U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Overview: Advanced Combustion Systems and Fuels R&D

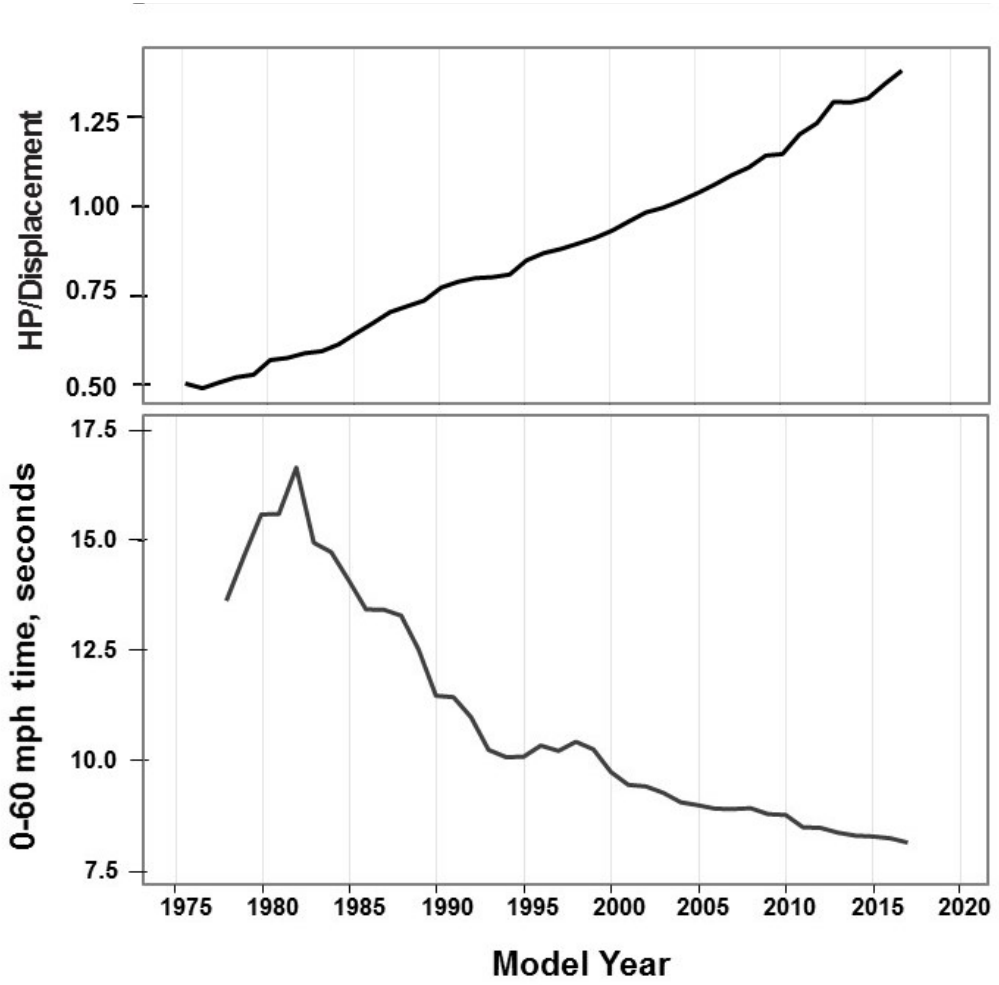
Gurpreet Singh, Program Manager

Advanced Combustion Systems and Fuels
Vehicle Technologies Office

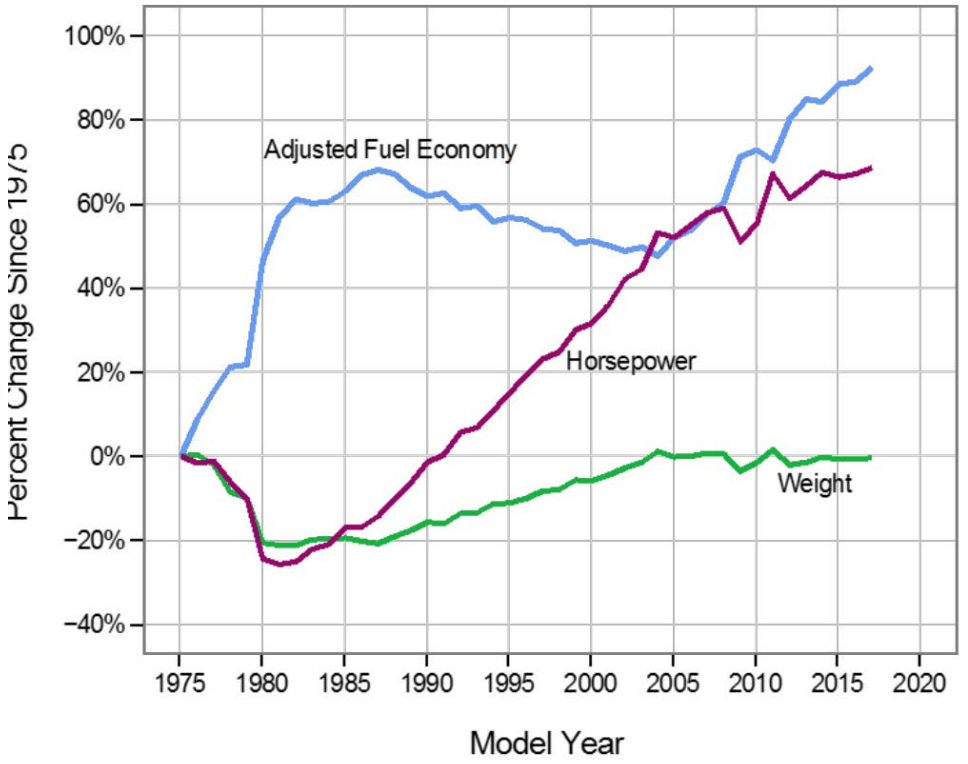





Improved Engines Increase Vehicle Fuel Economy



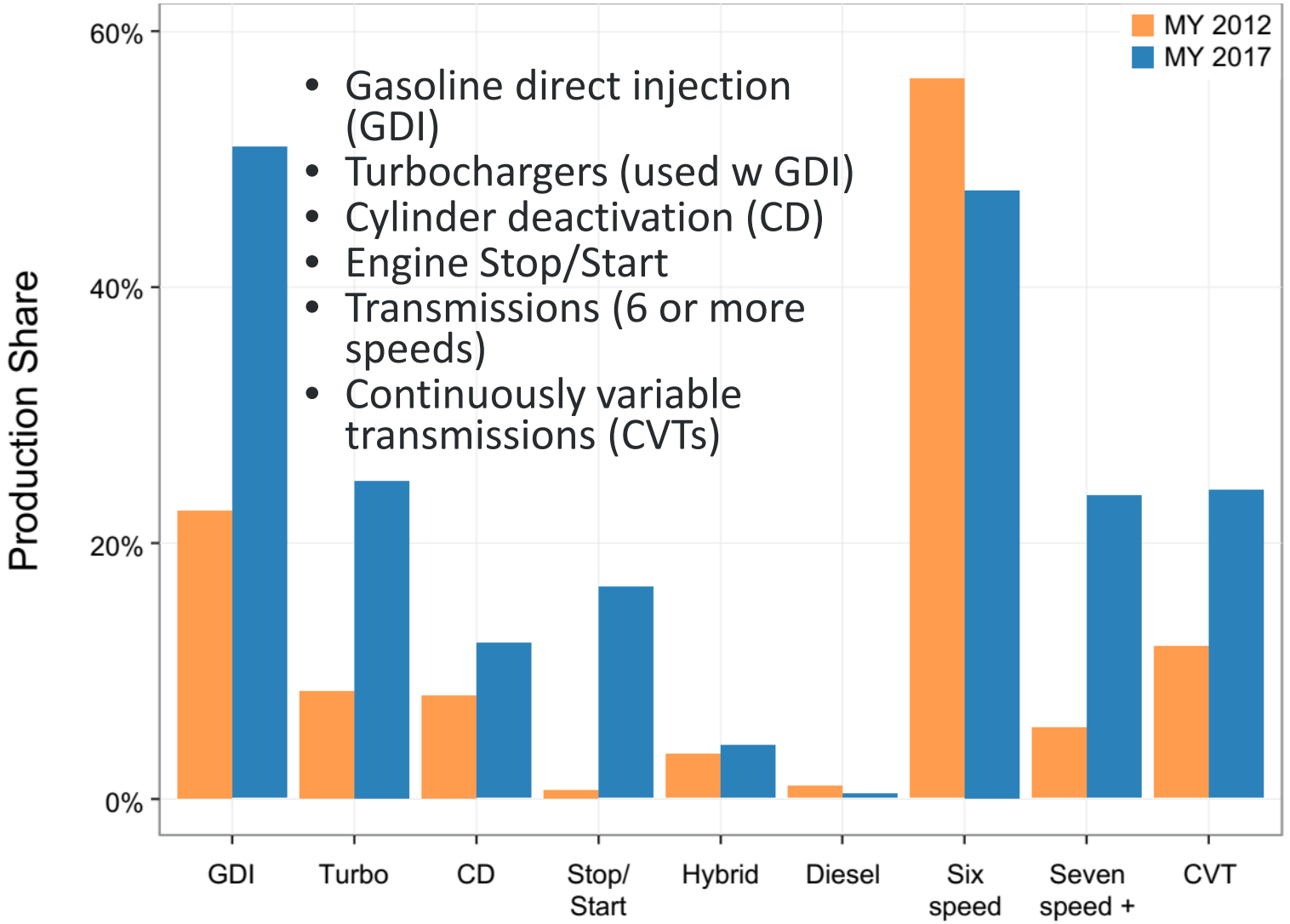
More power, smaller engine, faster acceleration



