Design of a Carbon Neutral Airport

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***Abstract*— Historic data shows an increase in carbon dioxide (CO_2) emissions at airports caused by an increase in aircraft flights, associated ground support equipment, flight operations, and passenger movements. Despite rising concerns over the potential effects of anthropogenic activities on earth's climate, there is no singular ownership of the problem and therefore no commitment to fund change. There exists a need for a system to ensure compliance and accountability to enable preparation for future legislation for emission regulations at airports through reduction of CO_2 for all components of flight operations. The purpose of this project is to provide the airport manager at major airports, such as Dulles International Airport, a tradeoff analysis for strategies to achieve carbon neutral growth at airports by 2020 with a 2005 baseline and net reductions of all aviation emissions by 2050. A decision support tool, the Airport Inventory Tool (AIT), was developed to create an emissions inventory to model airport operations from 2005 and create projections to 2050 using a 2% and 4% growth rate for airport operations to evaluate mitigation strategies. Ground support equipment and aircraft were the two largest sources of emissions. The combination of all design alternatives provides reduction of CO_2 emission levels such that the CO_2 emissions for 2050 meet the goal of carbon neutral for a 2% growth rate but do not achieve carbon neutrality with a 4% growth rate.**

I. INTRODUCTION

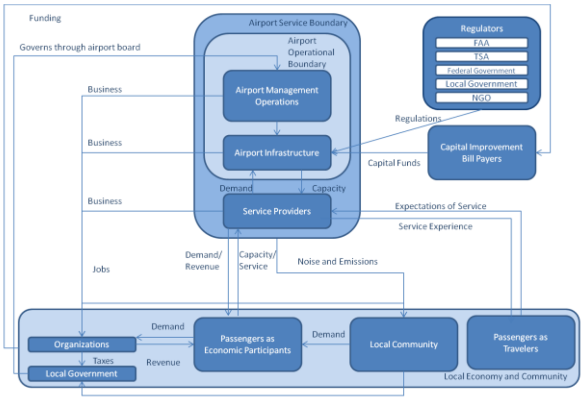
Existing legislation in the United States such as the Clean Air Act and National Ambient Air Quality Standards require the monitoring of air pollutants in stationary sources in aviation to improve the air quality with respect to a target fixed by legislation [10]. Presently, there is no legislation for aviation in the United States which imposes caps for CO_2 emissions from stationary and non-stationary sources involved in aviation. An absence of legislation on emissions from aviation leads to a deficiency in the ability to monitor and regulate emissions by assigning penalties for sources which exceed legislated caps. Lack of stakeholder ownership, through these assigned penalties, leads to a conflicting opinion of who should be responsible for the overall emissions problem. No ownership of the identified problem leads to no one absorbing the cost and time to make changes and no significant changes can occur.

As the global economy becomes more aware of the impact of greenhouse gas (GHG) emissions from both stationary and non-stationary sources within aviation, there will be a desire to reduce the impact of aviation related emissions. To achieve a reduced impact on the environment, the aviation sector of industry will work toward a carbon neutral state in which there is no net emission of greenhouse gases. This implies that the total amount of gases emitted will be equal to the total amount of emissions offset.

The case study of this project will be Washington Dulles International Airport (IAD) of the Metropolitan Washington Airports Authority (MWAA).

II. STAKEHOLDER ANALYSIS

Identification of airport stakeholders is important to evaluate overall performance at an airport level and to determine which stakeholders "can affect or be affected by the airports objectives"[9]. Major stakeholder groups at the airport include airport management operations, airport infrastructure, service providers, community organizations, local government, passengers (as economic participants), local community, passengers (as travelers), regulators, and capital improvement bill payers. A model of the airport organization through stakeholder interactions is shown in Fig. 1.



Based on *Analysis of Airport Stakeholders*
Scharr and Sherry, 2010

Fig. 1. Stakeholder Interaction Diagram. Blocks show major stakeholders and loops show interactions. Loops highlight the stress between stakeholders since no single stakeholder claims ownership of emissions reduction.

Interactions between stakeholders are evaluated through feedback loops in the stakeholder interaction diagram and can be grouped into three categories: environmental, financial, and legislative. The environmental feedback loop includes the local community which is concerned

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over the impact of airport emissions entering their local environment. These local communities hold voting power over the local government which governs the airport board. This airport board affects the airport organizational boundary through airport management and operations which dictates the capacity for service providers to operate within the airport service boundary; this loops back to the amount of operations generating emissions. This feedback loop is very weak through the stakeholder model since emissions have a slow effect on the surrounding environment and the cycle for community members to influence the airport board through elections occurs every 12 months [5].

