Aviation Sector
Technology Assessment

September 9, 2014

Diamond Bar, California

California Environmental Protection Agency

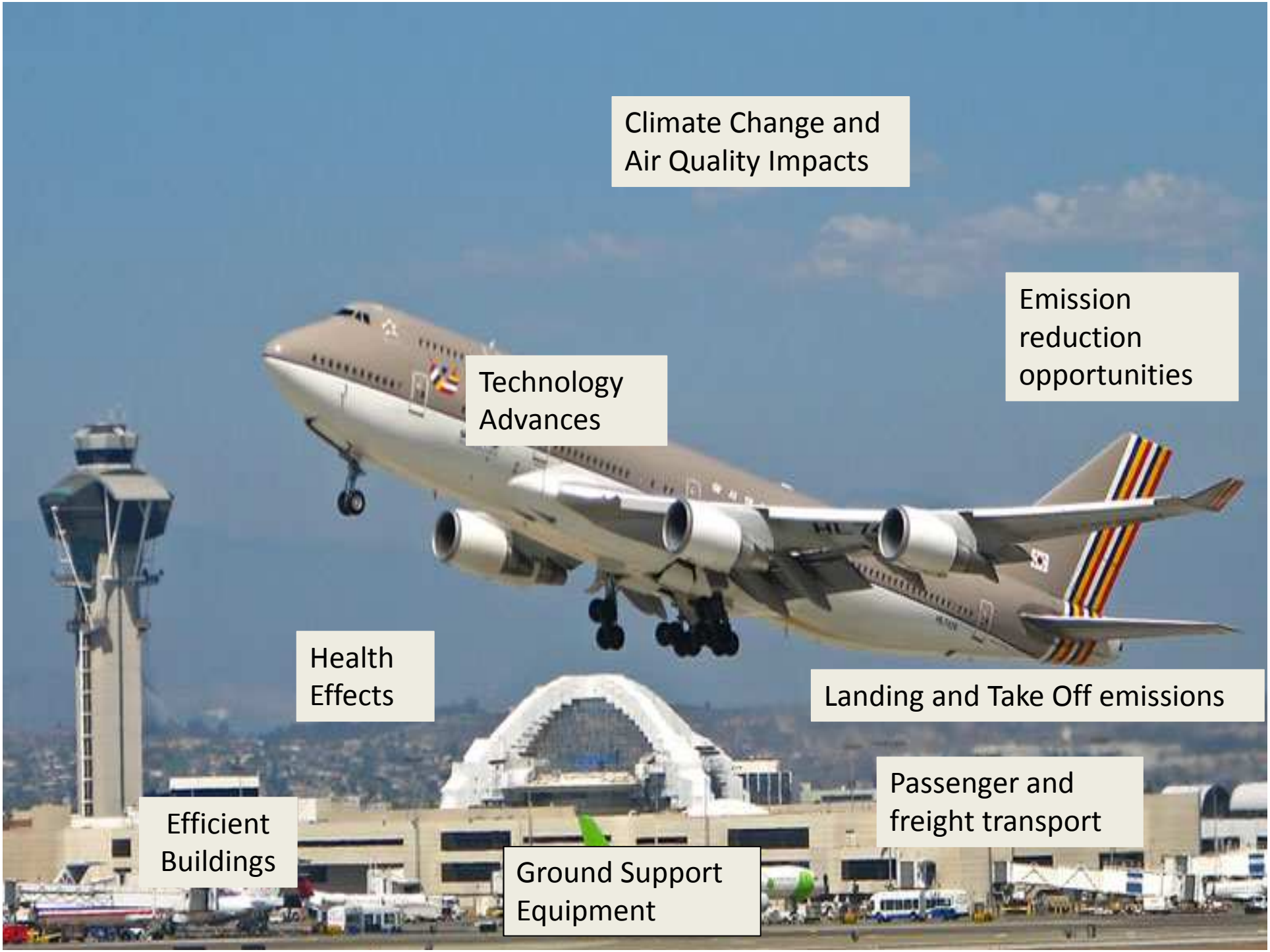
Air Resources Board

Outline

- Emission Reduction Potential
- Aviation Background Information
- Current Regulations and Future Industry Goals
- Technologies Evaluated
- Summary

