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AVIATION AND CLIMATE CHANGE

Aircraft Emissions Expected to Grow, but Technological and Operational Improvements and Government Policies Can Help Control Emissions

GAO-09-554

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Highlights

Highlights of GAO-09-554, a report to congressional committees

AVIATION AND CLIMATE CHANGE

Aircraft Emissions Expected to Grow, but Technological and Operational Improvements and Government Policies Can Help Control Emissions

Why GAO Did This Study

Aircraft emit greenhouse gases and other emissions, contributing to increasing concentrations of such gases in the atmosphere. Many scientists and the Intergovernmental Panel on Climate Change (IPCC)—a United Nations organization that assesses scientific, technical, and economic information on climate change—believe these gases may negatively affect the earth's climate. Given forecasts of growth in aviation emissions, some governments are taking steps to reduce emissions. In response to a congressional request, GAO reviewed (1) estimates of aviation's current and future contribution to greenhouse gas and other emissions that may affect climate change; (2) existing and potential technological and operational improvements that can reduce aircraft emissions; and (3) policy options for governments to help address commercial aircraft emissions.

GAO conducted a literature review; interviewed representatives of government agencies, industry and environmental organizations, airlines, and manufacturers, and interviewed and surveyed 18 experts in economics and aviation on improvements for reducing emissions from aircraft.

GAO is not making recommendations. Relevant agencies provided technical comments which we incorporated as appropriate and EPA said emissions standards can have a positive benefit to cost ratio and be an important part of policy options to control emissions.

To view the full product, including the scope and methodology, click on GAO-09-554. For more information, contact Susan Fleming at (202) 512-2834 or flemings@gao.gov.

What GAO Found

According to IPCC, aviation currently accounts for about 2 percent of human-generated global carbon dioxide emissions, the most significant greenhouse gas—and about 3 percent of the potential warming effect of global emissions that can affect the earth's climate, including carbon dioxide. IPCC's medium-range estimate forecasts that by 2050 the global aviation industry, including aircraft emissions, will emit about 3 percent of global carbon dioxide emissions and about 5 percent of the potential warming effect of all global human-generated emissions. Gross domestic product growth is the primary driver in IPCC's forecasts. IPCC also made other assumptions about future aircraft fuel efficiency, improvements in air traffic management, and airport and runway capacity. IPCC's 2050 forecasts for aviation's contribution to global emissions assumed that emissions from other sectors will continue to grow. If other sectors make progress in reducing emissions and aviation emissions continue to grow, aviation's relative contribution may be greater than IPCC estimated; on the other hand, if other sectors do not make progress, aviation's relative contribution may be smaller than estimated.

While airlines currently rely on a range of improvements, such as fuel-efficient engines, to reduce emissions, some of which may have limited potential to generate future reductions, experts we surveyed expect a number of additional technological, operational, and alternative fuel improvements to help reduce aircraft emissions in the future. However, according to experts we interviewed, some technologies, such as advanced airframes, have potential, but may be years away from being available, and developing and adopting them is likely to be costly. In addition, according to some experts we interviewed, incentives for industry to research and adopt low-emissions technologies will be dependent to some extent on the level and stability of fuel prices. Finally, given expected growth of commercial aviation as forecasted by IPCC, even if many of these improvements are adopted, it appears unlikely they would greatly reduce emissions by 2050.

A number of policy options to address aircraft emissions are available to governments and can be part of broader policies to address emissions from many sources including aircraft. Market-based measures can establish a price for emissions and provide incentives to airlines and consumers to reduce emissions. These measures can be preferable to other options because they would generally be more economically efficient. Such measures include a cap-and-trade program, in which government places a limit on emissions from regulated sources, provides them with allowances for emissions, and establishes a market for them to trade emissions allowances with one another, and a tax on emissions. Governments can establish emissions standards for aircraft or engines. In addition, government could increase government research and development to encourage development of low-emissions improvements.

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Abbreviations

ACARE	Advisory Council for Aeronautics Research in Europe
ADS-B	Automatic Dependent Surveillance-Broadcast
ATA	Air Transport Association
CDA	Continuous Descent Arrival
CER	certified emissions reduction
CO_2	carbon dioxide
DG Environment	Directorate-General of the Environment
EEC	European Economic Community
EPA	Environmental Protection Agency
ERU	emission reduction unit
EU	European Union
EU ETS	European Union Emissions Trading Scheme
FAA	Federal Aviation Administration
GDP	gross domestic product
GIACC	Group on International Aviation and Climate Change
ICAO	International Civil Aviation Organization
IETA	International Emissions Trading Association
IPCC	Intergovernmental Panel on Climate Change
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NOx	nitrogen oxides
RNAV	area navigation
RNP	Required Navigation Performance
SESAR	Single European Sky Air Traffic Management Research Program
UNFCCC	United Nations Framework Convention on Climate Change

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Congressional Requesters

Many sources, including manufacturing, residential, and transportation sources, emit greenhouse gases that contribute to the accumulation of these gases in the earth's atmosphere. Greenhouse gases disperse and trap heat in the earth's atmosphere. This heat-trapping effect, known as the greenhouse effect, moderates atmospheric and surface temperatures, keeping the earth warm enough to support life. However, according to the Intergovernmental Panel on Climate Change (IPCC)—a United Nations organization that assesses scientific, technical, and economic information on the effects of climate change—global atmospheric concentrations of these greenhouse gases have increased markedly as a result of human activities over the past 200 years, contributing to a warming of the earth's climate. These trends, if unchecked, could have serious negative effects, such as rising sea levels and coastal flooding worldwide.

Aircraft emit a variety of greenhouse and other gases, including carbon dioxide—the most significant greenhouse gas emitted by aircraft—and nitrogen oxides, as well as other substances such as soot and water vapor that are believed to negatively affect the earth's climate. Airlines have a financial incentive to reduce carbon dioxide emissions, as those emissions are a direct result of fuel burn, which represents a large portion of their operating costs—about 30 percent for U.S. airlines in 2008. Some experts expect aviation to grow at a fast rate until 2021, when the Federal Aviation Administration (FAA) forecasts that U.S. domestic commercial aviation will serve over 1 billion passengers a year. While the current economic downturn could delay this growth somewhat, experts believe that growth in the aviation sector means greater productivity and mobility, but is also likely to increase emissions. To counteract expected increases in emissions, many governments and international organizations have set goals for future emissions reductions. For example, a number of developed countries have set a goal to reduce carbon dioxide emissions by 50 percent by 2050. In addition, the Kyoto Protocol, an international agreement to minimize the adverse effects of climate change, set binding targets for the reduction of greenhouse gases for 37 industrialized countries and the European Economic Community (EEC) to achieve during the 2008 through 2012 commitment period.[1] Although the United States is a signatory to the Kyoto Protocol, it is not bound by its terms or emissions target because it has not ratified the Protocol. The Protocol also requires industrialized nations and the EEC to pursue "limitations or reduction of emissions of greenhouses gases… from aviation… working through the International Civil Aviation Organization."[2] Finally, some governments have taken actions designed to control aviation emissions. For example, in 2003, the European Union (EU) established a cap-and-trade program known as the EU Emissions Trading Scheme (EU ETS) to control carbon dioxide emissions from various energy and industrial sectors. The EU ETS was first implemented in 2005 and was amended in 2008 to include aviation. Beginning in 2012, the ETS will include all covered flights into or out of an EU airport.[3]

You asked us to provide information on aviation emissions of greenhouse gases and other emissions that may affect climate change. To do so, we identified (1) aviation's current and estimated future contribution to the emissions of greenhouse gases and other emissions that may affect climate change, (2) existing and potential future technological and operational improvements that the commercial aviation industry can use to reduce commercial aircraft emissions, and (3) policy options for the U.S. government and other governments to help reduce commercial aviation emissions and the potential costs and benefits of each option. You also asked that we describe the EU's plans to add the aviation industry to its existing ETS and the potential legal implications of doing so. (See app. I for this description.) To address these objectives, we reviewed studies on the impact of aviation on climate change. We also collaborated with the National Academy of Sciences to identify and recruit experts with experience in climate change and the aviation industry. We interviewed 18 such experts (see app. II for a list of the experts). After these interviews,

[1]Kyoto Protocol to the United Nations Framework Convention on Climate Change (hereinafter the Kyoto Protocol). The Kyoto Protocol was adopted in December 1997 and was open for signature between Mar. 16, 1998, and Mar. 15, 1999. As of Jan. 14, 2009, 183 countries and the EEC had ratified the Kyoto Protocol. The binding emissions targets varies by country and is generally higher for more highly developed countries. For instance, the EEC has agreed to reduce their aggregate emissions by 8 percent from 1990 emissions levels.

[2]Kyoto Protocol, art. 2(2).

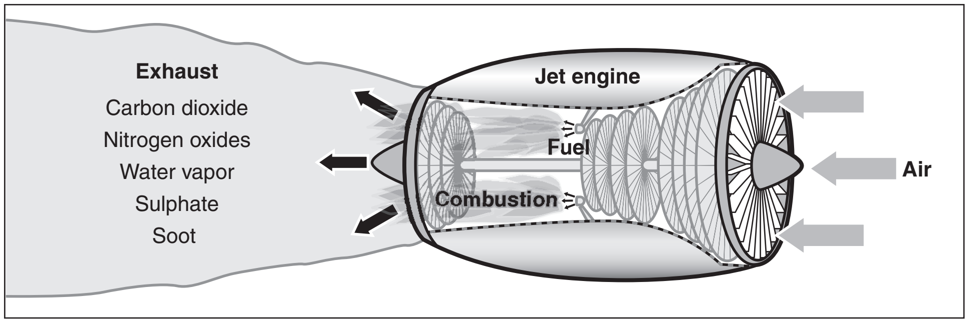
[3]This would also include those airports in non-EU countries currently participating in the EU ETS—Norway, Iceland, and Liechtenstein. See app. I for further explanation of the EU ETS.

we asked the experts to complete a survey in which they assessed a list of options to reduce emissions on a variety of predetermined factors, such as potential for emissions reductions and costs (see app. III for complete results). In addition, we spoke with government, airline, and interest group officials in the United States, the EU, and the United Kingdom, focusing on commercial aviation. (See app. IV for a more detailed description of our scope and methodology.) We conducted our work from March 2008 through June 2009 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Emissions from a variety of human-generated sources, including commercial aircraft, trap heat in the atmosphere and contribute to climate change. During flight operations, aircraft emit a number of greenhouse gas and other emissions, including carbon dioxide, nitrogen oxides (NOx), soot, and water vapor. Figure 1 shows the primary emissions from commercial aircraft. Carbon dioxide emissions from aircraft are a direct result of fuel burn. For every gallon of jet fuel burned, about 21 pounds of carbon dioxide are emitted. Reducing the amount of fuel burned, therefore, also reduces the amount of carbon dioxide emitted. Water vapor emissions and certain atmospheric temperature and humidity conditions can lead to the formation of contrails, a cloudlike trail of condensed water vapor, and can induce the creation of cirrus clouds. Both contrails and cirrus clouds are believed to have a warming effect on the earth's atmosphere. Aircraft also emit other pollutants that affect local air quality. Finally, airport operations are sources of greenhouse gas and other emissions, which we are not examining in this report.

Figure 1: Selected Greenhouse Gas and Other Emissions from Aircraft at Cruising Altitude



Source: GAO.

Historically, the commercial aviation industry has grown substantially in the United States and worldwide and is a contributor to economic growth. Between 1981 and 2008, passenger traffic increased 226 percent in the United States on a revenue passenger mile basis and 257 percent globally on a revenue passenger kilometer basis.[4] According to the FAA, in 2006 the civil aviation industry in the United States directly and indirectly contributed 11 million jobs and 5.6 percent of total gross domestic product (GDP) to the U.S. economy. Globally, the International Air Transport Association estimated that in 2007 the aviation industry had a global economic impact of over $3.5 trillion, equivalent to about 7.5 percent of worldwide GDP. Recently, however, the airline industry has experienced declining traffic and financial losses as the result of the current recession.

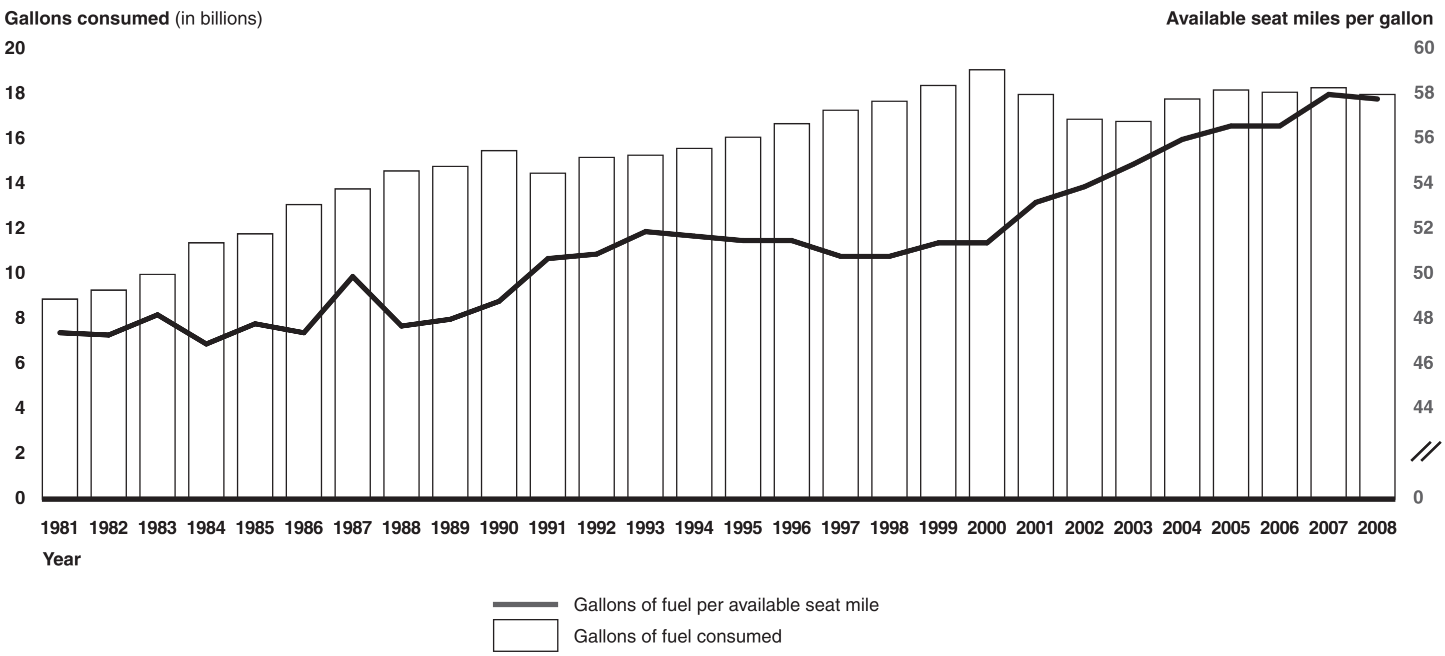
The fuel efficiency of commercial jet aircraft has improved over time. According to IPCC, aircraft today are about 70 percent more fuel efficient on a per passenger kilometer basis than they were 40 years ago because of improvements in engines and airframe design.[5] The cost of jet fuel is a large cost for airlines. In the 2008, when global fuel prices were high, jet fuel accounted for about 30 percent of U.S. airlines' total operating expenses, compared with 23 percent during 2007. Fuel efficiency (measured by available seat-miles per gallon consumed) for U.S. carriers increased about 17 percent between 1990 and 2008, as shown in figure 2. Internationally, according to the International Air Transport Association,

[4]Fuel consumption of U.S.-based airlines roughly doubled during that same period.

[5]However, some aircraft available in the 1950s were about equally as fuel efficient as jets currently available today.

fuel efficiency (measured by revenue passenger kilometers) improved 16.5 percent between 2001 and 2007. According to FAA, between 2000 and early 2008 U.S. airlines reduced fuel burn and emissions while transporting more passengers and cargo.

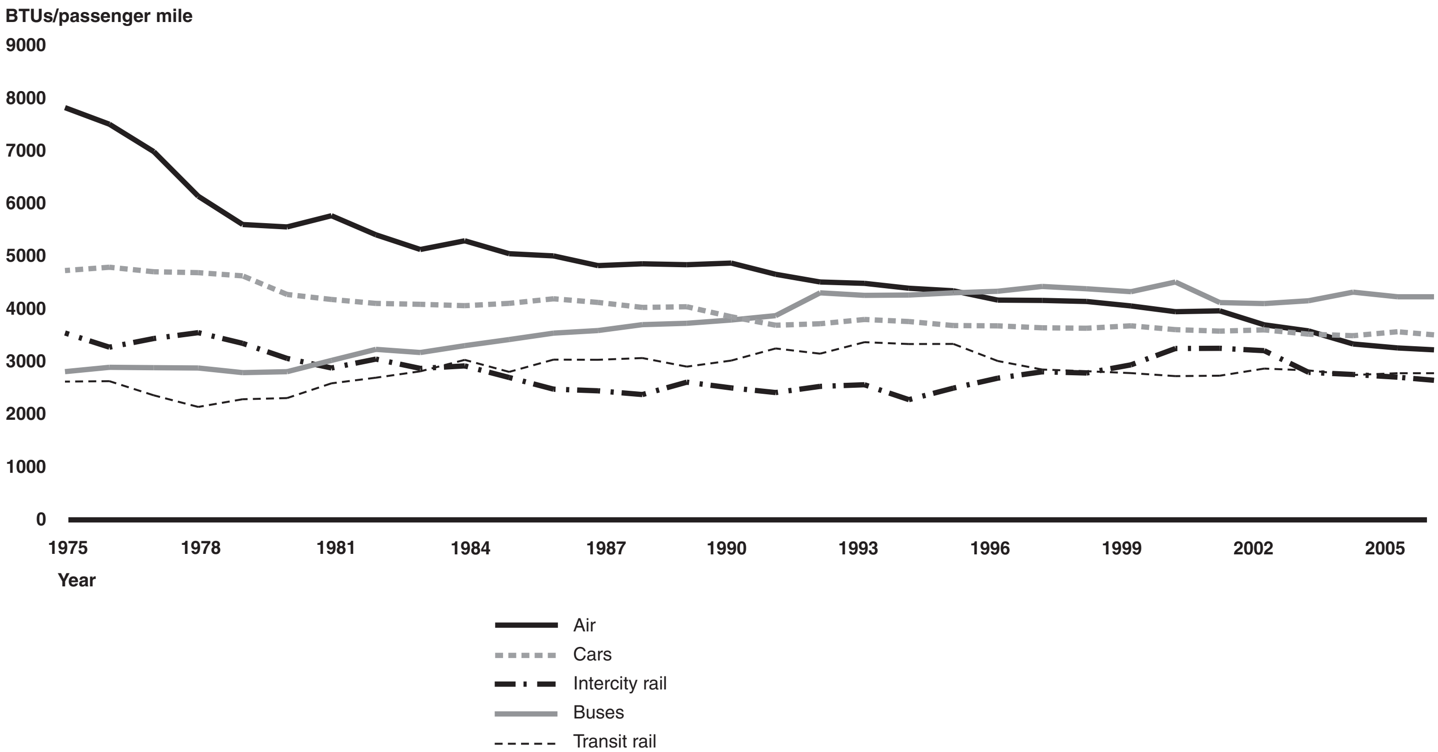
Figure 2: Total Fuel Consumption and Fuel Efficiency of U.S. Airlines



Source: U.S. Department of Transportation.

In addition, commercial aviation has become less energy intensive over time—that is, to transport a single passenger a single mile uses less energy than it previously did, measured in British thermal units. See figure 3 showing energy intensity over time of aviation and other modes of transportation.

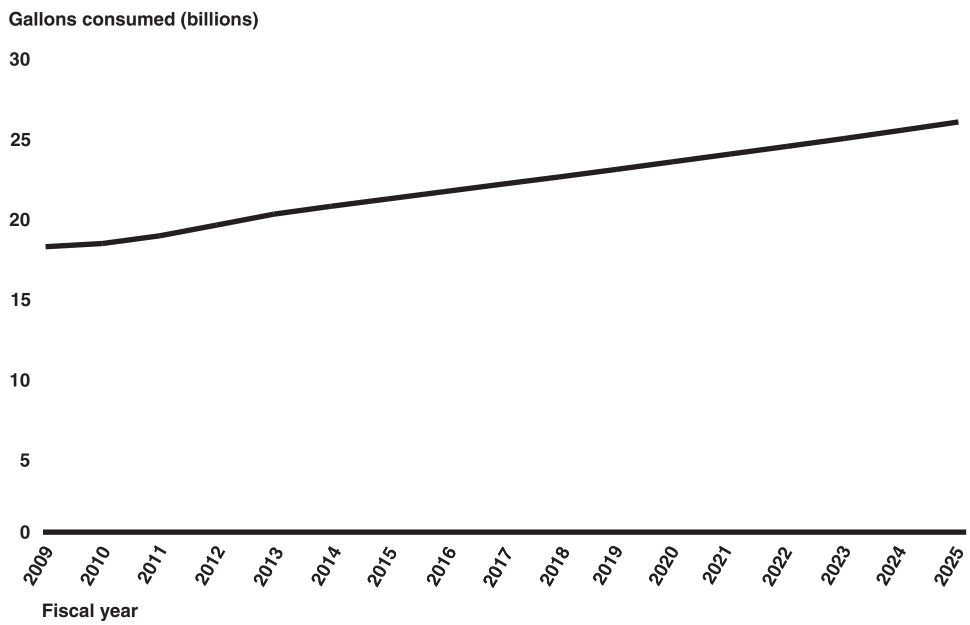
Figure 3: Energy use per Passenger-mile, by Mode of Transportation



Source: Department of Energy.

However, despite these efficiency improvements, overall fuel burn and emissions of U.S. airlines are expected to grow in the future. FAA forecasts that between 2008 and 2025 fuel consumption of U.S.-based airlines will increase an average of 1.6 percent per year while revenue passenger miles will increase an average of 3.1 percent per year over the same period. As seen in figure 4, FAA forecasts that between 2008 and 2025 fuel consumption of U.S.-based airlines will increase an average of 1.6 percent per year.

Figure 4: Forecasted Fuel Consumption by U.S. Airlines



Source: FAA Aerospace Forecast, FY 2009-2005.

To develop a better understanding of the effects of human-induced climate change and identify options for adaptation[6] and mitigation,[7] two United Nations organizations established IPCC in 1988 to assess scientific, technical, and socio-economic information on the effects of climate change. IPCC releases and periodically updates estimates of future greenhouse gas emissions from human activities under different economic development scenarios. In 1999, IPCC released its report, *Aviation and the Global Atmosphere, conducted at the request of the International Civil Aviation Organization* (ICAO)—a United Nations organization that aims to promote the establishment of international civilian aviation standards and recommended practices and procedures. In 2007, IPCC released an

[6]According to IPCC, adaptation is an adjustment that occurs in response to expected or actual climatic stimuli or effects in order to moderate damages or exploit beneficial opportunities.