The financial loop drives feedback through the stakeholder interaction model since airports depend on both capital and operating revenue to pay for capital projects and operating expenses. This feedback loop flows through interactions between community organizations, capital improvement and bill payers, airport infrastructure, service providers, passengers, and the local community. While this feedback loop is the strongest in response time due to heavy dependence on revenue to continue operational activities, this feedback loop can have runaway growth since other loops are weak and provide little resistance. The main concern of the financial interactions is the underlying problem of no one stakeholder owning the problem of emissions reduction. If no one stakeholder feels that they are responsible for the emissions at an airport, no stakeholder will feel they are obligated to cover the financial implications associated with these environmental concerns.

Legislative interactions with airport stakeholders involve regulator groups (FAA, TSA, Federal government, local government, and Non-Government Organizations (NGOs)). Each of these regulators has domain over specific airport objectives. These regulators interact with the airport infrastructure, community organizations, local government, and the airport management operations. While each stakeholder’s goal is to support airport operations, stakeholder goals may not align regarding environmental and emissions decisions. These conflicting objectives create tension between stakeholders in decision making. This feedback loop has a long response time since policy takes years to formulate, approve, and implement [9].

III. STATEMENT OF NEED

There is a need to provide the decision makers at major airports a tradeoff analysis for strategies to achieve carbon neutral growth at airports by 2020 with a 2005 baseline and net reductions of all aviation emissions by 2050.

IV. CONOPS

A. *Statement of Work*

This tradeoff analysis is augmented by the decision support tool which provides a baseline carbon dioxide (CO2) calculation and change in CO2 for each alternative implemented. The decision support tool shall be able to receive operational data as input, calculate CO2 emissions, analyze data to identify sources to reduce emissions output and verify compliance with emissions caps.

B. *Mission Requirements*

Mission requirements derived from the sponsor statement of work are as follows:

- The system shall report total aviation related CO2 emissions for stationary and non-stationary sources
- The system shall account for aviation related emissions within the boundary of the landing/take-off (LTO) cycle around the airport.
- The system shall report GHG emissions by source.
- The system shall provide structure for additional GHGs to be calculated.

C. *Scope*

The scope of this emissions inventory is geographically limited to airport operations within the landing and take-off (LTO) cycle below mixing altitude. The mixing altitude is the where pollutant mixing and chemical reaction occurs in the atmosphere. Above the mixing altitude, pollutants do not mix with ground level emissions and have little effect on ground level concentrations. The geographic scope covers a radius of 12 nautical miles (22 km) and an altitude of 3,000 feet within the LTO cycle. The LTO is divided into four main operational modes:

- Approach: the portion of flight from the time the aircraft reaches the mixing height or 3,000 ft altitude and lands and exits the runway;
- Taxi/idle: the time the aircraft is moving on the taxiway system until reaching the gate / departure from the gate until taxied to the runway;
- Take-off: the movement down the runway through lift-off up to about 1,000 ft; and
- Climb-out: the departure segment from takeoff until exiting the LTO cycle.

Within the airport boundary, this project will account for all stationary and non-stationary sources of GHG emissions. Stationary sources include: Boilers (facility, heating, and fuel), airport fire department training fires, waste management devices (waste disposal and incinerators), and construction activities. Non-stationary sources are broken up into 3 additional areas: Aircraft, Ground Support Equipment (GSE), and Ground Access Vehicles (GAV). Aircraft accounts for all aviation related emissions including their Aircraft Power Units (APU). GSE accounts for emissions for airport related activities including: tugs, catering trucks, transporters, fuel trucks, baggage trucks, belt and cargo loaders, baggage lifts, and mobile lounges. GAVs include all non-airport related emission activities including: personal passenger vehicles, and public transportation such as taxis, buses, and trains.

The emissions inventory will only measure CO_2 emissions. To calculate CO_2 emissions, the tool will convert total fuel consumption and fuel economy into kilograms of CO_2.

V. Method of Analysis

A. Decision Support Tool

In order to evaluate solutions for reduction of emissions, a decision support tool is needed to evaluate the current state of emissions. The Airport Inventory Tool (AIT) is used to inventory stationary and non-stationary aviation-related CO2 emissions within the LTO boundary around an airport. An overview of the AIT is shown in Fig. 2 below.

