FUTURE PROPULSION SYSTEM MIX AND ITS IMPACT ON AUTOMOTIVE PGM USAGE

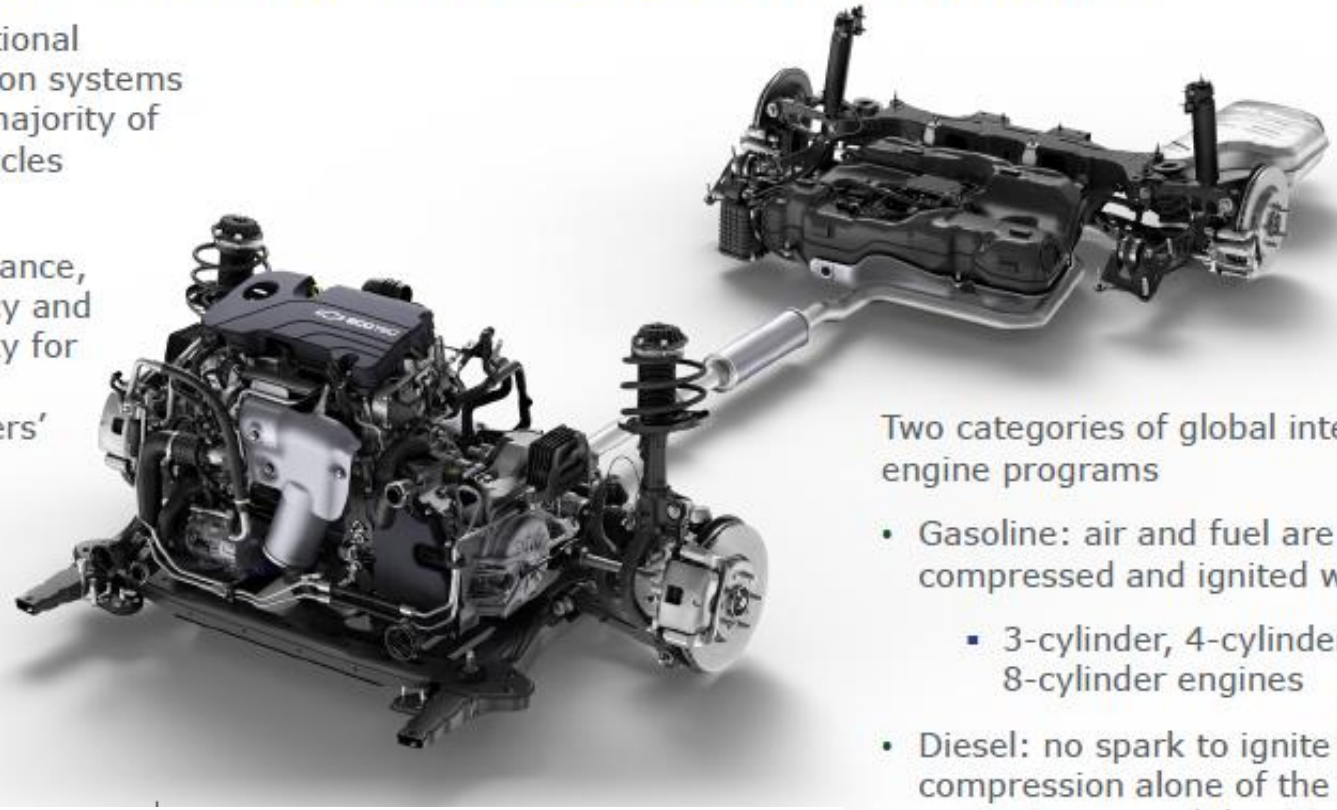
Rahul Mital
Technical Fellow Diesel Aftertreatment
General Motors

PRESENTATION OUTLINE

- Internal Combustion Engines
  - Projected General Motors North America PGM usage
- Gold as a Catalyst
- Other Propulsion Systems
- Projected Propulsion System Mix in Future
- Impact on PGM usage due to Future Propulsion System Mix

