Integrated Powertrain and Vehicle Technologies for Fuel Efficiency Improvement and CO_2 Reduction

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U.S. DEPARTMENT OF ENERGY

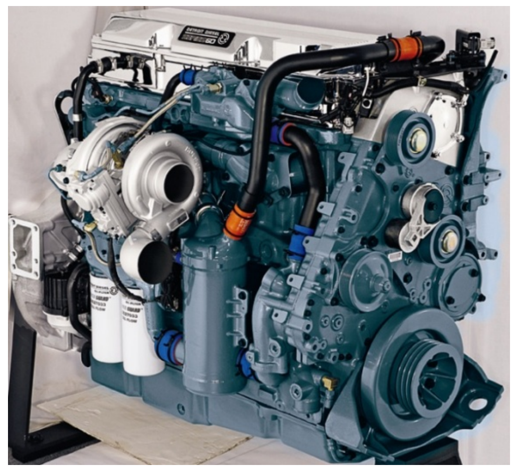
Outline

- Historical fuel efficiency trends
- Contribution of DOE projects
- Changing regulatory environment
- Engine and vehicle fuel efficiency technologies
  - In production
  - In development
  - In concept phase
- Summary

Engine Development Challenges

Regulations:
Emissions, Noise, Diagnostics

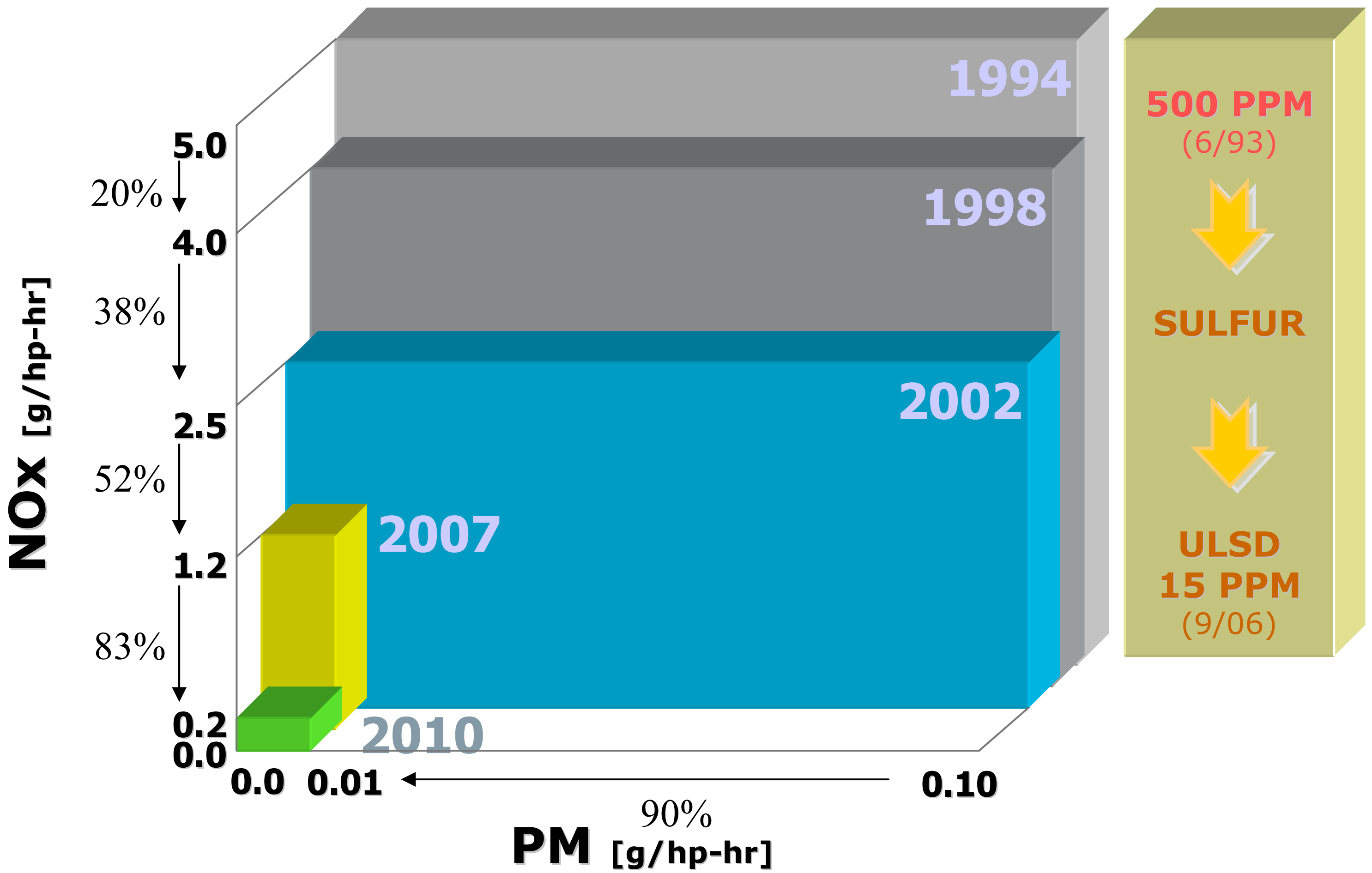
Technical constraints:
- Material limits
- Heat rejection
- Controller speed and bandwidth
- Weight



