

State of Engine Technology and Dedicated Transportation Systems as an Enabler

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Acknowledgments

Direct-injection Engine Research Consortium (DERC)

Caterpillar

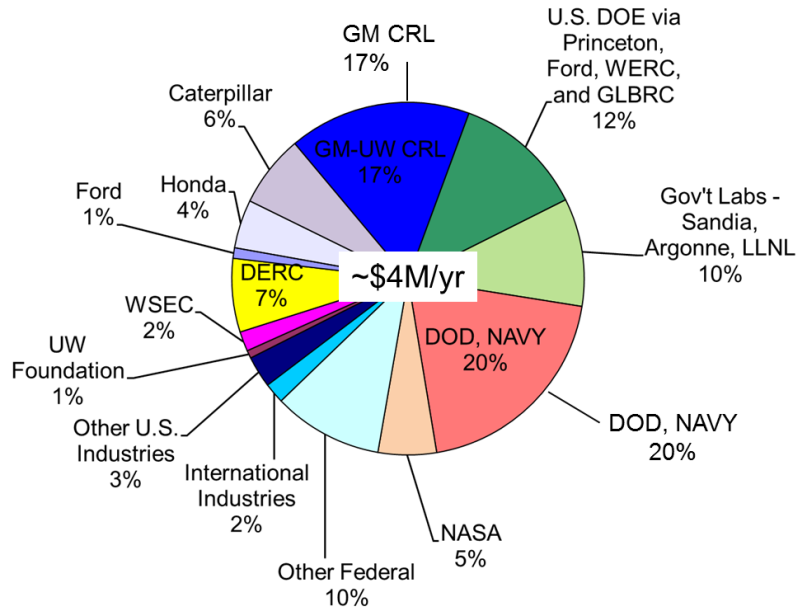
Office of Naval Research (ONR)



Engine Research Center



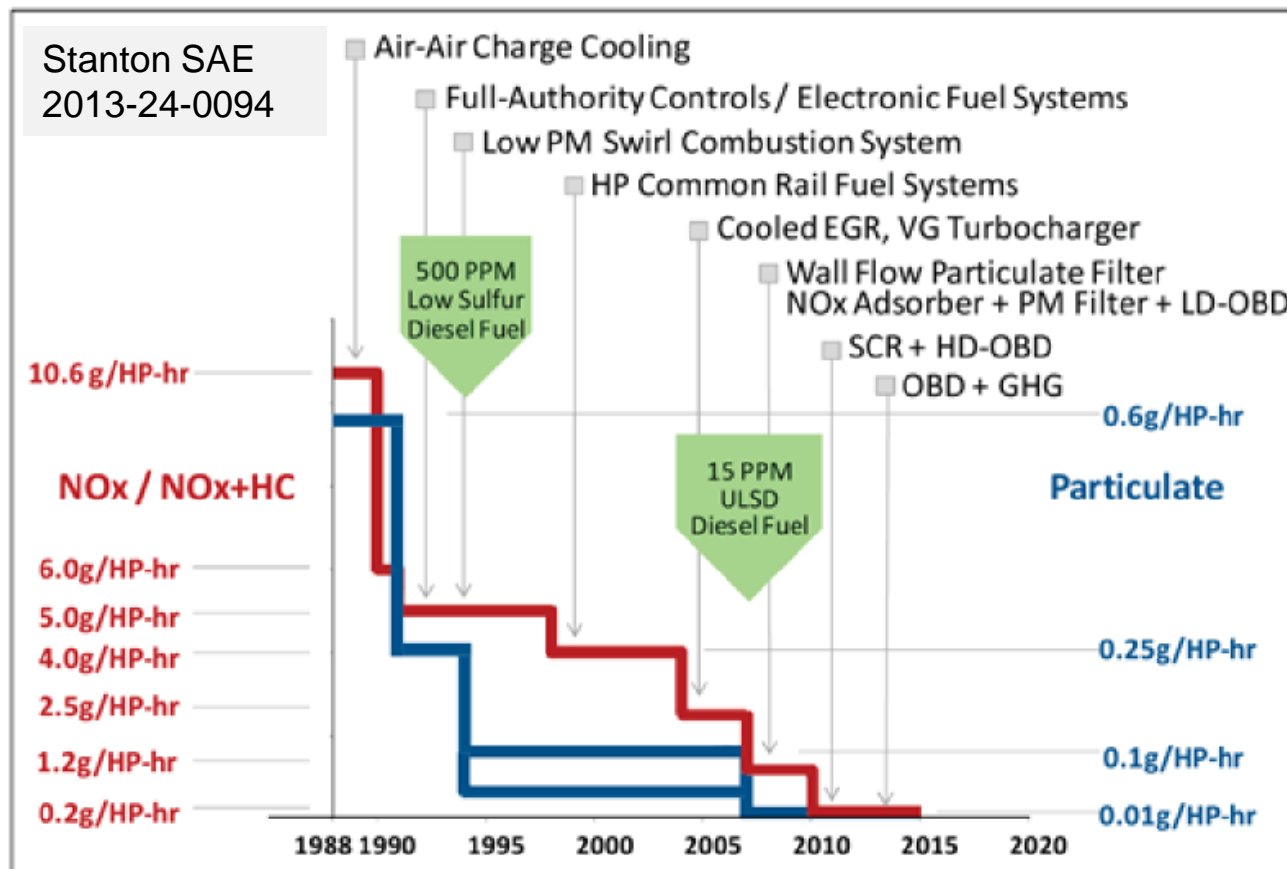
- Founded in 1946 (70 year history)
- Largest academic institution focused on engine research in the United States
- Six active faculty focused on topics ranging from fundamental combustion to engine applications
- 50 graduate students, 10 Post Docs and Research Staff
- \$4 Million per year in external funding (50% Government and 50% Industry)
- Direct-injection Engine Research Consortium (DERC) consists of ~40 member companies



