Progress (and Challenges) along the Path to 2025

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Fiat Chrysler Automobiles (FCA)
- Multi-national company, formed in 2014
- Two main subsidiaries: FCA Italy and FCA US
- World’s seventh-largest auto maker
Light Duty Vehicle Brands: Mass-Market
Light Duty Vehicle Brands: Luxury

- Alfa Romeo
- Maserati
Light Duty Mass-Market: Gasoline Engines

NAFTA High Volume Engine Families – “Today”

- **FIRE I4**
- **Tigershark I4**
- **Pentastar V6**
- **HEMI® V8**
Light Duty Mass-Market: Gasoline Engines

NAFTA Engine Offerings – “Today”

[Graph showing power and displacement for different engine offerings.]
The Pentastar family replaced seven V-6 Engines (four families) and provided significant CO2 reduction with improvements in performance and refinement.

More than 3 Million Pentastar Engines produced since 2010CY

Three-time “Ward’s 10 Best Engines” winner

The Pentastar engine family provided improvements in power and a 7% improvement in fuel efficiency across the fleet.
Global Engine Offerings – Example, looking to the Future

The new family of engines will be available in many power levels but will share cylinder geometry and combustion system architecture for maximum efficiency.

Performance
Efficiency
Value

Displacement per Cylinder
Regulatory Challenges

NAFTA (that we all know too well)

[Graph showing regulatory challenges with percentages and year-over-year improvements for passenger cars and light trucks, along with details on SULEV30 and LEV III standards.]

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THE Industry Challenge

At the center is cost effective CO2 reduction

- Simultaneously balancing all requirements, INCLUDING...
- Finding solutions the customer will want to buy

Customer
- Fuel Economy
- Cost of Ownership
- Performance
- Drivability
- Utility

Cost Effective CO$_2$ Reduction

Corporate
- Profitability
- Sustainability
- Image

Regulatory
- CO$_2$ / CAFE
- Criteria Pollutants
- OBD

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Where to start...

Get the most out of existing engines: Follow the path of engine “Ideal Operation”

- How to do it?
  - CVT
  - Hybrid
  - Planetary stepped transmission with more gears and wider ratio range
8 and 9 Speed Transmissions

FCA US Strategy to achieve engine ideal operation and more…

- FCA US focused on transmissions first – moving from 4, 5, and 6 speeds to 8 and 9 speeds gaining efficiency, performance, and refinement
  - 1st in segment with 9-speed FWD transmission
  - 1st domestic automaker to offer 8-speed RWD transmissions in Luxury Sedan, SUV, and Truck
  - 6-10% improvement in fuel economy over their 4, 5, and 6 speed predecessors
Engine efficiency metrics, as a way to identify opportunities for improvement

\[ \eta_{\text{engine}} = \eta_{\text{combustion}} \times \eta_{\text{thermodynamic}} \times \eta_{\text{gas exchange}} \times \eta_{\text{mechanical}} \]

Results shown are from a DOE sponsored project.
Award #: DE-EE0003347
Awardee: FCA
Title: A MultiAir®/MultiFuel (MAMF) Approach to Enhancing Engine System Efficiency
Combustion Efficiency

Production Example: Integrated Exhaust Manifolds

- Component temperature protection due to material durability limits, is often satisfied via running $\lambda < 1$ (rich)
- Integrated exhaust manifolds allow the excess heat to be removed via the cooling system, extending the $\lambda = 1$ operation range

Pentastar V6
**Thermodynamic Efficiency**

Development Example: 3-Spark Plugs per Cylinder and Cooled EGR

- MAMF – DoE funded project, in collaboration with ANL
- Two combustion approaches with one design
- Both are full-range \( \lambda = 1 \) concepts
- Both were measured on multi-cylinder engines with real boosting systems

\( \text{SI} = 41\% \text{ BTE} \)  
(Octane on Demand)

\( \text{SI/CI} = 45\% \text{ BTE} \)  
(Mixed-Mode)

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Gas Exchange Efficiency

Production Example: Variable Valvetrain (MultiAir and Cylinder Deactivation)

- MultiAir increases gas exchange efficiency with variable lift and duration
  - Capable of cylinder-by-cylinder and cycle-by-cycle control

- HEMI® with “Fuel Saver Technology” (formerly known as “Multi-Displacement System”)
  - Collapsing lifters disable valvetrain in 4 cylinders of V8 engine
  - Firing cylinders increase IMEP, requiring intake manifold pressure to increase, reducing pumping work
  - 2000 rpm/2 bar BMEP BSFC: 340 g/kW-hr → 280 g/kW-hr (18% improvement)
Mechanical Efficiency

Production Example: Thermal Management and Variable Displacement Oil Pump

- Thermal Management System (TMS) effectively distributes engine heat via coolant to the Transmission and Engine oil to maximize drivetrain efficiency by reducing viscosity.

