Gopal Duleep
H-D Systems

Vehicle Attribute Forecasts

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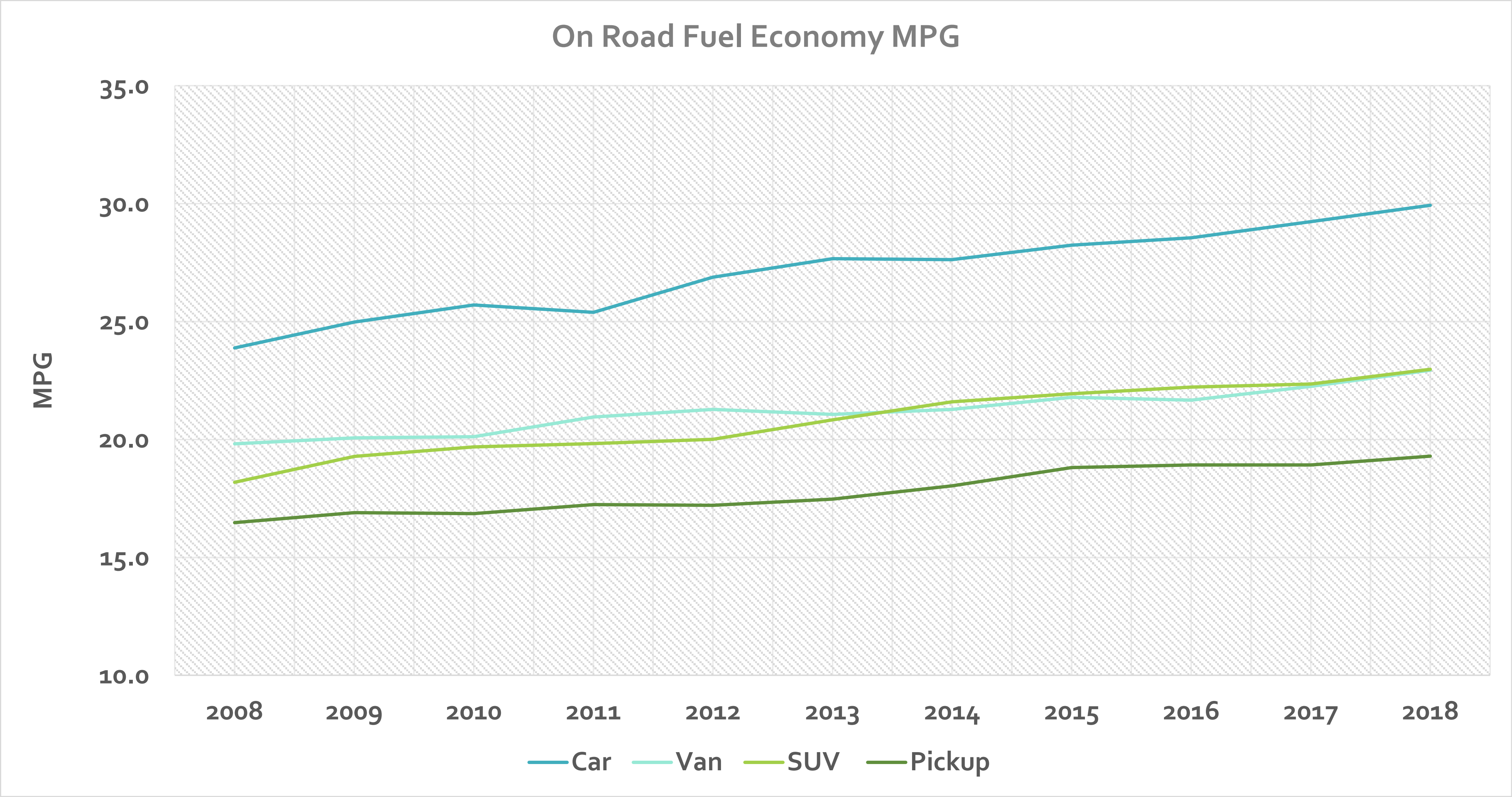
Overview

- Vehicle Attribute forecasts are required by the California Energy Commission demand model to obtain information on vehicle technology, performance, weight and cost at the size/market class
- HDS and its staff have been providing Energy Commission with these forecasts since the 1990s and has also supported the development of the Department of Energy's National Energy Modeling System (NEMS) transport model of fuel demand during various periods.
- Our forecasting model simulates the "supply" side i.e., the auto industry and how they will respond to demand and the regulatory framework, but vehicle demand by size class is predicted by the Energy Commission model for both light duty and heavy duty vehicles.
- Unfortunately, our models do not interact dynamically so that the supply and demand frameworks are coordinated externally.

