2022 AQMP Mobile Source Working Group Meeting #1 – Aircraft

February 4, 2021

Cleaning The Air That We Breathe...

Agenda

1. Aircraft Operations and Emissions - AQMD
2. Strategies for Reducing Emissions from Aviation - CARB
3. Update on Aircraft Emissions Standards – U.S. EPA
4. Federal Initiatives Addressing Aviation Emissions - FAA

Agenda Item #1

Aircraft Operations and Emissions in South Coast AQMD

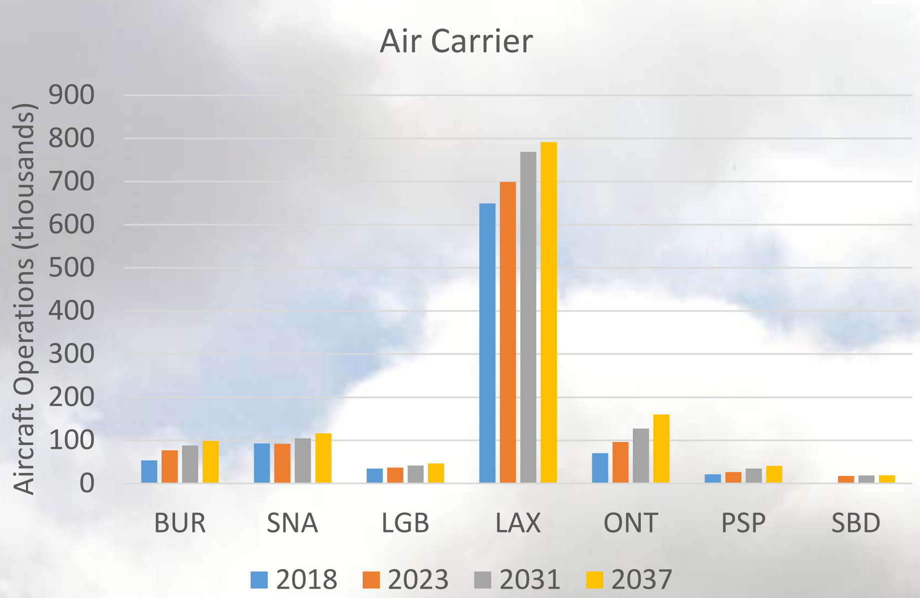
Airports in South Coast AQMD

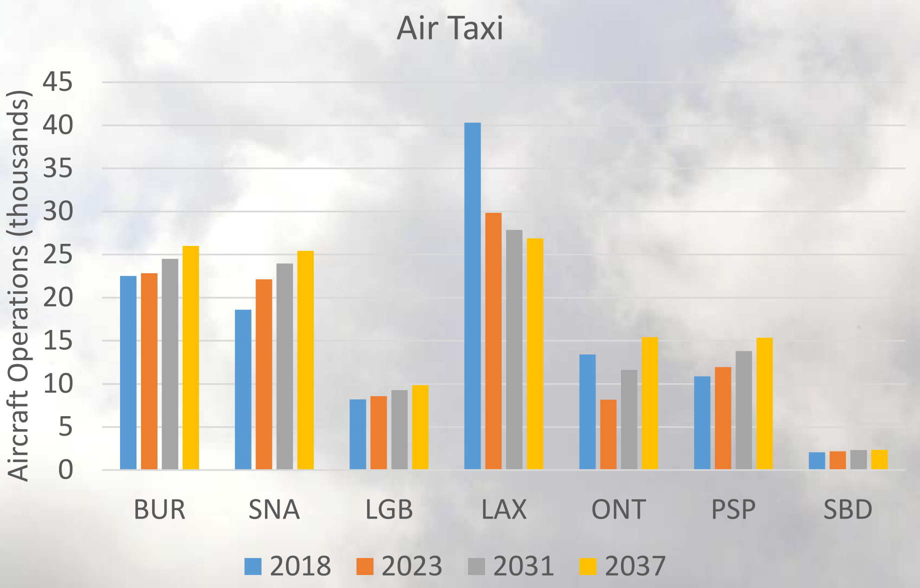
- Commercial
  - LAX, Ontario, Burbank, John Wayne, Long Beach, Palm Springs, San Bernardino
- General Aviation
  - 31 airports
    - Van Nuys, Riverside, Hawthorne, Fullerton, Chino, Cable
- Military
  - 3 airports
    - March Air Reserve Base, Los Alamitos Army Air Base, San Clemente Island Naval Air Station

Major aircraft types

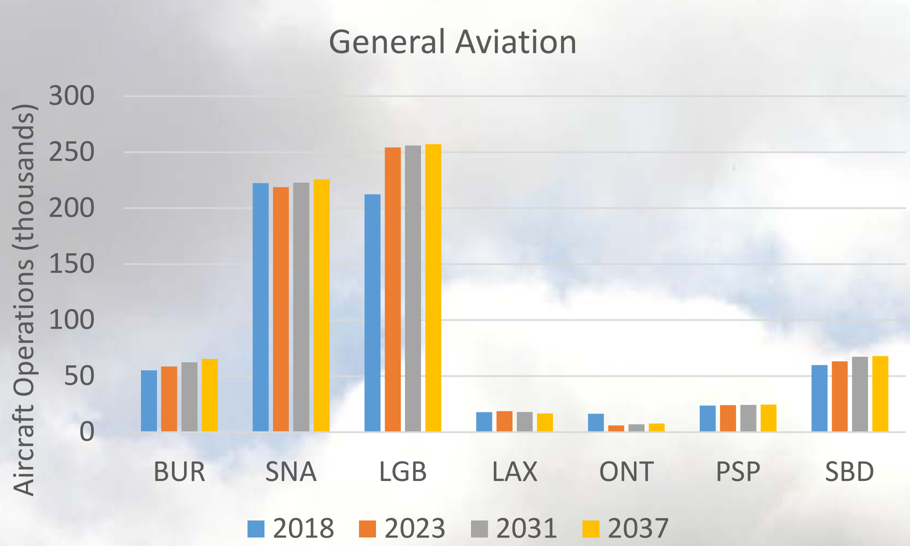
- Air Carrier (passenger and cargo)
  - aircraft with seating capacity of more than 60 seats or a maximum payload capacity of more than 18,000 pounds, carrying passengers or cargo for hire or compensation
- Air Taxi
  - aircraft designed to have a maximum seating capacity of 60 seats or less or a maximum payload capacity of 18,000 pounds or less, carrying passengers or cargo for hire or compensation
- General Aviation
  - all civil aircraft, except for air carriers or air taxis
- Military
  - all military aviation

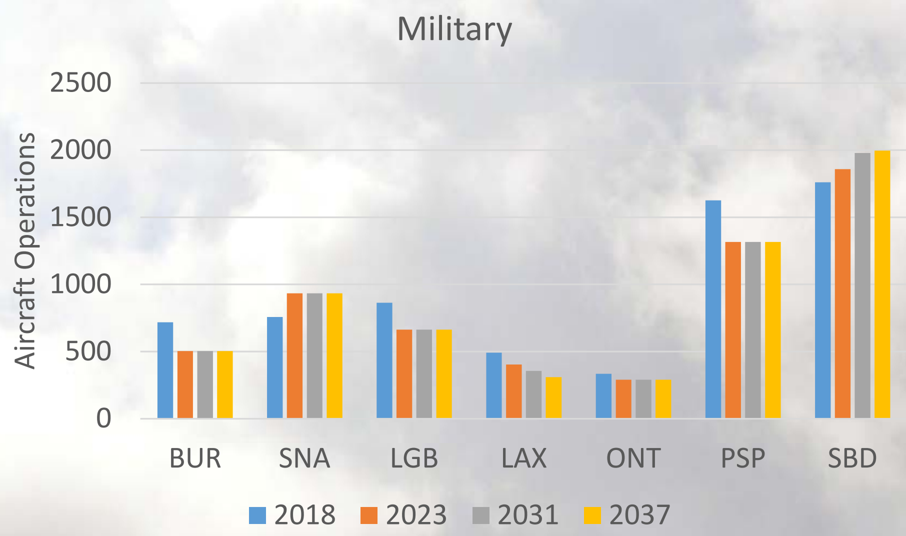
Aircraft operations by major aircraft type and airport





Aircraft operations by major aircraft type and airport (cont'd)





Aircraft emission calculation methodology

- Number of aircraft operations
  - Airports, FAA's databases
- FAA's Aviation Environmental Design Tool (AEDT)
  - Comprehensive model with detailed aircraft/engine emissions calculation algorithm
    - Example: Aircraft: Boeing 737-300 → Engine: CFM56-7B20
- EPA's emission factors (for aircraft operations with unknown aircraft/engine data)
  - Average emission factors for major aircraft types
    - Commercial, Air taxi, General aviation, Military
- FAA's survey data
  - Air taxi and General Aviation
    - Piston/jet engines

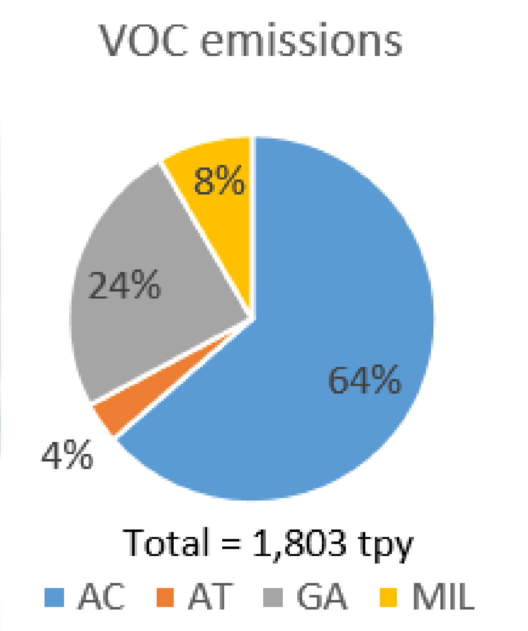
AEDT model example of aircraft/engine combination (Boeing 777-200)

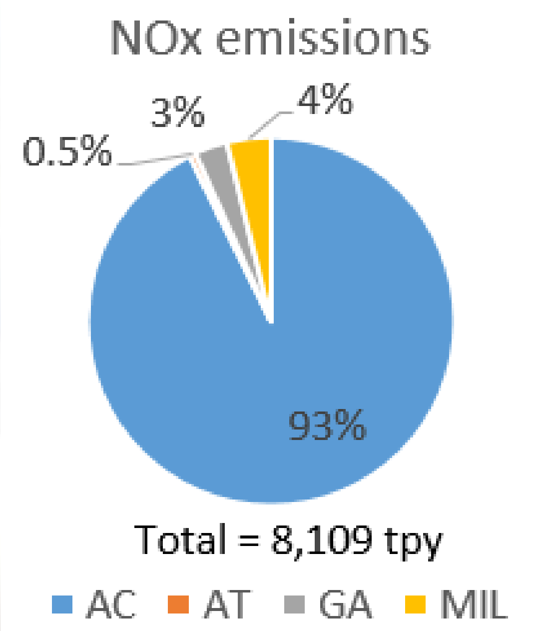
GE Aircraft Engines	Pratt & Whitney	Rolls-Royce plc
3GE059	1PW041	2RR022
3GE061	1PW053	2RR023
3GE062	1PW054	2RR024
3GE063	1PW055	2RR025
3GE064	1PW056	2RR026
3GE065	1PW058	2RR027
3GE066	2PW060	3RR029
6GE087	2PW061	5RR040
6GE088	3PW063	14RR071
6GE089	5PW074	
6GE090	5PW076	
7GE097	8PW089	
7GE098	10PW097	
7GE099	10PW098	
8GE100	10PW099	
9GE120	12PW101	
9GE122	12PW102	
9GE123		
9GE127		

AEDT model example of aircraft/engine Emission Coefficients (Boeing 777-200)

Select NOx Emission Coefficients (grams/kilogram fuel)					
Engine Code	Manufacturer	Takeoff	Climbout	Approach	Idle
3GE059	GE Aircraft Engines	45.53	35.68	12.46	5.73
6GE087	GE Aircraft Engines	40.41	31.77	15.09	5.64
7GE097	GE Aircraft Engines	44.44	33.85	15.78	5.11
8GE100	GE Aircraft Engines	56.41	41.74	17.38	6.09
9GE120	GE Aircraft Engines	42.68	33.82	14.43	5.01
1PW041	Pratt & Whitney	32.50	24.60	11.60	5.00
2PW060	Pratt & Whitney	38.10	31.50	11.00	4.20
5PW074	Pratt & Whitney	22.50	18.00	11.10	4.30
10PW097	Pratt & Whitney	44.68	34.05	11.63	3.81
12PW101	Pratt & Whitney	31.74	25.03	11.91	3.72
2RR022	Rolls-Royce plc	39.11	30.01	10.34	5.60
3RR029	Rolls-Royce plc	31.25	24.66	10.01	4.52
5RR040	Rolls-Royce plc	47.79	34.29	11.39	5.11
14RR071	Rolls-Royce plc	35.56	26.82	10.42	4.66

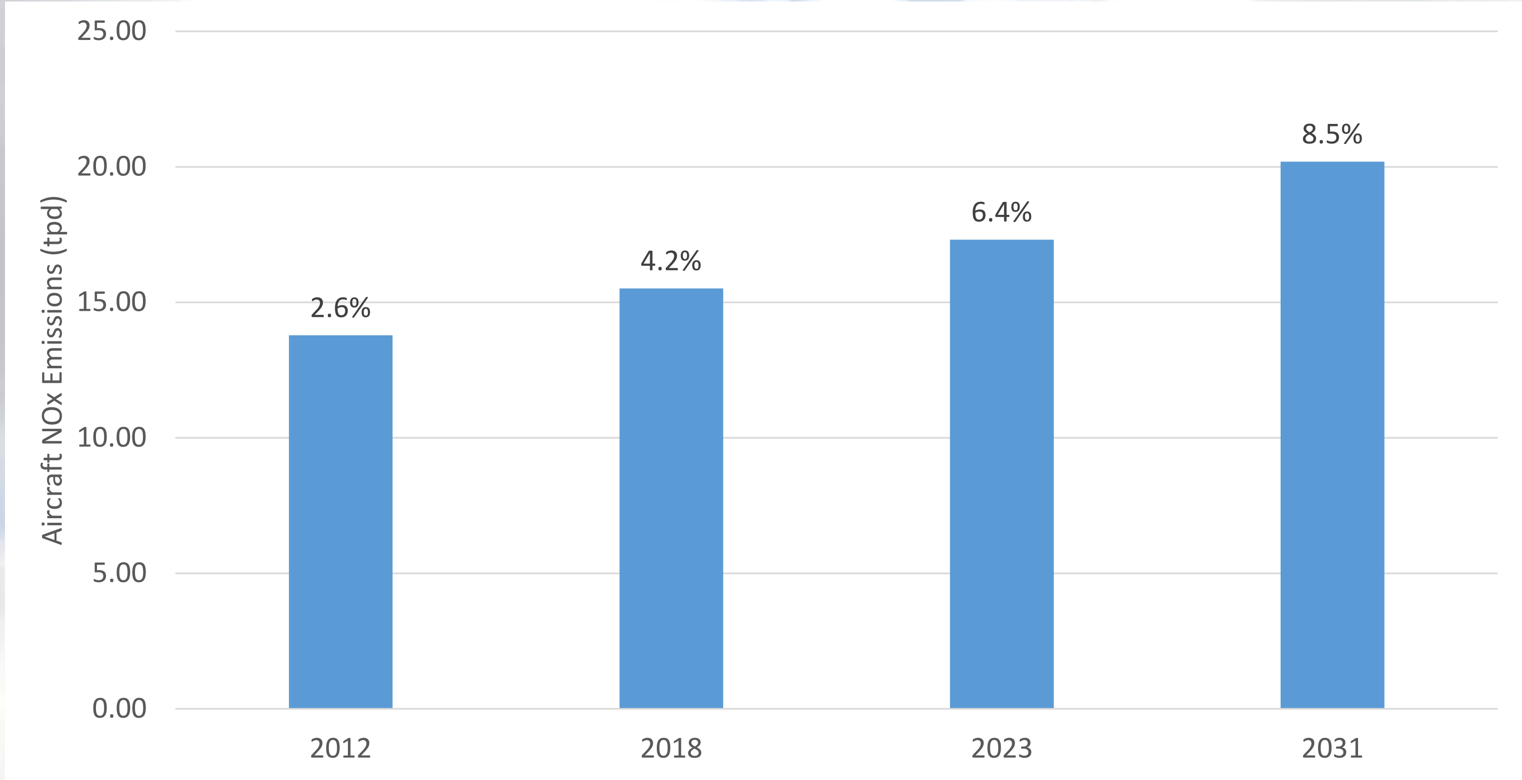
Aircraft emissions by major aircraft type



