New Engine Concepts for the … Uncertain Future

Panelist Remarks

Zoran Filipi

Clemson University

Transformation of Personal Mobility

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  - Disruption w/ BEVs is under way. Pace ?

OPINION | GOODBYE TO GASOLINE

Electric Cars Reach a Tipping Point ?

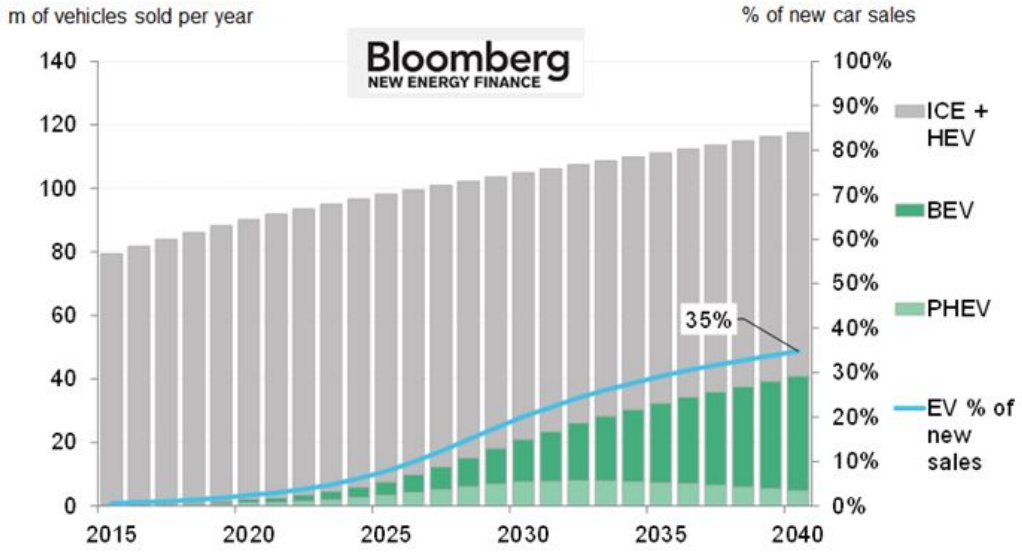
A hard target from Beijing will be a tipping point for the world auto industry.

By David Fickling
September 10, 2017, 10:40 PM EDT

Qilai Shen/Bloomberg

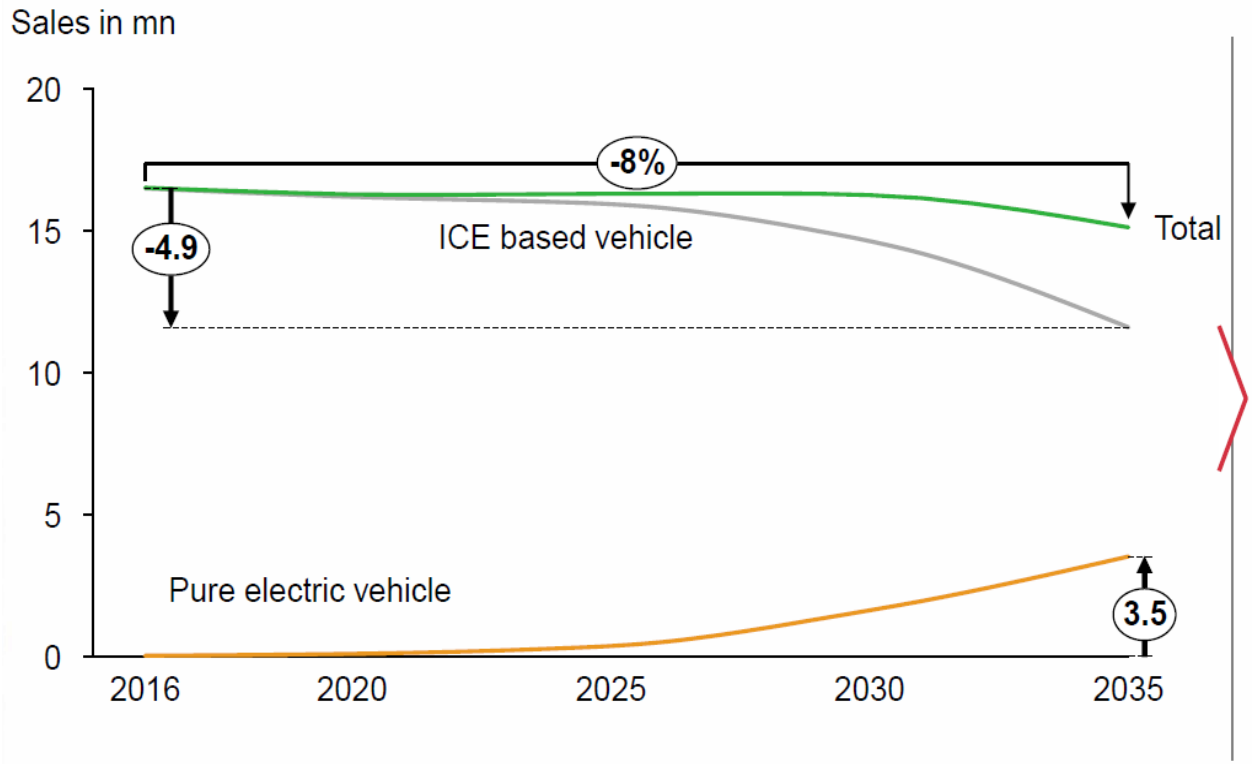
Say goodbye to gasoline. The world's slow drift toward electric cars is about to enter full flood.

