Turbocharging for Improved Engine Performance & Reduced CO2 Emissions

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Turbocharging for Improved Engine Performance & Reduced CO2 Emissions

- Powertrain Technologies for Fuel Savings
- Global Engine Downsizing Trends
- Turbocharger & Engine Boosting Performance
- Why Boosting with Engine Downsizing?
- Conclusions
Powertrain Technologies for Fuel Savings

Automatic Transmissions

- DCT (17%)*
- CVT (8%)*
- 6/7/8/9 Spd (5%)*
- 3/4/5 Spd (-11%)*
- Other (8%)*

Light Vehicle Turbochargers

- (5%)* Diesel
- (14%)* Gasoline

Thermal Systems

- Electronically-Controlled (26%)*

Variable Cam Timing

- (11%)* VCT Systems

Global industry volumes; units in millions
*CAGRs are shown in parentheses
Global Engine Downsizing Trends

- 4 cylinder engines maintain their dominance
- 2 and 3 cylinder engines have highest % growth
- 6 cylinder production is flat and 8 cylinder in decline

Light Vehicle Engines Produced – by Engine Size

<table>
<thead>
<tr>
<th>Engine Size</th>
<th>Millions of Engines</th>
<th>2012E</th>
<th>2017E</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 and 10 cylinder engines</td>
<td></td>
<td>2.9</td>
<td>0.9</td>
</tr>
<tr>
<td>6 cylinder engines</td>
<td></td>
<td>7.8</td>
<td>7.9</td>
</tr>
<tr>
<td>4 cylinder engines</td>
<td></td>
<td>63.3</td>
<td>79.7</td>
</tr>
<tr>
<td>2 and 3 cylinder engines</td>
<td></td>
<td>6.4</td>
<td>12.4</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>0.9</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Source: IHS Automotive, BorgWarner forecasts (Jan 2012)
*CAGRs are shown in parentheses
Turbocharging for Improved Engine Performance & Reduced CO2 Emissions

- Turbocharger & Engine Boosting Performance
Brief History of Turbocharging

1927: Swiss engineer Alfred Buchi is granted the first Patent for exhaust driven Turbo-Supercharging or Turbocharger.

1952: Garrett (Honeywell) & Schwitzer (BorgWarner) begin Turbocharger production for Caterpillar & Mack Truck.

1962: First Passenger Car Turbo application, General Motors Corvair is introduced, followed by 1963 Oldsmobile Jetfire Turbo-Rocket V8.

1979: Beginning of Downsized Turbo Era with Ford Mustang 2.3-liter, 4 cylinder engine, Chrysler & GM also Compete with Turbo Models.

1980: BorgWarner and IHI Japan form 50/50 Joint Venture, Warner-Ishi. MHI of Japan begins development for US.


1999: Kuhlman Corporation, parent of Schwitzer is purchased by BorgWarner and becomes part of BorgWarner Turbo Systems.

Energy Available for Boosting

For our purposes, we will assume an engine of average thermal efficiency and typical heat losses through exhaust and cooling water.

Turbocharging improves efficiency by using exhaust gas energy that would otherwise be lost.
Turbo System in Operation

Engine

Charge-Air Cooler

Compressed Air Flow

Ambient Air Inlet

Turbocharger

Exhaust Discharge

Engine Exhaust
Turbocharger Performance Basics

Boosting device that uses an exhaust turbine to drive a compressor by way of a common shaft.

**Advantages**
- Utilizes exhaust gas energy that would otherwise lost
- Power when needed for transient performance
- Allows downsizing for fuel economy and emissions

**Main Challenge**
- Maintaining transient performance (reduced lag)
Turbocharging Configurations

- Improved Transient Response & Higher BMEP
- Twin Scroll WG
- Variable Turbine Geometry
- Variable Twin Scroll Turbine
- Regulated 2-Stage
- Regulated 3-Turbocharger System
- Mono Scroll WG
- Twin Scroll WG

Improved Response & Higher BMEP
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- Why Boosting with Engine Downsizing?
Smaller Displacement Equals Improved Fuel Economy

The Horsepower needed to maintain speed on level road is quite low.

Aerodynamic Drag & Rolling Resistance of the Tires
Why Boosting with Downsizing?

- A Practical Example
  - Typical Mid Size 4-Door Passenger Car
    - 3600 Pound Vehicle Weight
    - 2 liter Naturally Aspirated 4 cylinder Engine
    - 3.3 liter V6 Engine
    - 2 liter Turbocharged 4 Cylinder Engine

- Prediction of Passing Performance*
  - 2-lane Road, 55 mph Speed Limit Passing Capability
  - 40 to 60 mph Acceleration
  - Measure Time Required to Complete Maneuver

* Using GT Drive™ Model
2 Liter Naturally Aspirated

141 hp @ 6000 RPM and 187 Nm @ 4500

Vehicle Speed

6.5 Sec

Speed [mile/hr]

Time [sec]
3.3 Liter Naturally Aspirated

278 hp @ 6400 RPM and 350 Nm @ 5200 RPM

Vehicle Speed

3.2 Sec

Speed [mile/hr]

Time [sec]
2 Liter Turbocharged

224 hp @ 5500 RPM and 355 Nm @ 1500 RPM

Vehicle Speed

2.8
Sec

Time [sec]

Speed [mile/hr]
Summary Comparison

Turbocharging provides the fuel economy potential of the I4 with the performance of a V6 when needed.
Future Development - Game Changers

Goal: Acceleration of CO₂ reduction

<table>
<thead>
<tr>
<th>5 YEAR HORIZON</th>
<th>10 YEAR HORIZON</th>
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<tbody>
<tr>
<td>Downsizing &amp; Downspeeding</td>
<td>Energy Management</td>
</tr>
<tr>
<td>Increased Low End Torque</td>
<td>Energy Recuperation</td>
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**eBooster™**

**eTurboCompound™ & EAT™**

**Key Technologies Enabler**
Integration of Turbo Machinery, High Speed Motors & Power Electronics

- eBooster™
- Electrically Assisted Turbo™ (EAT)
- eTurboCompound™
Conclusions

- Global Fuel Consumption & CO2 Emission Reduction Targets Will Continue Into The Future

- Internal Combustion Engines Will Remain Dominant & Improve Meet These Demands

- Turbocharging Plays a Huge Role in Meeting Current & Future Fuel Economy and Performance Goals

- Driver Performance Expectations Will be Met
Thank You,

Thomas Grissom, BorgWarner Turbo Systems

feel good
about driving

better fuel economy
reduced emissions
great performance