The Current and Future State of EV and AV Technologies

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Purpose

Provide real-world context and highlight current capabilities and challenges of Electric Vehicle (EV) and Autonomous Vehicle (AV) technologies

Highlight current and expected trends and adoption patterns of EV and AV

Discuss design constraints and lessons learned from developing an at-scale AV shuttle system ConOps and preliminary system design

Agenda

- Overview of EV Technologies
- Overview of AV Technologies
- Charging and Fleet Considerations
- Overview of AV Pilot Deployments and State of the Industry
- Adoption Patterns and Future Trends of EV and AV Technologies
- Lessons Learned from AV Shuttle System ConOps and Preliminary Design

Why EV and AV Technologies Matter

- Have impacts on:
  - Emission targets and sustainability
  - Safety outcomes
  - Operating costs
  - Agency policies and legal frameworks
- EVs/AVs have become connected, software defined nodes in the transportation system
- Growing from individual trips and drivers to transit fleets and automated services
- Has implications on ITS:
  - Integration of vehicles, infrastructure, and grid systems rather than vehicles being passive users of the transportation network

Overview of EV Technologies

- Battery Electric Vehicles (BEVs):
  - Fully electric powertrain; dependence on standardized grid charging and depot/home infrastructure using standard EV connectors
- Plug-in Hybrid Electric Vehicles (PHEVs):
  - Combination of gasoline and electric vehicles
    - Have a battery, an electric motor, a gasoline tank, and an internal combustion engine
  - Use both gasoline and electricity as fuel sources

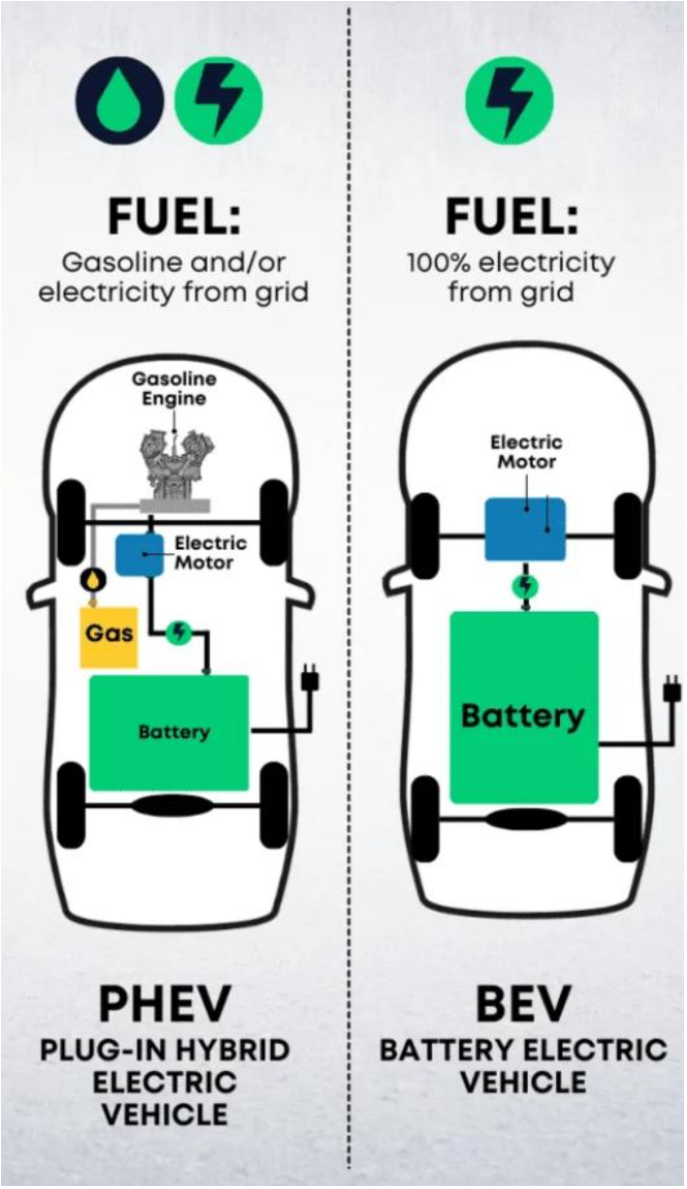


Image Source: REGENY-feb-2023-768x960.png (768×960)