Source: Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2017, EPA-420-R-18-001, January 2018.

Engine performance improvements have increased fuel economy although vehicle size and weight have increased.

Engine Technologies in Production Vehicles (MY 2012 vs MY 2017)

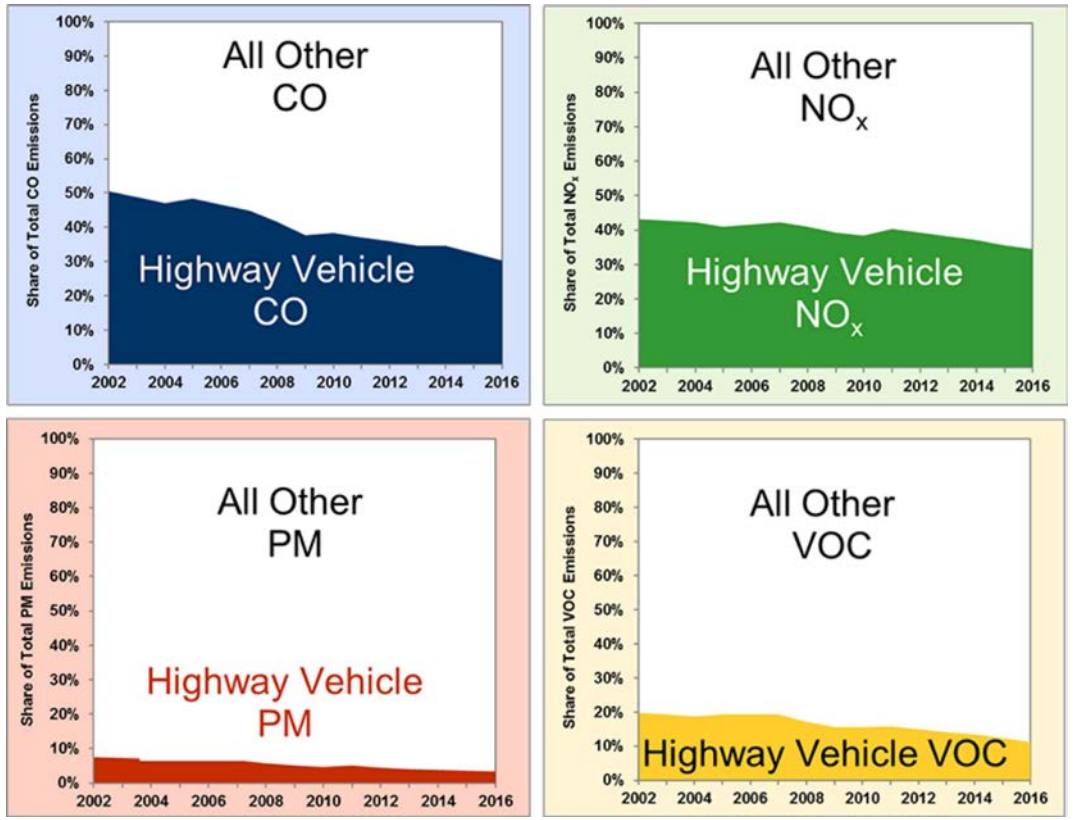


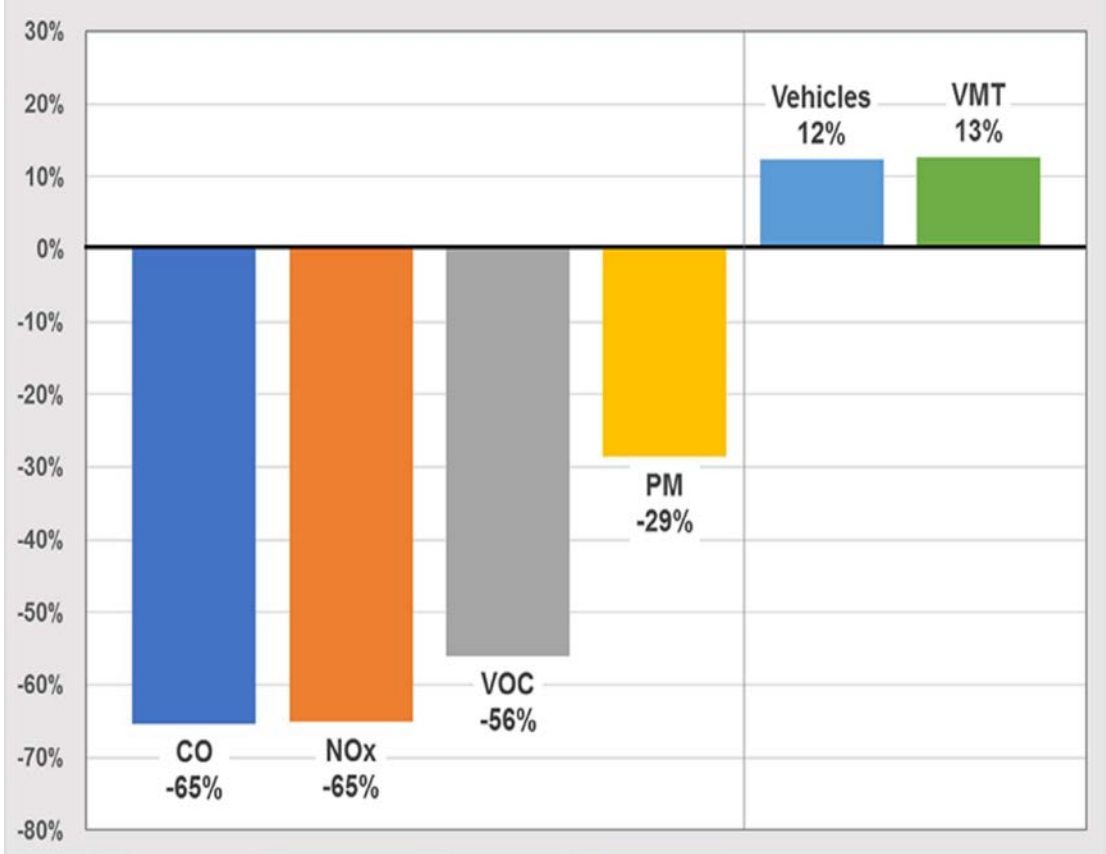
- Gasoline direct injection (GDI)
- Turbochargers (used w GDI)
- Cylinder deactivation (CD)
- Engine Stop/Start
- Transmissions (6 or more speeds)
- Continuously variable transmissions (CVTs)

Source: *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2017*, EPA-420-R-18-001, January 2018.