Emission Reduction Potential

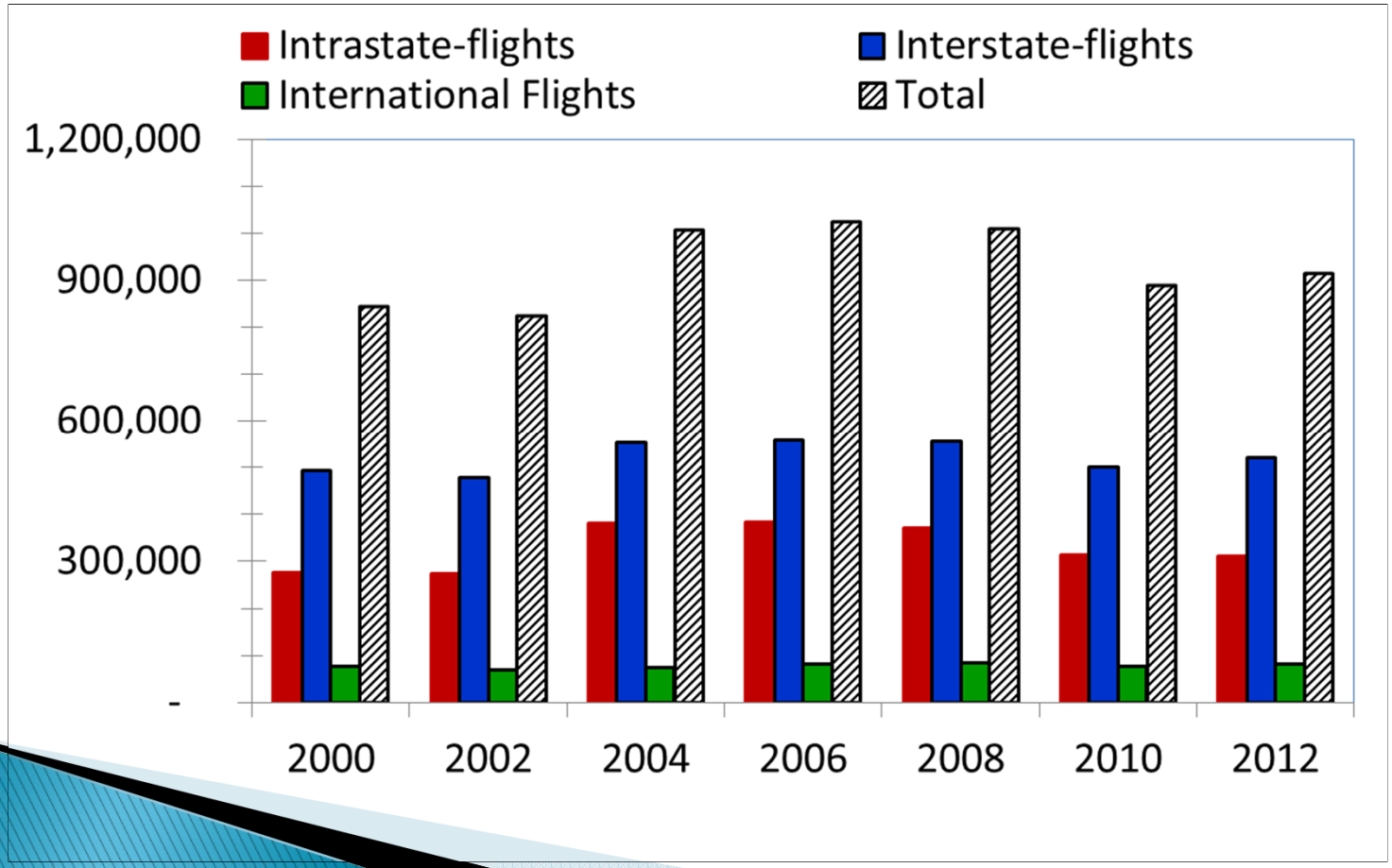
Technology Group	Benefit Estimates	Next Steps to Achieve
Aircraft Modifications	5 - 20% fuel	Development
APU-Ground Power	Typical reductions of 40 gallons/LTO	Installation
Aircraft Taxiing	Up to 85% jet fuel use on ground	Demonstration
GSE & Shuttle Transportation	Zero-emission	Demonstration & Penetration
Jet Fuel/ Renewable	5-40%	Development & Demonstration
Airport Energy Efficiency	~ 7% at some airports	Installation


Climate Change and Air Quality Impacts
Emission reduction opportunities
Technology Advances
Health Effects
Landing and Take Off emissions
Passenger and freight transport
Efficient Buildings
Ground Support Equipment

Background Information

Airport Activity in California

- 11 California (CA) airports are in the top 100 nationally
- ~ 180 million passengers travel through CA (2012)
- ~ 4 million tons of air cargo moved
- ~ 4 billion Jet Fuel , 15 million gallons aviation gasoline sold in CA



Aircraft Emission Impacts

Health and Air Quality

- Major airports are located in densely populated areas that do not meet the National Ambient Air Quality Standards.
- Lead (Pb) in AvGas is a known toxic. The Federal Aviation Administration (FAA) and the Environmental Protection Agency (EPA) are working towards unleaded AvGas certification.
- Studies conducted to quantify aircraft emissions show elevated levels of pollutants at various airports.
- Aircraft and airport related activity has shown to substantially increase ultrafine PM concentrations in neighborhoods around airports.

Aircraft Emission Impacts

Climate Change

- By 2050 carbon dioxide (CO_2) emission projections are expected to be 2.5 billion tons worldwide under 'business as usual' scenario.
- Intrastate flights = 1% of GHGs from transportation
- In addition to CO_2, NOx emissions further enhance the warming trend.
- Reductions in CO_2 are often achieved by engine fuel efficiency improvements. However, these may result in increased NOx emissions.
- To mitigate these impacts alternate sustainable fuels are currently being tested.

Aviation in California
–Economic Impact–

	Aviation Activity (direct)	Economic Activity
1	Airlines	$27.9 billion
2	Aircraft, Aircraft Engine and Parts Manufacturing	$25.3 billion
3	Airport Operations	$ 6.7 billion
4	Air Courier	$ 5.9 billion
5	General Aviation	$ 3.6 billion

