CALIFORNIA
AIR RESOURCES BOARD

3rd Public Workshop
Statewide Clean Aviation Initiative (SCAI)

October 27, 2026

Workshop Instructions

- Telephone Call-In: (855) 758-1310 (US Toll Free)
- Access Code: 480496
- Workshop is being recorded
- Slides and recording will be available on CARB's Statewide Clean Aviation Initiative (SCAI) webpage

Workshop Questions

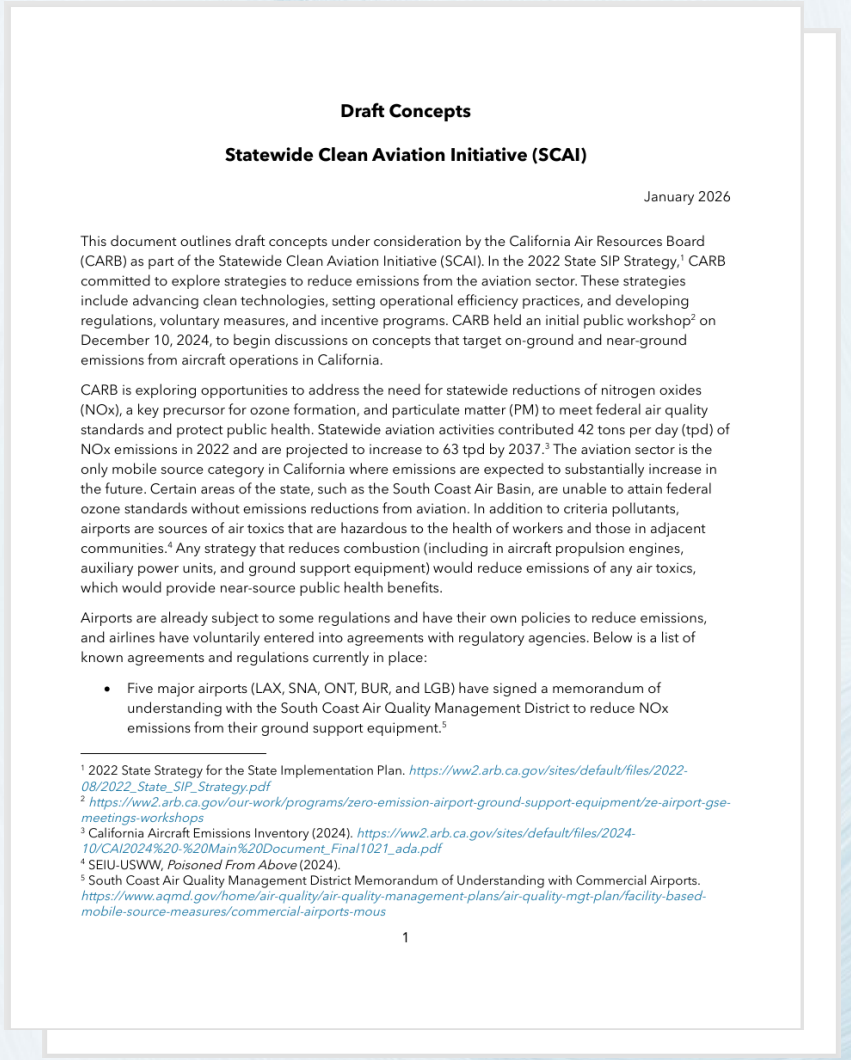
- We will pause for questions half-way and at the end of the workshop.
- Please raise your hand if you would like to ask a question
  - Include slide numbers
  - In Zoom: Use “Raise Hand” feature
  - On phone:
    - #2 to “Raise Hand”
    - *6 to Mute/Unmute
- Additional questions may be submitted after the workshop to: aircraft@arb.ca.gov or to Mo Chen (mo.chen@arb.ca.gov)

Agenda

- Recap of draft SCAI concepts
- Updates on contracts
- Funding opportunities
- Updates on GSE Inventory
- **Q&A #1**
- Cost analysis for APU-off concept
- Cost analysis for GSE turnover concept
- Timeline and Next steps
- **Q&A #2**

CARB continues to explore strategies to reduce airport emissions

- Jan 2026 Draft Concepts document - available online
- 9 comment letters received – available online
- Conducted follow up discussions with stakeholders
- Any input is still accepted and appreciated. Please email comments to aircraft@arb.ca.gov



Draft Concepts

Statewide Clean Aviation Initiative (SCAI)

January 2026

This document outlines draft concepts under consideration by the California Air Resources Board (CARB) as part of the Statewide Clean Aviation Initiative (SCAI). In the 2022 State SIP Strategy,[1] CARB committed to explore strategies to reduce emissions from the aviation sector. These strategies include advancing clean technologies, setting operational efficiency practices, and developing regulations, voluntary measures, and incentive programs. CARB held an initial public workshop[2] on December 10, 2024, to begin discussions on concepts that target on-ground and near-ground emissions from aircraft operations in California.

CARB is exploring opportunities to address the need for statewide reductions of nitrogen oxides (NOx), a key precursor for ozone formation, and particulate matter (PM) to meet federal air quality standards and protect public health. Statewide aviation activities contributed 42 tons per day (tpd) of NOx emissions in 2022 and are projected to increase to 63 tpd by 2037.[3] The aviation sector is the only mobile source category in California where emissions are expected to substantially increase in the future. Certain areas of the state, such as the South Coast Air Basin, are unable to attain federal ozone standards without emissions reductions from aviation. In addition to criteria pollutants, airports are sources of air toxics that are hazardous to the health of workers and those in adjacent communities.[4] Any strategy that reduces combustion (including in aircraft propulsion engines, auxiliary power units, and ground support equipment) would reduce emissions of any air toxics, which would provide near-source public health benefits.

Airports are already subject to some regulations and have their own policies to reduce emissions, and airlines have voluntarily entered into agreements with regulatory agencies. Below is a list of known agreements and regulations currently in place:

- Five major airports (LAX, SNA, ONT, BUR, and LGB) have signed a memorandum of understanding with the South Coast Air Quality Management District to reduce NOx emissions from their ground support equipment.[5]

[1] 2022 State Strategy for the State Implementation Plan. *https://ww2.arb.ca.gov/sites/default/files/2022-08/2022_State_SIP_Strategy.pdf*
[2] *https://ww2.arb.ca.gov/our-work/programs/zero-emission-airport-ground-support-equipment/ze-airport-gse-meetings-workshops*
[3] California Aircraft Emissions Inventory (2024). *https://ww2.arb.ca.gov/sites/default/files/2024-10/CAI2024%20-%20Main%20Document_Final1021_ada.pdf*
[4] SEIU-USWW, *Poisoned From Above* (2024).
[5] South Coast Air Quality Management District Memorandum of Understanding with Commercial Airports. *https://www.aqmd.gov/home/air-quality/air-quality-management-plans/air-quality-mgt-plan/facility-based-mobile-source-measures/commercial-airports-mous*

1

CARB

SCAI concepts under consideration

Ground Support Equipment (GSE)



Transition airport GSE fleets to zero-emission

Phase out older engine tier combustion equipment

Auxiliary Power Units (APUs)



Minimize APU usage during turnaround operations

Plug in to ground power and pre-conditioned air while at the gate

Aircraft taxiing



Increase use of single-engine taxiing

Adopt zero-emission taxiing technologies for capable operations

Aircraft landings and takeoffs



Adopt an airport differentiated landing fee program to incentivize cleaner aircraft to fly to California airports

CARB

Seeking your feedback

Current Infrastructure



What infrastructure is available to support emissions reductions?

If ZE infrastructure is available, how much is it used?

Cost Information



Equipment costs and depreciation rates?

Infrastructure installation costs?

Maintenance costs?

Realistic Timeframes



Installation timeframes?

Lifetime of equipment?

Maintenance schedules?

Operational Feasibility



What are your concerns with these emission reduction strategies?

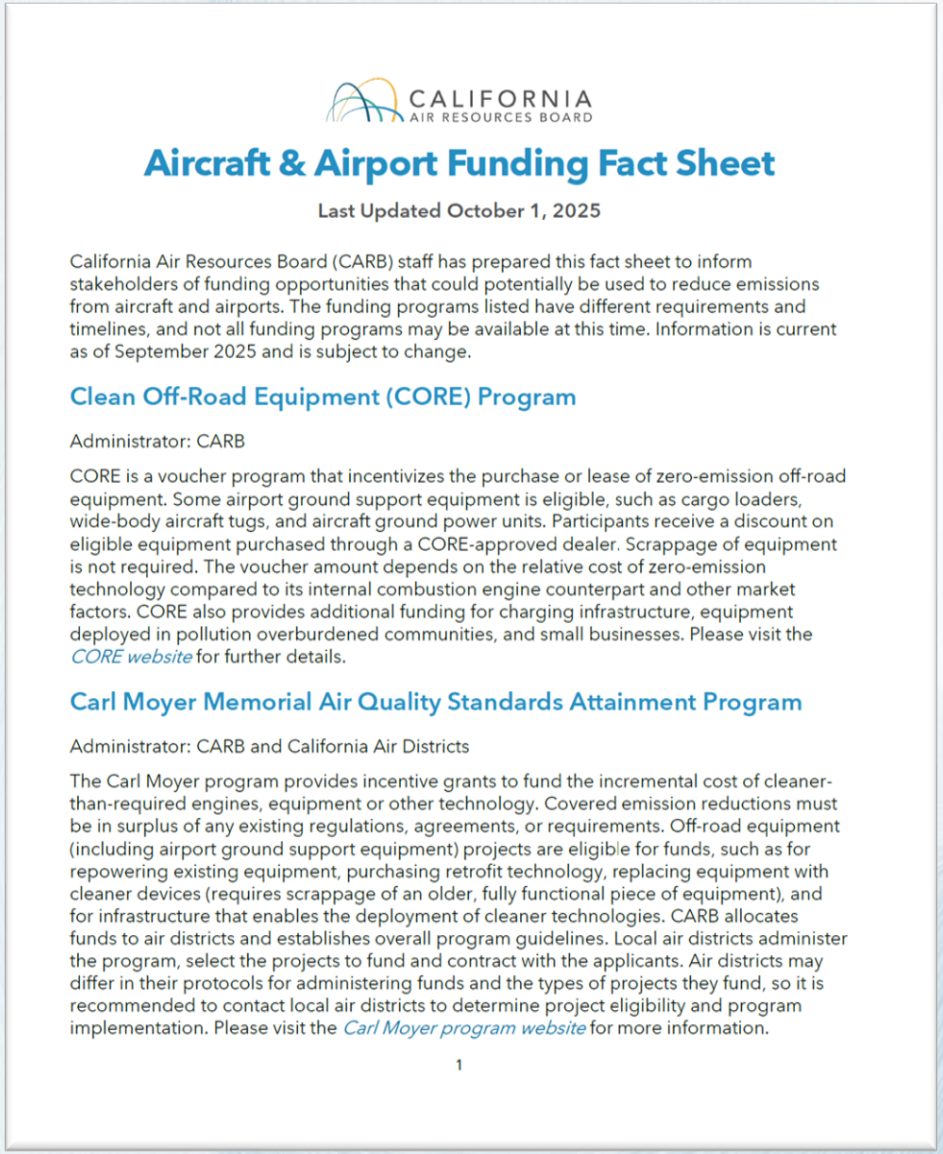
What other strategies could reduce emissions at your airport?