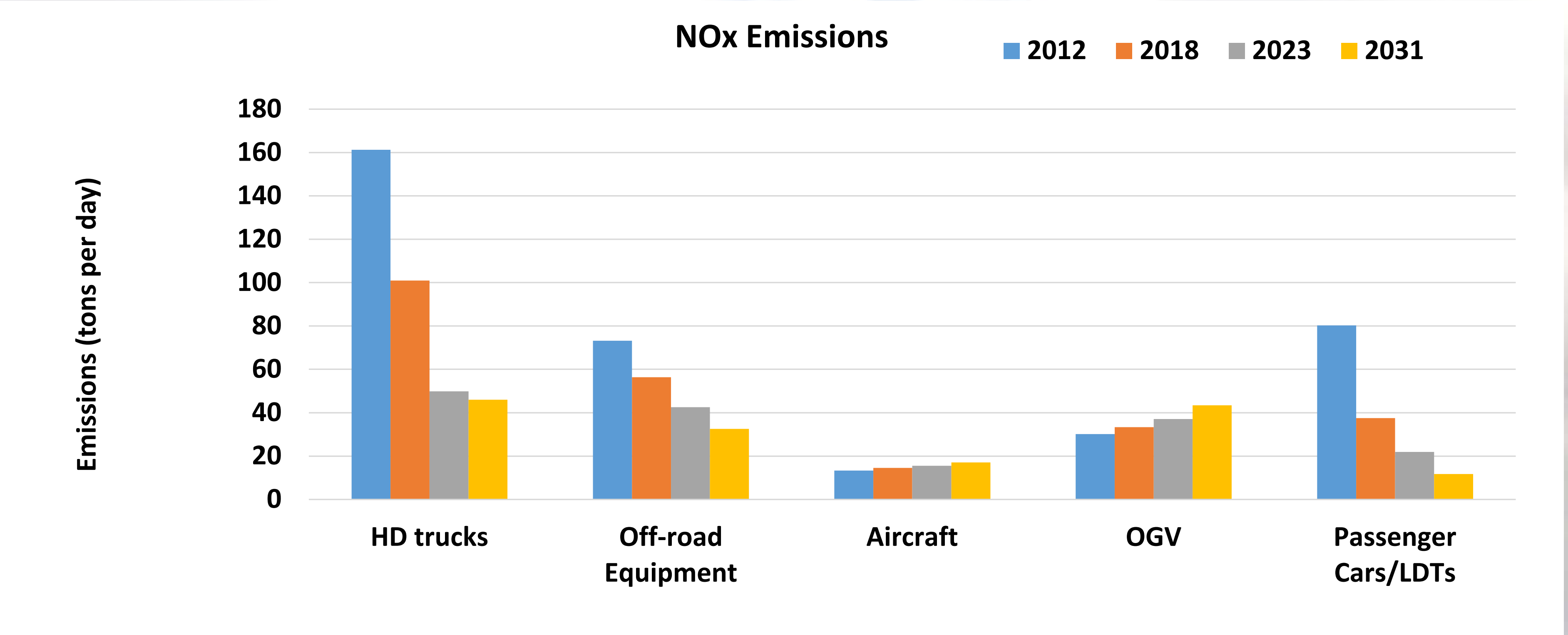


Source: Aircraft Emissions Inventory for the 2016 AQMP, August 2016.

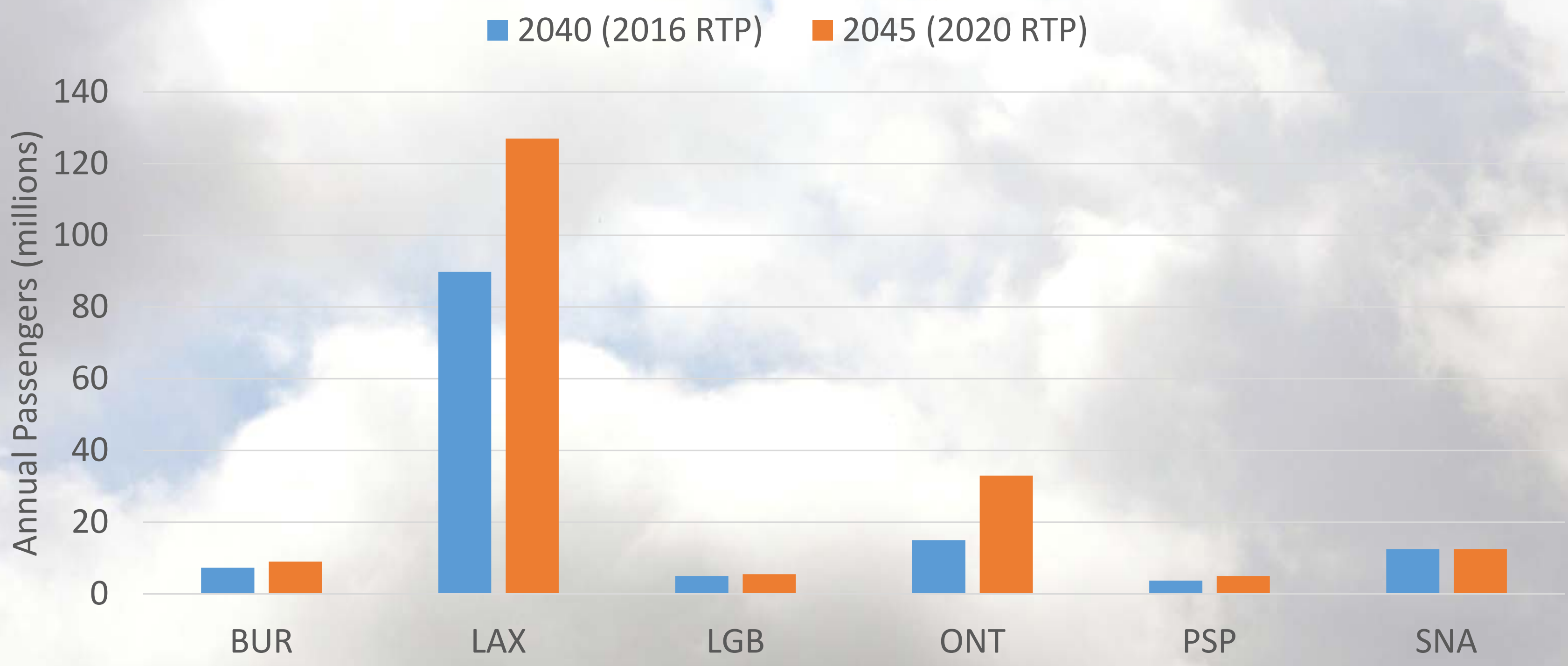
Growing contribution of aircraft emissions



Aircraft emissions compared with other major mobile source categories



Air passengers forecast in 2016 and 2020 Regional Transportation Plans



Next Steps

- Aircraft emissions being updated
  - AEDT Model
  - Updated forecasts
  - 2018 base year
  - 2023, 2031, and 2037 forecast years
- Draft report to be available in late February

2022 AQMP Overall Schedule

Preliminary 2018 emissions inventory
January 2021

April 2021
Updated base and future emissions inventory

Draft control measures
June/August 2021

June/August 2021
Carrying Capacity

Release Draft AQMP
Late Fall 2021

June 2022
South Coast AQMD Board Hearing

CARB Board Hearing
July 2022

August 3, 2022
70 ppb Ozone SIP due to EPA

Mobile Source Working Groups
December 2020 – June /August 2021

Staff Contact Information

Zorik Pirveysian
Planning and Rules Manager
(909) 396-2431
ZPirveysian@aqmd.gov

Xinqiu Zhang
Senior Staff Specialist
(909) 396-3158
xzhang@aqmd.gov

Sang-Mi Lee
Program Supervisor
(909) 396-3169
SLee@aqmd.gov

Eric Praske
Air Quality Specialist
(909) 396-2948
EPraske@aqmd.gov

AQMP Mobile Source Working Groups
AQMPMobileSources@aqmd.gov

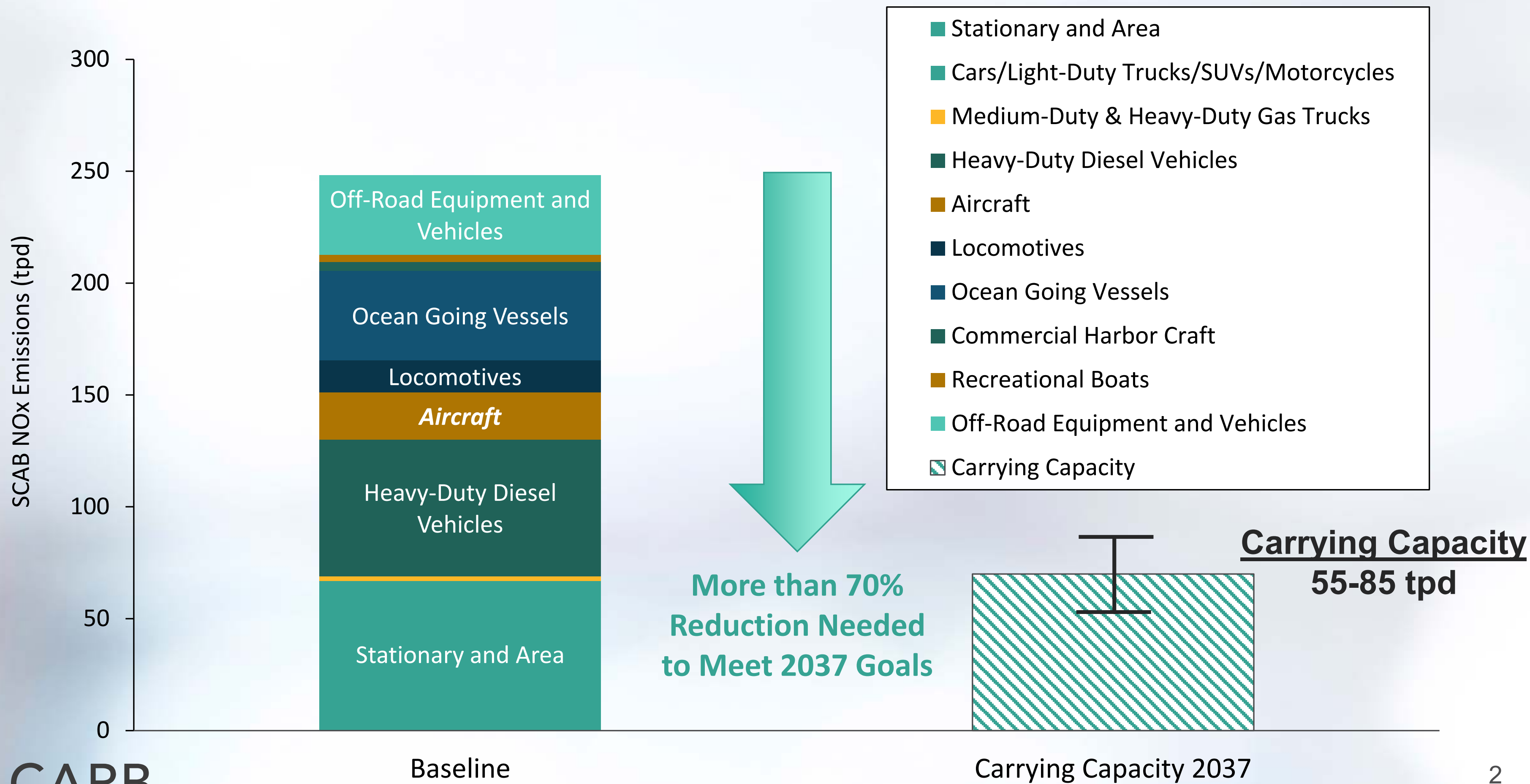
CALIFORNIA
AIR RESOURCES BOARD

Strategies for Reducing Emissions from Aviation

2022 AQMP Mobile Source Working Group

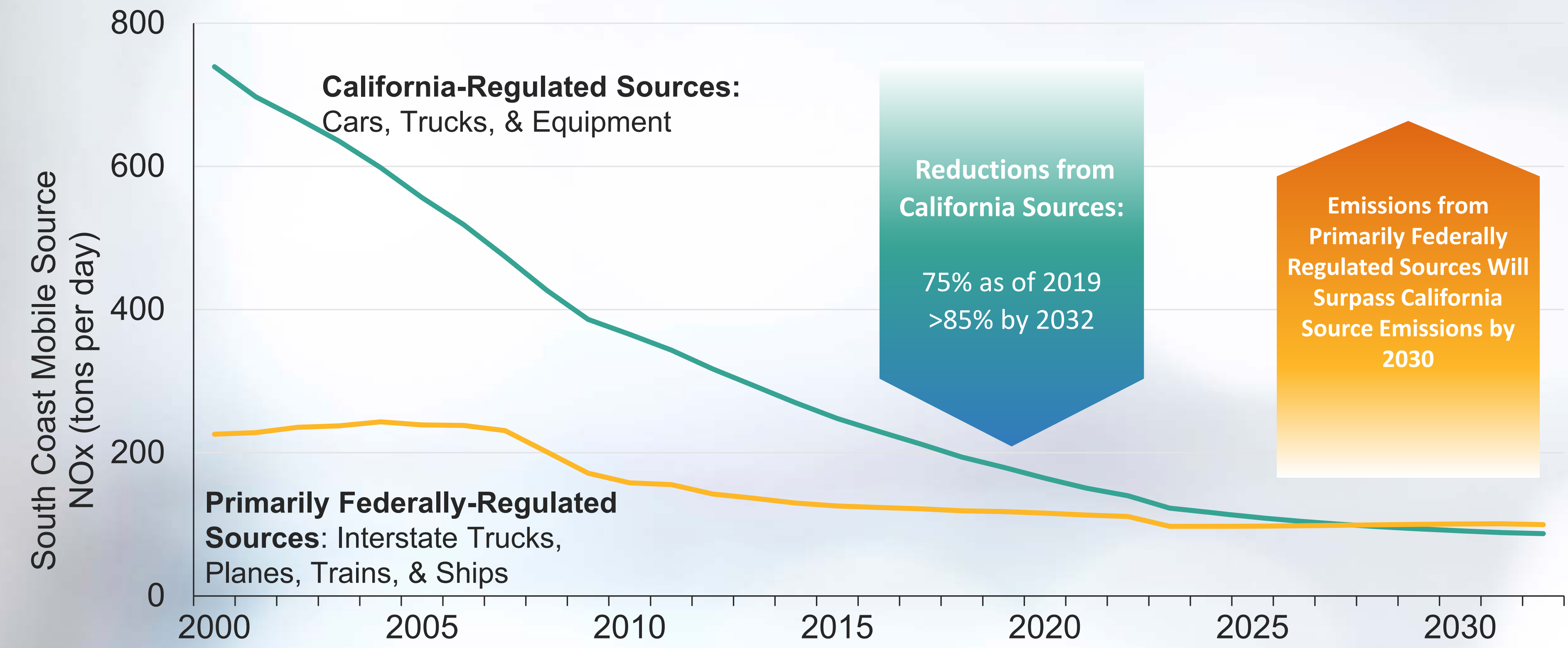
February 4, 2021

South Coast 2037 Draft Attainment Goal



CARB

Controlling Federal Sources is Critical to Achieving our Clean Air and Climate Targets



Source: CARB, CEPAM 2016 SIP - Standard Emission Tool (v1.05), https://www.arb.ca.gov/app/emsinv/fcemssumcat/fcemssumcat2016.php

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Aviation Sector

- Aircraft jet engines
  - o Emissions: 70% CO_2, 29% H_2O, 1% pollutants (NOx, PM, CO, HC, etc.)
  - o 90% of all emissions (except CO and HC) occur at higher altitude
  - o 10% occur during landing, takeoff, and ground operation
- Auxiliary power units (APUs)
  - o APUs start the aircraft main engines and power electrical systems
  - o Emissions: NOx, PM, CO, HC, etc.
- Airport ground transport
  - o covered under off-road diesel regulation and amendments, as well as MOUs

