FUTURE PROPULSION SYSTEM MIX AND ITS IMPACT ON AUTOMOTIVE PGM USAGE
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

Exhaust System

Tier 2 Converter "Canner" ~30%

Tier 3 Catalyst "Coater" ~20%

Substrate ~15%

PGM Platinum, Palladium, Rhodium ~35%
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.
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
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

1. Internal Combustion Engines
   - Projected General Motors North America PGM usage
2. Gold as a Catalyst
3. Other Propulsion Systems
4. Projected Propulsion System Mix in Future
5. Impact on PGM usage due to Future Propulsion System Mix
Beyond Conventional Powertrain Solutions
Hybrids, Battery Electric Vehicles, & Hydrogen Fuel Cells

CONSERVATION

Petroleum and Biofuels
(Conventional and Alternative Sources)

Increasingly Electrified Propulsion Systems

Electricity and Hydrogen
(Zero Emissions Energy Sources)

Light Electrification

HEV
PHEV

Extended-Range Electric

Battery-Electric

Fuel Cell-Electric

PETROLEUM DISPLACEMENT
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. eAssist provides up to 25 percent better fuel economy.

Buick LaCrosse, Buick Regal, Chevrolet Silverado, GMC Sierra

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.

Buick LaCrosse  Cadillac ELR  Chevy Volt
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
**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

Impact of broader mobility trends

Regulation driven

TCO driven

Volume (millions)

<table>
<thead>
<tr>
<th>Year</th>
<th>Gasoline</th>
<th>Diesel</th>
<th>MHEV</th>
<th>HEV</th>
<th>PHEV</th>
<th>BEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>87</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>93</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>96</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>102</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td>104</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2023</td>
<td>104</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td>105</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td>105</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2026</td>
<td>106</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2027</td>
<td>107</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2028</td>
<td>108</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2029</td>
<td>109</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td>109</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.
*Broader mobility trends include such changes in consumer mobility behavior as car and ride sharing.
THERE ARE MANY FORECASTS...

Source: IHS
HOW DOES PROPULSION SYSTEM MIX IMPACT FUTURE 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