Ongoing Contract 25AQP004: Airport Landing Fees and Zero-Emission Zones

- Contractors:
  - Dr. Mark Jacobsen, UC San Diego
  - Dr. James Sallee, UC Berkeley
  - Dr. Jasenka Rakas, UC Berkeley
- Contract term: June 1, 2026 – April 1, 2028
- **Scope of work**
  - Determine how economic incentives could impact emission reduction efforts such as aircraft routing, fleet investments, and technological shifts
  - Evaluate current landing and takeoff patterns at California airports
  - Explore policy and operational shifts that could be made to reduce emissions during landings and takeoffs

Funding Opportunities

- **Demonstrations**, such as $7.6 million for zero-emission agriculture spraying drones through Sustainable Heavy-Duty Initiatives for Future Technology (SHIFT)
- **Vouchers** for discounts on ZE equipment, such as through CARB's Clean Off-Road Equipment (CORE) Program
- **Equipment Replacement** programs, such as the Carl Moyer Program
- **Infrastructure improvements** such as through CEC's Distributed Electricity Backup Assets (DEBA) program
- **Federal incentives** such as FAA's Voluntary Airport Low Emissions (VALE) Program



CALIFORNIA AIR RESOURCES BOARD

Aircraft & Airport Funding Fact Sheet

Last Updated October 1, 2025

California Air Resources Board (CARB) staff has prepared this fact sheet to inform stakeholders of funding opportunities that could potentially be used to reduce emissions from aircraft and airports. The funding programs listed have different requirements and timelines, and not all funding programs may be available at this time. Information is current as of September 2025 and is subject to change.

Clean Off-Road Equipment (CORE) Program

Administrator: CARB

CORE is a voucher program that incentivizes the purchase or lease of zero-emission off-road equipment. Some airport ground support equipment is eligible, such as cargo loaders, wide-body aircraft tugs, and aircraft ground power units. Participants receive a discount on eligible equipment purchased through a CORE-approved dealer. Scrappage of equipment is not required. The voucher amount depends on the relative cost of zero-emission technology compared to its internal combustion engine counterpart and other market factors. CORE also provides additional funding for charging infrastructure, equipment deployed in pollution overburdened communities, and small businesses. Please visit the *CORE website* for further details.

Carl Moyer Memorial Air Quality Standards Attainment Program

Administrator: CARB and California Air Districts

The Carl Moyer program provides incentive grants to fund the incremental cost of cleaner-than-required engines, equipment or other technology. Covered emission reductions must be in surplus of any existing regulations, agreements, or requirements. Off-road equipment (including airport ground support equipment) projects are eligible for funds, such as for repowering existing equipment, purchasing retrofit technology, replacing equipment with cleaner devices (requires scrappage of an older, fully functional piece of equipment), and for infrastructure that enables the deployment of cleaner technologies. CARB allocates funds to air districts and establishes overall program guidelines. Local air districts administer the program, select the projects to fund and contract with the applicants. Air districts may differ in their protocols for administering funds and the types of projects they fund, so it is recommended to contact local air districts to determine project eligibility and program implementation. Please visit the *Carl Moyer program website* for more information.

1

https://ww2.arb.ca.gov/resources/documents/aviation-funding-fact-sheet

CARB

$3M to Fund Deployment of ZE Taxiing Technology

- CARB-funded feasibility study found that about 79% of commercial taxi-out movements at the 14 California airports studied could be compatible with ZE taxiing.
- Based on the feasibility shown, CARB plans to fund a $3M real-world deployment of commercially available ZE taxiing technology at a California commercial airport.
- Funding can support one technology unit, pilot training, and supporting infrastructure for a real-world demonstration.
- Timeline:
  - Expected RFP release: January 2027
  - Expected contract start: May 2027



$3M to Fund Deployment of ZE Taxiing Technology

- **Potential value to airports and airlines**
  - **Fuel Savings**: Reduced main-engine use during taxi-out could provide fuel-cost savings of up to approximately $500,000 per year under high utilization.
  - **Job creation potential**: Deployment could support equipment operation, maintenance, and technical-support roles.
  - **Reduced ground-worker exposure**: Less main-engine operation could reduce exposure to aircraft exhaust and noise during ground operations.



ZE Taxitow technology at Schiphol Airport

$3M to Fund Deployment of ZE Taxiing Technology

What will make a good proposal?

- **Feasible Deployment Plan**
  - Aircraft main engines to remain off for at least 75% of the proposed taxi-out distance
  - A credible and feasible deployment route
  - Practical plan for pilot and operator training, infrastructure procurement, and real-world airport operations
- **Strong Project Partnership**
  - Clear alignment between participating airline(s), airport(s) and equipment manufacturers
- **Technology Deployment Readiness**
  - Commercially available ZE taxiing technology
  - Applicable FAA certification for the proposed technology



CORE Voucher Incentive Project - Overview

- CORE provides incentives to California businesses to purchase or lease zero-emission off-road equipment
- Helps offset higher zero emission cost
- First-come, first-served streamlined voucher process
- Can be combined with other incentives
- Does not require scrapping an old piece of equipment
- Higher funding for small businesses and for charging or fueling infrastructure

CaliforniaCore.Org

CORE Incentive Project - AGSE

- CORE eligible AGSE equipment types include:
  - Airport Cargo Loaders;
  - Wide-body and Narrow-body Aircraft Tugs; and
  - Aircraft ground power units (GPU)
- CORE AGSE does not include:
  - Carts (including lavatory carts);
  - Baggage belt loaders; and
  - Baggage tractors
- Curb weight requirement were removed for Aircraft Tugs as part of FY 2026-27 program updates

CORE Incentive Project - New Funding & AGSE Voucher Amounts

- Program launch slated for December 1, 2026
- $1M Baseline funding for AGSE equipment category
- Additional funding will be allocated to equipment categories based on demand

Equipment Type	Base Voucher Amount
Cargo Loader (10-20k lb capacity)	Up to **$50,000**
Cargo Loader (>20k lb capacity)	Up to **$100,000**
Aircraft Tug (Lead Acid)	Up to **$80,000**
Aircraft Tug (Lithium or Fuel Cell)	Up to **$200,000**
GPU (Lithium or Fuel Cell)	Up to **$300,000**

Infrastructure Enhancement	Voucher Amount
Charging (<50kW)	Up to **$3,000**
Charging (≥50kW)	Up to **$30,000**
Hydrogen Fueling	Up to **$30,000**

CORE Contact Information

- **Policy Lead**: Jessica Monterrosa, jessica.monterrosa@arb.ca.gov
- **Equipment Eligibility**: Isaiah Wood, isaiah.wood@arb.ca.gov
- **CORE Manager**: Duong Trinh, duong.trinh@arb.ca.gov
- **CARB CORE Email**: core@arb.ca.gov
- **CORE Webpage**: californiacore.org

Zero-Emission Technology Application (ZETA)

Overview of Provisions and Applicability to Airport GSE

In-Use Off-Road Diesel-Fueled Fleets Regulation

Background

- In effect since 2008
- Applicability:
  - Off-road vehicles with diesel engines 25 horsepower and up
  - **Airport GSE**, Construction, mining, industrial equipment, and others
  - Some two-engine on-road vehicles and workover rigs

Requirements

- Fleet average emissions targets / turnover requirements
- Phase out and ban on adding older vehicles
- Renewable diesel
- Reporting and labeling
- Idling limits





Vehicle Label

Flexibility Provisions to Encourage Zero-Emission Adoption

- Similar size vehicle-to-vehicle provision
- Zero-Emission Technology Application (ZETA)
- GSE Fleet Owners/Operators can apply

Voluntary flexibility provisions to encourage adoption of zero-emission technologies and to provide compliance flexibility

Voluntary Zero-Emission Flexibility: Vehicle to Vehicle



For each Zero-Emission (ZE) vehicle adopted, the fleet may continue to operate a Tier 1 or Tier 2 vehicle for two additional years beyond the phase-out years

- Must perform work of a diesel equivalent
- Must be similar max power rating as the ICE vehicle
- Must report vehicle information to CARB

Alternate Compliance Pathway through Zero-Emission Technology Application (ZETA)

ZETA Submittal

- Compliant at time of submittal
- Submit 4 months prior to next compliance date

ZETA Review

- Turnover to ZE
  - ❑ 15% (2030)
  - ❑ 50% (2035)
- ZETA must include:
  - Vehicle turnover
  - ZE acquisition
  - List of milestones
  - Estimated completion dates

Annual ZETA Updates

- All milestones complete
  - ☑ Continue
- Some progress is shown
  - ? Adjust milestones
- No progress
  - ☒ Revoke

If denied or revoked → Comply with tier phase-out and fleet average requirements

CARB

ZETA Contact Information

- **Zero-Emission Off-Road Lead Staff**: Holmes Bassette
  - Air Pollution Specialist, Off-Road Implementation Section
  - holmes.bassette@arb.ca.gov