Current Engine Technology



- Current engine technology has been driven by criteria pollutants: high pressure EGR, injection timing retard, after-treatment (DOC+DPF+SCR)

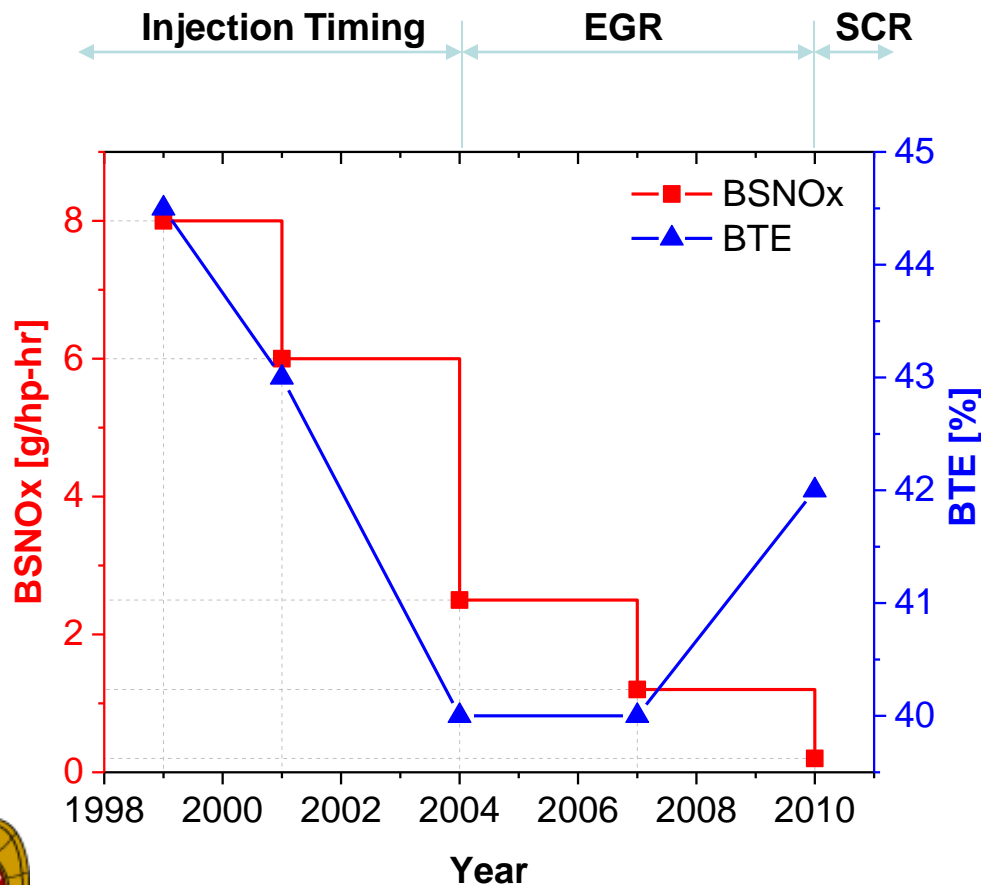


Current Engine Technology



- Historically, meeting NOx targets has resulted in increased fuel consumption (reduced BTE)

$$BTE = \frac{Work}{Fuel\ Energy}$$



EGR

- Increases burn duration
- Increases pumping loss
- +Reduces heat transfer
- +Reduces injection timing retard required

SCR

- +Reduces EGR required
- +Reduces injection timing retard required
- Requires additional fluid that is similar cost to diesel fuel (~1% DEF per g/kW-hr NOx reduction)

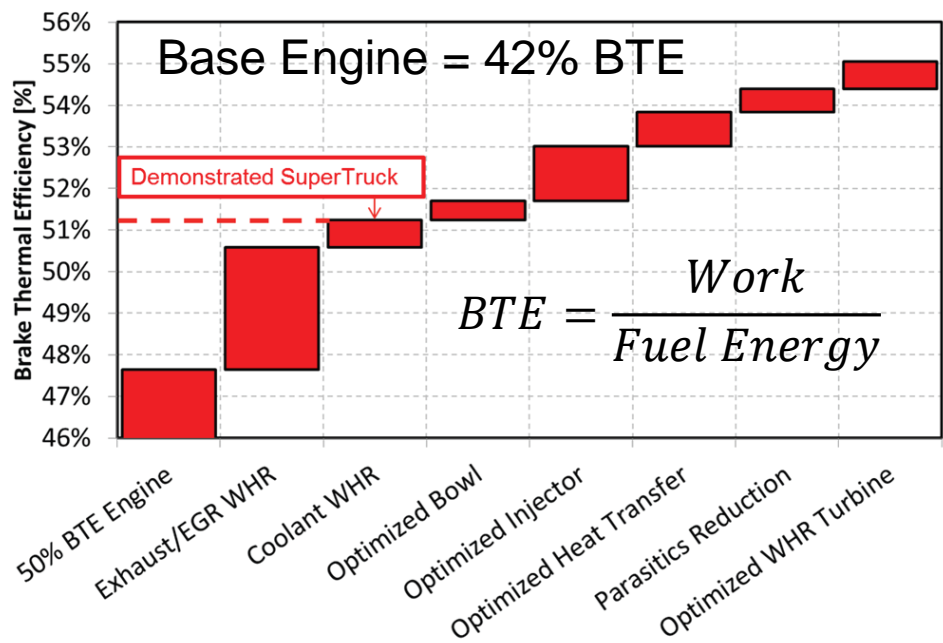
Source: Technologies and Approaches to Reducing Fuel Consumption of Medium- and Heavy-duty Vehicles (NAP, 2010)



Future Engines – Near Term

- DOE SuperTruck Program has shown that it is possible to increase efficiency at current NOx levels
- As an example, Cummins demonstrated 51% BTE and 86% increase in freight efficiency
- Pathway to 55%

Path to 55% BTE for Conventional Diesel Combustion Cruise Condition



Improvements from Systematic Reduction of Losses

- Largest benefits are:
 - Optimized Combustion System (5% to 7%)
 - Waste Heat Recovery (2% to 5%)
- Technology cost is to be determined, but has the potential for over \$6,000 per year fuel savings (assuming 1% = \$700)