Overview of EV Technologies

- Fuel Cell Electric Vehicle (FCEVs) – niche today:
  - Generates electricity on-board by combining hydrogen gas with oxygen from the air, producing water vapor as the only emission.
  - Unlike BEVs, FCEVs do not rely solely on stored electricity – uses a hydrogen powered fuel cell, often with a small battery for backup

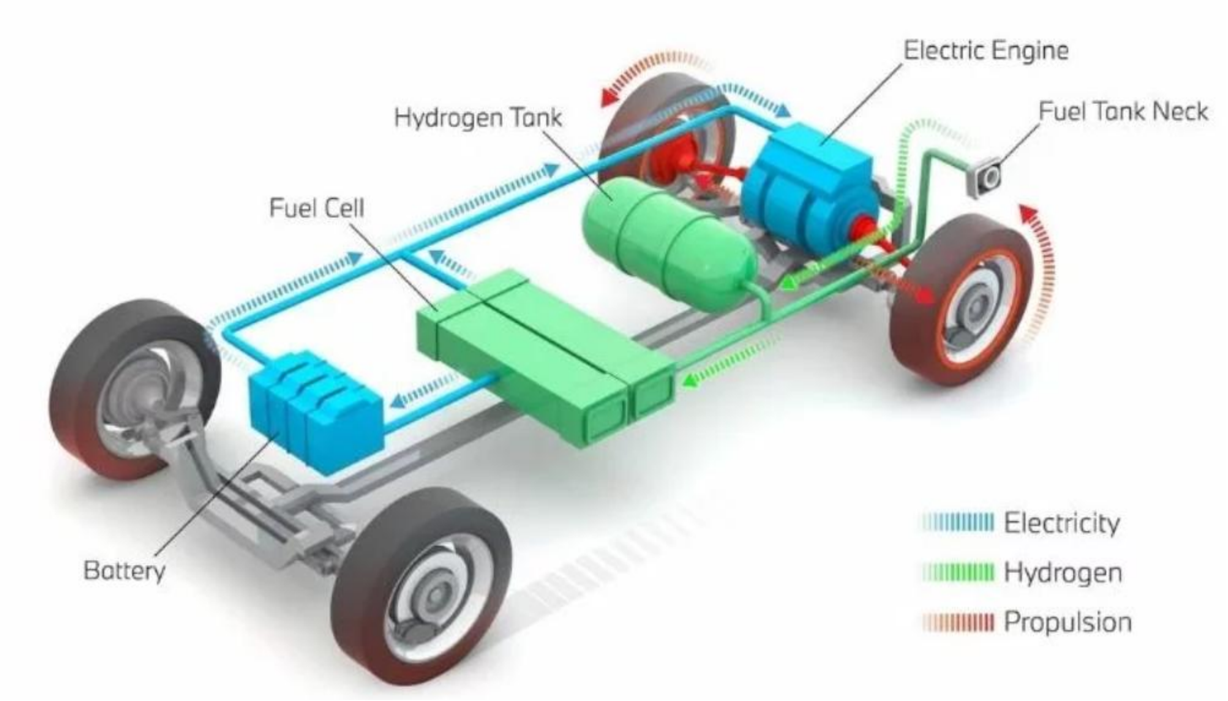


Image Source:
[FCEV - Fuel Cell Electric Vehicle | evmojo.com]

Overview of AV Technology

- AVs in use today use EV propulsion
- SAE J3016 defines varying levels of automation and need for human inputs (discussed in later slides)
- AVs use a combination of sensors, perception inputs, and vehicle control software to perform the "dynamic driving task" (i.e. driving itself)
  - Cameras
  - LiDAR
  - GPS
  - Vehicle telematics
  - Vehicle mapping
  - CV2X (where needed or desired for SPaT, MAP, and other CV apps)
  - Software stack and computer perception and prediction technologies
  - Etc.

