Addressing the Environmental Challenges facing Aviation

FAA Office of Environment and Energy R&D Program

Presented to: UTIAS International Workshop on Aviation and Climate Change

By: Dr. James I. Hileman, Chief Scientific and Technical Advisor for Environment and Energy, Federal Aviation Administration

Date: May 19, 2016

Aviation Environmental Challenges

- Aviation impacts community noise, air quality, water quality, energy usage, and climate change
- Environmental impacts from aviation could pose a critical constraint on capacity growth
- FAA are pursuing aircraft technology, alternative jet fuels, operations, and policy measures to address the environmental challenges facing aviation

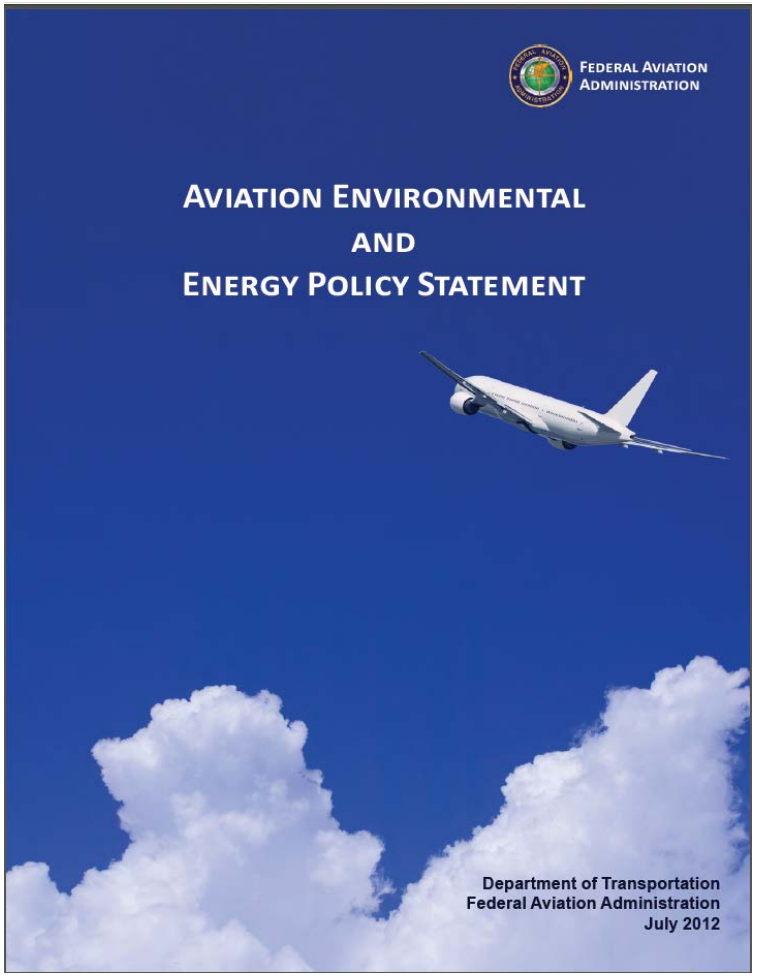
Vision and Principles

Vision:

Environmental protection that allows sustained aviation growth

Guiding Principles:

1. Limit and reduce future aviation environmental impacts to levels that protect public health and welfare.
2. Ensure energy availability and sustainability.

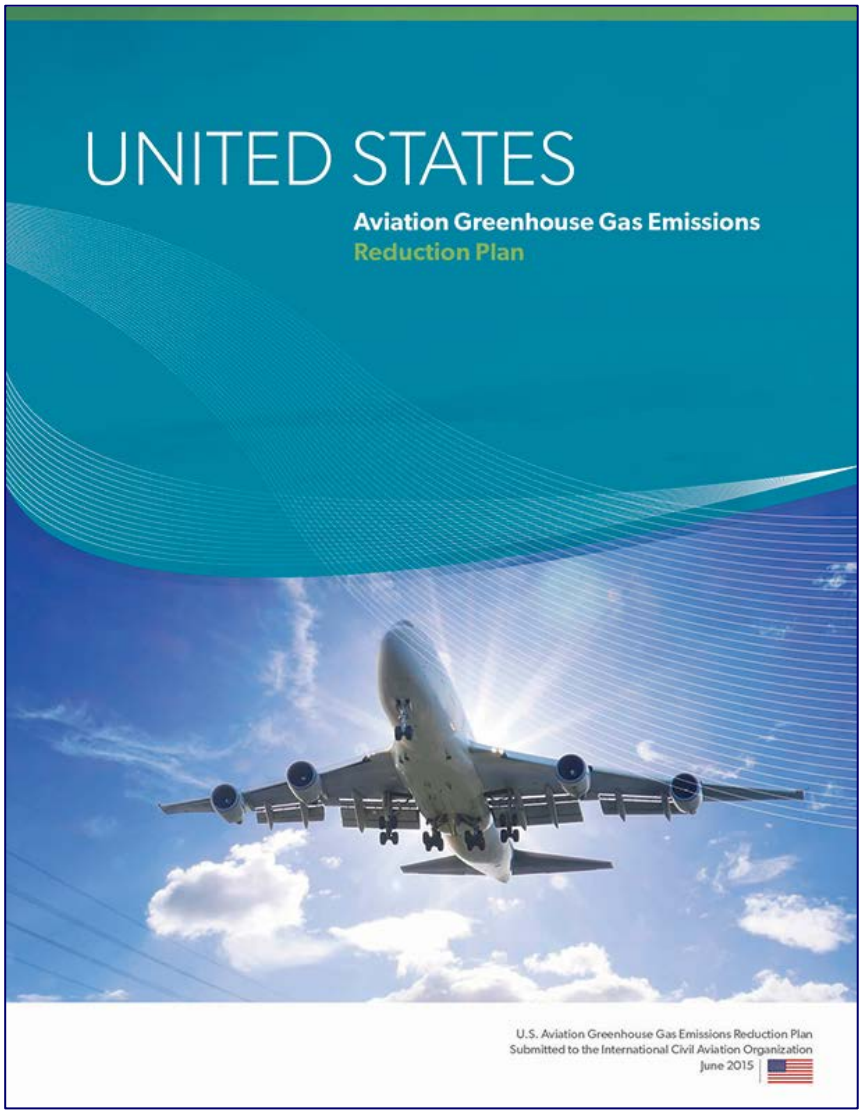


Want increased mobility with reduced environmental impacts and enhanced energy availability and sustainability

Aviation E&E Policy Statement (Federal Register 77-141, 2012): http://www.faa.gov/about/office_org/headquarters_offices/apl/environ_policy_guidance/policy/media/FAA_EE_Policy_Statement.pdf

