Emission Standards and Test Procedures*, 70 Fed. Reg. 69,664, 69,675 (Nov. 17, 2005), *available at* <http://www.epa.gov/EPA-AIR/2005/November/Day-17/a22704.htm>.

[657] Telephone Interview with Sam Sampath, Mgr. and Sr. Fellow on Combustion and Emissions, Pratt & Whitney (May 26, 2006).

[658] IPCC, *supa* note 434 at § 7.9.5.3.

[659] H.C. Eatock & P. Sampath, *Low Emissions Combustor Technology for Small Aircraft Gas Turbines*, Paper presented at the 82nd Symposium, Technology Requirements for Small Gas Turbines, Advisory Group for Aerospace Research and Development, Oct. 1993, AGARD Propulsion and Energetics Panel, Specialised Printing, Sussex Ltd., Laughton, Essex, UK, *cited in* IPCC, *supra* note 434.

[660] US EPA, *Control of Air Pollution from Aircraft and Aircraft Engines; Emission Standards and Test Procedures*, 70 Fed. Reg. 69,665, 69,673 (Nov. 17, 2005), *available at* <http://www.epa.gov/fedrgstr/EPA-AIR/2005/November/Day-17/a22704.pdf>. *See* US EPA, 43 Fed. Reg. 12,615 (Mar. 24, 1978) (6,000 lbs thrust or equivalent power or greater, used for commercial applications).

661 Eclipse Aviation, *Specifications*, *available at* <http://www.eclipseaviation.com>.

662 Jack L. Marinelli & Roger L. Benefiel, Beech Aircraft Corp., *Designing For Noise And Emission Control In General Aviation*, AIAA-1973-1158, Presented at the CASA/AIAA Aeronautical Meeting in Montreal, Oct. 29-30, 1973, *available for fee at* <http://www.aiaa.org/content.cfm?pageid=406&gTable=mtgpaper&gID=95334>.

663 *See infra* notes 701-703 (referencing ICAO and other emissions database).

664 Telephone Interview with Walter Desrosier, GAMA, July 3, 2008.

665 This engine has a wide-cord fan, multi-stage axial-flow compressor, straight-through, low emission combustor, 5 high and low pressure turbine stages, no centrifugal-flow compressor, pressure ratio of 25:1 to 26:1, 4.5:1 bypass ratio, specific fuel consumption > 0.525 lbs/thrust, 50% lower NOx, 35% lower CO, and lower CO_2 than ICAO CAEP/6. *See generally* CAEP, *at* <http://www.icao.org>. It is claimed by the manufacturer that this engine has a fuel burn 5-10% less compared with current leading engines, will reduce CO by over 35%, and NO_x UHCs, and smoke emissions by over 50% below ICAO standards, satisfying anticipated emissions standards for the next 10 to 15 years.

666 *See* Walter Engines, *at* <http://www.walterengines.com/products/aircraft-engines/description.htm>, and <http://www.walterengines.com/editor/image/download1_soubory/4.doc> (listing aircraft types using Walter turbines).

667 Incorporating TALON 2 combustor technology; surpassing ICAO emission standards by 33%, meets Zurich 5 low-emission requirements for no surcharges.

668 Diamond, *at* <http://www.diamond-air.at>.

669 A scaled derivative of the Williams FJ44.

670 Vern Raburn, CEO, Eclipse Aviation, *The New Eclipse 400*, Presentation, June 5, 2008, AERO-NEWS NETWORK, *at* <http://www.aero-news.net> (an hourly fuel burn at max cruise thrust at 350 kts. at 45 and ½ gal per hour – 305 pounds per hour).

671 "Green Factor" - Eclipse Aviation promotes the "green factor" of its twin engine VLJ touting low emissions and noise from the 500's P&W engines, reductions in hazardous materials in the manufacturing process, and recyclability of materials used in the aircraft itself.

672 Eclipse Aircraft, *at* <http://www.eclipseaviation.com/index.php?option=com_newsroom&task=viewpr&id=1044&Itemid=348>.

673 Reduced SFC by 3.5%, NO_x by 17%, and smoke 50%.

674 Honda Turbofan Engine, *at* <http://world.honda.com/HondaJet/Background/TurbofanEngine/>.

675 Note: (a) some engine power ratings are periodically upgraded, (b) power ratings are for single engines, and (c) Smoke Number refers to the take-off phase of flight.

676 *Flying by the Numbers, Emission Control*, PRIVATE AIR, Feb./Mar. 2008, at p. 168, *available at* <http://www.privateairdaily.com/magazine/article/15629.html>.