- **Webpage**: Zero-Emission Technology Application

GSE Emission Inventory

Statewide GSE Inventory Development Recap

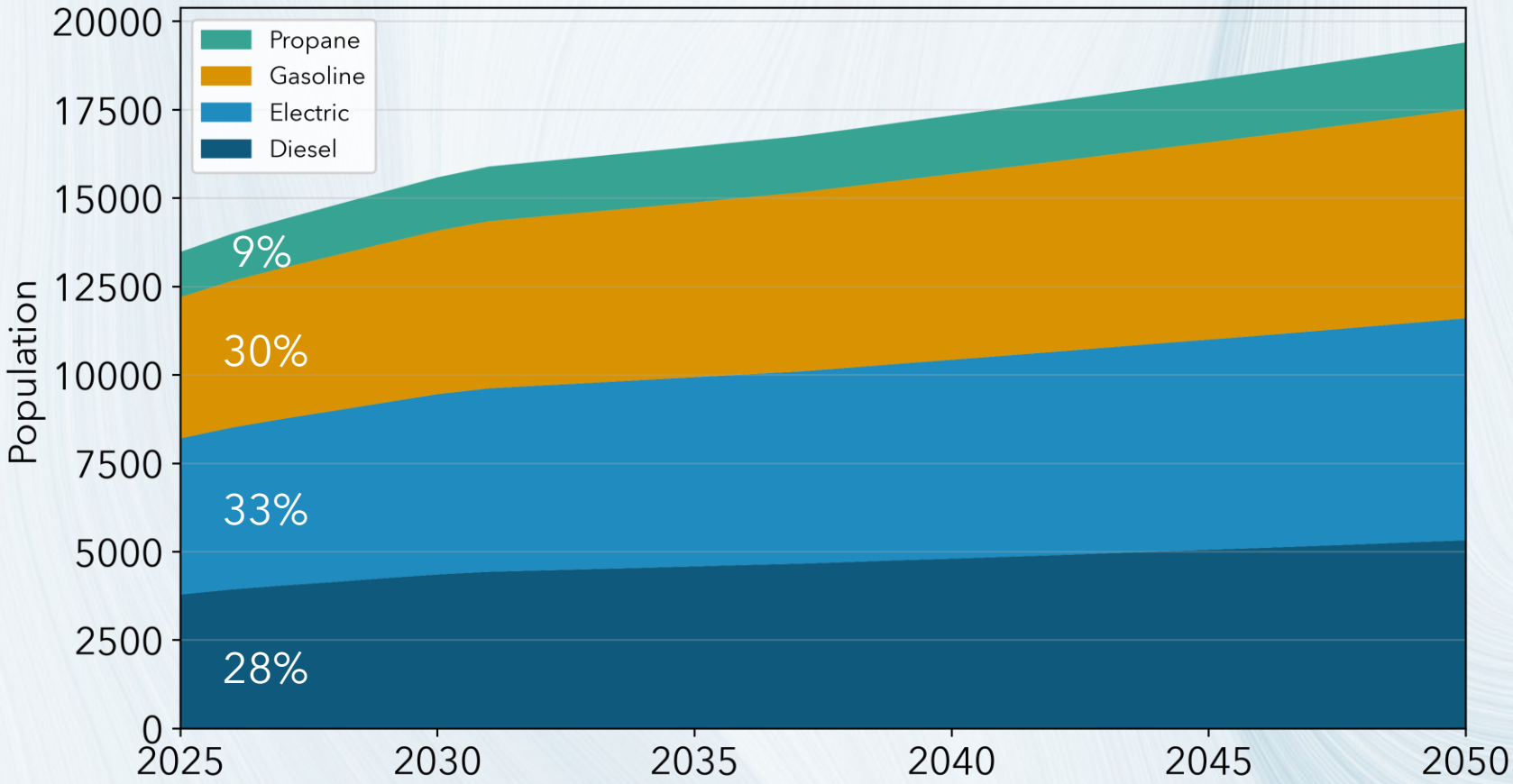
- **Scope:** Aircraft-servicing GSE at 30+ California airports, with a 2025 population and emissions baseline.
- **Data compiled:** CARB DOORS records, South Coast AQMD MOU data for five major airports, and voluntary fleet data.
- **Data gaps:** Use airport activity and GSE ratios from South Coast airports to estimate fleets where data are limited.
- **Activity survey:** About 700 data points by June 2025 to improve equipment activity and fuel use estimates.
- **Forecast:** Apply growth from CARB's CAI2024 operations outlook to project equipment totals at each airport through 2050.

Updates to the GSE Emissions Inventory

- Added 2023 South Coast MOU data to the GSE inventory
- Applied CARB's new off-road load-dependent NOx emission factors for diesel equipment.
- Applied CARB's updated off-road PM, HC, and CO emission factors for diesel equipment.



Business-as-Usual GSE Forecast, 2025-2050



Overview of Updated Off-Road Emission Factors

Two-part update

1. New load-dependent NOx emission factors & methodology
   - Identifies idle/non-idle NOx emissions
   - Based on real-world activity monitoring and emissions testing
   - Updates for Tier 2 and newer diesel engines

2. New PM, HC, and CO emission factors
   - Based on U.S. EPA engine certification data and California sales data from 2017 to 2023
   - Updates CARB's 2017 emission factors

Why Update the NOx Emission Factors?

- First time CARB has quantified off-road diesel NOx emissions based on real-world data, and at different load bins.
- Portable Emissions Measurement Systems (PEMS) reflect real-world operations.
  - ❑ PEMS are large, expensive, and difficult to install
  - ❑ Certification data is collected in lab settings at specific speed and torque, not during real-world operation
  - ❑ The most common test cycle may not be representative because it has only one short period below 50% torque

PEMS



Methodology Visualization (Example Only)

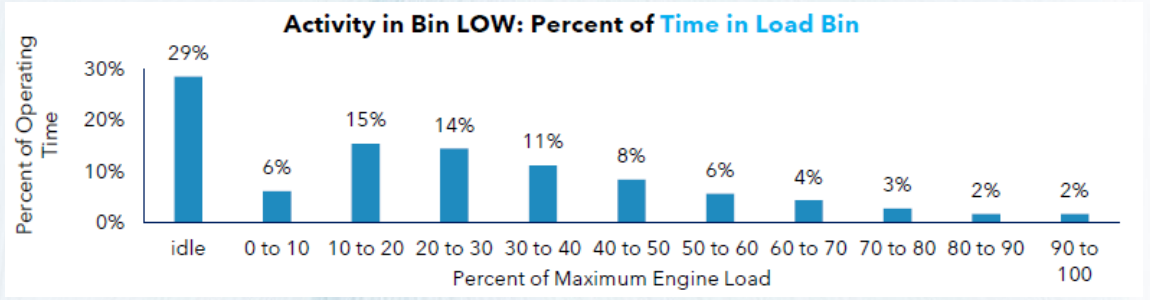
Old Method (example)

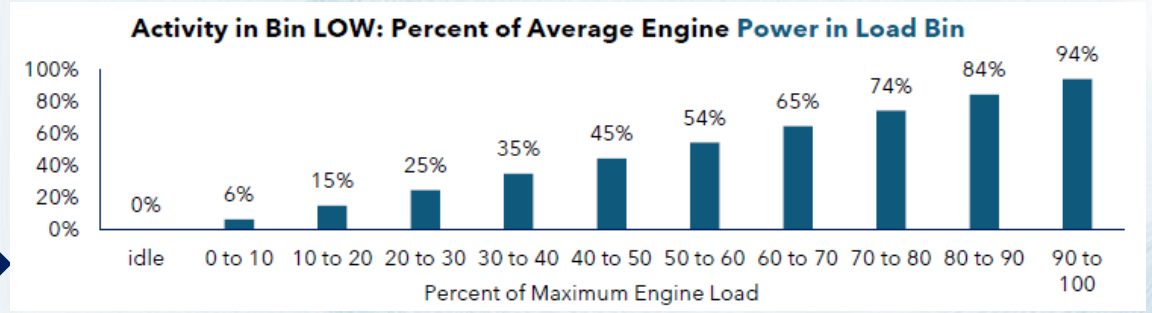
- Assumes a constant NOx emission factor and average load for 100% of activity.
- NOx Emission Factor: 2.3 g/bhp-hr
- Average Load: 0.48

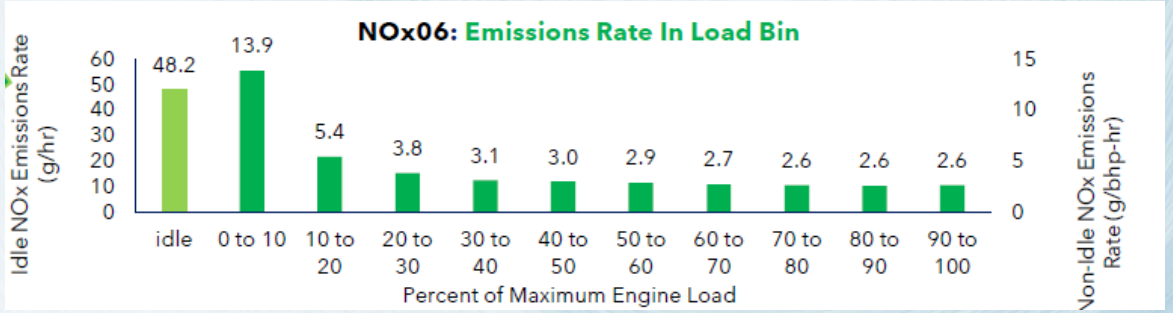
New Load-Dependent Method

- Activity time by load (**Activity Group**)
- Find average power by load (**Average Load**)
- Find NOx emission rate by load (**NOx Group**)

Load-dependent NOx Emission Factor =
[Time in Load Bin] x [Power in Load Bin] x [Emission Factor in Load Bin]