[7]IPCC defines mitigation as technological change and substitution that reduce resource inputs, such as energy use, and emissions per unit of output. Although several social, economic, and technological policies would produce an emissions reduction, with respect to climate change, mitigation means implementing policies to reduce greenhouse gas emissions.

update on emissions from transportation and other sectors called the *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. These reports were developed with input from over 300 experts worldwide and are internationally accepted and used for policy-making.

A variety of federal agencies have roles in addressing aviation emissions. In 2004, FAA and other organizations including the National Aeronautics and Space Administration (NASA) released a report, *Aviation and the Environment: A National Vision Statement, Framework for Goals and Recommended Actions*, through the collaborative PARTNER program,[8] stating a general goal to reduce overall levels of emissions from commercial aviation and proposing actions to deal with aviation emissions. FAA also is involved in a number of emissions-reduction initiatives—including work on low-emissions technologies and low-carbon alternative fuels; the implementation of a new air traffic management system, the Next Generation Air Transportation System (NextGen);[9] and climate research to better understand the impact of emissions from aviation. NASA has been involved in research that has led to the development of technologies that reduce aircraft emissions. Currently, NASA's Subsonic Fixed-Wing project, part of its Fundamental Aeronautics program, aims to help develop technologies to reduce fuel burn, noise, and emissions in the future. Both FAA and NASA are involved in the Aviation Climate Change Research Initiative, whose goals include improving the scientific understanding of aviation's impact on climate change. Also, as mandated under Title II of the Clean Air Act, the Environmental Protection Agency (EPA) promulgates certain emissions standards for aircraft and aircraft engines[10] and has adopted emission standards matching those for aircraft set by ICAO.[11] While neither ICAO nor EPA has established standards for aircraft engine emissions of carbon dioxide, ICAO is

[8]The PARTNER program—the Partnership for AiR Transportation Noise and Emissions Reduction—is a cooperative research organization sponsored by FAA, NASA, and Transport Canada, with members including universities and other organizations with expertise.

[9]NextGen is a new, satellite-based air traffic management system that is expected to increase the safety and enhance the capacity of the air transport system. NextGen will transform the current radar-based air traffic control system.

[10]42 U.S.C. § 7571.

[11]However, EPA has the authority to set emissions standards. As the technical agency with responsibility for international civil aviation in the United States, FAA, in consultation with EPA, works with representatives of other ICAO member countries to formulate the standards.

currently discussing proposals for carbon dioxide emissions standards and considering a global goal for fuel efficiency.[12] In addition, in 2007 a coalition of environmental interest groups filed a petition with EPA asking the agency, pursuant to the Clean Air Act, to make a finding that "greenhouse gas emissions from aircraft engines may be reasonably anticipated to endanger the public health and welfare" and, after making this endangerment finding, promulgate regulations for greenhouse gas emissions from aircraft engines.[13]

International concerns about the contribution of human activities to global climate change have led to several efforts to reduce their impact. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC)—a multilateral treaty whose objective is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous human interference with the climate system—was signed.[14] By 1995, the parties to the UNFCCC, including the United States, realized that progress toward this goal was not sufficient. In December 1997, the parties reconvened in Kyoto, Japan, to adopt binding measures to reduce greenhouse gas emissions. Under the resulting Kyoto Protocol, which the United States has not ratified, industrialized nations committed to reduce or limit their emissions of carbon dioxide and other greenhouse gases during the 2008 through 2012 commitment period.[15] The Protocol

[12]In addition, H.R. 2454, the American Clean Energy and Security Act of 2009, § 221(b), 111th Cong. (2009), would require EPA to issue standards for greenhouse gas emissions from new aircraft and new engines used in aircraft by Dec. 31, 2012.

[13]In addition, in 2007, the Supreme Court ruled that greenhouse gases meet the Clean Air Act's definition of an air pollutant and that EPA has the statutory authority to regulate greenhouse gas emissions from new motor vehicles under the Act. *Massachusetts v. Environmental Protection Agency*, 549 U.S. 497 (2007). As a result of the opinion, EPA must take one of three actions: 1) issue a finding that greenhouse gas emissions cause or contribute to air pollution that may endanger public heath or welfare; 2) issue a finding that greenhouse gases do not endanger public health or welfare; or 3) provide a reasonable explanation as to why it cannot or will not exercise its discretion to issue a finding. In response to this case, EPA issued an Advance Notice of Proposed Rulemaking, "Regulating Greenhouse Gas Emissions Under the Clean Air Act," 73 Fed. Reg. 44354 (July 30, 2008). EPA subsequently issued a proposed finding that carbon dioxide, methane, nitrous oxide, and hydrofluorocarbon emissions from new motor vehicles are contributing to air pollution which is endangering public health and welfare. 74 Fed. Reg. 18886 (Apr. 24, 2009). EPA is moving forward with the proposed finding while it develops proposed standards for regulating greenhouse gas emissions from motor vehicles.

[14]To date, 192 countries have ratified the UNFCCC.

[15]The emissions reduction goal varies by country and is generally higher for more highly developed countries. Some European countries, for example, agreed to reduce emissions by 8 percent compared to 1990 levels.

directed the industrialized nations to work through ICAO to reduce or limit emissions from aviation, but international aviation emissions are not explicitly included in Kyoto's targets. In 2004, ICAO endorsed the further development of an open emissions trading system for international aviation, and in 2007 called for mutual agreement between contracting states before implementation of an emissions trading scheme. In part to meet its Kyoto Protocol requirements, the EU implemented its ETS in 2005, which sets a cap on carbon dioxide emissions and allows regulated entities to buy and sell emissions allowances with one another. In 2008, the European Parliament and the Council of the European Union passed a directive, or law, to include aviation in the ETS. Under the directive, beginning in 2012 a cap will be placed on total carbon dioxide emissions from all covered flights by aircraft operators into or out of an EU airport.[16] Many stakeholders and countries have stated objections to the EU's plans and legal challenges are possible. (See app. I for a discussion of the ETS's inclusion of aviation.) In December 2009, the parties to the UNFCCC will convene in Copenhagen, Denmark, to discuss and negotiate a post-Kyoto framework for addressing global climate change.

Aviation Emissions Represent a Small but Growing Share of All Emissions

IPCC estimates that aviation emissions currently account for about 2 percent of global human-generated carbon dioxide emissions and about 3 percent of the radiative forcing[17] of all global human-generated emissions (including carbon dioxide) that contribute to climate change. On the basis of available data and assumptions about future conditions, IPCC forecasted emissions to 2015 and forecasted three scenarios—low, medium, and high—for growth in global aviation carbon dioxide emissions from 2015 to 2050. These scenarios are driven primarily by assumption about economic growth—the factor most closely linked historically to the aviation industry's growth—but they also reflect other aviation-related assumptions. Because IPCC's forecasts depend in large part on assumptions, they, like all forecasts, are inherently uncertain. Nevertheless, as previously noted, IPCC's work reflects the input of over

[16] In addition to the current 27 EU member states, other European countries not part of the EU, such as Norway, Iceland, and Liechtenstein, participate in the ETS. These airports are included in the amended ETS.

[17] Radiative forcing is a measure for the change of the Earth's energy balance due to a change in concentrations of greenhouse gases and other emissions that contribute to climate change.

300 leading and contributing authors and experts worldwide and is internationally accepted and used for policy making.[18]

Aviation Contributes about 2 Percent of Global Carbon Dioxide Emissions

According to IPCC, global aviation contributes about 2 percent of the global carbon dioxide emissions caused by human activities.[19] This 2 percent estimate includes emissions from all global aviation, including both commercial and military. Global commercial aviation, including cargo, accounted for over 80 percent of this estimate.[20] In the United States, domestic aviation contributes about 3 percent of total carbon dioxide emissions, according to EPA data.[21]

Many industry sectors, such as the electricity-generating and manufacturing sectors, contribute to global carbon dioxide emissions, as do residential and commercial buildings that use fuel and power. The transportation sector also contributes substantially to global carbon dioxide emissions. Specifically, it accounts for about 20 percent of total global carbon dioxide emissions.[22] Road transportation accounts for the largest share of carbon dioxide emissions—74 percent—from the transportation sector; aviation accounts for about 13 percent of carbon

[18]According to IPCC, the report was compiled by 107 lead authors from 18 countries. Successive drafts of the report were circulated for review by experts, followed by review of governments and experts. Over 100 contributing authors submitted draft text and information to the lead authors and over 150 reviewers submitted suggestions for improvement during the review process.

[19]According to IPCC, global aviation's global carbon dioxide emissions totaled an estimated 480 million tons in 2000.

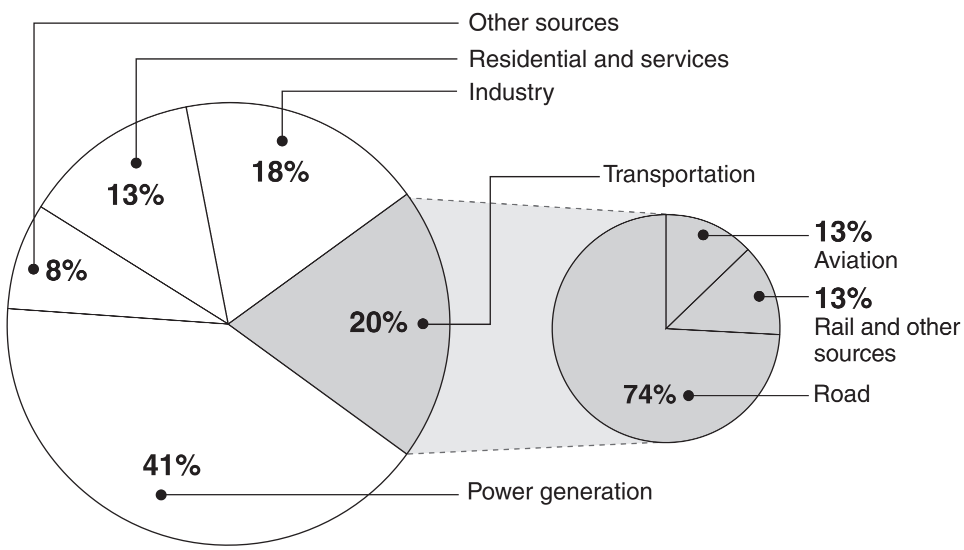
[20]According to EPA, in 2007 commercial aviation represented about 82 percent of all aviation emissions, and about 2.5 percent of U.S. carbon dioxide emissions. In the United States, military aviation represents less than 10 percent of total aviation emissions.

[21]EPA, *Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007*, (March 2009). The aviation estimates do not include fuel consumed for international air transport per UNFCCC's reporting guidelines; according to the EPA, in 2006, when those international fuels were included, domestic and international commercial, military, and general aviation flights represented about 3.4 percent of U.S. carbon dioxide emissions.

[22]In the United States according to EPA, carbon dioxide emissions from fossil fuel combustion in the transportation sector account for an estimated 31 percent of carbon dioxide emissions (in carbon dioxide equivalents not including fuels used for international flights). Carbon dioxide equivalents provide a common standard for measuring the warming potential of different greenhouse gases and are calculated by multiplying the emissions of the non-carbon-dioxide gas by its global warming potential, a factor that measures its heat-trapping ability relative to that of carbon dioxide.

dioxide emissions from all transportation sources; and other transportation sources, such as rail, account for the remaining 13 percent. Figure 5 shows the relative contributions of industry, transportation, and all other sources to global carbon dioxide emissions and breaks down transportation's share to illustrate the relative contributions of road traffic, aviation, and other transportation sources.

Figure 5: Global Transportation's and Global Aviation's Contributions to Carbon Dioxide Emissions, 2004



Sources: GAO presentation of International Energy Agency and IPCC data.

Aviation Contributes about 3 Percent of All Human-Generated Emissions

When other aviation emissions—such as nitrogen oxides, sulfate aerosols, and water vapor—are combined with carbon dioxide, aviation's estimated share of global emissions increases from 2 percent to 3 percent, according to IPCC. However, the impact of these other emissions on climate change is less well understood than the impact of carbon dioxide, making IPCC's combined estimate more uncertain than its estimate for carbon dioxide alone.

Aviation emissions may contribute directly or indirectly to climate change. Although most aviation emissions have a warming effect, sulfate aerosols and a chemical reaction involving methane have a cooling effect. The warming effect is termed "positive radiative forcing" and the cooling effect "negative radiative forcing." Aviation emissions also may contribute to the formation of cirrus clouds, which can cause atmospheric warming, but the scientific community does not yet understand this process well enough to quantify the warming effect of aviation-induced cirrus clouds. Table 1 describes the direct or indirect effects of aviation emissions on climate change.

Table 1: Types of Aviation Emissions and Their Effects at Cruising Altitude

Direct greenhouse gases and emissions	
Carbon dioxide	Carbon dioxide has a warming effect on the climate and remains in the atmosphere for hundreds of years. Carbon dioxide emissions from aviation have the same effect as those from other industry sectors because the carbon dioxide emitted from aircraft remains in the atmosphere long enough to be well mixed with the carbon dioxide emitted from ground-based sources.
Water vapor	Water vapor has a warming effect on the climate and is generated from the hydrogen contained in aviation fuel. It remains for only a short period in the troposphere (the lowest portion of the earth's atmosphere), where most emissions from aviation occur. The quantity of water vapor emitted by aviation is small compared with the quantities emitted from natural atmospheric sources.
Soot particles	Soot particles are produced during combustion and have a small warming (positive radiative forcing[a]) effect on the climate as they absorb incoming sunlight and heat the atmosphere.
Indirect greenhouse gases and emissions	
Ozone (from NOx)	Nitrogen emissions do not contribute to global warming directly, but the ozone generated from increased nitrogen oxides (NOx) is a greenhouse gas that produces a warming effect on the climate. The effect is higher at cruising altitude than on the ground because of longer lifetimes and greater radiative forcing in the higher levels of the atmosphere.
Methane (NOx related)	Very little or no methane is emitted by aircraft, but NOx emissions initiate a destruction of methane molecules, which generates an overall cooling effect on the climate. Overall, the warming effect of NOx emissions due to ozone formation is estimated to be higher than the cooling that results from methane destruction.
Sulfate aerosols	Sulfate aerosols, which arise from sulfur in jet fuel, scatter incoming sunlight back to the atmosphere and have a relatively small cooling effect on the climate.
Cloud formation	
Contrails	Contrails are formed through emissions of water and particles under certain atmospheric conditions such as temperature and humidity. They mainly consist of water already contained in the atmosphere, and aircraft operations only trigger their formation in these areas. Contrails cool the climate through increased reflection of solar radiation, but also trap heat on the earth, which contributes to global warming. Overall, contrails have a warming effect, although uncertainties about the magnitude of this effect remain.
Cirrus clouds	Cirrus cloud formation might be augmented through aviation-induced contrails and cloud seeding from emission particles. Cirrus clouds have a warming effect, but exact quantifications are not yet possible. Consequently, IPCC did not include the impact of cirrus cloud formation in its estimates of aviation's contribution to human-generated emissions.[b]

Source: IPCC, the Aviation Climate Change Research Initiative, and the European Topic Center on Air and Climate Change.

[a]According to the IPCC, radiative forcing has advantages over global warming potential (GWP) for estimating aviation's impact from short-lived aviation emissions and aerosols and contrails. GWP is used to measure the heat-absorbing ability of long-lived gases using carbon dioxide as a reference. Each measure has limits and several other impact measures including a modified GWP are under consideration to address some of the limitations.

[b]University and government organizations, including NASA, are conducting research on them to better understand their effects.

According to IPCC, when the positive radiative forcing effects of carbon dioxide and the positive and negative radiative forcing effects of other aviation emissions are combined, global aviation contributes about 3 percent[23] of human-generated positive radiative forcing. When the radiative forcing effects of the various aviation emissions are considered, carbon dioxide, nitrogen oxides, and contrails have the greatest potential to contribute to climate change.

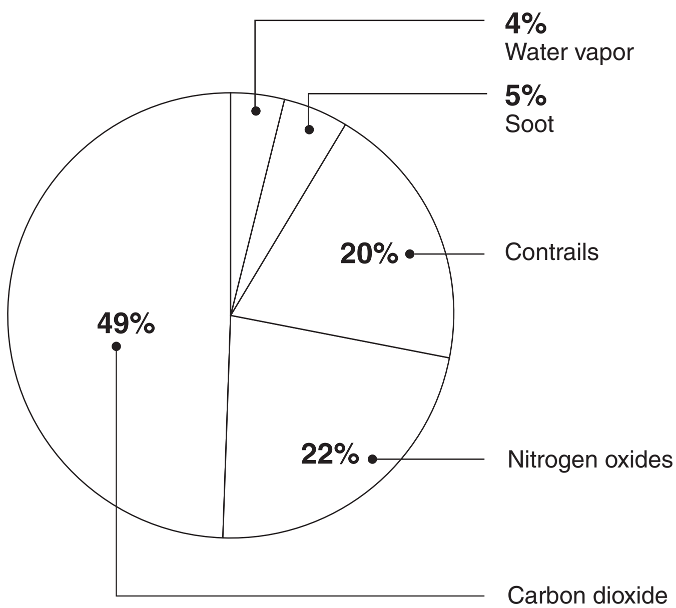
The level of scientific understanding about the impact of particular aviation emissions on radiative forcing varies, making estimates of their impact on climate change uncertain to varying degrees. A recent report that described levels of scientific understanding of aviation emissions found that the levels for carbon dioxide were high; the levels for nitrogen oxides, water vapor, sulfates, and soot were medium; and the levels for contrails and aviation-induced cirrus clouds were low.[24] Aviation's contribution to total emissions, estimated at 3 percent, could be as low as 2 percent or as high as 8 percent, according to IPCC. Figure 6 shows IPCC's estimate of the relative positive radiative forcing effects of each type of aviation emission for the year 2000. The overall radiative forcing

[23]This 3 percent radiative forcing estimate for aviation is based on more recent research, included in IPCC's 2007 *Fourth Assessment Report*. Originally, IPCC calculated a 3.5 percent estimate for 1992, which it published in its 1999 special report, *Aviation and the Global Atmosphere*.

[24]See *Aviation Climate Change Research Initiative: A Report on the Way Forward*, (2008) citing Forster, P., et al. (2007), Changes in atmospheric constituents and in radiative forcing. In: IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA; and Sausen, R. et al., *Aviation radiative forcing in 2000: An update on IPCC* (1999), Meteorologische Zeitschrift, 14-4, 555–561, 2005.

from aviation emissions is estimated to be approximately two times that of carbon dioxide alone.[25]

Figure 6: Estimated Relative Contribution of Aviation Emissions to Positive Radiative Forcing



Source: GAO presentation of IPCC reported study.

Note: This figure portrays the relative contributions of emissions that have a net positive radiative forcing effect. The effect of sulfate emissions, which have a negative radiative forcing, or cooling, effect, is not included. The result reported for nitrogen oxides is the net warming effect calculated by subtracting the cooling effect of methane from the warming effect of ozone. The aviation radiative forcing impact estimates described by IPCC in 2007 are reported as (positive) warming and (negative) cooling in milliwatts per meter squared: carbon dioxide (+ 25.3), ozone production from nitrogen oxides (+21.9), reduction of atmospheric methane as a result of nitrogen oxides (-10.4), water vapor (+2.0), sulfate particles (-3.5), soot particles (+2.5), and contrails (+10.0). For cirrus clouds, IPCC had no best estimate due to uncertainty, but a possible range of +10 to +80 was reported. The relative contributions of emissions in this chart are an approximation because of the uncertainty surrounding the non-carbon dioxide forcing estimates.

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[25]The 1999 IPCC report originally estimated that aviation's impact could be two to four times that of carbon dioxide alone. The use of a radiative forcing ratio of the forcing of all aviation emissions over carbon dioxide is an approximation and is an area for further research and understanding.

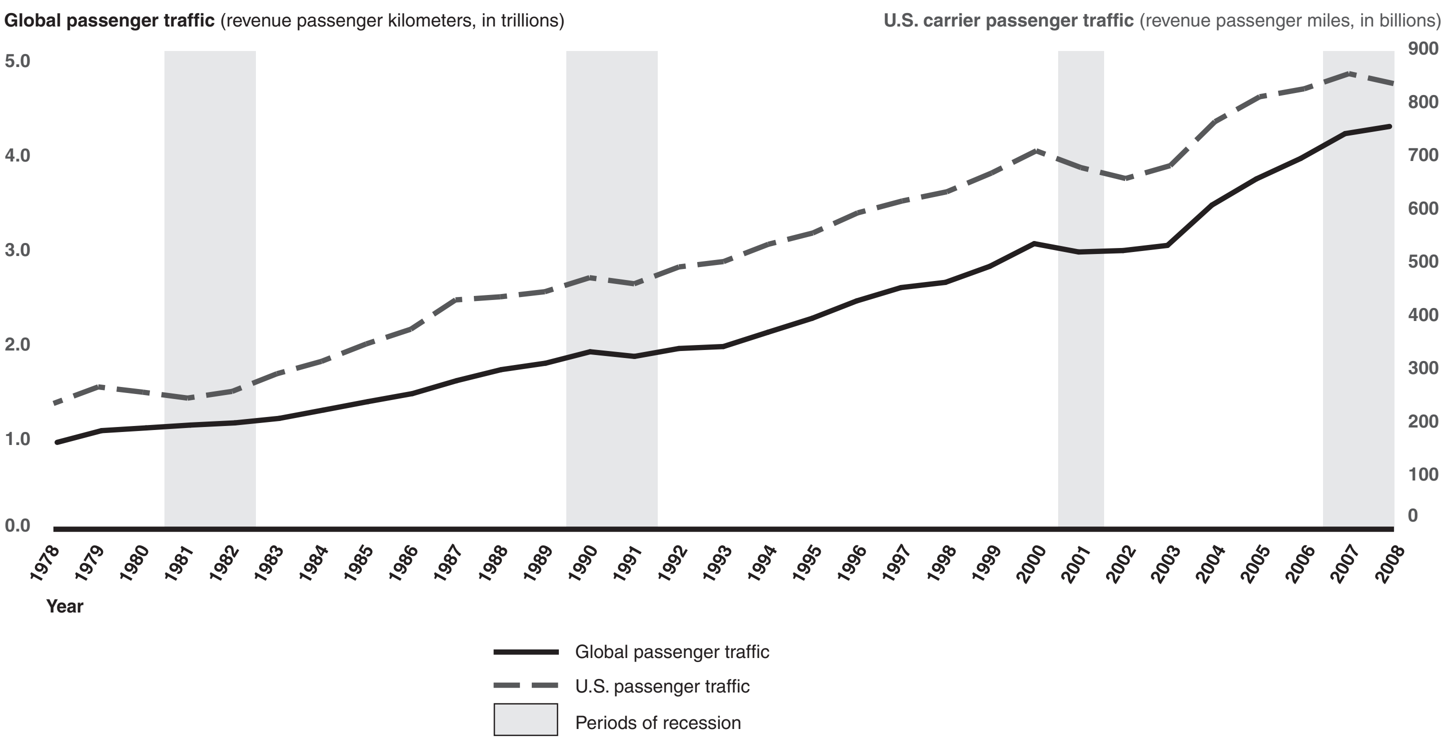
Global Aviation Emissions Are Expected to Grow but Forecasts Vary, Primarily Reflecting Different Economic Growth Assumptions

IPCC generated three scenarios that forecasted the growth of global aviation carbon dioxide emissions from the near-term (2015) to the long-term (2050) and described these scenarios in its 1999 report. These forecasts are generated by models that incorporate assumptions about future conditions, the most important of which are assumptions about global economic growth and related increases in air traffic. Other assumptions include improvements in aircraft fuel efficiency and air traffic management and increases in airport and runway capacity. Because the forecasts are based on assumptions, they are inherently uncertain.