U.S. Aviation GHG Emissions Reduction Plan

- Summarizes efforts across U.S. Government
- Follows five pillar environment and energy strategy
  - Aircraft and engine technology improvement
  - Operational improvements
  - Alternative fuels development and deployment
  - Policies, environmental standards, and market based measures
  - Scientific understanding through research, modeling and analysis
- Includes analysis examining potential for GHG emissions reductions



US Aviation GHG Emissions Reduction Plan Available at: http://www.icao.int/environmental-protection/Lists/ActionPlan/Attachments/30/UnitedStates_Action_Plan-2015.pdf

Systems Approach to CO2 Emissions Reduction

$$CO_2 = \sum_{ops} \left(\frac{CO_2 \text{ Emission}}{\text{Fuel Energy}} \right) \bullet \left(\frac{\text{Fuel Energy}}{\text{Aircraft Productivity}} \right) \bullet (\text{Operation Efficiency})$$

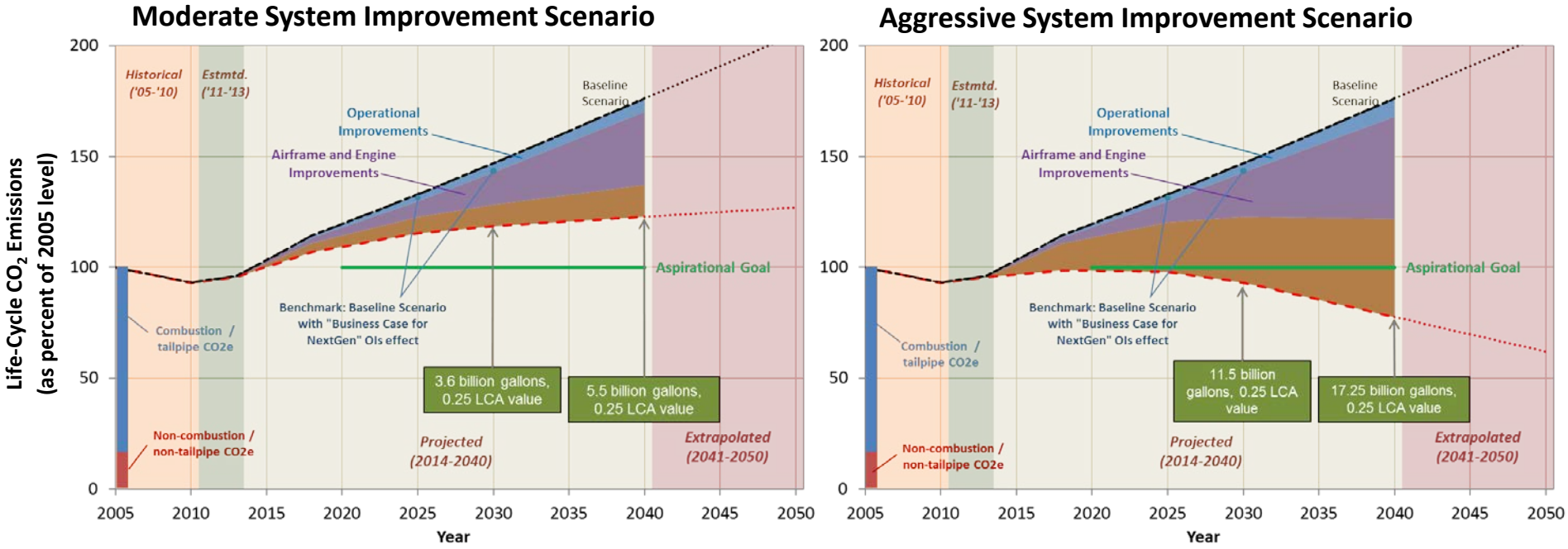
- Demand
- Alternative Fuels
- Aircraft: engine, airframe, integration
- Ops: load factor, air traffic mgmt, operation

Additional information on this decomposition and its use to examine the current and future fleet can be found in Hileman et al. (Progress in Aero Sciences, 2013)

Projected Future CO_2 Emissions
Analysis from U.S. Aviation GHG Emissions Reduction Plan

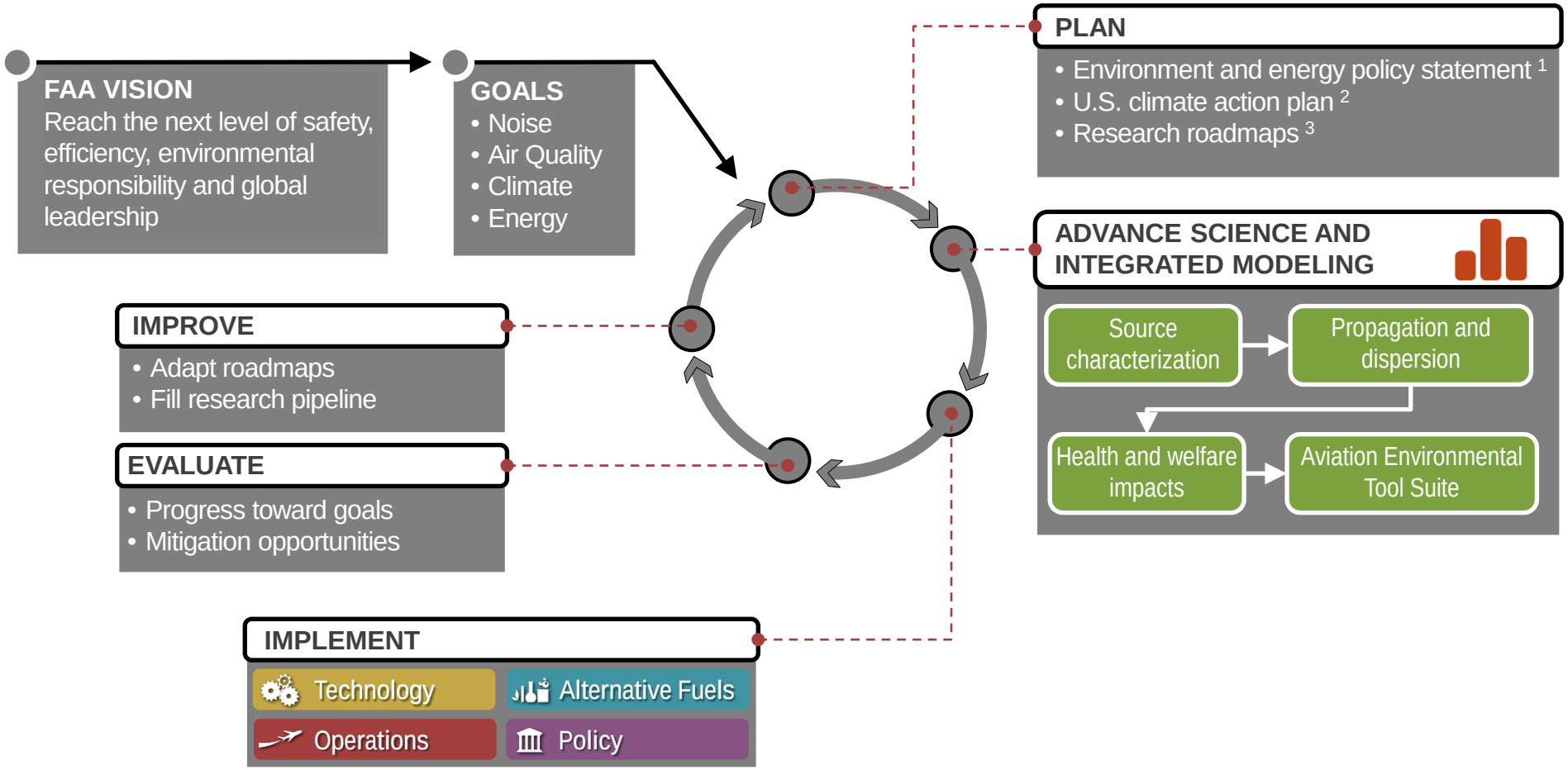
Forecasting progress against FAA performance goals