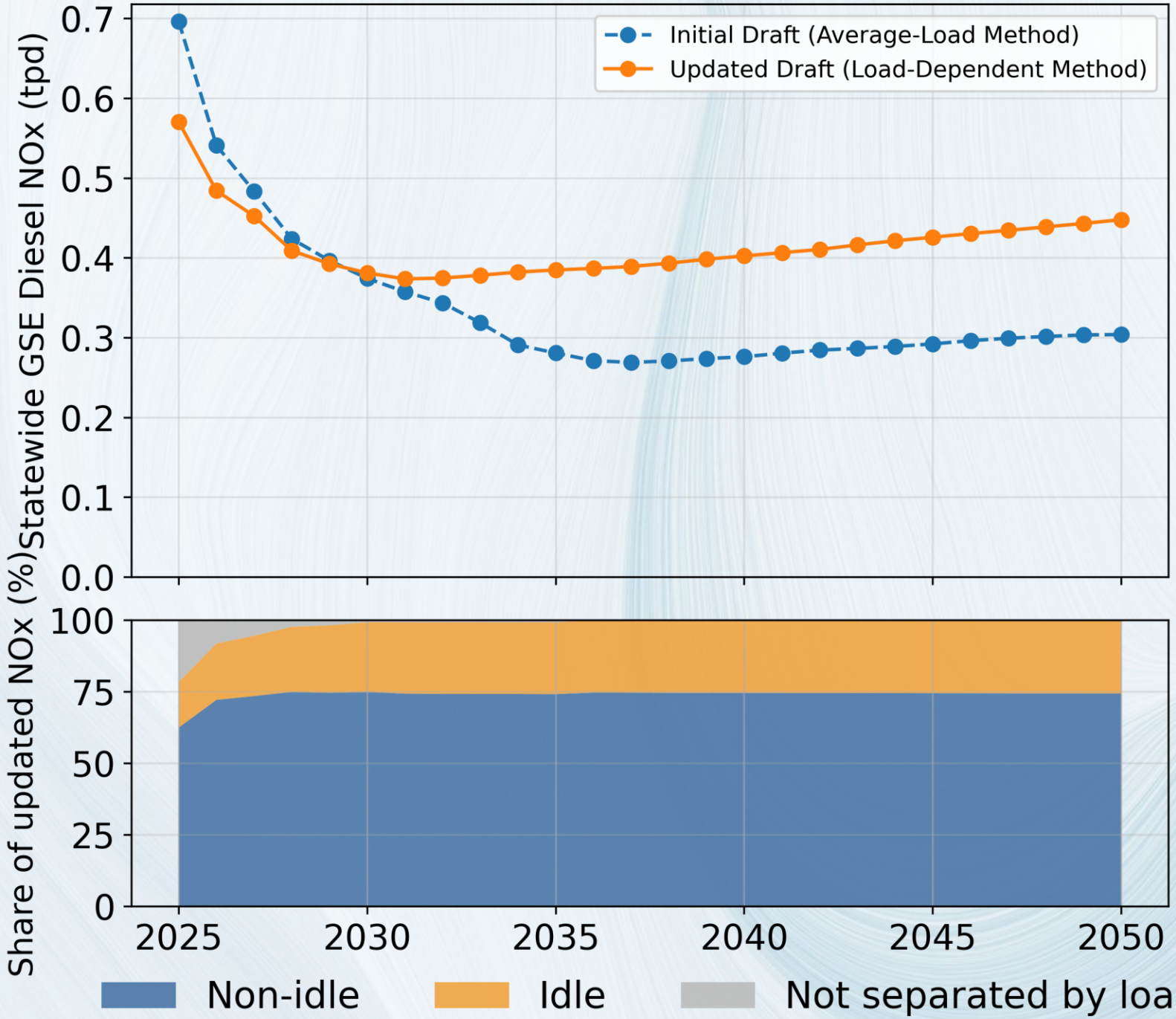




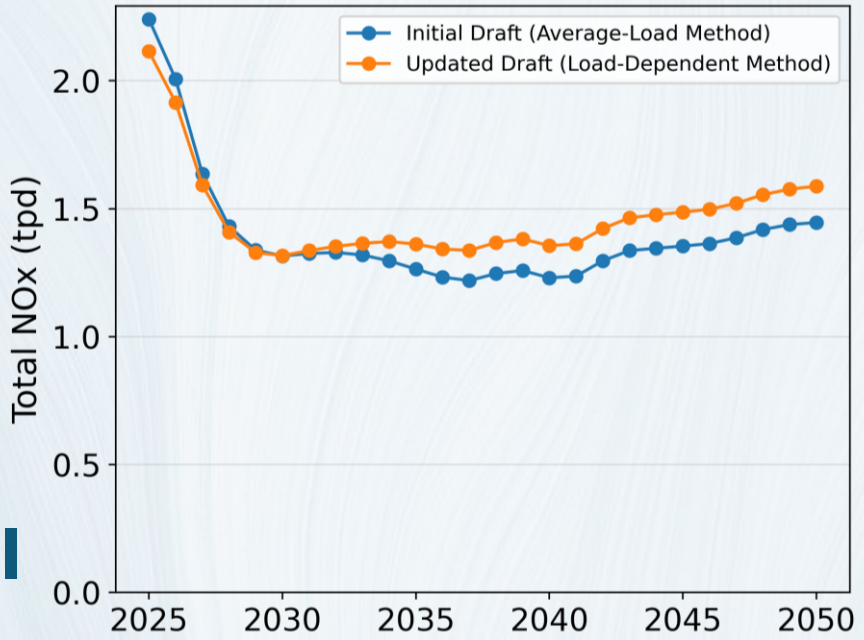
CARB

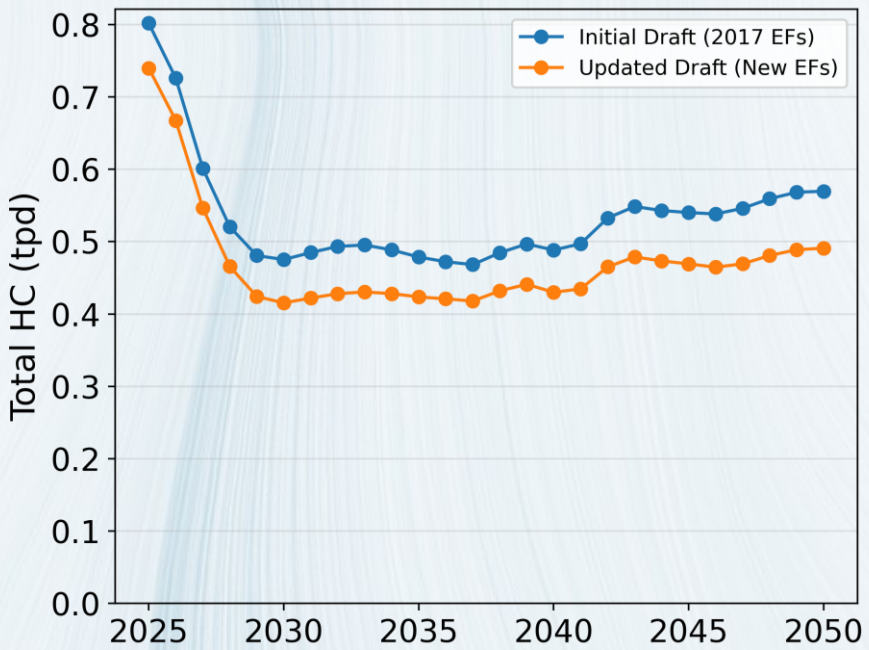
Technical documentation

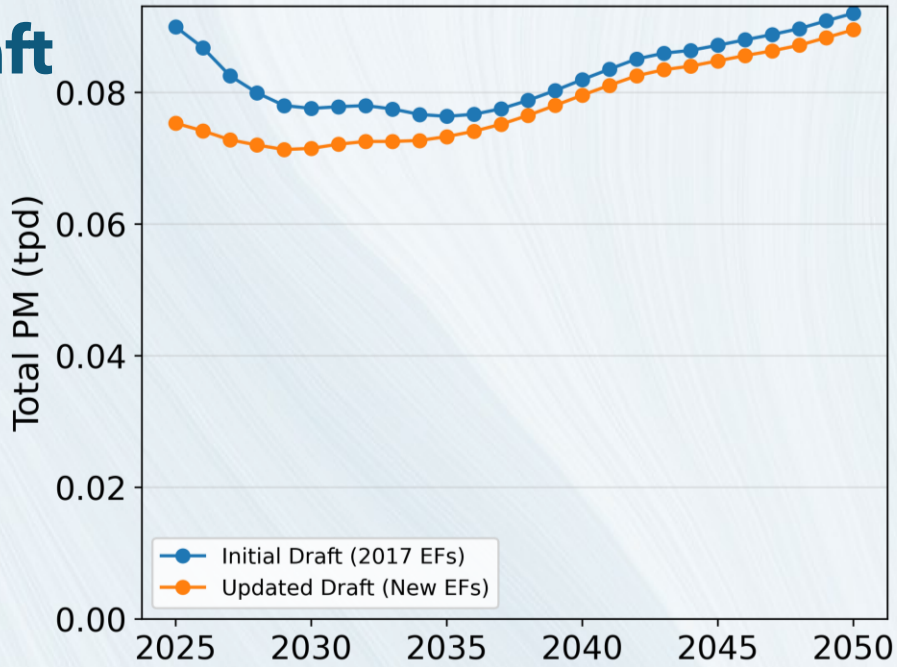
Statewide GSE Diesel NOx: Comparison of Draft Estimates

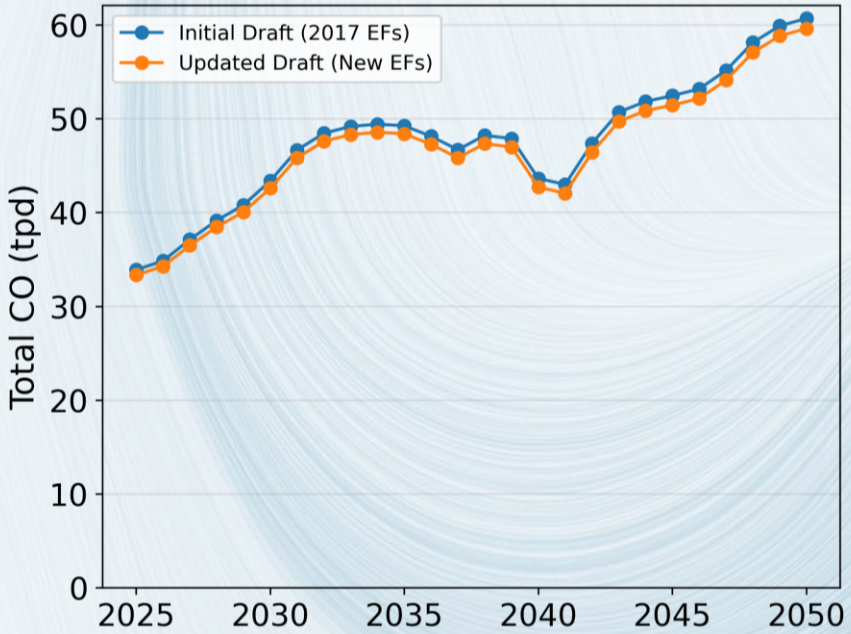


Statewide GSE Total Emissions: Comparison of Draft Estimates









CARB

Opportunities for GSE Inventory Improvement

- **GSE population**: Additional fleet data from airports, airlines, and FBOs are welcome to improve inventory coverage and accuracy.
- **Activity data**: Additional equipment operating hours and load data would help improve emissions estimates.
- **SCAQMD collaboration**: Continue incorporating updated, publicly available MOU data into the inventory and forecasts.

Question and Answer (1 of 2)

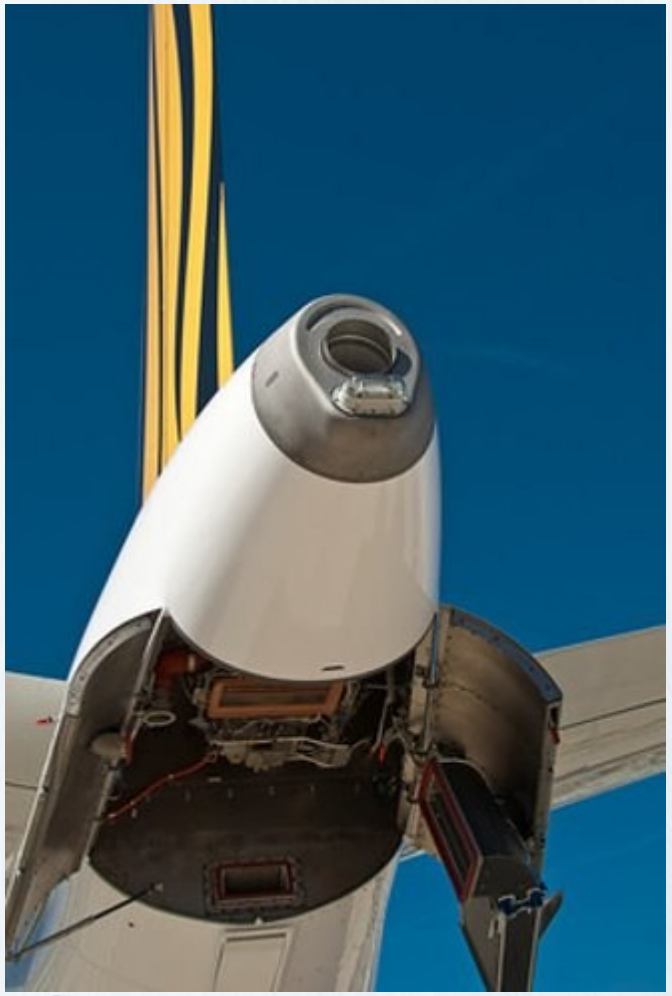
- Please raise your hand if you would like to ask a question
  - Include slide numbers, if possible
  - In Zoom: Use “Raise Hand” feature
  - On phone:
    - #2 to “Raise Hand”
    - *6 to Mute/Unmute
- Additional questions may be submitted after today to: aircraft@arb.ca.gov or to Mo Chen (mo.chen@arb.ca.gov)

Cost Analysis

Cost Analysis Overview

- The **cost analysis** evaluates the financial impacts of SCAI concepts
- Evaluates the cost difference between zero-emission technology compared to business-as-usual (BAU)
- We will present cost analysis framework and preliminary results on APU and GSE concepts during this workshop

APU Concept Cost Analysis





Aircraft Auxiliary Power Units (APUs)

On the ground, APUs are used to:

- Power aircraft electrical systems
- Supply compressed air for climate control
- Start the main engines

However, aircraft APU operation is inefficient, with an efficiency of 8–14% and generates emissions and noise.