Forecasts of Global Economic Growth and Air Traffic Primarily Drive IPCC's Emissions Estimates

Historically, global economic growth has served as a reliable indicator of air traffic levels. Aviation traffic has increased during periods of economic growth and slowed or decreased during economic slowdowns. As figure 7 shows, U.S and global passenger traffic (including the U.S.) generally trended upward from 1978 through 2008, but leveled off or declined during economic recessions in the United States.

Figure 7: Changes in Global and U.S. Aviation Passenger Traffic, 1978 through 2008

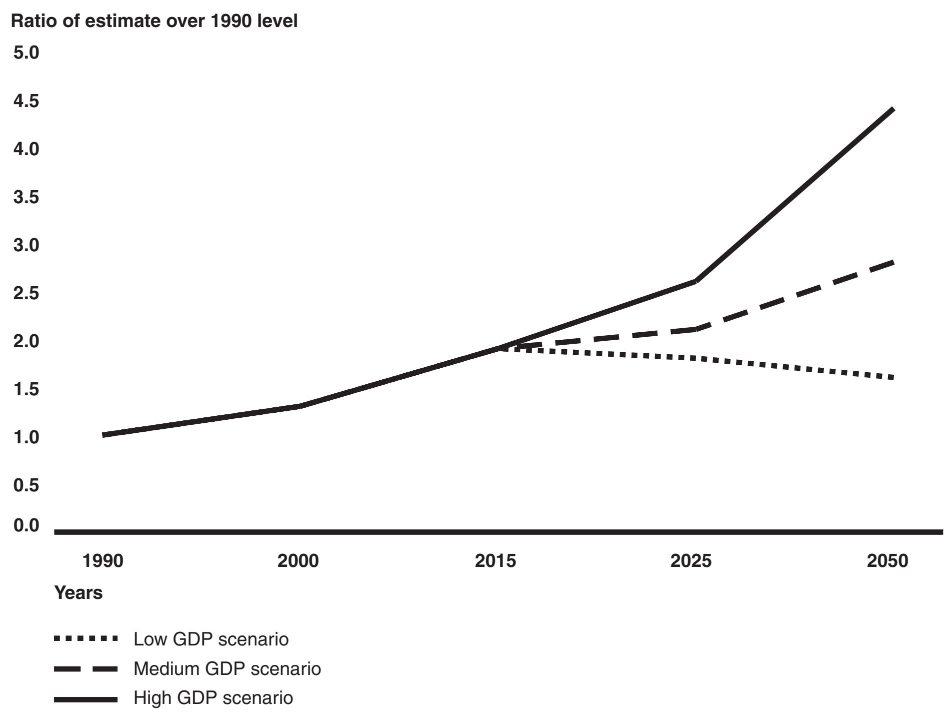


Sources: U.S. Department of Transportation data and ICAO data from the Air Transport Association.

Forecast models described in IPCC's report incorporate historical trends and the relationship between economic growth and air traffic to produce scenarios of global aviation's potential future carbon dioxide emissions. IPCC used a NASA emissions forecast for carbon dioxide emissions until 2015. IPCC used an ICAO emissions forecasting model to forecast emissions from 2015 to 2050 using three different assumptions for global economic growth—low (2.0 percent), medium (2.9 percent), and high (3.5 percent). As a result, IPCC produced three different potential scenarios for future air traffic and emissions.[26] The 2050 scenarios include a 40 percent to 50 percent increase in fuel efficiency by 2050 from improvements in aircraft engines and airframe technology and from deployment of an advanced air traffic management system (these are discussed in more detail below). Figure 8 shows IPCC's low-, mid-, and high-range scenarios for carbon dioxide emissions for 2015, 2025, and 2050 as a ratio over 1990 emissions. IPCC used the medium economic growth rate scenario to estimate aviation's contribution to overall emissions in 2050.

[26]IPCC assumed a maturing global market with the above economic growth rates from 1990 to 2025 and slightly lower economic growth rates thereafter.

Figure 8: IPCC's Scenarios for Global Aviation Carbon Dioxide Emissions



Source: IPCC.

Note: Includes advanced air traffic management and 40 percent to 50 percent fuel efficiency gain by 2050.

IPCC compared aviation and overall emissions for the future and found that global aviation carbon dioxide emissions could increase at a greater rate than carbon dioxide emissions from all other sources of fossil fuel combustion. For example, for the medium GDP growth rate scenario, IPCC assumed a 2.9 percent annual average increase in global GDP, which translated into almost a tripling (a 2.8 times increase) of aviation's global carbon dioxide emissions from 1990 to 2050. For the same medium GDP growth scenario, IPCC also estimated a 2.2 times increase of carbon dioxide emissions from all other sources of fossil fuel consumption worldwide during this period. Over all, using the midrange scenario for global carbon dioxide emissions and projections for emissions from other sources, IPCC estimated that in 2050, carbon dioxide emissions from aviation could be about 3 percent of global carbon dioxide emissions, up from 2 percent. IPCC further estimated that, when other aviation emissions were combined with carbon dioxide emissions, aviation would account for about 5 percent of global human-generated positive radiative forcing, up from 3 percent.[27] IPCC concluded that the aviation traffic estimates for the low-range scenario, though plausible, were less likely given aviation traffic trends at the time the report was published in 1999. IPCC's 2007 *Fourth Assessment Report* included two additional forecasts of global aviation carbon dioxide emissions for 2050 developed through other studies.[28] Both of these studies forecasted mid- and high-range aviation carbon dioxide emissions for 2050 that were within roughly the same range as the 1999 IPCC report's forecasts.[29] For example, one study using average GDP growth assumptions that were similar to IPCC's showed mid- and high-range estimates that were close to IPCC's estimates.

In 2005, FAA forecasted a 60 percent growth in aviation carbon dioxide and nitrogen oxide emissions from 2001 to 2025. However, FAA officials recently noted that this estimate did not take into account anticipated aircraft fleet replacements, advances in aircraft and engine technology, and improvements to the air transportation system, nor did it reflect the recent declines in air traffic due to the current recession. After taking these factors into account, FAA reduced its estimate in half and now estimates about a 30 percent increase in U.S. aviation emissions from 2001 to 2025.[30] To account for some uncertainties in FAA's emissions forecasting, FAA officials said they are working on creating future

[27]This 5 percent estimate of aviation's contribution to 2050 global radiative forcing is based on IPCC's midrange estimate. IPCC did not provide this estimate for the 2050 high- and low-range scenarios.

[28]B. Owen and D.S. Lee, *Allocation of International Aviation Emissions from Scheduled Air Traffic—Future Cases, 2005 to 2050*, Manchester Metropolitan University (Manchester, UK, March 2006) and Ralf Berghof, Alf Schmitt et al., *CONSAVE 2050 Final Technical Report* (July 2005).

[29]The 1999 IPCC report included a high-growth emissions scenario for 2050 from an environmental organization that showed aviation contributing 9.8 percent of global carbon dioxide emissions. This estimate assumed air traffic levels for 2050 that were more than double those used in the highest IPCC estimate. IPCC concluded that such an estimate for 2050, though not impossible, was unlikely because it would require countries to build more than 1,300 new airports with 15 gates each, or the equivalent of 2 new airports per month for 60 years, which would be unprecedented compared with historical increases in global airport capacity.

[30]This estimate is based on emissions of carbon dioxide and nitrogen oxides. In terms of fuel consumption, FAA estimates a 28 percent increase in US carriers commercial aviation jet fuel from 2001 to 2025 (see *FAA Aerospace Forecast, Fiscal Years 2009-2025*, table 22).

scenarios for the U.S. aviation sector to assess the influence of a range of technology and market assumptions on future emissions levels.

Other Forecasts Show Continued Long-term Growth, but Emissions Could Fall below Estimated Levels during the Current Economic Downturn

While recent aviation forecasts are generally consistent with IPCC's expectation for long-term global economic growth, the current economic slowdown has led to downward revisions in growth forecasts. For example, in 2008, Boeing's annual forecast for the aviation market projected a 3.2 percent annual global GDP growth rate from 2007 to 2027. However, this estimate was made before the onset of negative global economic growth in 2009 and could be revised downward in Boeing's 2009 forecast. According to FAA's March 2009 Aerospace Forecast, global GDP, which averaged 3 percent annual growth from 2000 to 2008, will be 0.8 percent from 2008 to 2010 before recovering to an estimated average annual growth rate of 3.4 percent from 2010 to 2020.[31] The International Air Transport Association has predicted that global air traffic will decrease by 3 percent in 2009 with the economic downturn. Moreover, according to the association, even if air traffic growth resumes in 2010, passenger air traffic levels will be 12 percent lower in the first few years after the slowdown and 9 percent lower in 2016 than the association forecasted in late 2007. To the extent that air traffic declines, emissions also will decline.

Assumptions about Other Factors Could Affect IPCC's Forecasts

In developing its forecasts, IPCC made assumptions about factors other than economic growth that also affected its forecast results, as IPCC itself, experts we interviewed, and FAA have noted:

- IPCC assumed that advances in aircraft technology and the introduction of new aircraft would increase fuel efficiency by 40 percent to 50 percent from 1997 through 2050.[32]
- IPCC assumed that an ideal air traffic management system would be in place worldwide by 2050,[33] reducing congestion and delays.

[31]Two main methods, market exchange rates and purchasing power parity are used to convert the GDP of a country in national currency terms to a common currency, usually the U.S. dollar. GDP growth rates can differ depending on the conversion method used.

[32]However, the forecast doesn't account for the possibility that some airlines might adopt low-carbon alternative fuels.

[33]The United States is currently working on its future air traffic management system, NextGen, as is Europe through the Single European Sky Air Traffic Management Research Program (SESAR).

- IPCC assumed that airport and runway capacity would be sufficient to accommodate future air traffic levels.

However, if IPCC's assumptions about improvements in fuel efficiency and air traffic management are not realized, aircraft could produce higher emissions levels than IPCC estimated and IPCC's estimates would be understated. Conversely, if airports and runways have less capacity than IPCC assumed, then air traffic levels could be lower and, according to IPCC and some experts, IPCC's forecast could overstate future aviation emissions. Finally, IPCC pointed out that its estimate that aviation will contribute 5 percent of positive radiative forcing in 2050 does not include the potential impact of aviation-induced cirrus clouds, which could be substantial.[34]

Because IPCC's forecasts are based on assumptions about future conditions and scientific understanding of the radiative forcing effects of certain aviation emissions is limited, IPCC's forecasts are themselves uncertain. According to FAA officials, given the numerous assumptions and inherent uncertainties involved in forecasting aviation emissions levels out to the year 2050, along with the significant shocks and structural changes the aviation community has experienced over the last few years, IPCC's projections are highly uncertain, even for the midrange scenario. If emissions from aviation and all other sectors continue to grow at about the same relative rate, aviation's contribution as a portion of overall emissions will not change significantly. However, if significant reductions are made in overall emissions from other sources and aviation emission levels continue to grow, aviation's contribution could grow.

[34]Other studies have estimated aviation's share of current climate change emissions and find aviation's contributions to climate change to be larger when the impact of cirrus clouds is included. For example, one environmental organization in a 2006 report included the upper range for aviation-induced cirrus clouds' radiative forcing (from Sausen et al, 2005, which was reported in IPCC) in its aviation radiative forcing total and calculated that aviation contributed 9 percent of total radiative forcing due to human activity worldwide in 2000.

Experts Believe Future Technological and Operational Improvements Are Likely to Help Reduce Emissions from Commercial Aircraft, but Likely Not by Enough to Fully Offset Estimated Market Growth

According to experts we interviewed, a number of different technological and operational improvements related to engines, aircraft design, operations, next-generation air traffic management, and fuel sources are either available now or are anticipated in the future to help reduce carbon dioxide emissions from aircraft. We interviewed and surveyed 18 experts in the fields of aviation and climate change and asked them to assess a number of improvements to reduce emissions using a variety of factors, such as potential costs and benefits, and then used the results to inform the following discussion. (Complete survey results can be found in app. III.) The development and adoption of low-emissions technologies is likely to be dependent upon fuel prices or any government policies that price aircraft emissions. Higher fuel prices or prices on emissions—for example through government policies such as an emissions tax—would make the costs of low-emissions technologies relatively cheaper and are likely to encourage their development. In addition, while fuel efficiency and emissions reductions may be important to airlines, so are a number of other factors, including safety, performance, local air quality, and noise levels, and trade-offs may exist between these factors.

Experts Believe That Although Many Technologies Are Expected to Help Reduce Emissions Growth in the Future, They Involve Trade-offs

Aircraft Engine Improvements

Improvements to aircraft engines have played a primary role in increasing fuel efficiency and reducing engine emission rates; experts we interviewed expect them to do so in the future—one study estimates that 57 percent of improvements in aircraft energy intensity between 1959 and 1995 were due to improvements in engine efficiency.[35] Such improvements have resulted from increasing engine pressure and temperatures (which increases their efficiency and decreases fuel usage) and improving the "bypass ratio," a

[35]Joosung J. Lee, Stephen P. Lukachko, Ian A. Waitz, and Andreas Schafer, "Historical and Future Trends in Aircraft Performance, Cost, and Emissions," *Annual Reviews on Energy and Environment*, vol. 26 (2001).

measure of airflow through the engine.[36] However, according to experts we surveyed, further advances in these technologies may face high development costs (see table 2), and some may not be available for commercial use any time soon because engineers still face challenges in improving engine technology.

Table 2: Selected Potential Aircraft Engine Improvements to Reduce Emissions

Improvement	Potential reduction in carbon dioxide emissions[a]	Potential research and development costs[a]	Estimated time frame for commercial use[b]	Potential for public acceptance[a]
Geared turbofan engine—more fuel efficient engine	Medium	Medium	Short-medium	High
Open rotor engine—engine fan blades not enclosed	High	High	Medium	Low-medium
Distributed propulsion systems—many small engines instead of few large ones	Medium	High	Long	High

Source: GAO survey of experts.

Note: Between 8 and 13 experts responded to each of our questions about technological improvements.

[a]We did not provide definitions for "low," "medium," or "high" in these cases.

[b]Short timeframe (<5 years); medium timeframe (5-15 years); long timeframe (>15 years).

Some technologies may be available sooner than others, but all present a range of challenges and tradeoffs:

- One latest-generation aircraft engine, the geared turbofan engine, is likely to be available for use in certain aircraft in the next few years; promises to reduce emissions according to its manufacturer, Pratt & Whitney; and may

[36]The higher the bypass ratio, the more air bypasses the engine, providing extra propulsion for the engine fan blades and increasing the engine's efficiency.

face few challenges to widespread adoption.[37] According to Pratt & Whitney, this engine design is estimated to reduce fuel burn and emissions by 12 percent, compared with similar engines now widely used, in part due to an increase in the engine's bypass ratio. The geared turbofan engine is the result of research conducted by NASA and Pratt & Whitney.[38]

- Another engine technology, which could be introduced in the next 5 to 15 years, is the "open rotor" engine. It may deliver even greater emissions reductions but may face consumer-related challenges. The open rotor engine holds the engine fan blades on the outside of the engine case, thereby increasing the air flow around the engine, the effective bypass ratio, and the efficiency of the engine's propulsion. However, this engine may be noisy and its large, visible engine blades could raise consumer concerns according to experts we surveyed. Research in the United States is currently a joint effort of NASA and General Electric. Rolls-Royce is also pursuing this technology.
- In the longer term, despite some engineering challenges, distributed propulsion technologies also hold promise for reducing aircraft emissions. Distributed propulsion systems would place many small engines throughout an aircraft instead of using a few large engines, as today's aircraft do. Experts we interviewed said that engineering challenges must be overcome with distributive propulsion, including determining the best and most efficient way to distribute power and store fuel. NASA is currently involved in distributed propulsion research.

Aircraft Improvements

Aircraft improvements also have played a role in reducing emissions rates in the past and experts we interviewed expected them to continue to do so. Through improvements in materials used to build aircraft and other improvements that increase aerodynamics and reduce drag, aircraft have become more fuel efficient over time. In the short term, improvements in aircraft materials, leading to decreased weight, and improvements in aerodynamics will help reduce fuel consumption and, thus, emissions rates. In the longer term, new aircraft designs, primarily a blended wing-body aircraft, hold potential for greater reductions in emissions rates. However, new aircraft concepts face engineering and consumer

[37] In addition, General Electric is developing a new fuel-efficient engine, the GEnx. According to General Electric, this engine will improve fuel burn by 15 percent, while also reducing NOx emissions, compared with General Electric's previous generation of engine technologies.

[38] The U.S. Air Force also is conducting research into more fuel efficient engines through its ADVENT program, a joint effort with engine manufacturers that Air Force officials told us is expected to have commercial applications.

acceptance challenges and new technologies are likely to incur high development costs (see table 3).

Table 3: Selected Aircraft Improvements to Reduce Emissions

Improvement	Potential reduction in carbon dioxide emissions[a]	Potential research and development costs[a]	Estimated time frame for commercial use[b]	Potential for public acceptance[a]
Blended wing-body—Fuselage and wings as part of one airframe	High	High	Long	Low-medium
Lightweight composite airframes—Lightweight materials	Medium	Medium	Medium	High
Winglets—Wing attachments to reduce drag	Low	Low	Short[c]	High

Source: GAO survey of experts.

Note: Between 11 and 14 experts responded to each of our questions about technological improvements.

[a]We did not provide definitions for "low," "medium," or "high" in these cases.

[b]Short timeframe (<5 years); medium timeframe (5-15 years); long timeframe (>15 years).

[c]Winglets are already available and used by a number of airlines.

The following improvements to aircraft should help reduce aircraft fuel consumption and emissions in the long term, despite costs and challenges:

- The use of lightweight composite materials in aircraft construction has led to weight and fuel burn reductions in the past and is expected to continue to do so in the future. Over time, aircraft manufacturers have increasingly replaced more traditional materials such as aluminum with lighter-weight composite materials in airframe construction. For example, according to Boeing, 50 percent of the weight of the airframe of the Boeing 787, expected to be released in 2010, will be attributable to composite materials, compared with 12 percent composites in a currently available Boeing 777. According to Airbus, it first began using composite materials in airframe construction in 1985, and about 25 percent of the airframe weight of an A380 manufactured in 2008 was attributable to composites. By reducing the weight of the airframe, the use of composites reduces aircraft weight, fuel burn, and emissions rates.
- Retrofits such as winglets—wing extensions that reduce drag—can be made to aircraft to make them more aerodynamic but may have limited

potential for future emissions reductions according to experts we surveyed. By improving airflow around wings, winglets reduce drag and improve fuel efficiency, thus reducing emissions by a modest amount. Boeing estimates that the use of winglets on a 737 reduces fuel burn by 3.5 percent to 4 percent on trips of over 1,000 nautical miles. Many new aircraft can be purchased with winglets, and existing aircraft also can be retrofitted with them. However winglets have already become very common on U.S. commercial airline aircraft and provide limited benefit for short-haul flights. According to experts we surveyed, there is low potential for future fuel consumption and emissions reductions from winglets.

- Redesigned aircraft, such as a blended wing-body aircraft—that is, an aircraft in which the body and wings are part of one airframe—hold greater potential for reducing emissions, according to experts we surveyed, though these face challenges as well. Several public and private organizations, including NASA and Boeing are conducting research on such aircraft. Many experts expect that blended wing-body aircraft will reduce emissions through improved aerodynamics and lighter weight. Estimates for potential emissions reductions include 33 percent compared with currently available aircraft according to NASA. However, these new designs face challenges; notably, according to experts we interviewed, development costs are likely to be substantial, their radically different appearance may pose consumer acceptance issues, and they may require investments in modifying airports.[39]

Experts Also Expect Operational Improvements to Help Reduce Aircraft Emissions in the Future, but Reductions May Be Limited

Airlines have already taken a number of steps to improve fuel efficiency over time; however, the potential for future improvements from these measures may be limited. Airlines have increased their load factors (the percentage of seats occupied on flights), increasing the fuel efficiency of aircraft on a per-passenger basis. Load factors were about 80 percent for U.S. carriers in 2008, compared with about 65 percent in 1995. However, some experts we interviewed said the potential for additional future emissions reductions from increasing load factors may be small because they are already so high. Airlines also have removed many unnecessary items from aircraft and minimized supplies of certain necessary items, such as water, carried on board. As a result, according to some experts we interviewed, there may be little additional improvement in reducing emissions by reducing on-board weight. Airlines also have made other

[39]However, National Aeronautics and Space Administration staff told us that no such investments will be necessary.

voluntary operational changes to reduce emissions, such as reducing speeds on certain routes, which reduces fuel use, and washing aircraft engines to make them cleaner and more efficient. Airlines also have retired less-fuel-efficient aircraft and replaced them with more-fuel-efficient models. For example, in 2008, American Airlines announced it was replacing more of its fuel-inefficient MD-80 aircraft with more efficient Boeing 737-800 aircraft. In addition, Continental Airlines, in 2008, replaced regional jets with turboprop planes on many routes. Still other improvements also are available for airlines to reduce emissions in the future, but the experts we interviewed ranked the potential for emissions reductions and consumer acceptance of these improvements as low (see table 4).

Table 4: Selected Operational Improvements to Reduce Emissions

Improvement	Potential reduction in carbon dioxide emissions[a]	Potential research and development costs[a]	Estimated time frame for commercial use[b]	Potential for public acceptance[a]
Air-to-air refueling—Air tankers fueling aircraft in flight	Low	High	Long	Low
Engine washing—To improve engine performance	Low	Low	Short	High
Formation flying—Multiple aircraft flying close together to reduce drag	Low	Medium-high	Medium-long	Low
Multi-stage long distance flights—Use of fueling stops on long-distance flights	Low-medium	Low	Short	Low

Source: GAO survey of experts.

