Advanced Clean Cars (ACC) II Workshop
September 16, 2020
[Updated]
Today’s Workshop Logistics

- Slides are posted at: https://ww2.arb.ca.gov/advanced-clean-cars-ii-meetings-workshops
- All webinar attendees will remain muted
- Questions can be sent via the GoToWebinar question box
  - Please include slide numbers
Agenda

1. Background
2. GHG Refrigerant Provision Proposal
3. LEV Criteria Emission Proposals
4. Break
5. ZEV-related Proposals
6. Update on BEV Costs
Role of Advanced Clean Cars II

Contribute to SIP Ozone Targets

Contribute to SB 32 and Carbon Neutrality Targets

LEV Criteria
Air Quality Improvements

LEV GHG
Greenhouse Gas Reductions

ZEV Technology Advancement
ACC II Rules Are Needed

California’s climate and air quality challenges still require deep reductions from light-duty vehicles.

**2017 Statewide GHG Emissions**
Total = 424 MMTCO2e

- Other Sectors: 59%
- Light-duty: 28%
- Medium-Duty: 2%
- Heavy-Duty: 7%
- Off-Road Mobile: 4%

**2017 Statewide NOx Emissions**
Total = 1294 tons per day

- Other Sectors: 20%
- Light-duty: 13%
- Medium-Duty: 6%
- Heavy-Duty: 26%
- Off-Road Mobile: 35%
2020 Mobile Source Strategy

- Forthcoming light-duty vehicle scenarios assume aggressive new ZEV sales and continued emission reductions from combustion vehicles
  - Include aggressive assumptions on decarbonizing electricity and hydrogen fuel
- Strong electrification is essential for emission reductions from the light-duty sector
  - Combination of multi-sector regulatory and non-regulatory policies will be needed to achieve these reductions
LDV Scenario* Fleet Mix for Deep Emission Reductions

* Forthcoming 2020 Mobile Source Strategy

* ~28% of on-road fleet
GHG Refrigerant Provision
Hydrofluorocarbon (HFC) Reductions

- Hydrofluorocarbons (HFCs): a class of chemicals replacing Ozone-Depleting Substances (ODS) such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)
  - Example: HFC-134a (R-134a) – being used as refrigerant in motor vehicle air conditioning (MVAC, or A/C) systems
- Many HFCs are potent GHGs with high Global Warming Potential (GWP) values – significant climate change contributors
  - Worldwide efforts to reduce HFC emissions
  - SB 1383 requires California HFC reduction of 40% below 2013 levels by 2030
Low-GWP LDV A/C Refrigerants – Current Regulations

- CARB and U.S. EPA’s current LDV GHG rules (MY 2017-2025) provide credit incentives for the use of low-GWP refrigerants, low-leak, and efficiency-improvement A/C technologies.
- CARB A/C Direct (Leakage) Credit for low-GWP A/C

<table>
<thead>
<tr>
<th></th>
<th>MaxCredit (gCO₂e/mi)</th>
<th>HiLeakPenalty * (gCO₂e/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>13.8</td>
<td>0-1.8</td>
</tr>
<tr>
<td>Truck</td>
<td>17.2</td>
<td>0-2.1</td>
</tr>
</tbody>
</table>

*HiLeakPenalty is calculated based on SAE J2727-evaluated A/C leak rate.

- CARB A/C Indirect (Efficiency) Credit for efficiency-improvement A/C technologies (e.g. reduced reheat with externally-controlled variable-displacement compressor; internal heat exchanger)

<table>
<thead>
<tr>
<th></th>
<th>MaxCredit (g/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>5.0</td>
</tr>
<tr>
<td>Truck</td>
<td>7.2</td>
</tr>
</tbody>
</table>
Low-GWP LDV A/C Refrigerants – Other Relevant Regulations

- A U.S. EPA Significant New Alternatives Policy (SNAP) rule changed HFC-134a and several other high-GWP LDV A/C refrigerants’ status from acceptable to unacceptable (from MY 2021)
  - The rule has since been vacated and remanded by court ruling to the extent that it requires HFC replacement
- EU MAC Directive (GWP<=150 for new vehicles from 2017)
Low-GWP LDV A/C Refrigerants – Industry Status