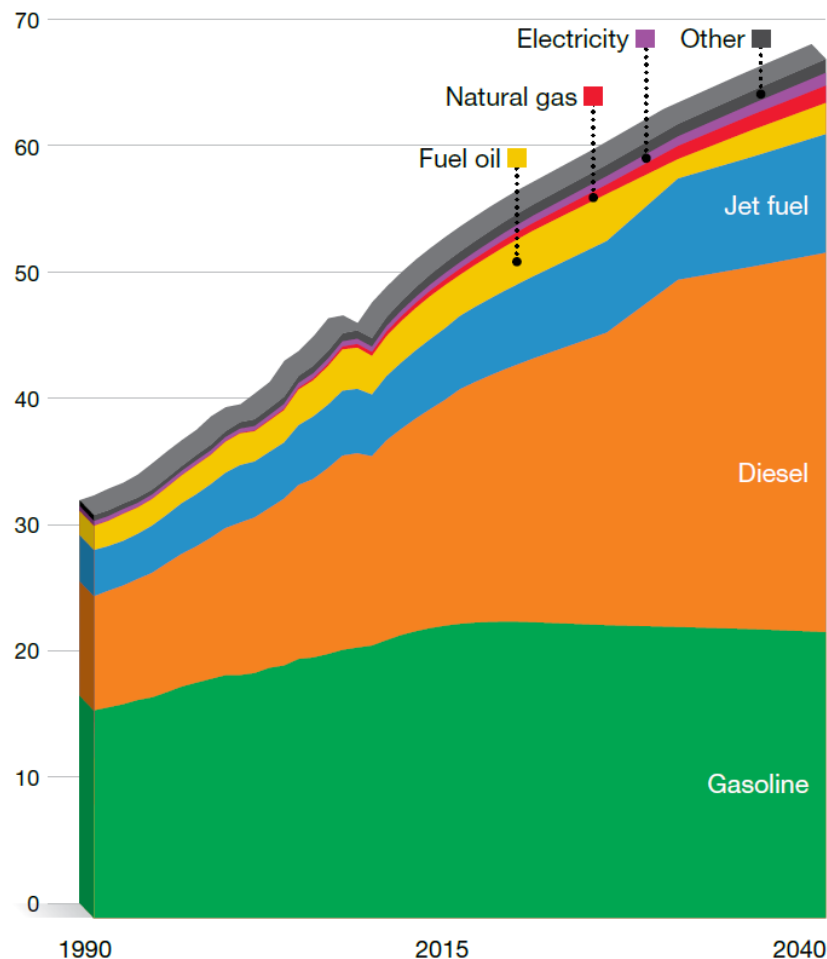


Future Engines – Long Term

- Projections show diverging transportation fuel demand
 → diesel usage increases while light fuels (e.g., gasoline) remains flat
 - Largest growth is driven by mid-range and heavy-duty application in emerging markets
- A significant amount of current academic and industrial research is focused on enabling gasoline usage in heavy-duty (compression ignition) engines

Transportation fuel demand

Millions of oil-equivalent barrels per day



Light-Fuels for Heavy-Duty Engines



- Gasoline Compression Ignition (GCI)
 - **Description:** Directly use gasoline in compression ignition mode
 - **Benefit:** Increased premixing to reduce soot emissions and potential to use higher EGR to reduce total fluid consumption
 - **Drawback:** Difficulties cold-starting and operating at low-loads
Sellnau et al. SAE 2012-01-0384
- Reactivity Controlled Compression Ignition (RCCI)
 - **Description:** Blend a small amount of diesel fuel with gasoline in-cylinder to control ignition characteristics
 - **Benefit:** Optimal fuel for every condition (cold start performance of diesel engine with benefits of GCI engine at higher loads)
 - **Drawback:** Two fuel systems
Kokjohn et al. IJER 2011

Advanced Comb. Engines (GCI and RCCI) have demonstrated the potential for ultra-low NO_x and soot emissions (can achieve 2025 targets in-cylinder at some conditions)

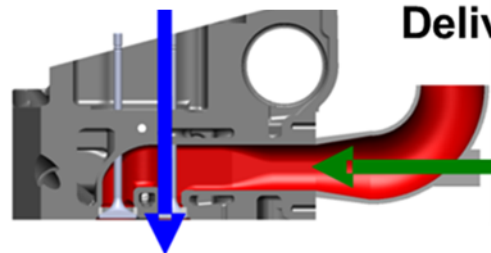
Efficiency of Advanced Combustion Engines