Note: Between 9 and 12 survey respondents answered each of our questions about operational improvements to reduce emissions.

[a]We did not provide definitions for “low,” “medium,” or “high” in these cases.

[b]Short timeframe (<5 years); medium timeframe (5-15 years); long timeframe (>15 years).

Airlines could make other operational changes to reduce fuel burn and emissions but are unlikely to do so, because the potential for consumer acceptance of such changes is low according to experts we surveyed. For example, aircraft could fly in formation to improve airflow and reduce fuel burn. More specifically, rather than flying individually, several aircraft could fly in proximity to one another, reducing drag of aircraft and subsequently fuel use. However, aircraft would fly closer to one another than FAA's regulations currently allow and additional technological and aerodynamics research needs to be done. Another potential option, currently used for military purposes, is air-to-air refueling. Under this option, aircraft would be fueled in flight by tanker aircraft, reducing the amount and weight of fuel needed for the flight. However, DOT staff told us that air-to-air refueling may pose safety risks similar to those posed by formation flying. Some experts also have suggested that airlines make in-route on-ground fueling stops on long-haul flights, so they could reduce the amount of fuel they carry. However, more fueling stops could have negative effects on air quality at airports used for these stops as well as on air traffic operations.

Air Traffic Management Improvements through NextGen Will Incorporate Technological and Operational Improvements to Help Reduce Aircraft Emissions According to Experts

According to FAA, some of the air traffic management improvements that are part of NextGen—the planned air traffic management system designed to address the impacts of future traffic growth—can help reduce aircraft fuel consumption and emissions in the United States. Besides improving air traffic management, NextGen has environmental goals, which include accelerating the development of technologies that will lower emissions and noise. According to FAA, it is conducting a review to develop a set of NextGen goals, targets and metrics for climate change, as well as for noise and local air quality emissions. NextGen has the potential to reduce aircraft fuel burn by 2025, according to FAA, in part through technologies and procedures that reduce congestion and create more direct routing. Some procedures and technologies of NextGen have already been implemented and have already led to emissions reductions. Similarly, in Europe through the Single European Sky Air Traffic Management Research Program (SESAR), air traffic management technologies and procedures will be upgraded and individual national airspace systems will be merged into one, helping to reduce emissions per flight by 10 percent according to EUROCONTROL, the European Organization for the Safety of Air Navigation. However, some experts we met with said that because some of SESAR's technologies and procedures have already been implemented, future fuel savings might be lower. Table 5 provides information on selected components of NextGen that hold potential for reducing aircraft emissions.

Table 5: Selected Air Traffic Management Improvements to Reduce Emissions

Improvement	Potential reduction in carbon dioxide emissions[a]	Potential research and development costs[a]	Estimated time frame for commercial use[b]	Potential for public acceptance[a]
Required navigation performance—More precise routes	Medium	Medium	Medium	High
Automatic Dependent Surveillance-Broadcast—Satellite navigation system	Medium	Medium	Short	High
Continuous Descent Arrival—More fuel efficient landings	Low-Medium	Medium	Short	High
NextGen Network-Enabled Weather—Advanced real-time weather data	Medium	Medium	Medium	High

Source: GAO survey of experts,

Note: 7 to 13 experts answered each of our survey questions about NextGen improvements

[a]We did not provide definitions for "low," "medium," or "high" in these cases.

[b]Short timeframe (<5 years); medium timeframe (5-15 years); long timeframe (>15 years)

NextGen has the potential to reduce fuel consumption and emissions through technologies and operational procedures:

- NextGen makes use of air traffic technologies to reduce emissions. For example, the Automatic Dependent Surveillance-Broadcast (ADS-B) satellite navigation system is designed to enable more precise control of aircraft during flight, approach, and descent, allowing for more direct routing and thus reducing fuel consumption and emissions. Also, Area Navigation (RNAV) will compute an aircraft's position and ground speed and provide meaningful information on the flight route to pilots, enabling them to save fuel through improved navigational capability. NextGen Network-Enabled Weather will provide real-time weather data across the national airspace system, helping reduce weather-related delays and allowing aircraft to best use weather conditions to improve efficiency.
- NextGen also relies on operational changes that have demonstrated the potential to reduce fuel consumption and emissions rates. Continuous Descent Arrivals (CDA) allow aircraft to remain at cruise altitudes longer

as they approach destination airports, use lower power levels, and therefore produce lower emissions during landings. CDAs are already in place in a number of U.S. airports and according to FAA, the use of CDAs at Atlanta Hartsfield International Airport reduces carbon dioxide emissions by an average of about 1,300 pounds per flight. Required Navigation Performance (RNP) also permits an aircraft to descend on a more precise route, reducing its consumption of fuel and lowering its carbon dioxide emissions. According to FAA, over 500 RNAV and RNP procedures and routes have been implemented. Funding and other challenges, however, affect FAA's implementation of these various NextGen procedures and technologies.[40]

Alternative Fuel Sources Have Potential for Reducing Aircraft Greenhouse Gas Emissions, but Challenges Exist

The use of alternative fuels, including those derived from biological sources (biofuels), has the potential to reduce greenhouse gas emissions from aircraft in the future; however, these fuels also present a number of challenges and environmental concerns. While the production and use of biofuels result in greenhouse gas emissions, the extent to which they provide a reduction in greenhouse gas emissions depends on whether their emissions on an energy-content basis are less than those resulting from the production and use of fossil fuels.[41] To date, some assessments of biofuels have shown a potential reduction in greenhouse gas emissions when compared with fossil fuels, such as jet fuel. However, researchers have not agreed on the best approach for determining the greenhouse gas effects of biofuels and the magnitude of any greenhouse gas reductions attributable to their production and use.[42] FAA, EPA, and U.S. Air Force officials we met with said that quantifying the life-cycle emission of

[40]For more information on challenges in NextGen implementation see GAO, *Next Generation Air Transportation System: Issues Associated with Midterm Implementation of Capabilities and Full System Transformation*, GAO-09-481T (Washington, D.C.: Mar. 25, 2009).

[41]Although plants converted into biofuels remove carbon dioxide from the air during growth, the biofuel production process is not emissions-free. For instance, nitrous oxide—a powerful greenhouse gas—may be emitted when nitrogen-based fertilizers are applied to soils to increase yields of important biofuel feedstocks such as corn. In addition, fossil fuels are burned during the harvesting, transporting and refining of biofuel feedstock plants. Finally, researchers have raised concerns that increased biofuel production could result in additional greenhouse gas impacts due to the conversion of lands not previously used for biofuel crop production.

[42]On May 26, 2009, EPA issued a Notice of Proposed Rulemaking regarding the renewable fuel standard, as required by the Energy Independence and Security Act of 2007 (EISA). When finalized, the proposed rule would implement EISA's changes to the renewable fuel standard. 74 Fed. Reg. 24904 (May 26, 2009).

biofuels is difficult, but work in this area is currently under way.[43] For example, according to EPA, the agency has developed a comprehensive methodology to determine the life-cycle emissions, including both direct and indirect emissions, of a range of biofuels. This methodology, which involved extensive coordination with experts outside of and across the federal government, was included in the recent notice of proposed rulemaking on the renewable fuel standard. Non-oil-energy sources, such as hydrogen, have potential for providing energy for ground transport, but many experts we met with said that such sources are unlikely to have use for commercial aircraft given technological, cost, and potential safety issues.[44]

According to experts we interviewed, a variety of sources could be used to produce biofuels for aircraft, including biomasses such as switchgrass and forest and municipal waste; and oils from jatropha (a drought-resistant plant that can grow in marginal soil), algae, camelina (a member of the mustard family that can grow in semiarid regions), palm, and soy. However, many experts claim that some of these crops are unsuitable for use as biofuels because they may have negative environmental and economic consequences, such as potentially reducing the supply and quality of water, reducing air quality and biodiversity, and limiting global food supplies. For example, cultivating palm for biofuel production might lead to deforestation, thereby increasing both greenhouse gas emissions and habitat loss. In addition, jatropha has been identified as an invasive species in some regions and, because of its aggressive growth, may have the potential to reduce available habitat for native species. According to experts we met with, algae, on the other hand, are seen as a potentially viable source: they can be grown using saltwater and in a variety of other environments. In addition, according to DOT, camelina appears to be a potential biofuel source in the short term as it is not currently used for food and uses limited water for development.

[43] In addition, FAA and the U.S. Air Force, through the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) program—an FAA-NASA-Transport Canada-sponsored Center of Excellence, is sponsoring a project that aims to develop a tool that can estimate the life-cycle environmental impact from alternative jet fuels. The U.S. Air Force is leading an interagency working group including EPA, FAA, the Department of Energy and researchers to develop a document of life-cycle analysis best practices.

[44] While in 2008 Boeing conducted a test flight of a small aircraft powered by hydrogen fuel cells, the manufacturer indicated it does not expect that large aircraft will be able to derive their primary energy from such sources.

However, many experts we interviewed raised questions about the availability of future supplies of biofuels. According to the experts, large investments in fuel production facilities will likely be needed because little industrial capacity and compatible infrastructure currently exist to create biofuels.[45] The cost of current algae conversion technology has, for example raised obstacles to the commercial-scale production needed to obtain significant supplies in the future. Given that future alternative fuels will have many uses, airlines will compete with other sources, including road transportation, for those limited supplies. Compared with the market for ground transport, the market for fuels for commercial aviation is small, leading some experts to believe that fuel companies are more likely to focus their biofuel efforts on the ground transport market than on the commercial aviation market. Some experts we met with said that given the relatively small size of the market, limited biofuel supplies should be devoted to road transportation since road transportation is the largest contributor of emissions from the transportation sector.[46]

A large number of industry and government participants, including airlines, fuel producers, and manufacturers, are currently conducting research and development on alternative fuels for aircraft. One effort is the Commercial Aviation Alternative Fuels Initiative, whose members include FAA, airlines, airports, and manufacturers. The goal of this initiative is to "promote the development of alternative fuels that offer equivalent levels of safety and compare favorably with petroleum-based jet fuel on cost and environmental bases, with the specific goal of enhancing security of energy supply." Any developed biofuel will be subject to the same certification as petroleum-based jet fuel to help ensure its safety. In addition, other government efforts are under way, most notably the Biomass Research and Development Initiative. This initiative is a multiagency effort to coordinate and accelerate all federal biobased products and bioenergy research and development. The Department of Transportation is one of the initiative's participants.

[45]For a discussion of biofuel production see GAO, *Biofuels: DOE Lacks a Strategic Approach to Coordinate Increasing Production with Infrastructure Development and Vehicle Needs* GAO-07-713 (Washington, D.C.: June 8, 2007).

[46]However, according to DOT, it could also be argued that because aircraft do not face the potential for non-liquid fuel sources of energy—for example, electricity—and because there is a proportionally higher premium for refining jet fuel, aviation may be a more certain consumer of biofuel supplies.

Finally, the aviation industry has conducted a number of test flights using a mixture of biofuels and jet fuel. These test flights have demonstrated that fuel blends containing biofuels have potential for use in commercial aircraft. In February 2008, Virgin Atlantic Airlines conducted a demonstration flight of a Boeing 747 fueled by a blend of jet fuel (80 percent) and coconut- and babassu-oil-based fuels (20 percent). In December 2008, Air New Zealand conducted a test flight of a Boeing 747 fueled by a blend consisting of an equal mixture of jet fuel and jatropha oil. In January 2009, Continental Airlines conducted a test flight using a fuel blend of 50 percent jet fuel, and a jatropha and algae biofuel blend on a Boeing 737.[47] In January 2009, Japan Airlines conducted a test flight of a Boeing 747 fueled by a blend including camelina oil. According to the airlines, the results of all these tests indicate that there was no change in performance when engines were fueled using the biofuel blends. For example, the pilot of the Air New Zealand test flight noted that both on-ground and in-flight tests indicated that the aircraft engines performed well while using the biofuel.

Improvements to Reduce Emissions from Aircraft Face Challenges and According to Experts Adopting Them May Not Be Enough to Offset Future Market and Emissions Growth

Future fuel prices are likely to be a major factor in influencing the development of low-emissions technologies for commercial aviation. According to the airline industry, fuel costs provide an incentive for airlines to reduce fuel consumption and emissions. However, according to some experts we interviewed, short-term increases in fuel prices may not provide enough of an incentive for the industry to adopt certain low-emission improvements. For example, the commercial airlines would have greater incentive to adopt fuel saving technologies if the projected fuel savings are greater than the improvement's additional life-cycle cost. The higher existing and projected fuel prices are, the more likely airlines would undertake such improvements, all else the same. One expert said that if fuel costs were expected to consistently exceed $140 per barrel in the future, much more effort would be made to develop a finished open rotor engine quickly. The price of fuel as a factor in providing an incentive for the development and adoption of low-emission technologies is seen in some historical examples in NASA research. While winglets were first developed through a NASA research program in the 1970s, they were not used commercially until a few years ago when higher fuel prices justified their price. Additionally, although NASA currently is sponsoring research into open rotor engines, the agency also did so in the 1980s in response to

[47]Algae-based biofuel composed only 2.5 percent of the fuel blend.

high fuel prices. That research was discontinued before the technology could be matured, however, when fuel prices dropped dramatically in the late 1980s.

In addition, the current economic recession has impacted commercial airlines and may cause some airlines to cut back on purchases of newer and more fuel-efficient aircraft. For example, the U.S. airline industry lost about $3.7 billion in 2008, and while analysts are uncertain about its profitability 2009, some analysts predict industry profits of around $4 billion to $10 billion. In addition, Boeing has reported a number of recent cancellations of orders for the fuel-efficient 787 Dreamliner. According to one expert we met with, when airlines are low on cash, they are unlikely to undertake improvements that will reduce their fuel consumption and emissions, even if the savings from fuel reductions will ultimately be greater than the cost of the improvement because they have so little cash. This expert said, for example, that although it may make financial sense for airlines to engage in additional nonsafety-related engine maintenance to reduce fuel burn and emissions, they may not do so because they lack sufficient cash.

Although some airlines may adopt technologies to reduce their future emissions, these efforts may not be enough to mitigate the expected growth in air traffic and related increase in overall emissions through 2050. Although IPCC's forecast, as mentioned earlier, assumes future technological improvements leading to annual improvements in fuel efficiency, it excludes or doesn't account for the possibility that some airlines might adopt biofuels or other potential breakthrough technologies. Nonetheless, even if airlines adopt such technologies, some experts believe that emissions will still be higher in 2050 under certain conditions than they were in 2000. One expert we met with did a rough estimate of future emissions from aircraft assuming the adoption of many low-carbon technologies such as blended wing-body, operational improvements, and biofuels. He used IPCC's midrange forecast of emissions to 2050 as a baseline for future traffic and found that even assuming the introduction of these technologies, global emissions in 2050 would continue to exceed

2000 emissions levels.[48] Had a lower baseline of emissions been used, forecasted emissions may have been lower. He acknowledged that more work needs to be done in this area. Another study by a German research organization modeled future emissions assuming the adoption of technological improvements, as well as biofuels, to reduce emissions. This study assumed future traffic growth averaging 4.8 percent between 2006 and 2026 and 2.6 percent between 2027 and 2050.[49] While this study forecasted improvements in emissions relative to expected market growth, it estimated that by 2050 total emissions would still remain greater than 2000 emissions levels.

Governments Can Use a Variety of Policy Options to Help Reduce Commercial Aircraft Emissions, but the Costs and Benefits of Each Vary

Governments have a number of policy options—including policies that set a price on emissions, market-based measures like a cap-and-trade program or a tax, regulatory standards, and funding for research and development—they could use to help reduce greenhouse gas emissions from commercial aviation and other sectors of the economy. The social benefits (for example, resulting from emissions reductions) and costs associated with each option vary, and the policies may affect industries and consumers differently. However, economic research indicates that market-based policies are more likely to better balance the benefits and costs of achieving reductions in greenhouse gases and other emissions (or, in other words, to be more economically efficient). In addition, research and development spending could complement market-based measures or standards to help facilitate the development and deployment of low-emissions technologies. However, given the relatively small current and forecasted percentage of global emissions generated by the aviation sector, actions taken to reduce aviation emissions alone, and not

[48]This analysis assumed that biofuels are first available in 2015 and their usage increases at a rate of 2 percent per year, and through life-cycle carbon emissions, biofuels emit 20 percent the carbon dioxide as jet fuel. For blended-wing body aircraft, the analysis assumed an 18 percent fuel burn reduction and introduction of the aircraft into global fleets in 2025 with a 30-year time frame to achieve a penetration of 33 percent of global aircraft fleets. The analysis also assumed the adoption of other improvements, including the use of lightweight materials, open rotor engines, formation flying, and multistage long-distance travel. We did not review the reliability of this analysis.

[49]A lower assumed traffic growth rate would have reduced the study's forecast of emissions. With respect to biofuels, this study assumed that biofuels would be used between 2010 and 2050 (at which time they would represent 25 percent of aviation fuels) and would produce 10 percent of the carbon dioxide emissions of fossil fuels. We did not review the reliability of this analysis.

emissions from other sectors, could be costly and have little potential impact on reducing global greenhouse gas emissions.[50]

Market-Based Policies Could Be Used to Provide Airlines and Other Sources with an Economic Incentive to Reduce Greenhouse Gas Emissions

Economists and other experts we interviewed stated that establishing a price on greenhouse gas emissions through market-based policies, such as a cap-and-trade program or a tax on emissions from commercial aircraft and other sources, would provide these sources with an economic incentive to reduce their emissions. Generally, a cap-and-trade program or an emissions tax (for example, on carbon dioxide) can achieve emissions reductions at less cost than other policies because they would give firms and consumers the flexibility to decide when and how to reduce their emissions. Many experts we surveyed said that establishing a price on emissions through a cap-and-trade program or a tax would help promote the development and adoption of a number of low-emissions technologies for airlines, including open rotor engines and blended wing-body aircraft. Another market-based policy, subsidy programs, such as a payment per unit of emissions reduction, can in principle provide incentives for firms and consumers to reduce their greenhouse gas emissions. However, subsidy programs need to be financed—for example through existing taxes or by raising taxes—and can create perverse incentives resulting in higher emissions.

Cap-and-Trade Program

One market-based option for controlling emissions is a cap-and-trade program. Also known as an emissions trading program, a cap-and-trade program would limit the total amount of emissions from regulated sources. These sources would receive, from the government, allowances to emit up to a specific limit—the “cap.” The government could sell the allowances through an auction or provide them free of charge (or some combination of the two). In addition, the government would establish a market under which the regulated sources could buy and sell allowances with one another. Sources that can reduce emissions at the lowest cost could sell their allowances to other sources with higher emissions reduction costs. In this way, the market would establish an allowance price, which would represent the price of carbon dioxide (or other greenhouse gas) emissions. Generally, according to economists, by

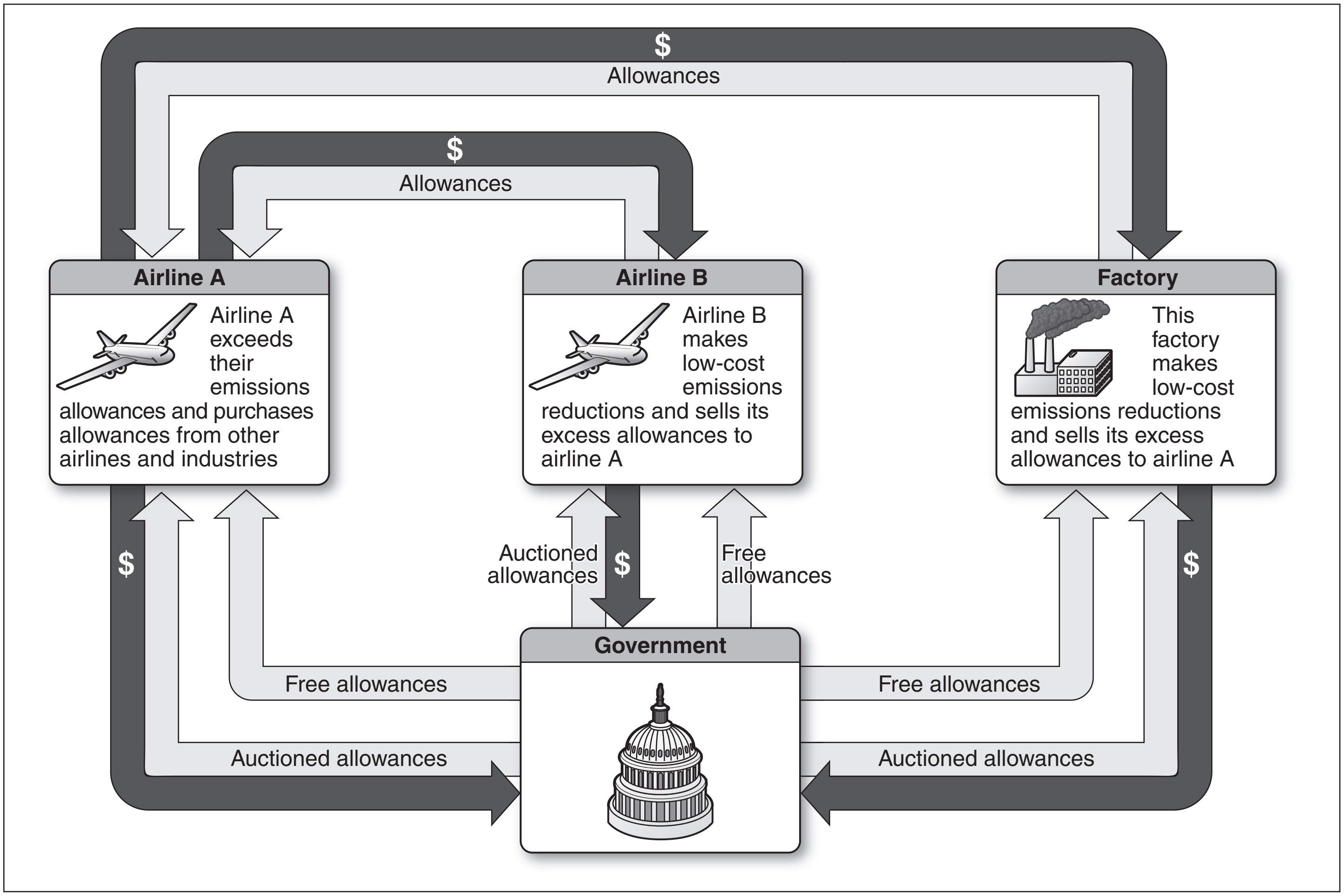
[50]For a comprehensive discussion of the economics of policy options to address climate change as well as discussion of a combination of such options, see GAO, *Climate Change: Expert Opinion on the Economics of Policy Options to Address Climate Change*, GAO-08-605 (Washington, D.C.: May 9, 2008).

allowing sources to trade allowances, policy makers can achieve emissions reductions at the lowest cost.