CARB

APU efficiency: Fleuti, E., & Ruf, C. (2018). *Aircraft ground energy systems at Zurich Airport* (Version 3). Flughafen Zürich AG.



Strategies to Reduce APU Emissions

Shut off the APU

- For power needs:
  - Connect to fixed ground power (GP), which uses airport building electricity
  - Connect to mobile GP units
- For climate control needs:
  - Use electricity-powered preconditioned air (PCA) units at gates
  - Use mobile PCA units



Cost-Benefit Analysis Framework for APU Reduction Strategies

Operational Inputs

- Turnaround time
- Plug-in time
- Aircraft type
- Electricity usage

Cost inputs

- Fuel usage
- Fuel price
- Electricity price
- Equipment cost
- Maintenance cost

Net benefit

- Annual fuel savings
- Annual equipment costs

Turnaround Time & Suggested Plug-in Time

Turnaround time

Narrow body aircraft type	Average turnaround time (minutes)
United A320	75
American A320	68
Southwest B738	62
Delta A320	79
JetBlue A320	76

Wide body aircraft type	Average turnaround time (minutes)
United B789	121
United B777W	131
American B789	115
American B777W	128
Delta A333	117
Delta A350	112

Suggested plug-in time (based on draft SCAI concepts)



Arrival

Upon arrival:
Plug-in and turn off APUs within **5 minutes** of arrival

Before departure:
Minimize APU usage
15 minutes before departure for code C or below
25 minutes before departure for code D or above



Departure

Narrow body turnaround time assumption: 72 minutes
Wide body turnaround time assumption: 120 minutes

Narrow body plug-in time assumption: 42 minutes
Wide body plug-in time assumption: 70 minutes

Grant, J. (2023, April 12). Formula One science in aircraft turnarounds. OAG. https://www.oag.com/blog/science-aircraft-turnarounds

Fuel cost for utilizing APU

Annual Fuel Cost per Gate = Annual Arrivals × Passenger Aircraft Share × Ground Operating Time × Fuel Use Rate × Fuel Price/ Number of Gates

APU fuel use rate:

- Narrow body 112 kg/h
- Wide body 210 kg/h



APU jet fuel price

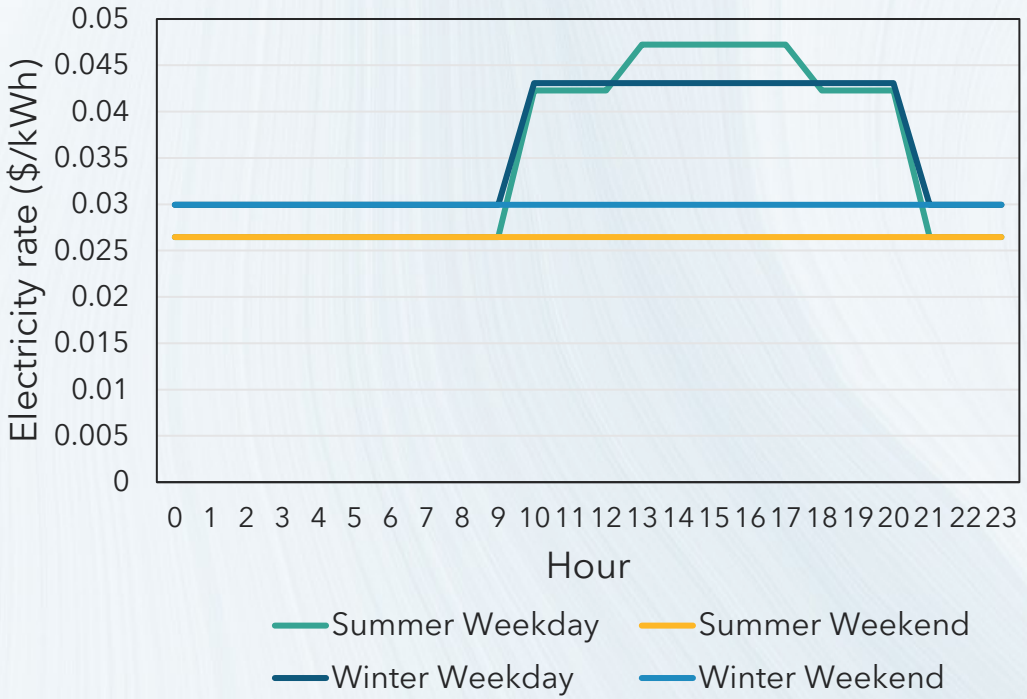
Calendar Year	Jet Fuel ($/dge)
2022	3.74
2023	2.92
…	…
2026	4.89

Passenger aircraft share: Fleuti, E., & Ruf, C. (2018). *Aircraft ground energy systems at Zurich Airport* (Version 3). Flughafen Zürich AG.
Fuel use rate: Grant, J. (2023, April 12). *Formula One science in aircraft turnarounds*. OAG.
Annual arrivals: California Air Resources Board (CARB). (2024). *California Aviation Inventory (CAI) Model*.
APU fuel use rate: Marina. (2024). *How to Track Your APU Fuel Consumption on Ground?* OpenAirlines
APU jet fuel price: California Energy Commission (2025). Transportation Fuel Price Forecasts. Transportation Energy Forecasting Unit, Demand Analysis Office, Energy Assessments Division.

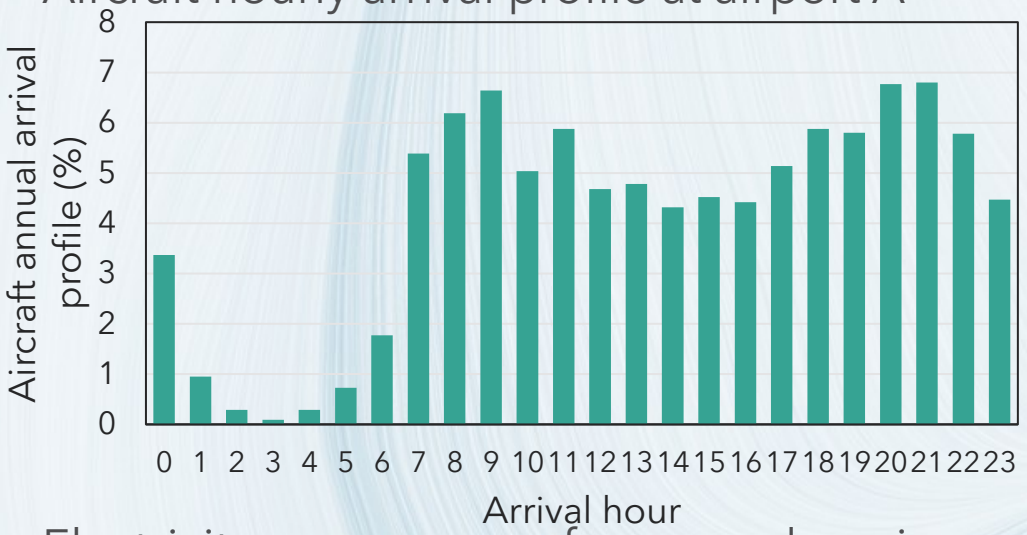
Electricity cost for plugging-in

Annual Electricity Cost per Gate = Annual Arrivals × Passenger Aircraft Share × Ground Operating Time × Electricity Use Rate × Electricity Price/Number of Gates