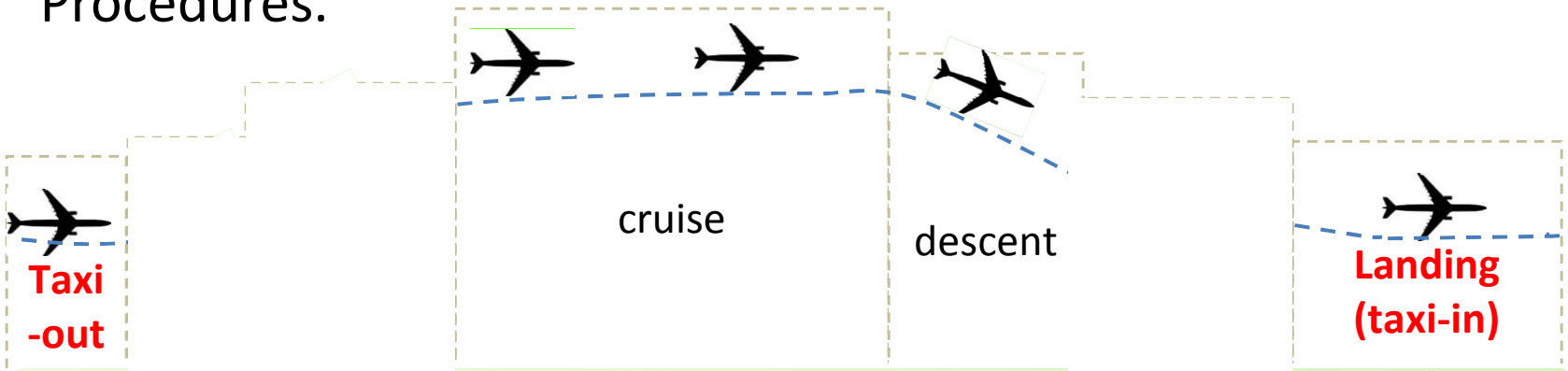
	Aviation Activity (indirect)	Economic Activity
1	Visitor Expenditures – Airlines	$82.9 billion
2	Visitor Expenditures – General Aviation	$ 1.2 billion
3	Travel Arrangements	$ 1.1 billion

Ref: http://www.faa.gov/.../FAA_Economic_Impact_Reportby_State_2011.pdf

Current Regulations And Future Goals

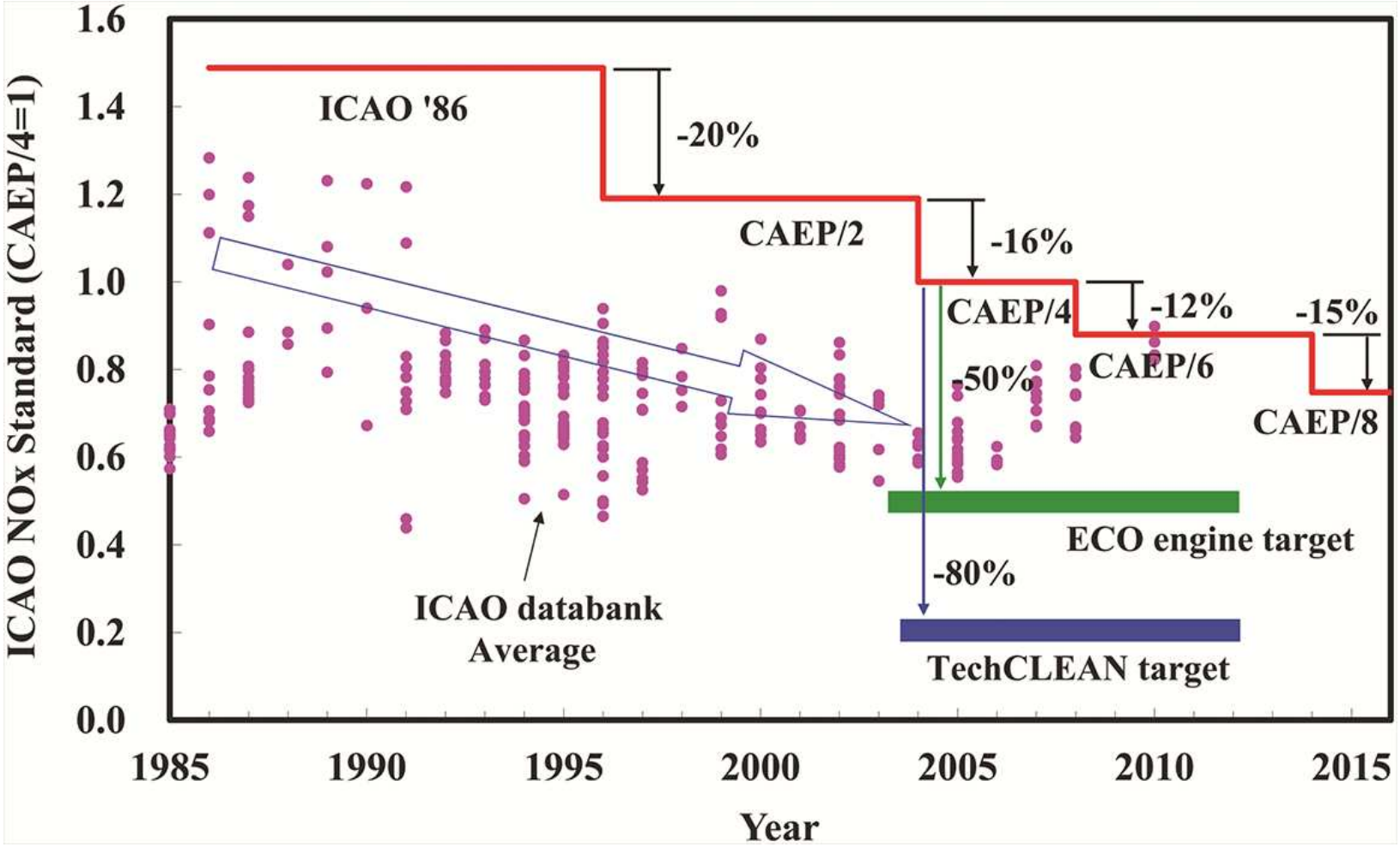
Aircraft Emission Regulations

United Nations' International Civil Aviation Organization (ICAO) and the Committee on Aviation Environmental Protection (CAEP) develop Regulations, Standards and Test Procedures.