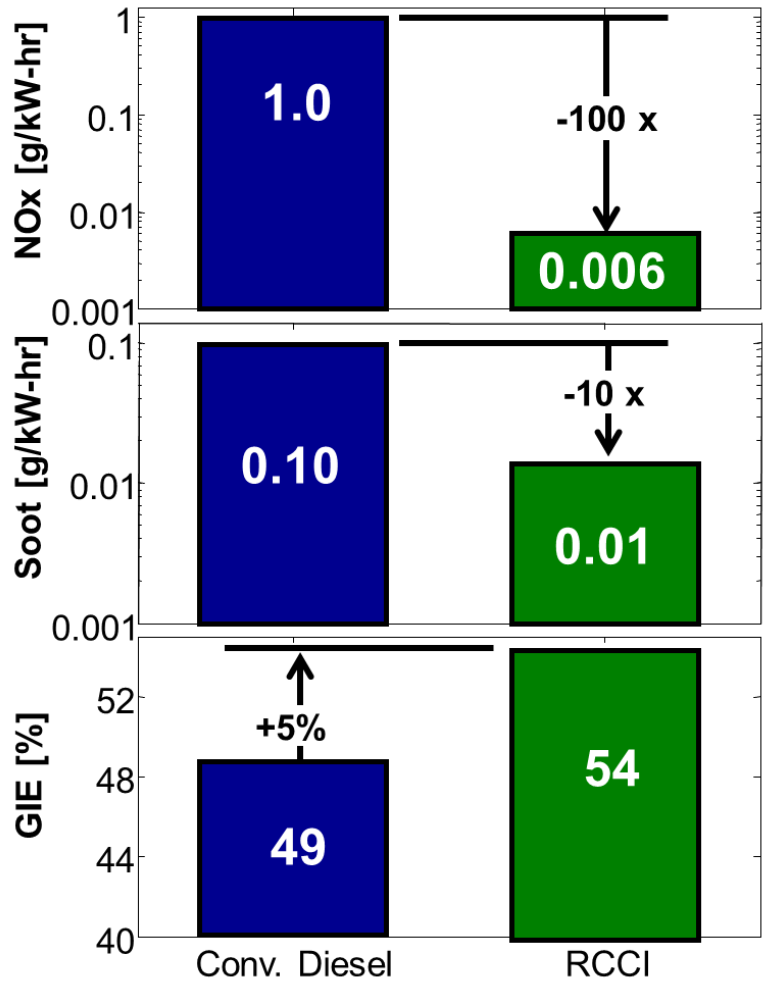
- Heavy-duty RCCI has demonstrated near zero NOx and soot and a peak efficiency of 56%
- Conventional diesel shows 49% efficiency at identical conditions with an order of magnitude higher NOx and soot
- Efficiency improvement is primarily explained by reduced heat transfer due to low temperature combustion

High Reactivity Fuel
(Diesel fuel, bio-diesel, DME, etc..)

Fuel Delivery Strategy



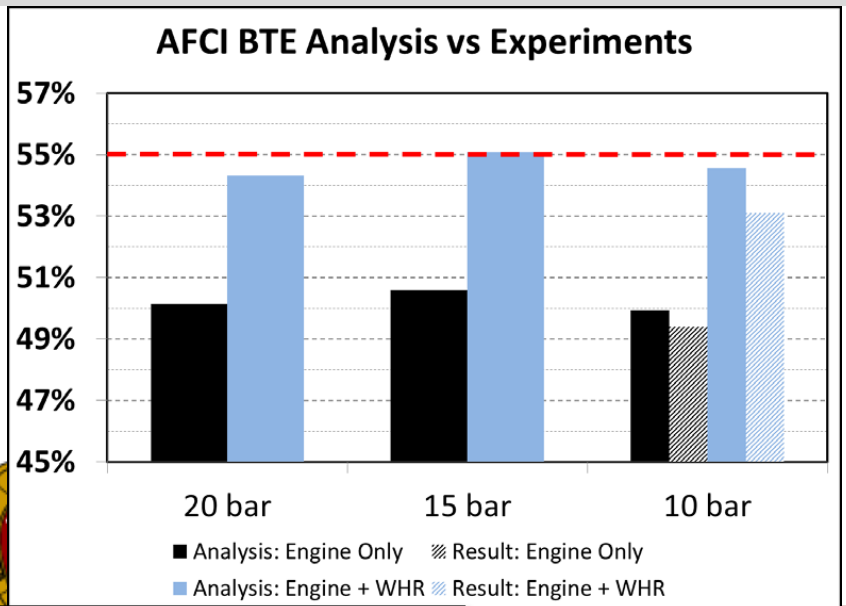
Low Reactivity Fuel (Gasoline, ethanol, natural gas etc...)