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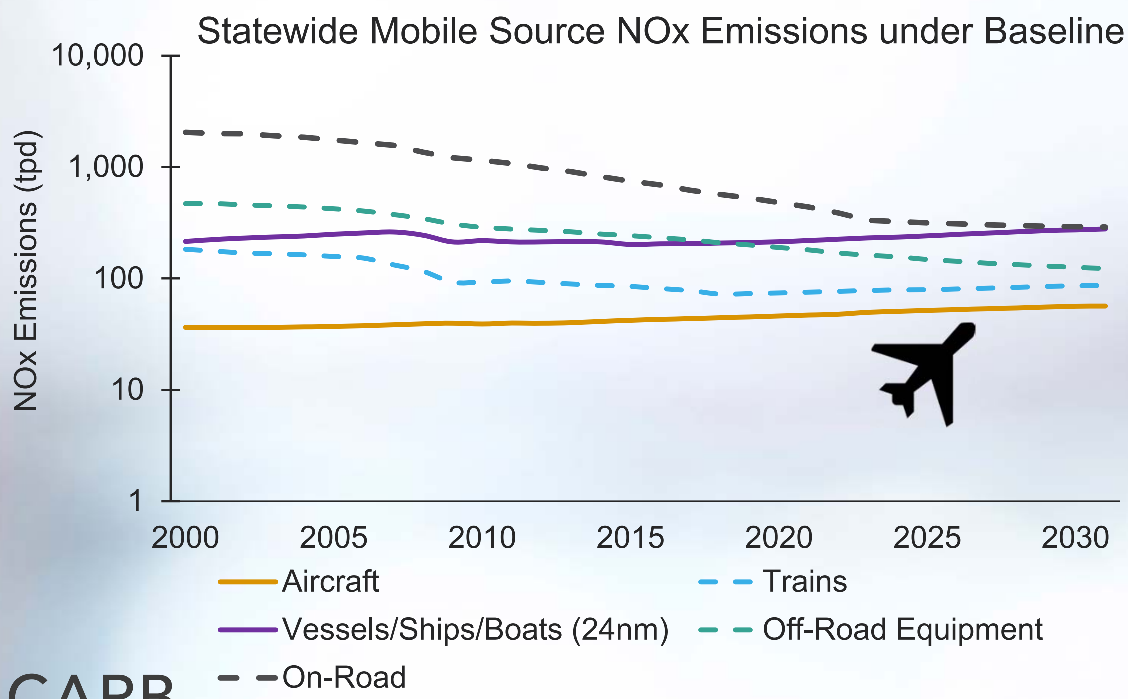
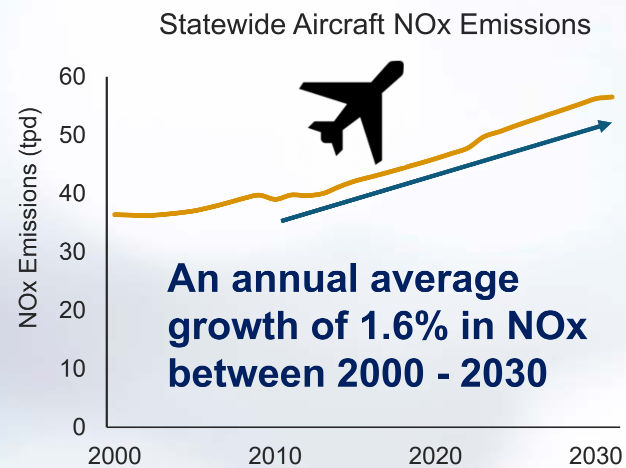
Aircraft Emissions Growing Statewide

- **Aircraft** and marine vessels are the only two mobile sectors with emissions growing from 2000-2030, primarily due to more stringent engine emission standards in other categories





Source: CEPAM 2019 Summer

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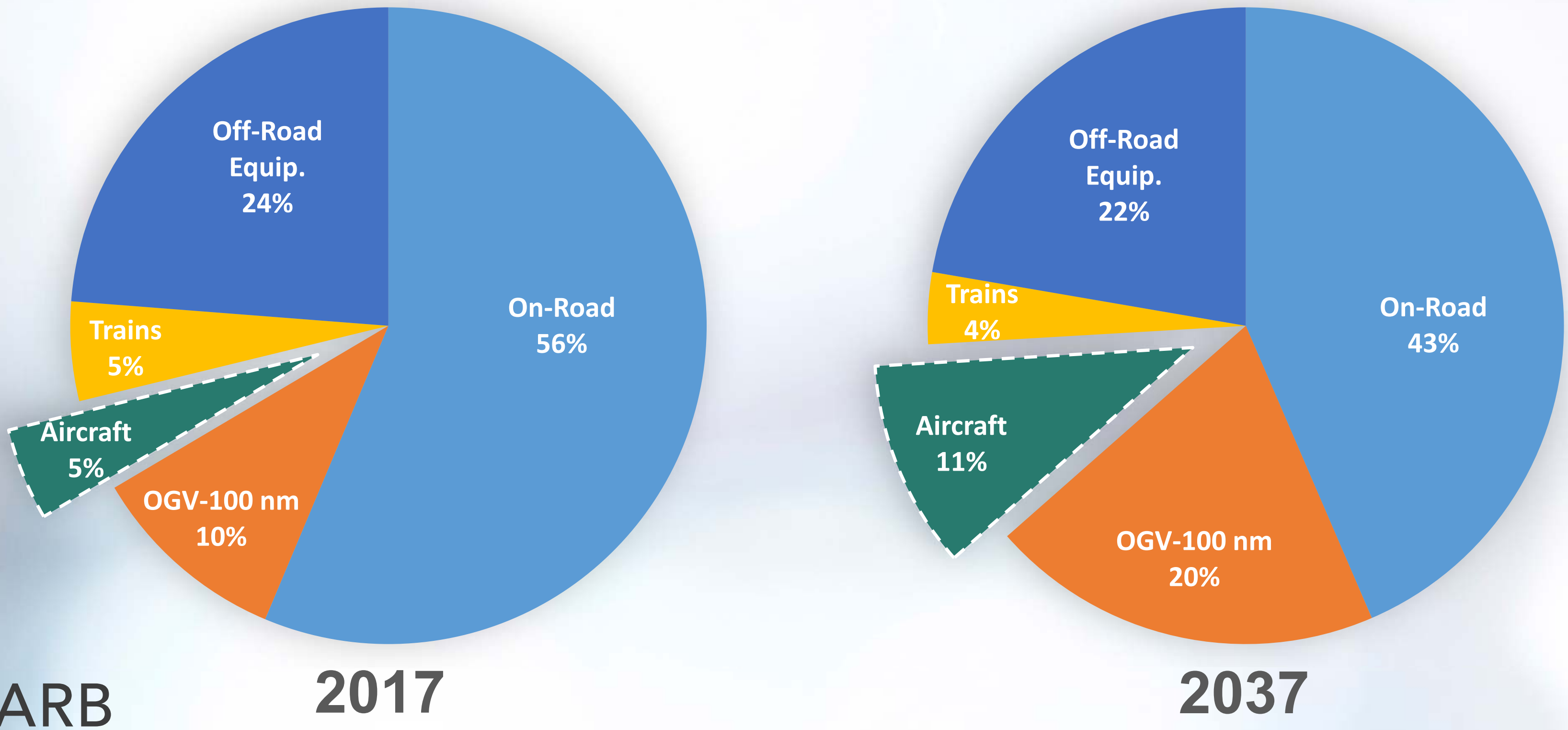
Aircraft Emission Contribution Growing in South Coast

- **Aircraft** makes up 11% of mobile source NOx emission in 2037, up from 5% in 2017



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Aircraft Regulations and Standards

- The International Civil Aviation Organization (ICAO) sets international emission standards for jet engines
  - CAEP/8: latest NOx standard adopted in 2011, 50% below CAEP/1
  - CAEP/10: first CO2 standard adopted in 2017
  - CAEP/11: first non-volatile PM mass and number standard adopted in 2019
- U.S. EPA has adopted ICAO standards historically
  - Finalized first GHG regulation on aircraft in Dec 2020
- Standards are mostly *technology following* instead of being *technology forcing*

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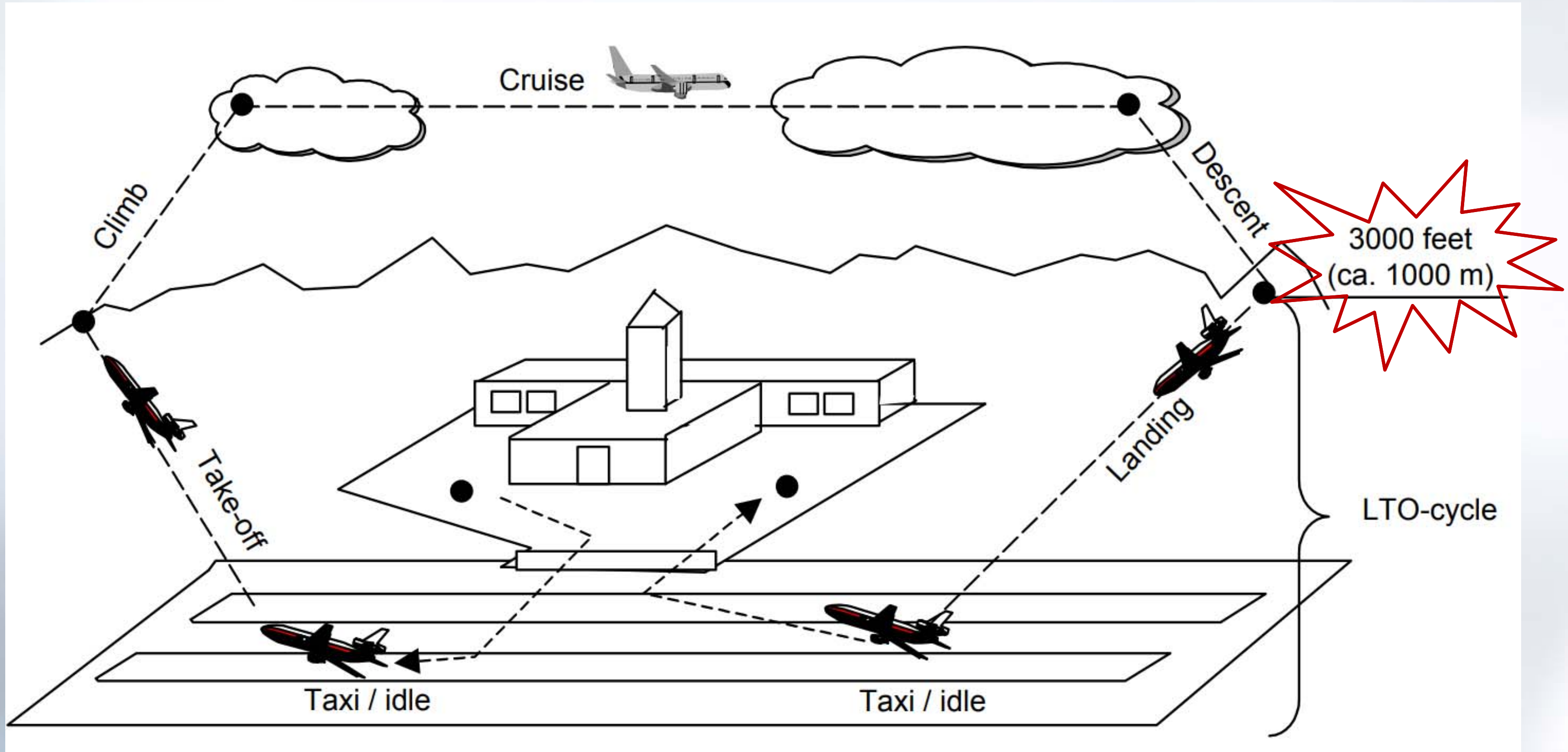
Aircraft Standard Flying Cycles



EMEP/EEA emission inventory guidebook 2009

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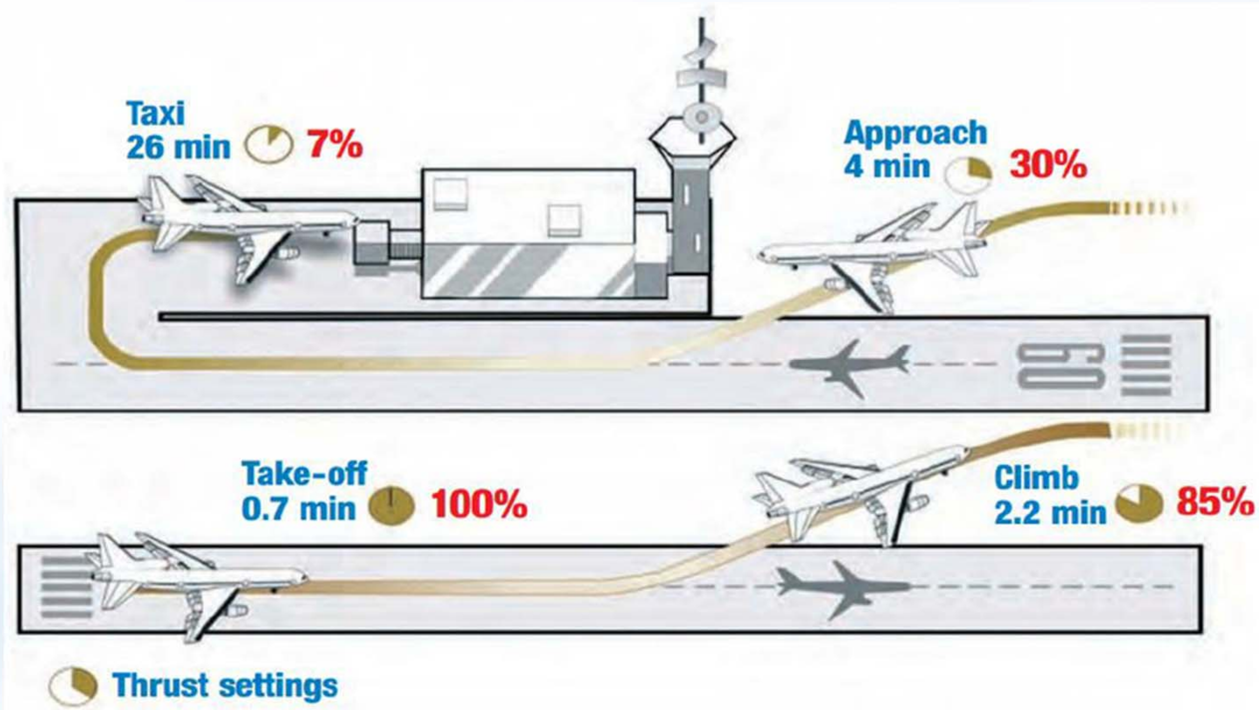
Aircraft Landing & Take-Off (LTO) Cycle

- LTO cycle includes all airport activities that are below 3000 ft

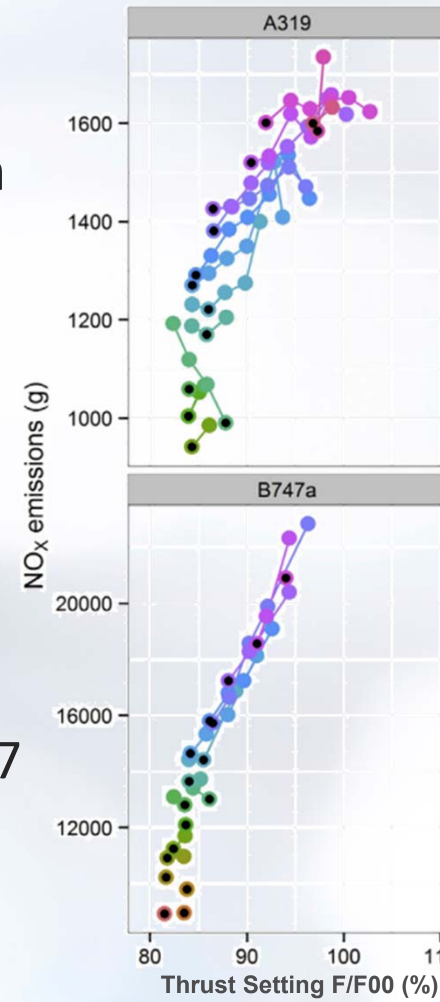


https://www.icao.int/environmental-protection/Pages/LAQ_TechnologyStandards.aspx

2020 Mobile Source Strategies (MSS)

Operational efficiency improvement:

- De-rated take-offs (using less than maximum power on take-offs)
  - Research shows reduced thrust could significantly reduce emissions and fuel usage[1] (averages shown below), plus extending engine life
    - Fuel use: 13 percent reduction
    - NOx: 35 percent reduction
    - Black carbon: 59 percent reduction
- Single engine taxiing (SET) shown to reduce taxiing fuel by 7 percent, and emissions by up to 14 percent[2]



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[1] Koudis et al, 2017; [2] Stettler et. al, 2018.