Overview of AV Technology

- For managed AV fleets and commercial operations additional technologies are needed:
  - Central Control Center for remote monitoring and control, emergency intervention, teleoperations, vehicle health monitoring, etc.
  - Technologies for transit applications such as:
    - Passenger information systems
    - Emergency communications
    - Fare payment collection
  - Other technologies dependent on AV application, ex. charging depot and curb management systems
  - Integration with transportation agency systems for data collection, operational monitoring, KPIs, and fleet management

SAE J3016™ LEVELS OF DRIVING AUTOMATION™

Learn more here: sae.org/standards/content/j3016_202104

	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/ acceleration support to the driver	These features provide steering **AND** brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Image Source:
SAE Levels of Driving Automation™ Refined for Clarity and International Audience - SAE International

Overview of AV Technology

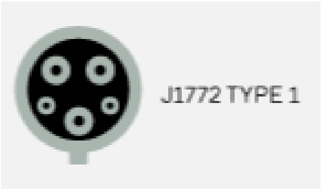
- The Operational Design Domain (ODD) defines the environment that an AV is designed and expected to operate safely within, including factors such as:
  - Level of automation
  - Weather
  - Road type(s)
  - Speed limits
  - Other considerations such as interaction with pedestrians, normal traffic, etc.
- ODD definition is crucial to define when designing an AV system with high-levels of automation

The Human Element of AV Technology

- Scheduling, supervision, and maintenance remain human roles
- Fleet orchestration and management of wired charging operations
- Remote monitoring and teleoperations
- On site response to incidents
- Customer assistance
- Interfaces between AV operations centers and agency TMCs for incident coordination, detours, work zones, etc.
- Fleet management and ITS operations (signals, DMS, lane control systems)

Overview of EV and AV Charging – Wired

	Level 1 Chargers	Level 2 Chargers	Level 3 (DC Fast) Chargers
Compatibility	Most EVs in USA	Most EVs in USA	Most modern EVs, but vehicle dependent
USA Standard Connector Type	SAE J1772, or “J Plug”	SAE J1772, or “J Plug”	CCS1 (Combined Charging System Type 1) or NACS (North American Charging Standard, SAE J3400)**
Power Requirement	120-volts (residential)	208-volts (commercial) 240-volts (residential)	480-volts or 1,000-volts (commercial)
Operating Voltage	120-volts	208 – 240 volts	400 – 1,000 volts
Output Power Range	1.1 - 1.9 kW	3 – 19.2 kW	15 – 350+ kW
Typical Full Charge Time for EV Shuttle*	Varies widely on battery size ~16 – 40+ hours	~8 hours (+/-)	~2 hours (+/-)



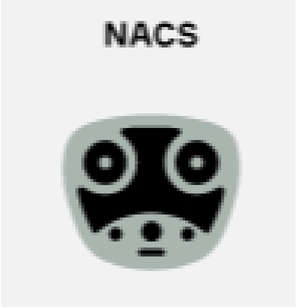


Image source:
https://www.aptiv.com/

*Vehicle charging times are dependent on charger output, vehicle battery capacity, and vehicle charge acceptance rates

**SAE announced in June 2023 that it would standardize the NACS connector developed by Tesla as SAE J3400. Most EV models on the market today use the CCS1 connector, but most vehicle manufacturers have committed to incorporate the J3400 connector beginning in 2025. These companies have also indicated that they will provide J3400 adapters to owners of CCS vehicles beginning in 2024. NACS can also be used for AC Level 1 and Level 2 charging and is compatible with the J1772 connector for these charging speeds through an adapter (https://driveelectric.gov/charging-connector)

Overview of Inductive Charging

- Generally considered as fast and efficient as L2 wired charging options (up to ~20 kW)
- Higher speeds available (ex. WAVE, inc. reports up to 250 kW)
- Uses resonant electromagnetic induction to transmit electrical current
- Magnetic coil in the charger sends current to a
- magnetic coil on the car's underside

*Not widely adopted in the USA at large scale. Charging infrastructure solutions are available; however, vehicle retrofits are required and are costly

Overview of Inductive Charging

- **Static** - EV is not moving while charging. The wireless charging equipped EV is parked over the wireless charging coil in a designated space (ex. Shuttle stops)
- **Dynamic** – EV is moving while charging. Inductive charging technology is built into the roadway, allowing EVs to charge while in motion at potential speeds of 65 mph (future, anticipated)
- Benefits may include:
  - Maintaining ideal battery charge levels, extending battery life
  - Extending operational range without stopping for wired charging
  - Reduction in human effort for plugging / unplugging vehicles