CONVENTIONAL PROPULSION SYSTEMS

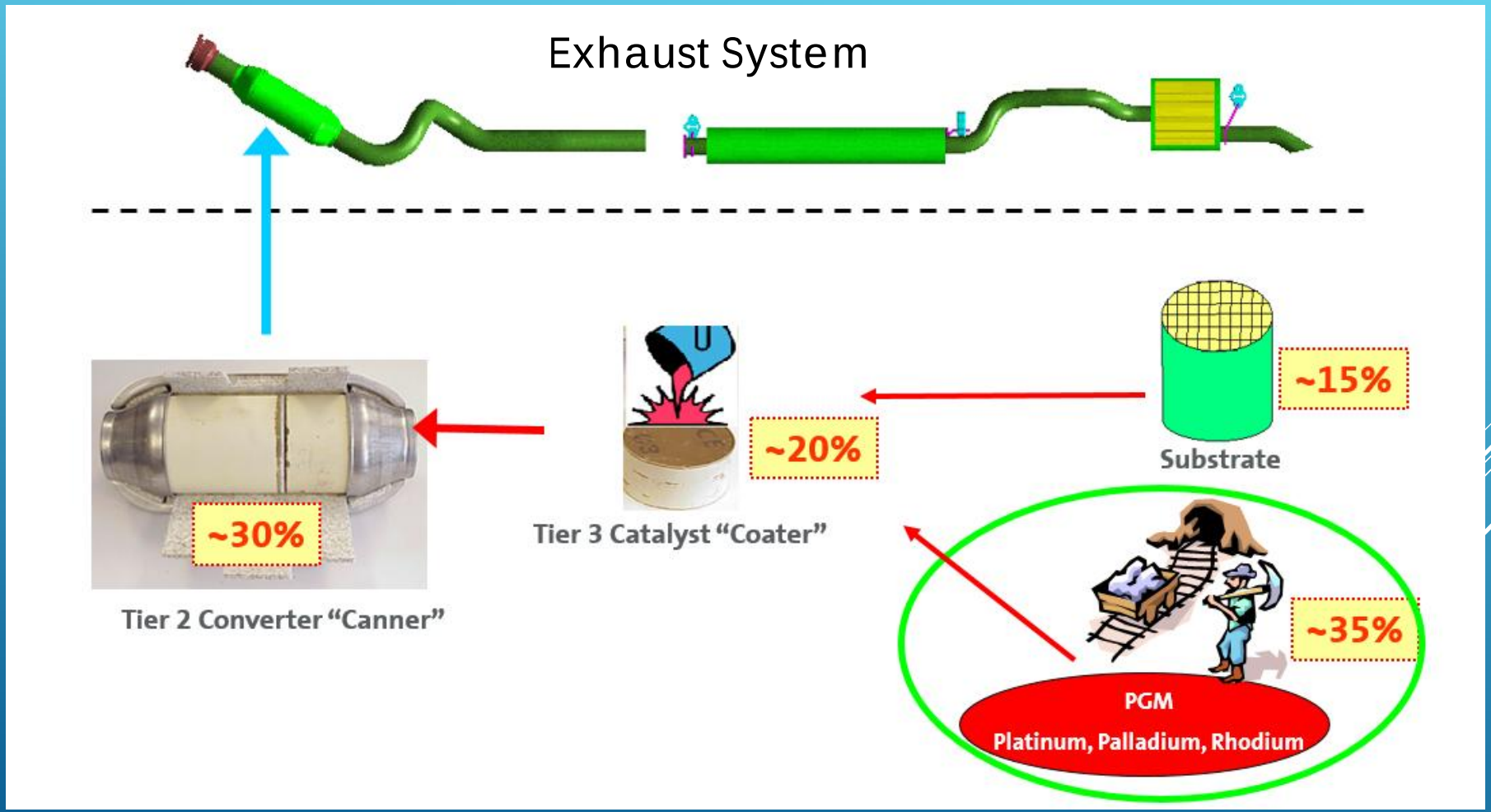
- Conventional propulsion systems power majority of our vehicles
- Deliver performance, efficiency and durability for our customers' varying needs



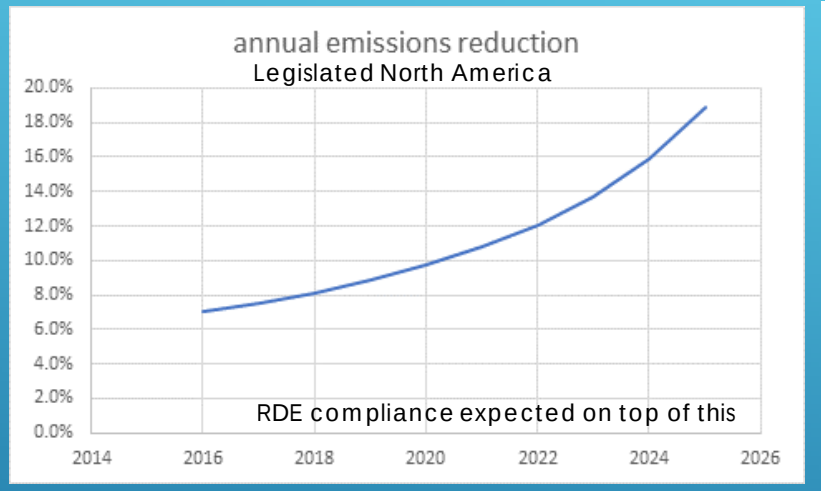
Two categories of global internal combustion engine programs