Forecasting Methodology

- The general assumption for all forecasting models is that, on average across all models, vehicle prices are related to costs. This is true in any competitive industry although manufacturers can cross subsidize models for some time periods.
- Costs of increased fuel economy and performance are related to costs of technology which have been extensively studied by regulatory agencies and the National Academy of Sciences. Technology costs are used to construct a “fuel economy supply curve” by size class starting from a baseline year.
- In a free market scenario, manufacturers adopt all technology (subject to lead time constraints) that pay for themselves in fuel savings over 3 years. In a regulatory scenario, technologies are adopted to meet standards applicable to the class (footprint area) based standard of the vehicle

Fuel Economy Under Regulation



Forecasting Issues

- Under stringent regulations for fuel economy, the fuel economy and cost of vehicles become detached from fuel prices at the size class level as regulations drive technology adoption.
- While most fuel economy technology like high compression ratio engines, advanced transmissions, weight reduction, etc., are transparent to the customer, electrification is more visible.
- In this modeling, conventional technology improvements are modeled as manufacturer choices, while all electrified vehicle types and alternative fuel vehicles are modeled based on consumer demand. Our vehicle supply model has separate forecasts for all electrified and alternative fuel vehicles as well as conventional gasoline vehicles.
- Growth in vehicle performance (HP/WT) has declined to near zero at size class level since 2010 due to the need to meet stringent standards.