Highway Vehicle Emissions Have Declined

Highway vehicles share of pollutants is declining (VTO FOTW #998, 10/9/2017)



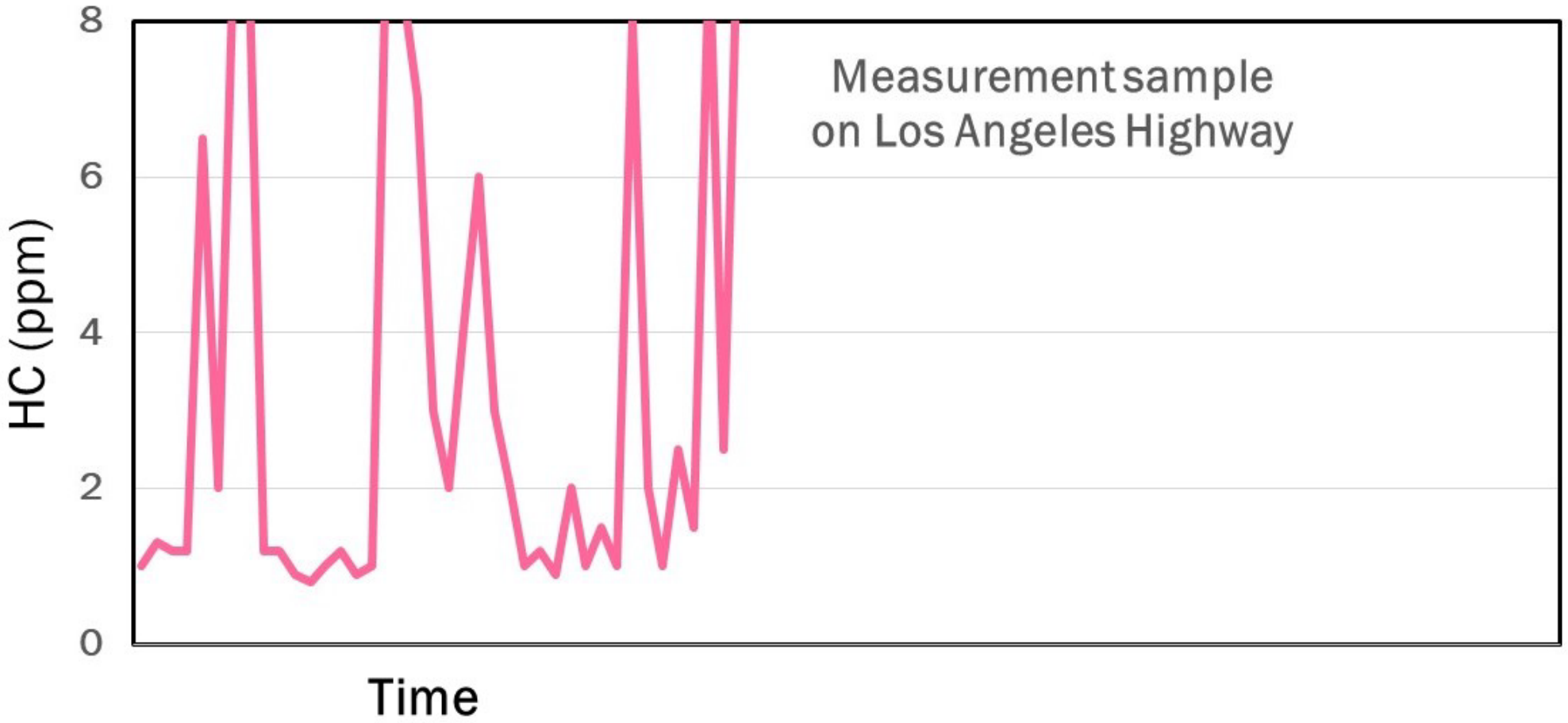


Total highway vehicle emissions have declined (from 2002 to 2015),even as the number of vehicles and VMT have increased (VTO FOTW #999, 10/16/2017)

Sources: U.S. Environmental Protection Agency, National Emissions Inventory and Air Pollutant Emissions Trends Data.
U.S. Department of Transportation, Federal Highway Administration, Traffic Volume Trends, December 2016,
Highway Statistics 2002 and Highway Statistics 2015.

New Cars Clean the Air

Tailpipe Emissions are Lower than Ambient Levels on the LA Freeway



NOTE: Curves replotted to approximate Figure 1 curves of source document.

Source: Johnson, T. and Joshi, A., "Review of Vehicle Engine Efficiency and Emissions," SAE Technical Paper 2018-01-0329, 2018, doi:10.4271/2018-01-0329.

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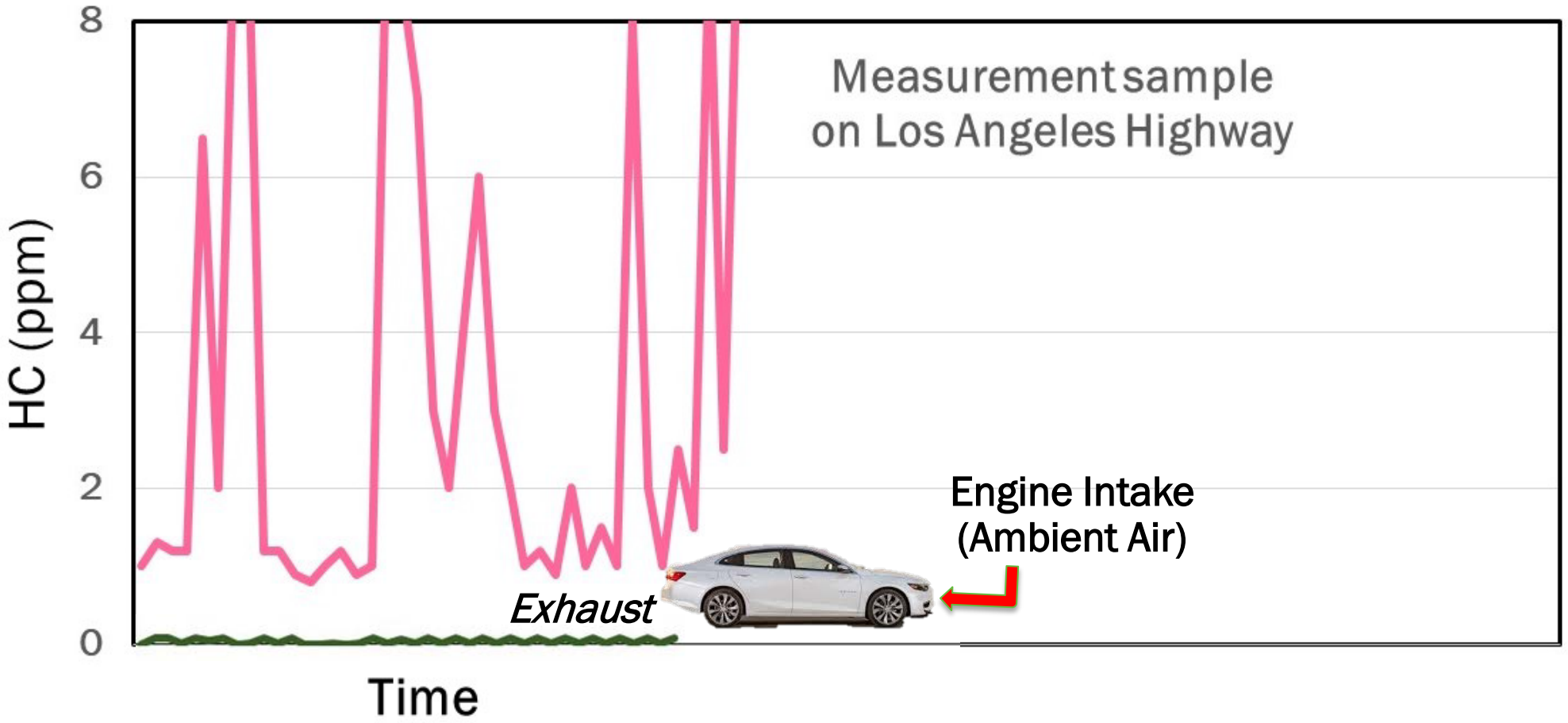

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Advanced Combustion Engines and Fuels R&D Contribute Significantly to Quantified VTO Benefits

Program Area	Annual Petroleum Savings (million bpd)			Annual Emissions Reduction (million tons CO_{2e})		
	2025	2035	2050	2025	2035	2050
Electrification	0.03–0.19	0.28–0.61	0.34–1.44	5–29	57–123	74–272
Advanced Combustion Engines and Fuels	0.25–0.32	0.66–1.01	0.85–1.01	47–62	122–194	151–182
Materials Technology	0.02–0.03	0.06–0.12	0.06–0.08	4–7	11–24	11–15
Hydrogen Fuel Cells	0.00–0.05	0.11–0.45	0.35–0.96	0–6	14–46	59–148