1) 26 minute Taxi-out and Taxi-in @ 7% thrust
2) 0.7 minute takeoff @100% thrust
3) 2.2 minutes to 3000 feet at 85% thrust
4) 4 minute approach @ 30% thrust

ICAO Emission Standards



Ref: J. Eng. Gas Turbines Power 135(3), 031502, Feb 21, 2013

European Aviation Goals

Advisory Council for Aeronautics Research (ACARE)

	Goals	Technology Benefit Relative to Year 2000 for Reference Aircraft	
		By 2020	**By 2050**
1	CO2 reduction/passenger km	-50%	-75%
2	NOx reduction	-80%	-90%
			-65%
4	Taxiing		Emission free
5	Manufacturing and design		All aircraft recyclable

U.S. Aviation Goals

- The goal is to reduce noise and energy usage; improve air and water quality and minimize impact on climate change.
- FAA's Continuous Lower Energy, Emissions and Noise (CLEEN) program has developed these guidelines

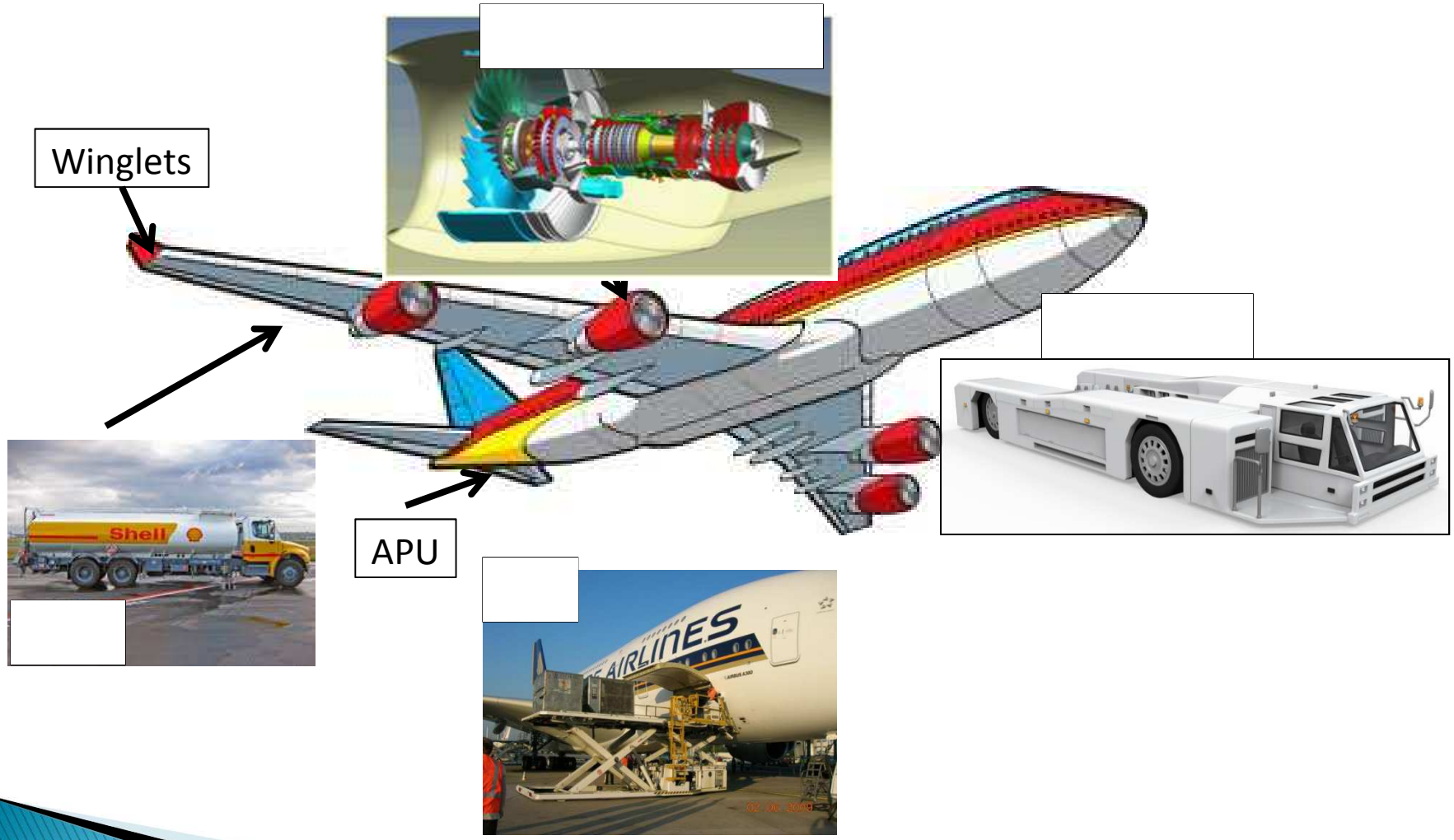
	Goals	2015 (relative to 1998)	2020-2025 (relative to 1998)	2030-2035 (relative to 2005)
1	Noise (cumulative below stage 4)	-32dB	-42dB	-71dB
2	LTO NOx Emissions (below CAEP 6)	-60%	-75%	Better than -75%
3	Aircraft Fuel Burn	-33%	-50%	Better than -70%