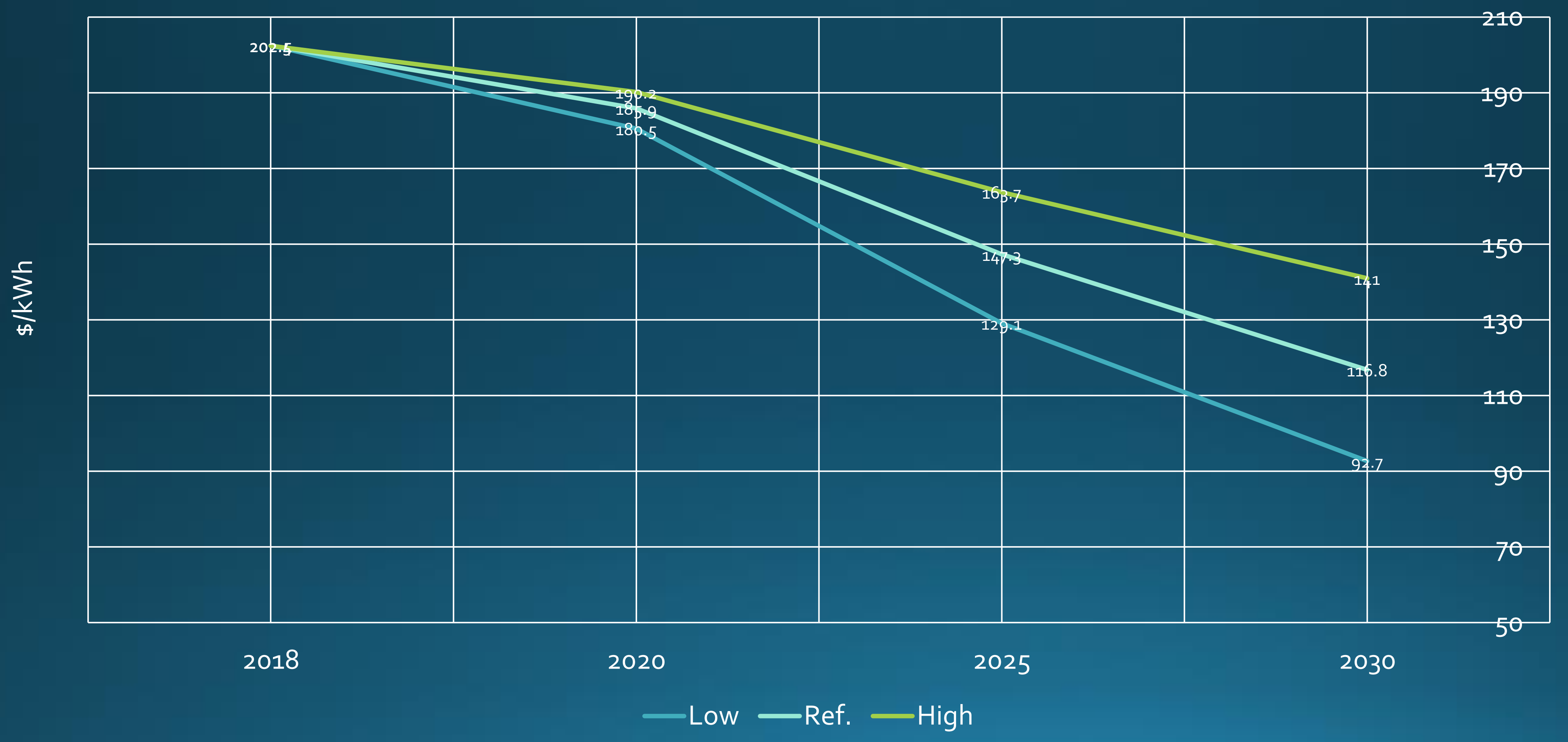
Light Duty Electric Vehicles

- Forecasts of future EV prices are largely dependent on estimates of battery costs. Very aggressive cost reduction forecasts for batteries are in the public domain and are key to EV competitiveness in the future.
- Costs vary significantly between a cell, a module (or collection of cells) and an entire automotive battery which includes safety, battery monitoring and battery cooling systems housed in a crash-proof box.
- While press reports suggest current (battery?) costs of ~$170/kWh, analysis of Tesla financials suggest costs of ~$210/kWh. Cost reductions of 40 to 50 percent may be possible by 2030. Future cost decline rates are handled on a scenario basis.
- The trade-off between range and costs must be decided externally from the modeling and vehicles with at least 200 mile range seems to the direction of the industry. However, cheaper small urban vehicles with ~100 mile range are likely to be available in the market as well.

Battery Costs

- Many financial houses (e.g. Bloomberg, UBS) are reporting battery costs from financial analysis and teardown analysis. Our review suggests 2018 costs of about $180 +/- $10 per kWh are reported for Tesla-Panasonic which is the most efficient producer, while Tesla's net cost in the vehicle may be around $210/ kWh.
- Some studies do not include battery manufacturer profit and most do not include vehicle integration cost which includes battery safety, thermal management and monitoring systems. Costs depend on size and number of battery packs on vehicle.
- We have used data from ANL's BATPAC model and EPA/NHTSA vehicle integration costs and learning curves from the 2018 rulemaking for the reference case. Their data shows battery production cost of $160/kWh in 2020, and at $180/kWh with profit and vehicle integration cost.
- Costs for other scenarios are based on optimistic and pessimistic learning curve rates to model range of public estimates.

Battery Cost Forecast (Installed in EV)