677 Eclipse Aviation, Press Release, *Eclipse Aviation Introduces Eclipse 400 Single-Engine Jet*, May 30, 2008, *available at* <http://www.eclipseaviation.com/index.php?option=com_newsroom&task=viewpr&id=1378&Itemid=52>.

678 *Supra* text accompanying notes 406-475.

679 Section 231(a)(2)(A), 42 U.S.C. § 7571(a)(2)(A), *available at* <http://www.epa.gov/air/caa/caa.txt> (authorizing the US EPA Administrator to issue emission standards for aircraft and aircraft engines "which in his judgment causes, or contributes to, air pollution which may reasonably be anticipated to endanger the public health or welfare."). *See* Commentary to AMCC V.a, *available at*

<http://www.secureav.com/Comment-AMCC-V.a-Environmental.pdf> (introducing the CCA and describing the relationship of international environmental accords, such as via ICAO, on domestic aviation emissions standards).

[680] CAA § 231(a)(2)(B)(i), *available at* <http://www.epa.gov/air/caa/caa.txt>.

[681] US EPA, *Control of Air Pollution From Aircraft and Aircraft Engines; Emission Standards and Test Procedures*, 70 Fed. Reg. 69,665, 69,676 (Nov. 17, 2005), *available at* <http://www.epa.gov/fedrgstr/EPA-AIR/2005/November/Day-17/a22704.pdf>, citing *Husqvarna AB v. EPA*, 254 F.3d 195 (D.C. Cir. 2001), *available at* <http://caselaw.lp.findlaw.com/cgi-bin/getcase.pl?court=DC&navby=case&no=001270A>.

[682] US EPA, *Control of Air Pollution from Aircraft and Aircraft Engines, Emission Standards and Test Procedures for Aircraft*, 38 Fed. Reg. 19,088-19,103 (July 17, 1973) [Title 40 – Protection of Environment, Ch. 2, EPA, Part 87 – Control of Air Pollution from Aircraft and Aircraft Engines]. The rule also created a separate class for turboprop engines.

[683] *Id*. at 19,089 [US EPA, July 17, 1973].

[684] 38 Fed. Reg. 19,092 (July 17, 1973), at § 87.41 (for engines manufactured on or after Dec. 31, 1979). This standard was promulgated primarily to control CO emissions at high-activity GA airports. 45 Fed. Reg. 1,420 (Jan. 7, 1080).

[685] US EPA, 38 Fed. Reg. 19,089 (July 17, 1973).

[686] *See supra* note 342 (fuel venting regulations).

[687] US EPA, 43 Fed. Reg. 12,615 (Mar. 24, 1978) (also extending the effective date for all newly manufactured turbine gaseous emissions standards that would have otherwise been effective on Jan 1, 1979 –until Jan. 1, 1981).

[688] US EPA, 45 Fed. Reg. 1,419 (Jan. 7, 1980).

[689] US EPA, 47 Fed. Reg. 58,468 (Dec. 30, 1982).

[690] US EPA, 45 Fed. Reg. 1,420 (Jan. 7, 1980).

[691] US EPA, 43 Fed. Reg. 12,618 (Mar. 24, 1978).

[692] US EPA, 47 Fed. Reg. 58,464 (Dec. 30, 1982).

[693] US EPA, 47 Fed. Reg. 58,472 (Dec. 30, 1982) (SN-187 $(rO)^{-0.168}$ for rO=100 kW).

[694] US EPA, 62 Fed. Reg. 25,356 (May 8, 1997).

[695] US EPA, *Control of Air Pollution from Aircraft and Aircraft Engines; Emission Standards and Test Procedures*, 70 Fed. Reg. 69,664-69,687 (Nov. 17, 2005) [Rules and Regs.], *at* <http://www.epa.gov/fedrgstr/EPA-AIR/2005/November/Day-17/a22704.htm> (A unit of measure equal to 1000 newtons. The newton (N) is the unit of force in the International System of Units (SI) required to accelerate a body with a mass of one kilogram at a rate of one meter per second.).

[696] US EPA, *Control of Air Pollution From Aircraft and Aircraft Engines; Emission Standards and Test Procedures*, 70 Fed. Reg. 69,665, 69,673 (Nov. 17, 2005), *available at* <http://www.epa.gov/fedrgstr/EPA-AIR/2005/November/Day-17/a22704.pdf> (withdrawing emission standards "for all gas turbine engines used only for general aviation applications" and for gas turbine engines of rated thrust less than or equal to 26.7 kN). *See* US EPA, *Control of Air Pollution from Aircraft and Aircraft Engines; Emission Standards and Test Procedures*, Final Rule, 47 Fed. Reg. 58,462 (Dec. 30, 1982), at pp. 38-39, *available at* <http://www.epa.gov/otaq/regs/nonroad/aviation/420r05004.pdf>, and <http://www.epa.gov/otaq/aviation.htm>.