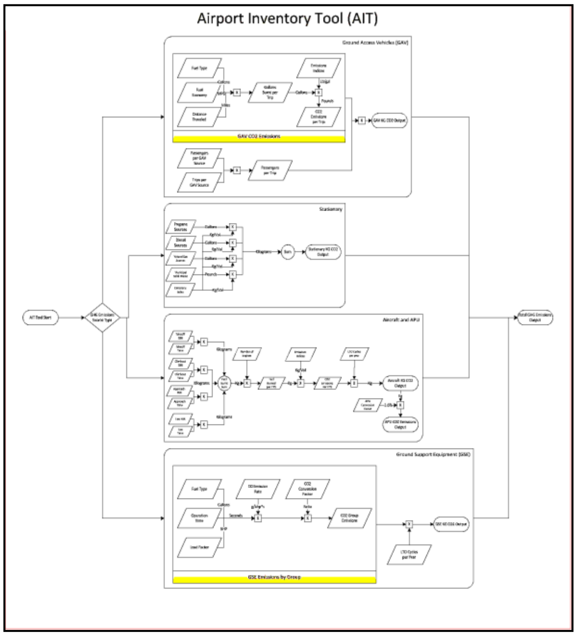


Fig. 2: Airport Inventory Tool Diagram [9]

Table 1: AIT Model Equation Variables

Variable	Description
N_{eng}	Number of engines
F	Fuel rate (gal/min, kg/sec, or miles/gal)
E	Emissions index
D	Distance travelled (miles)
i	Phase of LTO
f	Amount of fuel consumed (gal, lbs, or ft^3)
v	Vehicle
T	Time (minutes)
m	Stationary source
R	Rated horsepower
L	Load factor
g	GSE
C	CO to CO2 conversion factor

Ground access vehicles (GAV) are distinguished by fuel and vehicle types and include private vehicles (gas and hybrid), rental cars (gas and hybrid), taxi/limo, buses, and airporter/SuperShuttles. GAV emissions for a singular vehicle, shown in (1), are determined by distance travelled by vehicle (D), fuel economy of vehicle (F), and the CO_2 emissions index value (E) of the vehicle (v).

$$\text{GAV Emissions} = \left(\frac{D_v}{F_v}\right)(E_v) \tag{1}$$

Total GAV emissions are found by multiplying the total trips per vehicle type by the GAV emissions for that vehicle type. A trip is a predefined distance of travel using average distances from the Seattle-Tacoma Emissions Reduction Study. Passengers per vehicle type was derived by using the annual total domestic and international passengers obtained from MWAA and extracting 73% to represent the origin and destination (O&D) passengers from this annual passenger count by using an accepted percentage from the Seattle-Tacoma inventory report [6]. Origin and destination passengers are those that arrive and regress from the airport via GAV transportation and do not continue on to another airport through air transportation [3]. This O&D passenger percentage was verified with actual passenger data from MWAA [11]. Passengers per vehicle type were derived from O&D passengers by using a fixed percentage per vehicle type [6]. Total vehicle movements were derived from the passengers per vehicle type by using average vehicle occupancy levels. These occupancy levels were based on observation at the airport and stakeholder agreement.

Stationary source emissions calculations as shown in (2) are a function of total fuel consumed (f) and the emissions index of each fuel type (E) per source (m).

$$\text{Stationary Emissions} = \sum f_m * E_m \tag{2}$$

Aircraft emissions are calculated as shown in (3) and are a function of number of engines (N), time (T), fuel burn rate (F), and emissions index (E) for each LTO mode (i).

$$\text{Aircraft Emissions} = (N_{eng}) \sum (T_i * F_i * E_i)(LTO) \tag{3}$$

Aircraft APU emissions are 1.6% of CO_2 emissions per aircraft [13]. The fleet mix represented in the AIT is the actual fleet mix for Dulles Airport from 2005 [11].