*Applied analysis estimates VTO Advanced Combustion Engines and Fuels program benefit of **0.85 –1.01 mbpd petroleum savings in 2050 (over 13 – 15 billion gallons of fuel cumulative)***

Source: Stephens, et al. (2017), Vehicle Technologies and Fuel Cell Technologies Office Research and Development Programs: Prospective Benefits Assessment Report for FY 2018. http://www.ipd.anl.gov/anlpubs/2017/11/140256.pdf

Advanced Combustion Systems and Fuels R&D Budget

Major Activities	FY 2016 Enacted	FY 2017 Enacted	FY 2018 Enacted
Advanced Engine and Fuel Technologies R&D	**$59,641**	**$71,400***	**$65,200K**
Advanced Combustion Engine R&D	***$37,141K***	***$38,800K****	
Combustion and Emission Control	*37,141*	*38,800*	
Fuels and Lubricant Technologies	***$22,500K***	***$32,600K****	
Fuels and Lubricants	*22,500*	*32,600*	

*Transition to Current Major Activities in FY 2017

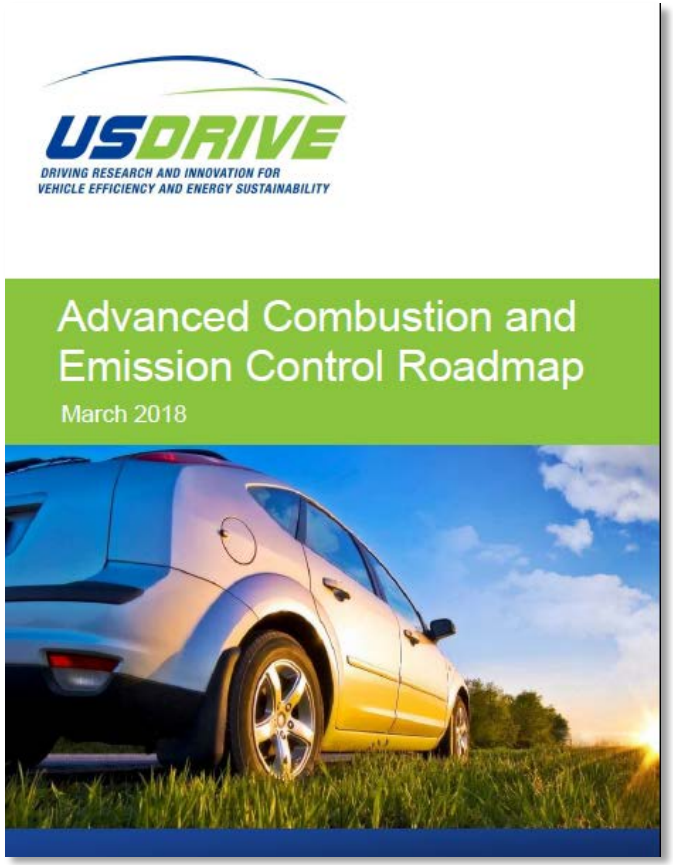
Technical Challenges

- Develop combustion strategies that maximize engine efficiency while:
  - Operating over the full load-range
  - Improving transient response, and noise, vibration, and harshness (NVH)
  - Reducing in-cylinder emissions formation
- Improve understanding of how fuel properties impact the efficiency of modern engines
- Develop effective aftertreatment technologies for lean, low temperature exhaust emissions while:
  - Reducing cost and energy penalty
  - Reducing volume and weight
- Reduce overall cost of engine system

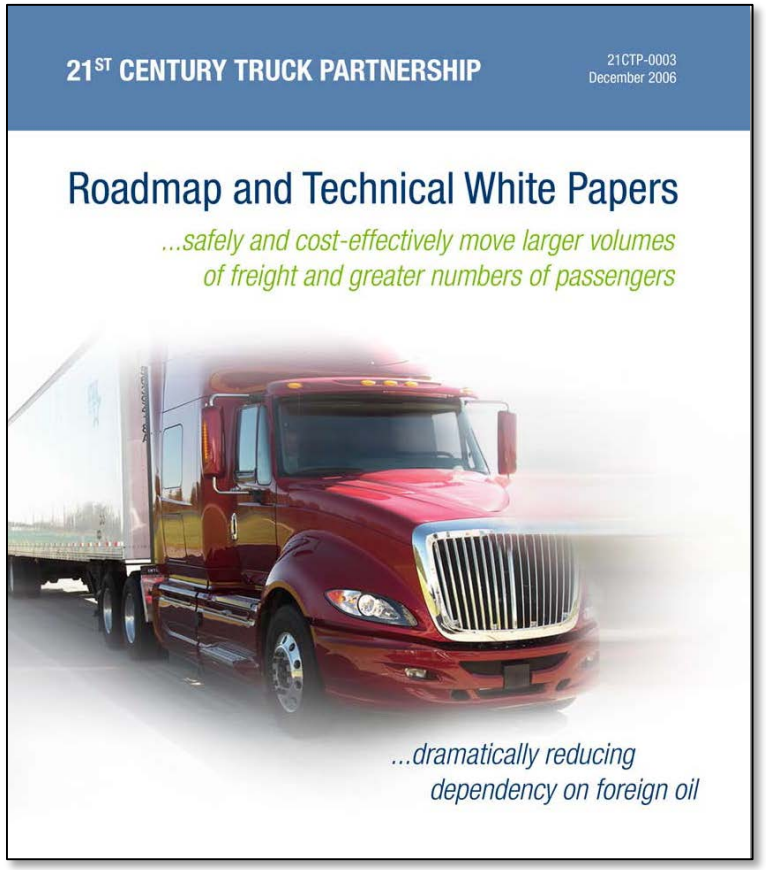
Market Challenges

- Fuel Economy
- Emissions (more stringent regulations)
- Cost to Consumer

Government-Industry Partnership Technology Roadmaps



U.S.DRIVE ACEC Tech Team Technology Roadmap (https://www.energy.gov/sites/prod/files/2018/03/f49/ACEC_TT_Roadmap_2018.pdf)



*currently being updated

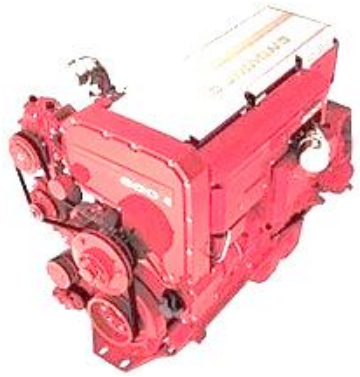
21st Century Truck Technology Roadmap (https://www.energy.gov/sites/prod/files/2014/03/f8/21ctp_roadmap_2007.pdf)

Advanced Engine and Fuel Technologies R&D

Strategic Goal: Improve understanding of, and ability to manipulate, combustion processes, generating knowledge and insight necessary for industry to develop the ***next generation engines and fuels*** capable of improving the fuel economy of passenger and commercial vehicles.

Program Goals

	Light-Duty			Heavy-Duty	
	2020	2025	2025	2020	2025
Engine brake thermal efficiency	--	--	--	55%	57%
Fuel economy improvement*	20%	25%	35%**	30%	35%
NOx & PM emissions	Tier3/ LEV III	Tier 3/ LEV III	Tier 3/ LEV III	EPA Standards	EPA Standards