Sales in US ~1%



Price to purchase, fast-charging infrastructure ?

US View, taking into consideration location of the residence, expected range and willingness to pay extra for EV



- Light duty vehicle sales are projected to peak in 2025 to 2030 timeframe
- Shared mobility adoption as a main driver for sales reduction
- Pure electric vehicle sales growth driven by:
  - Battery price drop
  - Improved charging infrastructure
  - Electric range increase

Source: *Mayank Agochiya, FEV Consulting – Consumer expectations (2018)*

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Outcome of the US CAFE Midterm Evaluation is highly uncertain

The New York Times

Calling Car Pollution Standards 'Too High,' E.P.A. Sets Up Fight With California

By HIROKO TABUCHI APRIL 2, 2018

EPA Administrator Pruitt: GHG Emissions Standards for Cars and Light Trucks Should Be Revised

EPA United States Environmental Protection Agency

04/02/2018

"EPA Administrator Scott Pruitt announced the completion of the Midterm Evaluation (MTE) process for the greenhouse gas (GHG) emissions standards for cars and light trucks for model years 2022-2025, and his final determination that, in light of recent data, the current standards are not appropriate and should be revised.

Scott Pruitt Declares War on California; California Declares War Back

California will not weaken its nationally accepted clean car standards, and automakers will continue to meet those higher standards, bringing better gas mileage and less pollution for everyone." – CARB Chair, Mary D. Nichols

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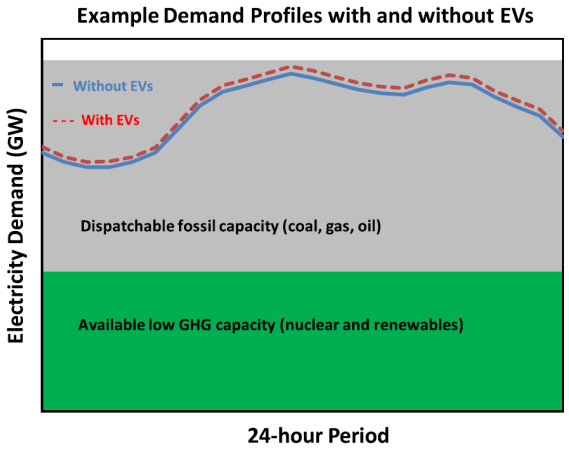
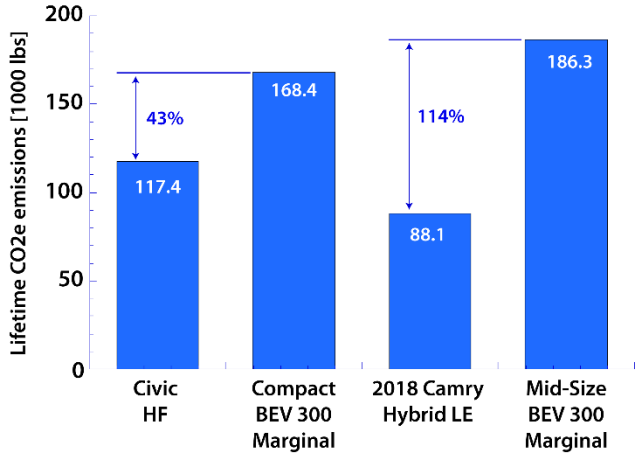
Life cycle considerations