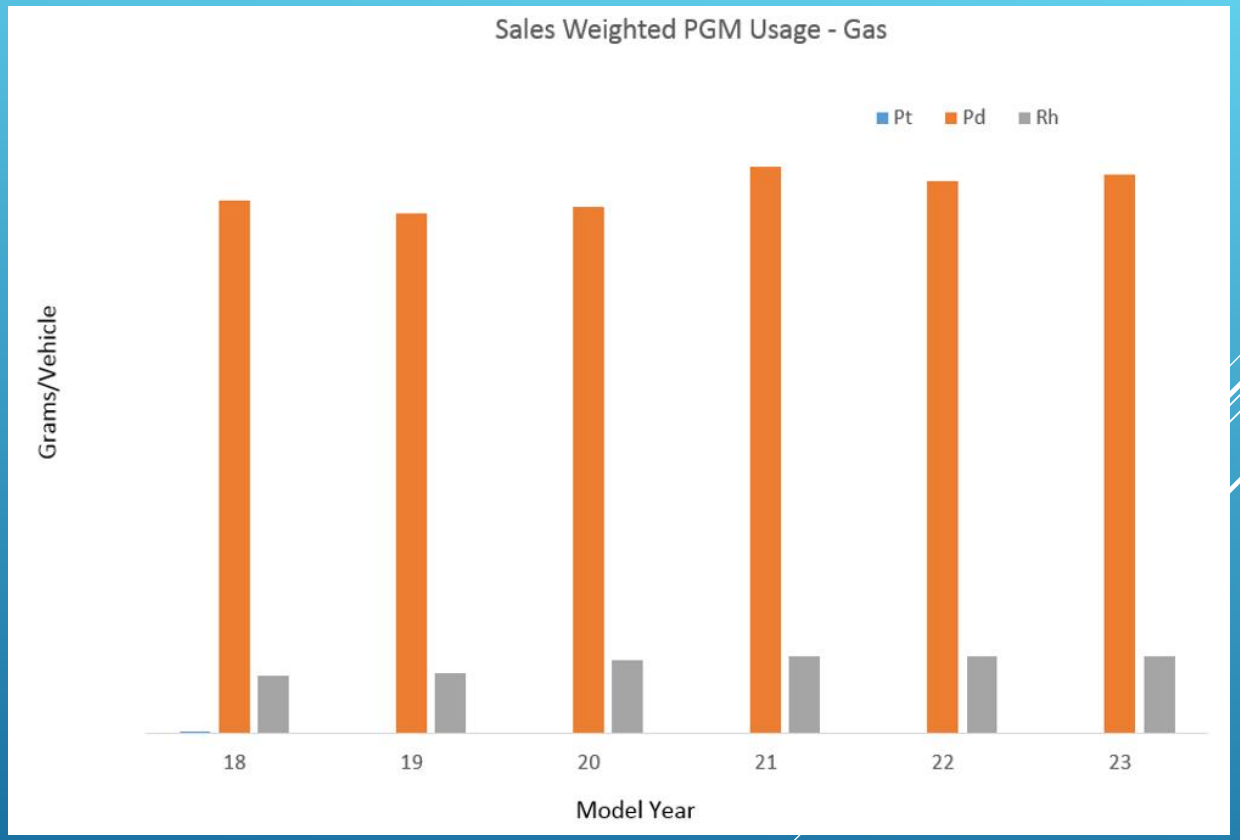
- Gasoline: air and fuel are mixed, compressed and ignited with a spark
  - 3-cylinder, 4-cylinder, 6-cylinder and 8-cylinder engines
- Diesel: no spark to ignite the fuel mixture; compression alone of the mixture generates enough heat to ignite it

COST OF PGM IN THE CATALYTIC CONVERTER



OVERVIEW – GM GASOLINE PGM USAGE

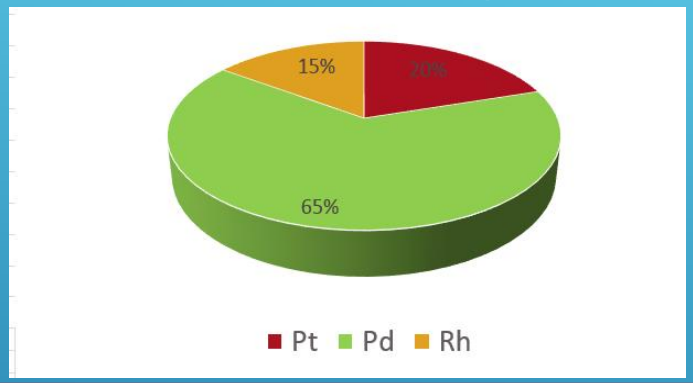




- Most OEMs are reducing fleet average emissions with time as shown in the chart above.
- GM is also in a performance enhancement environment (lower emissions year over year).
- GM projects it can hold PGM constant while increasing performance.