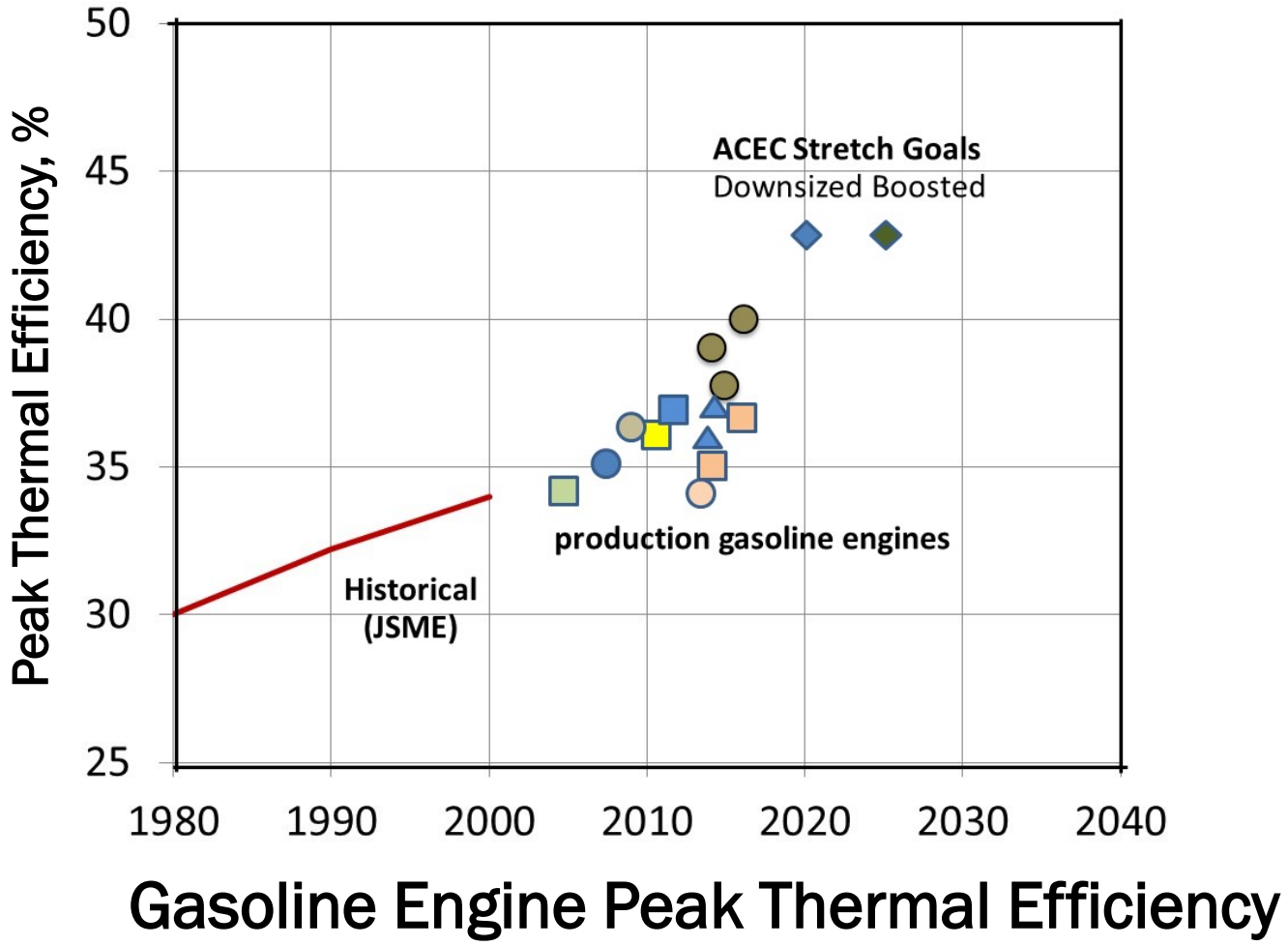


*Compared to: LD baseline is 2015 direct-injected boosted gasoline vehicle
HD baseline is 2009 HD diesel engine

**Includes improvement from Co-optimization of Fuels and Engines

VTO Advanced Engine and Fuel Technologies R&D –
Improve Engine Efficiency, Increase Vehicle Fuel Economy

More efficient engines will improve fuel economy of over 90% of new passenger vehicles in the near- to mid-term.



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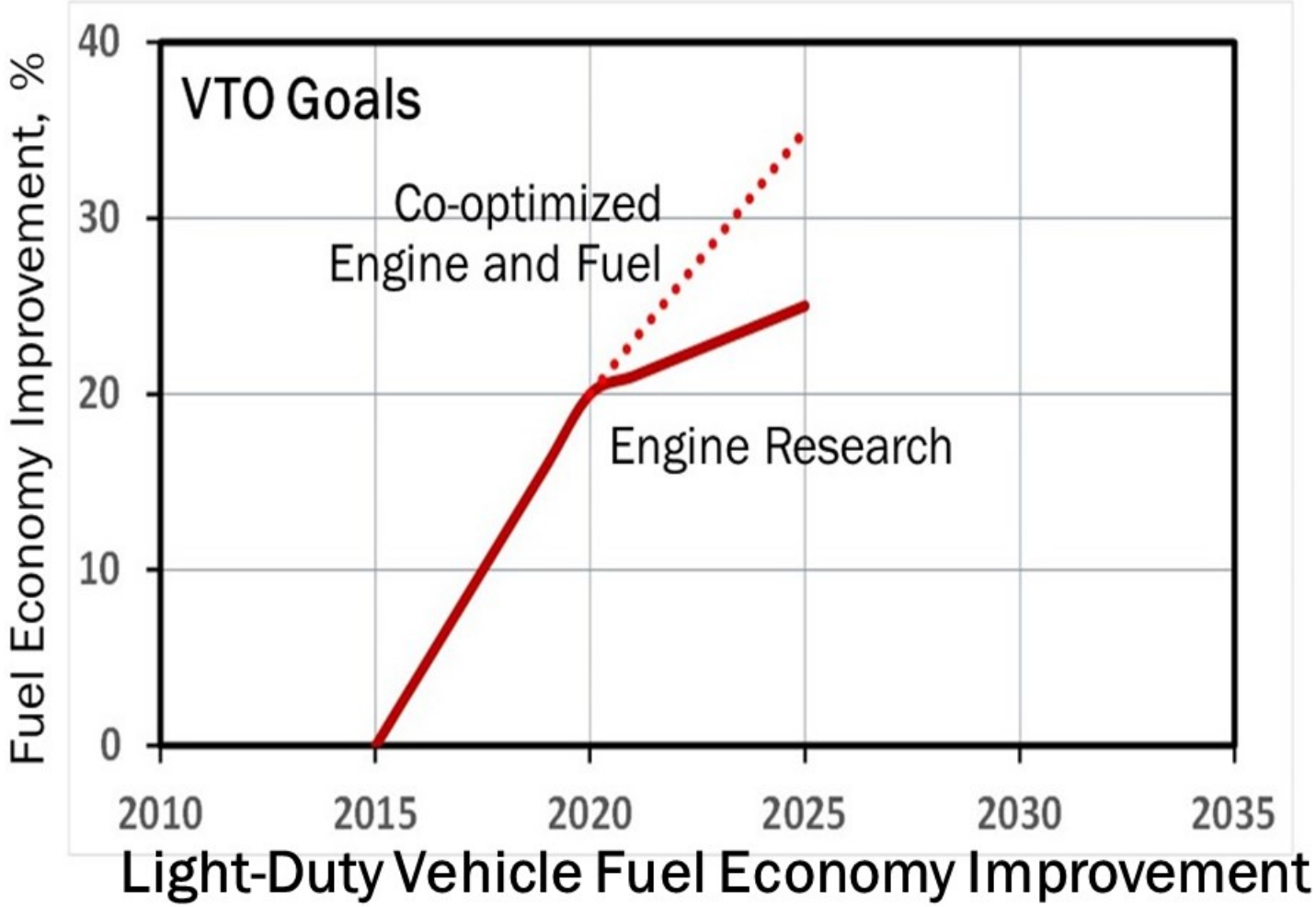
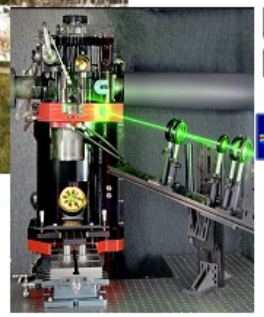


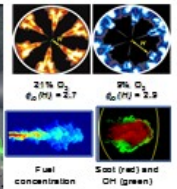
Advanced Engine and Fuel Technologies R&D

Early Stage Cutting-Edge Research using Unique National Lab Facilities and Core Capabilities strengthens the knowledge base and improves understanding of *high-efficiency, advanced combustion engines and fuels*.