Technologies Evaluated

Emission Reduction Technologies

Group	Concept
Aircraft Configuration	Truss-Braced Wing/ Strut-Braced Wing, Hybrid Wing Body, Cruise Efficient Short Take-off and Landing, Morphing Airframe, Flying without landing gear
Aerodynamics	Advanced Wingtip Devices, High Lift Devices, Drag Reduction Coatings, Natural/hybrid Laminar Flow, Variable Camber with existing control surfaces, Variable Camber with new control surfaces
Structural	Active Load Alleviation, Composite Primary Structures, Composite Secondary Structures, Smart Wing Technologies, smart actuators, Morphing Wing
System	APU, Landing Gear, Flight Control System, More Electric Architecture, Zonal Dryer, Energy harvesting devices for wingtip sensors, for cabin switches, System health monitoring
Material	Glare, CentraAl (Central Reinforced Aluminum), Floropolymers, High Strength Glass Microspheres, Morphing Material, Advanced Alloys
Processes	Laser Beam Welding, Friction Stir Welding

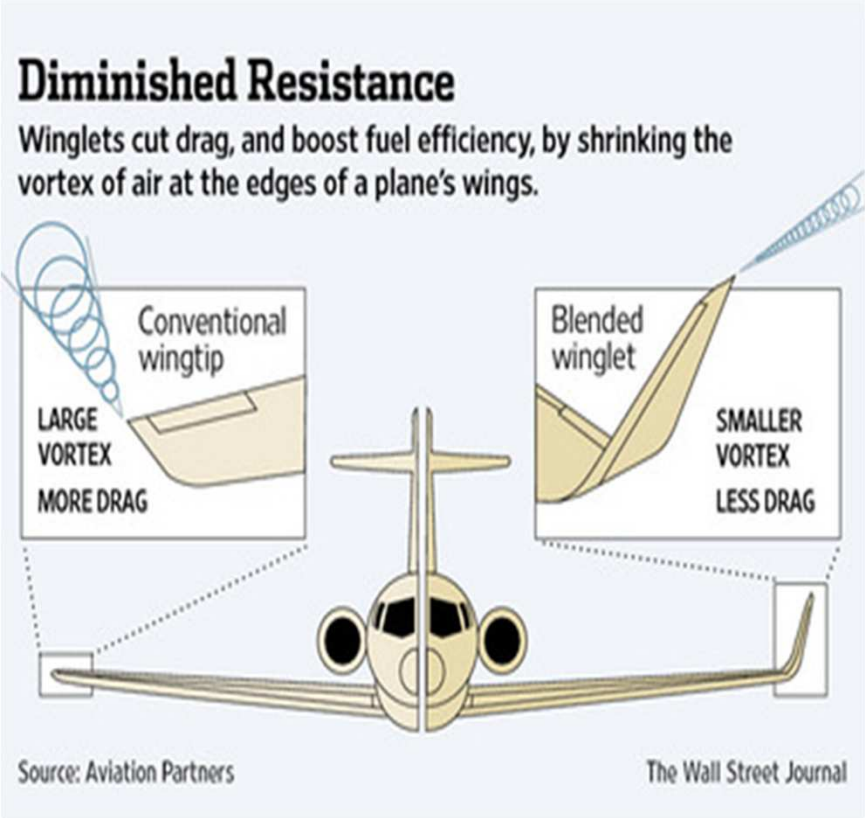
Technologies Evaluated



Aircraft Modifications

Aircraft Modification

Wingtip Devices



Approximate Emission Benefits:

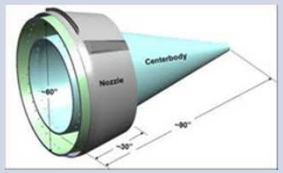
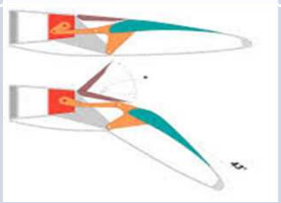
1) During Takeoff and Approach
   - 1.4 percent fuel savings
   - 6 percent noise reductions
   - 5-8 percent NOx reductions
2) Cruise Range Fuel Savings 6 percent

Current Status

- Over 5000 aircrafts are retrofitted
- Standard on most new aircrafts
- Assists in direct climb to 41,000 feet, instead of step-climb from 35,000-41,000 feet.