- Considering aviation growth and improvements in operations, technology, and alternative jet fuels
- ASCENT Projects 1 and 10 will provide information for future update



Notes:
- See slide 2 for link to US Aviation GHG Emissions Reduction Plan
- Aircraft technology assessment based on work of Ga Tech in PARTNER Project 36 - http://partner.mit.edu/projects/eds-capability-demonstration-assessing-cleen-program
- Alternative jet fuel assumptions provided on previous slide

Environmental & Energy Strategy



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2. U.S. Aviation GHG Emissions Reduction Plan: http://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan.aspx
3. Environment and Energy Website: http://www.faa.gov/go/environment

Reducing Aviation's Environmental Footprint

For increased mobility with reduced environmental impacts and enhanced energy availability and sustainability, we need to:	**Aircraft & Engine Design**	**Fuel Composition**	**Fuel Production**	**Operations**	**Policy Measures**
NOISE: Reduce noise footprint for each flight	X			X	X
AIR QUALITY: Reduce NOx, SOx, and soot emissions	X	X		X	X
CLIMATE: Reduce GHG emissions and their impacts	X	X	X	X	X
SUSTAINABILITY: Develop sustainable alternative fuels			X		X

Develop a systems approach that accounts for interdependencies among environmental impacts that can examine many types of solutions

Improved Scientific Knowledge for Solution Development

Aspect	Enviornment and Energy Goal[1]	Key Research Questions
Noise	Reduce the number of people exposed to significant noise around U.S. airports in absolute terms, notwithstanding aviation growth, and provide additional measures to protect public health and welfare and our national resources.	How do we define significance in regards to aircraft noise? What are the public health and welfare impacts of aircraft noise?
Air Quality	Achieve an absolute reduction of significant air quality health and welfare impacts attributable to aviation, notwithstanding aviation growth.	How do we define significance in regards to aircraft emissions that degrade air quality?
Energy	Improve National Airspace System (NAS) energy efficiency and develop and deploy alternative jet fuels for commercial aviation.	How do we characterize annual variations in system-wide fuel efficiency? How do we define sustainability of alternative jet fuels?
Climate	Limit the impact of aircraft CO2 emissions on the global climate by achieving carbon neutral growth by 2020 compared to 2005, and net reductions of the climate impact from all aviation emissions over the longer term (by 2050).	What is the incremental impact of non-CO2 aircraft emissions on global and regional climate?

1. Aviation E&E Policy Statement (Federal Register 77-141, 2012): http://www.faa.gov/about/office_org/headquarters_offices/apl/environ_policy_guidance/policy/media/FAA_EE_Policy_Statement.pdf

Aviation Sustainability Center (ASCENT) Overview

- Partnership among universities, commercial firms, and government laboratories to conduct research and education
- Expands environment and energy research carried out by PARTNER to address alternative jet fuel research request in 2012 FAA Modernization and Reform Act
- ASCENT brings together expertise of PARTNER COE with USDA AFRI Regional Bioenergy Coordinated Agriculture Projects (CAPS) and SunGrant Initiative
- Engaging U.S. government agencies (FAA, USDA, DoE, U.S. Navy, U.S. Air Force, DLA-Energy, EPA, NASA) and Transport Canada

- PARTNER has reached the end of its 10-year cycle and we transitioned its research to ASCENT.
- PARTNER held 10 year symposium on March 1, 2013 – briefings online http://web.mit.edu/aeroastro/partner/reports/public-symposium-2013.pdf

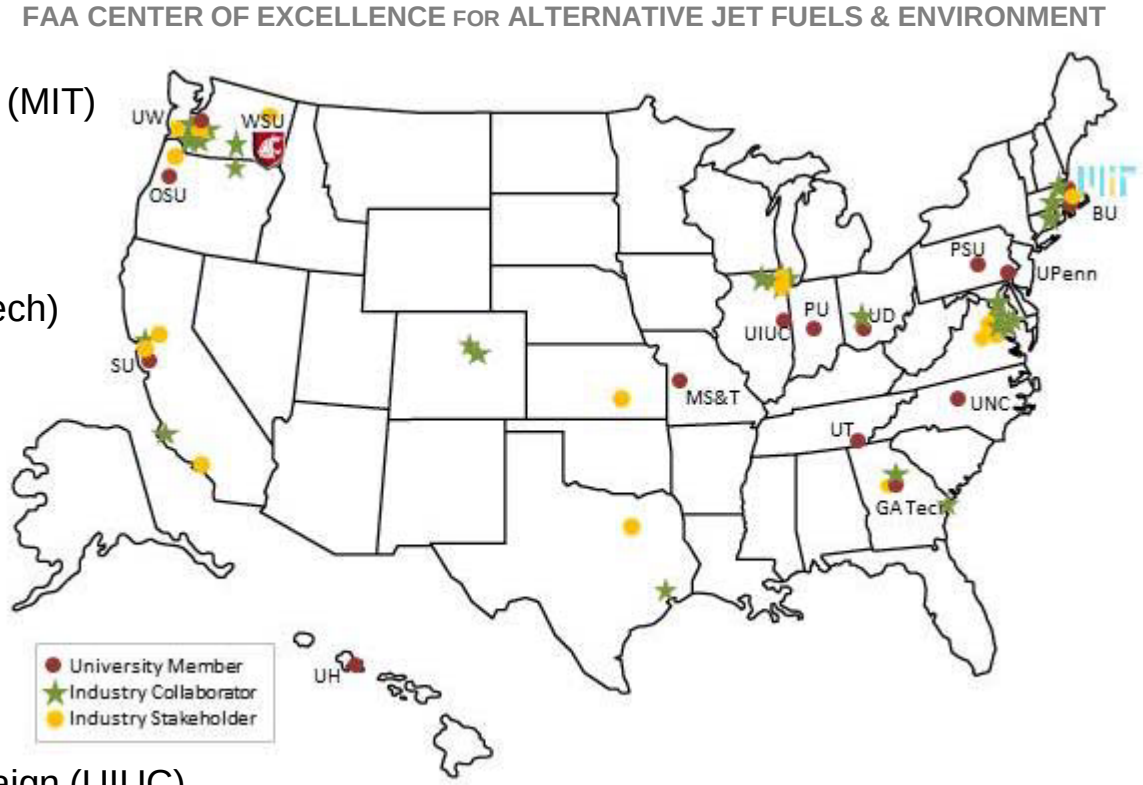
ASCENT Universities

Lead Universities:

- Washington State University (WSU)
- Massachusetts Institute of Technology (MIT)

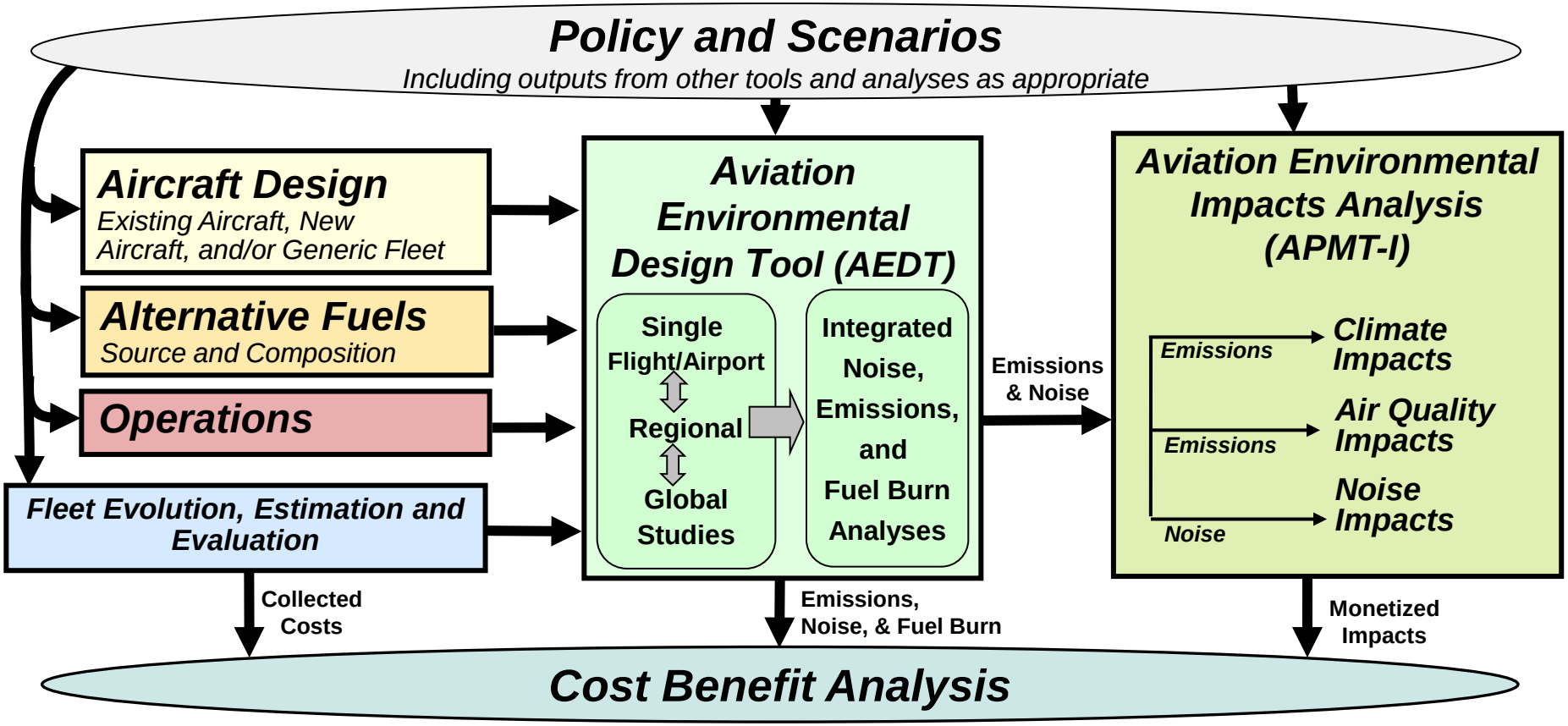
Core Universities:

- Boston University (BU)
- Georgia Institute of Technology (Ga Tech)
- Missouri University of Science and Technology (MS&T);
- Oregon State University (OSU)
- Pennsylvania State University (PSU)
- Purdue University (PU)
- Stanford University (SU)
- University of Dayton (UD)
- University of Hawaii (UH)
- University of Illinois at Urbana-Champaign (UIUC)
- University of North Carolina at Chapel Hill (UNC)
- University of Pennsylvania (UPenn)
- University of Tennessee (UT)
- University of Washington (UW)



Aviation Environmental Tool Suite

Modeling wide range of solutions and their consequences on fuel use, noise and emissions (e.g., basket of measures for CO_2 and a balanced approach for noise)



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SUSTAINABILITY: Develop sustainable alternative fuels			X		X

Mature New Aircraft Technologies

Aircraft Technology Maturation
Continuous Lower Energy, Emissions & Noise (CLEEN)

CLEEN Program Details:

- Reducing environmental impacts via aircraft technology and alternative jet fuels
- Five year effort to accelerate technology maturation ***(2010-2015)***
- 50% cost share; total FAA budget: ***~$125M***

CLEEN Program Goals:

- **32 dB** cumulative noise reduction
- **60%** landing/take-off NOx emissions reduction
- **33%** fuel burn reduction

Conducting ground and/or flight test demonstrations of certifiable aircraft technologies with entry into service by **2018**

Based on 5-year cost share agreements with industry

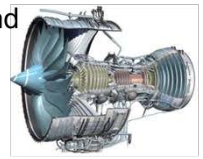
Boeing

Ceramic Matrix Composite Nozzle

Adaptive Trailing Edge

Rolls-Royce

Ceramic Matrix Composite Blade Tracks and Dual-Walled Turbine Airfoils

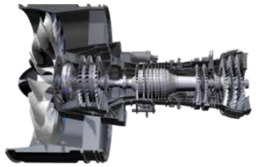


Honeywell

New coatings, higher temperature impeller, advanced seals and improved turbine cooling.