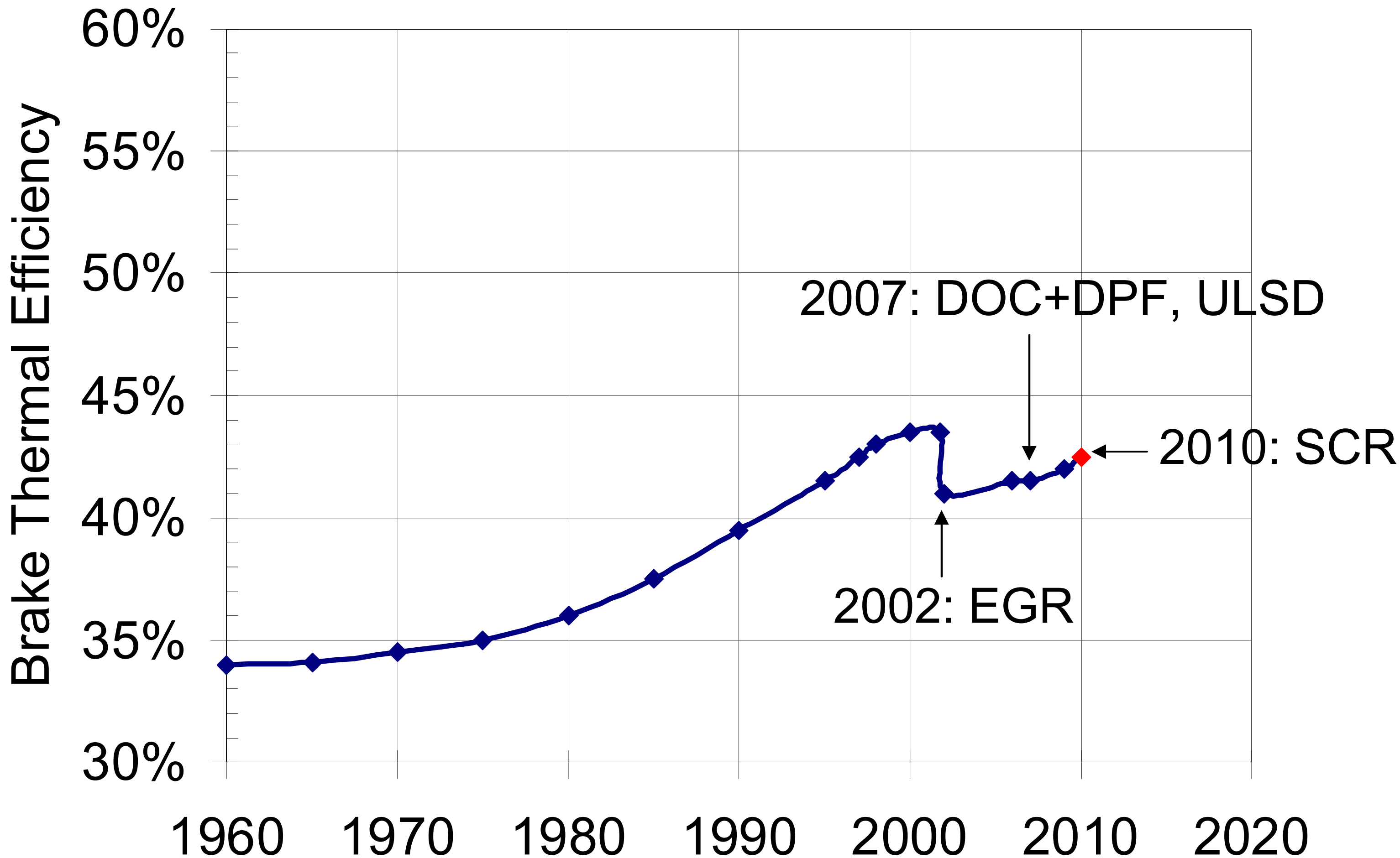
Economic constraints:
- Initial cost
- Cost of ownership
- Development costs