2020 Mobile Source Strategies (MSS)

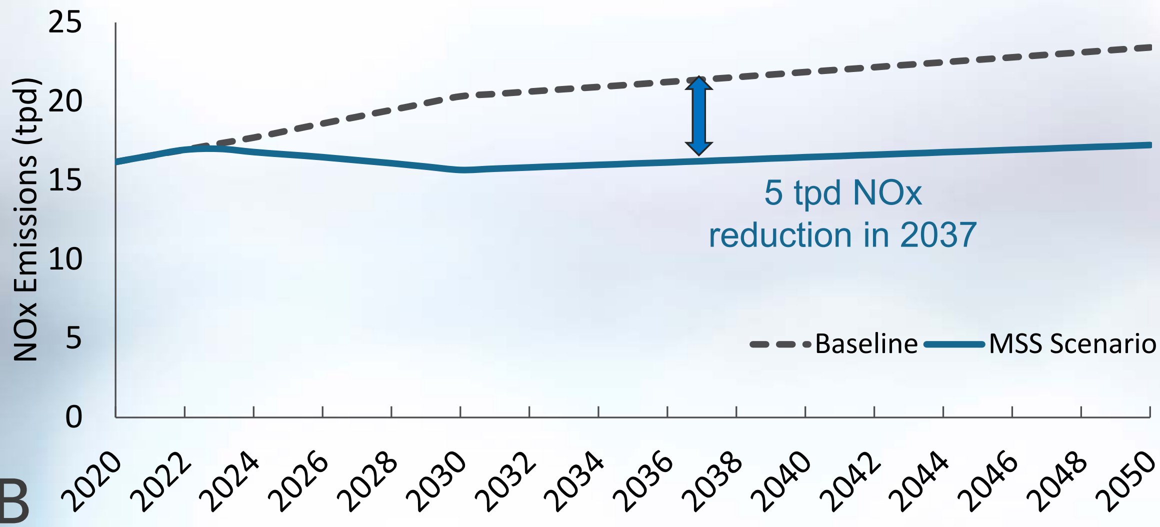
- **Operational efficiency improvement:** Reduced taxiing time
  - Require real-time optimization of air traffic with constant feedback from all associated airports
  - Reductions depend on reduced time spent taxiing; reductions of up to 60 percent shown possible[3]
  - Zero-emission tow-out vehicles possible as future alternative

- **Transition to zero emission auxiliary power units (APUs)**
  - Ground power management could reduce emissions in near term, with longer term technology development needed for full zero emission APUs

[3]Deonandan, 2010

NOx Reductions Under Mobile Source Strategy Scenario in South Coast

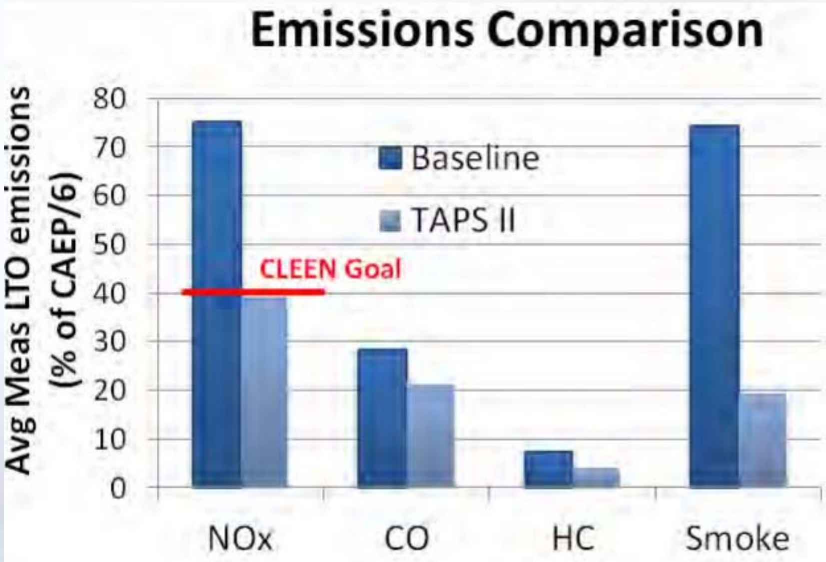
- MSS Scenario assumes:
  - o 25 percent NOx reduction during take-off for 90% of take-offs
  - o 40 percent reduction in Taxi time for 90% of take-offs
  - o Single engine taxiing for 90% of aircrafts
  - o 40 percent reduction in APU usage



More stringent federal standards needed for additional emission reductions.

More Stringent Federal Standards Needed

- NOx emissions can be further reduced beyond the CAEP/8 standards
- FAA's Continuous Lower Energy, Emissions, and Noise (CLEEN) Program incentivizing new aircraft technologies and sustainable aviation fuels since 2010
- General Electric's TAPS II combustor (a lean burn system) could reduce LTO NOx emissions by 60% below CAEP/6, ~50% below CAEP/8
- Currently onboard Airbus 320neo, Boeing 737 MAX, and COMAC C919 aircraft



Source: TAPS II Combustor Final Report
https://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen/reports/media/taps_ii_public_final_report.pdf

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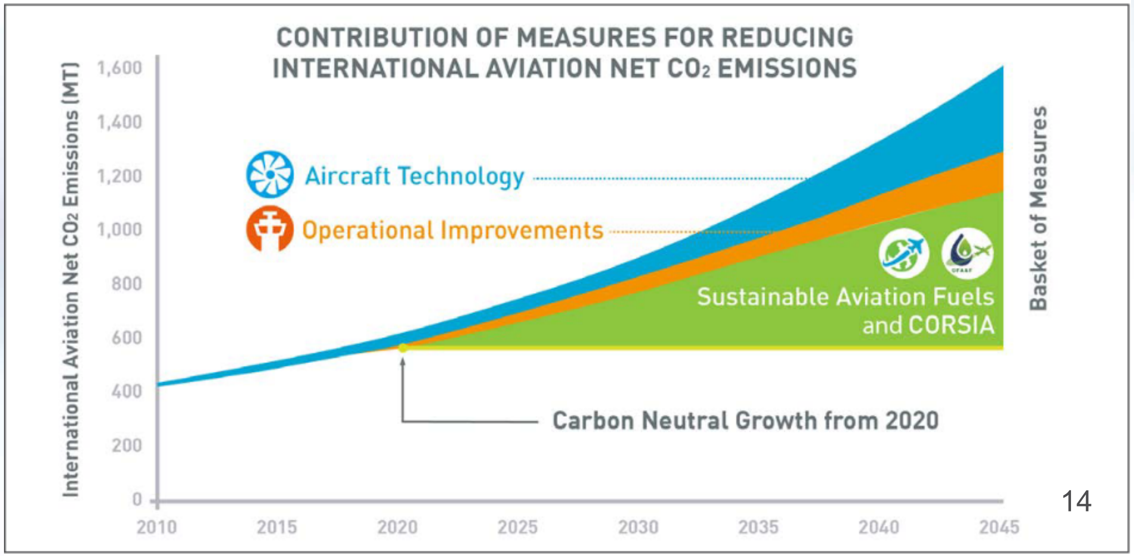
Sustainable Aviation Fuel (SAF)

- Drop-in substitutes of petroleum jet fuels that are derived from renewable feedstock
  - Interchangeable with conventional jet fuel when blended
  - Require no modifications to aircraft or fuel supply infrastructure
- Significant GHG, PM, and SOx emissions reductions
- ICAO envisions a significant increase in the use of SAFs to achieve carbon neutral growth from 2020



Source: Introduction to the ICAO Basket of Measures to Mitigate Climate Change https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg111-115.pdf

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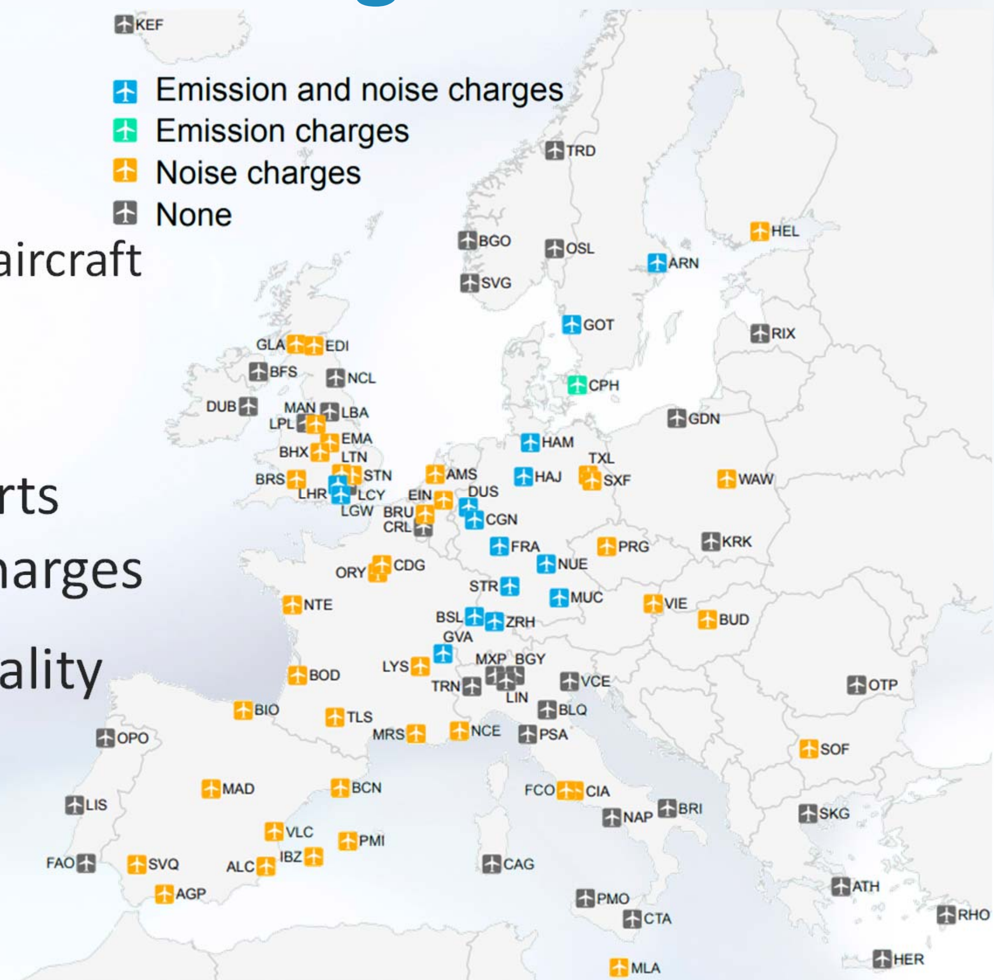
Environmental Charges

- In Europe, some airports impose environmental charges to:
  - o incentivize the use of lower-emission aircraft by airlines
  - o fund local mitigation measures
- 60% of the busiest EU28+EFTA airports have implemented environmental charges
- Focused on local noise and/or air quality (NOx) impacts



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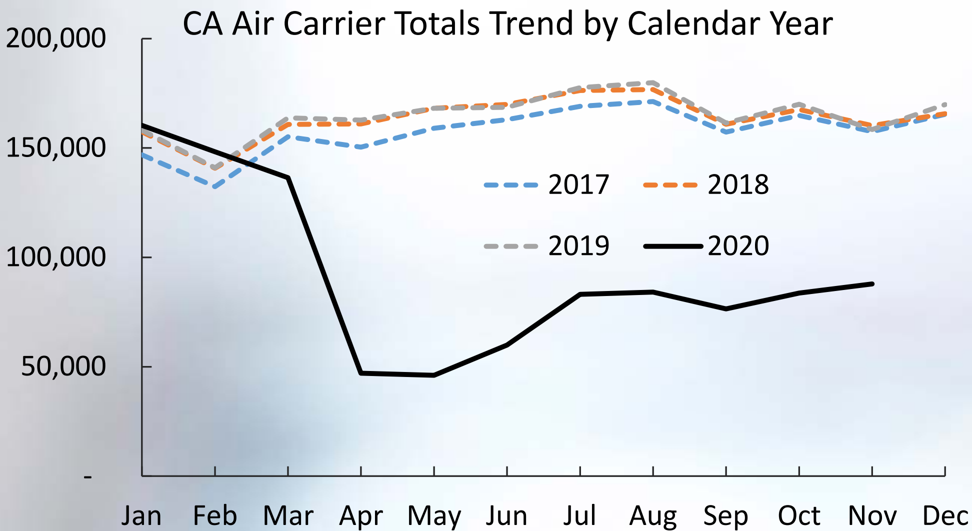
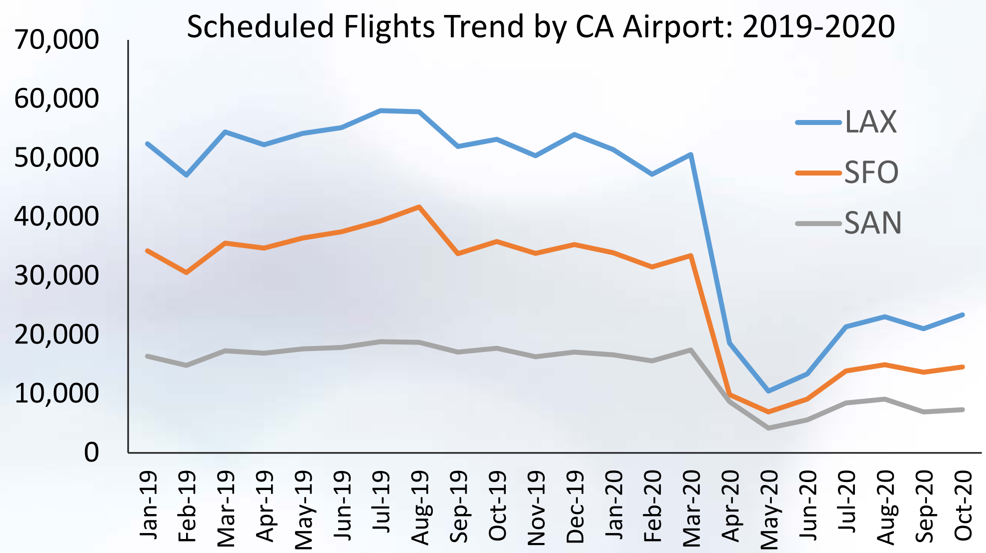
https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf

Impacts of COVID on Air Transportation

- Short-term emission reductions:
  - ~65% drop in aircraft activities in April when COVID hit
  - Slowly recovering to ~50% of previous activity level by Oct/Nov 2020
  - Older engines used less, newest/cleanest engines in service



Source: OPSNET, FAA: https://aspm.faa.gov/opsnet/sys/main.asp



Source: ASPM, FAA: https://aspm.faa.gov/apm/sys/main.asp

CARB

Contacts and Sources

Liang Liu
Air Resource Engineer, MSS lead
Off-Road Diesel Analysis Section
Liang.Liu@arb.ca.gov

David Chou
Manager, Lead on inventory
Off-Road Gasoline Inventory Section
David.Chou@arb.ca.gov

Cory Parmer
Manager, MSS manager
Off-Road Diesel Analysis Section
Cory.Parmer@arb.ca.gov

References

1. Koudis et al, 2017: Airport emissions reductions from reduced thrust takeoff operations https://doi.org/10.1016/j.trd.2017.02.004
2. Stettler et. al, 2018. The impact of single engine taxiing on aircraft fuel consumption and pollutant emissions https://www.cambridge.org/core/journals/aeronautical-journal/article/impact-of-single-engine-taxiing-on-aircraft-fuel-consumption-and-pollutant-emissions/495FF8A62B2949D921456BC07BA68A64
3. Deonandan, 2010: Evaluation of strategies for reducing taxi-out emissions at airports https://dspace.mit.edu/handle/1721.1/81189

Update on Aircraft Emission Standards

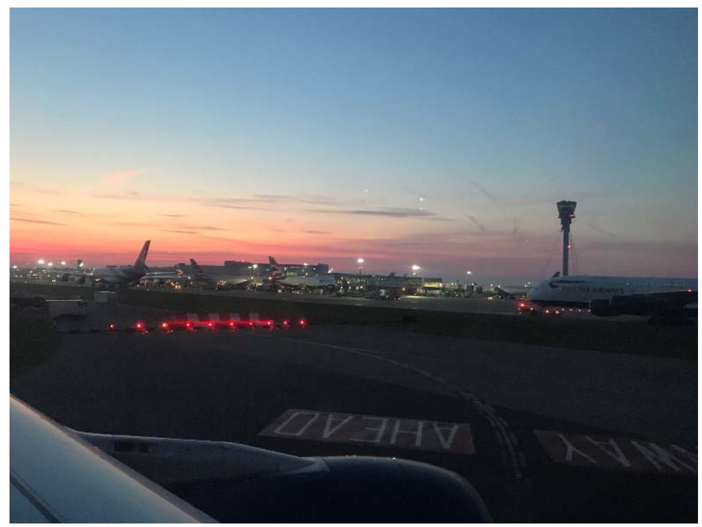
2022 AQMP Mobile Source Working Group - Aircraft (Meeting #1)