Planning for AV and EV Fleets: Charging and Staffing Analyses

First, need to determine transit fleet demands

- Inputs:
  - Passenger demands
  - Route lengths
  - Travel times, dwell times, etc.
- Output:
  - Minimum fleet size to meet demands

Then, need to apply vehicle charging capabilities and range per charge to determine:

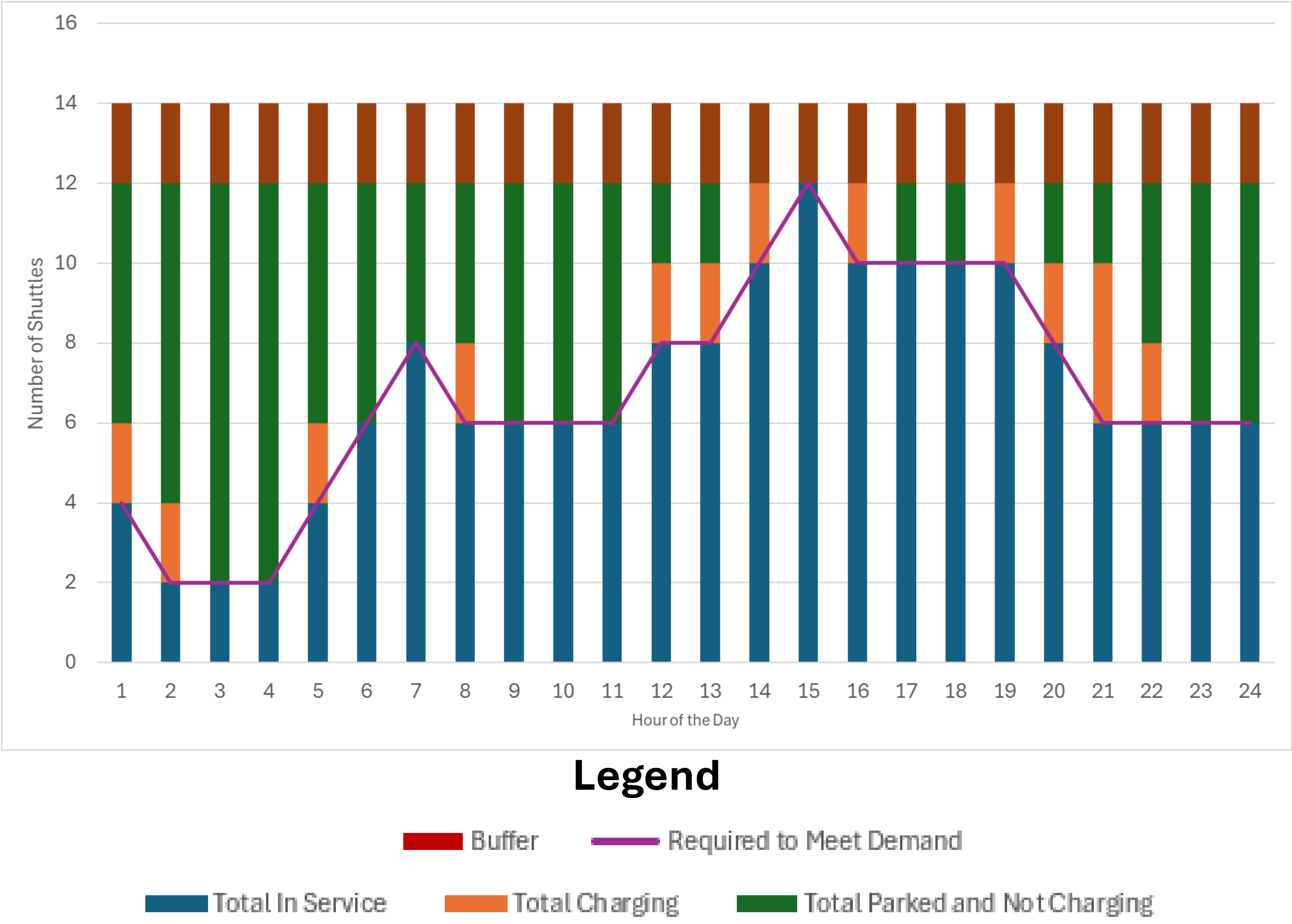
- Charging infrastructure needs
- Additional vehicles needed to support charging operations
- Spare vehicles needed to accommodate operations and maintenance