Customer requirements:
Fuel economy, Performance, Durability

On-Highway Emission Regulations



Thermal Efficiency Trends – Heavy-Duty Diesels



Based on Lysinger, DEER 2006; updated

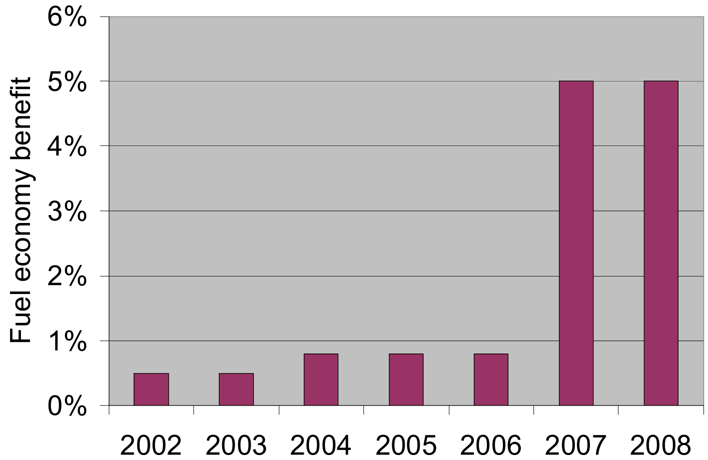
Contribution of DOE Projects

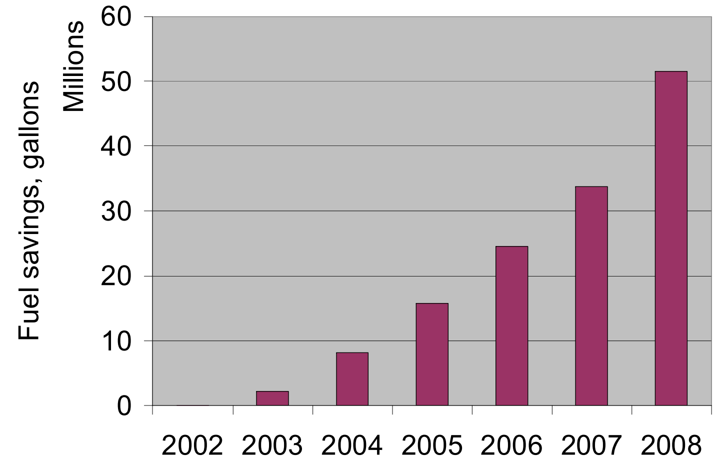
Technology	Description	Funding Sources	Engine	Start of production	BSFC improvement (%)
VGT control	Increase EGR rate and controllability; transient improvement	NZ-50/DELTA	Series 60	2002	0.5 - 1
EGR cooler	Reduce pressure drop, increase heat transfer, reduce fouling	NZ-50	Series 60	2004	0.5 - 1
Virtual EGR Controller	Reduce hardware cost, improve control robustness	NZ-50/LEADER	Series 60	2007	0.5 - 1
DOC/DPF	Reduce regeneration frequency, pressure drop, and failure rate	LEADER/DELTA	Series 60, DD15	2007	2 - 2.5
Dual solenoid injectors/cam	Reduce parastic loss; higher injection pressure at lower speeds and loads	Smart Materials / NZ-50	Series 60	2007	1.5 - 2
Advanced combustion and piston design	Reduce emissions at low loads and improve BSFC	NZ-50	Series 60	2007	1 - 1.5

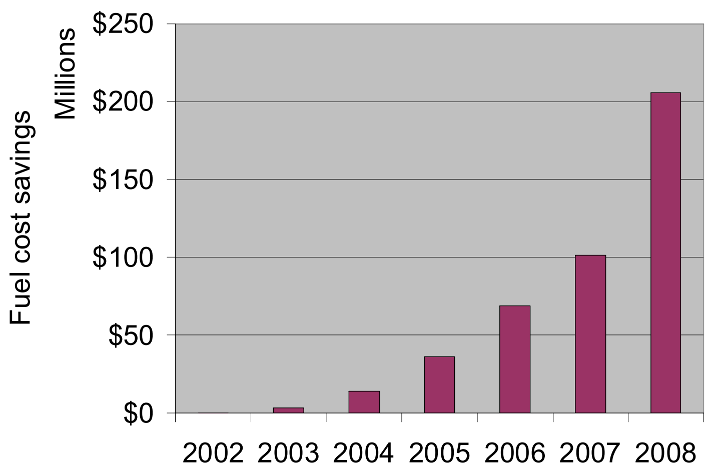
Notes:

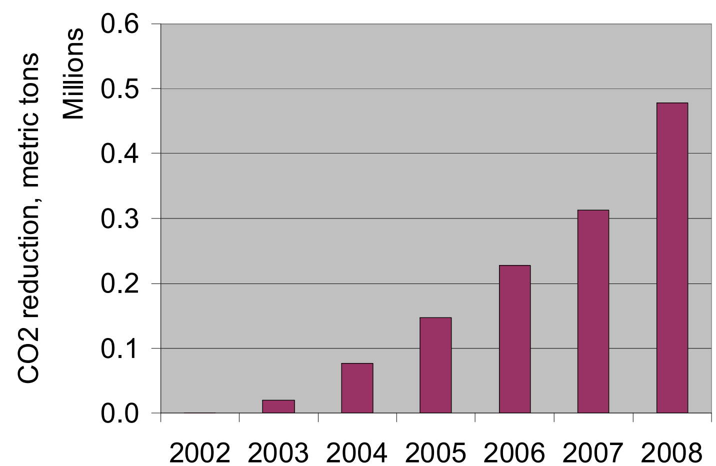
1. Commercial spin-off conducted as separate industry funded projects
2. BSFC improvements from individual technologies are not additive

Contribution of DOE Projects (Continued)









Changing Regulatory Environment

- NOx and PM are at near-zero levels
  - Government leadership on regulation
  - Engine manufacturers investment
  - End-user costs
- On-board diagnostics (OBD)
- Fuel efficiency and CO_2
  - Various agencies involved
  - Timing, content not yet clear
  - May potentially complicate DOE-Industry cooperation on technology development
  - Increased importance of engine/powertrain/vehicle integration

Technologies for Heavy-Duty On-Highway Diesel Engines and Vehicles

- In production
  - Turbocompounding
  - Predictive cruise control
  - SCR (few months away)
- In development
  - Model based controls
  - Aerodynamic enhancements
- Concept phase
  - Waste heat recovery
  - Hybridization