A cap-and-trade program can be designed to cap emissions at different points in the economy. For example, a cap-and-trade program could be designed to cap "upstream" sources like fuel processors, extractors, and importers. Under this approach, a cap would be set on the emissions potential that is inherent in the fossil fuel. The upstream cap would restrain the supply and increase the prices of fossil fuels and thus the price of jet fuel relative to less carbon-intensive alternatives. Alternatively, under a "downstream" program, direct emitters, such as commercial airlines, would be required to hold allowances equal to their total carbon emissions each year. (See fig. 9.) However, economic research indicates that both types of programs would provide commercial airlines with an incentive to reduce their fuel consumption in the most cost-effective way for each airline, such as by reducing weight, consolidating flights, or using more fuel-efficient aircraft, if they were included in such a program. To the extent that airlines would pass along any program costs to customers through higher passenger fares and shipping rates, travelers and shippers could respond in various ways, including by traveling less frequently or using a different, cheaper transportation mode.[51]

[51]However, to the extent that a cap-and-trade program regulates other transportation sectors as well, costs of using alternative transportation modes are likely to be higher as well.

Figure 9: A Potential Cap-and-Trade Program Regulating Airlines and Other Emissions Sources



Source: GAO.

The effectiveness of a cap-and-trade program in balancing the benefits and costs of the emission reductions could depend on factors included in its design. Generally, by establishing an upper limit on total emissions from regulated sources, a cap-and-trade program can provide greater certainty than other policies (for example, an emissions tax) that emissions will be reduced to the desired level. Regulated sources would be required to hold allowances equal to their total emissions, regardless of the cost. However, allowance prices could be volatile, depending on factors such as changes in energy prices, available technologies, and weather,[52] making it more expensive for sources to meet the cap. To limit price volatility, a cost-containment mechanism called a "safety valve" could be incorporated into the cap-and-trade program to establish a ceiling on the price of allowances. For example, if allowance prices rose to the safety-valve price, the government could sell regulated sources as many allowances as they would like to buy at the safety-valve price.[53] Although the safety valve could limit price spikes, the emissions cap would be exceeded if the safety valve were triggered.

In addition, the baseline that is used to project future emissions and set the emissions cap can affect the extent to which a cap-and-trade program will contain or reduce emissions.[54] The point in time on which a baseline is set also can influence the environmental benefits of a cap-and-trade program. For example, some environmental interest groups in Europe have claimed that the environmental benefits of including aviation in the EU ETS will be minimal, since the emissions cap will be based on the mean average of aviation emissions from 2004 through 2006, leading to minimal future emissions reductions.[55]

In addition, industry groups and other experts have raised concerns that a cap-and-trade program could be administratively burdensome to the government, which would need to determine how to allocate the allowances to sources, oversee allowance trading, and monitor and enforce compliance with the program. Generally speaking, an upstream

[52]For example, the demand for energy may increase during unexpectedly hot or cold periods, leading to price spikes and making it more expensive for sources to meet the cap.

[53]The safety valve would help prevent the price of allowances from exceeding the expected benefits of the emissions reductions. Under a cap-and-trade program, the emissions cap could be set at a level that balances the expected marginal cost of meeting the cap with an estimate of the marginal benefits. The safety valve price could be set just above the expected marginal costs to avoid the possibility that the cap is overly stringent.

[54]We have reported on the importance of setting an emissions baseline. For example, setting a baseline with poor historical data could lead to the creation of a baseline that is above actual emissions, leading to no emission reductions. See GAO, *Climate Change Science: High Quality Greenhouse Gas Emissions Data Are a Cornerstone of Programs to Address Climate Change*, GAO-09-423T (Washington, D.C.: Feb. 24, 2009).

[55]However, some interest groups have expressed concern that an emissions cap does not take into account emissions reductions that airlines have achieved in recent years and claim that it unfairly penalizes those airlines that have reduced emissions.

program may have lower administrative costs than a downstream program because it would likely involve fewer emissions sources.

Some members of the aviation industry have said they view open and global cap-and-trade programs positively, although they report that not all types of cap-and-trade programs will work for them. For instance, ICAO and other industry organizations have said they would prefer an open cap-and-trade program (in which airlines are allowed to trade allowances with other sectors and sources) to a closed one (in which airlines are allowed to trade emissions allowances only with one another) because an open program would give airlines more flexibility in meeting their emissions cap. Staff we met with at the Association of European Airlines expressed willingness for aviation to participate in a cap-and-trade program as long as it is global in scope, is an open system, is not in addition to similar taxes, and does not double-count emissions.[56] In addition, some industry groups and government agencies we met with said that a global program would best ensure that all airlines would take part in reducing emissions.

Cap-and-Trade Plans and Legislation

Some countries are planning to address aviation emissions through cap-and-trade programs. The European Union originally implemented the EU ETS in 2005, covering industries representing about 50 percent of its carbon dioxide emissions.[57] The EU is planning on including all covered flights by aircraft operators flying into or out of EU airports, starting in 2012.[58] Please see appendix I for more details on the EU ETS, including a comprehensive discussion of the potential legal implications and

[56]For example, Association of European Airlines expressed a concern that because some countries in Europe have taxes on aircraft carbon dioxide emissions, airlines may be subject to those taxes as well as the ETS, meaning that their emissions would be counted twice by two different regulations.

[57]We have reported on lessons learned from the EU ETS. See GAO, *International Climate Change Programs: Lessons Learned from the European Union's Emissions Trading Scheme and the Kyoto Protocol's Clean Development Mechanism*, GAO-09-151 (Washington, D.C.: Nov. 18, 2008).

[58]With respect to aircraft, the ETS currently regulates only carbon dioxide emissions. However, according to the European Commission, it has agreed to address nitrogen oxide emissions from aircraft through a separate legislative measure. As of May 2009, no EU legislative proposal has specifically addressed nitrogen oxide emissions from aircraft.

stakeholders' positions on this new framework. Other countries are considering cap-and-trade programs that would affect the aviation sector.[59]

In addition, the United States is currently considering and has previously considered cap-and-trade programs:

- H.R. 2454, the American Clean Energy and Security Act of 2009, 111th Cong. (2009), would create a cap-and-trade program for greenhouse gas emissions for entities responsible for 85 percent of emissions in the United States. The current language proposes to regulate producers and importers of any petroleum-based liquid fuel, including aircraft fuel, as well as other entities, and calls for an emissions cap in 2050 that would be 83 percent lower than 2005 emissions. The bill also calls for the emissions cap in 2012 to be 3 percent below 2005 levels, and in 2020 to be 20 percent below 2005 levels. In addition, the Obama Administration's fiscal year 2010 budget calls for the implementation of a cap-and-trade program to regulate emissions in the United States. The budget calls for emissions reductions so that emissions in 2020 are 14 percent below 2005 levels and emissions in 2050 are 83 percent below 2005 levels.
- Additionally in this Congress, the Cap and Dividend Act,[60] also proposes a cap-and-trade program for carbon dioxide emissions beginning in 2012, which would include jet fuel emissions. This program's covered entities would include entities that would make the first sale in U.S. markets of oil or a derivative product used as a combustible fuel, including jet fuel. The bill would require the Secretary of the Treasury, in consultation with the EPA Administrator, to establish the program's emission caps in accordance with the following targets: the 2012 cap would equal 2005 emissions; the 2020 cap would equal 75 percent of 2005 emissions; the 2030 cap would equal 55 percent of 2005 emissions; the 2040 cap would equal 35 percent of 2005 emissions; and the 2050 cap would equal 15 percent of 2005 emissions.
- A number of bills creating a cap-and-trade program also were introduced in the 110th Congress but did not pass. For example, a bill sponsored by Senators Boxer, Warner, and Lieberman would have established a cap-and-trade program that covered petroleum refiners and importers, among other entities.[61] The costs of the regulation would have been borne by

[59]For example, Japan is considering creating a voluntary cap-and-trade program and Japan Airlines already has indicated that it will participate in the scheme, but only based on its domestic flights.

[60]H.R. 1862, 111th Cong. (2009).

[61]S. 3036, 110th Cong. (2008).

these refiners and importers who would likely have passed on those costs to airlines through increases in the price of jet fuel.

Emissions Taxes

An emissions tax is another market-based policy that could be used to reduce emissions from commercial aviation and other emissions sources. Under a tax on carbon dioxide (or other greenhouse gas), the government would levy a fee for every ton of carbon dioxide emitted. Similar to a cap-and-trade program, a tax would provide a price signal to commercial airlines and other emission sources, creating an economic incentive for them to reduce their emissions. A carbon tax could be applied to "upstream" sources such as fuel producers, which may in turn pass along the tax in the form of higher prices to fuel purchasers, including commercial airlines. Similar to a cap-and-trade program, emissions taxes would provide regulated sources including commercial airlines with an incentive to reduce emissions in the most cost-effective way, which might include reducing weight, consolidating flights, or using more fuel-efficient aircraft.

According to economic theory, an emissions tax should be set at a level that represents the social cost of the emissions.[62] Nonetheless, estimates of the social costs associated with greenhouse gas emissions vary. For example, IPCC reported that the social costs of damages associated with greenhouse gas emissions average about $12 per metric ton[63] of carbon dioxide (in 2005 dollars) with a range of $3 to $95 per ton (in 2005 dollars).

Economic research indicates that an emissions tax is generally a more economically efficient policy tool to address greenhouse gas emissions than other policies, including a cap-and-trade program, because it would better balance the social benefits and costs associated with the emissions reductions. In addition, compared to a cap-and-trade program, an emissions tax would provide greater certainty as to the price of emissions. However, it would in concept provide less certainty about emissions

[62]For example, the social cost of carbon reflects the present value of economic damages caused by an additional quantity of emissions. Under an economically optimal policy, the price would be set at a point where the marginal damages from global warming equal the marginal cost of controlling emissions.

[63]A metric ton equals 2,205 pounds.

reductions because the reductions would depend on the level of the tax and how firms and consumers respond to the tax.[64]

Subsidies

Subsidies are another market-based instrument that could, in principle, provide incentives for sources to reduce their emissions. For example, experts we met with said that the government could use subsidies to encourage industry and others to adopt existing low-emissions technologies and improvements, such as winglets. In addition, some experts told us that NextGen-related technologies are candidates for subsidies because of the high costs of the technologies and the benefits that they will provide to the national airspace system. According to IPCC, subsidies can encourage the diffusion of new low-emissions technologies and can effectively reduce emissions. For example, as newer, more fuel-efficient engines are developed and become commercially available, subsidies or tax credits could lower their relative costs and encourage airlines to purchase them.

Although subsidies are similar to taxes, economic research indicates that some subsidy programs can be economically inefficient, and need to be financed (for example, using current tax revenue or by raising taxes). For example, although some subsidy programs could lead to emissions reductions from individual sources, they may also result in an overall increase by encouraging some firms to remain in business longer than they would have under other policies such as an emissions tax.

Distribution of Costs under Market-based Measures

Both a cap-and-trade program and an emissions tax would impose costs on the aviation sector and other users of carbon-based fuels. The extent to which the costs associated with an emissions control program are incurred by commercial airlines and passed on will depend on a number of economic factors, such as the level of market competition and the responsiveness of passengers to changes in price. Officials of some industry organizations we met with said that because airlines are in a competitive industry with a high elasticity of demand,[65] they are constrained in passing on their costs, and the costs to industry likely will

[64]The extent to which a cap-and-trade program would provide greater certainty about emissions reductions depends on the design of the particular program. For example, some programs may include cost containment measures that allow total emissions to exceed the cap under certain conditions.

[65]Price elasticity of demand is a measure of the responsiveness in quantity demanded as a result of a change in price. Goods and services with a high elasticity of demand will see larger changes in the quantity demanded than the change in price.

be large. The Association of European Airlines reported that airlines will have very limited ability to pass on the costs of the EU ETS. Furthermore, the International Air Transport Association has estimated that the costs to the industry of complying with the EU ETS will be €3.5 billion in 2012,[66] with annual costs subsequently increasing.[67] Others we interviewed, however, stated that airlines will be able to pass on costs, and the increases in ticket prices will not be large. For example, the EU estimates that airlines will be able to pass on most of the costs of their compliance with the EU ETS, which will result in an average ticket price increase of €9 on a medium-haul flight.[68] However, the revenue generated by the tax or by auctioning allowances could be used to lessen the overall impact on the economy, or the impact on certain groups (for example, low income) or sectors of the economy by, for example, reducing other taxes.[69]

Finally, according to some airline industry representatives, a program to control greenhouse gas emissions would add to the financial burden the aviation industry and its consumers already face with respect to other taxes and fees. For example, passenger tickets in the United States are subject to a federal passenger ticket tax of 7.5 percent, a segment charge of $3.40 per flight segment, and fees for security and airport facilities (up to $4.50 per airport). In addition, international flights are subject to departure taxes and customs-related fees. However, none of these taxes and fees attempt to account for the cost of greenhouse gas emissions, as a tax or cap-and-trade program would do. In addition, the revenue generated from an emissions tax or by auctioning allowances under a cap-and-trade program, could be used to offset other taxes, thereby lessening the economic impact of the program.

[66]Equivalent to about $4.5 billion based on exchange rates on Apr. 20, 2009.

[67]According to industry interests groups we met with, to the extent that airlines incur the costs of a tax or for cap-and-trade allowances, their resources for upgrading their fleets with more fuel-efficient aircraft and for implementing other emissions-reduction measures will be more limited.

[68]Equivalent to about $11.60 based on exchange rates on April 20, 2009.

[69]Some organizations we met believe that revenues collected through the auctions of allowances should be used for climate change mitigation and adaptation as well as to help fund low-emissions technologies.

Emissions Standards Could Limit Emissions from Specific Technologies, but Are Generally Not an Economically Efficient Approach for Reducing Greenhouse Gas Emissions

Mandating the use of certain technologies or placing emissions limits on aircraft and aircraft engines are also potential options for governments to address aircraft emissions. Standards include both technology standards, which mandate a specific control technology such as a particular fuel-efficient engine, and performance standards, which may require polluters to meet an emissions standard using any available method. The flexibility in the performance standards reduces the cost of compliance compared with technology-based standards and, according to DOT, avoids potential aviation safety implications that may occur from forcing a specific technology across a wide range of operations and conditions.

For example, by placing a strict limit on aircraft emissions, a standard would limit the emissions levels from an engine or aircraft. Regulations on specific emissions have been used to achieve specific environmental goals. ICAO's nitrogen oxide standards place limits on nitrogen oxide emissions from newly certified aircraft engines. These standards were first adopted in 1981 and became effective in 1986. Although no government has yet promulgated standards on aircraft carbon dioxide emissions or fuel economy, emissions standards are being discussed within ICAO's Committee on Aviation Environmental Protection and, in December 2007, a number of environmental interest groups filed petitions with EPA asking the agency to promulgate regulations for greenhouse gas emissions from aircraft and aircraft engines. In addition, the American Clean Energy and Security Act of 2009 would require EPA to issue standards for greenhouse gas emissions from new aircraft and new engines used in aircraft by December 31, 2012.[70]

Although standards can be used to limit greenhouse gas emissions levels from aircraft, economic research indicates that they generally are not as economically efficient as market-based instruments because they do not effectively balance the benefits and costs associated with the emissions reductions.[71] For example, unlike market-based instruments, technology standards would give engine manufacturers little choice about how to reduce emissions and may not encourage them to find cost effective ways

[70]H.R. 2454, § 221(b), 111th Cong. (2009).

[71]Emissions standards typically do not equalize marginal costs across sources, a basic condition for efficiency. In the case of greenhouse gas emissions, emissions are uniformly mixed and abatement costs vary widely across sources. These characteristics favor market-based instruments, which can achieve significant cost savings by encouraging low-cost sources to make the bulk of the emissions reductions.

of controlling emissions.[72] In addition, according to IPCC, because technology standards may require emissions to be reduced in specified ways, they may not provide the flexibility to encourage industry to search for other options for reducing emissions. However, according to EPA, performance standards to address certain emissions from airlines, such as those adopted by ICAO and EPA, gave manufacturers flexibility in deciding which technologies to use to reduce emissions.[73] Nonetheless, although performance standards can provide greater flexibility and therefore be more cost-effective than technology standards, economic research indicates that standards generally provide sources with fewer incentives to reduce emissions beyond what is required for compliance, compared to market-based approaches. Moreover, standards typically apply to new, rather than existing, engines or aircraft, making new engines or aircraft more expensive, and as a result, the higher costs may delay purchases of more fuel-efficient aircraft and engines.

Current international aviation standards also may require international cooperation. Because ICAO sets standards for all international aviation issues, it may be difficult for the U.S. government, or any national government, to set a standard that is not adopted by ICAO, although member states are allowed to do so. Industry groups we met with said that any standards should be set through ICAO and then adopted by the United States and other nations and, as mentioned earlier, some environmental groups have petitioned EPA to set such standards.

[72]According to FAA and EPA, existing aircraft engine standards do not mandate specific technologies and are developed on the basis of technological practicability.

[73]According to EPA, well designed standards could give aircraft engine manufacturers the flexibility to make cost-effective reductions. In addition, according to an official in EPA's Office of Air and Radiation, with the projected increase in jet fuel consumption and related emissions, addressing greenhouse gas emissions will require consideration of technology measures and market-based measures. However, under a market-based program such as cap-and-trade, emissions caps set the total emissions level and sources would need to determine how to accommodate business growth while complying with the cap. Such an approach gives sources an incentive to innovate and search for low-cost ways to reduce emissions.

Government-Sponsored Research and Development Can Help Encourage the Development and Adoption of Low-Emissions Technologies, but May Be Costly to Governments

Government-sponsored research into low-fuel consumption and low-emissions technologies can help foster the development of such technologies, particularly in combination with a tax or a cap-and-trade program. Experts we surveyed said that increased government research and development could be used to encourage a number of low-emissions technologies, including open rotor engines and blended wing-body aircraft. According to the *Final Report of the Commission on the Future of the United States Aerospace Industry*, issued in 2002, the lack of long-term investments in aerospace research is inhibiting innovation in the industry and economic growth. This study also asserted that national research and development on aircraft emissions is small when compared with the magnitude of the problem and the potential payoffs that research drives. Experts we met with said that government sponsorship is crucial, especially for long-term fundamental research, because private companies may not have a sufficiently long-term perspective to engage in research that will result in products for multiple decades into the future. According to one expert we interviewed, the return on investment is too far off into the future to make it worthwhile for private companies. NASA officials said that private industry generally focuses only on what NASA deems the “next generation conventional tube and wing technologies,” which are usually projected no more than 20 years into the future. Furthermore, raising fuel prices or placing a price on emissions through a tax or cap-and-trade program is likely to encourage greater research by both the public and private sectors into low-emissions technologies because it increases the pay off associated with developing such technologies.

Various U.S. federal agencies, including NASA and FAA, have long been involved in research involving low-emissions technologies.[74] For example, NASA’s subsonic fixed-wing research program is devoted to the development of technologies that increase aircraft performance, as well as reduce both noise levels and fuel burn. Through this program, NASA is researching a number of different technologies to achieve those goals, including propulsion, lightweight materials, and drag reduction. The subsonic fixed-wing program is looking to develop three generations of aircraft with increasing degrees in technology development and fuel burn improvements—the next-generation conventional tube and wing aircraft, the unconventional hybrid wing-body aircraft, and advanced aircraft

[74]In addition, the U.S. Air Force conducts research that has potential for applicability for commercial aviation. For example, through the ADVENT program, the Air Force is researching fuel-efficient engine technologies.

concepts.[75] NASA follows goals set by the *National Plan for Aeronautics Research and Development and Related Infrastructure* for fuel efficiency improvements[76] for each of these generations (see table 6).[77]

Table 6: NASA's Subsonic Fixed-Wing Research Fuel-Reduction Goals

	Research generation		
	Next generation tube and wing	**Unconventional hybrid wing-body**	**Advanced aircraft concepts**
Aircraft fuel burn reduction goal	33 percent fuel reduction (relative to Boeing 737)	40 percent fuel reduction (relative to Boeing 777)	Better than 70 percent fuel reduction
Time frame	2015	2020	2030-2035

Source: NASA.

However, budget issues may affect NASA's research schedule. As we have reported, NASA's budget for aeronautics research was cut by about half in the decade leading up to fiscal year 2007, when the budget was $717 million.[78] Furthermore, NASA's proposed fiscal year 2010 budget calls for significant cuts in aeronautics research, with a budget of $569 million. As NASA's aeronautics budget has declined, it has focused more on fundamental research and less on demonstration work. However, as we have reported, NASA and other officials and experts agree that federal research and development efforts are an effective means of achieving emissions reductions in the longer term.[79] According to NASA officials, the research budget for its subsonic fixed-wing research program, much of which is devoted to technologies to reduce emissions and improve fuel efficiency, will be about $69 million in 2009.

[75]NASA refers to the three generations of technologies as N+1, N+2, and N+3.

[76]The plan also sets goals for future noise levels and nitrogen oxide emissions.

[77]National Science and Technology Council, *National Plan for Aeronautics Research and Development and Related Infrastructure* (Washington, D.C., Jan. 18, 2008).

[78]GAO, *Aviation and the Environment: FAA's and NASA's Research and Development Plans for Noise Reduction Are Aligned, but the Prospects of Achieving Noise Reduction Goals Are Uncertain*, GAO-08-384 (Washington, D.C., Feb. 15, 2008).

[79]GAO, *Aviation and the Environment: NextGen and Research and Development Are Keys to Reducing Emissions and Their Impact on Health and Climate*, GAO-08-706T (Washington, D.C., May 6, 2008).

FAA has proposed creating a new research consortium to focus on emissions and other issues. Specifically, FAA has proposed the Consortium for Lower Energy, Emissions, and Noise, which would fund, on a 50-50 cost share basis with private partners, research and advanced development into low-emissions and low-noise technologies, including alternative fuels, over 5 years. FAA plans that the consortium will mature technologies to levels that facilitate uptake by the aviation industry. The consortium contributes to the goal set by the National Plan for Aeronautics, Research and Development and Related Infrastructure to reduce fuel burn by 33 percent compared with current technologies. The House FAA Reauthorization Bill (H.R. 915, 111th Cong. (2009)) would provide up to $108 million in funding for the consortium for fiscal years 2010 through 2012.

Lastly, the EU has two major efforts dedicated to reducing aviation emissions. The Advisory Council for Aeronautics Research in Europe (ACARE) is a collaborative group of governments and manufacturers committed to conducting strategic aeronautics research in Europe. According to officials with the European Commission Directorate General of Research, about €150 million to €200 million per year[80] is devoted to basic research through ACARE. Another research effort in Europe is the Clean Sky Joint Technology Initiative, which will provide €1.6 billion[81] over 7 years to fund various demonstration technologies.

Agency Comments and Our Evaluation

We provided a draft copy of this report to the Department of Defense, the Department of State, the Department of Transportation, the National Aeronautics and Space Administration, and the Environmental Protection Agency for their review.