Courtesy: Paul Miles

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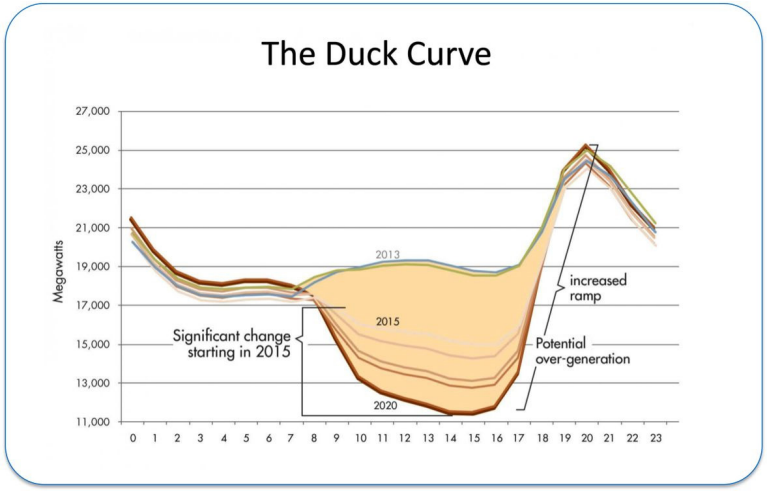

Only the large scale deployment of renewables on the grid makes BEVs green, but increase of solar generation creates a mismatch between the rates of generation and consumption: store or …

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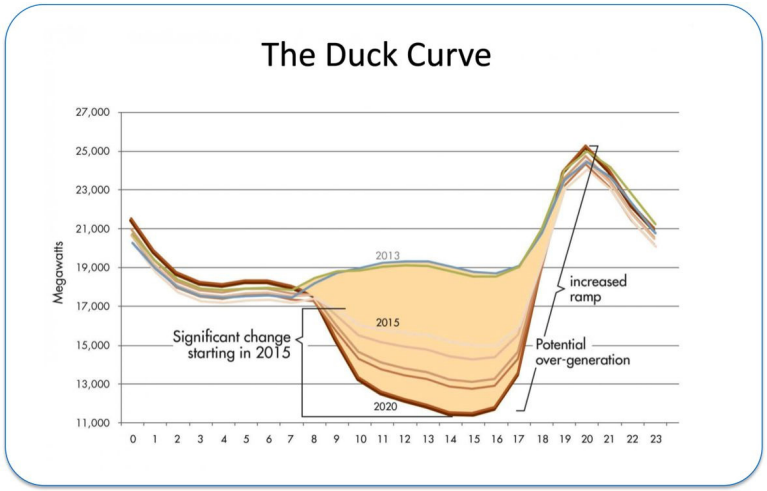