Engine Turbocompound

Measure
Turbocompound

Mode of operation
All time

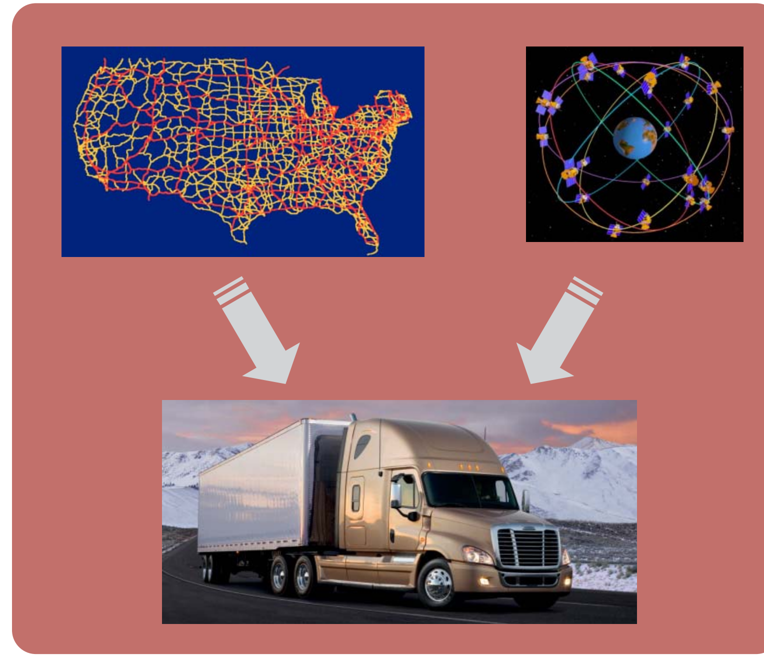
Potential
≈ 3 % Fuel

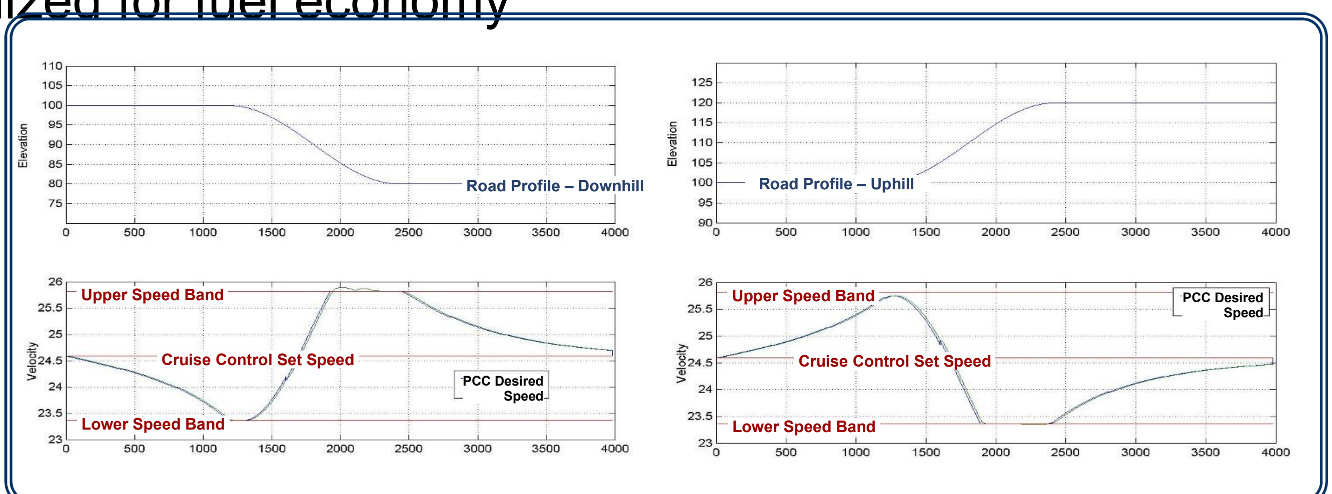
Status
In production

Limitations
Turbo compound achieves high efficiency primarily at high torque. Limited effectiveness at low torque.

Predictive Cruise Control

- Enables the truck to "see" the road that lies ahead
  - Uses on-board GPS and 3D digital maps
  - Contains high precision slope data for over 200,000 highway miles in 48 states
  - '*Sees*' upcoming hills up to 2 kilometers ahead
- Enables vehicle systems to be optimized for fuel economy





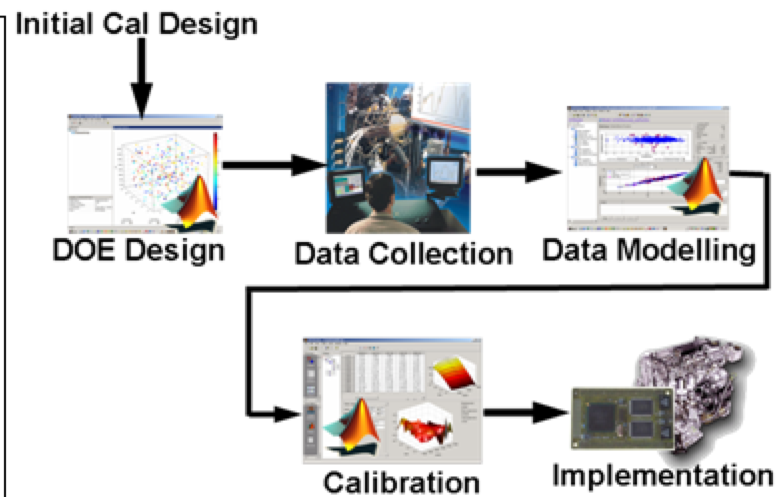
Engine Calibration Management

Measure
Optimize combustion strategy <u>off-board</u> by leveraging fuel injection rate shape, multiple injection events, increased injection pressure, and corresponding adjustments in air/EGR management, within design and regulatory constraints.