For Human Driven EV, also need to factor in driver staffing needs which impact fleet sizes*

*Minimum fleet sizes increase once charging capabilities, vehicle range, and staffing needs are applied. In comparison to AV fleets, which are most directly impacted by their charging capabilities and range per charge, EV fleet sizes are impacted most by staffing needs, as full-time driver shifts are generally short than EV ranges per charge. Inductive charging can keep vehicles in service for longer periods of time through opportunity charging vs. strict stop and plug-in charging operations. Even for AV deployments, they will have a human element to manage vehicles and charging operations

Example AV Fleet Charging Analysis Curve

(Based on Hourly Demands)



Requirements	Design Case
Required Total Fleet Size	**14**
Total Operational Vehicles in Fleet[1]	12
Assumed Out-of-Service Vehicles (10%)	2
Required Dedicated Fast Chargers	4

1. This includes all operational shuttles that are either servicing passengers, parked and charging, or parked and not charging.
2. Data from third analysis day is shown on graphs since this is when patterns have stabilized and represent normal operations.

AV Protypes to Advanced Pilots – State of the Industry

- Early AV deployments:
  - Low speed, fixed route deployments (campuses, business parks, controlled environments).
  - Primary objectives: validate basic safety, operations, and public interaction.
- Current AV pilot patterns:
  - Geofenced robotaxi and delivery services in specific zones and dedicated guideways
  - Pilot operations with and without onboard safety operators, depending on maturity and regulation

AV Protypes to Advanced Pilots – State of the Industry

- Current AV operational characteristics include:
  - Tight ODD definitions for roads, times of day, weather constraints, and speed limits
  - Intensive testing and simulation prior to expanding zones or conditions
  - Structured incident logging, safety case development, and performance monitoring
- ITS integration points may include:
  - Coordination with signal systems (priority, SPaT, MAP) in AV operating areas
  - Use of Central Control Center data to route and manage AV fleets
  - Data sharing agreements for AV probe data to support planning and real time operations

Adoption Patterns

- **EV:** Increasing adoption in light duty and targeted heavy-duty applications where duty cycles and economics are favorable
  - Likely to continue steady increase as EV tech becomes more efficient and affordable
- **AV:** Increase in localized pilots. Increase in at-scale deployments for high value, constrained use cases and additional ODDs, replacing human drivers
  - Widespread adoption is generally following demonstrable and validated deployments
  - Value and feasibility is measured within existing infrastructure and policy constraints
- EVs and AVs are rapidly becoming more reliable and observable elements of the transportation system

Future Trends

- General advancement of battery, charging, sensor technologies, and computer perception / decision making
- Enhanced ITS integration:
  - Increase in resources for integrated mobility energy systems
  - AV fleets providing enhanced data, safety, and analytics
  - Convergence of AV/EV integration with signal systems, curb management, MaaS platforms, and smart city programs
- Core questions are about technology standardization, integration, control, data, and operations
- Additional questions surround AV policies and legal frameworks
  - Pending AV legislation
  - Design standards (ex. ASCE-21)

Lessons Learned

- Derived from developing a ConOps and preliminary system design for a fully autonomously operated AV shuttle system for an airport use case
- Design constraints and risks included:
  - Need for dedicated guideways
  - Limited space in highly developed urban environment
  - Lack of a formal design vehicle to better inform preliminary design decisions
  - Clearance and roadway geometry limitations
  - Power distribution limitations
  - Gaps in standards for AV system designs
    - There is no specific AV standard, ASCE-21 is a “best fit”
  - Unclear scope of design of ITS and supporting field technology elements in addition to AV technologies

Lessons Learned

- Lessons Learned include:
  - Beyond physical design of the roadway, AV shuttle system technology needs are complex and include many integrated elements (in-vehicle systems, ops centers, and ITS) – all must be coordinated for seamless operations
  - Iterative designs aided in "weeding out" less desirable options (route configurations, charging operations analyses, etc.)
  - Defining KPIs and system data needs early aided to ID systems that are "must haves" vs. "nice to haves"
  - ASCE-21 was researched heavily to guide preliminary tech designs. However, ASCE requirements require substantial modification to be applicable to AV use cases
  - Close coordination with AV vendors will be required as shuttle system designs progress

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