Aviation Sector
Technology Assessment

September 9, 2014
Diamond Bar, California
Outline

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

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

Technology Advances

Climate Change and Air Quality Impacts

Emission reduction opportunities

Passenger and freight transport

Landing and Take Off emissions

Ground Support Equipment

Efficient Buildings
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 (CO₂) 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 CO₂, NOx emissions further enhance the warming trend.
• Reductions in CO₂ 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–

<table>
<thead>
<tr>
<th>Aviation Activity (direct)</th>
<th>Economic Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Airlines</td>
<td>$27.9 billion</td>
</tr>
<tr>
<td>2 Aircraft, Aircraft Engine and Parts Manufacturing</td>
<td>$25.3 billion</td>
</tr>
<tr>
<td>3 Airport Operations</td>
<td>$ 6.7 billion</td>
</tr>
<tr>
<td>4 Air Courier</td>
<td>$ 5.9 billion</td>
</tr>
<tr>
<td>5 General Aviation</td>
<td>$ 3.6 billion</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aviation Activity (indirect)</th>
<th>Economic Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Visitor Expenditures – Airlines</td>
<td>$82.9 billion</td>
</tr>
<tr>
<td>2 Visitor Expenditures – General Aviation</td>
<td>$ 1.2 billion</td>
</tr>
<tr>
<td>3 Travel Arrangements</td>
<td>$ 1.1 billion</td>
</tr>
</tbody>
</table>

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.

Technology Assessment aims at understanding emission reduction opportunities for these zones

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

## European Aviation Goals

**Advisory Council for Aeronautics Research (ACARE)**

<table>
<thead>
<tr>
<th>Goals</th>
<th>Technology Benefit Relative to Year 2000 for Reference Aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>By 2020</td>
</tr>
<tr>
<td>1 CO2 reduction/passenger km</td>
<td>-50%</td>
</tr>
<tr>
<td>2 NOx reduction</td>
<td>-80%</td>
</tr>
<tr>
<td>3 Noise reduction</td>
<td>-50%</td>
</tr>
<tr>
<td>4 Taxiing</td>
<td></td>
</tr>
<tr>
<td>5 Manufacturing and design</td>
<td></td>
</tr>
</tbody>
</table>


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.

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<tr>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Noise (cumulative below stage 4)</td>
<td>-32dB</td>
<td>-42dB</td>
<td>-71dB</td>
</tr>
<tr>
<td>2</td>
<td>LTO NOx Emissions (below CAEP 6)</td>
<td>-60%</td>
<td>-75%</td>
<td>Better than -75%</td>
</tr>
<tr>
<td>3</td>
<td>Aircraft Fuel Burn</td>
<td>-33%</td>
<td>-50%</td>
<td>Better than -70%</td>
</tr>
</tbody>
</table>
Technologies Evaluated
# Emission Reduction Technologies

<table>
<thead>
<tr>
<th>Group</th>
<th>Concept</th>
</tr>
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<tbody>
<tr>
<td>Aircraft Configuration</td>
<td>Truss-Braced Wing/ Strut-Braced Wing, Hybrid Wing Body, Cruise Efficient Short Take-off and Landing, Morphing Airframe, Flying without landing gear</td>
</tr>
<tr>
<td>Aerodynamics</td>
<td>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</td>
</tr>
<tr>
<td>Structural</td>
<td>Active Load Alleviation, Composite Primary Structures, Composite Secondary Structures, Smart Wing Technologies, smart actuators, Morphing Wing</td>
</tr>
<tr>
<td>Material</td>
<td>Glare, CentraAl (Central Reinforced Aluminum), Floropolymers, High Strength Glass Microspheres, Morphing Material, Advanced Alloys</td>
</tr>
<tr>
<td>Processes</td>
<td>Laser Beam Welding, Friction Stir Welding</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>INDUSTRY</th>
<th>TECHNOLOGY</th>
<th>GOAL IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing</td>
<td>• Ceramic Matrix</td>
<td>Fuel-burn</td>
</tr>
<tr>
<td></td>
<td>• Composite Acoustic Nozzle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adaptable Trailing Edges</td>
<td>Fuel-burn, Noise</td>
</tr>
<tr>
<td>GE</td>
<td>Open Rotor Engine</td>
<td>Fuel-burn, Noise</td>
</tr>
<tr>
<td>Pratt &amp; Whitney</td>
<td>Ultra-high Bypass Ratio Geared Turbo Fan</td>
<td>Emissions, Noise</td>
</tr>
</tbody>
</table>


# Aircraft Engine Emissions

<table>
<thead>
<tr>
<th>Technology Group</th>
<th>Fuel Benefits</th>
<th>Time Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geared Turbofans</td>
<td>10-15%</td>
<td>before 2020</td>
</tr>
<tr>
<td>Open Rotor Fan</td>
<td>15-20%</td>
<td>After 2020</td>
</tr>
<tr>
<td>Very High Bypass Ratio Fan</td>
<td>2-6%</td>
<td>Before 2020</td>
</tr>
<tr>
<td>Advanced Combustor</td>
<td>5-10%</td>
<td>Before 2020</td>
</tr>
<tr>
<td>New Engine Core concepts</td>
<td>25-30%</td>
<td>After 2030</td>
</tr>
</tbody>
</table>
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 electrically driven 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
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

Savings = $700/flight
Annual Savings ~ $1.1 million/aircraft

Ref: www.wheeltug.gi
Aircraft–Taxiing Emissions

**TaxiBot**

- Currently TaxiBots use 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

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

<table>
<thead>
<tr>
<th>Type of GSE</th>
<th>Total at LAX</th>
<th>% Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baggage Tug</td>
<td>650</td>
<td>46</td>
</tr>
<tr>
<td>Belt Loader</td>
<td>259</td>
<td>60</td>
</tr>
<tr>
<td>Cargo Tractor</td>
<td>247</td>
<td>65</td>
</tr>
<tr>
<td>Carts</td>
<td>139</td>
<td>94</td>
</tr>
</tbody>
</table>

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

- Gasoline 61.1%
- Jet Fuel 15.8%
- Diesel 16.1%
- Residual Fuel Oil 4.7%
- Avgas 0.1%
- Propane 2.2%

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 footprint 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

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<thead>
<tr>
<th>Technology Group</th>
<th>Conclusions</th>
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</thead>
</table>
| 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

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

Thank you
Contacts

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