Aircraft Engine Emissions

Continuous Lower Energy, Emissions and Noise

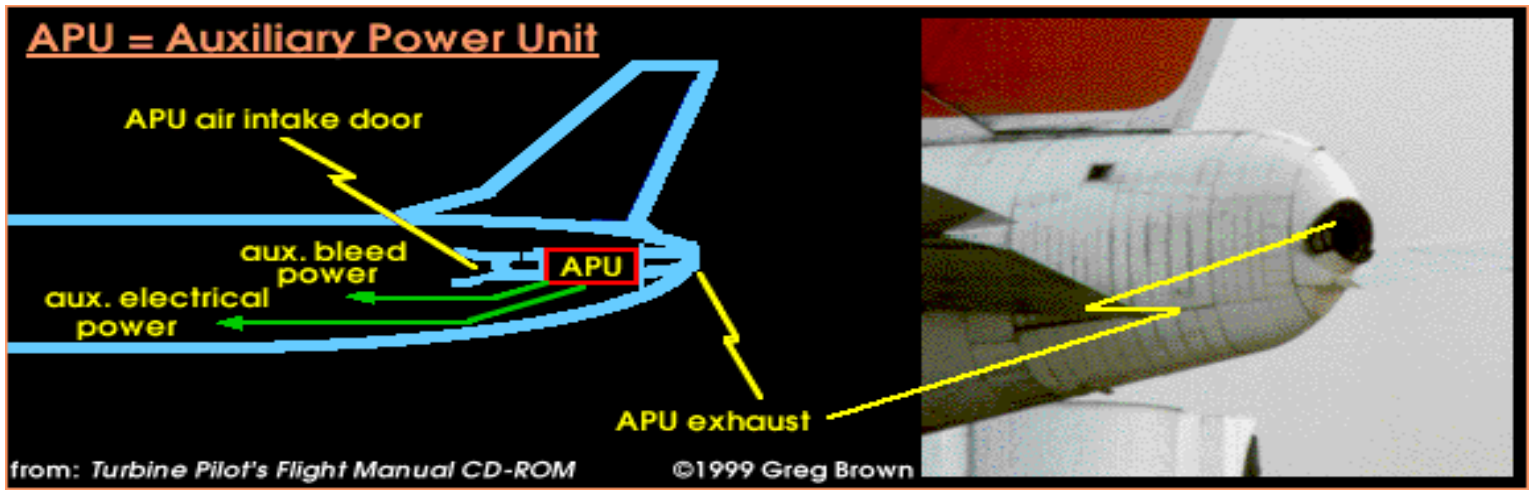
INDUSTRY	TECHNOLOGY	GOAL IMPACT
Boeing	• Ceramic Matrix • Composite Acoustic Nozzle 	Fuel-burn Noise
	Adaptable Trailing Edges 	Fuel-burn Noise
GE	Open Rotor Engine 	Fuel-burn Noise
Pratt & Whitney	Ultra-high Bypass Ratio Geared Turbo Fan 	Emissions Noise

Aircraft Engine Emissions

Technology Group	Fuel Benefits	Time Frame
Geared Turbofans	10-15%	before 2020
Open Rotor Fan	15-20%	After 2020
Very High Bypass Ratio Fan	2-6%	Before 2020
Advanced Combustor	5-10%	Before 2020
New Engine Core concepts	25-30%	After 2030

Auxiliary Power Units (APUs)

Auxiliary Power Unit



1) APU is a turbine engine
2) Installed in the tail section
3) Uses jet fuel
4) Provides power to start main engine
5) Emergency electric power to start main engine in-flight

- Provides pneumatic and electrical power to various aircraft operations
  - Flight deck and cabin lights
  - Inflight entertainment
  - Ovens, chillers
  - Preconditioned air
- Usage: 20 minutes – several hours

APU-Emission Reductions

Jet Bridge – for Power and Preconditioned Air

- APU's produce noxious emissions and fuel gas odor
- Approximately 550 liter/hour of fuel is used by a 747-400
- Noise levels can be as high as 80dB
- APU efficiency is about 10-12 percent

- Ground based equipment can provide <u>electrically driven</u> preconditioned air
- No fuel is used – therefore zero emissions at point of use
- Noise levels are low (about 70dB)
- Oakland International Airport (OAK) has installed ground power unit and preconditioned air at its gates

APU – Fuel Cell Replacement

- Airbus and Boeing have both researched
- Likely option PEM and SOFC
- Airbus has completed tests with small PEM units- Plans to test larger unit within next few years
- Requires jet fuel to hydrogen conversion
- Potential to cut ground APU fuel use by 75%
- Added potential to cut inflight non-propulsion fuel use by 40%, in sync with the More Electric Aircraft architecture
- Weight, volume and fuel sulfur are of concern

Aircraft Taxiing

Aircraft-Taxiing Emissions

Wheel Tug

Commercial aviation practice:

- Utilize a tug for aircraft pushback from gate
- Forward taxi using aircraft's engines

Electric Wheel Tug:

1) Drives the aircraft with use of APU, not jet engines.
2) Eliminates the use of airport tow tugs and jet engines
3) Allows faster flight turnarounds, increasing fuel efficiency/trip
4) Reduces aircraft noise and emissions at airports
5) Adds approx. 300lbs – Impacts fuel savings for longer flights
6) Boeing has successfully tested it

Fuel Cell Wheel Tug:

- First tested by DLR Airbus A320
- ~17 percent emission reduction at airports
- Eliminating all noise during taxiing

Aircraft-Taxiing Emissions

Electric Wheel Tug with APU Power

Ref: www.wheeltug.gi

Aircraft-Taxiing Emissions

TaxiBot

- Currently TaxiBots uses diesel engines (~700 HP total power for narrow-body taxiing)
- A TaxiBot slides under the aircraft nose wheel. There are no motors or equipment that needs to go on the jet
- TaxiBot could cut up to 85 percent of the ground activity jet fuel burn
- Certification testing completed on B737 in Frankfurt
- Wide-body plane prototype built

Ground Support Equipment (GSE)

Ground Support Equipment

Common Types of GSE at Airports

Equipment	Function	Fuel Type(s)
Baggage Tug	Tow baggage carts	Gasoline, Electric
Aircraft Tug/Tractor	Tow and push aircraft	Diesel, Electric
Cargo Container Loader	Large container	Gasoline, Diesel, Electric
Baggage Belt Loader	Mobile conveyor	Gasoline, Diesel, Electric
Ground Power Unit	Mobile generator for parked aircraft	Diesel
Other (trucks, lifts, carts etc.)	Maintenance, power, air conditioning, etc.	Gasoline, Diesel, Electric