Ground support equipment (GSE) emissions are calculated as shown in (4) and are a function time (T), rated horsepower (R), load factor (L), and a CO_2 conversion factor (C).

$$\text{GSE Emissions} = (T_g)(R_g)(L_g)(C) \tag{4}$$

Groups of GSE vehicles were determined by examining fleet mix and associated GSE. Individual GSE emissions are calculated and used to find the group GSE emissions. Since aircraft is assigned one GSE group, the emissions per GSE group are multiplied by annual LTOs for aircraft to receive total GSE emissions. First emission for the individual GSE are calculated

B. Risk

Specific data related to fuel consumption and airport operations at Dulles is not publically available for use in the development of the AIT. To validate AIT development, the fleet mix for Dulles airport will be combined with acceptable distributions from previous inventories performed at Seattle-Tacoma and Denver International Airports to determine distribution of ground support equipment and ground access vehicles as well as accepted averages for aircraft and associated ground service equipment fuel consumption.

The AIT and inventory results will be turned over to MWAA for data entry and validation, with results being returned to the team without privileged data included.

C. Limitations

The AIT is a Level-1 Inventory tool, defined in ACRP, which focuses on only CO_2 emissions [4]. The AIT focuses on emissions generated through fuel consumption within the LTO boundary. It does not include electric power usage and associated emissions and costs.

Dispersion is not modeled in the analysis since this identifies emissions outside of the airport operational boundary. The analysis follows the Intergovernmental Panel on Climate Change (IPCC) LTO methodology for calculating aircraft emission which does not include helicopters in the inventory model [2]. In the case of Dulles International Airport, there are less than 10 helicopter landings and takeoffs per year. The model does not account for deicing activities since these occur on an infrequent basis with high variability due to weather conditions.

VI. DESIGN ALTERNATIVES

The long term goal of carbon neutrality is to achieve a net zero carbon footprint relative to a baseline amount. Design alternatives for mitigation of emissions have been selected from the ACRP Report 56: Handbook for Considering Practical Greenhouse Gas Emission Reduction Strategies for Airports [12]. The design alternatives are based on the emissions source classifications: Ground Access Vehicles (GAV), Ground Support Equipments (GSE), Aircraft (including APUs), and Stationary Sources.

A. Proposed Alternatives for Ground Access Vehicles (GAV)

Alternatively fueled vehicles for rental cars and commercial vehicles can reduce emissions through an increase in vehicle fuel economy; burning less fuel releases less emissions. This is modeled in the AIT by shifting 50% of the current gasoline fueled rental vehicles to hybrid rental vehicles.

Providing transit fare discounts and/or alternative mode subsidies could reduce emissions by promoting the use of low emission vehicles for airport transport. Transit discounts (i.e. parking fees) could be reduced for compliance. This will be modeled in the AIT by a 5% conversion of GAV converted to hybrid vehicles.

Alternatively fueled taxis have the potential for reduced emissions due to the higher fuel economy of hybrid vehicles. Taxis also idle while on airport property. Hybrid vehicles use electric power during idle. Dulles airport is unique in operation because the taxi fleet is determined through a contract with the airport authority and is rebid on a tri-annual cycle. This taxi fleet conversion can be controlled by setting energy efficiency requirements for equipment in contract agreements. This will be modeled in the AIT by converting 50% of the taxi fleet to hybrid vehicles.

Providing priority vehicle parking for emission friendly vehicles could reduce airport CO_2 emissions by encouraging passengers to drive emissions friendly vehicles to airport. These vehicles have lower emissions than traditional gas or diesel combustion engine vehicles. This alternative is modeled in the AIT by changing 1% of GAV traffic to hybrid vehicles.

B. Proposed Alternatives for Ground Support Equipment (GSE)

The majority of existing ground support equipment use gasoline or diesel fuel. Investing in new energy efficient technology by converting GSE from gas/diesel fuel to electric power would reduce emissions since electric vehicles have negligible CO_2 emissions. This will modeled in the AIT by converting 50% of GSE equipment to electric power by changing their emissions index value to zero.

Currently, push back tugs are used to transport aircraft from the gate to the taxi way. Expanding the use of push back tugs to transport aircraft to taxiways, runway ends, and/or take-off areas would minimize taxi time of aircraft requiring less total engine time and less fuel burned per LTO. This is modeled in the AIT by reducing taxi times of each aircraft by 50% and increasing the operational time of each push back tug by 50%.

C. Proposed Alternatives for Aircraft and APU

A majority of existing aircraft and APUs use aircraft fuel (Jet A-1). Development of alternative fuels for aircraft could potentially lower the CO_2 emissions for aircraft since alternative fuels have a lower emissions index than Jet A-1 fuel. This is modeled in the AIT by increasing the efficiency of one engine of an aircraft by 50% to model the implementation of alternative fuels.