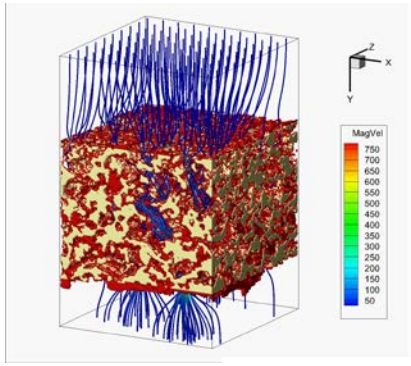
SNL/Livermore Combustion Research Facility

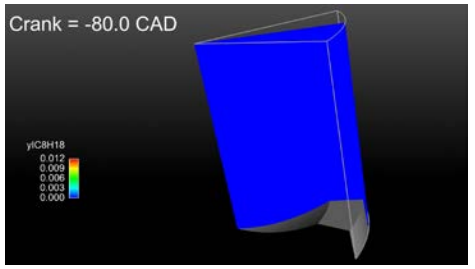
Sandia National Laboratories





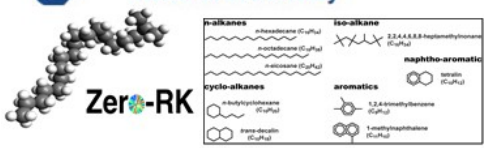
SNL optical engine with laser and optical diagnostics



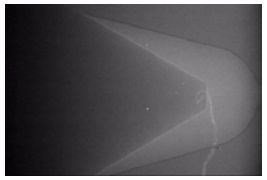


Interfaces to common CFD codes (licensed to Convergent Sciences)

Lawrence Livermore National Laboratory



LLNL's Zero-RK chemistry software

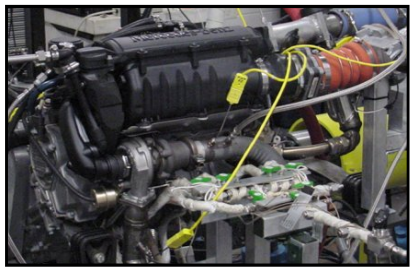


Pacific Northwest NATIONAL LABORATORY

Argonne NATIONAL LABORATORY

ReFUEL (Renewable Fuels and Lubricants Laboratoy

NREL



Multi-cylinder Engines (Diesel, LTC, Lean-burn Gasoline) at ORNL/NTRC

OAK RIDGE National Laboratory

High Performance Computing

Argonne NATIONAL LABORATORY

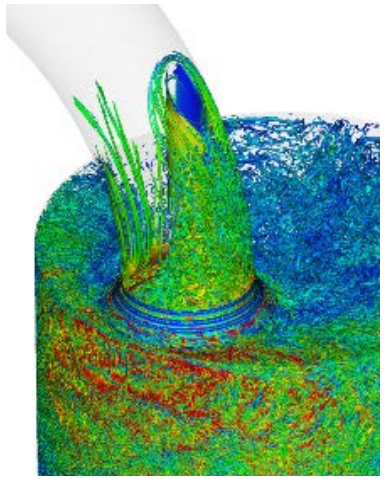
OAK RIDGE National Laboratory

NREL National Renewable Energy Laboratory

Co-Design of Engines and Fuels will be Enabled by Exascale Computing

„, the accurate simulation of engine combustion is challenging …

- Complex geometries with moving boundaries
- Turbulence models are lacking
- Multi-phase reacting sprays
- Ability to model real fuels: 1000+ chemical species
- Time scales: 10^{-9} – 1 sec
- Length scales: 10^{-6} – 10^{-2} m



Predictive and high-throughput engine simulation require exascale computing

Racing to match China's growing computer power, U.S. outlines design for exascale computer

By Robert F. Service | Feb. 7, 2018, 11:00 AM

(exa) - 10^{18} 2021

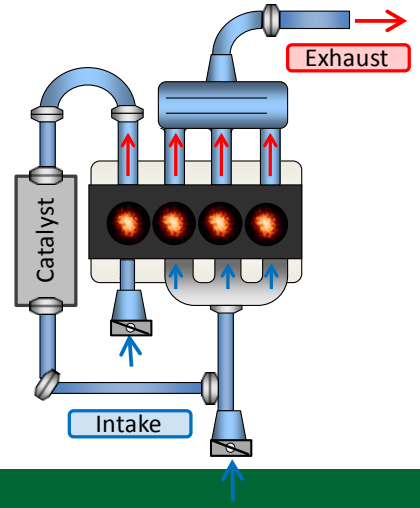
Developing highly scalable, accurate code with multi-physics models to fully leverage DOE's computing assets

Combustion Research – Addressing Technical Barriers to Higher Engine Efficiency

- Co-Optimization of engines with fuels to avoid knock and allow for higher compression ratios
- Advanced ignition systems to improve dilution tolerance
- World leading spray and combustion diagnostics to enable conceptual model development and effective use of direct-fuel injection while meeting emissions
- Predictive modeling tools to optimize air-fuel mixing and combustion while limiting convective heat loss
- Advanced engine concepts that push the limits of efficiency

Engine Simulation

Multi-mode SI/ACI



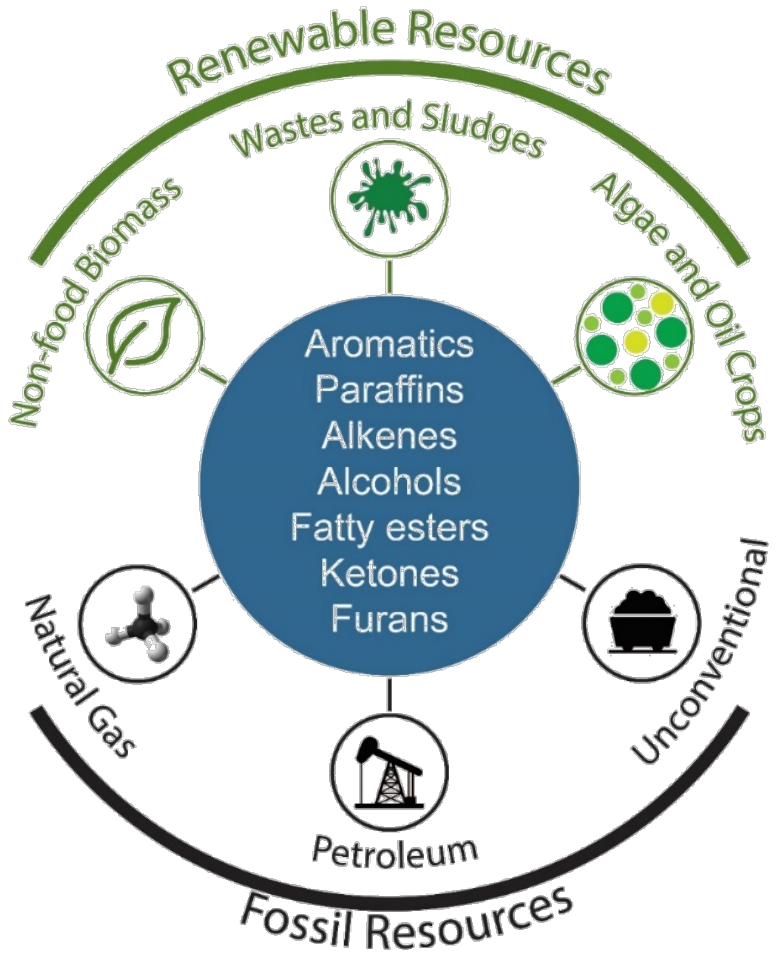
Close collaboration with industry *carries* *research to products*

Advanced Engine Combustion MOU

- Identify potential pathways for efficiency improvement and emission reduction.

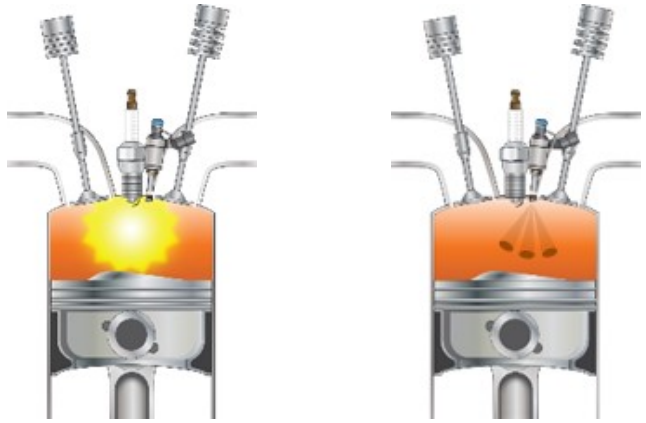
Co-Optimization of Fuels and Engines

Desired fuel properties (independent of fuel composition) that optimize engine performance to enable better fuel economy and lower emissions.