Ground Support Equipment

GSE – Regulations and Incentive Programs

- Engine Standards
  - Tier 4 off-road compression ignition engine
  - Off-Road large park ignition (LSI) engine
- Fleet Rules
  - In-use Off-Road Diesel Fleet Regulation
  - LSI Engine Fleet Rule
  - Portable Air Toxic Control Measure

Incentive Programs

- Carl Moyer Program
- Voluntary Airport Low Emissions Program
- National Clean Diesel Emissions Reduction Program
- Energy Efficiency and Renewable Energy program

GSE–Zero Emission Alternative

Some Electric Options at Los Angeles International Airport (LAX) (2013)

Type of GSE	Total at LAX	% Electric
Baggage Tug	650	46
Belt Loader	259	60
Cargo Tractor	247	65
Carts	139	94

Challenges to Electrification

- Duration of operation
- Distance
- Load
- Topography at point of use

Future

- Some diesel GSE can be retrofitted to electric
- Industry is looking into feasibility of fuel cell GSE

GSE–Zero Emission Alternative

Fuel Cell –GSE Demonstration Project

A baggage Tow Tractor is being developed with partial funding from Department Of Energy and partnering with

- Plug Power Incorporated – Development of 80V fuel cell
- Charlatte America – baggage tow tractor
- Nuvera –for Hydrogen power
- FedEx Express –Client for their operations at

  Memphis International Airport (Tennessee)

  Oakland International Airport (CA)

Airport Ground Transportation

Airport Ground Transportation

Airport Shuttle Buses:

- Short Range travel – between terminal and parking lots
- Often owned by airport authority (regulated under CCR Sections 2020, 2022 and 2022.1)
- Some airports contract with independent operators requiring a certain percentage of the fleet to be 'alternate fuel'
- Typical fuel used:
  - Diesel,
  - CNG

Airport Actions to Reduce Emissions

At LAX

- All Shuttles owned by Los Angeles World Airports are CNG
- Plans to consolidate hotel shuttles into a single shared system

At OAK

- Alt Fuel Fleet since 1999
- Requires 50 percent of taxi cabs, shuttles, vans and buses to use alt fuel
- In the process of replacing diesel AirBART by CNG

At SFO

- Clean vehicle policy in 2000 (SFO)
- AirTrain people mover (hydro-electricity)
- BART near zero electric rail system

(Ref: http://www.marketwired.com/ (Jan 14, 2010)

Hybrid Electric Buses

- Airport shuttle buses operate similarly to transit buses
- Many hybrid electric transit bus demonstrations and fleet introductions since early 2000's

- Ideal for highly transient, high-power applications
- Improved fuel economy
- Emissions need to be carefully scrutinized for potentially negative impacts on NOx

Battery Electric Buses

- Best for defined routes with many stops and starts, idle periods, and low speeds
- Fixed routes of airport shuttles with scheduled stops allow for recharging
- Quieter and less vibration than conventional diesel
- Higher initial capital cost with potential for operational savings
- Limited range
- Frequent charging time

- Schiphol – Amsterdam (2013) airport shuttle demonstration
- CA transit agencies already introducing technology into fleets

Fuel Cell Electric Buses

- Range comparable to conventional diesel
- Zero tailpipe GHG and criteria pollutant emissions
- Costs higher than battery electric or conventional diesel
- Current hydrogen fueling infrastructure limited

Airport Demonstrations

- Munich Airport, Germany (2004)
- Centair Airport, Japan (2006)
- Haneda Airport, Japan (2011)
- Logan Airport, Boston (planned)