- HFC-134a (GWP=1,430) still common in in-use LDV fleet, but being replaced by low-GWP alternatives in new LDVs
- U.S. EPA SNAP-approved low-GWP alternatives:
  - HFO-1234yf (GWP=4) being used in millions of new vehicles
  - CO₂ (R-744) (GWP=1) being offered in EU markets
  - HFC-152a (GWP=124) in secondary-loop configuration being developed by industry

Data sources:
Global HFO-1234yf Regulatory Summary and Light Vehicle Conversion Update, Rick Winick, October 2019
ACC II A/C Refrigerant Concepts

- Prohibit high-GWP (>150) refrigerants in new LDV A/C systems (post-MY 2025)
  - Contribute to meeting State’s HFC reduction goals
  - Ensure continued industry low-GWP transition
  - Align with EU MAC Directive

- Continue to offer A/C credits (Leakage or Efficiency or both)
  - Use best and latest knowledge to inform credit program update
LEV Criteria Emission Proposals
Criteria Emissions Reductions from Combustion Vehicles

Increase Stringency
- NMOG+NOx fleet average
- SFTP stand-alone standard
- Robust PM emission control
- Optimize emission control for heavier vehicles
- Evaporative emissions

Real-World Reductions
- Better control of engine start emissions
- Address unique challenges for PHEV engine start emissions

Future Workshop
- PHEV Test Procedures
- PHEV NMOG+NOx credits
Current NMOG+NOx Fleet Average

Current ACC regulations require 0.030 g/mile ("30 mg/mi") NMOG+NOx fleet average beyond 2025
Item #1: Preserve Fleet Average of Non-ZEVs to Help Meet Future Ozone Targets

Non-ZEVs can emit at higher levels and still meet overall fleet average.

As ZEV share increases past 2025MY...

Fleet average 0.030 g/mile
Option A: Keep ZEVs In but Lower the Fleet Average

Account for expected or required ZEVs and set declining fleet average beyond 2025

Annual reduction of ~7 mg/mile

Each 5% increase in ZEV share ~3 mg/mile reduction
Option B: Transition to Non-ZEV Fleet Average

- **2025**
  - 5-20% ZEV share
  - \( \sim 0.032-0.038 \text{ g/mile} \)
  - Non-ZEV fleet avg.

- **2027+**
  - Require 0.030 g/mile non-ZEV fleet avg.
  - Annual reduction of \( \sim 7 \text{ mg/mile} \)

- **2 year phase-in**
  - Annual reduction of \( \sim 1-4 \text{ mg/mi} \)
Item #2: Further Emission Reductions for Non-ZEVs

Additional Investigations

- Reduce NMOG+NOx fleet average from 0.030 to 0.020 g/mile for a larger portion of the fleet
- Evaluating elimination of highest emission bins to promote transition to cleaner conventional vehicles
  - LEV160 and ULEV125
Item #3: NMOG+NOx Standards for Aggressive Driving

Less than 3% of vehicles are currently certified using stand-alone standards.
Composite Standards May Not Ensure Robust Control of Emissions

Theoretical Example
Composite SFTP standard can be met even with high emissions on SC03 and US06 cycles.

- Weighted average of FTP, SC03, and US06 meets composite standard: 0.030 g/mile
- FTP SULEV: 0.030 g/mile
- SC03: +50%
- US06: +100%
Nearly all test groups already meet stand alone SFTP…
but there are a few high emitters

ACC II Proposal: Require all to certify to stand-alone SFTP standards
Item #4: Evaporative Emissions

- Evaporative hydrocarbon emissions already exceed exhaust
- Diurnal and running loss expected to be equal share

Exhaust compared to Evaporative Emissions:
Light & Medium Duty

California Reactive Organic Gases (tons/day)
## Evaporative Emissions: Current Standards & Emissions

<table>
<thead>
<tr>
<th>Type of emissions:</th>
<th>Standard:</th>
<th>Last Revision:</th>
<th>Fleet Emissions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diurnal + Hot Soak</td>
<td>0.300 g/day</td>
<td>MY 2018</td>
<td>26 Tons/day</td>
</tr>
<tr>
<td>Running Loss</td>
<td>0.05 g/mile</td>
<td>MY 1995</td>
<td>26 Tons/day</td>
</tr>
</tbody>
</table>

1 Evaporative emissions in 2040, California, Source: EMFAC 2017
Evaporative Running Loss Emissions: Most Vehicles Well Below Standard