Light-Duty

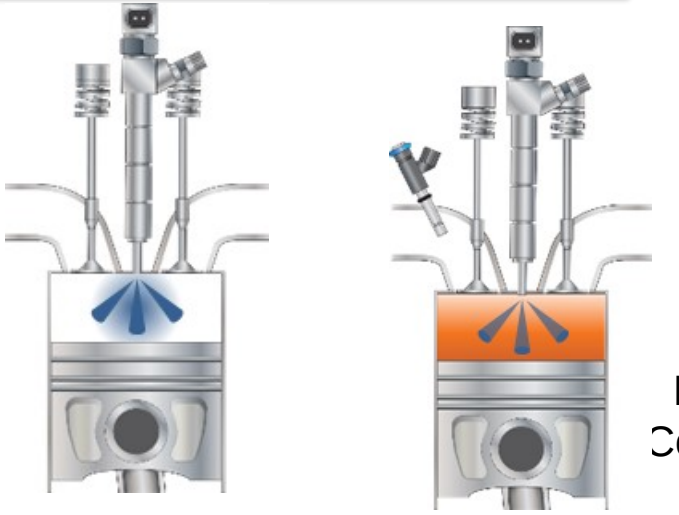
Boosted SI



Multi-Mode SI/ACI

Heavy-Duty

Mixing Controlled CI

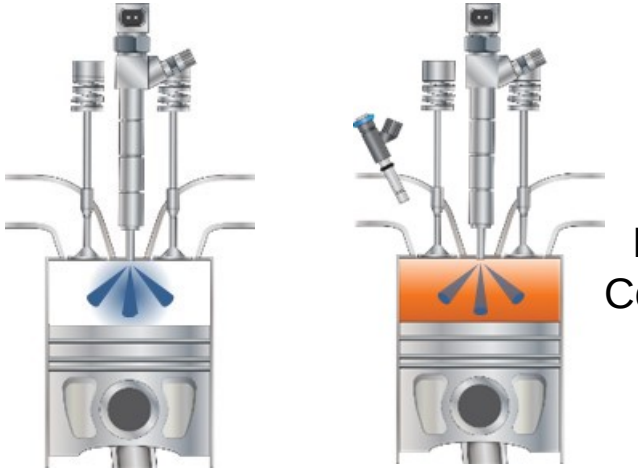


Kinetically Controlled CI

Co-Optima MD/HD Opportunities

- Multi-cylinder compression ignition (Diesel) combustion extremely efficient due in part to Supertruck

Mixing Controlled CI



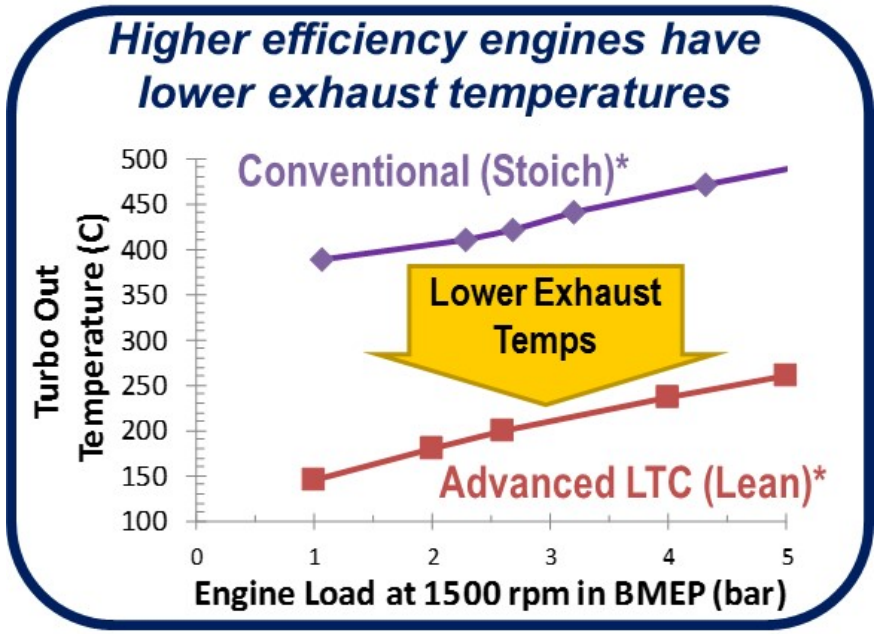
Kinetically Controlled CI

- Advanced Compression Ignition offers high thermal efficiency low soot and NOx emissions

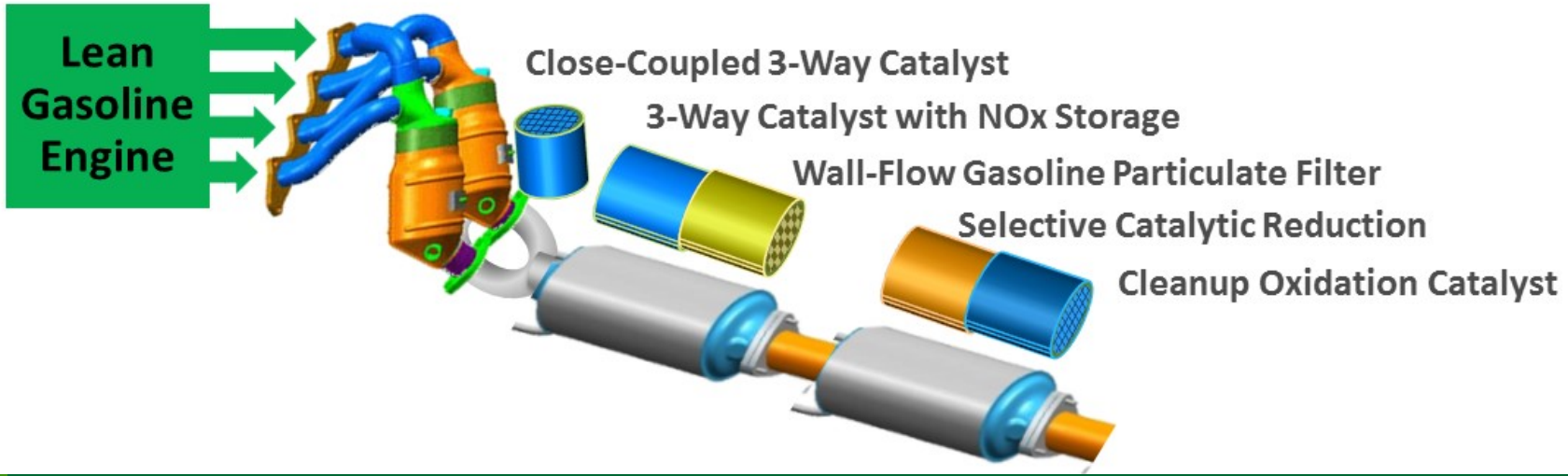
- Opportunities in optimizing fuels, emissions
  - New distillate sources help refinery gasoline/diesel balance
  - Bio-distillates offset petroleum diesel, can reduce soot

Co-Optima oral presentations – *Wednesday, June 20, 2018, a.m. and p.m.; Thursday, June 21, 2018, a.m.*

Emission Control R&D



- Develop more efficient approaches for reducing NO_x, and oxidizing PM, HC, and CO in low temperature exhaust (150^{o}C).
- Reduce energy penalty and cost of emission control systems.