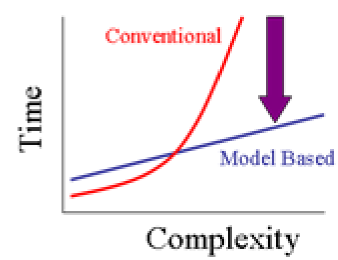
Mode of operation
All times.

Potential
~ 1%-4% fuel economy potential depending on range of engine/vehicle duty cycle.

Status
In use today for development and release of today's product. More comprehensive tool suites and applications in future.



Model Based Calibration
time = a*complexity



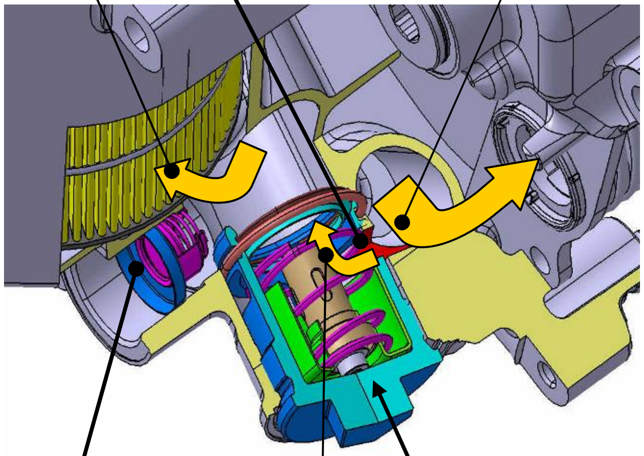
Engine Thermatic Oil Cooler

Measure
Thermatic control of oil temperature

Mode of operation
Active thermostat control to keep oil temperature at 110°C .

Potential
≈ 1.5 % average – more in cold weather.

Status
In production



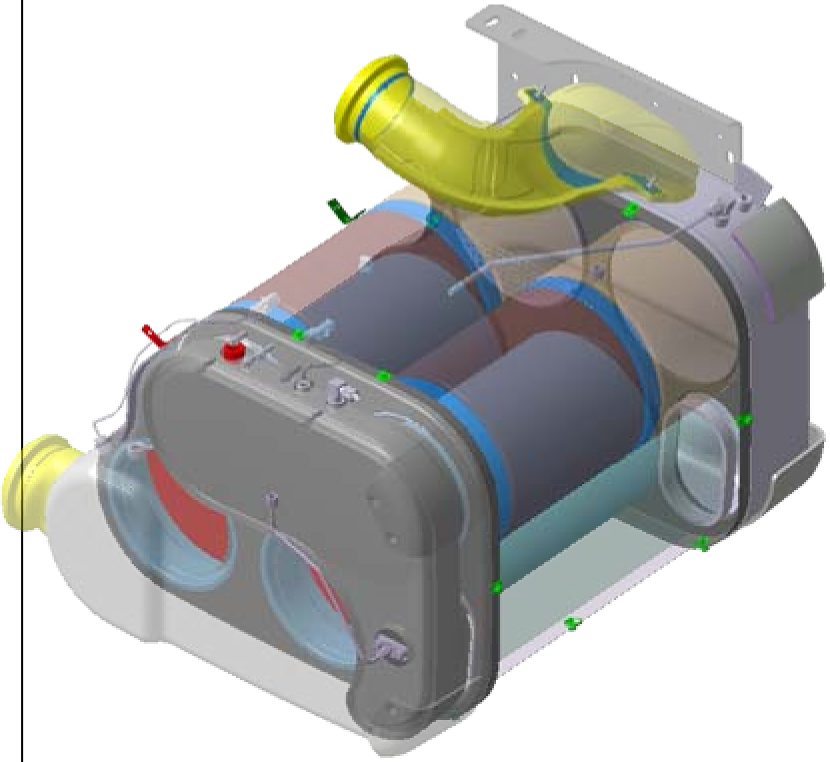
Engine Aftertreatment

Measure
NOx aftertreatment enables combustion optimization to yield improved isfc
Substrates, canning designed for minimal back-pressure (reduced pumping work)
Optimized combustion to yield low engine-out PM and increased regeneration intervals