Minimizing the use of auxiliary power units (APUs) by supplementing ground power for APU usage at the gate would decrease emissions. Ground power has negligible emissions compared to the fuel burn rates for APU. This is modeled in the AIT by reducing the APU emissions by 50% to represent a 50% reduction in total operational time.

Implementing fuel efficiency targets for aircraft would decrease emissions through less fuel burn by the engines and therefore lower emissions from engine fuel burn. Fuel efficiency targets could be enforced by limiting the aircraft allowed to land at the airport to only those that comply with the efficiency target. This is implemented in the AIT by shifting all LTOs to the most efficient engine within a specific aircraft class. For example, a 737-200 has a possibility of three different engines. The most efficient engine would be selected and all 1,399 737-200 LTOs would be shifted to this engine.

Implementing emissions-based incentives and landing fees would incentivize airlines to land more efficiency aircraft to receive a deduction of landing fees assessed. This is modeled similarly to fuel efficiency targets for aircraft but shift from one aircraft to another have been made after considering passenger capacity and fuel burn rate for aircrafts.

D. Proposed Alternatives for Stationary Sources

Stationary sources include facilities sources such as power generators, steam boilers, heaters or waste incinerators. These facility sources have very low emissions and little room for reduction of CO_2 emissions. The design alternative for stationary sources is to offset CO_2 emissions by installing sustainable, long-term vegetation on the airport property. CO_2 removed by trees varies based on tree diameter but can best be estimated by trees per acre, assuming each tree is mature. Goals for this design alternative are measured in acres of trees planted on airport property.

VII. ANALYSIS

The AIT verification and validation plan was to run baseline simulations to ensure that the model accurately calculated and displayed emissions output information. Inventory data from Seattle-Tacoma and Denver International [6][7] as well as data from MWAA [11] was input to model and results were checked to verify they matched expected output.

An emissions inventory baseline was developed for Dulles by inputting collected data to the AIT. The output showed CO_2 emissions data by source for one year of operations at Dulles Airport. Identified design alternatives were used to manipulate this baseline data to determine the net reduction in kilograms of CO_2 for each design alternative. Using the 2005 baseline, a 2% and 4% growth rate were applied to show projections in CO_2 for operations through 2050.

The utility function was developed through numerous conversations and interviews with MWAA Stakeholders as well as recommendations from the ACRP Report 56. Although the fundamental objective is to reduce CO_2 emissions, the solution must also be feasible for implementation at the airport and within the control of the airport authority. The top level weights of implementation time, maturity of reduction strategy, airport control, and emissions reduction were accepted through a stakeholder Delphi agreement. The final utility function with weights (5) is below.

$$\text{Utility} = 0.15\ \textit{implementation time} + 0.15\ \textit{maturity of reduction strategy} + 0.3\ \textit{airport control} + 0.4\ \textit{emissions reduction} \quad (5)$$

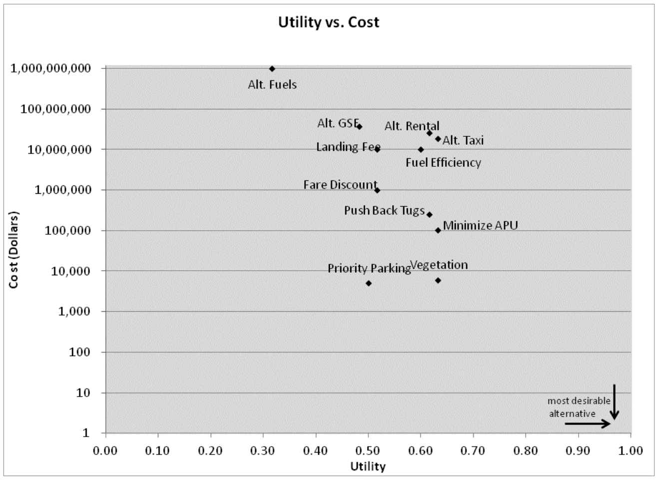
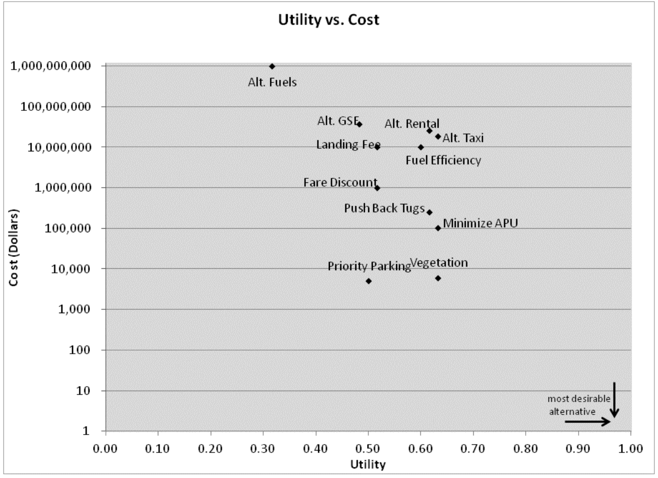