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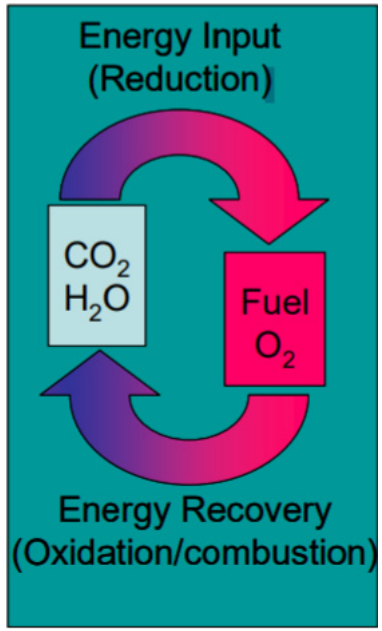
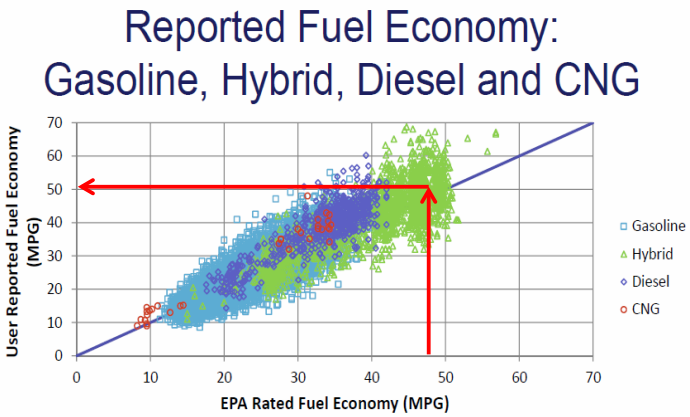
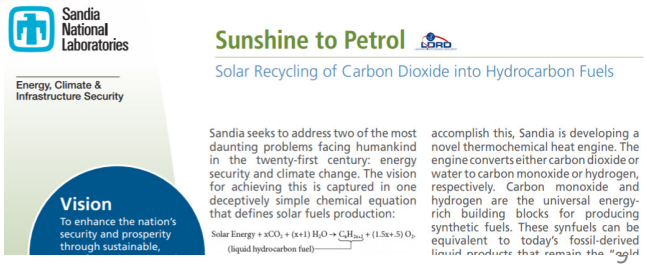


So, How Should We Think About IC Engine Future?

- Transformation of mobility spurred by huge investments in autonomous driving will require vehicle platforms capable of providing electricity for sensing/computing/actuation
  - Both HEV and BEV are contenders
- IC Engines are likely remain a mainstay in transportation for many years to come, particularly in combination w/ HEV
  - Impact of hybridization on engine design?
- Availability of new fuels might change the outlook, disrupt the disruption :
  - Renewables
  - E-fuels



Source: FuelEconomy.gov



So, How Should We Think About IC Engine Future?

Still plenty of opportunity to innovate and take alternative pathways … although we all rely on same fundamentals to guide us

Hybridization may unlock additional potential, chances for true synergies

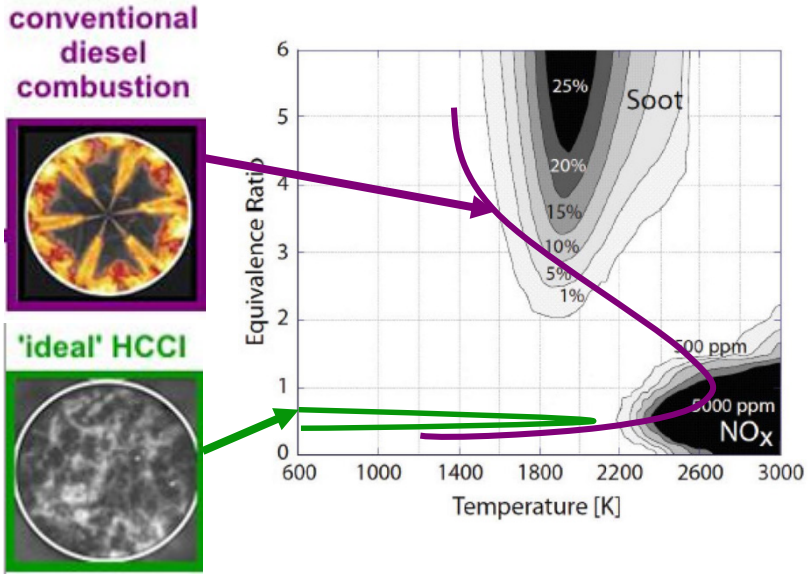
Engine Development is as Vigorous as Ever, OEM's Willing to Take Bets