Mode of operation
All times

Potential
3-4% demonstrated in truck tests

Status
Product launch in January, 2010



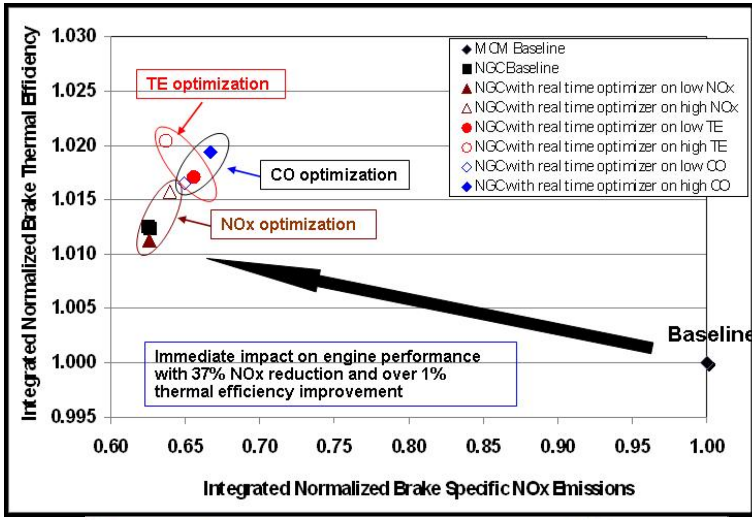
Next Generation On-Board Controller

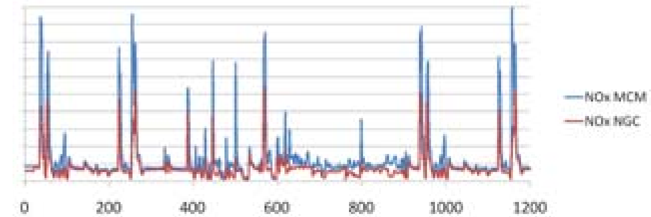
Measure
Next Generation Controller (NGC) consisting of Engine / ATS integrated forward and inverse controllers, including <u>on-board</u> real time optimizers and engine models, continuously operating within applicable design and regulatory constraints, and learned customer application patterns.

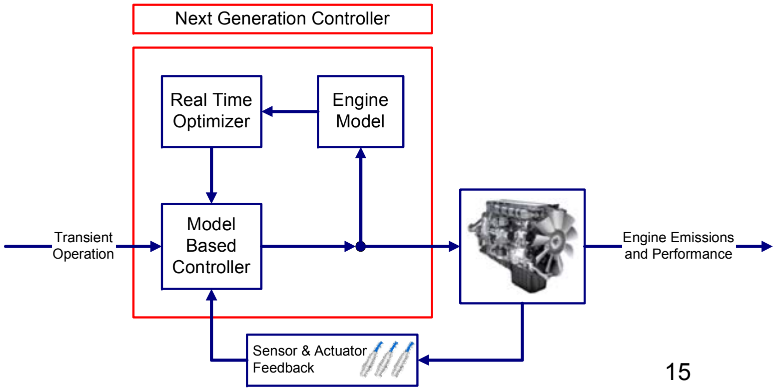
Mode of operation
All times.

Potential
~ 1% - 4% fuel economy potential.

Status
Development phase







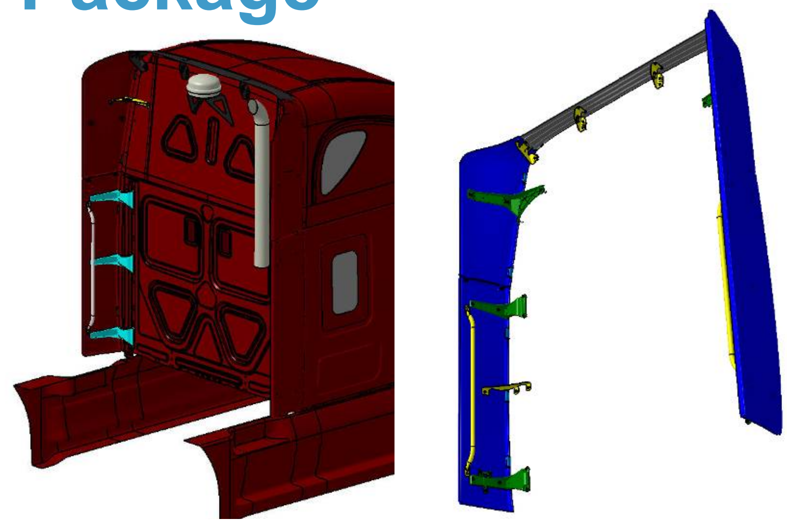
Technologies In Development
Aerodynamic Enhancement Package

Measure
Developments are underway to improve tractor and traier aerodynamics by reducing crosswind sensitivity, matching roof profiles commonly requested 5th wheel heights, and other minor enhancements.

Mode of operation
Effective during freeway operation, and in particular when crosswinds are present.

Potential
≥ 2.5%, result is a function of vehicle specification and ambient conditions. Confirmed in fuel economy and wind tunnel tests.