87% of 2019MY fleet at or below 0.010 g/mile
ACC II Proposal for Evaporative Emissions: Tighten Running Loss Standard

• Change standard from 0.05 g/mile to 0.010 g/mile
• Eliminate remaining high emitters and ensure good designs remain the norm
• Draft estimate of ~4 tons/day in HC reductions\(^1\)

\(^1\) Draft evaporative emissions in 2040, statewide, EMFAC 2017
Item #5: Emission Control for Heavier Vehicles

Recently adopted heavy-duty low NOx rules will apply to engine-certified medium-duty vehicles

- Mix of chassis dyno certified and engine dyno certified in medium-duty vehicles
  - Options vary based on weight class, fuel, and type of vehicle
  - Intent was to allow primarily LD OEMs to certify MDVs similarly and vice versa for HD OEMs
- Need to look at corresponding stringency change for chassis standard to avoid inconsistency
**Equivalency Complicated by Test Cycle Differences**

- Chassis cycle, based on LD, focuses on speeds/loads more common in LD usage
  - Engine cycle, necessarily, focuses on speeds/loads more common in HD usage
- Option to use engine or chassis cert not tied to expected usage of vehicle
  - Creates a mismatch in medium-duty vehicles used more like HD but certified like LD and vice-versa
- Emission controls optimized for one cycle don’t necessarily ensure good control in other operation

Chassis dyno testing covers different region of engine operation than HD engine dyno testing
Ongoing Work to Better Ensure Equivalency

- **ACC II Target**: Better ensure equivalent in-use emission control between chassis and engine certification testing
- Ongoing work:
  - Chassis dyno + On-road PEMS testing of medium-duty vehicles
  - Exploring effects of higher loads and towing on emissions
  - Evaluating ‘HD-like’ in-use standards for this category
    - E.g., 3 bin moving average window using PEMS
For more robust emission control, PM emissions are regulated on two test cycles: FTP and US06.
Ensure Robust PM Emission Control

- > 80% of vehicles tested were below 3 mg/mile on US06.
- Certification data reported 86% of test groups had US06 PM below 3 mg/mile.
- ACC II Proposal: Recognizing higher variability, phase-in more stringent US06 PM standard to ensure all vehicles can meet ~3 mg/mile standard.
Item #7: Clean Up the High Emissions from Cold Starts That Follow Intermediate Soaks

More than 40% of real-world vehicle starts follow intermediate soaks of 20 minutes to 5 hours.
Regulatory Concepts Being Evaluated

- Modify official FTP test procedure to account for intermediate soaks
  - Require emissions to be below standards following any cold soak between 10 min. and 36 hours
- Considering additional requirements for shorter intermediate soaks
  - Catalyst (and engine) temperatures above ambient should allow quicker light-off
  - Targeting same rate of catalyst heating used on overnight soak
Item #8 Better Control of Engine Start Emissions: Initial Idle Real-World Data

Real-World vs. Lab Test
- FTP cycle has a 20 second initial idle to warm-up catalyst
- In-use data indicates median value for initial idle is ~7 seconds
- Due to shorter idle, real-world emissions may exceed FTP levels

Initial Idle Time for a Trip

<table>
<thead>
<tr>
<th>Seconds</th>
<th>Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6</td>
<td>0-1</td>
</tr>
<tr>
<td>6-12</td>
<td>1-2</td>
</tr>
<tr>
<td>12-18</td>
<td>2-3</td>
</tr>
<tr>
<td>18-24</td>
<td>3-4</td>
</tr>
<tr>
<td>24-30</td>
<td>4-5</td>
</tr>
<tr>
<td>30-36</td>
<td>5-6</td>
</tr>
<tr>
<td>36-42</td>
<td>6-7</td>
</tr>
<tr>
<td>42-48</td>
<td>7-8</td>
</tr>
<tr>
<td>48-54</td>
<td>8-9</td>
</tr>
<tr>
<td>54-60</td>
<td>9-10</td>
</tr>
<tr>
<td>&gt;1</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>
Better Control of Engine Start Emissions: Initial Idle Testing

### Test Results

- Emissions with a 5 sec initial idle were double, on average, of the emissions observed with a standard 20 second initial idle.
- With 20 sec idle, focus is clearly on warming up catalyst while engine out emissions are low.
- With 5 sec idle, focus would need to be minimizing engine out emissions, while drive off is heating up catalyst.
Consider Regulatory Proposal with Additional Testing for Shorter Initial Idles

- Establish unique emission limit for 5 sec idle FTP
  - Could link to current certification standard (e.g., limit is 1.x standard FTP)
  - Could be weighted 3-bag or single cold start bag
  - Need to ensure continuity between the two points
    - Require compliance for any initial idle from 5-20 secs?