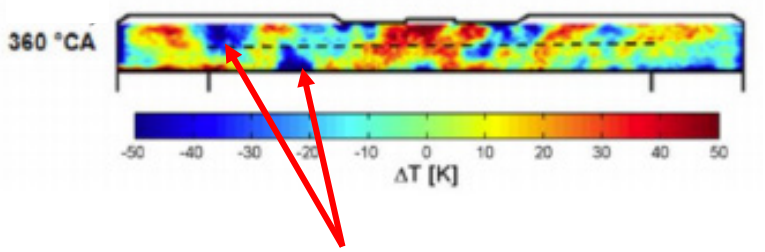
- OEMs perspective: different camps
  - High-efficiency NA engine, start with fundamentals, but push improvement of every aspect to the extreme
  - System level: downsize-turbocharge … and more, e.g. VCR, high EGR rate etc.
  - Novel mode of combustion: lean, CI … but w/ gasoline
- Innovation from small companies:
  - Opposed piston 2-stroke, Achates Power
  - Tula software company, Dynamic Skipfire (DSF, mDSF, eDSF)

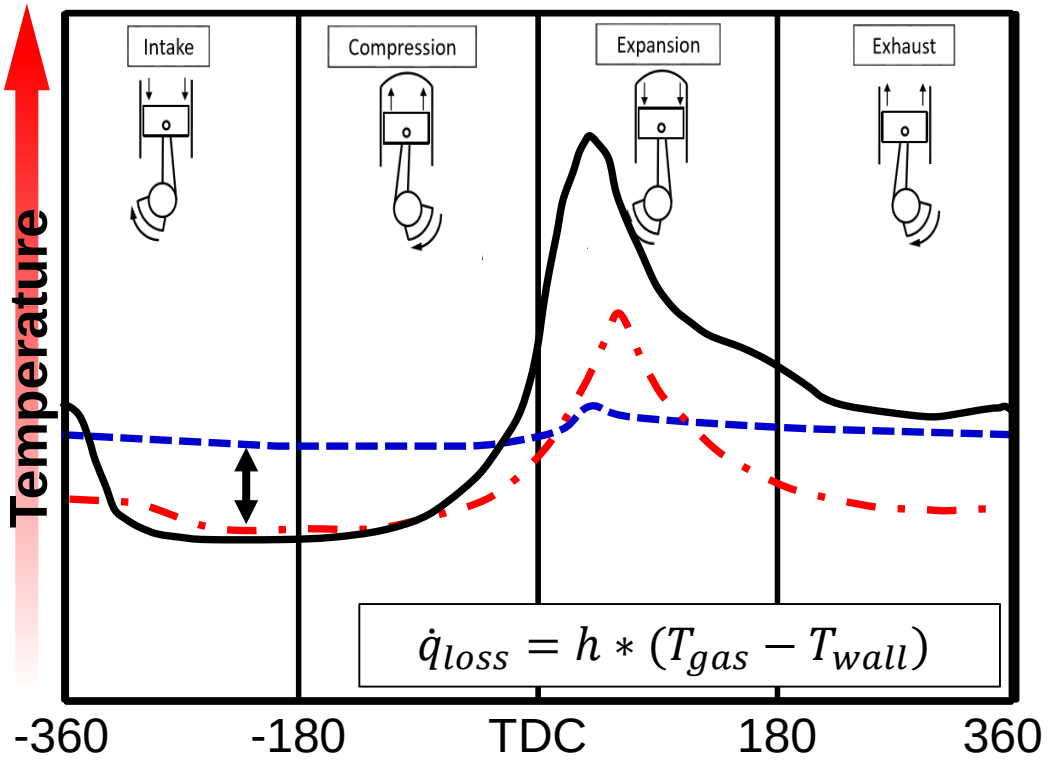
Recurring Theme Pertaining to All New Concepts: Need to Reduce Heat Loss during Combustion


Clemson University International Center for Automotive Research (CU-ICAR)
Automotive Engineering Department
is an Academic Anchor on the CU-ICAR campus, surrounded by industry engineering centers and small companies

Clemson Research with NSF/DoE Support: Low Heat Rejection for Low Temperature Combustion