February 4, 2021

By: EPA's Bryan Manning

Outline

- International Civil Aviation Organization
- Standard Development Timelines
- NOx Standards
- PM Standards
- CO2 Standards

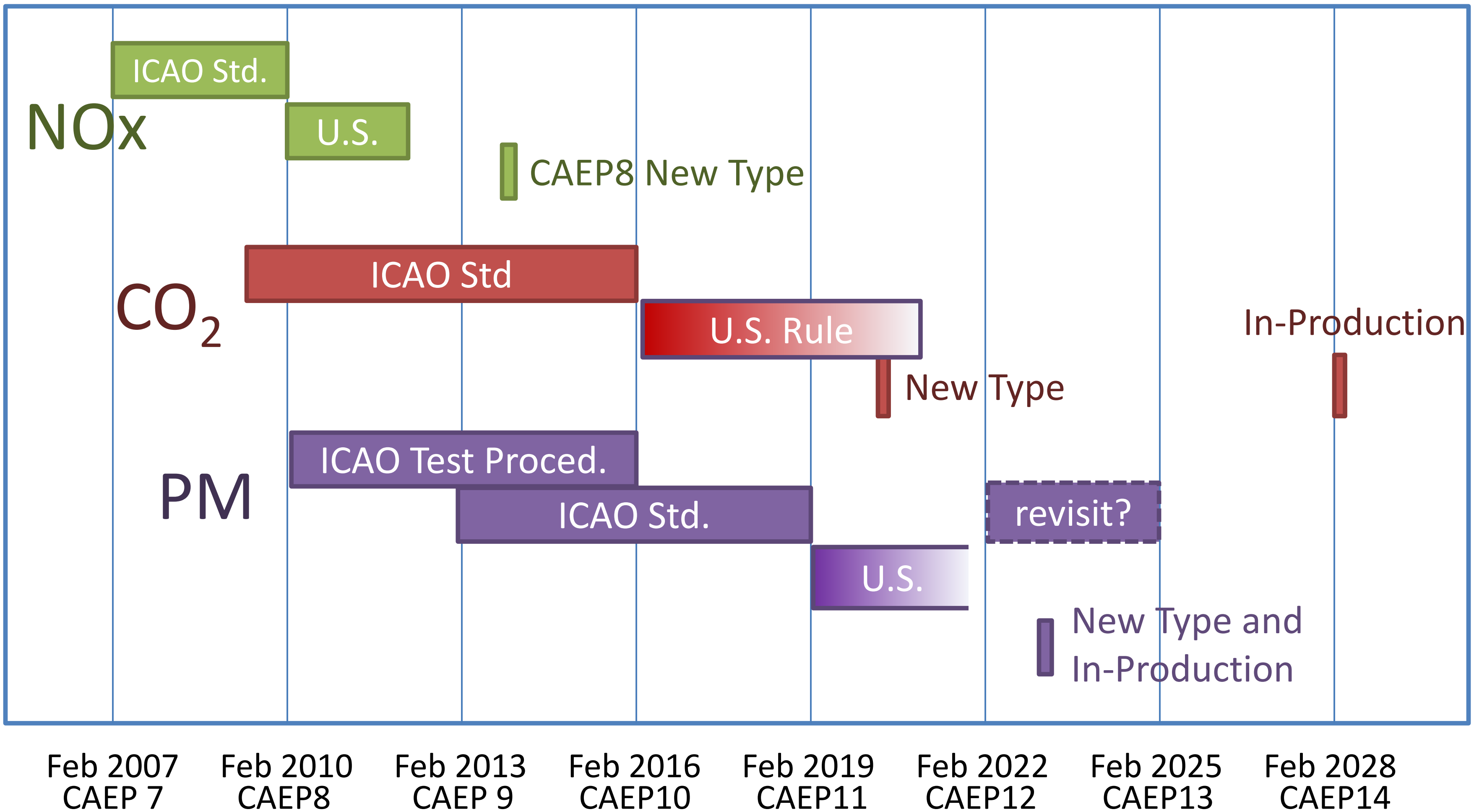


International Civil Aviation Organization (ICAO)

- International Civil Aviation Organization is a specialized agency of the U.N.; a global organization that brings together States, manufacturers, NGOs, and industry organizations
  - Sets standards and regulations for aviation safety, security, efficiency, and environmental protection
  - Environmental organization is Committee on Aviation Environmental Protection (CAEP)
- US Delegation to ICAO is led by the Federal Aviation Administration
  - EPA acts as an advisor to FAA and contributes analysis to the working groups
- ICAO emissions standards are not self-implementing, but must be implemented through domestic regulation – via section 231 of the Clean Air Act in the U.S. (FAA, via CAA §232, has responsibility to prescribe regulations to ensure compliance)

Standard Development Timelines

- It can take 3-9 years to develop an international standard at ICAO
- Additional lead time is then needed to implement the standard



Aircraft NOx Standards

- CAEP's first aircraft engine NOx standards were adopted in 1981 (effective 1986), & standards have been tightened several times subsequently
  - 1992, 1998, 2004, and 2010 (effective at least 4 years later)
  - In 2010, CAEP adopted latest NOx standard for only new type engines (effective 2014); not in-production engines
  - Technology following / anti-backsliding standards
- This CAEP cycle (ends 2022) does not include further NOx stringency/requirements, and currently not expected in next CAEP cycle (ends 2025)

Aircraft PM Standards

- CAEP 2016: agreed to first aircraft engine non-volatile PM (nvPM) transition standard (all-pass) and test procedures
  - nvPM mass concentration standard provides equivalent visibility control as existing smoke visibility standard
  - In-production engine standard & reporting requirement, effective 2020

- EPA 2018: issued information collection request to domestically implement this CAEP 2016 requirement

- CAEP 2019: agreed to initial stringency of aircraft engine nvPM standards
  - nvPM mass and number standards, effective 2023
  - New type (anti-backsliding) and in-production (all-pass) standards
  - Replace ICAO's existing smoke number std. in 2023 for engines >26.7 kN
  - Reporting of nvPM loss corrections

- CAEP will review nvPM technology development during this CAEP cycle and potentially revisit standards during next cycle

Airplane CO_2 Standards

- CAEP 2016: agreed to first airplane CO_2 standards
  - Applies to new type airplanes in 2020 and in-production aircraft in 2028
  - Anti-backsliding and technology following standards
- EPA 2016: issued aircraft endangerment finding for six well-mixed GHGs
- EPA 2021: promulgated airplane GHG standards on that match ICAO/CAEP standards
- This CAEP cycle does not include further CO_2 stringency, and it is uncertain for the next cycle

APPENDIX

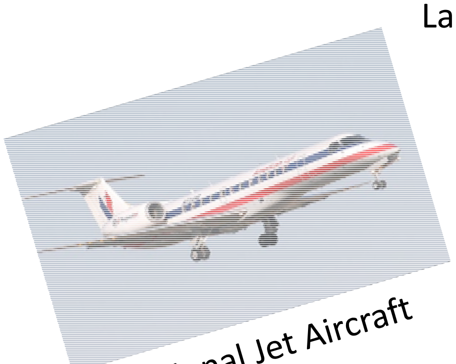
Covered vs. Non-Covered Aircraft

Aircraft Included in ICAO CO_2 Standard

~90%
of U.S. GHG emissions from aviation sector

Large Transport Jet

Large Turboprop



Regional Jet Aircraft

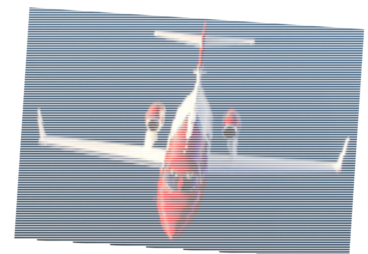
Large Business Jet

Aircraft Excluded from ICAO CO_2 Standard

~ 10%
of U.S. GHG emissions from aviation sector

Small Turboprop

Piston Engine



Small Business Jet

Helicopters

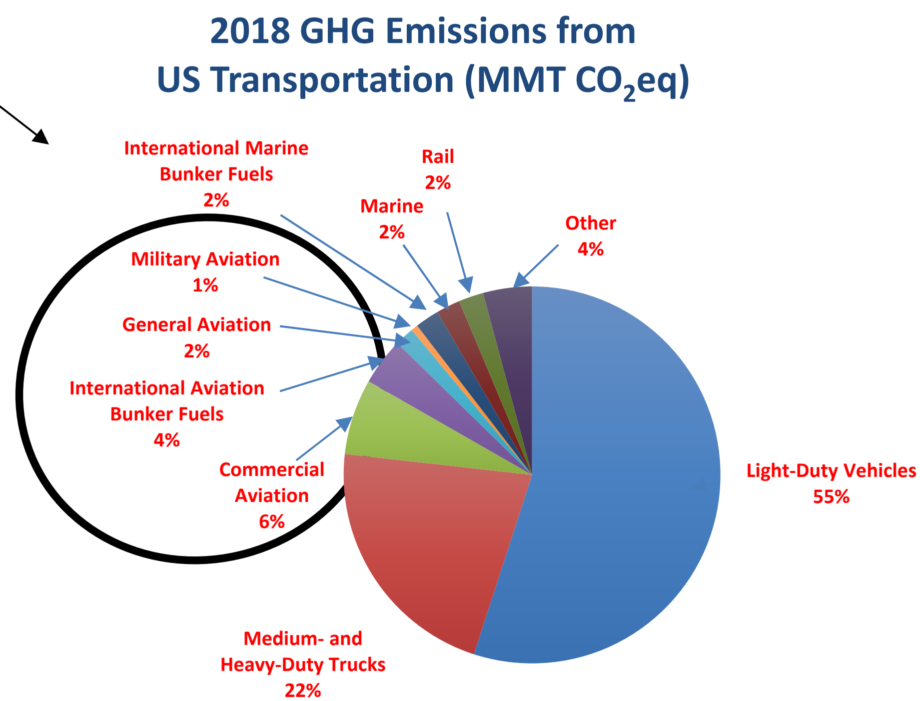
Military

Aircraft GHG Emissions Inventory

- Aircraft sector contributes ~13% of U.S. transportation GHG
  - Largest remaining transportation category not yet regulated for GHG.
  - 4% of total U.S. GHG emissions (not pictured). Total transportation is about a third.

- U.S. covered aircraft comprise the vast majority of aviation sector GHG -emissions (U.S. ~90%).

- CO_2 accounts for nearly all (~99% CO_2-eq) of well-mixed GHGs emitted from aircraft engines.
  - Less than 1% N_2O emitted; methane considered negligible from modern engines; no HFCs, PFCs, or SF_6 emitted from aircraft engines.



Source: EPA, 2020: Inventory of U.S. GHG Emissions and Sinks: 1990-2018

ICAO Terminology for Applicability

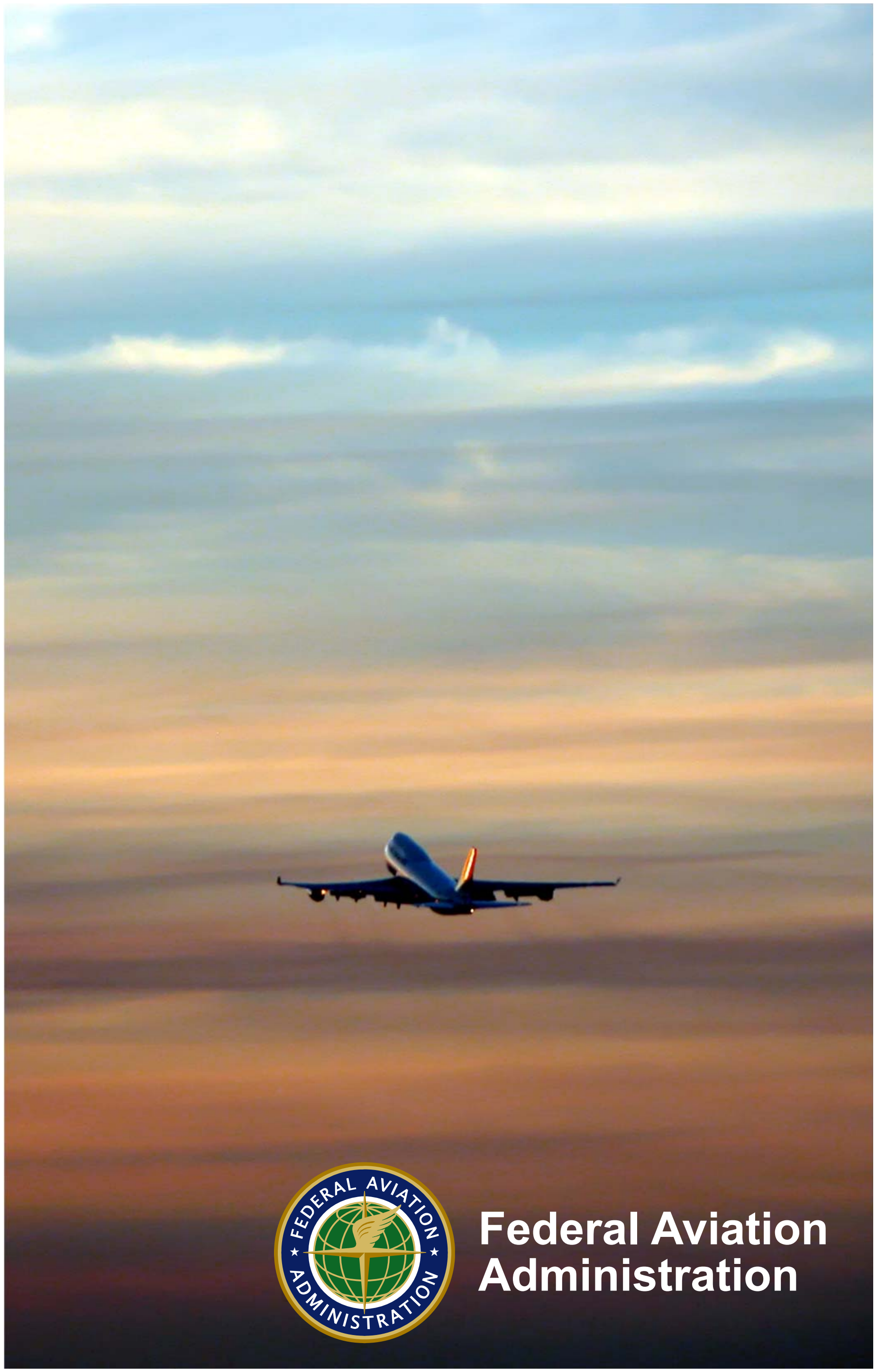
- New type aircraft are clean sheet designs which come out rarely. (No new type aircraft have yet been announced that would be affected by a 2020 standard)
- In-production aircraft are newly built aircraft using an existing design
  - Boeing 777 was a new type in 1995; in 2022, it will be upgraded with new engines and new wings, but still will not be a new type; thus, the 2020 standard will not apply

Federal Initiatives Addressing Aviation Emissions

Presented to: SCAQMD Aviation Workgroup

By: Ralph Iovinelli

Date: February 4, 2021



Content

- U.S. Aviation Emissions Trends
- Fleet Mix Changes
- Aviation Emissions Source Reductions
- Aviation Emissions Tools

Economic Benefits of Aviation (pre-pandemic)