Status
In development



Roof Riser + Long Side Extenders

Chassis Fairing Extensions

Bumper closure – fleet HP ratings

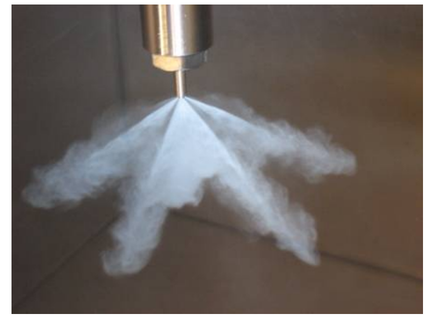
Variable Fuel, Air, and EGR Management

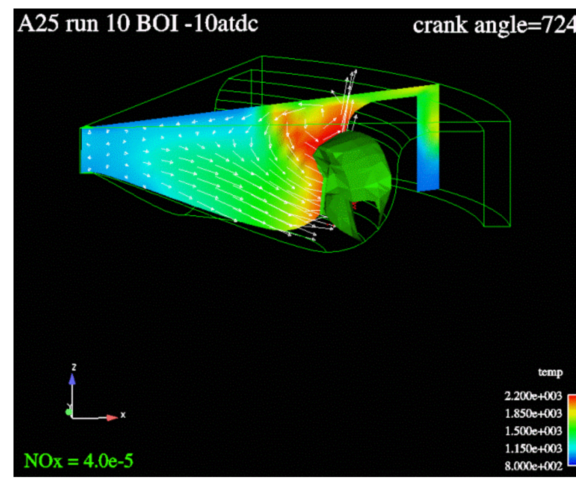
Measure
Enhanced in-cylinder combustion efficiency /emission management via variable geometry fuel, air, and EGR hardware. Integrated and optimized to final ATS and vehicle configuration.

Mode of operation
All times.

Potential
~ 1%-4% fuel economy potential depending on range of operating application.

Status
Development phase





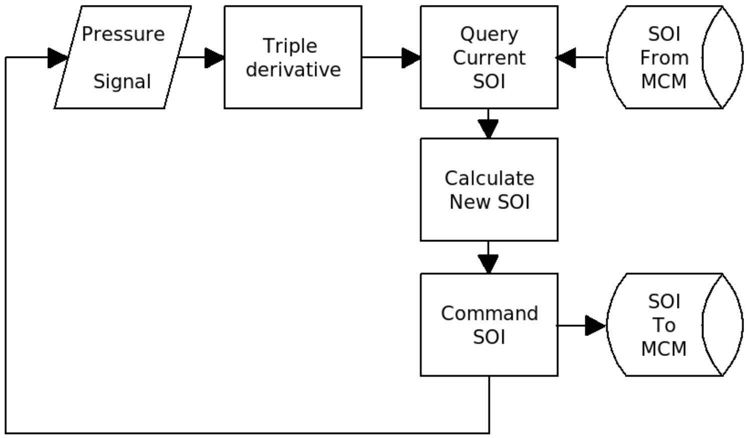
Real Time Combustion Control

Measure
Incorporate Start-Of-Combustion sensors in individual cylinders and use this signal for closed-loop combustion control

Mode of operation
All times.

Potential
~ 1% - 4% fuel economy potential.

Status
Concept phase



Courtesy: Woodward

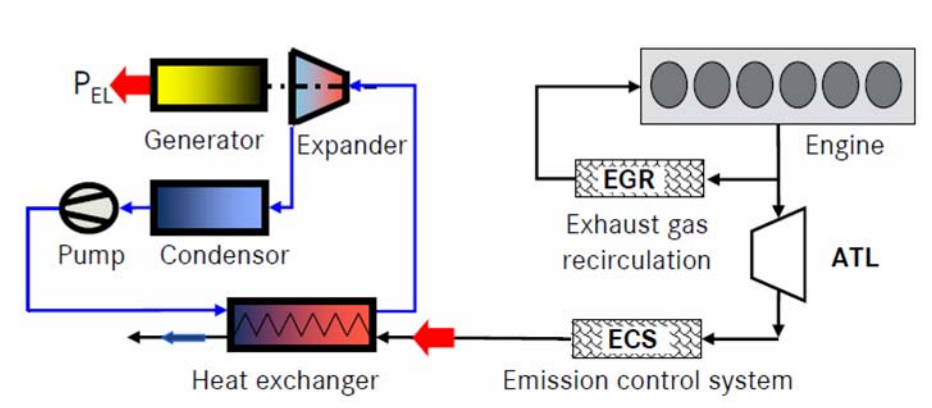
Waste Heat Recovery

Measure
Energy recovery from various sources, i.e. engine exhaust, EGR, engine coolant.

Mode of operation
All times – with warmed up engine.

Potential
~ 2-8% fuel economy potential depending on system used and transfer of power. Most likely scenario is in combination with hybrid.