Pratt & Whitney

Ultra-high Bypass Ratio Geared Turbofan

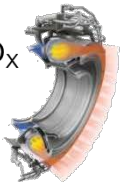


General Electric

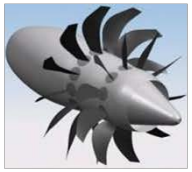
Flight Management System / Air Traffic Integration

Flight Management System / Engine Integration

Twin Annular Premixing Swirler (TAPS) II Low NO_X Combustor



Open Rotor Engine



Aircraft Technology Maturation
Continuous Lower Energy, Emissions & Noise II (CLEEN II)

CLEEN II Program Details:

- Reducing environmental impacts via aircraft technology and alternative jet fuels
- Five year effort to accelerate technology maturation ***(2015-2020)***
- 50% cost share; total FAA budget: ***~$100M***

CLEEN II Program Goals:

- **32 dB**[1] cumulative noise reduction
- **70%**[2] landing/take-off NOx emissions reduction
- **40%**[1] fuel burn reduction

Conducting ground and/or flight test demonstrations of certifiable aircraft technologies with entry into service by ***2026***

Based on 5-year cost share agreements with industry

Awardees:

- Aurora Flight Sciences
- Boeing
- Delta Tech Ops, America's Phenix, MDS Coating Technologies
- General Electric (GE) Aviation
- Honeywell Aerospace
- Pratt & Whitney
- Rolls-Royce
- Rohr, Inc. / UTC Aerospace Systems

[1] Common baseline with CLEEN I goals

[2] 70% reduction in landing and take-off NOx relative to CAEP/8 standard. Relative to CLEEN I baseline of CAEP/6 this is a 75% reduction.

CLEEN II Program Technologies

Company	Technology
Aurora Flight Services	D8 Double-Bubble Fuselage
Boeing	Structurally Efficient Wing
Delta Tech Ops, America's Phenix, MDS Coating Technologies	Protective Coating on Leading Edge of Gas Turbine Engine Fan Blades
General Electric (GE) Aviation	TAPS III Combustor, More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG), Flight Management System / Engine Integration Technologies, Alternative Jet Fuel Test and Evaluation
Honeywell Aerospace	Compact, Low Emissions Radial In-Flow Combustor (SABER) and Advanced Turbine Blade Outer Air Seal System
Pratt & Whitney	Compressed Aero-Efficiency Technologies and Turbine Thermal and Aero-Efficiency Technologies
Rolls-Royce	CSD Low NOx Combustor and Alternative Jet Fuel Test and Evaluation
Rohr, Inc. / UTC Aerospace Systems	Integrated Thrust Reverser

Aircraft Performance Analysis

PARTNER Project 36 (Georgia Tech)

- Environmental Design Space (EDS) used to provide independent assessment of technologies (leveraged PARTNER Project 14 and NASA efforts)
- Modeled most, but not all CLEEN Technologies. Did not model all GE technologies
  - Open rotor engine
  - Engine control/flight management system integration
  - Flight management system/air traffic management integration

Follow-on Efforts

- ASCENT Project 10 (GeorgiaTech-Stanford-Purdue) – evaluating all CLEEN technologies for CO_2, NO_X and noise
- ASCENT Project 37 (GT) CLEEN II Technology Evaluation

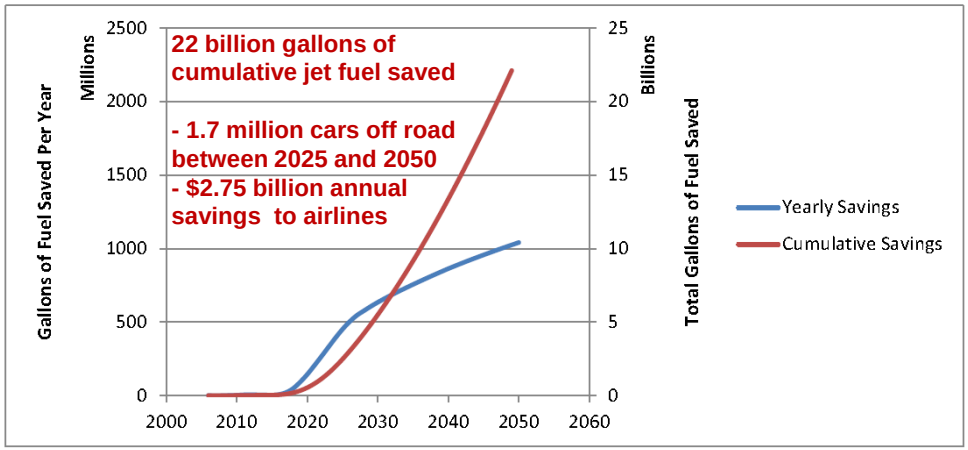


FIGURE 40: POTENTIAL FUEL BURN SAVINGS PROVIDED BY CLEEN TECHNOLOGIES MODELED IN THIS STUDY

PARTNER Project 36 report can be downloaded at:
http://partner.mit.edu/sites/partner.mit.edu/files/PARTNER-Project-36-final-report.pdf

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CLIMATE: Reduce GHG emissions and their impacts	X	X	X	X	X
SUSTAINABILITY: Develop sustainable alternative fuels			X		X

Develop Sustainable Alternative Jet Fuels

Alternative Fuels Principles – Vision

- Alternative Jet Fuels must:
  - Be drop-in
  - Have equivalent safety as petroleum-based jet fuel
  - Have better environmental performance than petroleum-based jet fuel
- Enable all possible fuels that meet criteria
- Government role to address key barriers
- Work through public-private partnerships
- Address the whole supply chain
- Leverage expertise and resources of other government agencies and other countries
- Aviation should be a lead user of alternative fuels