- Require continuation of catalyst warm-up strategy during drive off
  - Data supports initial drive off is not aggressive so peak torque not necessary
  - But extra heat to catalyst could be minimal incremental benefit
Item #9 Unique Challenges for PHEV Starts

**Car PHEVs**
- High power cold start emissions are similar to certification value

**Truck/SUV/Minivan PHEVs**
- High power cold start emissions are significantly higher than certification standard
Controlling PHEV Starts Emissions

 ACC II
Propose new standard based on test data of best performers
ZEV-related Proposals
Building ZEV Assurance

What actions can we take to support success for wide-scale adoption?

• Consumers still hesitate to purchase ZEVs

Need to think more broadly and imagine a world where 50% of on-road fleet is a ZEV

• How long are these vehicles expected to be on the road?
• How and where would those vehicles be repaired? Under warranty? Out of warranty?
• What does the used vehicle market look like?
Staff Proposal: ZEV Assurance Measures

1. Standardized DC Fast Charge Inlet
2. Require vehicle and battery data standardization
3. Require consumer facing battery state of health (SOH) indicator
4. Add ZEVs into existing service info requirements 
   *(to be discussed at future workshop)*
5. Add a useful life requirement
6. Add minimum warranty requirements
Fast Charge Inlet Standardization

What problem are we solving?
• Current BEVs have one of three different fast charge ports
  • SAE Combo (CCS 1)
  • CHAdeMO
  • Tesla
• Causes uncertainty in:
  • consumers knowing where they can charge
  • infrastructure planning, adding unnecessary cost for EVSE suppliers

<table>
<thead>
<tr>
<th>Connector</th>
<th>CHAdeMO</th>
<th>CCS1</th>
<th>Tesla</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Power</td>
<td>150kW</td>
<td>150 – 350kW</td>
<td>120 - 250kW</td>
</tr>
<tr>
<td>Comm. Protocol</td>
<td>CAN</td>
<td>PLC</td>
<td>CAN</td>
</tr>
<tr>
<td>Year</td>
<td>2009</td>
<td>2014</td>
<td>2012</td>
</tr>
</tbody>
</table>
Fast Charging Landscape

DC Connector Market Share (California)\(^1\)

- CCS, 32%
- CHAdeMO, 27%
- Tesla, 41%

\(^1\)August 2020 AFDC Database for California

BEV Models by Fast Charging Inlet Standard (current and expected)

- CCS1
- Tesla
- CHAdeMO

Number of Models

<table>
<thead>
<tr>
<th>Year</th>
<th>CCS1</th>
<th>Tesla</th>
<th>CHAdeMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>4</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2018</td>
<td>7</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2020</td>
<td>13</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2022</td>
<td>51</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Model Year

August 2020 AFDC Database for California
Staff Proposal: Standardize on-vehicle DCFC Inlet

- Following market trends, staff proposes all 2026 and subsequent model year vehicles that are fast charge capable use SAE Combined Charging System (CCS) 1 standard.
- Like the Level 2 charge connector standard we previously adopted (CCR 1962.3), OEMs may comply with requirement by providing an adapter.
Unlocking and Standardizing Data

Access and standardization of vehicle data is crucial for many parties:

• **Current drivers**: understanding warranty coverage or need for repair
• **Prospective drivers**: used car valuation for seller/purchaser
• **Repair technicians**: assessment of need for repair/rebuild
• **Battery refurbishment or reuse industry**: Assessment of remaining battery pack value for use in a second life application (e.g., grid storage)
• **CARB**: understanding compliance to applicable requirements (e.g., full useful life, warranty)
Staff Proposal: Battery State of Health

• Standardize what battery state of health represents:
  1. Usable battery capacity, as determined by SAE J1634 dyno testing, and within a defined accuracy and minimum update frequency
  2. Normalized (e.g., 0-100%) so understandable and relative to what it could do when new

• Require that it can be accessed by a consumer without the use of a tool
Staff Proposal: Data Standardization