Status
Concept phase

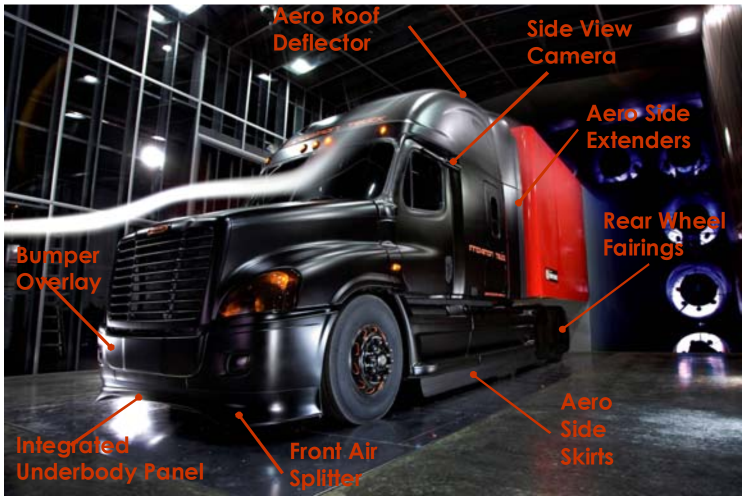


Courtesy: Daimler Trucks

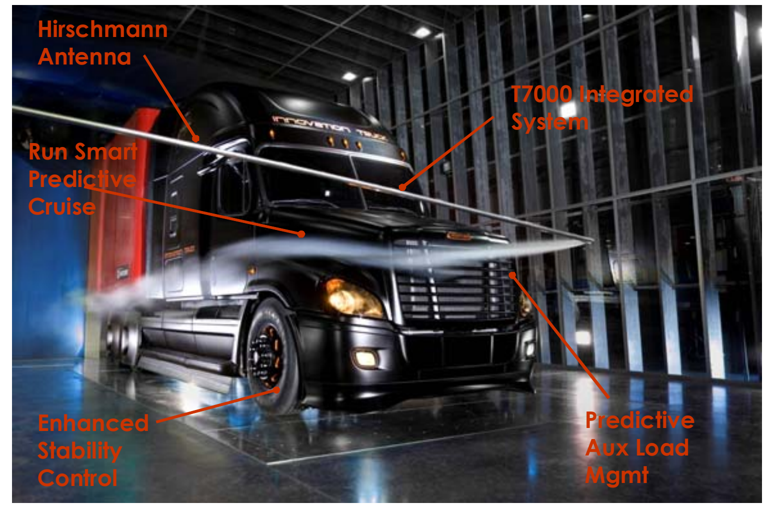
DETROIT DIESEL

Innovation Truck

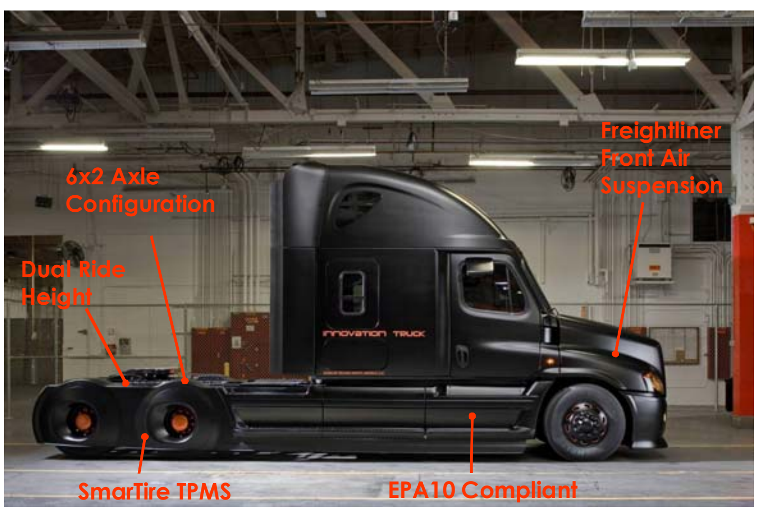
Aerodynamics



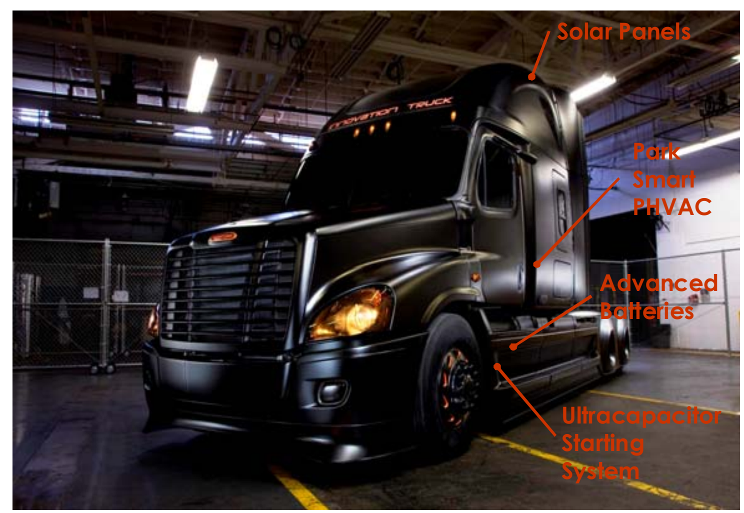
Mechatronics



Chassis



Power Systems



DETROIT DIESEL

Lessons of the Last Decade

- Meeting the most stringent emission standards in the world (EPA2002, EPA2007, EPA2010) required the strength of global organizations
- EPA2002 emission regulation was associated with a significant drop in engine thermal efficiency
- DOE support of R&D program helped avoid further efficiency drop in 2007
- EPA2010 will lead to simultaneous improvements in emissions and fuel efficiency for most manufacturers

DETROIT DIESEL

Preparing for the Future

- Emphasis is shifting to fuel efficiency and CO_2
- Vehicle level regulatory targets are likely
  - Growing importance of engine/powertrain/vehicle integration
- Regulatory-driven and customer-driven technology development will now move in the same direction
- DOE support in evaluating high risk, high reward technologies is critical