Electricity rate at airport A



Aircraft hourly arrival profile at airport A



Electricity power usage for ground equipment

	Wide body	Narrow body
Ground Power	108 KW	54 KW
Pre-conditioned Air	80 KW	40 KW

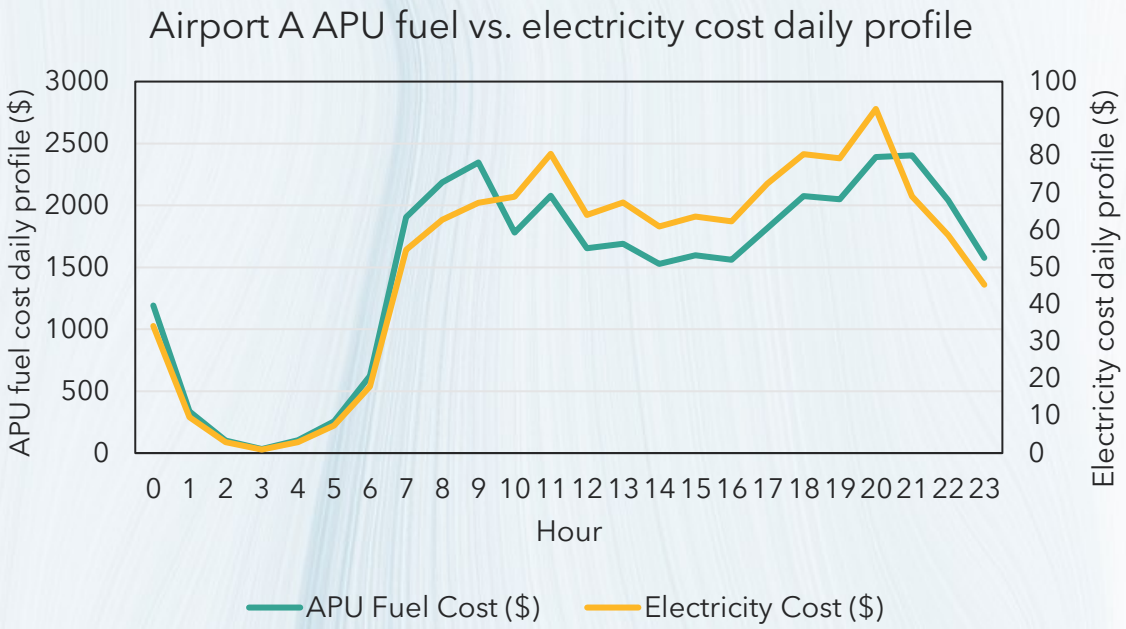
CARB

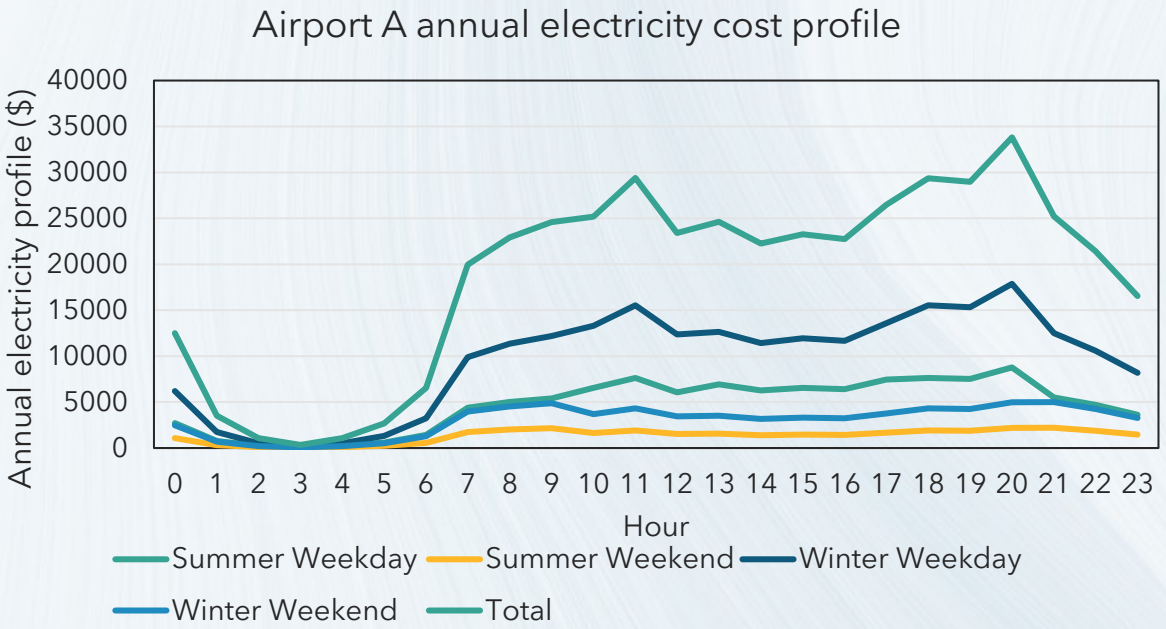
Aircraft arrival profile: He, Y., Kelly, K., Jeffers, M., Vercellino, R., Ge, Y., & Lunacek, M. (2026). Energy, power, and infrastructure demands from electrifying airport ground support equipment at United States airports. *Nature Communications*. https://doi.org/10.1038/s41467-026-71125-4

Electricity power usage: Airbus (2023), *A320 Aircraft Characteristics – Airport and Maintenance Planning*.

Costs results

Baseline: Currently 36% of aircraft operations are not using GP or PCA at all





- **Annual energy cost savings per gate at airport A: $76,837**
- **Annual arrival flight being quantified at airport A:**





CARB

Baseline assumption: Rakas, J., Achatz Antonelli, P., Walia, C., Rouzbahani, P., & Gikas, G. (2023). *Reducing Emissions through Monitoring and Predictive Modeling of Gate Operations of Idle Aircraft: A Case Study on San Francisco International Airport.* Institute of Transportation Studies, University of California, Berkeley.

Installation & Maintenance costs



	Ground Power	Pre-conditioned Air	Sources
Capital Cost	$38,000	$122,000	OEM
Component Replacement	$1.3k /yr	$5.3 /yr	VALE document
Maintenance Cost	$50 /hr	$50 /hr	Previous regulation
Maintenance Hours	50 hr/yr	50 hr/yr	VALE document

Annual operating savings per gate at airport A:

Energy cost savings: $77k

Maintenance cost: $12k

Net savings: $65k

Infrastructure cost – 5-year payback:

- **GP and PCA installation annualized payment : $39k**
- **Net saving during payback: $26k**

CARB

Vale document: Miami-Dade County. (2023). *Recommendation for Approval to Award a Non-competitive Designated Purchase for ITW GSE PCA & 400Hz GPU Preventative Maintenance and Repair.* Miami-Dade County Board of County Commissioners, Agenda Item No. 8(P)(5), December 12, 2023.

GSE Concept Cost Analysis

Major GSE Cost Analysis Assumptions

- The zero-emission equipment and charger costs are based on **current market values** provided by manufacturers and in literature
  - The capital cost may decrease over time
  - Capital costs of zero-emission adoption does not yet include combustion salvage values at the end of lifetime
- The operating costs are based on **current operation patterns** from the GSE inventory
- We welcome all feedback to enhance our analysis framework

GSE Cost Analysis Overview

Measuring the cost difference per unit between zero-emission technology pathway compared to business-as-usual (BAU) baseline case; all cost values defined in 2025 US dollars

Business-as-usual case

- Base GSE inventory, with ~67% of population using combustion engines
- Combustion units will be adopted during turnover

Emission reduction case

- Use zero-emission (ZE) GSE to replace existing combustion unit during turnover
- Additional charging infrastructure
- Zero-emission units will perform same amount of operation as combustion units

Cost change

- ZE GSE acquisition and charging installation
- Shifted energy use and cost changes during operation and maintenance

GSE Concept Data Source

Cost category	Cost Element	Input Data
Capital cost	GSE count (by year and fuel type)	CARB GSE inventory
	Unit cost by GSE type	Literature/data from manufacturers
	Electric vehicle supply equipment (EVSE)	Costs from literature and FAA VALE grants
Operation and maintenance (O&M) cost	Energy efficiency of GSE	• CARB GSE inventory • For eGSE, the equipment HP is imputed with manufacturer data and energy efficiency from literature
	Energy cost	• Base electricity rates in 2025 by time-of-use schedule at airport level: from utility website • Growth factor of electricity rate and other fuel costs: CEC energy cost projection
	GSE operation	CARB GSE inventory
	Maintenance cost	CARB GSE inventory and empirical methods from literature
	Insurance cost	Using equipment insurance rates (1% of equipment cost per year) from UW Equipment Insurance Rate Calculator

***References provided toward the end of this section*

Unit Equipment Cost (off-road type)

Current market value of GSE equipment

- The GSE cost by type and horsepower (HP) bins are collected from manufacturers or literatures
  - Data in the red box can benefit from more data
- The zero-emission unit is assumed to be **25%** more expensive than combustion units

Average Equipment Cost

GSE type	Combustion	Zero-emission
Aircraft Tractor	$ 271,500	$ 356,800
Baggage Tractor	$ 82,300	$ 145,900
Belt Loader	$ 45,300	$ 86,400
Ground Power Unit	$ 87,400	$ 169,100
Cargo Loader	$ 378,300	$ 474,900
Air Conditioner	$ 166,100	$ 133,400
Cart	$ 21,700	$ 24,900
Lift	$ 92,900	$ 125,900
Passenger Stand	$ 101,700	$ 123,500

Unit Equipment Cost (truck type)

Current market value of GSE equipment

- For GSE types that use on-road chassis, the zero-emission unit cost is imputed due to limited data from commercial products
- Discussed with manufacturer: zero-emission unit cost = base combustion unit cost + delta cost for zero-emission chassis

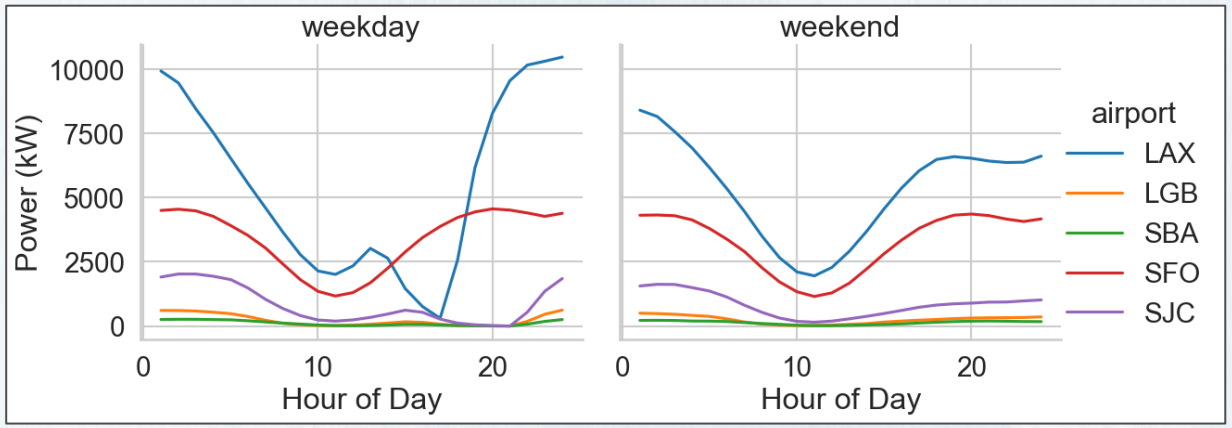
Average Equipment Cost

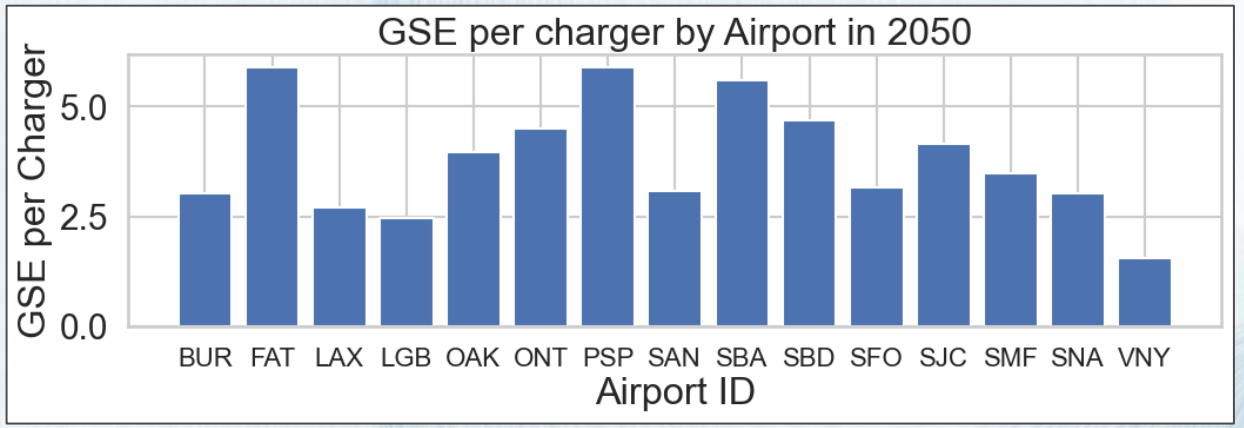
GSE type	Combustion	Zero-emission
Bobtail	$ 74,300	$ 192,700
Catering Truck	$ 126,100	$ 176,000
Fuel Truck	$ 273,500	$ 399,500
Lavatory Truck	$ 113,000	$ 163,000
Service Truck	$ 43,500	$ 212,700
Water Truck	$ 104,900	$ 155,100