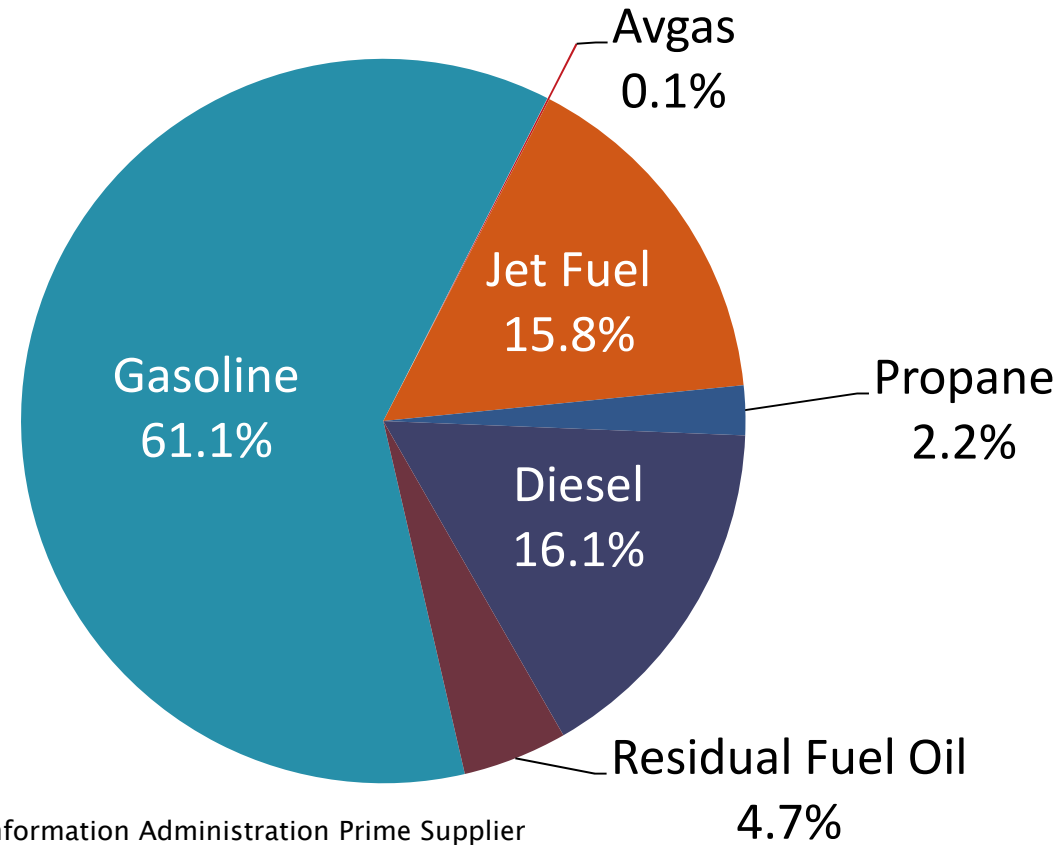
Transit Bus Demonstrations

- Zero Emission Bay Area (ZEBA) Oakland, CA
- SunLine Transit Thousand Palms, CA

Aircraft Fuels

Aviation Fuels

2012 EIA Reported CA Fuel Supply Sales Volume



Source: U.S. Energy Information Administration Prime Supplier Sales Volume

American Society for Testing and Materials (ASTM) Alternative Fuel Approval

Drop-In Fuels Process Approved by ASTM D7566:

- Fischer-Tropsch (2009)
- Hydroprocessed Esters and Fatty Acids (2011)
- Synthesized Iso-Paraffin approved (2014)

Other Processes (under consideration):

- Alcohol to Jet Synthetic Paraffin Kerosene
- FT Synthetic Paraffinic Kerosene with Aromatics
- Hydroprocessed Depolymerized Cellulosic Jet

Fuel Industry and Sustainability

- Boeing is actively working on renewable fuel for its engines
- Airbus has tested some renewable fuels on over 1,500 commercial flights worldwide
- Feedstock sustainability work
  - Spain has certified Biojet Fuel Feedstock
  - Aviation Sustainable Biofuels Initiative started in the Midwest
  - Brazil is developing a Biofuels Platform
- Commercial flight examples
  - United flight from Houston to Chicago in 2011
  - KLM weekly flights from New York to Amsterdam in 2013
  - Brazilian Airline (GOL) flights during 2014 World Cup

Biojet fuel Flights Out of LAX

- United Airlines scheduled to operate flights out of LAX this year
- Purchasing 15M gallons of HEFA
- Operation to last 3 years – 5M gallons/year
- AltAir Fuels is the supplier
  - Retrofitting a pre-existing refinery
  - Located in Los Angeles
  - Expected production capability: Up to 30 million gallons renewable diesel and jet fuel per year

Airport Energy Efficiency

Airport Building Infrastructure

Airport Authorities are taking various steps to reduce their carbon foot print and maximize the energy savings

Some Actions:

- Installing light emitting diodes (LED) taxiways
- Energy efficient heating, ventilation and air-conditioning
- Replacing fluorescent and halide lights with compact fluorescent lights or LED
- Installing voltage regulators and usage monitors on escalators and automated walkways
- Solar energy harvesting

Airport Actions to Reduce Emissions

At LAX

- Implemented measures: 7%/passenger or $150,000/year
- Green power consumed: ~ 13% or 30,000 MWh

At OAK

- Proposed HVAC estimated savings of $500,000/year
- Solar panel energy generated: ~ 1,000 MWh/year

At SFO

- Proposed HVAC measures: $6.1 million/year
- Implemented measures: 12% or 11,000 MWh/year
- Solar panel energy generated: 750 MWh/year
- Electric infrastructure reductions of 6.3%

Summary
Emission Reduction Potential

Technology Group	Conclusions
Aircraft Modifications	• Good potential for large efficiency/emissions benefits but long time for development and fleet penetration • National and International goals prompting research and development
APU-Ground Power	• Technology for bridge-power is available • Significant potential to displace fuel use and NOx emissions on ground
Aircraft Taxiing	• Technology deployment is promising • Significant potential to decrease jet engine emissions on ground

Summary
Emission Reduction Potential

Technology Group	Conclusions
GSE & Shuttle Transportation	• Significant potential for GHG reductions and zero-emission technology • Captive fleet/Low mileage makes it a promising vocation for use of clean technologies
Jet Fuel/ Renewable	• Fuels are currently being certified and demonstrations are occurring • Significant opportunity for emission benefits
Airport Energy Efficiency	• Technologies exist to increase airport efficiency

QUESTIONS?

Thank you

Contacts

- Aviation Sector Manager:
  - Dave Salardino dsalardi@arb.ca.gov (626-575-6679)
- Aviation Sector Lead:
  - Sulekha Chattopadhyay schattop@arb.ca.gov (626-459-4420)
- Team Members:
  - Dinh Quach dquach@arb.ca.gov
  - Neva Lowery nlowery@arb.ca.gov
  - Rhonda Runyon rrunyon@arb.ca.gov
  - Thomas Lovejoy tlovejoy@arb.ca.gov