5.1% of U.S. GDP

10.6 Million U.S. jobs

$1.6 Trillion in U.S. economic activity annually

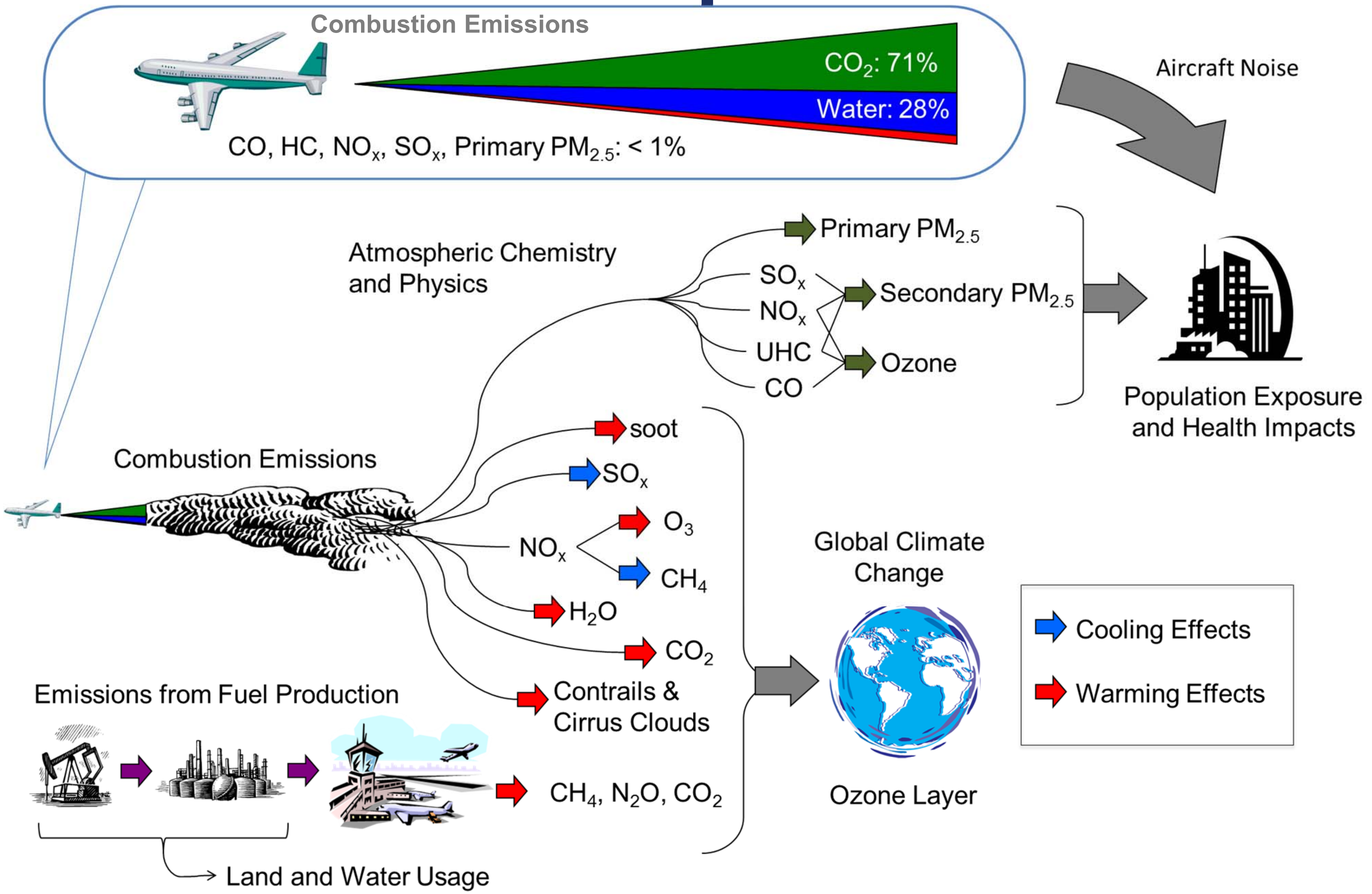
$59.9 Billion of U.S. Trade Balance (exports-imports)

SOURCE: FAA Air Traffic Organization

Aviation equipment (aircraft, spacecraft, and related equipment) is largest export sector in U.S. economy accounting for over 8% of total exports.

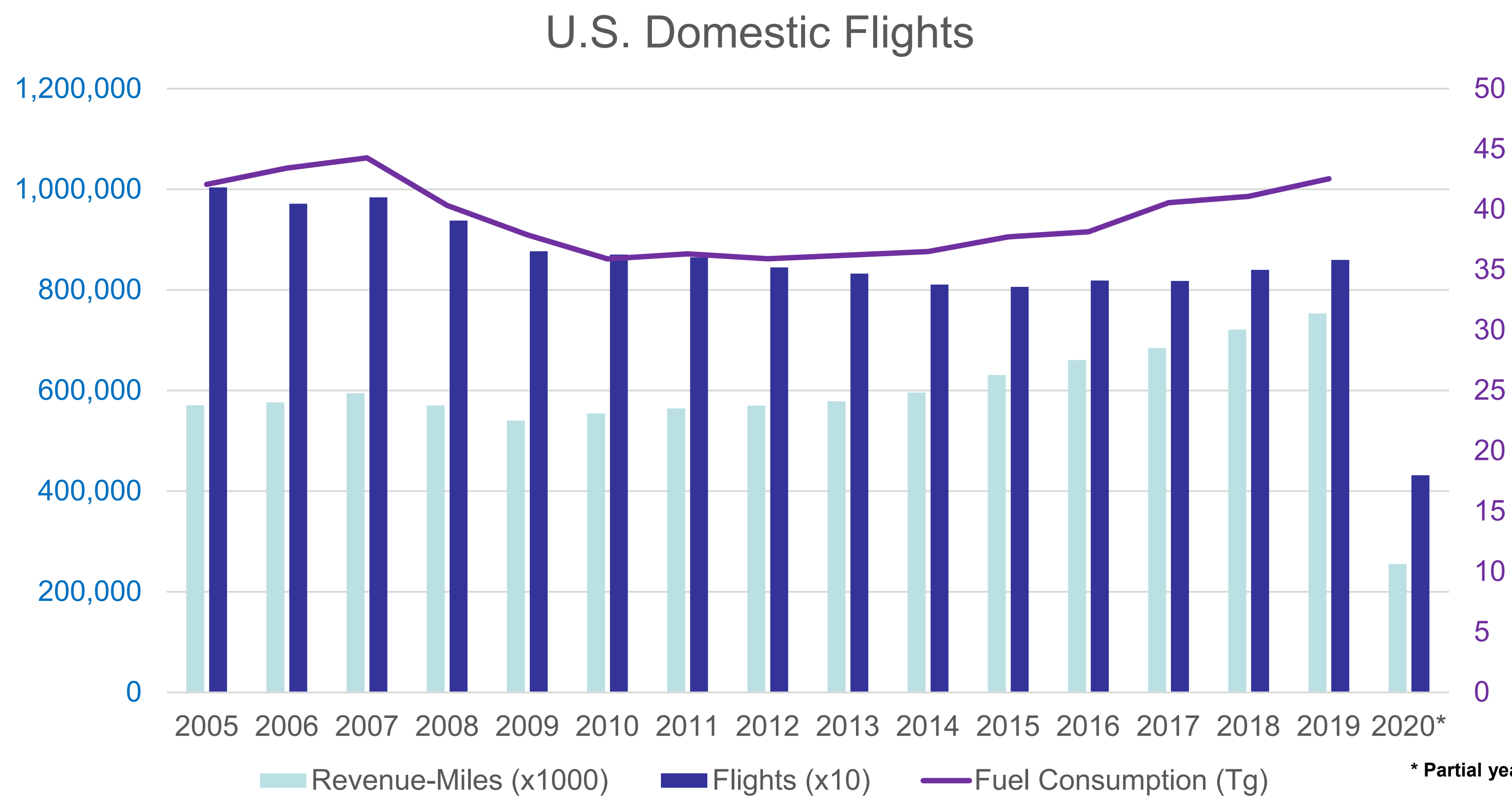
SOURCE: U.S. International Trade Commission

Environmental Impacts of Aviation



U.S. Aviation Emissions Trends

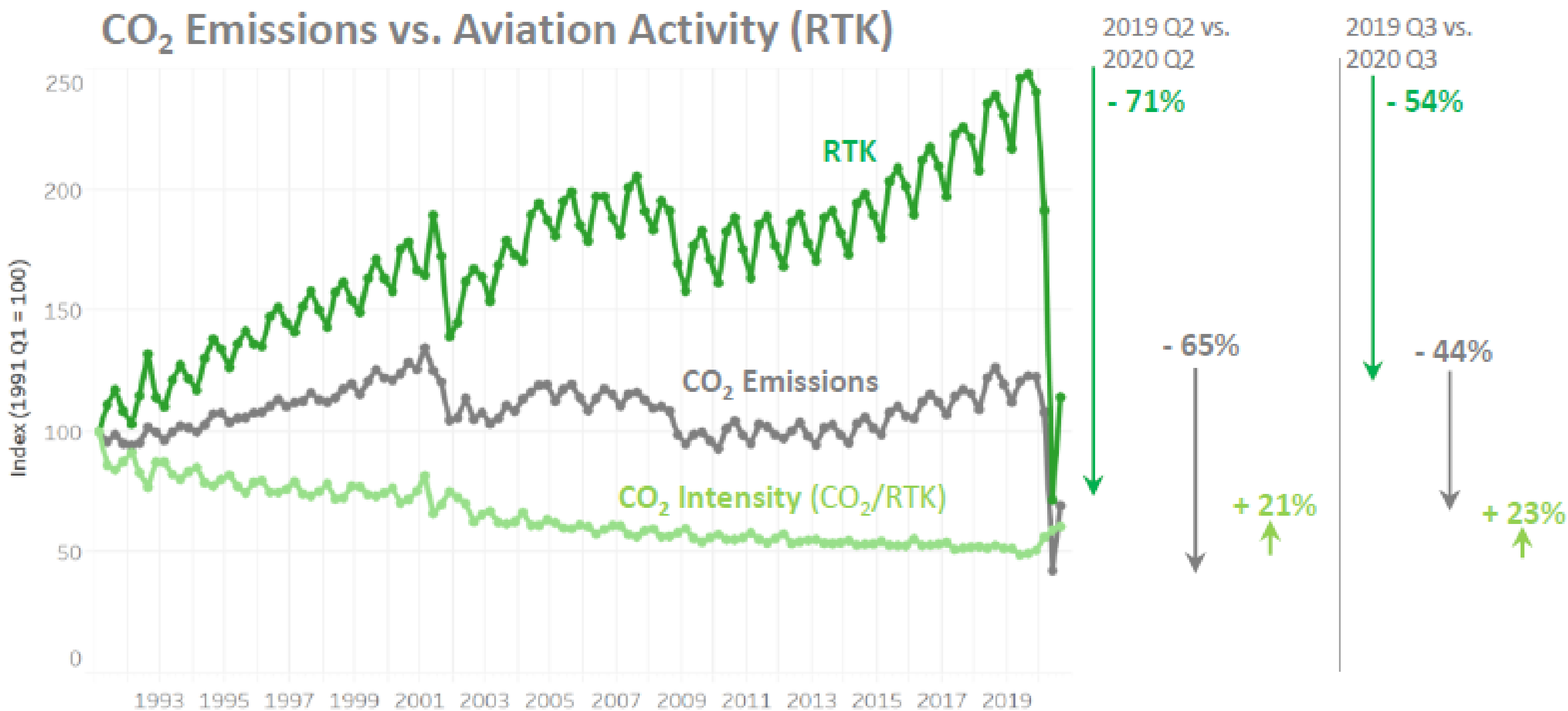
U.S. Aviation Emissions Trends



* Partial year, JAN-OCT.

SOURCE: Bureau of Transportation Statistics www.bts.gov SOURCE: EPA GHG Sources and Sinks Report www.epa.gov

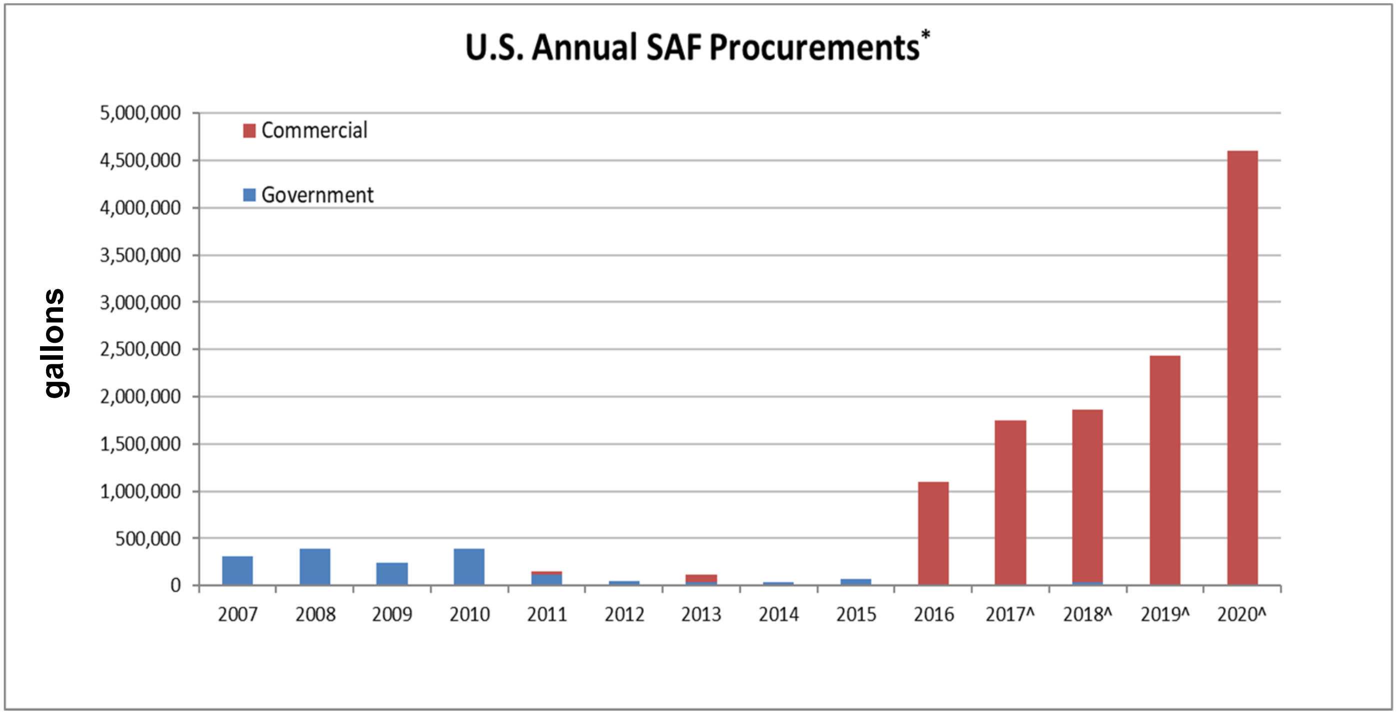
U.S. Aviation Emissions Trends



RTK = Revenue Ton Kilometers

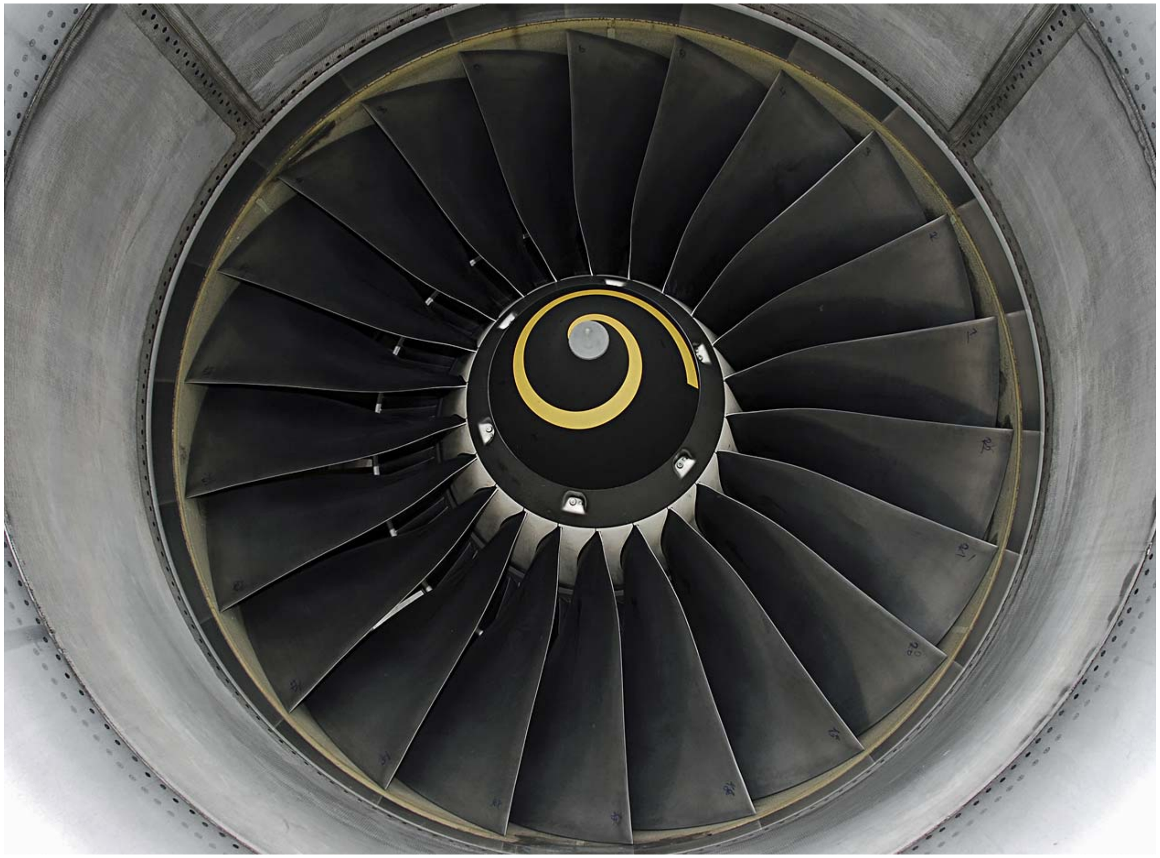
SOURCE: Bureau of Transportation Statistics www.bts.gov