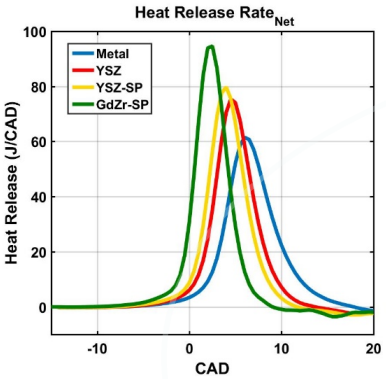


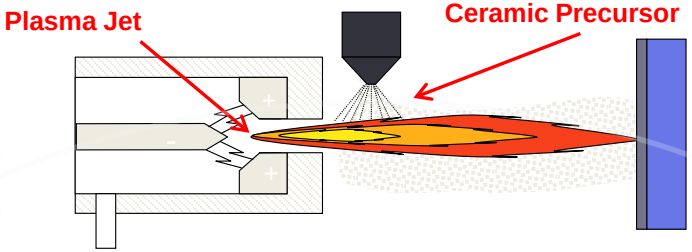


Heat transfer to wall cause cold pockets of gas that burn slowly or fail to combust – lowers combustion efficiency

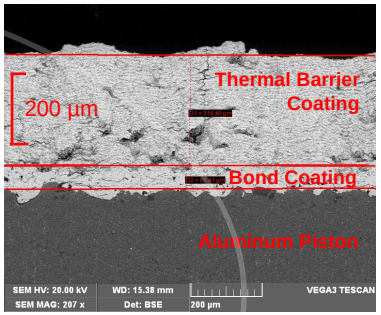
→ Use thermal barrier coating to increase wall temperature during combustion-relevant crank angles

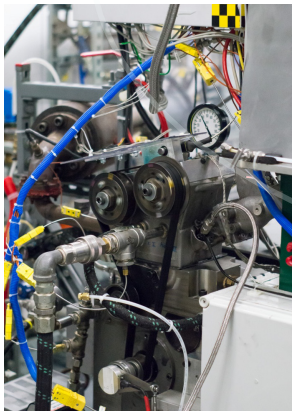
Thermal Barrier Coatings for LTC Engines Can Add Another Percentage Point or Two of Efficiency



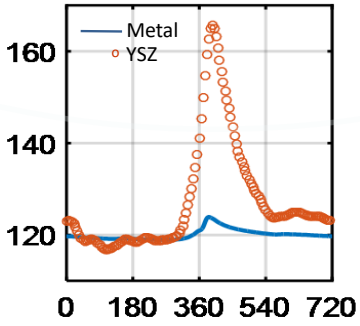


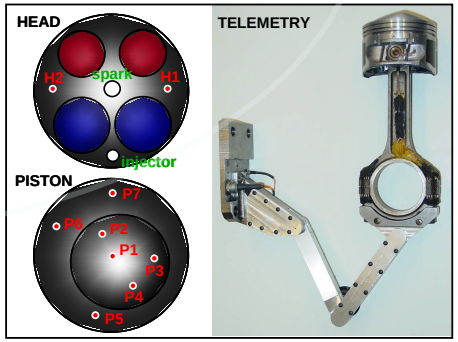
YSZ SPPS w/ IPB Coating
Cross Section





Surface Temperature (ºC)