• Staff proposes to require standardized data to address following purposes:
  1. SOH Metric
  2. Grid Energy Use
  3. Dynamometer Testing
  4. Battery Repairs
  5. Activity/Inventory

• Require vehicle to have standardized data connector and use standardized communication protocols (e.g., like conventional cars)

*See Appendix Slides for proposed data parameters
Staff Proposal: Adding Service Info Requirements for ZEVs

• Mimic what is done for conventional cars for service and repair information (CCR 1969)

• OEMs would be required to make ‘powertrain’ service and repair information available to independent technicians
  • Powertrain includes all components and systems related to refueling and propulsion (including regenerative braking)

• Also includes standardized reprogramming and licensing with aftermarket diagnostic tool providers
Update on BEV Costs
How Have BEV Costs Been Estimated Previously?

1. Define BEV performance specifications – range, vehicle mass, battery size, power, efficiency

2. Define costs for BEV specific components – battery, electric motor and gearbox, etc…

<table>
<thead>
<tr>
<th>TAR 2025MY BEV200 Vehicle Type</th>
<th>Incremental Vehicle Costs (2013 $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcompact</td>
<td>$ 12,001</td>
</tr>
<tr>
<td>MdC / SmMPV</td>
<td>$ 13,422</td>
</tr>
<tr>
<td>Large Car</td>
<td>$ 16,746</td>
</tr>
</tbody>
</table>
BEV Powertrain Modeling

1. Decide on range and power requirements
2. Size battery pack capacity and electric motors across vehicle sizes
   a. Estimate vehicle road load
   b. Initial sizing
   c. Verify desired performance/range
   d. Iterate/resize as needed
Developing Battery Costs

• Work to date relying on multiple tools, reports, and projections including:
  • Argonne National Laboratory Battery Pack and Costing model (BatPaC)
  • U.S. DOE Targets and Projections
  • Total Battery Consulting, BNEF, UBS, and others

• General methodology has been:
  • Use BatPaC to generate initial starting point for now/near future
  • Account for additional learning/technology advancements projected for rulemaking timeframe
    • Battery chemistry
    • Design improvements
    • Manufacturing improvements
Battery pack costs are expected to continue to fall quickly in the near term.
Non-Battery Component Cost Projections

• Method:
  • Near term costs estimated from numerous teardowns and vehicle comparison reports
  • Additional 1.5% per year cost reduction projected for future years

• Example Cost:
  • BEV300 Passenger Car non-battery component costs start at ~$4,100 in 2027 and fall $500 from learning to ~$3,600 in 2035
Ongoing Work

• Past modeling has not included any improvement in component efficiency over time

• Other areas of investigation
  • Manufacturing efficiency/cost differences
  • Capturing current/future criteria pollutant emission costs (e.g., design, calibration, hardware, compliance)
  • Capturing differences from BEV specific platform (e.g., design, calibration, assembly)

BEV product simplification yields floor space and capital efficiencies

CEO Strategic Update, Ford Motor Company, October 3, 2017
Other Opportunities for Comments

• Written comments may be submitted through October 16, 2020 to: cleancars@arb.ca.gov

• Subscribe to the Clean Cars email list for updates on future workshops on:
  • Plug-in hybrid and fuel cell technology cost assessment
  • GHG fleet average stringency
  • ZEV credit requirements
  • And more…
Appendix Slides
Proposed Data Parameters

<table>
<thead>
<tr>
<th>SOH Metric</th>
<th>Grid Energy Use</th>
<th>Vehicle Dyno testing</th>
<th>Data for Battery Repair/Rebuilders</th>
<th>Activity/Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOH</td>
<td>Total Grid Energy (DC) into battery(^1,2)</td>
<td>Vehicle speed(^1)</td>
<td>Total current throughput (amp-hr)(^2)</td>
<td>odometer(^1)</td>
</tr>
<tr>
<td>distance since last SOH update</td>
<td>Total Grid Energy (AC) into car(^*)</td>
<td>Accelerator pedal position(^1)</td>
<td>Individual cell active voltage (^*)</td>
<td>Distance since code clear(^1)</td>
</tr>
<tr>
<td></td>
<td>Total Grid Energy Used during Cd(^1,2)</td>
<td>SOC(^1)</td>
<td>Individual module active voltage</td>
<td>Ignition cycles since code clear(^1)</td>
</tr>
<tr>
<td></td>
<td>Total distance travelled in Cd(^1,2)</td>
<td>Battery voltage(^1)</td>
<td>Individual cell most recent OCV (^*)</td>
<td>Ignition cycles(^1,2)</td>
</tr>
<tr>
<td></td>
<td>Total Propulsion System Active (PSA) time(^1,2)</td>
<td>Battery current (cumul. current for last 1 sec)</td>
<td>Individual module most recent OCV</td>
<td>Positive Kinetic Energy (PKE)(^1,2)</td>
</tr>
<tr>
<td></td>
<td>Total energy into battery from regen braking(^*)</td>
<td>Power consumption (cumul. power for last 1 sec)</td>
<td>Individual cell most recent calculated resistance</td>
<td>Total PSA time at idle(^1,2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AC inlet current (cumul current for last 1 sec)(^*)</td>
<td>BMS detected faults</td>
<td>Total PSA time at city speeds(^1,2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AC inlet voltage(^*)</td>
<td>Battery temp sensors?</td>
<td></td>
</tr>
</tbody>
</table>