Sustainable Aviation Fuel (SAF)



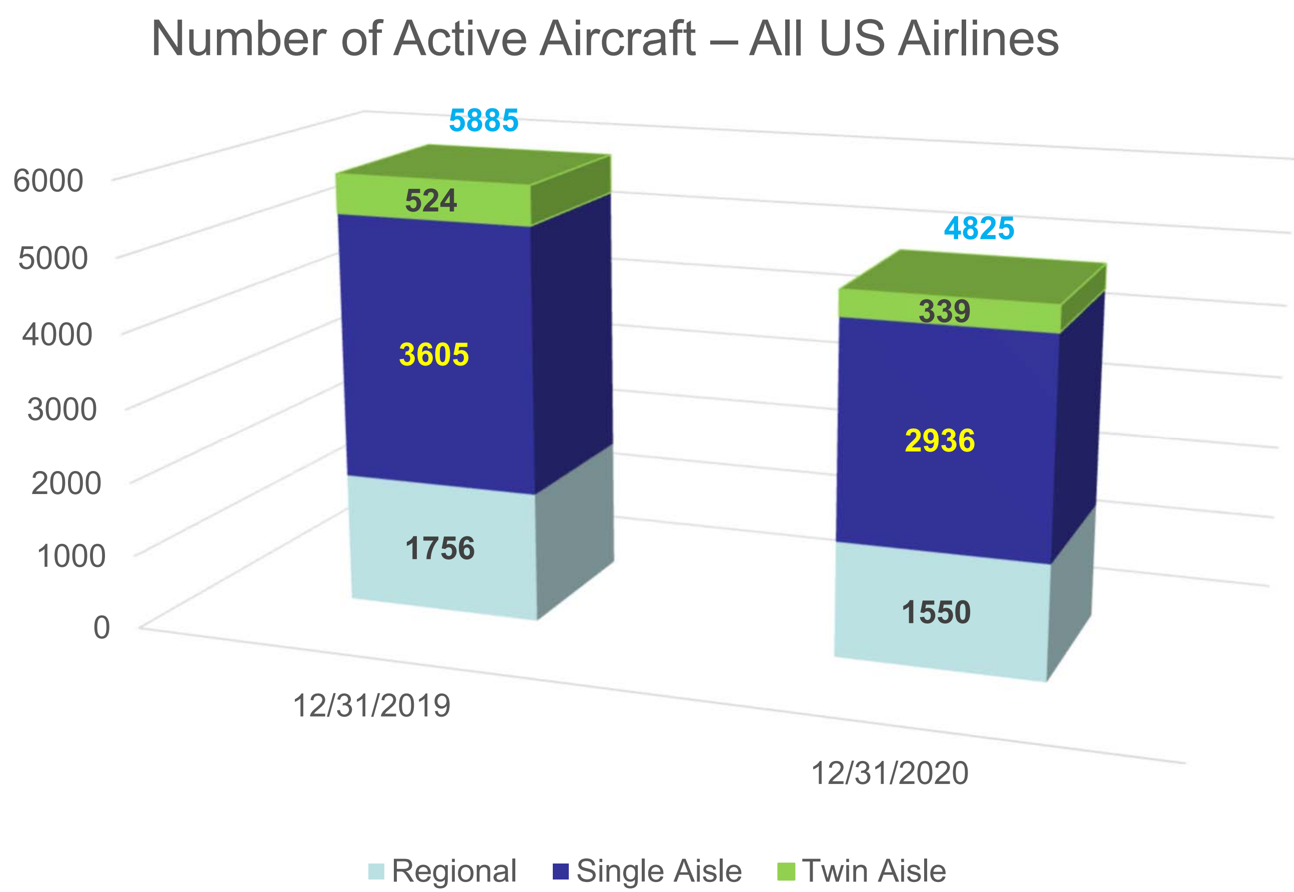
- **Five years of sustained & increasing commercial use**
- **80+% reduction in CO_2 emissions**
- **No sulfur emissions**
- **Very low particulate matter emissions**

*Reflects voluntarily reported data on use by U.S. airlines, U.S. government, manufacturers, other fuel users, and foreign carriers uplifting at U.S. airports.
^ 2017-2020 calculation incorporates data reported by EPA for RFS2 RINs for renewable jet fuel.



Fleet Mix Changes

Modern Airplanes in California?



Source: Cirium Database 2021.

Federal Aviation Administration

U.S. Regional Airplanes: Dec2019 v. Dec2020

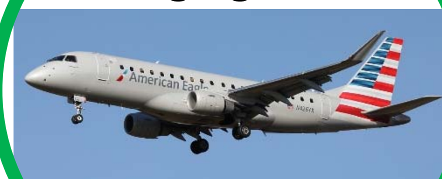
ERJ 140/145
avg age 18

-81, 33%

E170
avg age 15.5

-2, 3%

E175
avg age 5.1



+29, 6%

E190
avg age 12.7

-33, 42%

Q400
avg age 12.6

-1, 3%

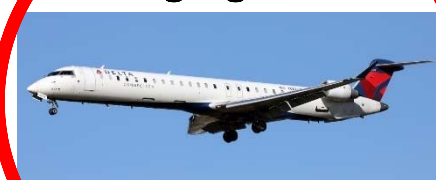
CRJ100/200
avg age 17.9

-83, 26%

CRJ700
avg age 15.1

-15, 7%

CRJ900
avg age 9.4



-20, 7%

XX = airplanes entering/leaving the fleet, YY% increase/reduction relative to total number of airplane type registered by US airlines

Source: Cirium Database 2021.

Grand Totals:
-206, 12%

U.S. Single Aisle: Dec2019 v. Dec2020

A220
avg age 1.3

+4, 14%

A319
avg age 17.1

-90, 26%

A320
avg age 13.0

-87, 15%

A321
avg age 5.3

+4, 1%

B717
avg age 19.1

-44, 41%

B737NG
avg age 11.5

-285, 16%

B737MAX +5

B757
avg age 22.7

-103, 44%

M80/90
avg age 28.6

-73, 100%

XX = airplanes entering/leaving the fleet, YY% increase/reduction relative to total number of airplane type registered by US airlines

Source: Cirium Database 2021.

Grand Totals:
-669, 19%

U.S. Twin Aisle: Dec2019 v. Dec2020

B767
avg age 23

-96, 64%

B777
avg age 15

-73, 41%

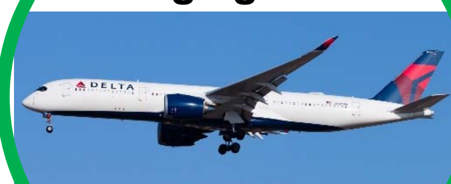
B787
avg age 9

+14, 16%

A330
avg age 20

-32, 34%

A350
avg age 2.6



+2, 15%

XX = airplanes entering/leaving the fleet, YY% increase/reduction relative to total number of airplane type registered by US airlines

Source: Cirium Database 2021.

Grand Totals:
-185, 35%

Aviation Emissions Source Reductions

Technology-based Regulations

United Nations: International Civil Aviation Organization (ICAO)

Annex 16 Volume II

Creates technology-based international standards…

United States: Environmental Protection Agency (EPA)

Sets regulatory levels…

Title 40 Code of Federal Regulations Part 87

United States: Federal Aviation Administration (FAA)

Enforces regulatory levels…

Title 14 Code of Federal Regulations Part 34

Continuous Lower Energy, Emissions & Noise (CLEEN) Program

- FAA led public-private partnership with 100% cost share from industry
- Reducing fuel burn, emissions and noise via aircraft and engine technologies and alternative jet fuels
- Conducting ground and/or flight test demonstrations to accelerate maturation of certifiable aircraft and engine technologies
- FAA in the process of finalizing the third phase of CLEEN with an announcement coming in the coming weeks…

	Phase I (Completed)	Phase II (Ongoing)
Time Frame	2010-2015	2016-2020
FAA Budget	~$125M	~$100M
Noise Reduction Goal	25 dB cumulative noise reduction cumulative to Stage 5	
Fuel Burn Goal	33% reduction	40% reduction
NO_X Emissions Reduction Goal	60% landing/take-off NO_X emissions	75% landing/take-off NO_X emissions (-70% re: CAEP/8)
Entry into Service	2018	2026

For more information on CLEEN program: http://www.faa.gov/go/cleen
CLEEN III Industry Day: https://faaco.faa.gov/index.cfm/announcement/view/32134
CLEEN III Solicitation: https://faaco.faa.gov/index.cfm/announcement/view/31885

CLEEN Phase I Technologies

Engine Core
- Boeing: Ceramic Matrix Composite Exhaust Nozzle
- GE: TAPS II Combustor
- Honeywell: Engine core efficiency technologies
- Rolls-Royce: Ceramic Matrix Composite Blade Tracks
- Rolls-Royce: Dual-Wall Turbine Airfoils

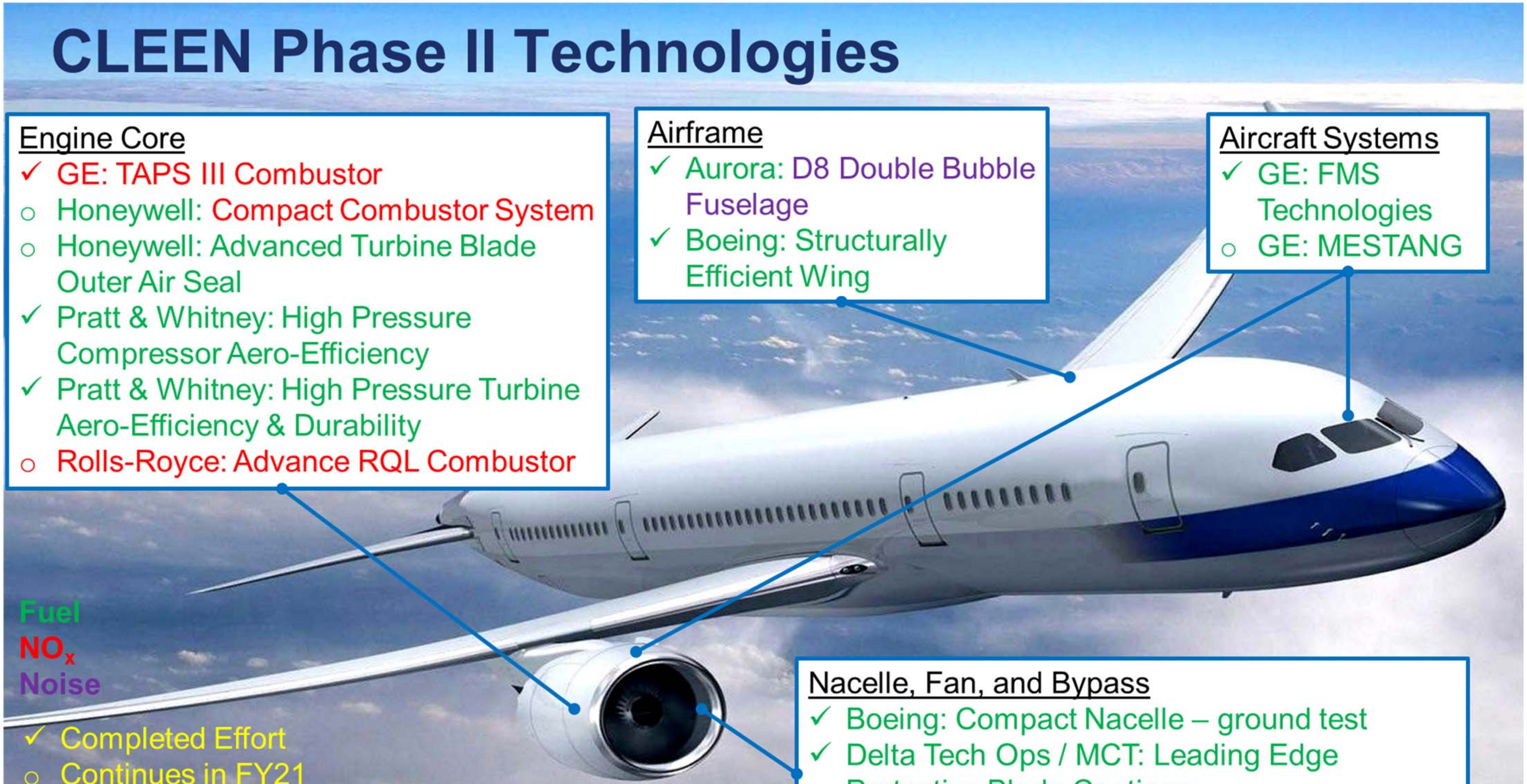
Airframe
- Boeing: Adaptive Trailing Edge

Aircraft Systems
- GE: FMS-Air Traffic and FMS-Engine Integration Technologies

Nacelle, Fan, and Bypass
- GE: Open Rotor Engine Technology
- Pratt & Whitney: Ultra-High Bypass Ratio Geared Turbofan Technologies

Fuel
NO_x
Noise
✓ Completed Effort

CLEEN Phase II Technologies



Engine Core
- ✓ GE: TAPS III Combustor
- o Honeywell: Compact Combustor System
- o Honeywell: Advanced Turbine Blade Outer Air Seal
- ✓ Pratt & Whitney: High Pressure Compressor Aero-Efficiency
- ✓ Pratt & Whitney: High Pressure Turbine Aero-Efficiency & Durability
- o Rolls-Royce: Advance RQL Combustor

Airframe
- ✓ Aurora: D8 Double Bubble Fuselage
- ✓ Boeing: Structurally Efficient Wing

Aircraft Systems
- ✓ GE: FMS Technologies
- o GE: MESTANG

Nacelle, Fan, and Bypass
- ✓ Boeing: Compact Nacelle – ground test
- ✓ Delta Tech Ops / MCT: Leading Edge Protective Blade Coatings
- o GE: Low Pressure Ratio Advanced Acoustics
- ✓ Collins Aerospace: Nacelle Technologies

Fuel
NO_x
Noise

✓ Completed Effort
o Continues in FY21

CLEEN Technologies that have entered into the fleet:

Boeing

Adaptive Trailing Edge
~ 2% fuel burn reduction
~ 1.7 EPNdB cum noise reduction in some single and twin aisles

- **Boeing has adopted technologies from this project for use in commercial and defense products.**

Delta/MDS/America's Phenix

Leading Edge Protective Coating for Turbofan Blades
~1% fuel savings for Mainline and Regional Commercial carriers

- **Currently in service in the Delta fleet for operational evaluation.**

General Electric

TAPS II Combustor
> 60% margin to CAEP/6 LTO NOx achieved.

