DRIVING AUTOMOTIVE INNOVATION
Turbocharging & Miller Cycle

• Turbocharging enables engine downsizing for significant fuel economy benefits without performance compromise.

• More stringent regulation is demanding more efficiency from internal combustion engines.

• One solution to increasing engine efficiency is by adopting a Miller Cycle strategy.

• Technologies available today including, VNT (variable nozzle turbines) Turbochargers, Variable Valve Timing & Valve Lift, and Direct Injection, allow engines to use higher levels of Miller to meet future regulation.
How a Turbocharger Works

Compressor Section

- Compressor Air Discharge
- Compressor Ambient Air Inlet
- Compressor Wheel

Turbine Section

- Turbine Housing
- Turbine Wheel
- Turbine Exhaust Gas Outlet
- Turbine Exhaust Gas Inlet
Modern Turbo Gasoline Engines

No-Compromise Solution

3L 6 Cylinders
Naturally Aspirated

2L 4 Cylinders
Turbocharged

240
Horsepower

= 240
Horsepower

+30% Torque

+25% Fuel Efficiency

20% CO₂

More Stringent Regulations

Enacted Targets*

<table>
<thead>
<tr>
<th>Country</th>
<th>MPG</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>54</td>
<td>~24% By 2021</td>
</tr>
<tr>
<td>China</td>
<td>48</td>
<td>~39% By 2020</td>
</tr>
<tr>
<td>USA</td>
<td>56</td>
<td>~54% By 2025</td>
</tr>
<tr>
<td>India</td>
<td>49</td>
<td>~17% By 2022</td>
</tr>
<tr>
<td>Brazil</td>
<td>41</td>
<td>~11% By 2017</td>
</tr>
</tbody>
</table>

*Source ICCT Fuel Economy Standards – August 2015 Light Vehicles Only. MPG Improvement vs 2014 Levels.
†Equivalent Standards to Euro 5 (5mg/km PM, 60-180mg/km NOx) and Euro 6 (5mg/km PM, 60-80mg/km NOx)

Turbochargers are a Key Enabler to Current & Future Regulation
Increasing Gasoline Engine Efficiency

Ideal conversion efficiency [%]

Geometric Compression Ratio => $\epsilon$ [-]

Increasing Compression Ratio

Normal Combustion

Flame Propagation

Knock

$\gamma = 1.4$

Increase Is Key, But Knock Is A Challenge
**Miller Cycle**

*What is Miller?* - Delayed closing of the intake valve during the compression stroke.

*Why do it?* – Reduces work by the engine to compress air resulting in fuel economy improvement and enables higher efficiency/compression ratios without Knock

*How is this done?* – Turbocharging, variable valve timing/valve lift, & direct Injection

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**Normal Compression Stroke**

**Step 1**

**Step 2**

**Old Concept Made Possible with Modern Engine Technology**
Miller Cycle Benefits

Increased CR + Miller = Fuel Efficiency At All Load
Conclusion

• Miller Cycle can improve gasoline engine efficiency and fuel economy and is currently being used on many engines today.

• New technologies allow higher amounts of Miller pushing the benefits further without sacrificing engine performance.

• VNT Turbos, a key enabler for higher levels of Miller, have been available on main stream diesel engines for over 25 years and have been adapted to Gasoline applications.

Gasoline VNT