The Department of Defense had no comments. The Department of State provided comments via email. These comments were technical in nature and we incorporated them as appropriate.

The Department of Transportation provided comments via email. Most of these comments were technical in nature and we incorporated them as appropriate. In addition, DOT stated that our statements indicating that the use of future technological and operational improvements may not be

[80]About $200 million to $267 million per year based on exchange rates on Apr. 29, 2009.

[81]Equivalent to approximately $2.1 billion based on exchange rates on Mar. 31, 2009.

enough to offset expected emissions growth is not accurate given the potential adoption of alternative fuels. We agree that alternative fuels do have potential to reduce aircraft emissions in the future; to the extent that a low-emission (on a life-cycle basis) alternative fuel is available in substantial quantities for the aviation industry, emissions from the aviation industry are likely to be less than they otherwise would be. However, we maintain that given concerns over the potential environmental impacts of alternative fuels, including their life-cycle emissions, as well as the extent to which such fuels are available in adequate supplies at a competitive price, there may be a somewhat limited potential for alternative fuel use to reduce emissions from commercial aircraft in the future, especially the short term. DOT also suggested that we clarify the sources for our discussion about policy options that can be used to address aviation emissions. As much of that discussion is based on economic research and experience with market-based instruments and other policies, we clarified our sources where appropriate.

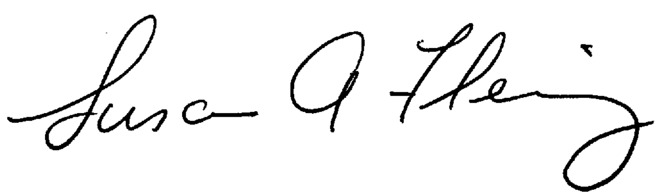
NASA provided a written response (see app. V) in which they stated that our draft provided an accurate and balanced view of issues relating to aviation and climate change. NASA also provided technical comments that were incorporated as appropriate. EPA provided technical comments via email that were incorporated as appropriate and also provided a written response. (see app. VI).

EPA was concerned that characterizing aircraft emissions standards as being economically inefficient especially compared to market-based measures, might lead readers to believe that emissions standards cannot be designed in a manner that fosters technological innovations and economic efficiency. EPA officials explained that, based on their experience, standards can be designed to optimize technical responses, provide regulated entities with flexibility for compliance and that studies show that EPA regulations have generated benefits in excess of costs. We agree that allowing regulated sources more flexibility in how they meet emissions standards can reduce the costs associated with achieving the emissions reductions. However, economic research indicates that for addressing greenhouse gas emissions, market-based measures such as emissions taxes or cap-and-trade programs would be economically efficient (that is, would maximize net benefits) compared to other approaches, in part because market-based measures can give firms and consumers more flexibility to decide when and how to reduce their emissions. Emissions standards, for example, generally give regulated sources fewer incentives to reduce emissions beyond what is required for compliance. The ultimate choice of what specific policy option or combination of options governments might use and how it should be designed is a complex decision and beyond the scope of our discussion.

Finally, EPA was concerned that our draft report did not adequately discuss the increases in fuel consumption and emissions that have resulted from high rates of market growth and expected continued growth. We believe that our report adequately discusses fuel efficiency as well as fuel consumption and emissions output. In addition, our report discusses that aviation emissions are expected to grow in the long term, despite the potential availability of a number of technological and operational options that can help increase fuel efficiency. In response to this comment, we added additional information on forecasted fuel use by U.S.-based commercial airlines.

We are sending copies of this report to the Secretaries of Defense, State, and Transportation and the Administrators of the Environmental Protection Agency and the National Aeronautics and Space Administration. This report is also available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staffs have any questions concerning this report, please contact me at (202) 512-2834 or flemings@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Staff members making key contributions to this report are listed in appendix VII.



Susan Fleming
Director, Physical Infrastructure Issues

List of Congressional Requesters

The Honorable Bart Gordon
Chairman
The Honorable Ralph Hall
Ranking Member
Committee on Science and Technology
House of Representatives

The Honorable James L. Oberstar
Chairman
The Honorable John L. Mica
Ranking Member
Committee on Transportation and Infrastructure
House of Representatives

The Honorable Jerry F. Costello
Chairman
The Honorable Thomas E. Petri
Ranking Member
Subcommittee on Aviation
Committee on Transportation and Infrastructure
House of Representatives

Appendix I: Legal Implications of European Union Emissions Trading Scheme

The European Union's recent decision to include aviation in the European Union's Emissions Trading Scheme (EU ETS), which includes U.S. carriers flying in and out of Europe, is a complex and controversial matter. Preparations by U.S. carriers are already underway for 2012, the first year aircraft operators will be included in the ETS. The inclusion of aviation in the current EU ETS implicates a number of international treaties and agreements and has raised concerns among stakeholders both within and outside the United States. Many stakeholders within the United States have posed that the inclusion of aviation in the ETS violates provisions of these international agreements and is contrary to international resolutions. Others, primarily in Europe, disagree and find aviation's inclusion in the current ETS to be well within the authority set forth in these agreements. In light of these disagreements, the EU may confront a number of hurdles in attempting to include U.S. carriers in the current EU ETS framework.

EU ETS Law

In 2005, the EU implemented its ETS, a cap-and-trade program to control carbon dioxide emissions from various energy and industrial sectors. On December 20, 2006, the European Commission set forth a legislative proposal to amend the law, or directive, which established the ETS so as to include aviation in the ETS.[1] On July 8, 2008, the European Parliament adopted the legislative resolution of the European Council and on October, 24, 2008, the Council adopted the directive, signaling its final approval.[2] The directive was published in the Official Journal on January 13, 2009, and became effective on February 2, 2009.[3]

Under the amended ETS Directive, beginning on January 1, 2012, a cap will be placed on total carbon dioxide emissions from all covered flights by

[1]The European Commission initiates the legislative process by drafting specific pieces of legislation and proposing them to the Council of the European Union and European Parliament, who together serve as the EU's legislative branch.

[2]Under the EU's co-decision procedure, the legislative procedure for environmental and certain other types of laws, both the Council of the European Union and European Parliament must approve legislation in order to enact a law. Once both bodies approve identical texts of the legislation, it must be published in the Official Journal of the European Union. The law goes into force 20 days after publication. Thereafter, each member state has 1 year to transpose the directive into national law.

[3]Directive 2008/101/EC, 2009 O.J. (L 8) 3. The directive was amended on Mar. 26, 2009.

aircraft operators flying into or out of an EU airport.[4] Emissions will be calculated for the entire flight.[5] For 2012, the cap for all carbon dioxide emissions from covered flights will be set at 97 percent of historical aviation emissions.[6] For the 2013-2020 trading period and subsequent trading periods, the cap will be set to reflect annual emissions equal to 95 percent of historical aviation emissions.[7]

The cap represents the total quantity of emissions allowances available for distribution to aircraft operators. In 2012 and each subsequent trading period, 15 percent of allowances must be auctioned to aircraft operators; the remaining allowances will be distributed to these aircraft operators for free based on a benchmarking process.[8] Individual member states, in accordance with the EU regulation, will conduct the auctions for aircraft operators assigned to that member state.[9] The auction of allowances will be open for anyone to participate. The number of allowances each member state has to auction depends on its proportionate share of the

[4]Some flights are excluded from the cap, including military flights, flight operations for emergency purposes, such as firefighting, as well as airlines with very limited operations. *See* 2008/101/EC, 2009 O.J. (L 8) 3, Annex I.

[5]For instance, a flight from Los Angeles to London will have to surrender allowances for its travel in U.S. airspace, international airspace, and U.K. airspace.

[6]Historical aviation emissions is defined as the mean average of the annual emissions in calendar years 2004, 2005, and 2006. This will be the baseline for emissions reductions. *See* Directive 2008/101/EC, 2009 O.J. (L8) 3, art. 3c.

[7]*See* Directive 2008/101/EC, art. 3(c) (establishing the cap). The cap for subsequent trading periods can be adjusted by an amendment to the directive. *See also* Proposal for a Directive COM(2008) 16 (extending the trading periods to 8 years from 5 years). Although both the European Parliament and the European Council have signaled final approval of the proposed directive, final, formal approval had not occurred as of June 2, 2009.

[8]Three percent of the total quantity of allowances to be allocated will be set aside in a special reserve for new aircraft operators or aircraft operators with rapid growth. Eligible aircraft operators must apply to their assigned member states to obtain free allowances from the special reserve. The European Commission will determine how the allowances in the special reserve will be distributed. Any unallocated allowances will be auctioned.

[9]Aircraft operators will be assigned to the member state that either: (1) issued its operating license or (2) has the greatest estimated emissions from flights performed by that aircraft operator in 2006 or the operator's first year of operation. *See* Directive 2008/101/EC, 2009 O.J. (L 8) 3, art. 18(a). These assignments were made in February 2009 and most U.S. airlines were assigned to the United Kingdom. According to the Directorate-General of the Environment (DG Environment), the auctions will be open to anyone to participate and the Commission is currently developing the regulation containing detailed provisions for member state auctions.

total verified aviation emissions for all member states for a certain year.[10] The member states will be able to use the revenues raised from auctions in accordance with the amended directive.[11] For each trading period, aircraft operators can apply to their assigned member state to receive free allowances. Member states will allocate the free allowances in accordance with a process the European Commission establishes for each trading period.

After the conclusion of each calendar year, aircraft operators must surrender to their assigned member state a number of allowances equal to their total emissions in that year. If an aircraft operator's emissions exceed the number of free allowances it receives, it will be required to purchase additional allowances at auction or on the trading market for EU ETS allowances.[12] In addition, in 2012, aircraft operators will be able to submit certified emissions reductions (CER) and emission reduction units (ERU)—from projects in other countries undertaken pursuant to the Kyoto Protocol's Clean Development Mechanism and Joint Implementation—to cover up to 15 percent of their emissions in lieu of ETS allowances. For subsequent trading periods, aircraft operators' use of CERs and ERUs depends in part on whether a new international agreement on climate change is adopted. However, regardless of whether such an agreement is reached, in the 2013 through 2020 trading period,

[10]For 2012, each member state's total allowances will be based on verified 2010 emissions. In subsequent years, the total allowances will be based on verified emissions from 2 years prior.

[11]According to the 2008 directive, it shall be for member states to determine the use to be made of revenues generated from the auctioning of allowances. Those revenues should be used to tackle climate change in the EU and third countries, inter alia; to reduce greenhouse gas emissions; to adapt to the impacts of climate change in the EU and third countries, especially developing countries; to fund research and development for mitigation and adaptation, including in particular in the fields of aeronautics and air transport; to reduce emissions through low-emission transport; and to cover the cost of administering the Community scheme.

[12]Alternatively, if an aircraft operator has excess emissions allowances, it will be able to sell those excess allowances on the market.

each aircraft operator will be allowed to use CERs and ERUs to cover at least 1.5 percent of their emissions.[13]

If a country not participating in the EU ETS adopts measures for reducing the climate change impact of flights to participating countries, then the European Commission, in consultation with that country, will consider options to provide for "optimal interaction" between the ETS and that country's regulatory scheme—for example, the Commission may consider excluding from the ETS flights to participating EU ETS countries from that country.[14] Although 2012 is the first year aircraft operators must comply with the ETS law, preparations in the EU[15] and from U.S. carriers[16] began soon after the law went into force.

Legal Implications of the ETS

The inclusion of aviation in the newly amended EU ETS implicates a number of international agreements, policy statements, and a bilateral agreement specific to the United States, including the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol to the UNFCCC, the Convention on International Civil Aviation (the 'Chicago Convention'), Resolutions of the International Civil Aviation Organization, and the U.S.-EU Air Transport Agreement (the 'U.S.-EU Open Skies Agreement').

[13]The European Commission will determine the exact percentage of CERs and ERUs that aircraft operators can use in the 2013 through 2020 trading period. In determining the percentage of CERs and ERUs that each covered sector can use in the 2012 through 2020 trading period, the Commission will ensure that overall CER and ERU usage does not exceed 50 percent of the emissions reductions achieved in Phase II (2007 through 2012), measured from a baseline of 2005 emissions levels.

[14]According to the DG Environment, draft legislation and a number of bills proposed in the 110th Congress would have triggered such consideration. *See* McCain-Lieberman, S. 280, 110th Cong. (2007); Lieberman-Warner, S. 2191, 110th Cong. (2007); Dingell-Boucher, draft bill; and Waxman-Markey, H.R. 1590, 110th Cong. (2007), H.R. 6186, 110th Cong. (2008).

[15]On Feb. 11, 2009, the Commission adopted the Preliminary List of Aircraft Operators and their administering Member States, *Commission Notice Pursuant to Article 18a(3)(a) of Directive 2003/87/EC*, C(2009) 866. Additional preparations have included holding a number of stakeholder workshops to discuss implementing this directive and development of guidelines for monitoring, reporting, and verification of emissions, according to the DG Environment.

[16]All operators must submit their monitoring plan by the end of August 2009, according to the DG Environment.

The UNFCCC, a multilateral treaty on global warming that was signed in 1992 and has been ratified by 192 countries, including the United States, seeks to "achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."[17] Although the UNFCCC required signatory states to formulate a national response to climate change,[18] its mitigation provisions did not require mandatory national emissions targets.[19]

In order to strengthen the commitments articulated in the UNFCCC, the Kyoto Protocol was developed within the UNFCCC's framework and adopted in 1997. The Protocol entered into force in February 2005.[20] The Kyoto Protocol established binding greenhouse gas emissions targets for a number of industrialized nations[21] and the European Economic Community (EEC).[22] Notably, the agreement required these industrialized nations and the EEC to pursue "limitations or reduction of emissions of greenhouse gases … from aviation … working through the International Civil Aviation Organization."[23] As of January 2009, 183 countries had ratified the Kyoto Protocol, but not the United States.

Further, the Convention on International Civil Aviation, commonly known as the Chicago Convention, signed on December 7, 1944, sets forth rules on airspace, issues of sovereignty, aircraft licensing and registration, and general international standards and procedures, among others.[24] Notably,

[17]United Nations Framework Convention on Climate Change, 1992, Article 2, GE.05-62220. (E) 200705.

[18]*Id.* at Article 4(1)(b).

[19]*Id.* at Article 4.

[20]Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1999 [hereinafter Kyoto Protocol].

[21]The Kyoto Protocol recognized that industrialized nations are the largest contributors to greenhouse gas emissions and therefore divided the signatory countries into two groups—Annex I countries that are industrialized nations subject to binding targets, either emission reduction or limitation requirements, and Non-Annex I countries that are not subject to binding targets.

[22]Kyoto Protocol, *supra* note 20, art. 3(1).

[23]*Id.* at art. 2(2).

[24]Convention on International Civil Aviation, Dec. 7, 1944, Ninth ed., 2006, 61 Stat. 1180, 15 U.N.T.S. 295 [hereinafter Chicago Convention].

the treaty sets forth sovereignty provisions, recognizing that a contracting state has exclusive sovereignty over airspace above its own territory.[25] Provisions potentially applicable to the recent amendment incorporating aviation into the ETS include Article 11,[26] Article 12,[27] Article 15,[28] and Article 24.[29]

Established by the Chicago Convention in 1944, the International Civil Aviation Organization (ICAO) is an agency of the United Nations and is tasked with fostering the planning and development of international aviation. ICAO has issued a number of Assembly Resolutions, which are statements of policy rather than law, including a nonbinding ICAO Resolution A36-22 relating to environmental protection and aviation emissions.[30] This resolution, which supersedes ICAO Resolution A35-5 which had endorsed the further development of an open emissions trading scheme for international aviation, calls for mutual agreement between contracting states before implementation of an emissions trading scheme.[31] Additionally, the Resolution formed a new Group on

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[25]*See Id.* at art. 1.

[26]Article 11 provides that "[S]ubject to the provisions of this Convention, the laws and regulations of a contracting State relating to the admission to or departure from its territory of aircraft engaged in international navigation . . . shall be applied to the aircraft of all contracting States without distinction as to nationality, and shall be complied with by such aircraft upon entering or departing from or while within the territory of that State."

[27]Article 12 states that "[e]ach contracting State undertakes to adopt measures to insure that every aircraft flying over or maneuvering within its territory and that every aircraft carrying its nationality mark, wherever such aircraft may be, shall comply with the rules and regulations relating to the flight and maneuver of aircraft there in force. . . . Over the high seas, the rules in force shall be those established under this Convention, . . ."

[28]Article 15 provides in part that "[n]o fees, dues or other charges shall be imposed by any contracting State in respect solely of the right of transit over or entry into or exit from its territory of any aircraft of a contracting State or persons or property thereon." Moreover, charges that may be imposed must be non-discriminatory.

[29]Article 24 covers customs and related duties for aircraft of contracting states and includes the provision that "[f]uel . . . on board an aircraft of a contracting State, on arrival in the territory of another contracting State and retained on board on leaving the territory of that State shall be exempt from customs duty, inspection fees or similar national or local duties and charges."

[30]Consolidated Statement on Continuing ICAO Policies and Practices Related to Environmental Protection, ICAO Res. A36-22, 36th Session, Appendix L, 1(b)(1)(2007) [hereinafter ICAO Res. A36-22].

[31]Many positions referred to in this article cite to ICAO Resolution A35-5 rather than the A36-22.

International Aviation and Climate Change (GIACC) that was tasked with developing and recommending to the ICAO Council a program of action to address international aviation and climate change.[32] GIACC is due to report to the Council later this year.

Finally, the U.S.-EU Air Transport Agreement,[33] signed on April 25 and 30, 2007, and provisionally applied as of March 30, 2008, provided greater flexibility for flights between the United States and the EU, authorizing every U.S. and every EU airline to: operate without restriction on the number of flights, aircraft, and routes, set fares according to market demand; and enter into cooperative arrangements, including codesharing, franchising, and leasing. It includes enhanced opportunities for EU investment in carriers from almost 30 non-EU countries, and enhanced regulatory cooperation in regard to competition law, government subsidies, the environment, consumer protection, and security.[34] Among the provisions potentially applicable to the newly amended EU ETS is Articles 12 relating to charges for use of airports and related facilities and services and Article 3 which prohibits a party from unilaterally limiting service or aircraft type.[35]

Although a number of international agreements, policy statements, and bilateral agreements are in place currently, climate change policies are constantly changing. In December 2009, the Conference of the Parties to the UNFCCC will meet in Copenhagen to discuss and negotiate an "agreed outcome" in order to implement the UNFCCC "up to and beyond 2012."[36]

Stakeholder Positions on Legal Issues

A number of stakeholders have expressed concern as to the legal basis for aviation's inclusion in the EU ETS. In the United States, within the EU community, and in countries throughout the world, public and private entities, as well as legal scholars, have expressed opinions as to whether the inclusion of aviation into the ETS is in compliance with international law.

[32]ICAO Res. A36-22, *supra* note 30, Appendix K.

[33]This also is referred to as the U.S.-EU Open Skies Agreement.

[34]*See generally* Id.

[35]*Id.* at art. 12, 3.

[36]Bali Action Plan, Decision 1/CP.13, 1 (FCCC/CP/2007/6/Add.1).

Stakeholder Positions within the United States

Stakeholders within the United States, such as the executive branch, members of Congress, and the Air Transport Association (ATA), have weighed in on the legality of the newly amended EU ETS which requires compliance by U.S. carriers.

In 2007 and 2008, the executive branch expressed the view that the imposition of the ETS was inconsistent with international law, specifically, the Chicago Convention and the U.S.-EU Air Transport Agreement.[37] While the executive branch has not articulated a position on this issue since mid-2008, it has expressed the importance of climate change and developing a solution on a global level.[38]

The Air Transport Association (ATA), a trade association representing principle U.S. airlines, also has concluded that the EU ETS's inclusion of aviation violates international law, specifically the Chicago Convention.[39] ATA argues that imposition of the ETS on U.S.-based carriers is contrary to Articles 1, 12, 11,[40] 15[41] and potentially, in the alternative, Article 24.[42] In summary, ATA argues that the ETS, as amended, violates Article 1 and Article 12 provisions of sovereignty and authority. Article 1, which provides contracting states exclusive sovereignty over their airspace,[43] is violated by the EU's extraterritorial reach which covers emissions of non-EU airlines in another states' airspace. Further, Article 12, which requires

[37]Letter of U.S. Ambassador Kristen Silverberg to Jos Delbeke, Acting Director General General, Environment Directorate General, Oct. 30, 2008; and letter from the Ambassadors of Australia, Canada, China, Japan, Korea and the United States to Ambassador Peter Witt of Germany, Apr. 6, 2007 [hereinafter Ambassador Letter].

[38]*See* statement of Secretary Clinton: "President Obama and I recognize that the solutions to this crisis are both domestic and global, that all nations bear responsibility and all nations must work together to find solutions." *See also* statement of Special Envoy Stern: "Yet we can only meet the climate challenge with a response that is genuinely global. Eighty percent of greenhouse gas emissions are produced outside the United States, and a rapidly growing percentage is produced in emerging market countries."

[39]ATA's analysis is contained in a non-public Legal Analysis Summary provided to GAO.

[40]Chicago Convention, *supra* note 24, art. 11.

[41]*Id.* at art. 15.

[42]Article 24 provides that "fuel…on board an aircraft of a contracting State, on arrival in the territory of another… shall be exempt from customs duty, inspection fees or similar national or local duties and charges."

[43]Chicago Convention, *supra* note 24, art. 1. Article 1 provides that every contracting state has "complete and exclusive sovereignty over the airspace above its territory."

contracting states to ensure that aircraft under its jurisdiction are in compliance with rules and regulations relating to the flight and maneuver of aircraft,[44] also is violated. ATA argues that Article 12 gives ICAO primary authority, under the Convention, to set rules for the "flight and maneuver of aircraft" over the "high seas," which precludes the application of rules by one state over the airlines of another state to the extent inconsistent with ICAO rules. Thus, because ICAO has stated that one state can apply emissions trading to the airlines of another state only through mutual consent, ATA contends that the EU's emissions trading coverage of non-agreeing-EU airlines over the high seas is inconsistent with ICAO's authority.

Additionally, with respect to Article 11, ATA argues that although Article 11 provides authority to states to establish certain rules for admission and departure of aircraft, the authority is limited. States may only establish admission and departure rules consistent with the remainder of the Chicago Convention, which prevents the EU from arguing that Article 11 authorizes EU action. In any event, ATA contends that any rules may only apply "upon entering or departing from or while within the territory of that State," whereas the European scheme reaches outside European territory. Further, ATA finds that the ETS is contrary to Article 15[45] of the Chicago Convention because it imposes a de facto charge for the right to enter or exit an EU member state. In the alternative, ATA argues that there could be a violation of Article 24 of the Convention, which exempts fuel on board an aircraft from duties, fees, and charges. Because the law calculates emissions based on fuel consumption, the purchase of greenhouse gas permits may constitute a "similar … charge" of fuel on board, according to ATA. Additionally, Article 24 mirrors Article 11 of the U.S.-EU Air Transport Agreement but extends the freedom from taxation/charges on fuel to that purchased in the EU. Thus, ATA argues, the prohibition against the EU levying a fuel tax applies to fuel already on board as well as fuel purchased in the EU.