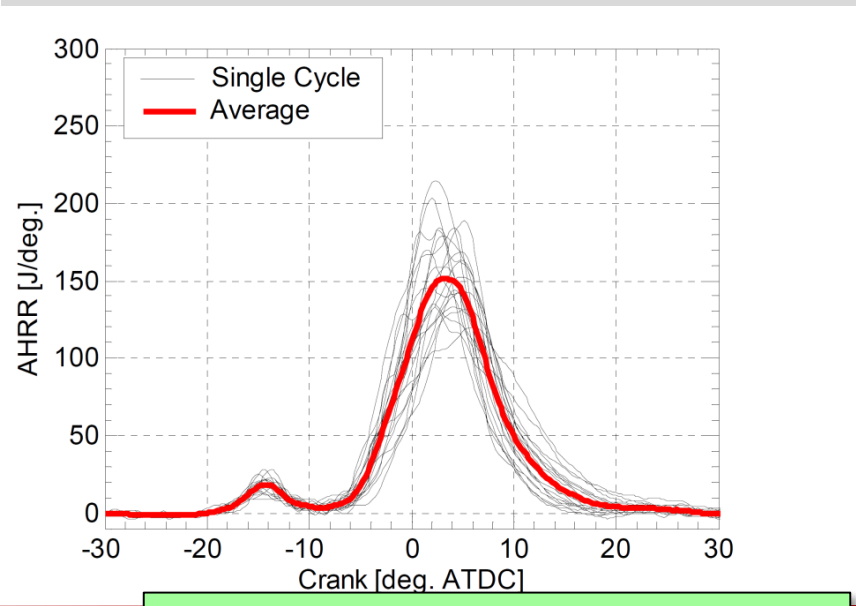
Advanced Combustion Engines

- Advanced combustion engines show promise to achieve high efficiency (above state of the art diesel engines) with near zero NOx and soot emissions
- A few challenges include
 - Load Limitations
 - Combustion Stability and Control