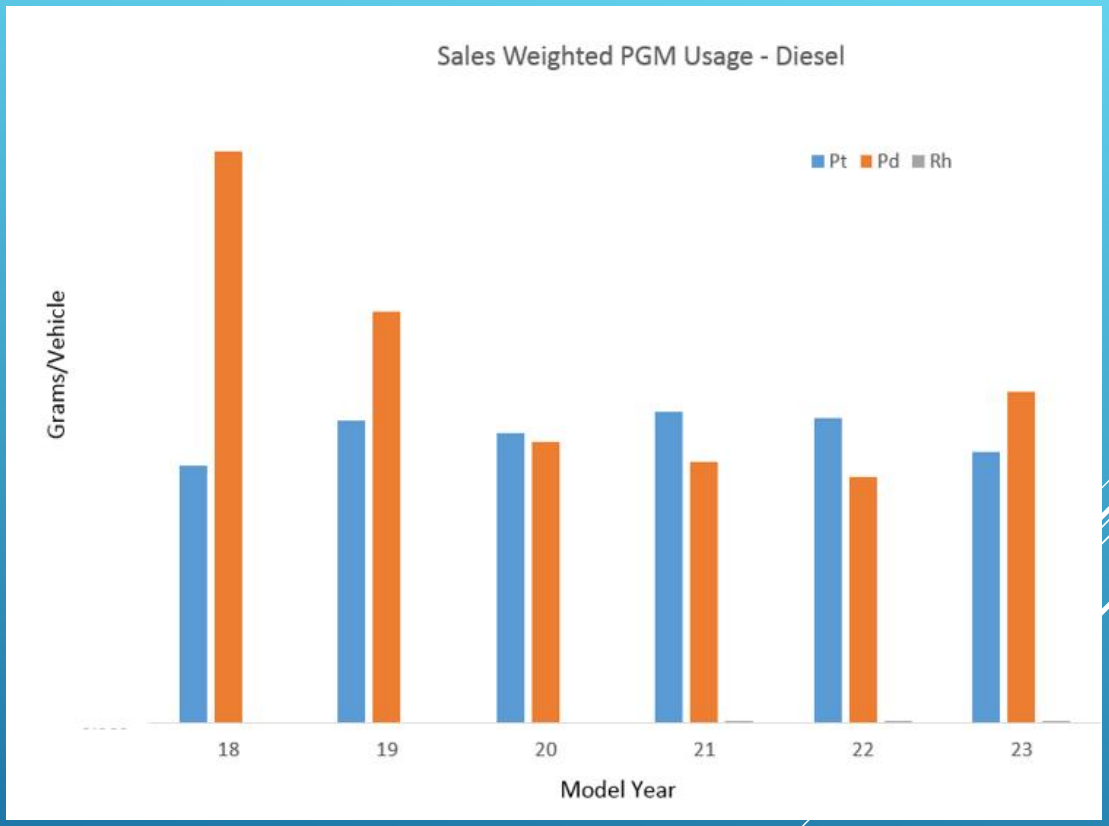
OVERVIEW – GM DIESEL PGM USAGE

GM Precious Metal Spend



Roughly 2/3 of GM spend is Pd due to gas engine loadings.

PGM usage in diesels is steady in the coming years with close to 50-50 Pt:Pd ratio.