ATA has publicly expressed harsh opposition to the ETS's inclusion of aviation and has stated that there will be a number of legal challenges from around the globe, including from the United States.[46] ATA has

[44] *Id.* at art. 12.

[45] *Id.* at art. 15.

[46] *See* Josh Voorhees, Greenwire, *EU brings airlines into climate scheme; industry vows court fight* (2008), at http://www.eenews.net/Greenwire/2008/07/08/archive/3.

additionally expressed discontent with the newly amended ETS law as a matter of policy, as it siphons money out of aviation which is counterproductive from reinvesting in improving technologies that reduce emissions.[47]

Finally, the Congress is considering the House FAA Reauthorization Bill, H.R. 915, 111th Cong. (2009), which includes an expression of the Sense of the Congress with respect to the newly amended EU ETS.[48] The bill states that the EU's imposition of the ETS, without working through ICAO, is inconsistent with the Chicago Convention, other relevant air service agreements, and "antithetical to building cooperation to address effectively the problem of greenhouse gas emissions by aircraft engaged in international civil aviation."[49] The bill recommends working through ICAO to address these issues.[50]

Stakeholder Positions outside the United States

Stakeholders in the EU community and a not-for-profit business organization have expressed both legal and policy views on the newly amended ETS, as well. An independent contractor for the European Commission's Directorate-General of the Environment (DG Environment) as well as the International Emissions Trading Association (IETA) have both issued opinions in support of aviation's inclusion in the ETS. [51] IETA supports the inclusion of aviation in the EU ETS from a policy perspective, but has not opined on the legality of its inclusion.[52] From a policy standpoint, IETA supports aviation's inclusion on both EU and non-EU carriers so as to share the burden to combat climate change.[53] However, the organization has expressed concerns over a number of issues, some of

[47]Press Release, Air Transport Association Chief Executive Says European Aviation Emissions Trading Scheme 'Contrary to International Law and Bad Policy' (Oct. 30, 2008), *available at* http://www.airlines.org/news/releases/2008/news_10-30-08.htm.

[48]A "Sense of the Congress" is not legally binding if passed.

[49]H.R. 915, Sec. 514(1), 111th Cong. (2009).

[50]*Id.* at Sec. 514(2).

[51]The legal assessment was conducted by an independent contractor for the DG Environment.

[52]IETA, *IETA's position on the Inclusion of Aviation in the EU ETS*, available at www.ieta.org/ieta/www/pages/getfile.php?docID=2413.

[53]*Id.* at 2.

which include access to project credits, amount of allowances available for auctioning, and allocation calculation.[54]

From a legal perspective, an independent contractor for the DG Environment[55] has issued an opinion supporting aviation's inclusion in the EU ETS.[56] The opinion states that alongside a state's inherent right to enact legislation and the provisions of the EC Treaty for collective action by member states, the legal basis for action is contained in the UNFCCC's requirement for developed countries to take measures to mitigate climate change, in the Kyoto Protocol which reinforces this position, and under EU law (the EC Treaty), which provides the basis for the EU to act by including aviation in the ETS.[57] Further, the opinion articulates that the ETS does not violate Articles 11,[58] 12,[59] 15,[60] or 24[61] of the Chicago Convention. First, Article 11 is consistent with the newly amended ETS law so long as the "laws and regulations" established do not "discriminate as to nationality of aircraft."[62] Further, Article 12 is inapplicable because emissions trading does not affect the flight or maneuver of aircraft but merely the terms for admission to and departure from EU territory. Additionally, the opinion stated that Article 15 is inapplicable because the coverage of aviation cannot be seen as an "airport charge or similar charge." Even if payment were to occur under an auction system, the allowances are not designed as compensation for the costs of operation and management of airports and air navigation facilities, and

[54]*Id.*

[55]The legal assessment was conducted by an independent contractor for the DG Environment.

[56]*Giving Wings to Emissions Trading, Inclusion of Aviation under the European emissions trading system (ETS): Design and Impacts* (The Delft Report), Report to the European Commission, DG Environment, No.ENV.C.2./ETU/2004/0074r, July 2005 [hereinafter Delft Report]. This report was prepared for and endorsed by the European Commission.

[57]*Id.* at 170-73.

[58]Chicago Convention, *supra* note 24, art. 11.

[59]Article 12 requires contracting states to ensure that aircraft under their jurisdiction are in compliance with rules and regulations relating to the flight and maneuver of aircraft.

[60]Chicago Convention, *supra* note 24, art. 15.

[61]*Id.* at art. 24.

[62]The Delft Report at 175-77.

consequently, Article 15 is inapplicable.[63] Finally, Article 24 of the Convention does not apply to the Emissions Trading System because trading allowances are "fundamentally different from customs duties."[64] Additionally, the opinion finds policy support for these legal findings in ICAO Resolution A35-5[65] and bilateral air transport agreements.[66]

Additionally, countries outside the European Community have joined the United States in an expression of concerns regarding the imposition of the ETS on non-EU carriers. In an April 2007 letter to the German Ambassador to the European Union, the United States, Australia, China, Japan, South Korea, and Canada conveyed a "deep concern and strong dissatisfaction" for the then-proposal to include international civil aviation within the scope of the EU ETS.[67] The letter asks that the EU ETS not include non-EU aircraft unless done by mutual consent.[68] Although supportive of the reduction of greenhouse gas emissions, the ascribing parties argue that the "unilateral" imposition of the ETS on non-EU carriers would potentially violate the Chicago Convention and bilateral aviation agreements with the parties to the letter.[69] Moreover, they write, the proposal runs counter to the international consensus that ICAO should handle matters of international aviation, which was articulated with the ICAO Assembly and the ICAO Council in 2004 and 2006, respectively.[70] The letter closes with a

[63]*Id.* at 176-77

[64]*Id.* at 177.

[65]Consolidated statement of continuing ICAO policies and practices related to environmental protection, ICAO Res. A35-5, 35th Session, Appendix 1 (2004) [hereinafter ICAO Res. A35-5]. "ICAO endorses an open emission system for international aviation" and requests council focus on two areas under this framework.

[66]The Delft Report further elaborates: "the operation of an ETS does not unilaterally limit the volume of traffic … or aircraft types, as it only provides incentives to reduce emissions over time; fair and equal opportunity to participate in the ETS is already covered under the Chicago Convention's non-discrimination clause and this must be adhered to under the ETS." *See* pp. 179-181.

[67]Letter to the German Presidency regarding Commission proposal to extend ETS to aviation (Apr. 6, 2007).

[68]*Id.*

[69]*Id.*

[70]*Id.*

reservation of right to take appropriate measures under international law if the ETS is imposed.[71]

Legal Scholar/Researcher Views

Given the controversial nature and complexity of aviation's inclusion in the EU ETS, a number of scholars in the legal community, both within the United States and the EU, have provided explanatory articles or position papers on the issue of the consistency of the EU's plans with its international legal obligations.[72]

One U.S. law review article by Daniel B. Reagan argues that international aviation emission reductions should be pursued through ICAO given the "political, technical, and legal implications raised by the regulation."[73] This article sets forth that politically, ICAO is the appropriate body because it can work towards uniformity in a complex regulatory arena, incidentally resulting in increased participation from a variety of stakeholders, reduction of resentment, and a reduced likelihood of non-compliance and legal challenges.[74] Further, ICAO has the expertise necessary to technically design aviation's emission reduction regime and is in a position to consider the "economic, political, and technical circumstances of its member states … ."[75] Finally, Reagan argues that pursuing an emissions reduction regime through ICAO could avoid likely legal challenges which present themselves under the current ETS, as ICAO could facilitate a common understanding of contentious provisions.[76] In conclusion, he proposes that the EU should channel the energy for implementation of the current regime into holding ICAO accountable for fulfilling environmental duties.[77]

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[71] *Id.*

[72] For brevity's sake, we have not included explanatory articles because they are repetitive of what is contained in this appendix. Here we highlight those articles which set forth legal positions on the issue.

[73] Daniel B. Reagan, *Putting International Aviation Into the European Union Emissions Trading Scheme: Can Europe Do It Flying Solo?*, 35 B.C. Envtl. Aff. L. Rev. 349 (2008).

[74] *Id.* at 380-81.

[75] *Id.* at 381-82.

[76] *Id.* at 382.

[77] *Id.* at 383.

In contrast, a law review article published in the European Environmental Law Review in 2007 by Gisbert Schwarze argues that bringing aviation into the EU ETS falls clearly within existing law and is, in fact, mandated.[78] The article presents the case that neither existing traffic rights in member states, bilateral air transport agreements, nor the Chicago Convention pose any legal obstacles.[79] He argues, in fact, that the EU has a mandate under the UNFCCC and the Kyoto Protocol to implement climate change policies which include aviation. First, the article sets forth that the inclusion of aviation does not restrict existing traffic rights or allow or disallow certain aircraft operations in different member states, but rather merely brings the amount of emissions into the decision-making process.[80]

Further, Schwarze explains that imposing the ETS on carriers flying in and out of the EU is well within the Chicago Convention. Article 1 of the Convention provides contracting states exclusive sovereignty over their airspace which provides the EU with the authority to impose obligations relating to arrival and departures, so long as there is no discrimination on the basis of nationality, as required by Article 11.[81] Additionally, the article sets forth that Article 12, regarding the flight and maneuver of aircraft, is not applicable because, as argued above, the ETS does not regulate certain aircraft operations. Article 15, which covers charges, is similarly inapplicable because emissions allowances on the free market or through the auctioning process do not constitute a charge.[82] Finally, Article 24 is inapposite as well because the emissions trading system does not constitute a customs duty.[83]

Additionally, Schwarze argues that the bilateral air transport agreements with various nations, such as the Open Skies Agreement with the United States, do not pose any legal barriers to inclusion of aviation in ETS.[84]

[78]Gisbert Schwarze, *Including Aviation into the European Union Emissions Trading Scheme*, European Environmental Law Review (2007).

[79]*Id.* at 12-15.

[80]*Id.* at 12-13.

[81]*Id.* at 13-14.

[82]In the alternative, as argued, even if this did constitute a charge, Article 15's only applicability is to discrimination as to nationality. *Id.*

[83]Gisbert Schwarze, *Including Aviation into the European Union Emissions Trading Scheme*, p. 13-14, European Environmental Law Review (2007).

[84]*Id.* at 14.

These agreements contain a prohibition of discrimination similar to Article 11 of the Chicago Convention and a fair competition clause which requires fair competition among signatories in international aviation as well as prohibits a party from unilaterally limiting traffic.[85] The article argues that so long as the ETS operates without discrimination, it is in conformity with the principle of a sound and economic operation of air services and therefore satisfies the fairness clause.[86] Finally, since the ETS gives only incentive to reduce emissions, it does not regulate the amount of air traffic.[87]

Finally, Schwarze argues that not only is the inclusion of aviation into the EU ETS legally sound, the UNFCCC and Kyoto Protocol mandate its inclusion. The UNFCCC requires all parties to the treaty to adopt national policies and take corresponding measures on the mitigation of climate change consistent with the objective of the convention, recognizing that this can be done "jointly with other parties."[88] Additionally, the Kyoto Protocol, which sought to strengthen UNFCCC, required Annex 1 parties to pursue "limitations or reduction of emissions of greenhouse gases … from aviation … working through the International Civil Aviation Organization."[89] And finally, although not legally binding, ICAO Resolution A35-5 endorses the development of an open emissions trading system for international aviation.[90]

Potential Legal Challenges and Dispute Resolution

Implementation of the new ETS directive will likely face legal challenges before 2012, the first year aircraft operators will be included in the ETS. A number of stakeholders, including ATA, have publicly expressed that there will be "government-to-government legal challenges" and potentially a "multilateral challenge from around the world."[91] Further, countries outside the EU community have joined in support of taking appropriate

[85] *Id.*

[86] *Id.*

[87] *Id.*

[88] United Nations Framework Convention on Climate Change, *supra* note 17, art. 4(2)(a).

[89] Kyoto Protocol, *supra* note 20, art. 2(2).

[90] Schwarze at 13. *See also* ICAO Res. A35-5, *supra* note 66, Appendix I Nr. 2(c)(1).

[91] *See* Voorhees, *supra* note 46.

actions under international law if the ETS is imposed.[92] If challenges are brought forth, they could potentially be brought forth under the Chicago Convention, air service agreements (e.g., U.S.- EU Air Transport Agreement) or potentially in individual member state courts. Each option has its own dispute resolution procedure.

If a challenge is brought forth under the Chicago Convention after failed negotiations, Article 84 of the Convention (Settlement of Disputes) is invoked. Article 84 provides that if there is a disagreement by two or more contracting states which cannot be settled by negotiation, it will be decided upon by the Council.[93] A decision by the Council can be appealed to an agreed-upon ad hoc tribunal or to the Permanent Court of International Justice (now the International Court of Justice) whose decision will be binding.[94]

Air service agreements additionally have dispute resolution procedures and the U.S.-EU Air Transport Agreement is no exception. Article 19 of the U.S.-EU Air Transport Agreement provides that parties to a dispute may submit to binding arbitration through an ad hoc tribunal if negotiations fail.[95] If there is noncompliance with the tribunal's decision and a subsequent agreement between the parties is not reached within 40 days, the other party may suspend the application of comparable benefits which arise under the agreement.[96]

In addition to bringing legal challenges under international treaties, carriers could potentially mount legal challenges in member states'

[92]*See* Ambassadors Letter, *supra* note 37.

[93]Chicago Convention, *supra* note 24, art. 84. The Council is composed of 36 contracting states elected by the Assembly. *See Id.* at art. 50. When a disagreement is submitted to the Council, the Council will invoke the Rules of the Settlement of Differences, established in 1957, which sets forth procedures for disputes.

[94]*Id.* at art. 84. Additional requirements for settlement of disputes and penalties are contained in Articles 85, 86, 87 and 88 of the Chicago Convention. Alternatively, a challenge could potentially be brought against a carrier. If a carrier chooses to move forward and not comply with the ETS, action could be brought under the Chicago Convention Article 87 and force the airline to cease operations over any contracting state.

[95]*See* U.S.-EU Air Transport Agreement, art. 19.

[96]*See Id.* at art. 19(7).

national courts, according to some legal scholars.[97] Additionally, a European state will potentially be able to take action against a noncompliant carrier under their civil aviation authority in the state's courts.[98]

[97]*See* Aimee Turner, Flight Global, *EU warns ICAO it will go it alone if no progress is made with ETS* (2007), available at www.flightglobal.com.

[98]*Id.*

Appendix II: List of Experts

Gerald Bernstein, Stanford Transportation Group
Dennis Bushnell, National Aeronautics and Space Administration
Kenneth Button, George Mason University
Anthony Dean, General Electric
Robert Deering, American Airlines
Christian Dumas, Airbus (France)
Jasper Faber, CE Delft (Netherlands)
Richard Golaszewski, GRA, Incorporated
Preston Henne, Gulfstream Aerospace Corporation
James Hileman, Massachusetts Institute of Technology
Jennifer Holmgren, Universal Oil Products
David Lee, Manchester Metropolitan University (United Kingdom)
Peter Morrell, Cranfield University (United Kingdom)
Andreas Schafer, University of Cambridge (United Kingdom)
Agam Sinha, MITRE Corporation
Julian Tishkoff, United States Air Force
Ian Waitz, Massachusetts Institute of Technology
Donald Wuebbles, University of Illinois

Appendix III: Detailed Survey Results

The survey tool used to assess options for reducing commercial aircraft emissions is below, complete with detailed results. We do not include the responses for open-ended questions.

United States Government Accountability Office

Aviation and Climate Change

Ranking Tool for Options to Reduce Aircraft Greenhouse Gas Emissions

Introduction

This rating tool follows up on our recent interview with you on commercial aviation and greenhouse gas emissions. The tool contains options for reducing commercial aviation emissions that were identified through our interviews with you and other experts, or by GAO. We have placed the options in three categories—technologies, operations, and alternative fuels—and are interested in your expert opinion on them. We ask that you rate the options across several factors, providing comments where appropriate.

Instructions for Completing This Tool

You can answer most of the questions by checking boxes or filling in blanks. A few questions request short narrative answers. Please note that these blanks will expand to fit your answer.

- Please use your mouse to navigate throughout the document by clicking on the field or checking the box you wish to fill in. **Do not** use the **"Tab" or "Enter"** keys, because doing so may cause formatting problems.
- To select a box, click on it once; to deselect a box, double click on it.

If you prefer, you may print this tool, complete it by hand, and return it by fax. Please use extra paper as necessary to complete the open-ended questions.

Deadline

We ask that you complete and return this document to Matthew Rosenberg by January 9, 2009. Please save the completed document to your desktop or hard drive and e-mail it as an attachment to

RosenbergMC@gao.gov. If you complete this tool by hand, please fax the completed tool to Matthew Rosenberg at GAO at 312-220-7726.

Contact Information

If you have any questions, please contact Matthew Rosenberg, Senior Analyst, at 312-220-7645 or RosenbergMC@gao.gov or Cathy Colwell, Assistant Director, at 312-220-7655 or ColwellC@gao.gov.

Thank you for your help.

Part 1: Technology Options

1. How would you rate your overall knowledge of technological options to reduce aircraft carbon dioxide (CO_2) emissions, such as aircraft engines and aircraft design technologies, and the costs of those technologies?

0 None → SKIP TO QUESTION #9
6 Minimal → SKIP TO QUESTION #9
4 Basic → CONTINUE TO QUESTION #2
1 Proficient → CONTINUE TO QUESTION #2
7 Advanced → CONTINUE TO QUESTION #2

2. In your expert opinion, what is the potential for future fuel savings and CO_2 emissions reductions for the following options?

		Low potential	Medium potential	High potential	Don't know
a.	Open rotor engines	0	5	8	1
b.	Geared Turbo Fan Engines	2	7	3	2
c.	Distributive Propulsion systems	2	2	5	5
d.	Lighter airframes (Composites)	2	5	6	1
e.	Increased Laminar Flow Control	2	6	3	2
f.	Blended wing-body aircraft	0	5	8	1
g.	Winglets	8	3	3	0
h.	Riblets	9	1	0	4

3. In your expert opinion, what would be the potential R&D costs to develop the following options for commercial use?

		Lowcosts	Medium costs	High costs	Don't know
a.	Open rotor engines	1	6	6	1
b.	Geared Turbo Fan Engines	3	7	3	1
c.	Distributive Propulsion systems	0	1	7	6
d.	Lighter airframes (Composites)	1	6	6	1
e.	Increased Laminar Flow Control	0	4	7	3
f.	Blended wing-body aircraft	1	1	12	0
g.	Winglets	14	0	0	0
h.	Riblets	7	3	0	4

4. Given your answer to question two, what would be the potential costs to the air transport industry to procure, operate and maintain the following options to achieve those fuel savings and CO_2 emissions reductions?

		Lowcosts	Medium costs	High costs	Don't know
a.	Open rotor engines	2	7	3	2
b.	Geared Turbo Fan Engines	2	9	1	2
c.	Distributive Propulsion systems	0	2	6	6
d.	Lighter airframes (Composites)	3	6	3	2
e.	Increased Laminar Flow Control	1	4	5	4
f.	Blended wing-body aircraft	2	3	9	0
g.	Winglets	14	0	0	0
h.	Riblets	9	1	0	4

5. In your expert opinion, what is the level of public acceptance for the following conceptual options?

		Low acceptance	Medium acceptance	High acceptance	Don't know
a.	Open rotor engines	6	7	0	1
b.	Geared Turbo Fan Engines	0	2	11	1
c.	Distributive Propulsion systems	2	2	4	6
d.	Lighter airframes (Composites)	0	3	9	2
e.	Increased Laminar Flow Control	0	4	8	2
f.	Blended wing-body aircraft	4	5	2	3
g.	Winglets	0	0	13	1
h.	Riblets	0	1	9	4

6. In your expert opinion, given our best knowledge about future market conditions, and absent government intervention, how long would it take for the private sector to adopt these technologies?

		Short timeframe (< 5 years)	Medium timeframe (5 - 15 years)	Long timeframe (> 15 years)	Never	Don't know
a.	Open rotor engines	1	9	3	0	1
b.	Geared Turbo Fan Engines	6	6	0	0	2
c.	Distributive Propulsion systems	0	0	6	2	6
d.	Lighter airframes (Composites)	3	9	1	0	1
e.	Increased Laminar Flow Control	2	4	5	0	3
f.	Blended wing-body aircraft	0	2	10	2	0
g.	Winglets	14	0	0	0	0
h.	Riblets	5	3	1	0	5a

7. What major challenges exist to widespread use of …

a.	Open rotor engines	
b.	Geared Turbo Fan Engines	
c.	Distributive Propulsion systems	
d.	Lighter airframes (Composites)	
e.	Increased Laminar Flow Control	
f.	Blended wing-body aircraft	
g.	Winglets	
h.	Riblets	

8. What actions could the U.S. federal government undertake to promote the development and/or adoption of …

a.	Open rotor engines	
b.	Geared Turbo Fan Engines	
c.	Distributive Propulsion systems	
d.	Lighter airframes (Composites)	
e.	Increased Laminar Flow Control	
f.	Blended wing-body aircraft	
g.	Winglets	
h.	Riblets	

Part 2: Operational Options

9. How would you rate your overall knowledge of operational options to reduce aircraft fuel usage and CO_2 emissions, such as air traffic management and airline operations?

0 None → SKIP TO QUESTION #17
5 Minimal → SKIP TO QUESTION #17
7 Basic → CONTINUE TO QUESTION #10
4 Proficient → CONTINUE TO QUESTION #10
2 Advanced → CONTINUE TO QUESTION #10

10. In your expert opinion, what is the future potential for fuel savings and CO_2 emissions reductions for the following options?