Electric Vehicle Supply Equipment (EVSE) Cost

- The charging load and charger need is simulated based on Yi, et al (2026)

Charger types: 40 kW for most GSE types, 120 kW for aircraft tractors and cargo loaders





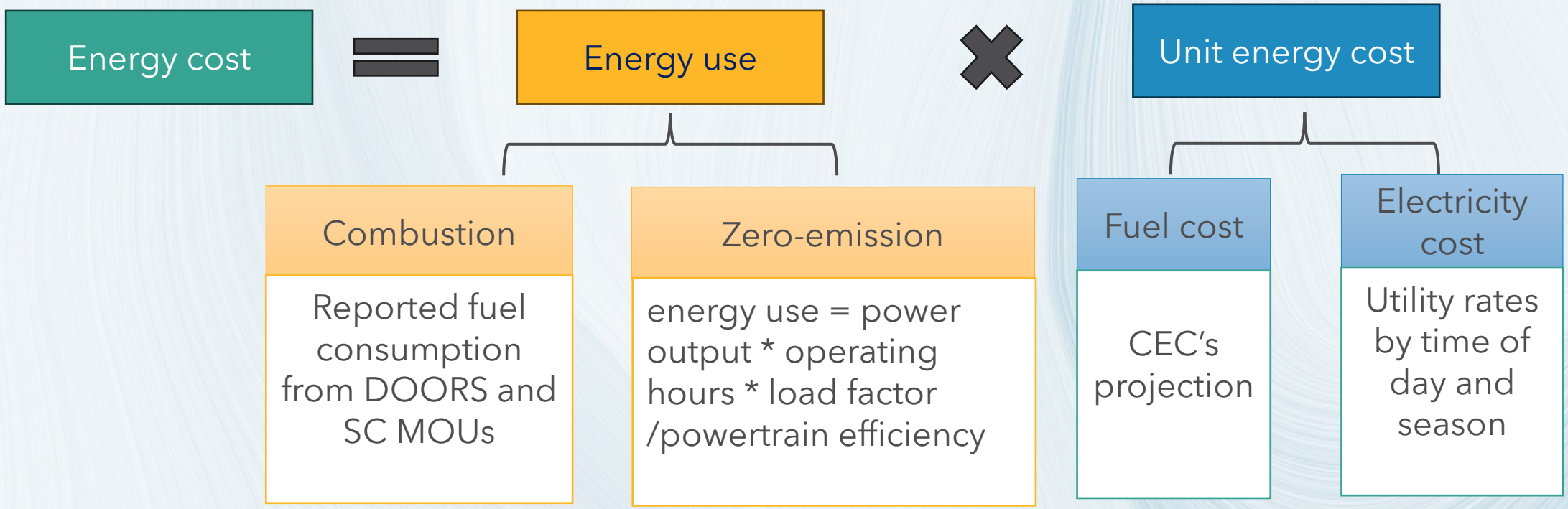
EVSE cost per charger

(from FAA VALE grant and literatures)

40 kW dual-port charger	120 kW dual-port fast charger
$74k	$92k

Unit GSE Operation Cost

In this analysis, the GSE **operation cost refers to energy cost**, as other cost (e.g., labor) does not vary by zero-emission technology adoption



*** Operating hours and load factor from CARB GSE inventory, and 80% efficiency applied from ANL's AFLEET Tool*

Unit GSE Maintenance and Insurance Cost

- Maintenance cost is estimated using empirical function and values from AFLEET 2024

Maintenance cost = **Annual operating hours** × **Unit cost per hour** × **Zero-emission adjustment factor**

Annual operating hours	Unit cost per hour	Zero-emission adjustment factor
Reported hours from DOORS and SC MOUs	Vehicle purchase cost / expected equipment lifetime in hours	Assumed 60%, accounting for less maintenance items needed

hours of life at full load' from US EPA, 2010

- Annual insurance cost assumed to be **1%** of equipment purchase cost using UW Equipment Insurance Rate Calculator

Unit GSE O&M Cost (Cont.)

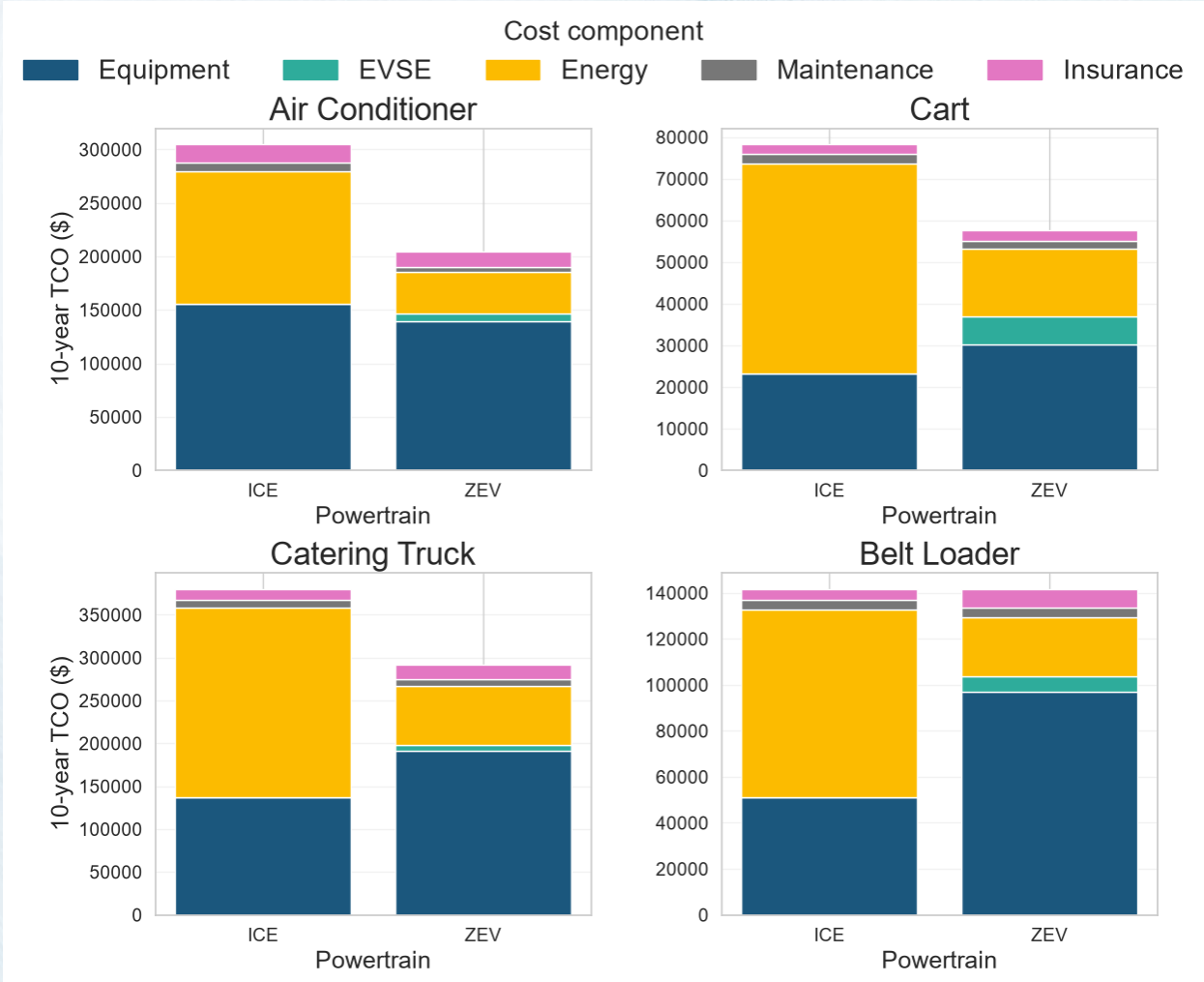
Average annual O&M cost in 2050, including current fuel types and zero-emission alternative

GSE type	Combustion ($/year)	Zero-emission ($/year)
Air Conditioner	$ 15,300	$ 4,900
Aircraft Tractor	$ 16,100	$ 7,400
Baggage Tractor	$ 15,800	$ 4,000
Belt Loader	$ 9,500	$ 2,800
Bobtail	$ 24,400	$ 9,200
Cargo Loader	$ 17,300	$ 11,100
Cart	$ 5,500	$ 1,200
Catering Truck	$ 25,800	$ 7,400
Fuel Truck	$ 39,100	$ 17,200
Ground Power Unit	$ 8,600	$ 3,300
Lavatory Truck	$ 21,700	$ 8,300
Lift	$ 6,900	$ 2,900
Passenger Stand	$ 6,600	$ 3,200
Service Truck	$ 27,700	$ 11,600
Water Truck	$ 22,800	$ 11,500

Preliminary Lifecycle Cost by Cost Element

- The cost analysis example demonstrates how the results can be used for assessing cost benefits of zero-emission GSE
- The equipment cost and the energy costs are often the two largest contributors to Total Cost of Ownership (TCO)

Average 10-year Total Cost of Ownership (TCO)



Request Data to Enhance Cost Analysis

General

- How are the costs being allocated across entities (airports, airlines, ground operators)

APU

- Fraction of flights already using GP/PCA instead of APU

GSE

- GSE new equipment cost (especially truck type GSEs), for both ICE and ZEV
  - Air conditioner, lavatory cart, lift, passenger stand, all truck-type GSEs
- GSE depreciation rate/salvage value
- Maintenance cost for zero-emission GSE