Alternative Jet Fuel Pathways

Start with hydrocarbon / organic building-blocks

Deconstruct & remove extraneous molecules

Process to workable intermediates

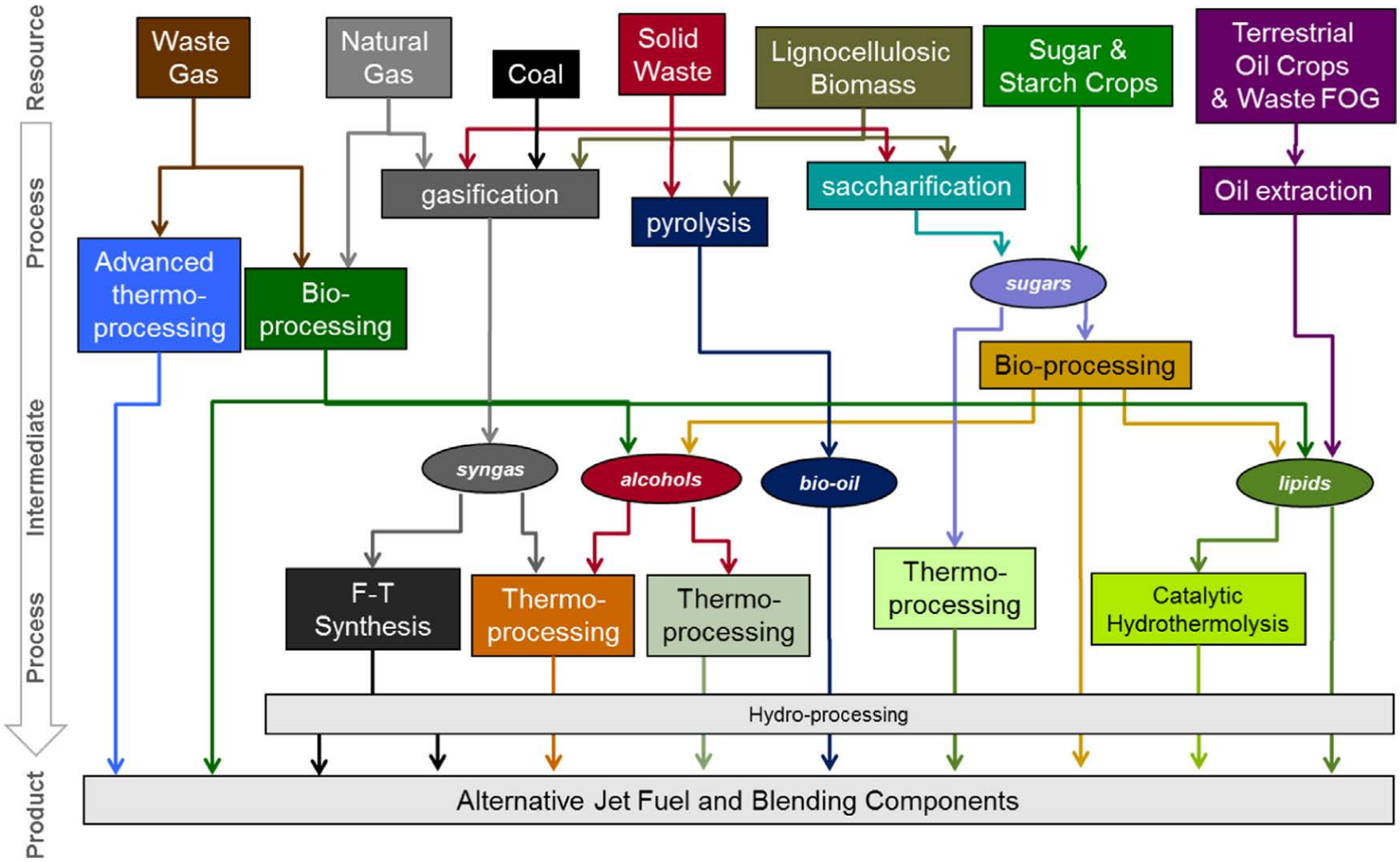
Reformulate to appropriate C_8-C_{16} molecules

Utilize standard refinery "finishing" processes

D7566 – Alternative Jet Fuel Blending Components

D1655 – Petroleum and D7566 Fuels

Some of the Pathways to Alternative Jet Fuels



Hileman and Stratton (Transport Policy, 2014)

Federal Aviation Administration

FAA Alternative Jet Fuel Activities

- **Testing**
  - Support Certification/Qualification testing
  - Improve Certification/Qualification process
  - Emissions measurements
- **Analysis**
  - Environmental sustainability
  - Techno-economic analysis
  - Future scenarios
- **Coordination**
  - Interagency
  - Public-Private
  - State & Regional
  - International

CAAFI: http://caafi.org
CLEEN Program: http://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen/
ASCENT: http://ascent.aero PARTNER: http://partner.aero
Volpe Center: http://www.volpe.dot.gov/our-work/policy-planning-and-environment

Production Pathway Certification

Alternative Jet Fuels – ASTM D7566 Annexes

Approved

- Fischer-Tropsch synthesis of biomass, natural gas, or coal (50% limit)
- Hydroprocessing of fats, oils, and greases (50% limit)
- Biochemical conversion of sugars (10% limit)
- Thermochemical conversion of alcohols to jet fuel (30% limit)

In- Process

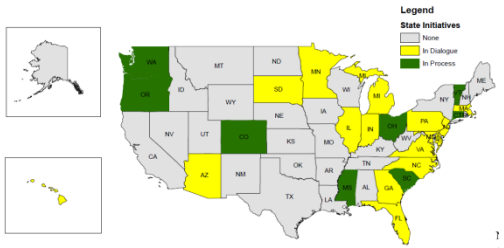
- Hydrothermal processing of fats, oils and greases
- Thermochemical conversion of sugars
- Renewable diesel (at low blend %)
- Thermochemical conversion of cellulose
- Refinery co-processing of biomass
- ATJ expansion to include ethanol

Alternative Jet Fuel Coordination

- **Interagency coordination across supply chain & Federal Alternative Jet Fuel R&D Strategy**

- **Commercial Aviation Alternative Fuel Initiative (CAAFI)**

- **Farm to Fly 2.0 & CAAFI State Activities**



- **International cooperation**

Commercialization News

Altair
GEVO
Altair
Fulcrum
Amyris/Total
Red Rock

Gulfstream And World Fuel Sign Renewable Fuels Agreement

Low-Carbon

Share

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United to start flying biofuels out of LAX in 2015; AltAir to supply 15

June 30, 2015 | Jim Lane

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United Airlines invests $30M in Fulcrum BioEne... inks $

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Amyris, Total to commercialize renewable, low-carbon jet fuel techn

June 30, 2015 | Jim Lane

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FedEx, Southwest Airlines combine to buy entire jet fuel output of Red Rock biorefinery, through 2024

July 21, 2015 | Jim Lane

16 Share
7

FedEx joins Southwest Airlines to buy out Red Rock's entire 8-year jet fuel inventory — key milestone for project

>100 Million

gallons / year by 2025

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gallons per year of renewable jet, diesel and naphtha fuels.

The plant is expected to produce 40% jet fuel, 40% diesel, and 20% naphtha, or 6 million gallons, 6 million and 3 million respectively.

The Southwest Airlines offtake agreement was signed last September. More on that here.

More background on the technology

Red Rock Biofuels: The Digest's 5-Minute Guide

Red Rock Biofuels: The Digest's 8-Slide Guide

United first commercial scale airline purchase

- **Feb 18th first deliveries to LAX**
- **March 11th kickoff of flights**
- **60% GHG reduction**
- **Blend into LAX fuel supply**

AltAir Fuels

United first commercial scale airline purchase

United to start flying biofuels out of LAX in 2015; AltAir to supply 15 million gallons in 3-year deal

June 30, 2015 | Jim Lane

9 Share

8 Share

Share

2 Share

In California, AltAir Fuels will begin regularly scheduled deliveries of sustainable biojet fuel to United Airlines LAX operations this year, the airline announced today.