		Low potential	Medium potential	High potential	Don't know
a.	Reduction of on-board weight	7	4	2	0
b.	Engine washing	8	4	0	1
c.	Limited use of paint on airframes	9	3	0	1
d.	Increased engine maintenance	8	3	1	1
e.	Single engine taxing	7	6	0	0
f.	Use of APU on ground at gate	10	2	0	1
g.	Automatic Dependent Surveillance – Broadcast (ADS-B)	2	6	1	4
h.	Required Navigation Performance (RNP)	2	4	2	5
i.	Continuous Descent Arrivals (CDA)	5	5	2	1
j.	NEXTGEN Weather	3	5	1	4
k.	Enhanced vision systems	6	3	0	4
l.	Synthetic vision systems	6	2	0	5
m.	Reduced Vertical Separation	3	8	1	1
n.	Flying at slower speeds	5	5	3	0
o.	Formation flying	5	2	2	4
p.	Air to air refueling	7	1	0	5
q.	Reduced flight frequency with larger aircraft	6	3	3	1
r.	Multi-stage long distance travel	6	4	1	2

11. In your expert opinion, what would be the potential R&D costs to develop the following options for commercial use?

		Low Costs	Medium Costs	High Costs	Don't know
a.	Reduction of on-board weight	8	4	1	0
b.	Engine washing	11	0	0	2
c.	Limited use of paint on airframes	13	0	0	0
d.	Increased engine maintenance	11	2	0	0
e.	Single engine taxing	13	0	0	0
f.	Use of APU on ground at gate	11	0	0	2
g.	Automatic Dependent Surveillance – Broadcast (ADS-B)	1	6	1	5
h.	Required Navigation Performance (RNP)	3	4	0	6
i.	Continuous Descent Arrivals (CDA)	4	7	0	2
j.	NEXTGEN Weather	1	4	3	5
k.	Enhanced vision systems	2	5	1	5
l.	Synthetic vision systems	2	5	1	5
m.	Reduced Vertical Separation	9	1	1	2
n.	Flying at slower speeds	13	0	0	0
o.	Formation flying	3	3	4	3
p.	Air to air refueling	0	3	5	5
q.	Reduced flight frequency with larger aircraft	12	0	1	0
r.	Multi-stage long distance travel	11	0	1	1

12. Given your answer to question ten, what would be the potential costs to the air transport industry to adopt the following options to achieve those fuel savings and CO_2 emissions reductions?

		Low costs	Medium costs	High costs	Don't know
a.	Reduction of on-board weight	8	5	0	0
b.	Engine washing	8	4	0	1
c.	Limited use of paint on airframes	11	2	0	0
d.	Increased engine maintenance	5	6	1	1
e.	Single engine taxing	13	0	0	0
f.	Use of APU on ground at gate	10	1	0	2
g.	Automatic Dependent Surveillance – Broadcast (ADS-B)	2	4	2	5
h.	Required Navigation Performance (RNP)	4	3	0	6
i.	Continuous Descent Arrivals (CDA)	8	3	0	1
j.	NEXTGEN Weather	2	3	1	6
k.	Enhanced vision systems	1	5	2	5
l.	Synthetic vision systems	1	6	1	5
m.	Reduced Vertical Separation	9	2	0	2
n.	Flying at slower speeds	11	2	0	0
o.	Formation flying	2	4	2	5
p.	Air to air refueling	0	4	5	4
q.	Reduced flight frequency with larger aircraft	9	1	3	0
r.	Multi-stage long distance travel	5	4	2	2

13. In your expert opinion, what is the level of public acceptance for the following options?

	Low acceptance	Medium acceptance	High acceptance	Don't know
Reduction of on-board weight	0	5	8	0
Engine washing	0	0	11	2
Limited use of paint on airframes	1	2	10	0
Increased engine maintenance	0	0	12	1
Single engine taxing	0	2	11	0
Use of APU on ground at gate	0	2	9	2
Automatic Dependent Surveillance – Broadcast (ADS-B)	0	0	9	4
Required Navigation Performance (RNP)	0	0	8	5
Continuous Descent Arrivals (CDA)	0	1	12	0
NEXTGEN Weather	0	1	8	4
Enhanced vision systems	0	1	9	3
Synthetic vision systems	1	1	8	3
Reduced Vertical Separation	1	6	6	0
Flying at slower speeds	7	5	1	0
Formation flying	8	3	1	1
Air to air refueling	10	1	0	2
Reduced flight frequency with larger aircraft	7	5	1	0
Multi-stage long distance travel	8	3	0	1

14. In your expert opinion, given our best knowledge about future market conditions, and absent government intervention, how long would it take for the private sector to adopt these technologies?

		Short timeframe (< 5 years)	Medium timeframe (5 -15 years)	Long timeframe (> 15 years)	Never	Don't know
a.	Reduction of on-board weight	8	5	0	0	0
b.	Engine washing	11	1	0	0	1
c.	Limited use of paint on airframes	9	4	0	0	0
d.	Increased engine maintenance	12	1	0	0	0
e.	Single engine taxing	13	0	0	0	0
f.	Use of APU on ground at gate	8	3	0	0	2
g.	Automatic Dependent Surveillance – Broadcast (ADS-B)	3	5	0	0	5
h.	Required Navigation Performance (RNP)	6	1	0	0	6
i.	Continuous Descent Arrivals (CDA)	7	5	0	0	1
j.	NEXTGEN Weather	2	5	0	0	6
k.	Enhanced vision systems	2	5	1	0	5
l.	Synthetic vision systems	1	4	3	0	5
m.	Reduced Vertical Separation	5	6	1	0	1
n.	Flying at slower speeds	11	0	2	0	0
o.	Formation flying	2	4	4	2	1
p.	Air to air refueling	0	1	8	1	3
q.	Reduced flight frequency with larger aircraft	8	3	1	1	0
r.	Multi-stage long distance travel	6	1	2	2	2

15. What major challenges exist to widespread use of …

a.	Reduction of on-board weight	
b.	Engine washing	
c.	Limited use of paint on airframes	
d.	Increased engine maintenance	
e.	Single engine taxing	
f.	Use of APU on ground at gate	
g.	Automatic Dependent Surveillance – Broadcast (ADS-B)	
h.	Required Navigation Performance (RNP)	
i.	Continuous Descent Arrivals (CDA)	
j.	NEXTGEN Weather	
k.	Enhanced vision systems	
l.	Synthetic vision systems	
m.	Reduced Vertical Separation	
n.	Flying at slower speeds	
o.	Formation flying	
p.	Air to air refueling	
q.	Reduced flight frequency with larger aircraft	
r.	Multi-stage long distance travel	

16. What actions could the U.S. federal government undertake to promote the adoption of ...

a.	Reduction of on-board weight	
b.	Engine washing	
c.	Limited use of paint on airframes	
d.	Increased engine maintenance	
e.	Single engine taxing	
f.	Use of APU on ground at gate	
g.	Automatic Dependent Surveillance – Broadcast (ADS-B)	
h.	Required Navigation Performance (RNP)	
i.	Continuous Descent Arrivals (CDA)	
j.	NEXTGEN Weather	
k.	Enhanced vision systems	
l.	Synthetic vision systems	
m.	Reduced Vertical Separation	
n.	Flying at slower speeds	
o.	Formation flying	
p.	Air to air refueling	
q.	Reduced flight frequency with larger aircraft	
r.	Multi-stage long distance travel	

Part 3: Alternative Fuel Options

17. How would you rate your overall knowledge of alternative fuel options to reduce aircraft CO_2 emissions, such as biofuels?

1 None → SKIP TO QUESTION #25
7 Minimal → SKIP TO QUESTION #25
2 Basic → CONTINUE TO QUESTION #18
3 Proficient → CONTINUE TO QUESTION #18
5 Advanced → CONTINUE TO QUESTION #18

18. In your expert opinion, compared to jet fuel currently in use, what is the potential for future reduction of CO_2 emissions (on a life-cycle basis) for the following options?

		No potential	Low potential	Medium potential	High potential	Don't know
a.	Coal to liquid	7	1	2	0	0
b.	Fischer-Tropsch-treated feedstocks such as switchgrass	1	3	3	3	0
c.	Fischer-Tropsch-treated forest waste	1	3	3	3	0
d.	Fischer-Tropsch-treated municipal waste	1	5	1	3	0
e.	Hydotreated algae	0	3	1	6	0
f.	Hydrotreated Palm and Soy Oils	2	3	3	1	1
g.	Hydrotreated camelina	1	2	3	2	2
h.	Hydrotreated jatropha	0	3	3	2	2
i.	Fuel cells	6	1	1	0	1
j.	Hydrogen	4	2	1	1	1

19. In your expert opinion, what would be the potential R&D costs to develop the following options for commercial use?

		Low costs	Medium costs	Highcosts	Don't know
a.	Coal to liquid	3	3	3	1
b.	Fischer-Tropsch-treated feedstocks such as switchgrass	1	3	4	2
c.	Fischer-Tropsch-treated forest waste	1	3	4	2
d.	Fischer-Tropsch-treated municipal waste	0	4	4	2
e.	Hydotreated algae	0	4	6	0
f.	Hydrotreated Palm and Soy Oils	2	3	3	2
g.	Hydrotreated camelina	2	3	2	3
h.	Hydrotreated jatropha	2	3	2	3
i.	Fuel cells	0	1	7	2
j.	Hydrogen	0	1	8	1

20. In your expert opinion, what is the level of public acceptance for the following options?

		Low costs	Medium costs	High costs	Don't know
a.	Coal to liquid	5	3	0	2
b.	Fischer-Tropsch-treated feedstocks such as switchgrass	0	3	6	1
c.	Fischer-Tropsch-treated forest waste	0	4	5	1
d.	Fischer-Tropsch-treated municipal waste	0	3	6	1
e.	Hydotreated algae	0	1	7	2
f.	Hydrotreated Palm and Soy Oils	5	1	2	2
g.	Hydrotreated camelina	0	5	2	3
h.	Hydrotreated jatropha	0	3	4	3
i.	Fuel cells	1	4	3	2
j.	Hydrogen	5	2	0	3

21. In your expert opinion, given our best knowledge about future market conditions, and absent government intervention, how long would it take for the private sector to adopt these technologies?

		Never	Short timeframe (<10years)	Medium timeframe (10-20 years)	Long timeframe (> 20 years)	Don't know
a.	Coal to liquid	7	2	0	0	1
b.	Fischer-Tropsch-treated feedstocks such as switchgrass	5	4	0	0	1
c.	Fischer-Tropsch-treated forest waste	5	4	0	0	1
d.	Fischer-Tropsch-treated municipal waste	5	4	0	0	1
e.	Hydotreated algae	3	4	2	0	1
f.	Hydrotreated Palm and Soy Oils	5	3	0	0	2
g.	Hydrotreated camelina	4	3	0	0	3
h.	Hydrotreated jatropha	4	3	0	0	3
i.	Fuel cells	0	3	6	0	1
j.	Hydrogen	1	0	7	1	1

22. What major challenges exist to widespread use of ...

a.	Coal to liquid	
b.	Fischer-Tropsch-treated feedstocks such as switchgrass	
c.	Fischer-Tropsch-treated forest waste	
d.	Fischer-Tropsch-treated municipal waste	
e.	Hydotreated algae	
f.	Hydrotreated Palm and Soy Oils	
g.	Hydrotreated camelina	
h.	Hydrotreated jatropha	
i.	Fuel cells	
j.	Hydrogen	

23. What actions could the federal government undertake to promote the development and/or adoption of ...

a.	Coal to liquid
b.	Fischer-Tropsch-treated feedstocks such as switchgrass
c.	Fischer-Tropsch-treated forest waste
d.	Fischer-Tropsch-treated municipal waste
e.	Hydotreated algae
f.	Hydrotreated Palm and Soy Oils
g.	Hydrotreated camelina
h.	Hydrotreated jatropha
i.	Fuel cells
j.	Hydrogen

24. What other government actions, if any, should be undertaken to address greenhouse gas emissions from commercial aircraft?

25. Do you have any other comments about anything covered in this rating tool? If so, please comment here.

Appendix IV: Scope and Methodology

To address our objectives, we interviewed selected officials knowledgeable about the aviation industry, the industry's impact on the production of greenhouse gas and other emissions that have an impact on the climate, and options for reducing these emissions. We interviewed federal officials from the Environmental Protection Agency (EPA), FAA, the National Aeronautics and Space Administration (NASA) and the Departments of Defense and State. We also met with representatives of ICAO—a United Nations agency. We interviewed representatives of industry groups, environmental groups, airlines, aircraft manufacturers, aircraft engine manufacturers, alternative fuels manufacturers, economists, and academics. We interviewed officials based in the United States and abroad. We interviewed representatives of the EU and associations about the EU ETS. We completed a literature search and reviewed relevant documentation, studies, and articles related to our objectives. To specifically address commercial aviation's contribution to emissions, we asked our interviewees to identify the primary studies that estimate current and future emissions. As a result, we reviewed and summarized the findings of the 1999 International Panel of Climate Change *Aviation and the Environment* report and its 2007 *Fourth Assessment Report*, which were most frequently named as the most authoritative sources on global aviation emissions.

To specifically address technological and operational options to reduce commercial aviation's contribution to greenhouse gases and other emissions that can have an impact on the climate, we contracted with the National Academy of Sciences to identify and recruit experts in aviation and environmental issues. We interviewed 18 experts identified by the Academy, including those with expertise in aeronautics, air traffic management, atmospheric science, chemistry, climate change modeling, economics, environmental science, and transportation policy[1]. In conducting these interviews, we used a standardized interview guide to obtain consistent answers from our experts and had the interviews recorded and transcribed. Based on these interviews, we assembled a list of options for reducing aviation emissions, and we asked our experts to assess these options on several dimensions. We provided each of our experts with a standardized assessment tool that instructed the experts to assess the potential of each technological and operational option on the following dimensions: potential fuel savings and emissions reductions, potential research and development costs, potential cost to the airline

[1]See Appendix II for a list of the experts we interviewed.

industry, potential for public acceptance, and time frames for adoption. For each dimension, we asked the experts to assess each option on a three-point scale. For example, we asked the experts to rate each option as having "low potential", "medium potential", or "high potential" [2] for fuel savings and carbon dioxide emissions reductions.[3] We directed the experts not to answer questions about areas in which they did not have specific knowledge or expertise. As a result, throughout our report, the number of expert responses discussed for each emissions reduction option is smaller than 18, the number of experts we interviewed. Besides asking the experts to assess the potential of technological options, such as new aircraft and engine designs, we asked them to assess the potential of alternative fuels to reduce carbon dioxide emissions[4]. Furthermore, for operational options we asked the experts to assess included options that the federal government must implement, such as air traffic management improvements, as well as options that the airlines can exercise to reduce fuel burn. We analyzed and summarized the experts' responses in order to identify those technological and operational options that the experts collectively identified as holding the most promise for reducing emissions. To analyze the results, for each option and dimension, we counted the numbers of experts that selected the "low," "medium," and "high" responses. We then determined an overall, or group, answer for each question based on the response the experts most commonly selected for each option and dimension. However, if approximately the same number of experts selected a second response, then we chose both responses as the group answer. For example, rather than reporting that the experts rated a particular option as having "high" potential, we instead reported that they rated it as having "medium-high" potential if approximately the same number of experts selected the "high" response as selected the "medium" response. Finally, if approximately the same number of experts

[2]We did not provide specific definitions for "low," "medium," and "high" and let each respondent determine what it meant to them.

[3]See app. III for a copy of the assessment tool that we asked the experts to complete as well as complete results. Additionally, we asked the experts to describe the major challenges to the widespread use of the options and the actions that the U.S. federal government could take to promote the development and/or adoption of any of these options.

[4]For alternative fuel options, we used a four-point scale to assess each option's potential to reduce carbon dioxide emissions ("no potential," "low potential," "medium potential "or "high potential").

selected all responses, then we determined that there was no consensus on that question and reported the result as such[5].

In order to determine government options for reducing aviation emissions, we interviewed relevant experts, including those 18 recruited by the National Academy of Sciences, about the potential use and the costs and benefits of these options. We asked our interviewees to provide opinions and information on a variety of governmental options, including carbon taxes, cap-and-trade programs, aircraft and engine standards, government-sponsored research, and governmental subsidies. We looked at governmental actions that have been taken in the past and at those that have been proposed. We reviewed economic research on the economic impact of policy options for addressing greenhouse gas emissions. Our review focused on whether policy options could achieve emissions reductions from global sources in an economically efficient manner (for example, maximize net benefits). We interviewed EU officials to understand how the EU ETS will work and to determine issues related to this scheme, which is slated to include certain flights into and out of EU airports starting in 2012. Additionally, we reviewed and summarized the EU ETS and the legal implications of the scheme (see app. I).

[5]We defined "approximately the same number of experts" as being either the exact same number of experts or as one fewer or one more expert.

Appendix V: Comments from the National Aeronautics and Space Administration

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

May 26, 2009

Reply to Attn of: Aeronautics Research Mission Directorate

Ms. Cristina Chaplain
Director, Acquisition and Sourcing Management
United States Government Accountability Office
Washington, DC 20548

Dear Ms. Chaplain:

Thank you for the opportunity to review draft report, "Aviation and Climate Change: Aircraft Emissions Expected to Grow, But Technical and Operational Improvements and Government Policies Can Help Control Emissions," (GAO-09-554).

We found the report to be complete, concise, and accurate. In our opinion, it provides a balanced view of the issues related to the potential of future impact of aircraft emissions on climate change. Technical comments to the draft report have been provided separately.

Again, thank you for the opportunity to provide comments on the draft report and for your continued interest in aviation and its affect on climate change.

Sincerely,

Dr. Jaiwon Shin
Associate Administrator for
Aeronautics Research Mission Directorate

cc: Matthew Rosenberg

Appendix VI: Comments from the Environmental Protection Agency

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

MAY 21 2009

OFFICE OF
AIR AND RADIATION

Ms. Susan Fleming
Director, Physical Infrastructure Issues
U.S. Government Accountability Office (GAO)
441 G Street, N.W.
Washington, D.C. 20548

Dear Ms. Fleming:

Thank you for the opportunity to review and comment on the draft Government Accountability Office (GAO) report entitled, "Aviation and Climate Change: Aircraft Emissions Expected to Grow but Technological and Operational Improvements and Government Policies Can Help Control Emissions," which was provided to the U.S. Environmental Protection Agency (EPA) Administrator Lisa P. Jackson on May 1, 2009. We have reviewed and commented substantially on two earlier statements of facts related to this draft report.

While GAO has incorporated a portion of our written inputs on the initial and revised drafts, there are two major points which we still believe are not fully and correctly characterized within the report. The first is related to the potential role of emission standards as part of an overall response strategy and the second is related to the characterization of jet fuel consumption.

The Role of Emission Standards

The report fails to mention or discuss the extensive EPA Advanced Notice of Proposed Rulemaking (ANPRM) on greenhouse gas control under the Clean Air Act that was published in July 2008.[1] We strongly suggest this be referenced in the text. Further, we are concerned about the characterization of the potential role of emission standards in the underlined subtopic text on page 45 and the four paragraphs which follow. The report expresses the view that potential regulatory actions would limit technology responses and be economically inefficient. Based on our 35 years of experience in setting and implementing standards, we do not agree with this assessment. In fact, past EPA rules clearly show that flexible regulatory programs can be designed which optimize technology responses and yield benefits that far outweigh costs.[2]

[1] See the EPA Advance Notice of Proposed Rulemaking, "Regulating Greenhouse Gas Emissions Under the Clean Air Act", published in the Federal Register on July 30, 2008, 73 FR 44353.
[2] OMB has issued many Reports to Congress showing the economic benefits of EPA rules (benefits to society outweighing costs), for examples, see http://www.whitehouse.gov/omb/inforeg/regpol-reports_congress.html

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Emission standards can be effectively used to limit emissions levels from aircraft. For mobile sources, EPA emission standards are typically not strict command and control requirements but are performance-based standards (not design or technology specific requirements) which provide manufacturers choices regarding which technology approaches to use to reduce emissions. In addition, emission standards typically include a variety of flexibility and incentive provisions to promote technology options and improve their overall economic efficiency by reducing costs.

These standards would include lead time and phase-in provisions (as in current aviation emission standards) to allow the manufacturers certainty and appropriate time to respond in the context of both market forces and future business needs. In addition, as is the case in most other EPA rules, they could include an emission averaging, banking, and trading program and other important flexibility provisions to optimize manufacturer technology response options, provide tools to improve compliance certainty, and reduce costs. Appropriate engine emission standards could drive measures for improved fuel specific fuel consumption and airframe-related standards could also reduce greenhouse gas emissions by improving efficiency. It now appears that the International Civil Aviation Organization will be considering both the engine and airframe approaches in the future and there is potential for EPA to do the same. With the projected increase in jet fuel consumption, achieving reductions in greenhouse gases will require consideration of technology measures and potentially market-based measures. Emission standards could in fact be complementary to the effective implementation of a market-based program.

Jet Fuel Consumption

Pages 4-7 discuss in detail the improved fuel efficiency of aviation operations. Aviation fuel efficiency has indeed improved significantly over the preceding three decades (see Figures 2 and 3 of the GAO report). However, there is not adequate discussion of the fact that the increase in aviation activity each year (more land-take-offs and more flying hours) results in an increase in total jet fuel consumption that has greatly outpaced the efficiency gains.

For example, according to data from the Air Transport Association, between 1978 and 2007, efficiency (as measured on a gallons per thousand revenue ton mile basis) improved by almost 110%.[3] However, according to information from the Bureau of Transportation Statistics, annual jet fuel consumption rose by 95% over that same period. As a result, jet fuel use was nine billion gallons higher in 2007 than in 1978.[4] Despite these noteworthy efficiency improvements, the annual Carbon Dioxide (CO2) inventory contribution from aviation was 94 million tons greater in 2007 than in 1978. Looking ahead, even with fleet turnover and the expected efficiency improvements from engine, air frame, and air traffic system upgrades in the future, the Federal Aviation Administration (FAA) projects an increase in jet fuel consumption of 31% (1.6% per year) between 2008 and 2025.[5] If these projections prove to be correct, the aviation jet

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[3] See http://www.airlines.org/economics/energy/fuel+efficiency.htm. retrieved on May 15, 2009
[4] See http://www.transtats.bts.gov/fuel.asp?pn=1, retrieved on May 15, 2009
[5] See Table 22 from http://www.faa.gov/data_research/aviation/aerospace_forecasts/2009-2025/media/2009%20Forecast%20Doc.pdf

fuel consumption and carbon dioxide inventory contribution from aviation will be 31% greater in 2025 than in 2008, and 150% greater than in 1978.

Thank you for the opportunity to review and comment on this draft report. We look forward to our continued interactions with GAO and other stakeholders as we assess and consider policy options for addressing greenhouse gas emissions from aviation.

Sincerely,

Elizabeth Craig
Acting Assistant Administrator

Appendix VII: GAO Contact and Staff Acknowledgments

GAO Contact

Susan Fleming, (202) 512-4431 or flemings@gao.gov

Staff Acknowledgements

In addition to the contact above, Cathy Colwell and Faye Morrison (Assistant Directors), Lauren Calhoun, Kate Cardamone, Brad Dubbs, Elizabeth Eisenstadt, Tim Guinane, Michael Hix, Sara Ann Moessbauer, Josh Ormond, Tim Persons (Chief Scientist), Matthew Rosenberg, and Amy Rosewarne made key contributions to this report.

The GAO staff that worked on this report dedicate it to their late colleague, Jacqueline McFarlane, in recognition of the valuable contributions she made

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