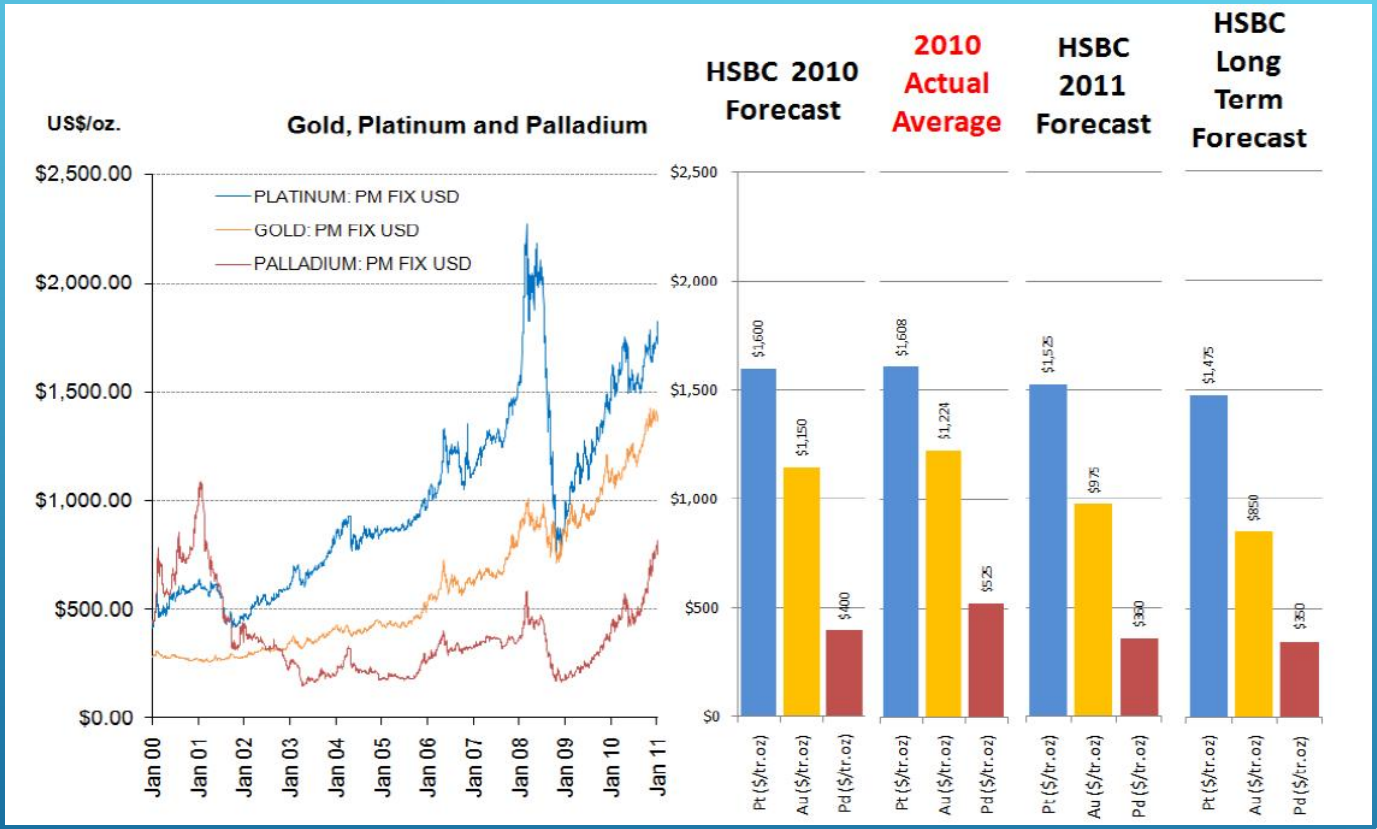


- There is significant interest in substituting Pd with Pt in the converters due to pricing.
- Pt works well for diesel but generally Pd is more durable for gasoline converters.

PRESENTATION OUTLINE

- Internal Combustion Engines
  - Projected General Motors North America PGM usage
- Gold as a Catalyst
- Other Propulsion Systems
- Projected Propulsion System Mix in Future
- Impact on PGM usage due to Future Propulsion System Mix

AU TECHNOLOGY BACKGROUND



Gold was less expensive than Pt during 2003- 2008. There was very high interest in replacing Pt with Gold in catalytic converters during this period.

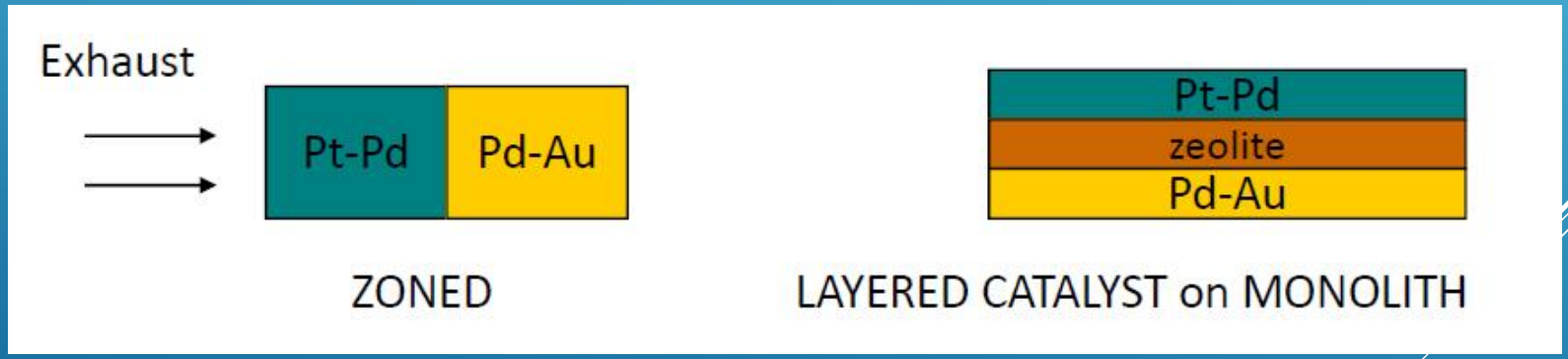
AU TECHNOLOGY INTRODUCTION

- Au has been known as a catalyst for a long time.
- It is not used in production as it is highly susceptible to S poisoning.
- Its low melting point makes it unfeasible for gasoline applications.
- It has high sintering potential when exposed to high temperatures.
- Au by itself is not as efficient as Pt for HC/CO oxidation and cannot provide the NO to NO2 oxidation functionality.
- PdAu alloy is required for catalyst stability and Pt is necessary for increasing S robustness, hence use of tri metal (PtPdAu) becomes necessary.

AU TECHNOLOGY INTRODUCTION

Tri-layered Design

- Pt function is physically separated from Pd-Au in a tri-layer or zoned design.
- Use of zeolite separating Pt and Pd-Au functions
- Au is in the bottom layer or in the rear of the zone catalyst to protect it from S, sintering and HC inhibition of CO oxidation.