Electric Vehicle Cost/Range

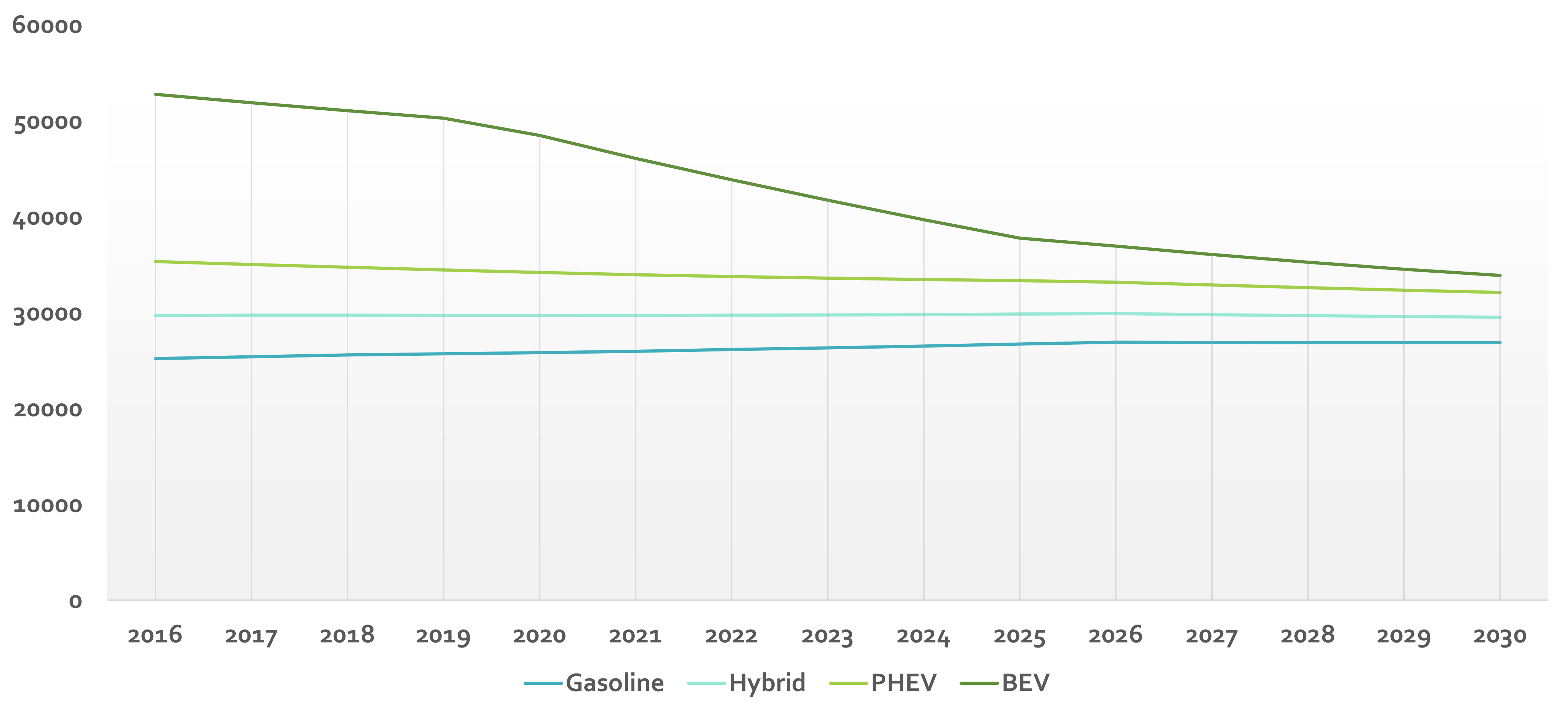
- As battery costs fall, EV manufacturers are keeping price relatively constant and offering more range. The trade-off between cost and range is given by maximizing sales volume V by increasing battery size B in kWh
  - $dV/dB = e_1 * P_b/P_c + e_2 * FE/R = 0$ for maximizing sales volume

  where e_1 is the price elasticity and e_2 the range elasticity, P_b battery cost in \$/kWh, P_c is vehicle cost and FE is the fuel economy
- The value of e_2 is not known and is itself a function of range so that the solution is used only in general terms. Demand for more battery storage should increase with vehicle cost and decrease as FE increases.
- We have estimated that mid-size vehicles (cars and SUVs) will see average increase to ~250 miles by 2025 and ~300 by 2030 while larger vehicles will have ranges of 300 to 350 miles. We expect that the smallest car class will offer urban EVs with a range of 100 to 125 miles.