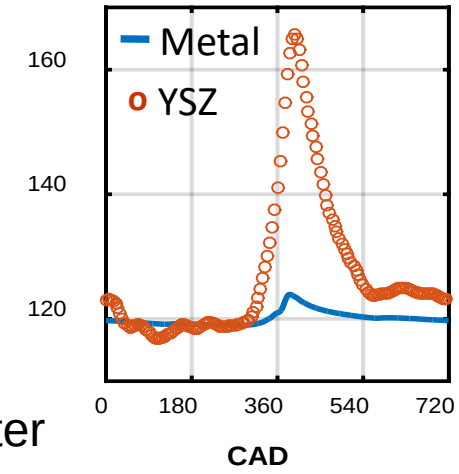


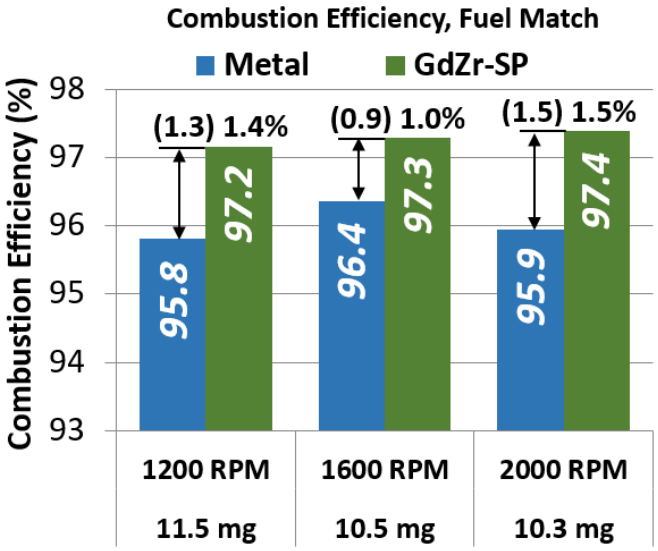


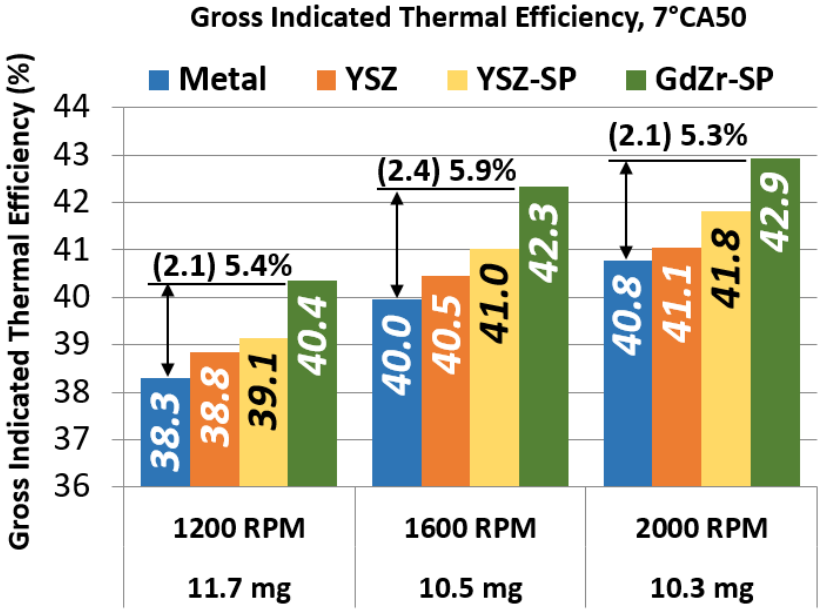
Thermal Barrier Coatings for LTC

- Winning formulation: dense coating of Gadolinium Zirconate
  - Up to 5.9% higher $\eta_{Gross,Ind}$ and 1.5% higher η_{comb} with GdZr-SP coating
  - Expansion of HCCI "operating envelope" by 37% with the GdZr-SP coating

Dense GdZr coating, after 150 hours of operation





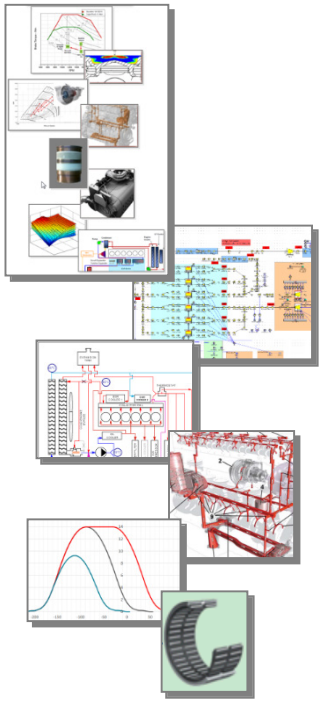


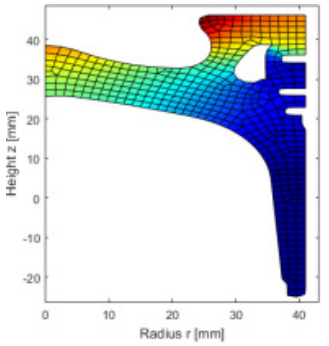
Next: Extend Research to Address HD Diesel

