FUTURE DIRECTIONS IN POWERTRAIN – LIGHT DUTY PERSPECTIVE

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ENVIRONMENT – GLOBAL FUEL ECONOMY

CO₂ OUTLOOK

Source:
GM Public Policy
Meeting MY2025 CO₂ regulations while delivering vehicles that customers want and can afford

<5% MY2014 vehicles meet MY2025 CO₂ and all are advanced powertrains

Significant US gasoline price volatility with a recent 40% drop

Source: US DOE Energy Information Administration

Conventional gasoline vehicles forecasted to dominate US sales.

Conventional vehicles are closing the gap to hybrids.


Source: US DOE Energy Information Administration
Annual Energy Outlook 2014
MEGATRENDS FOR FUTURE POWERTRAINS

EFFICIENCY IMPROVEMENTS

ELECTRIFICATION
Engine Focus
- Minimize pumping losses (VVA, downsizing/AFM, dilute combustion)
- Minimize parasitic losses (variable speed/displacement pumps)
- Minimize friction losses (low friction piston/bore interface, downsizing)
- Maximize work extraction (dilute combustion, waste heat recovery)
- Improved Fuels

Powertrain System Focus
- Wider transmission ratio spreads with small or infinite steps to enable efficient engine operation
- Advanced dampers enabling down-sized boost engines and cylinder deactivation

Vehicle/Powertrain Integration Focus
- Simultaneously solving the transmission, engine and vehicle equation to minimize CO$_2$
- Maximizing engine-off operation
- Active thermal management
- Intelligent electrification
- Connected and autonomous vehicles

SOURCE OF ENGINE CO$_2$ REDUCTION
DILUTE COMBUSTION

- GM is studying dilute combustion concepts to maximize efficiency.
- The physics say air dilution offers greater benefits than EGR, but the required lean aftertreatment has significant challenges (e.g., cost).

![Graph showing efficiency vs. peak charge temperature for Lean Burn Technology and Stoichiometric Burn with and without EGR. The graph illustrates efficiency values at 13% and 3%.](chart)
FUELS – OPTIMIZED FOR SI COMBUSTION

Increasing RON allows increased downsizing and/or compression ratio and thus engine efficiency.

*Graph showing the relationship between Brake Thermal Efficiency (%) and Brake Mean Effective Pressure (kPa).*

*Engine: Ford Ecoboost 1.6L 4-cylinder, turbocharged, direct-injection, 10.1 CR*
*Source: C.S. Sluder, ORNL*
Octane Index \( (OI = RON - K \times Sensitivity) \) is a good measure of fuel performance when “\( K \)” is adjusted to the engine/combustion mode.

Data based on 7 full blend gasoline fuels.
Engine Focus

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Powertrain System Focus

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WE NEED TO SELECT THE **RIGHT TRANSMISSION FOR THE SPECIFIC APPLICATION**

**Example: 3-cylinder Turbo Study**

![Diagram showing transmission energy and fuel consumption comparison]

- Step gear transmissions are mechanically efficient...
- For this application, CVT is the preferred technology.
- ...but CVT has better CO$_2$ performance due to ratio capability.

Transmission Energy (kJ) Loss

(= Pump + Trans Spin + Gear Efficiency + Shift Efficiency + Shift Energy + Torque Converter)
The engines of tomorrow may look very different than today’s engines

As the engine “transformer”, transmissions are likely impacted

Need to optimize at the propulsion system level to maximize overall value
SOURCE OF ENGINE CO₂ REDUCTION

**Engine Focus**
- Minimize pumping losses (VVA, downsizing/AFM, dilute combustion)
- Minimize parasitic losses (variable speed/displacement pumps)
- Minimize friction losses (low friction piston/bore interface, downsizing)
- Maximize work extraction (dilute combustion, waste heat recovery)
- Improved Fuels (high RON, high sensitivity)

**Vehicle/Powertrain Integration Focus**
- Simultaneously solving the transmission, engine and vehicle equation to minimize CO₂
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**Powertrain System Focus**
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**Opportunity vs. Time**
- 0%
- 100%
POWERTRAIN/VEHICLE BANDWIDTH

Vehicle bandwidth for a given engine (TWC, RL, Grade, 0-60)

Better CO₂ Performance

Biggest CO₂ Impact

Sub-optimization
MEGATRENDS FOR FUTURE POWERTRAINS

EFFICIENCY IMPROVEMENTS

ELECTRIFICATION
ELECTRIFICATION SOLUTIONS
REDUCE CONSUMPTION & DISPLACE PETROLEUM

Petroleum and Biofuels
(Conventional and Alternative Sources)

Electricity
(Zero Emissions Energy Sources)

Light Electrification
HEV
PHEV

Extended-Range Electric
Battery Electric

Increasingly Electrified Propulsion Systems
CONSERVATION
DISPLACEMENT
IMPACT OF ELECTRIFICATION ON POWERTRAINS

The Volt is a great example of the impact of electrification

2016 Chevrolet Volt

- 50 miles of EV range
- 400 miles of total driving range

Volt has to operate efficiently in two modes of operation:

**EV Mode** with energy coming from the battery and motors

**Extended Range Mode** with energy coming from the engine
EREV ENGINE VERSUS ELECTRIC MOTOR

Radically different capabilities drive significantly different transmissions

Electric motor’s advantage over the engine:

- ~60% More speed range
- ~2.6x More torque and available down to near zero speed
- Broad efficiency islands with up to 93% peak efficient (vs 37.5% for engine)
VEHICLE INTELLIGENCE
TECHNOLOGY INNOVATION
VALUE OF ELECTRONICS AND SOFTWARE

2000
- $400
- 20 ECUs
- 1M lines of code

Today
- $1,200
- 75 ECUs
- 100M lines of code
LANE FOLLOWING: Using a combination of GPS and optical cameras, Super Cruise watches the road ahead and adjusts steering to keep the car in the middle of its lane.

COLLISION AVOIDANCE: A long-distance radar system detects vehicles more than 300 ft. ahead. The vehicle will automatically accelerate or apply the brakes to maintain a preset following distance.
<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built-in Wi-Fi hotspot</td>
<td>Connect multiple mobile devices at once</td>
</tr>
<tr>
<td>Faster, more reliable connection</td>
<td>Connect to vehicle remotely</td>
</tr>
<tr>
<td>On more than 30 GM vehicle models</td>
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</tbody>
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V2X TO DEBUT ON 2017 CADILLAC CTS

Technology allows cars to communicate with each other (V2V), the infrastructure (V2I), and pedestrians (V2P)
WHAT DOES THIS MEAN TO THE POWERTRAIN?

- Access to information and computational power outside of the vehicle
- Information about surrounding vehicles and infrastructure
- The ability to manipulate vehicle operation when the driver has transferred control
- Route Information
SUMMARY

- Global convergence of CO$_2$ regulations will drive unprecedented scale opportunities for fuel economy enabling technologies

- Conventional powertrain technologies still have a significant potential for fuel economy improvements

- Engine innovation will be as part of a powertrain system solution and will be significantly impacted by:
  - Engine evolution
  - Powertrain electrification
  - Greater on-vehicle access to information
  - More automated driving

- Must keep the customer at the “center”
  - In the end, our customers will decide based on what they want and can afford