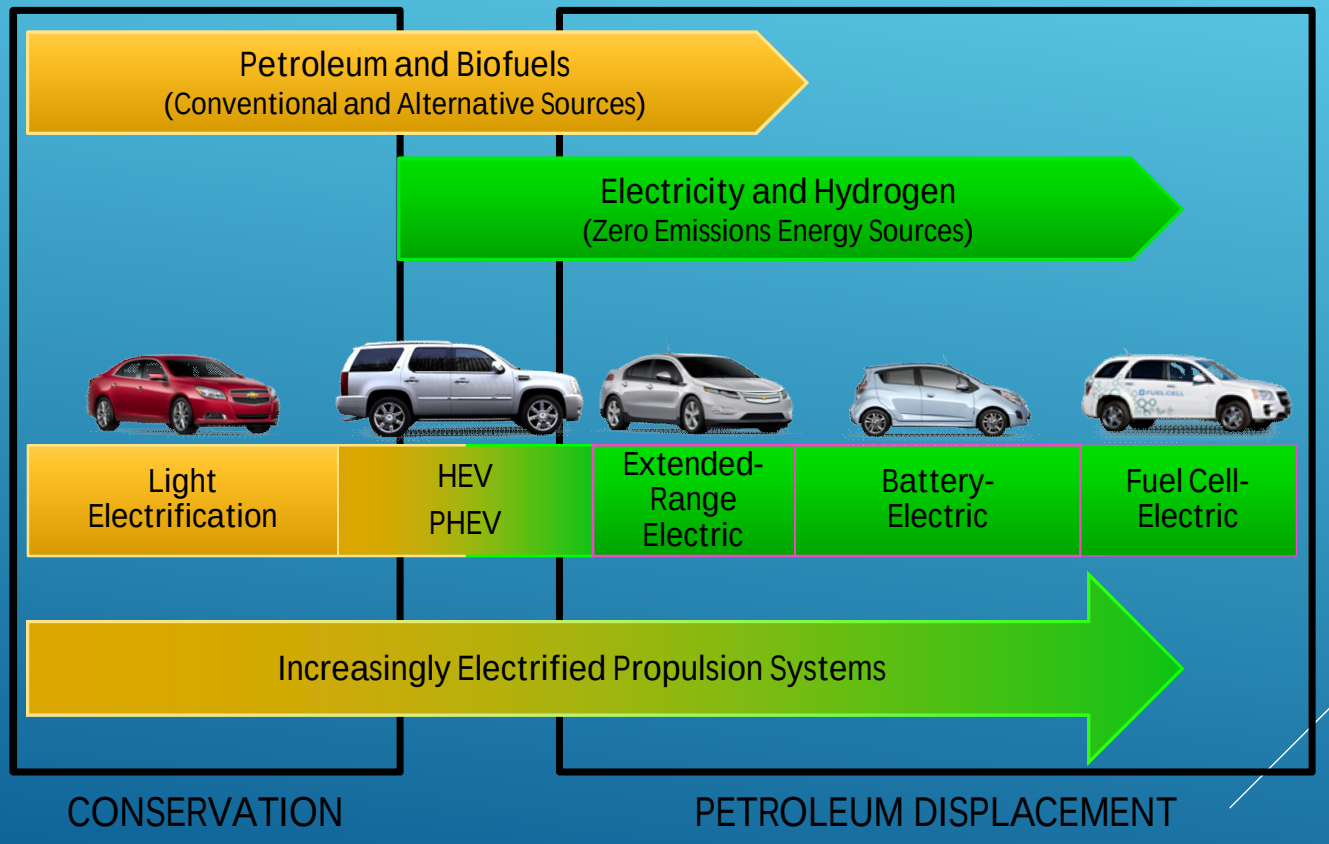
- Currently Au price is significantly higher than Pt so there is no business case.

PRESENTATION OUTLINE

- Internal Combustion Engines
  - Projected General Motors North America PGM usage
- Gold as a Catalyst
- Other Propulsion Systems
- Projected Propulsion System Mix in Future
- Impact on PGM usage due to Future Propulsion System Mix

Beyond Conventional Powertrain Solutions

Hybrids, Battery Electric Vehicles, & Hydrogen Fuel Cells



ELECTRIFIED PROPULSION SYSTEMS

HYBRIDS

eAssist: combines start-stop technology with regenerative braking and an on-board lithium-ion battery to provide an electric boost in certain conditions to improve fuel economy. e*Assist* provides up to 25 percent better fuel economy

- **Buick LaCrosse, Buick Regal, Chevrolet Silverado, GMC Sierra**

Buick LaCrosse

Extended-range electric vehicles (EREV): A vehicle that is capable of operating under all-electric propulsion for a portion of its range at all speeds, with the added security of an on-board engine that acts as a generator for additional electric power for longer trips

Cadillac ELR

Chevy Volt

ELECTRIFIED PROPULSION SYSTEMS

FULL-ELECTRIC VEHICLES

Directly displace petroleum fuel by charging the battery from an electric grid

Electric vehicles (EVs): Chevrolet Spark and Bolt

- Extensive global battery development team, with battery labs located in Warren, Mich., U.S.; Shanghai, China and Germany
- Labs capable of testing all new energy storage technologies as well as lithium-ion batteries for GM's future electrified vehicle programs
- Approximately 50-percent of GM Propulsion Systems' engineering workforce is involved in alternative or electrified powertrains