Advanced combustion load limited to approximately 50% load



Heat release fluctuations from engine experiments at a stable condition

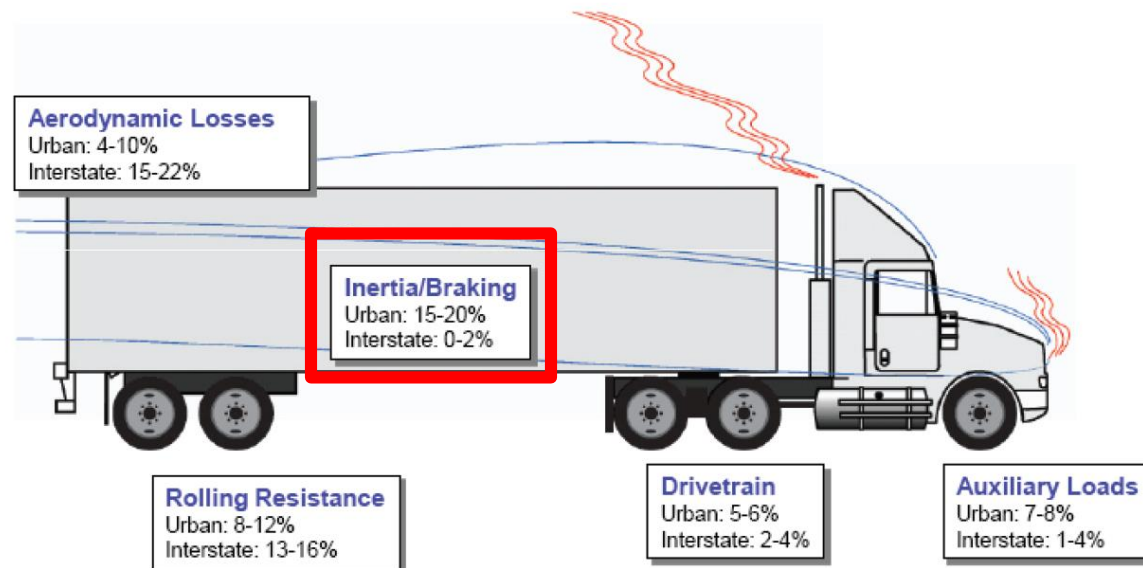


Benefits of Dedicated Transport Systems



Dedicated urban vehicles show benefit from hybrid electric vehicle (HEV) configuration (limited benefit for interstate operation)

- Hybrid configuration helps alleviate many of the challenges of implementing advanced combustion systems
 - **Load Limitations:** HEV allows battery assist to enhance load capability
 - **Combustion Stability and Control:** Transients can be avoided to avoid unstable combustion (with series hybrid configuration)

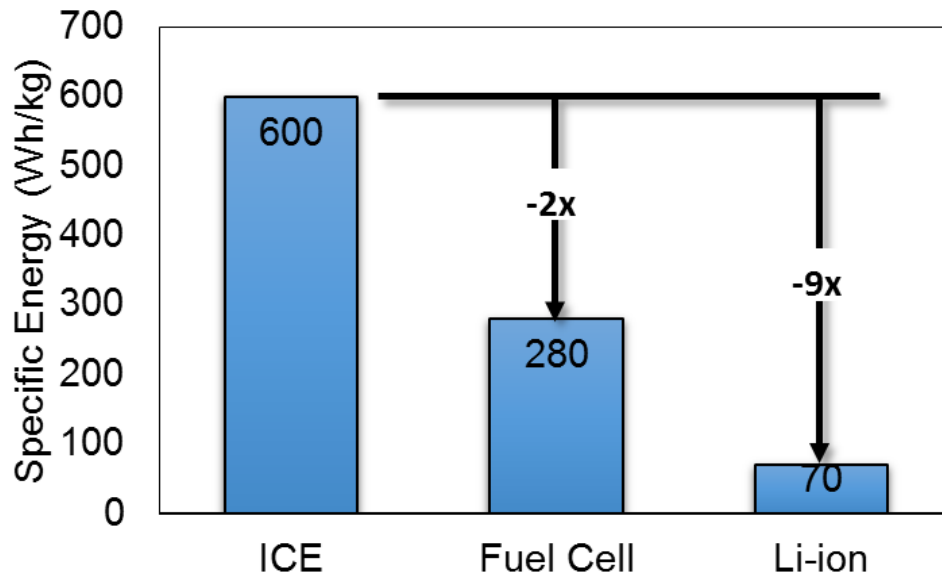


Benefits of Dedicated Transport Systems



Potential for alternative energy carriers

- Alternative fuels have shown promise for use in advanced combustion engines (dual-fuel approach shows highest BTE using neat ethanol)
- DME has many promising characteristics (low NO_x and soot-free combustion) → potential for “phase-in” usage without nationwide infrastructure investment
- Battery Electric Vehicles (BEV), fuel cells **may** make sense



The 435 lb battery in the Chevy Volt is roughly equivalent to 1 gal gasoline! (35–40 mile all-electric range; 35–40 mpg as a series hybrid using its IC engine)

Fansler, ICE Trends & Challenges 2015

Conclusions



- Near term engine technology is progressing to meet future GHG regulations
- DOE SuperTruck programs have demonstrated improvements from 42% to over 50% brake thermal efficiency using near term technology to minimize losses
- Advanced combustion technology shows potential for further efficiency improvement while enabling lower engine out emissions – reduced fluid consumption penalty
- Adopting transport system using vehicles with dedicated tasks (urban or rural) has potential to aid in addressing challenges in advanced engine and transportation system technology



Questions???

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More Information

- Kokjohn et al. IJER 2011
- Kokjohn et al. IJER 2013
- Kavuri et al. IJER 2015