\(^*\) if equipped

1 Parameters that are already standardized in SAE J1979 and may be appropriate fits (typically Mode $09$, InfoTypes $16$-$1C$ and Mode $01$)

2 Parameters that might need 'recent' and 'lifetime' values like already done for much of Mode $09$ InfoTypes $16$-$1C$
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC</td>
<td>Advanced Clean Cars</td>
</tr>
<tr>
<td>A/C</td>
<td>Air Conditioning</td>
</tr>
<tr>
<td>BEV</td>
<td>Battery Electric Vehicle</td>
</tr>
<tr>
<td>BMS</td>
<td>Battery Management System</td>
</tr>
<tr>
<td>BNEF</td>
<td>Bloomberg New Energy Forecast</td>
</tr>
<tr>
<td>CCR</td>
<td>California Code of Regulations</td>
</tr>
<tr>
<td>CCS</td>
<td>Combined Charging System</td>
</tr>
<tr>
<td>CFC</td>
<td>Chlorofluorocarbon</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DCFC</td>
<td>Direct Current Fast Charge</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMFAC</td>
<td>EMission FACtor, a model that estimates the official emissions inventories</td>
</tr>
<tr>
<td></td>
<td>of on-road mobile sources in California</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EVSE</td>
<td>Electric Vehicle Supply Equipment</td>
</tr>
<tr>
<td>FCEV</td>
<td>Fuel Cell Electric Vehicle</td>
</tr>
<tr>
<td>FTP</td>
<td>Federal Test Procedure (emission test representative of urban driving)</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
</tr>
<tr>
<td>GVWR</td>
<td>Gross Vehicle Weight Rating</td>
</tr>
</tbody>
</table>
### Acronyms and Terms (continued)

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
</tr>
<tr>
<td>HC</td>
<td>Hydrocarbon(s)</td>
</tr>
<tr>
<td>HCFC</td>
<td>Hydrochlorofluorocarbon</td>
</tr>
<tr>
<td>HD</td>
<td>Heavy Duty</td>
</tr>
<tr>
<td>HEV</td>
<td>Hybrid Electric Vehicle</td>
</tr>
<tr>
<td>HFC</td>
<td>Hydrofluorocarbon</td>
</tr>
<tr>
<td>HPCS</td>
<td>High Power Cold Start (Occurs for a plug-in hybrid when the combustion engine is required to supply high power immediately upon starting)</td>
</tr>
<tr>
<td>HV</td>
<td>High Voltage</td>
</tr>
<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial idle</td>
<td>Duration between the ignition-on event and drive-away</td>
</tr>
<tr>
<td>kW/kWh</td>
<td>Kilowatt / Kilowatt-Hour</td>
</tr>
<tr>
<td>LD</td>
<td>Light-Duty</td>
</tr>
<tr>
<td>LDT</td>
<td>Light-Duty Truck</td>
</tr>
<tr>
<td>LDV</td>
<td>Light-Duty Vehicle</td>
</tr>
<tr>
<td>LEV</td>
<td>Low Emission Vehicle</td>
</tr>
<tr>
<td>LEV160</td>
<td>Low Emission Vehicle certified to 0.160 g/mile NMOG+NOx</td>
</tr>
<tr>
<td>LVW</td>
<td>Loaded Vehicle Weight</td>
</tr>
<tr>
<td>MAC</td>
<td>Mobile Air Conditioning</td>
</tr>
<tr>
<td>MDPV</td>
<td>Medium-Duty Passenger Vehicle</td>
</tr>
</tbody>
</table>
## Acronyms and Terms (continued)