[697] US EPA, 68 Fed. Reg. 56,226 (Sept. 30, 2003).

[698] *At* <http://www.icao.int/icao/en/env/aee.htm>.

[699] ICAO, Committee on Aviation Environmental Protection (CAEP), *Engine Emissions Databank*, *at* <http://www.caa.co.uk/default.aspx?categoryid=702&pagetype=90> (but limited to turbine engines producing rated output greater than 26.7 kN). *See generally* CAA, Aircraft Engine Emissions, Emissions Databank, *at* <http://www.caa.co.uk/default.aspx?catid=702>.

[700] *See, e.g.*, FAA, *Emissions and Dispersion Modeling System, at* <http://www.faa.gov/about/office_org/headquarters_offices/aep/models/edms_model/> (utilizing the ICAO assessment mechanisms).

[701] *E.g.*, psiA Consult, *Final report on Air Traffic Emissions*, 5th Framework Program, Project ARTEMIS, Assessment and reliability of transport emission models and inventory systems project funded by the European Commission within The 5th Framework Research Programme, DG TREN Contract No. 1999-RD.10429, Deliverable No. 8 (2001), Sect. 4, *available at* <http://www.inrets.fr/ur/lte/publi-autresactions/fichesresultats/ficheartemis/non_road4/Artemis_del8_air.pdf>.

[702] ICAO's environmental work is undertaken primarily by its Committee on Aviation Environmental Protection (CAEP). Its periodic meetings have produced aircraft engine emissions standards. CAEP has held six meetings (convened every three years) as follows: 1986 (CAEP/1), 1991 (CAEP/2), 1995 (CAEP/3), 1998 (CAEP/4 – implementation date Dec. 31, 2003), 2001 (CAEP/5), 2004 (CAEP/6 – implementation date Dec. 31, 2007), and 2007 (CAEP/7).

[703] The interpolation is based upon the rated output to determine the NO_X limits for such engines: Oxides of Nitrogen: (37.572 + 1.6(rPR) - 0.2087(rO)) grams/kN rO.

[704] Moreover, from a marketing/sales perspective, commercial operators fly some Part 91 operations; other buyers recognize the larger market and resale value of aircraft that satisfy commercial standards.

[705] ICAO, CAEP, WG3, *Definition Of Technological Feasibility In The Context Of Considering Revised Engine Exhaust Emissions Standards And Transition Goals To Standards*, Feb. 5-26, 2007, *at* <http://www.tc.gc.ca/AviationCivile/Internationale/OACI/comites/pdf/working/CAEP7_WP09.pdf> (Emissions standards must be based on technological feasibility). US EPA, *Control of Air Pollution From Aircraft and Aircraft Engines; Emission Standards and Test Procedures*, 70 Fed. Reg. 69,665, 69,676 (Nov. 17, 2005), *available at* <http://www.epa.gov/fedrgstr/EPA-AIR/2005/November/Day-17/a22704.pdf> (US EPA requirements can be "technology-forcing" but are not required to be such. "EPA has greater flexibility . . . in determining what standard is most reasonable for aircraft engines." However, EPA must "provide the necessary time to permit the development and application of the requiste technology." *id.* at p. 69,667); *Train v. Natural Resources Defense Council*, 421 U.S. 60 (1975) (Congress intent for Clean Air Act to be technology-forcing).

[706] *See* Bruce C. Jordan, *An Assessment of The Potential Air Quality Impact of General Aviation Aircraft Emissions*, US EPA, Office of Air Quality Planning and Standards, OMSAPC-78-1, June 17, 1977, at p. 40 (copy on file with author) (concluding, in part, that there are "some preliminary indications that substantially more benfits can be gained through [control of] evaporative emission control" than via exhaust emissions controls.). *See supra* note 345 on evaporative emissions.

[707] *See, e.g.*, US EPA, *Emission Standards Reference Guide for Heavy-Duty and Nonroad Engines*, EPA420-F-97-014, Sept. 1997, at p. 15, *available at* <http://www.epa.gov/OTAQ/cert/hd-cert/stds-eng.pdf>; US DoT, *Federal Exhaust Emissions Standards for Newly Manufactured and In-Use Aircraft Engines*, Table 4-34, *at* <http://www.bts.gov/publications/national_transportation_statistics/html/table_04_34.html>.