- DoE funded Supertruck II aims for new heights -> 55% BTE
- Thermal Barrier Coatings are part of the Roadmap

Contemplating the Road

From 50% BTE to 55%





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High Efficiency Combustion

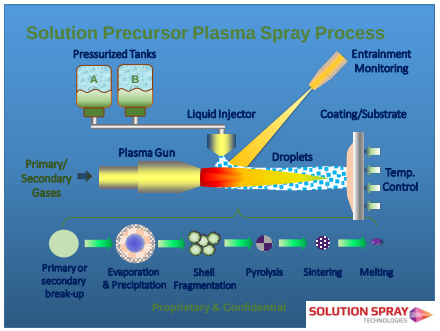
Low Pumping Losses

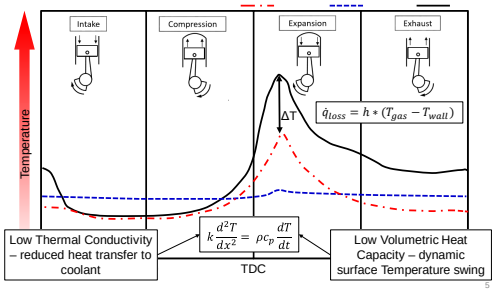
Expansion Ratio

Friction and Parasitics

Low heat rejection, Advanced WHR

Unconventional Approaches





Courtesy: Jeff Girbach, Daimler Trucks

In summary

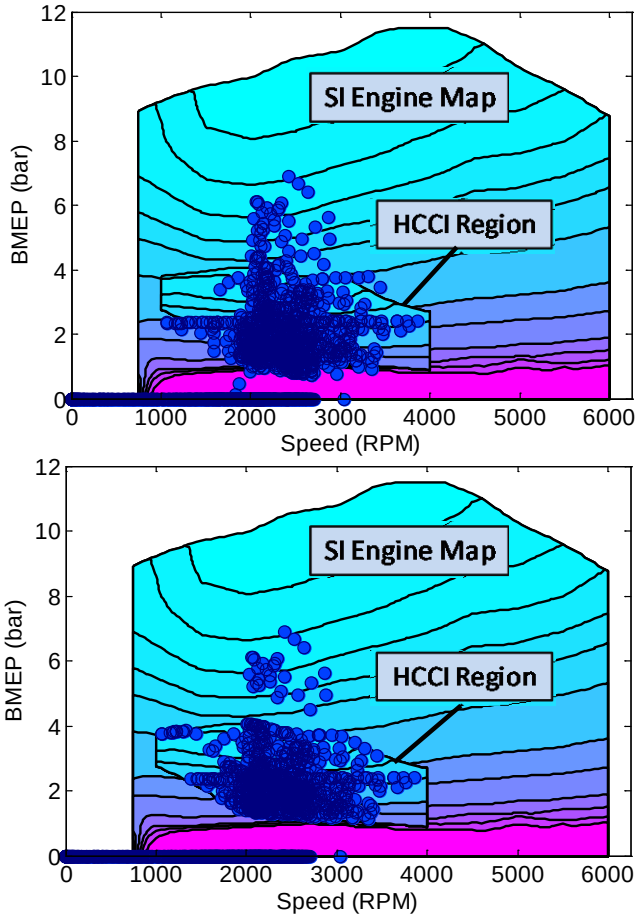
Heavy investments in electrification

while

ICE Engine research community remains vibrant, and the future uncertain

Hybridization Can Create New Opportunities

- Options
  - Low cost, highly optimized NA SI engine
  - Synergies with advanced concepts, such as LTC
  - New architectures for PHEVs



Existential Questions

- What will be the real impact of autonomous driving technology on powertrain choice and design ?
- Will there be a political will to use life-cycle analysis for major policy decisions ?
- How to maximize the benefits of renewables on the grid
  - Mega-storage or e-fuels ?
- Artificial intelligence in ICE/HEV development
- Impact of hybridization on ICE design
- Future R&D Investments? What do I tell my students?
  - Let's remember that educating/grooming new leaders requires research opportunities at universities