AltAir's Paramount, California-based refinery converts sustainable feedstocks, like non-edible natural oils and agricultural wastes, into low-carbon, renewable jet fuel. This fuel is price-competitive with traditional, petroleum-based jet fuel, but achieves a 50 percent reduction in carbon dioxide emissions on a life cycle basis when compared to traditional jet fuel.

United will purchase up to 15 million gallons of sustainable aviation biofuel from AltAir over a three-year period, with the option to purchase more.

Rewind to 2013

In 2013, the two companies announced the 15 million gallon deal, saying that they expected to be operating flights in 2014. At the time, AltAir Fuels said that it planned to retrofit the idled portions of its Paramount petroleum refinery to produce renewable jet fuel and other products from non-edible oils and agricultural waste. The refiner will be the first in the U.S. able to produce diesel and drop-in replacements for petroleum-based jet fuels.

The opening of the AltAir refinery will create 150 jobs in Paramount, California. The biofuel will be mixed with traditional jet fuel at a 30/70 blend ratio. The AltAir Fuels refinery will produce 30 million gallons of advanced biofuels, including low-carbon renewable jet fuel and other renewable products.

United will begin using the AltAir sustainable aviation biofuel on select flights operating out of our Los Angeles hub in 2015.

AltAir Fuels

Alternative Jet Fuel – Potential Availability

- Two scenarios derived from DOE One Billion Ton Study:

	Biomass Price	Biomass Availability	Alternative Jet Fuel Production*
Scenario 1 – "Moderate" Improvement	$40/ton	243 million tons of biomass in 2030 from agricultural residues and waste (52% of the total biomass), forestry residues and wastes (34%), and energy crops (14%)	3.6 billion gallons per year in 2030
Scenario 2 – "Aggressive" Improvement	$60/ton	767 million tons of biomass in 2030 from energy crops (52% of the total biomass), agricultural residues and waste (35%), and forestry residues and wastes (13%)	11.5 billion gallons per year in 2030

* Assuming one third of biomass would be converted to AJF at a conversion efficiency of 45 gallons/ton

- For system improvement analysis, AJF assumed to provide an LC-CO2 emissions reduction of 75% relative to conventional jet (in line with LC-CO2 calculations of waste and energy crop conversion to FT jet fuel from Stratton et al., 2010)
- Linear extrapolation used from 2030 to 2050, corresponding to annual growth in yields of ~3%

U.S. DOE Billion Ton Study:
http://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf

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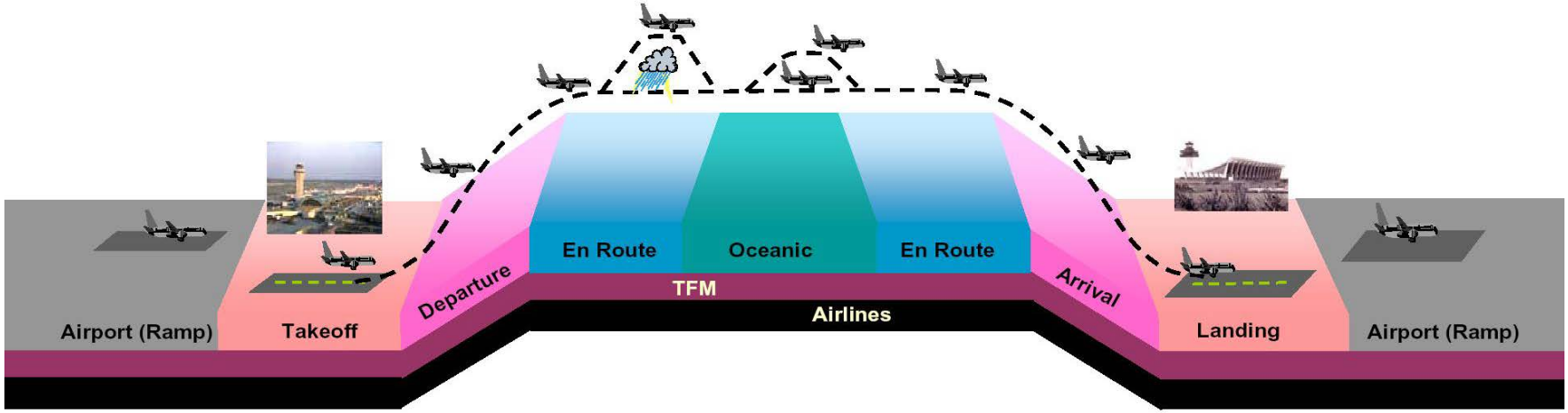
Develop and Implement Clean, Quiet and Energy Efficient Operational Procedures

Clean, Quiet and Energy Efficient Operational Procedures



- Increase efficiency of aircraft operations through the **Next Generation Air Transportation System (NextGen)**
- Engage with industry, research community, NASA, and Department of Defense
- Develop advanced operational procedures to optimize gate-to-gate operations
- Integrate infrastructure enhancements to the National Airspace System (NAS), improving environmental performance
- Calculate the environmental benefits of air traffic management modernization and operational improvements,

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Policies, Standards, and Measures

Science and Analysis to Support Decision-Making

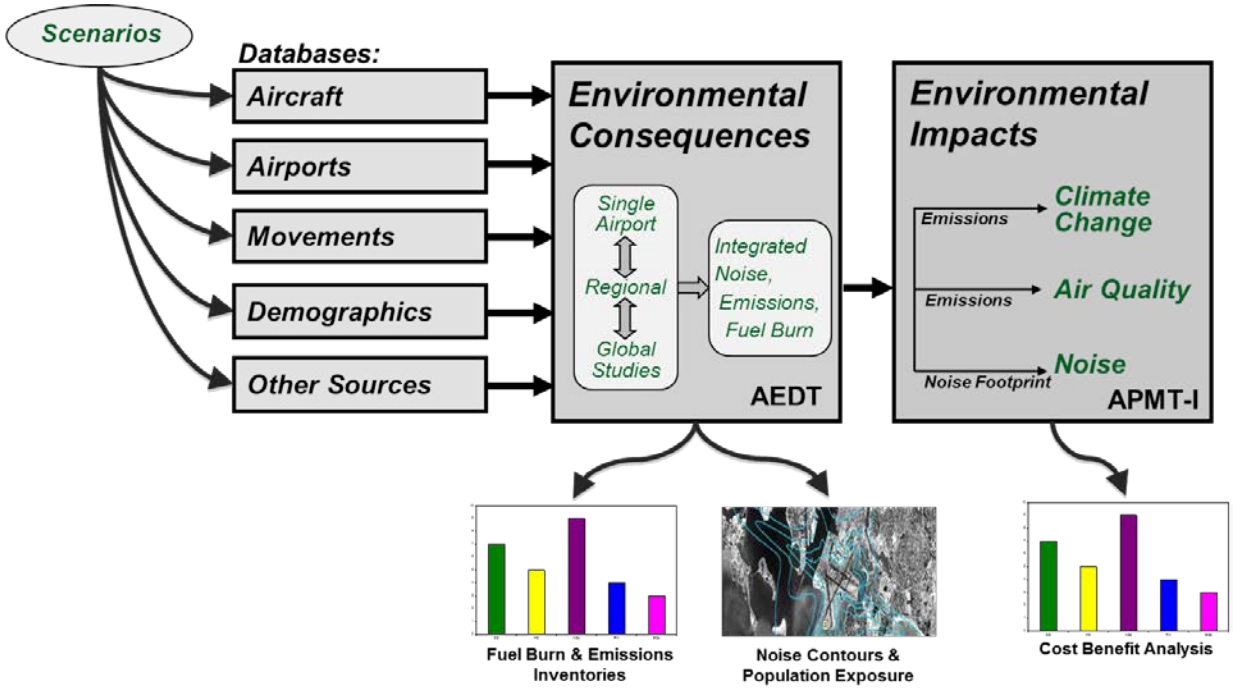
- Aviation environmental policies impact noise, climate and air quality. Using the aviation environmental tool suite to assess the impacts of noise and emissions for policy assessment.