OAK RIDGE National Laboratory

Industry Catalyst R&D Needs –
Defined by Government-Industry Partnerships

CLEERS Cross Cut Lean Exhaust Emissions Reduction Simulations

21st CENTURY TRUCK PARTNERSHIP

USDRIVE DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

*2015 CLEERS Industry Priorities Survey**

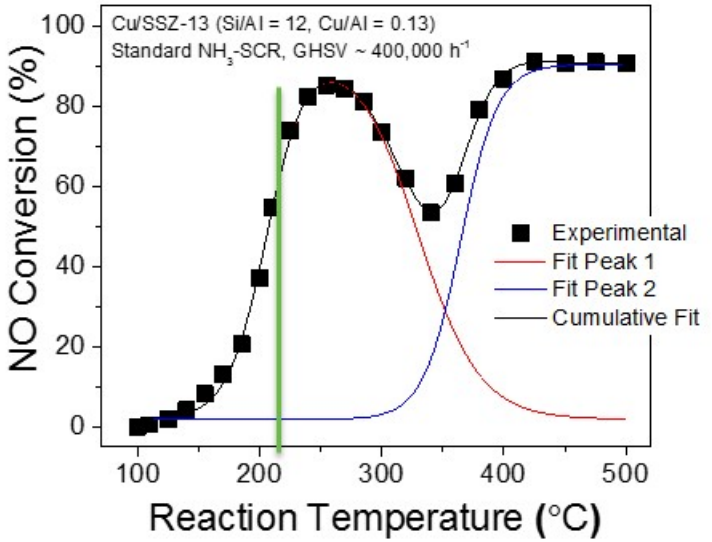
*USDRIVE "The 150ºC Challenge" Workshop Report**

*available at www.cleers.org

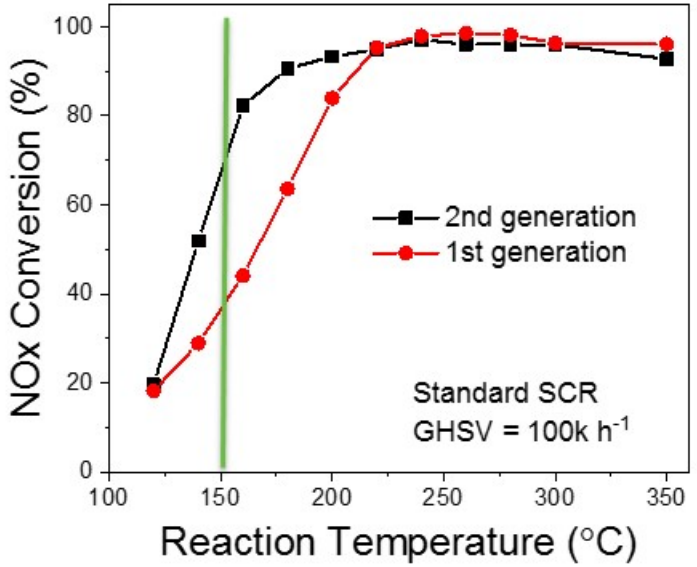
VTO Goal: Develop new emission control technologies to enable fuel-efficient engines with low exhaust temperatures (<150ºC) to meet emission regulations cost-effectively with low energy penalty

Technical Goal: >90% Conversion of CO, HCs, and NOx at 150ºC

Improving Low Temperature NH_3-SCR Activity



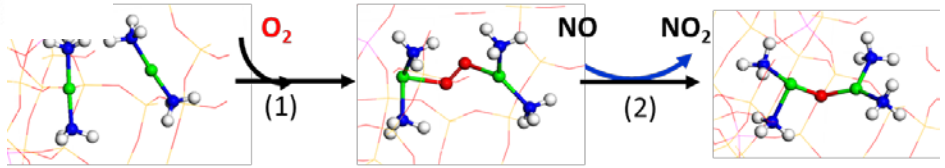
Cu/SSZ-13



Pacific Northwest NATIONAL LABORATORY

1

Applied research observed interesting kinetic transition



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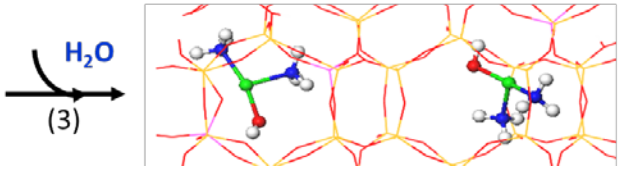


3

Fundamental insight identified pathway for activity improvement

Gao et al, *J. Am. Chem. Soc.* 2017, 139, 4935−4942

Fundamental understanding provides insight in improving catalyst activity at 150˚C

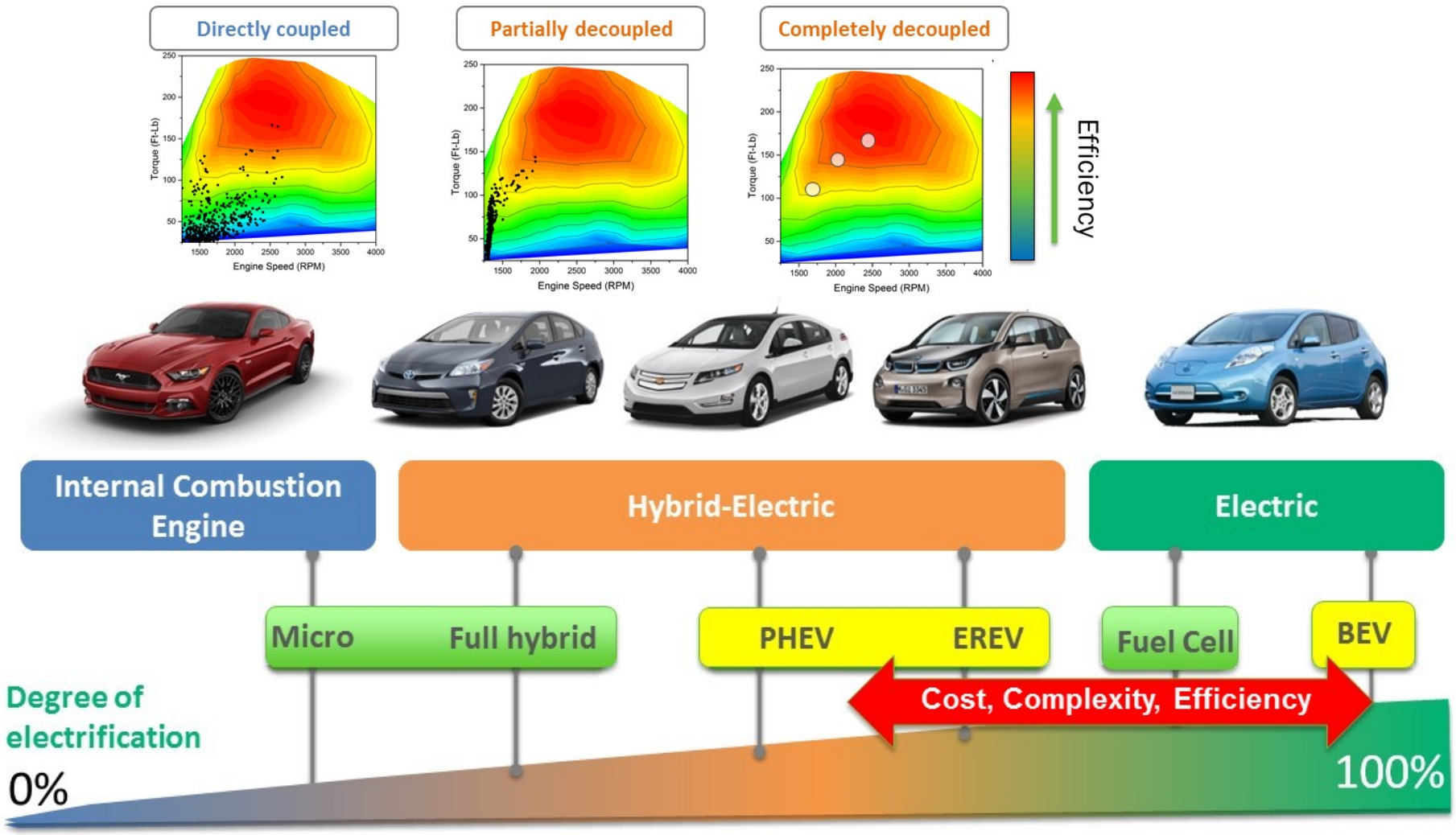
Advanced Technologies for Heavy-Duty Vehicles - SuperTruck II

Goal: Demonstrate a 55% or greater engine brake thermal efficiency in real-world operation, greater than 100% improvement in freight efficiency (ton-mpg) relative to a 2009 baseline, and a payback period of less than 3 years to foster more rapid market adoption of new energy efficient technologies.

- **SuperTruck II Project Leads**
  - Cummins Inc.
  - Daimler Trucks North America LLC
  - Navistar, Inc.
  - Volvo Technology of America, LLC
  - PACCAR Inc.

ORAL PRESENTATIONS ON THURSDAY, JUNE 21, 2018.

Advanced Engines and Fuels – A Bridge to the Future



Fuel-optimized engine hybrid-electric drivetrain provides a bridge to the future of mobility

Contact

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Web site:

Vehicle Technologies Office

www.vehicles.energy.gov

http://energy.gov/eere/vehicles/vehicle-technologies-office