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDV</td>
<td>Medium-Duty Vehicle</td>
</tr>
<tr>
<td>MMT</td>
<td>Million Metric Tonnes Carbon Dioxide Equivalent</td>
</tr>
<tr>
<td>CO$_2$e</td>
<td>Million Metric Tonnes Carbon Dioxide Equivalent</td>
</tr>
<tr>
<td>MVAC</td>
<td>Motor Vehicle Air Conditioning</td>
</tr>
<tr>
<td>MY</td>
<td>Model Year</td>
</tr>
<tr>
<td>NMOG</td>
<td>Non-Methane Organic Gases</td>
</tr>
<tr>
<td>NOx</td>
<td>Nitrogen Oxides</td>
</tr>
<tr>
<td>ODS</td>
<td>Ozone-Depleting Substance</td>
</tr>
<tr>
<td>OEM</td>
<td>Original equipment manufacturer</td>
</tr>
<tr>
<td>Overnight Soak</td>
<td>Soak of more than 12 hours</td>
</tr>
<tr>
<td>PC</td>
<td>Passenger Car</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEMS</td>
<td>Portable Emissions Measurement System</td>
</tr>
<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicle</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate Matter</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>SB 32</td>
<td>Senate Bill 32 (Chapter 249, Statutes of 2016, Pavley)</td>
</tr>
<tr>
<td>SB 1383</td>
<td>Senate Bill 1383 (Chapter 395, Statutes of 2016, Lara)</td>
</tr>
<tr>
<td>SC03</td>
<td>Emission test for driving in hot ambient air temperature with air conditioning in the vehicle turned on</td>
</tr>
<tr>
<td>Acronym</td>
<td>Definition</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>SFTP</td>
<td>Supplemental Federal Test Procedure</td>
</tr>
<tr>
<td>SIP</td>
<td>State Implementation Plan</td>
</tr>
<tr>
<td>SNAP</td>
<td>Significant New Alternatives Policy</td>
</tr>
<tr>
<td>Soak</td>
<td>Duration between engine-off event and the subsequent engine-on event</td>
</tr>
<tr>
<td>SOH</td>
<td>State of Health</td>
</tr>
<tr>
<td>SULEV</td>
<td>Super Ultra Low Emission Vehicle</td>
</tr>
<tr>
<td>TAR</td>
<td>Technical Assessment Report</td>
</tr>
<tr>
<td>UDDS</td>
<td>Emission test cycle representative of urban driving</td>
</tr>
<tr>
<td>ULEV</td>
<td>Ultra Low Emission Vehicle</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULEV125</td>
<td>Ultra Low Emission Vehicle certified to 0.125 g/mile NMOG+NOx</td>
</tr>
<tr>
<td>US06</td>
<td>Emission test for aggressive driving</td>
</tr>
<tr>
<td>US DOE</td>
<td>United States Department of Energy</td>
</tr>
<tr>
<td>US EPA</td>
<td>United States Environmental Protection Agency</td>
</tr>
<tr>
<td>ZEV</td>
<td>Zero Emission Vehicle</td>
</tr>
</tbody>
</table>
Battery Costing Sources

• Models
  • BatPaC v4.0

• Reports and Papers
  • Total Battery Consulting (TBC) xEV Insider Reports
  • Bloomberg New Energy Finance (BNEF) EV Outlook and Battery Costs Survey
  • UBS Chevrolet Bolt EV Teardown
  • U.S. DOE Targets and Projections
Battery Costing Sources (cont.)

- Conferences and Symposiums
  - Advanced Automotive Battery Conferences
  - SAE Hybrid and Electric Vehicles Symposium
- Automaker Announcements & Reports
  - Chris Davies “VW I.D. EV boast: We’ll hugely undercut Tesla’s Model 3 says exec,” SlashGear, July 17, 2017
  - Tesla 2018 Annual Shareholder Meeting, June 5, 2018
Non-Battery Component Costing Sources

• Munro Teardown and Comparison Reports

• CARB Agreement 15CAR018 - Advanced Strong Hybrid and Plug-In Hybrid Engineering Evaluation and Cost Analysis

• UBS Chevrolet Bolt EV Teardown