Electrified Vehicle Forecast
Example of Midsize Cars

- Prices of conventional vehicles will increase by about $1500 from 2016 to 2030 in constant 2018 dollars due to increased technology to meet Obama era standards, while FE will increase from 29 mpg to 41 mpg.
- Hybrid Vehicles will see a narrowing of the price differential from about $4500 in 2016 to $2700. The MPG benefit will decline from 46% to 36%.
- PHEV range is forecast to be ~50 miles to maximize ZEV credit. The price increment over hybrids will decline from $5600 to $2300. We expect a lot of PHEVs to be introduced, especially by European manufacturers.
- BEV range will increase to ~300 miles by 2030 and cost increment over PHEV will fall from $17,000 to $1700 over a PHEV. If range is maintained at under 200 miles, BEV costs will be competitive with conventional vehicle costs.

Retail Price Comparison: Midsize car



Light Duty Alternative Fuel Vehicles

- Diesel models are expected to be largely phased-out in cars, but we expect more diesel pickups, cargo vans and SUVs. Cost increment will stay high due to cost of meeting LEV3 regulations.
- E85 vehicles are widely available as flex-fuel vehicles. Due to the phase-out of fuel economy credits for CAFE compliance, their future is very uncertain and we forecast only a few models will be available after credits end in 2020, due to some demand in the Midwest. The number of available models has been declining since 2015.
- Fuel cell vehicles pose a difficult forecasting issue since future cost reductions depend on attaining economies of scale. We expect next generation FCVs to emerge in 2022/23 with significant cost reduction. To date, only low volume scenarios have been examined but high volume scenarios may be explored.

Heavy Duty Vehicles

- A wide range of HDT classes and fuel types are being modeled. The models were updated in 2017 for the Energy Commission forecast so no major forecast methodology revisions were required this year.
- As with light duty vehicles, the technology is being driven by GHG regulations which have not changed under the new Administration. Hence, modeling assumptions used in 2017 were re-utilized for the 2019 forecast.
- One major issue with heavy-trucks is the lack of well defined 2017 CA baseline for fuel economy and cost. We have used multiple sources of data to re-derive the 2016 baseline which resulted in changes to light-heavy truck baseline FE relative to last analysis.
- Alternative Fuel Trucks continue to be an issue and the emergence of electric trucks was re-examined for this forecast.

Vehicle/Fuel Types

(O-OEM, A-Aftermarket, P- Pilot production)

		Gasoline	Diesel	Diesel Electric Hybrid	Diesel Hydraulic Hybrid	Battery Electric Vehicles	FCV	E85	CNG	Liquefied Natural gas (LNG)	Propane
GVWR 3	GVWR 3	O	O	P		P		O	A		A
GVWR 4 to 6	GVWR 4	O	O	P		P		O	A		A
	GVWR 5	O	O			P		O	A		
	GVWR 6		O	P	P	P			A		
GVWR 7 & 8	GVWR 7		O	P					A		
	GVWR 8 Single Unit		O						A	A	
GVWR 8	Combination (California)		O			P	A		A	A	
GVWR 8	Garbage		O		A				A		
GVWR 8	IRP (combination)		O							A	
Motorhomes	GVWR 3	O	O								
	GVWR 4 to 6		O						A		
	GVWR 7 & 8		O						A		
Bus	Urban Transit		O	O	P	P	P		A		
	Motor Coach		O								
	School Bus	O	O			P			A		A

HDT Requirements for GHG Emissions

- HDT's are under requirements for Phase 2 of the GHG regulations that require significant improvements in fuel economy. Requirements vary by size class due to the different duty cycles.
- Regional and long-haul Class 8 tractor trailers have the most stringent requirements with a 19% to 25% reduction in fuel consumption required by 2027 from a 2017 baseline. A large part of the improvement comes from aero drag reduction.
- Medium duty trucks in urban and multi-purpose use also require improvements in the 15 to 20% range while light heavy trucks (class 3 to 5) require improvements of 22 to 24%. Urban use trucks benefit from idle reduction strategies.
- Urban buses and vocational vehicles like refuse trucks require only a 10 to 14% reduction due to the severe duty cycle

CNG/LNG Trucks

- CNG and LNG trucks continue to attract attention as a low emissions competitor to diesels, but have had limited market growth over the last decade.
- Currently, Cummins-Westport (and Westport) is the only supplier of NG engines. The Cummins Westport models use spark ignition and are~15% less energy efficient than diesel engines. Westport Volvo uses a dual fuel (diesel + NG) system that is more complex and expensive but more efficient. The Dual Fuel System is modeled for Class 8 trucks.
- Cost of engine + CNG tanks is still significant so that CNG and LNG are less competitive commercially with diesel. The engines have attained significant market share in buses and refuse trucks due to local or state requirements. Both these segments will see significant competition from electric and hybrid trucks.