Until the CAEP/4 standards, ICAO/EPA applied standards (at separate implementation dates) to newly manufacturerd (already certified) and newly certified engines. ICAO adopted a more stringent NOx standard that became effective in 2008 (2008+), and the EPA intends to adopt equivalent standards in the future. ICAO's latest standards for newly certified engines are 16.72 + 1.4080(rPR) for engines with a pressure ratio of 30 or less and 1.04 + 2(rPR) for engines with a pressure ratio of more than 30 but less than 82.6. rPR stands for rated pressure ratio. Email from Brian Manning, EPA, July 15, 2008.

[708] ICAO, CAEP, *Science Update: Effects Of Aircraft Emissions On Climate And Local Air Quality*, in Montreal, Can., Feb. 5-16, 2007, at p. A-10, *at* <http://www.tc.gc.ca/civilaviation/International/ICAO/committee/pdf/information/CAEP7_IP08.pdf>.

[709] Roger L. Wayson & Greg G. Fleming et al., *Derivation of A First Order Approximation of Particulate Matter From Aircraft*, Paper 69970, DoT Volpe Transp. Center, *available at* <http://www.volpe.dot.gov/air/docs/69970.pdf> (For example, "Small particles are not well represented by the smoke number, the combustion process varies by engine design, and the fuel-to-air ratio will change with each mode." The paper also highlights an approach to assess a first order approximation method for PM in commercial transport operations – "an emission index, such as grams of pollutants per kilogram of fuel burn, to be determined beginning with a known, reference emission index, and then corrected by changing smoke numbers (SN). The underlying assumption is that the change in mass emissions is correlated to the change in SN.").

[710] For example, *Pollution Number* [P= EI/(V/F) P expressed in g/km] quantifies emissions efficiency, such as NO_x efficiency which can be expressed as the amount of pollution produced per passenger Km – incorporating emission index, fuel consumption, and productivity.

[711] The SN represents the extent to which darkening occurs; its range is SN= 1-99. *See* US EPA, 38 Fed. Reg. 19,095 (July 17, 1973), at § 8782 (system for measuring smoke exhaust emissions).

[712] H.W. Jentink & J.F.F. van Veen, *In-Flight Spectroscopic Aircraft Emission Measurements*, Nationaal Lucht-en Ruimtevaarlaboratorium, National Aerospace Laboratory NLR, Netherlands Organisation for Applied Scientific Research NTO, Report NLR-TP-98390, Mar., 1999 (full report), citing ICAO, *Environmental Protection, International Standards and Recommended Practices*, Annex 16, vol. II, *Aircraft Emissions*, 2nd ed. (1993), *available at* <http://www.nlr.nl/id~4633/lang~en.pdf>.

[713] RUIJGROK, *supra* note 11, at p. 354 (table data). *See* US EPA, *Procedures for Emissions Inventory Preparation*, Vol. IV, Ch 5, *at* <http://www.epa.gov/oms/invntory.htm> (Generalized emissions tables).

[714] *See supra* note 367 (describing ADS-B).

[715] *See supra* note 369 (describing RNP).

[716] FAA, System for Assessing Aviation's Global Emission (SAGE), Ver. 1.5, *Global Aviation Emissions Inventories for 2000 through 2004*, FAA-EE-2005-02, Sept. 2005, *revised* Mar. 2008, *available at* <http://www.faa.gov/about/office_org/headquarters_offices/aep/models/sage/>.

[717] *Id.* at Table B-5, *Selected Country Fuel Burn and Emissions Inventory for 2004*, at pp. 69-70, *available at* <http://www.ipcc.ch/ipccreports/sres/aviation/016.htm#135> (presenting the U.S domestic flight emissions inventory for 2004).

[718] H.W. Jentink & J.J.F. van Veen, *In-flight spectroscopic aircraft emission measurements*, Nationaal Lucht- en Ruimtevaartlaboratorium, Nat'l Aerospace Laboratory, NLR-TP-98390, Mar. 29, 1999, *available at* <http://www.nlr.nl/id~4633/lang~en.pdf>.

[719] Regulation may focus on flight operations near and above the tropopause because of its impact on global warming. Such regulation may consider restrictions of high-altitude flight in addition to engine and aircraft design. RUIJGROK, *supra* note 11, at p. 358.

[720] *Code Examples* are examples from relevant codes of conduct that are presented for background, perspective, and comparison. Code Examples are not necessarily endorsed by the AMCC Commentary.

[721] *At* § 1.2 (emphasis added), *available at* <http://www.tcaa.go.tz/Public%20Register/public_register_body.php?pageID=29>.

[722] *Available at* <http://www.fai.org/environment/node/8>.

[723] *At* <http://www.canso.org/canso/web/> (copy on file with author).

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