All other relevant cost information not listed above

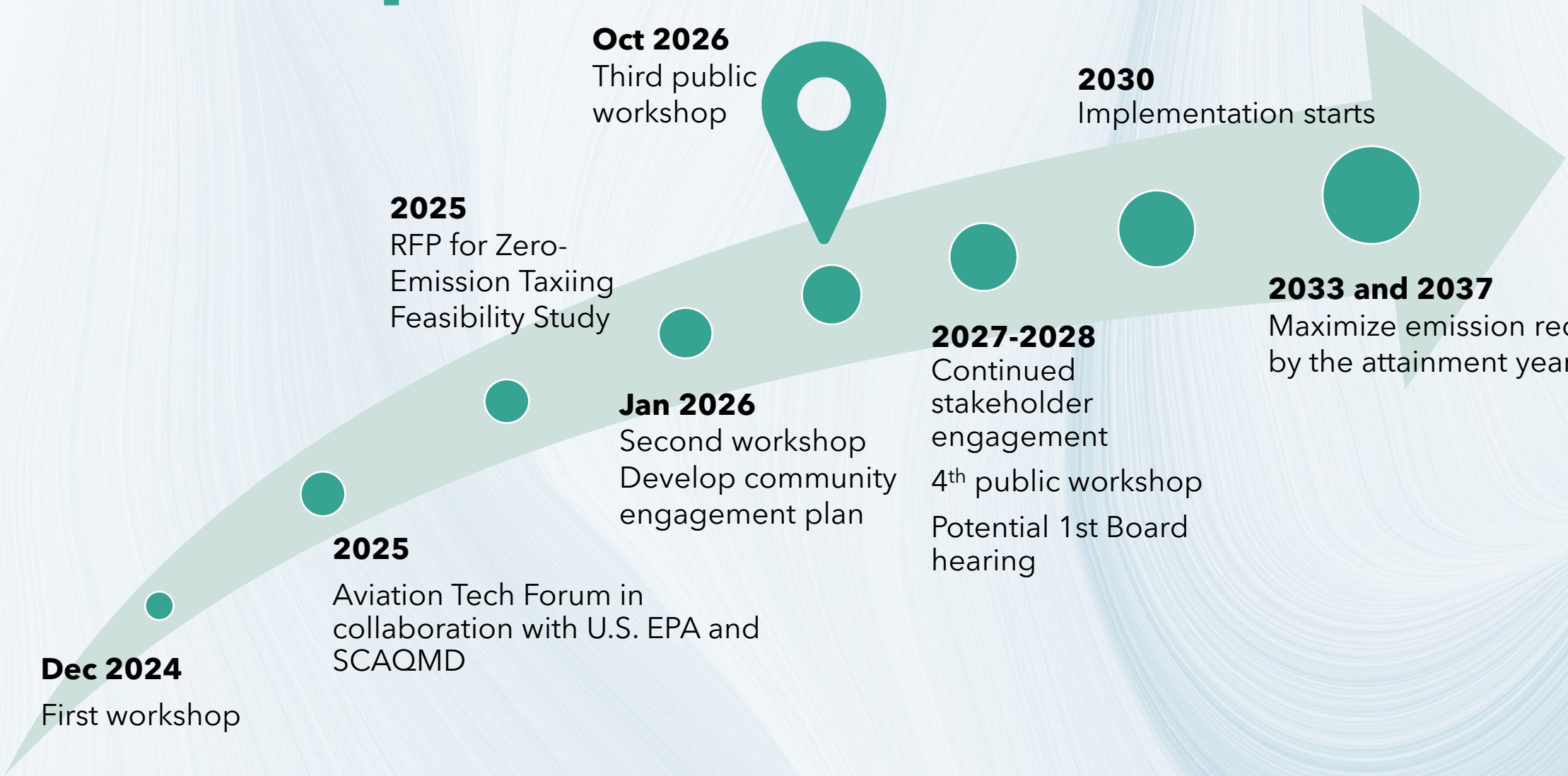
GSE References

Cost element	References
Equipment	1. Electric Power Research Institute. (2016). Airport electrification analysis at Wayne County Airport Authority (Report No. 3002008963). https://www.epri.com/research/products/3002008963. 2. CDM Smith. (2015). Los Angeles International Airport extremely low emission technology ground support equipment feasibility study report (Updated ed.). Los Angeles World Airports. https://www.lawa.org/sites/lawa/files/documents/LAX-eletGSE-Feasibility-Study-Report 3. Port Authority of New York and New Jersey. (2023). Zero-emission airside vehicles: Technology workgroup – Final technical report 1.0. https://www.panynj.gov/content/dam/airports/pdfs/final-TWG-technical-report-2023.pdf 4. Port Authority of New York and New Jersey. (2024). Zero-emission airside vehicles: Technology workgroup – Final technical report 2.0. https://share.google/mcPQh7tegEneiyuAN
Energy	1. Burnham, A. (2021). *AFLEET: Assess the impacts of conventional and alternative fuel vehicles* (No. DOE-ANL-CH11357). Argonne National Laboratory (ANL), Argonne, IL (United States). https://afleet.esia.anl.gov/ 2. He, Y., Kelly, K., Jeffers, M., Vercellino, R., Ge, Y., & Lunacek, M. (2026). Energy, power, and infrastructure demands from electrifying airport ground support equipment at United States airports. *Nature Communications*. https://doi.org/10.1038/s41467-026-71125-4 3. Port Authority of New York and New Jersey. (2023). Zero-emission airside vehicles: Technology workgroup – Final technical report 1.0. https://www.panynj.gov/content/dam/airports/pdfs/final-TWG-technical-report-2023.pdf 4. Port Authority of New York and New Jersey. (2024). Zero-emission airside vehicles: Technology workgroup – Final technical report 2.0. https://share.google/mcPQh7tegEneiyuAN 5. California Energy Commission (2025). Transportation Fuel Price Forecasts. Transportation Energy Forecasting Unit, Demand Analysis Office, Energy Assessments Division. 6. Burnham, A. (2021). *AFLEET: Assess the impacts of conventional and alternative fuel vehicles* (No. DOE-ANL-CH11357). Argonne National Laboratory (ANL), Argonne, IL (United States). https://afleet.esia.anl.gov/
Maintenance	1. Burnham, A. (2021). *AFLEET: Assess the impacts of conventional and alternative fuel vehicles* (No. DOE-ANL-CH11357). Argonne National Laboratory (ANL), Argonne, IL (United States). https://afleet.esia.anl.gov/ 2. U.S. Environmental Protection Agency. (2010). *Median life, annual activity, and load factor values for nonroad engine emissions modeling* (Report No. NR-005d; EPA-420-R-10-016). U.S. Environmental Protection Agency National Center for Environmental Publications and Information
Insurance	1. University of Washington. (accessed Sep 2026). *Equipment insurance rate calculator*. Risk Services. https://risk.uw.edu/insure/EIS/calc

EVSE References

1. California Energy Commission (2025). Transportation Fuel Price Forecasts. Transportation Energy Forecasting Unit, Demand Analysis Office, Energy Assessments Division.
2. He, Y., Kelly, K., Jeffers, M., Vercellino, R., Ge, Y., & Lunacek, M. (2026). Energy, power, and infrastructure demands from electrifying airport ground support equipment at United States airports. *Nature Communications*. https://doi.org/10.1038/s41467-026-71125-4
3. Federal Aviation Administration. (2023). Voluntary Airport Low Emissions (VALE) program grant summary. U.S. Department of Transportation. faa.gov
4. Wood, E., Borlaug, B., Moniot, M., Lee, D. Y. D., Ge, Y., Yang, F., and Liu, Z., 2023. The 2030 national charging network: Estimating US light-duty demand for electric vehicle charging infrastructure (No. NREL/TP-5400-85654). National Renewable Energy Laboratory (NREL), Golden, CO (United States).
5. Rocky Mountain Institute (RMI) 2019. *Reducing EV Charging Infrastructure Costs*. Retrieved from https://rmi.org/resources/reducing-ev-charging-infrastructure-costs/
6. CDM Smith. (2015). Los Angeles International Airport extremely low emission technology ground support equipment feasibility study report (Updated ed.). Los Angeles World Airports. https://www.lawa.org/sites/lawa/files/documents/LAX-eletGSE-Feasibility-Study-Report.pdf
7. Roland Berger. (2026, May 27). *Report on feasibility to reduce emissions during aircraft taxiing in California* (Draft Feasibility Study Report). California Air Resources Board. https://ww2.arb.ca.gov/sites/default/files/2026-05/20260518_Report%20on%20Feasibility%20to%20Reduce%20Emissions%20During%20Aircraft%20Taxiing_vEdited_sent_ada2.pdf

Next Steps


Dec 2024
First workshop
2025
Aviation Tech Forum in collaboration with U.S. EPA and SCAQMD
Jan 2026
Second workshop
Develop community engagement plan
Oct 2026
Third public workshop
2025
RFP for Zero-Emission Taxiing Feasibility Study
2027-2028
Continued stakeholder engagement
4th public workshop
Potential 1st Board hearing
2030
Implementation starts
2033 and 2037
Maximize emission reduction by the attainment years

Contact

Mo Chen, Ph.D.

Manager, Aviation Technology and Modeling Section

Email: Mo.Chen@arb.ca.gov

Phone: (279) 842-9577

SCAI website:

https://ww2.arb.ca.gov/our-work/programs/statewide-clean-aviation-initiative-scai

Click here to subscribe to updates on airport and aviation activities

Question and Answer (2 of 2)

- Please raise your hand if you would like to ask a question
  - Include slide numbers, if possible
  - In Zoom: Use “Raise Hand” feature
  - On phone:
    - #2 to “Raise Hand”
    - *6 to Mute/Unmute
- Additional questions may be submitted after today to: aircraft@arb.ca.gov or to Mo Chen (mo.chen@arb.ca.gov)

Cost Formulation Overview

Total cost of ownership (TCO) in 2025-dollar value by equipment type, technology type (diesel, electric, etc.), year and location/airport

Annual TCO (in 2025$):	TCO= annual capital cost + annual O&M	$annual\ TCO = CAP + O\&M$
Annual capital cost CAP:	Capital cost = loan payment of equipment (with tax) + charging infrastructure cost with installation	$\boldsymbol{CAP} = \sum PMT[Sale * RP \times (1 + tax)] + EVSE$
Operation and maintenance (O&M) costs $O\&M$ per year:	O&M cost = energy cost + maintenance cost + insurance cost	$\boldsymbol{O\&M} = \frac{EP}{EF} * HR + M + I$

- ***PMT***: periodic payment for a loan, is a function of equipment cost (with tax), financing terms z (typically 5 years) and annual interest rate r
- RP - Retail price ($)
- tax - Sales tax rate (sum of federal, state and local tax, 8.8% total)
- EP - energy price ($/gal or $/kWh)
- EF - energy efficiency (gal/hr or kW)

Scenario-specific inputs (vary with/without ZEV target):

- $Sale$ - New sales of equipment (unit/yr)
- ***EVSE***- Cost for purchasing and installing electric vehicle supply equipment $(EVSE)$ ($)
- HR - annual operation hours (hr/yr)
- M - maintenance and repair costs ($/yr)
- I - insurance fees ($/yr)

CARB

Unit GSE Operating Cost (Cont.)

- **Unit energy cost**
  - Electricity:
    - Base year: time-of-day energy cost by utility, aggregated with load profile in charging analysis
    - Future year: projected using growth rate derived from CEC energy cost projection (compound annual growth rate = 0.74%)
  - Other fuels: gasoline, diesel, nature gas, hydrogen
    - CEC fuel cost projection