Electric and Hybrid Trucks

- Electric and hybrid truck models have been introduced in the last 3 years in light-heavy (class 4/5) and medium- heavy classes of trucks. Tesla has shown a heavy-heavy tractor for potential introduction in 2021/22. The heavy-heavy truck is a new addition to the forecast.
- Truck batteries will be 40% more expensive per kWh of energy than light duty vehicle batteries because of the more severe duty cycle. We estimate future costs will have similar percent declines as light duty batteries but will continue to be more expensive.
- Electric motor and controller costs are also much higher since HDT motors are rated based on continuous power rather than short term peak power ratings of light duty vehicles
- List prices for currently available electric and hybrid trucks are more expensive than cost based calculations but are rumored to be discounted significantly. Sales are still quite low.

Catenary and Fuel Cell Trucks

- Catenary based electric trucks are being examined in the South Coast along specific routes. These trucks have a relatively small battery to drive ~10 miles off the catenary.
- Fuel cell trucks and buses are also under active investigation. As with batteries, fuel cells need to run at high power levels continuously to operate on a truck duty cycle, and are significantly more expensive than LDV units at the same maximum power.
- Our analysis of costs from a modified version of costs from a UC-Davis study, Class 8 applications were for day cab regional haul applications, to allow for limited range operations likely for both FCV and Catenary based trucks.

Cost Comparison of Class 8B Day Cab Trucks in 2020 – Low Volume Production

Component	Diesel	Catenary	Fuel cell (optimistic)	Battery Electric (200+ miles)
Glider	32,000	32,000	32,000	32,000
Engine or Motor/Controller	20,000	16,500	16,500	16,500
Emission Control or Battery	12,000	18,000	9,000	139,300
Transmission	6,500	2,200	2,200	2,200
Catenary/ Fuel cell	-	9,100	54,000	-
Hydrogen tanks			32,000	-
Retail Price/ Cost markup	52,900	77,600	145,700	150,000
Total	**123,400**	**154,600**	**289,400**	**340,000**

Forecasts to 2030

- Due to technology forcing by GHG regulations, vehicle prices and fuel economy are largely insensitive to fuel prices at the weight class and fuel type level.
- Battery prices are assumed to decline at different rates in each of the three scenarios modeled, with the highest rate on the high electricity demand scenario
- NG costs are expected to decline only slightly relative to diesel as we assume it remains a low volume product.
- Diesel and gasoline efficiency climb at slightly lower rates than EPA regulation due to less aggressive benefit for aero drag reduction (associated with higher traffic and lower speeds than the EPA assumption), especially for Class 8 regional and long haul.

Forecast Results

- The forecasts project that for all internal combustion engine powered vehicles from 2017 to 2030:
- Vehicles in Classes 3 and 4 (mostly large pickups and vans) will increase fuel economy by about 25% to 29% for a cost increase of about $1500
- Medium duty trucks in Classes 6 and 7 that operate in mixed suburban and urban routes will increase fuel economy by 22 to 25% for a cost increase of about $3200
- Vehicles in mostly urban use like garbage trucks and urban buses will have improvements in fuel economy of 9 to 12%
- Long haul trucks in classes 7 and 8 will see the largest improvement of 29 to 32% in fuel economy for a cost increase of about $9500
- Electric vehicles will have lower efficiency increases as motor is already very efficient but costs will decline sharply. Some of the cost decrease will be traded for range which is expected to grow from about 100 miles to 200 – 240 miles depending on class.
- Spark ignition CNG vehicles will be somewhat more competitive due to lower costs of emission control