![Graph showing the impact of adding TMS on FTP City and Highway Cycles.](image)

- Dual-mode variable displacement oil pump
  - Low pressure mode at low engine speeds, where oil pressure demand is low
  - High pressure mode at high engine speeds, where oil pressure demand is high

![Active Grille Shutters](image)
Non-Gasoline Solutions (1 of 3)

Production Example: Diesel

- The 3.0L EcoDiesel engine offers the Best-in-Class highway label fuel economy in Ram 1500 HFE (29 mpg) and Jeep Grand Cherokee (30 mpg)
  - 50 state Tier 2 Bin 5 (NMOG + NO\textsubscript{x} = 0.075 + 0.05 = 0.125 g/mi) compliance
  - 2000 bar fuel system, with solenoid injectors capable of 8 pulse per cycle injection
  - Cooled EGR
- FCA have considerable diesel experience
  - Invented common rail for light duty
  - ~50% of FCA European fleet is diesel
Non-Gasoline Solutions (2 of 3)

Production Example: CNG

- Ram 2500 is the only factory built bi-fuel truck in the US market
- Range / Fuel Tanks
  - 370 miles / 18.2 GGE CNG + 8 gallons Gasoline
  - 745 miles / 18.2 GGE CNG + 35 gallons Gasoline
- CNG is a ‘clean’ burning fuel and is an enabler for higher efficiency engines
- In Europe, FCA accounts for ~80% of the CNG market
- Though Ram 2500 is not a light duty vehicle, the technology can easily be implemented in light duty if / when there is market demand
Non-Gasoline Solutions (3 of 3)

Production Example: Nuclear, Wind, Solar, NG, Coal (aka BEV)

- Fiat 500e
  - Zero g/mi CO2 for GHG compliance
  - 108 MPGe highway label
  - EPA combined range of 87 miles
- PHEV minivan planned
Following industry trends for new SRT product:

- HEMI® engine displacement reduced: 392 ci → 376 ci
- Boosting system added: Lysholm screw compressor with water-to-air charge air cooler

The Result:

707 HORSEPOWER

... and we can’t build enough
Downsizing and Boosting

A more conventional example

- A new gasoline engine family which will incorporate numerous technologies
Fuel Economy Standards

Z-Curves

- Light duty standards are described by “Z-Curves”
- Different for cars and trucks
- Footprint-based
- Drives increased fuel efficiency for all vehicles

\[
\text{Footprint} = X \times Y
\]

![Diagram of Z-Curves for Passenger Cars and Light Trucks](image-url)
Propulsion System Efficiency (PSE)

- Similar to “ton-mile/gallon”, but better for light duty
- Accounts for aero, tire, and brake/hub/driveline losses
- Easily calculable from EPA data

\[
PSE = \frac{\text{Vehicle Demand Energy}}{\text{Fuel Energy Used}} = \eta_{\text{engine}} \times \eta_{\text{trans}} \times \eta_{\text{driveline}}
\]

Source: www.epa.gov/otaq/tcldata.htm

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Example of new product improvement

Propulsion System Efficiency (PSE)

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Source: www.epa.gov/otaq/tcldata.htm
Examples of Challenges that Remain

Propulsion System Efficiency (PSE)

- At current VDE (and footprint), ~35% PSE is required to meet 2025
  - Or, at current PSE (and footprint), an 18%-34% reduction in VDE is needed

![Propulsion System Efficiency Analysis for '15MY EPA New Cert. Vehicles](chart)

\[
PSE = \frac{\text{Vehicle Demand Energy}}{\text{Fuel Energy Used}}
\]

\[
= \eta_{\text{engine}} \times \eta_{\text{trans}} \times \eta_{\text{driveline}}
\]

Source: [www.epa.gov/otaq/tcldata.htm](http://www.epa.gov/otaq/tcldata.htm)
How to Achieve 35% PSE?

- Smaller engines (higher Load Factor) and diesels help, but are not enough
- Full hybrids may be enough, but are not likely to span the entire fleet

Propulsion System Efficiency Analysis for ‘15MY EPA New Cert. Vehicles

- Grand Cherokee 6.4L NA, 3.6L NA, 3.0L TD
- Challenger 6.2L SC, 6.4L NA
- Ferrari 6.3L NA (731 hp)
- Viper 8.4L NA (645 hp)
- Cherokee 3.2L NA
- Dart 1.4L T
- Competitor’s Hybrid Vehicle

Gasoline
DieSEL
Hybrid
Examples

PSE, %

Load Factor, %
(Average Cycle Power / Rated Engine Power)

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Fleet is projected to be 89% Non xEV in 2021

**With Gas Prices Less of a Worry, Buyers Pass Hybrid Cars By**

“In all, 55 percent of hybrid and electric vehicle owners are defecting to a gasoline-only model at trade-in time — the lowest level of hybrid loyalty since Edmunds.com began tracking such transactions in 2011. More than one in five are switching to a conventional sport utility vehicle, nearly double the rate of three years ago.”


**Hybrid and Electric Vehicles Struggle to Maintain Owner Loyalty**

“Overall, only 45 percent of this year’s hybrid and EV trade-ins have gone toward the purchase of another alternative fuel vehicle, down from just over 60 percent in 2012. Never before have loyalty rates for alt-fuel vehicles fallen below 50 percent.”

Other Technical Challenges / Lessons Learned

A few examples based on MAMF experience

- High efficiency can present aftertreatment temperature challenges

- Robust combustion control is required, if steady state results are to be realized in vehicle

- Degree of down speeding is limited by transient torque response (e.g. turbo lag) and driveline torsional vibration

- Accurate, predictive models that can operate on an engineering time scale are a necessity, especially as combustion systems become more complex
A great deal of work remains, to satisfy regulatory AND customer requirements for 2025

There is no one single solution that will satisfy all requirements
  ● It will be a collection of many

Consumer acceptance is key
  ● The current price of fuel further limits the consumer’s willingness to pay for fuel-efficient technology

The industry as a whole is hopeful the mid-term review will provide a balanced view of what is required for 2025
Thank you.

FCA US Technology Center in Auburn Hills, Michigan