Fig. 3: Utility v. Cost. Most desired design alternatives are in the lower right hand corner.

On the cost versus utility chart, show in Fig. 3, the alternatives with the lowest cost and highest utility are the best alternatives and can be located in the bottom right hand corner of the chart. The highest ranking alternatives are: minimize APU usage, provide priority vehicle parking, and utilization of tugs for aircraft taxiing.



VIII. FINDINGS AND RECOMMENDATIONS

Of the four categories of sources, ground access vehicles and aircraft were the two largest contributors to overall CO_2 emissions. As shown in Fig. 4, carbon neutral growth is feasible with 2% growth of airport operations when all design alternatives are combined together. In 2050, a 2% growth rate results in a reserve of 62 million kilograms of CO_2 or 8.3% under goal. When 4% growth of airport operations is modeled, shown in Fig. 5, carbon neutral growth is no longer feasible. In 2050, a 4% growth rate results in CO_2 emissions which exceed the target emissions level by 282 million kilograms of CO_2 or 42.9%.

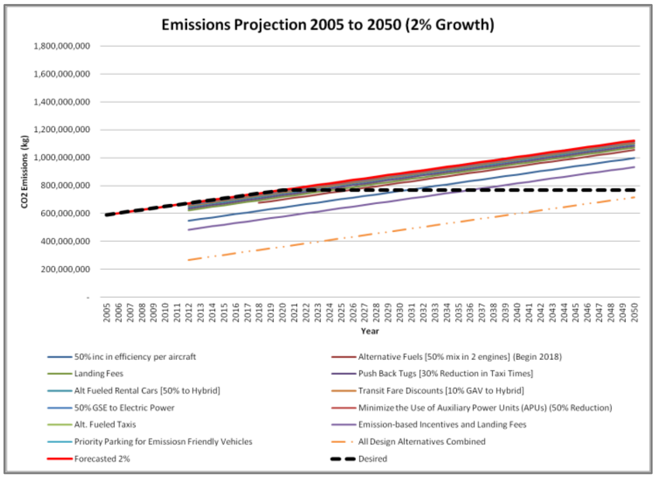


Fig. 4. Emissions Project 2% Growth. Dashed line shows the goals by proposed emissions caps while the increasing linear line shows what will happen if no emissions reduction strategies are implemented. The bottom line shows emissions levels if all reduction strategies are combined in implementation.

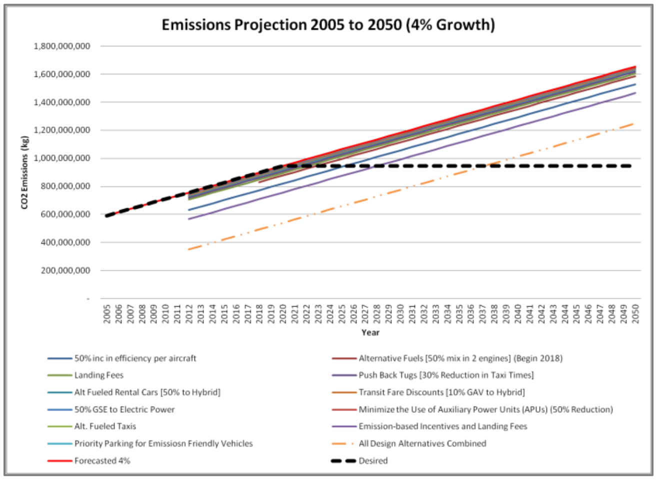


Fig. 5: Emissions Project 4% Growth. Dashed line shows the goals by proposed emissions caps while the increasing linear line shows what will happen if no emissions reduction strategies are implemented. The bottom line shows emissions levels if all reduction strategies are combined in implementation.

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