- **CLEEN Phase I NOx goal met.**
- **Entered fleet in 2016 on all LEAP engines for Airbus A320 Neo and Boeing 737MAX**

FMS/Engine and FMS/ATM Integration
0.7-1.0% fuel burn reduction

- **Entered into service on the LEAP engine on Boeing 737MAX, Airbus A320 Neo aircraft, and soon on the GE9X engine on Boeing 777X**

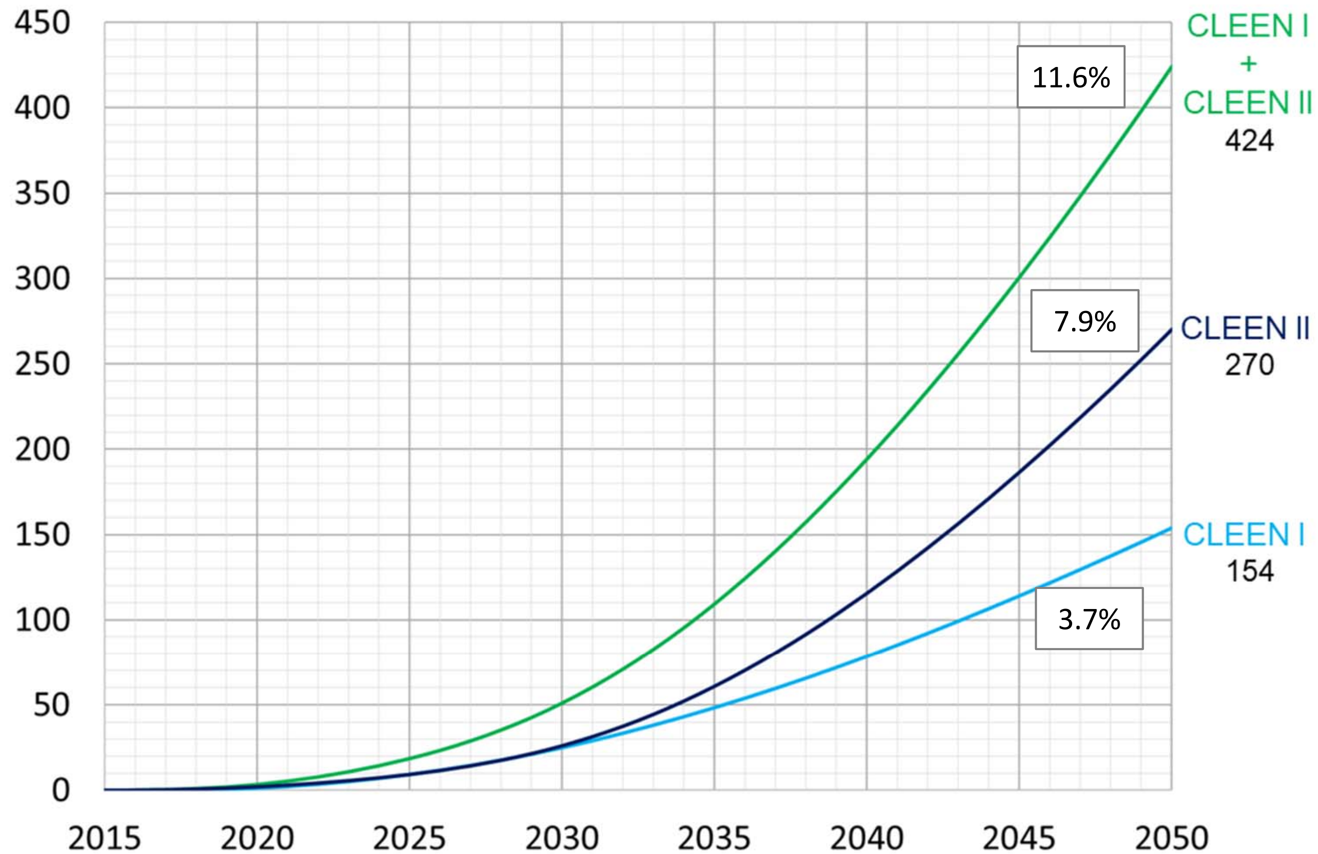
Twin Annular Pre-Swirler (TAPS) III Combustion System
~ 35% margin to the more stringent CAEP/8 (at 55 OPR) LTO NOx achieved.

- **Entering the fleet on the GE9X engine on Boeing 777X**

Improved tools and processes that have resulted from CLEEN technology maturation are leading to lower noise and emissions

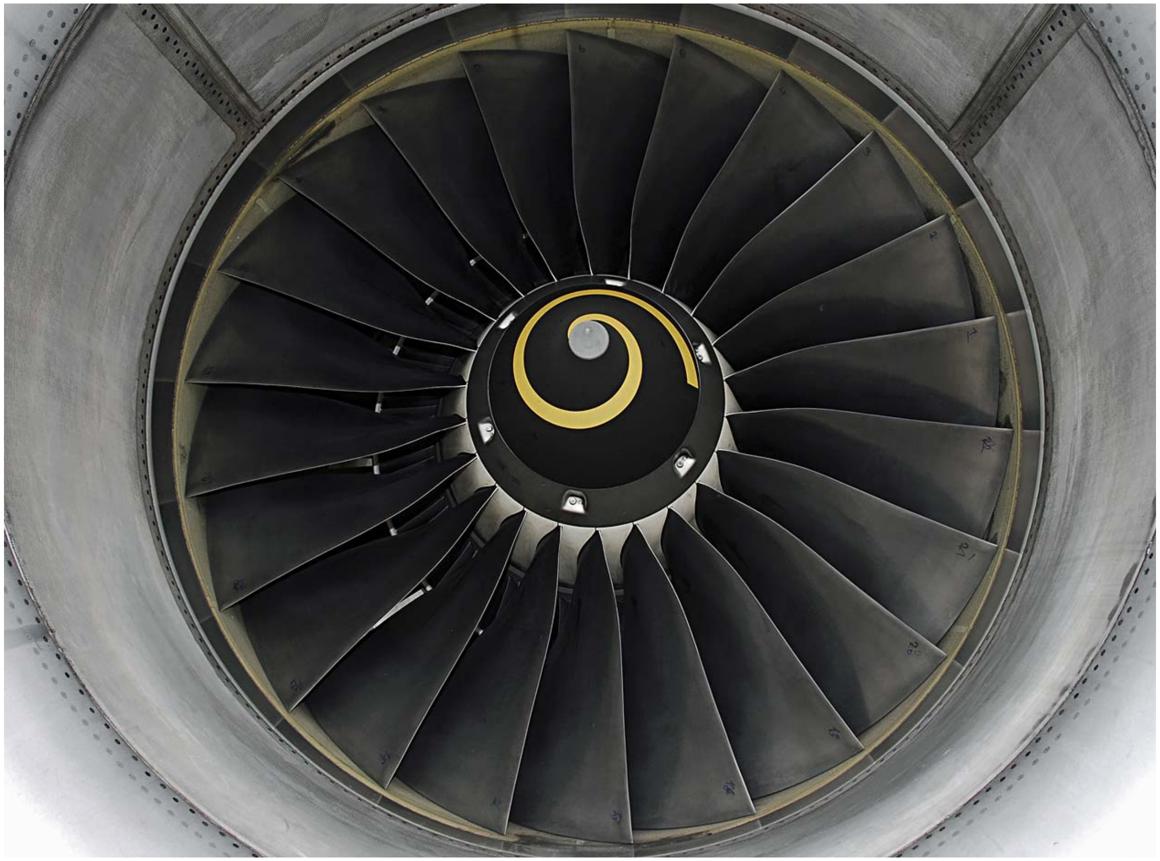
Estimated Fleet-Level CO_2 Reductions

Cumulative CLEEN CO_2 Savings relative to Evolutionary Scenario (Million Metric Tonnes)



Equivalent to removing 3.05 million cars from the road from 2020 to 2050

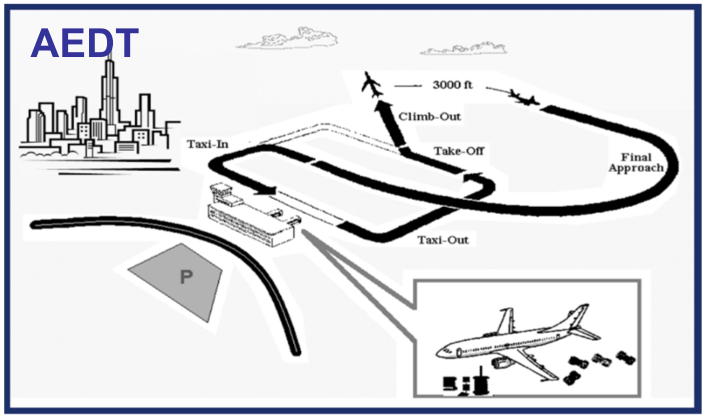
Note: Results assume a CO_2 production rate of 3.15kg CO_2/kg Fuel.
Analysis includes CLEEN Phase II fuel burn technologies modeled to date.



Aviation Emissions Tools

Aviation Environmental Design Tool (AEDT)

Global gold standard, in 46 countries



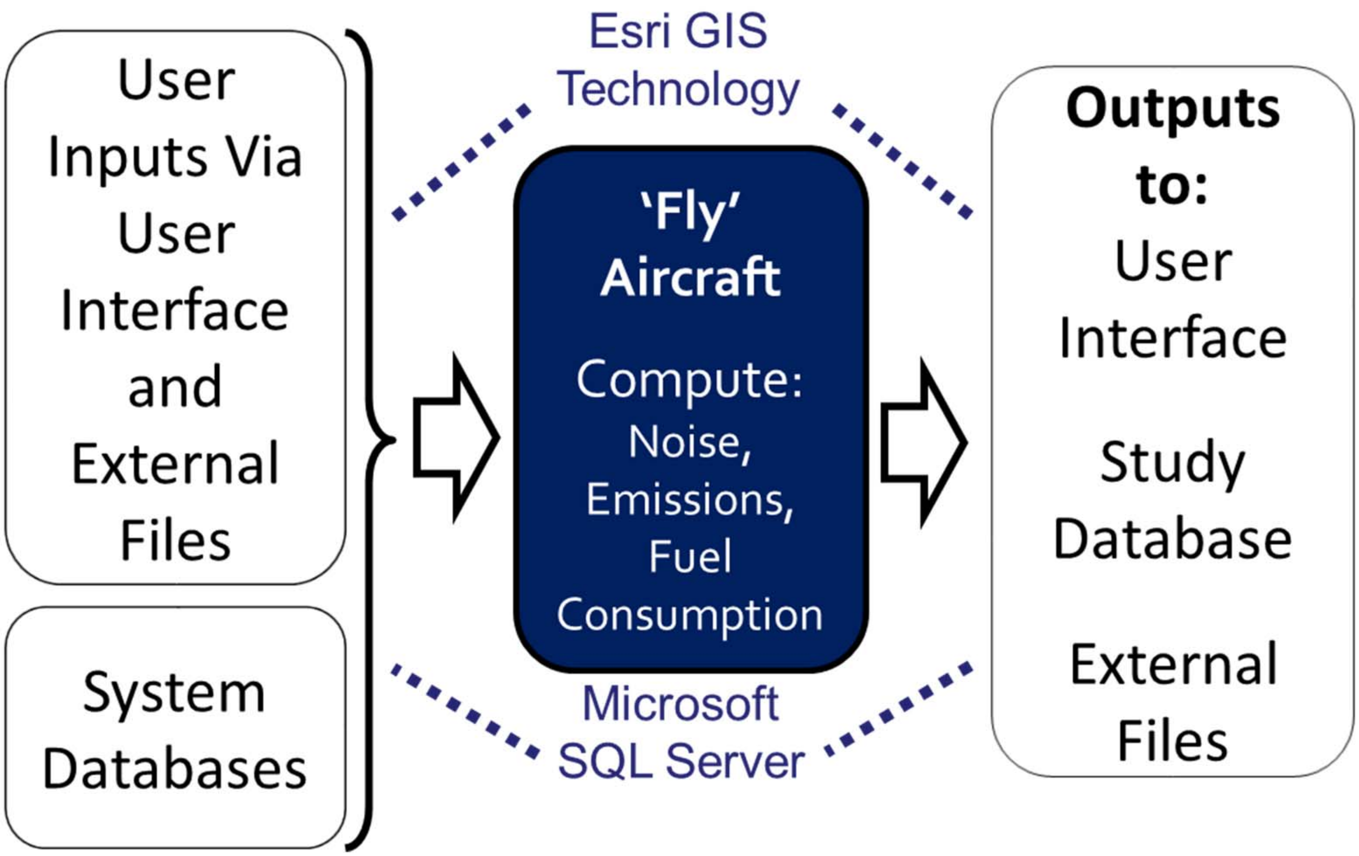
Features

- Computes noise, fuel burn, and emissions simultaneously, and local air quality
- Physics-based model – aircraft modeled in four dimensions
- Able to conduct analyses at airport, regional, national, and global scales

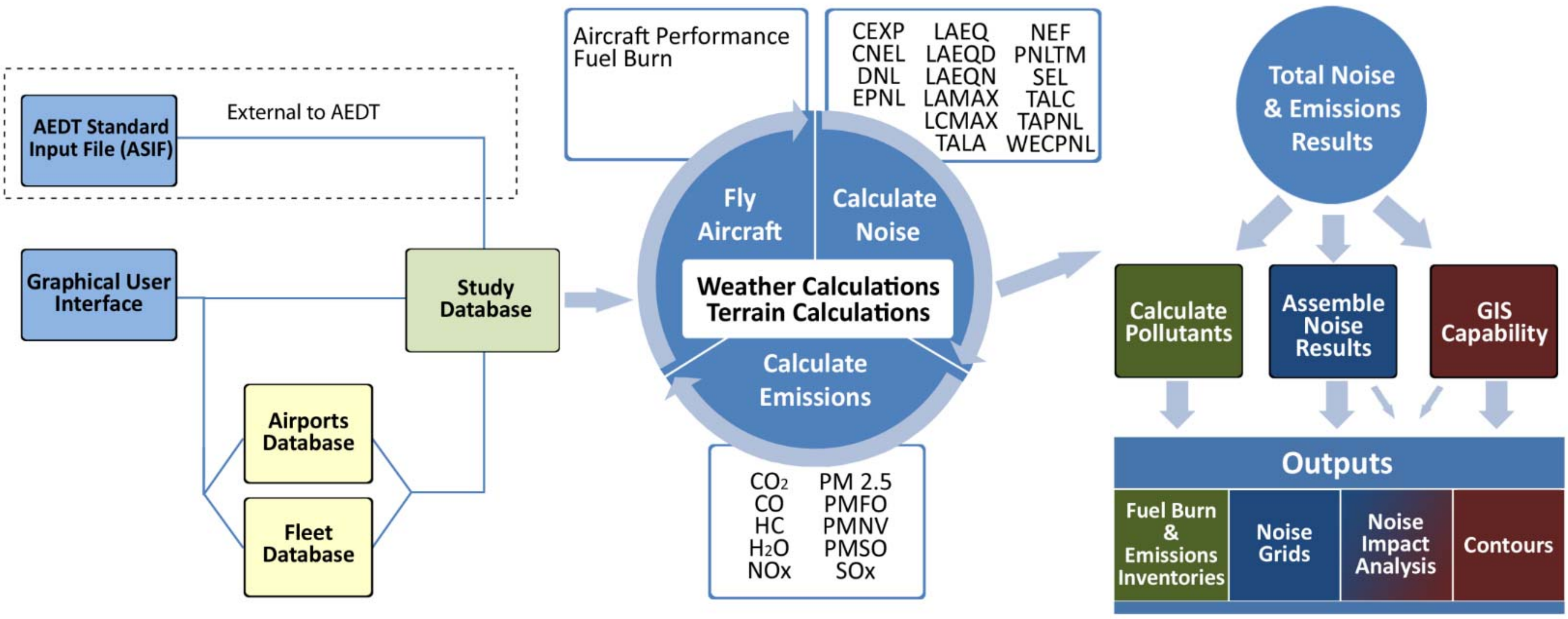
Applications

- Air space and airport design and planning (e.g., National Environmental Policy Act reviews)
- International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) analyses
- Assessing benefits from introducing NextGen and new aircraft and engine technologies (e.g., from FAA CLEEN and NASA Programs)
- Emissions Inventories – State Implementation Plans, etc.

AEDT System Overview



AEDT



External to AEDT
AEDT Standard Input File (ASIF)
Graphical User Interface
Study Database
Airports Database
Fleet Database
Aircraft Performance
Fuel Burn
CEXP CNEL DNL EPNL
LAEQ LAEQD LAEQN LAMAX LCMAX TALA
NEF PNLTM SEL TALC TAPNL WECPNL
Fly Aircraft
Calculate Noise
Weather Calculations
Terrain Calculations
Calculate Emissions
CO2 CO HC H2O NOx
PM 2.5 PMFO PMNV PMSO SOx
Total Noise & Emissions Results
Calculate Pollutants
Assemble Noise Results
GIS Capability
Outputs
Fuel Burn & Emissions Inventories
Noise Grids
Noise Impact Analysis
Contours

Summary

- FAA tracks trends in emissions and fuel burn
- Active development of cleaner & quieter technology with the CLEEN program
- COVID offers lower operations and younger, modern fleets
- AEDT is the premier tool for accurate emissions inventories

Ralph Iovinelli

Manager, Emissions Division

FAA Office of Environment and Energy
Washington, DC

ralph.iovinelli@faa.gov