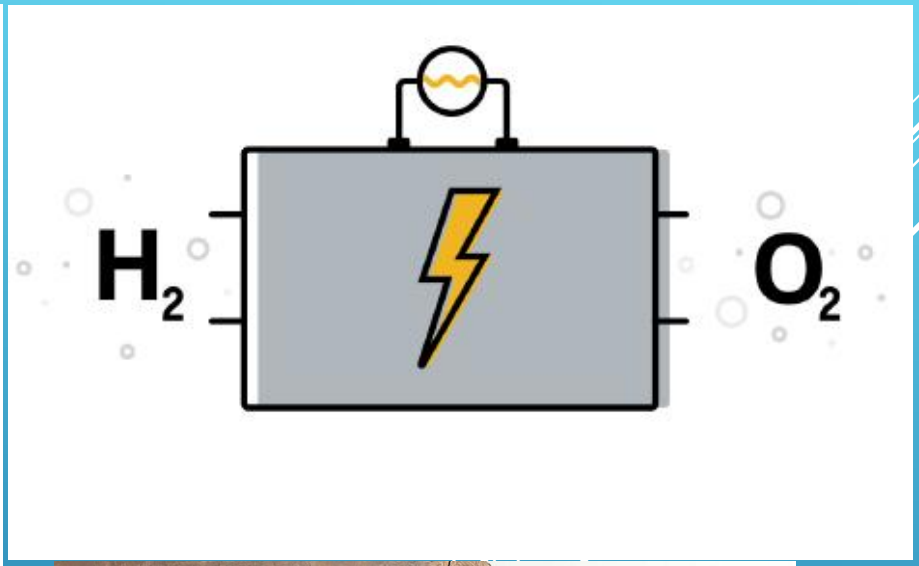
Chevy Bolt

Chevy Spark EV

FUEL CELLS

Hydrogen fuel cells work by converting high-energy hydrogen into electricity

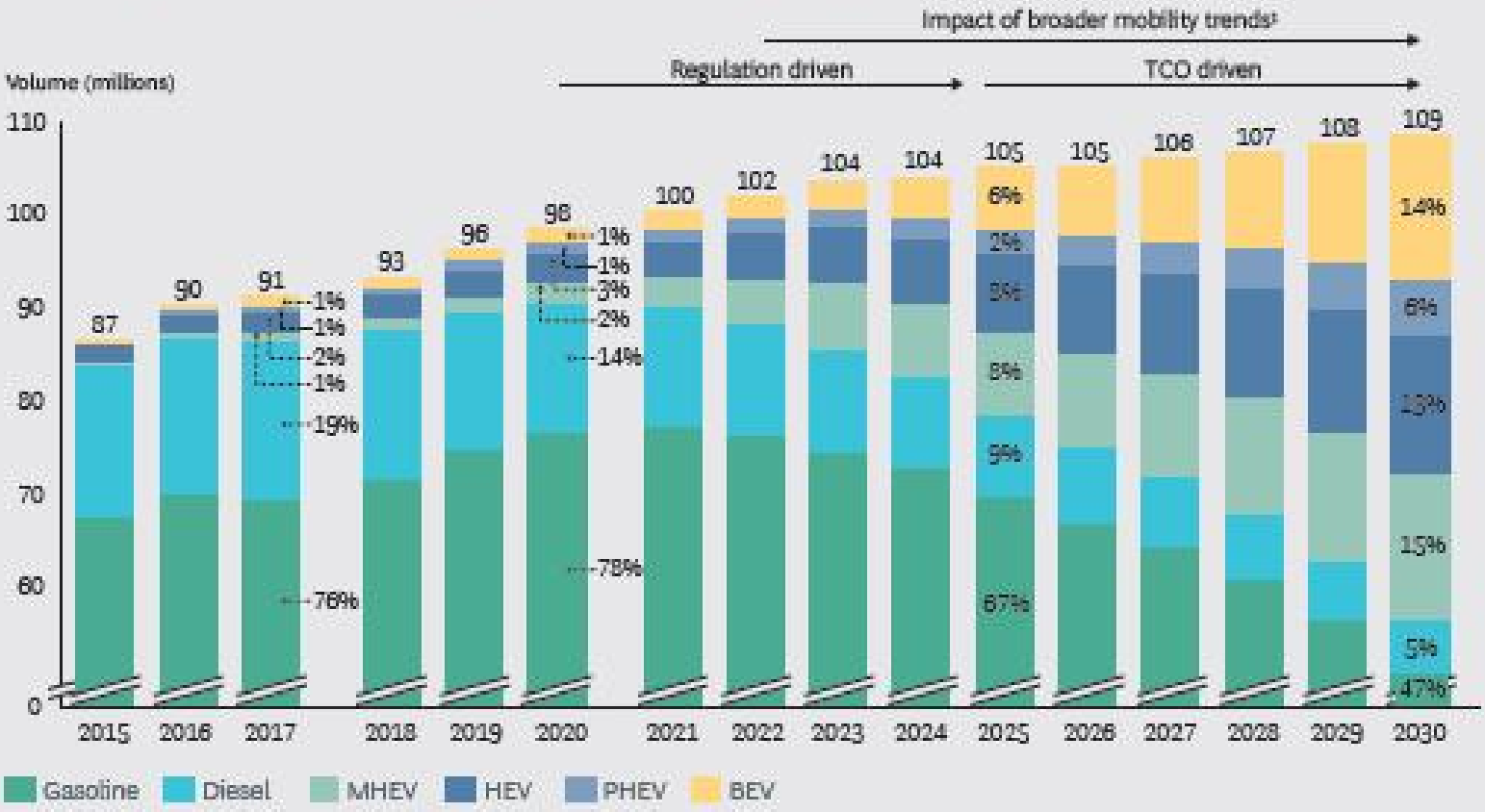
- Results: zero-emission vehicles with greater range and endurance than those powered with batteries
- Fuel cells address two major challenges: petroleum use and carbon dioxide emissions
- They can operate on renewable hydrogen sources including wind and biomass stored for later use;
- Recharging takes only minutes