- Elements of tool suite inform decision making:

  CAEP/10 CO_2 Standard (2016)

  CAEP/9 Noise Standard (2013)

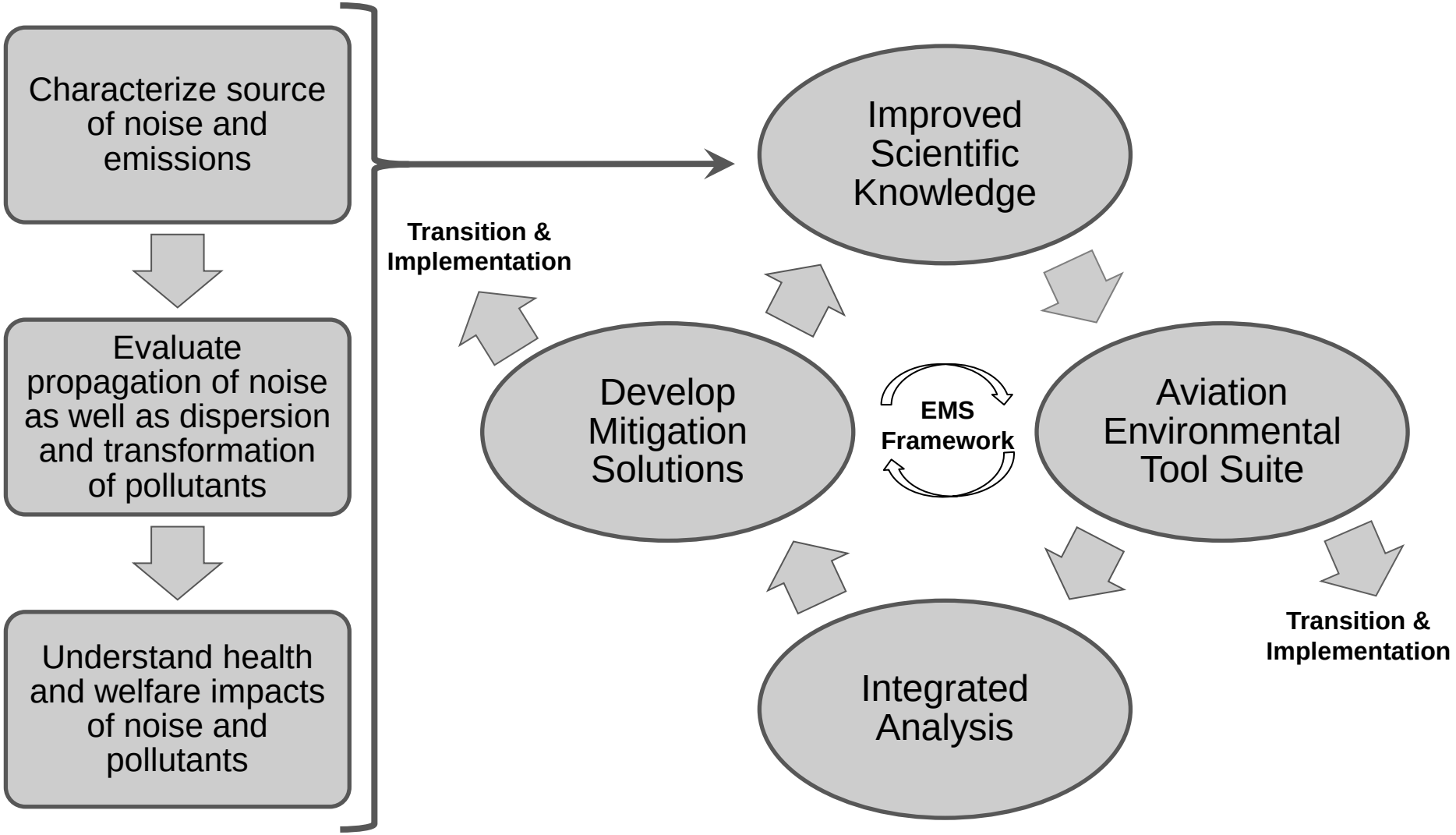
  CAEP/8 NOx Standard (2010)



- FAA uses cost/benefit analysis elements to supplement cost-effectiveness analysis and better inform decision-making process.

Additional information on APMT-Impacts and its use is available at:
http://partner.mit.edu/projects/valuation-and-trade-offs-policy-options

Recap:
Knowledge, Tools, Analysis, Mitigation, & Implementation



Closing Observations

- Environmental and energy constraints are significant
- Aviation noise causing considerable challenges today
- Aviation greenhouse gas emissions may prove the most significant long-term challenge to mobility
- Need a balanced approach to address aviation environmental impacts and energy concerns
- We are advancing understanding, but not waiting; we are using best available methods to seek solutions now

Dr. Jim Hileman

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Online Materials

FAA Environment and Energy

- http://www.faa.gov/go/environment

Center of Excellence (COE) Program

- University research on alt jet fuels and environment
- http://ascent.aero and http://partner.aero

Continuous Lower Energy, Emissions and Noise (CLEEN)

- Reduce aircraft fuel burn, emissions and noise through technology & advance alternative jet fuels
- http://www.faa.gov/go/cleen

Commercial Aviation Alternative Fuels Initiative (CAAFI)

- Coalition that focuses the efforts of commercial aviation to engage the emerging alternative fuels industry
- http://caafi.org