Chevrolet Colorado ZH2
fuel cell electric vehicle

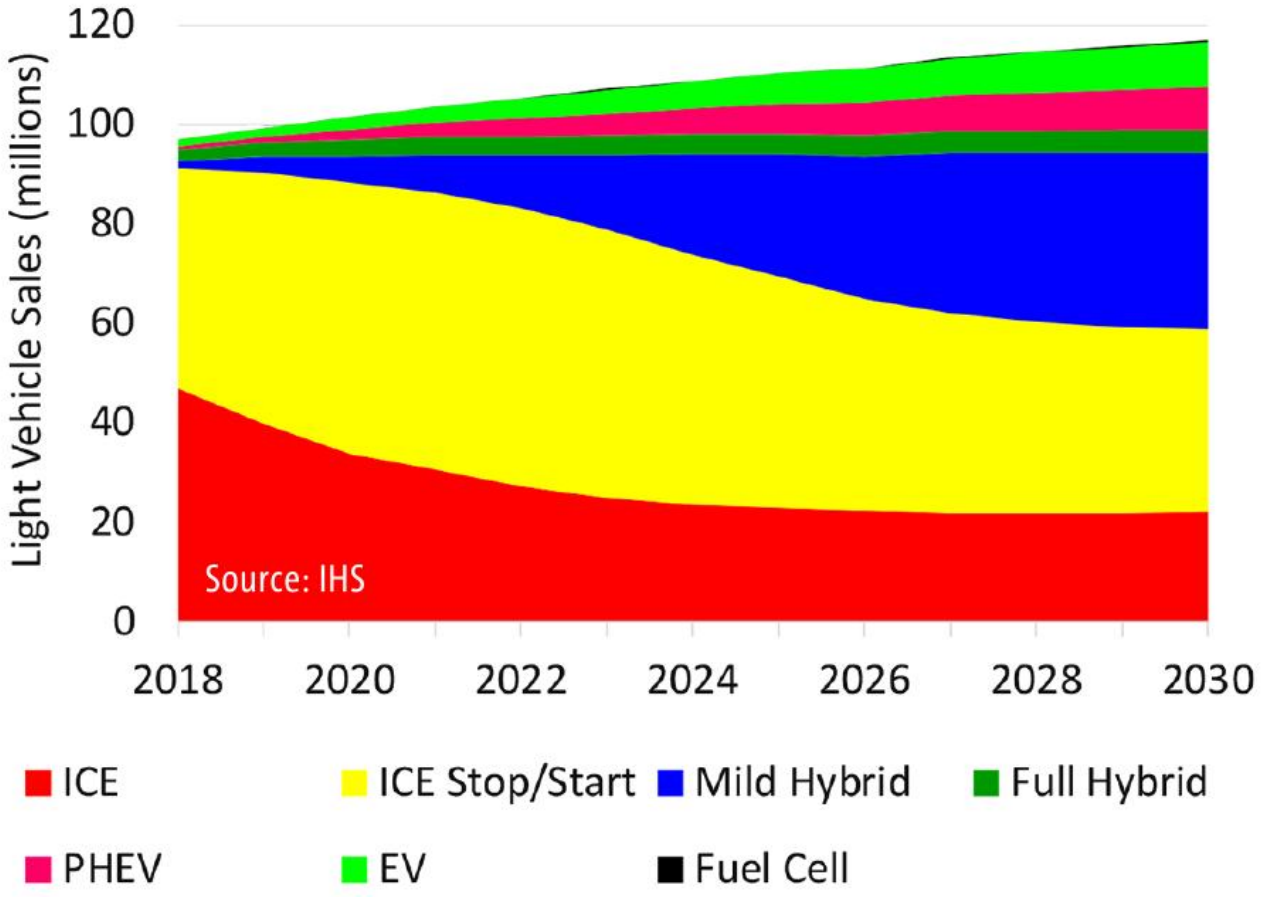
HOW DOES PROPULSION SYSTEM MIX CHANGE INTO THE FUTURE ?

Exhibit 1 | Global Car Sales by Fuel Source Through 2030



Source: BCG analysis.
Note: Percentages might not add to 100 because of rounding. TCO = total cost of ownership; BEV = battery electric vehicle; PHEV = plug-in hybrid electric vehicle; HEV = full hybrid electric vehicle; MHEV = mild hybrid electric vehicle.
[a]Broader mobility trends include such changes in consumer mobility behavior as car and ride sharing.

THERE ARE MANY FORECASTS…



HOW DOES PROPULSION SYSTEM MIX IMPACT FUTURE PGM USAGE ?

IMPACT ON PGM USAGE

- More than 85% of the passenger cars are expected to have internal combustion engines with converters in 2030.
- Cars with electrification will typically be certified to lower emission levels and their ICE converter PGM loading is not expected to decrease.
- Even for same certification level, Mild hybrid and Hybrid cars are expected to have similar amount of PGM as non-electrified cars.
- Sales of Fuel Cell cars, which currently use more PGM, are expected to grow to a maximum of 1 million units by 2030.
- Based on these assumptions, the PGM usage is expected to stay stable or decrease marginally by 2030.
- Diesel sales in the heavy duty industry are expected to stay steady with no change or slight increase in PGM usage as tougher regulations come into play.

THE END