Co-Optimization of Fuels & Engines
FINDINGS & IMPACT

SUBSTANTIALLY SHRINKING TRANSPORTATION ENERGY USE AND EMISSIONS

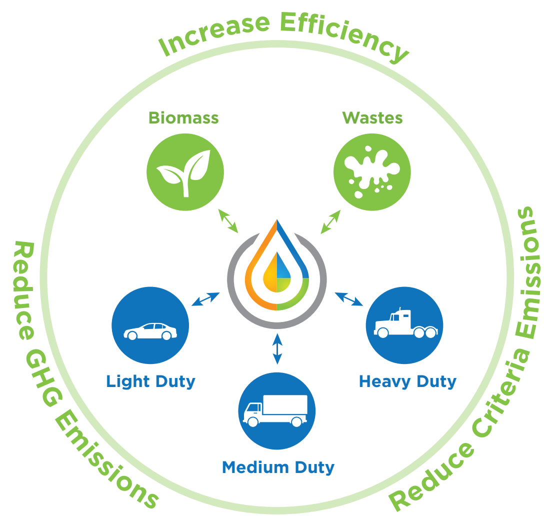
Cars and trucks account for more than 66% of all U.S. petroleum consumption and more than 25% of greenhouse gas (GHG) emissions. Each year, these vehicles gulp up more than 4 billion barrels of petroleum-based fuels and emit 1.6 billion tons of GHGs into the atmosphere.

While more and more zero-emission electric vehicles are hitting the nation's roads, widespread replacement of cars with internal combustion engines (ICEs) is likely at least a decade away. The U.S. Department of Energy (DOE) launched the Co-Optimization of Fuels & Engines (Co-Optima) initiative to bring clean, efficient, and affordable fuels and engines to market sooner.

Combined with other technology advancements already underway, Co-Optima breakthroughs can:

- Help improve fuel economy by 10% or more for light-duty (LD) vehicles.
- Trim engine-out criteria pollutant emissions by as much as 99% for medium-duty (MD) and heavy-duty (HD) engines.
- Supply new fuel components with GHG emissions 60% lower than petroleum fuels for all cars and trucks.

The initiative's immediate objective was to give American industry and policymakers the scientific knowledge, data, and tools needed to identify the most viable and beneficial alternatives for drivers, businesses, and the environment. Ultimately, commercial adoption of Co-Optima innovations can make it possible to reduce pollution and use of imported oil, helping the nation mitigate climate change and strengthen energy security.



Combined fuel and engine research can provide high-efficiency, low-emissions options for a range of on-road transportation modes. Photo from iStock

CONNECTING FUEL PROPERTIES AND ENGINE COMBUSTION

The Co-Optima team explored new options for bioblendstocks—components designed to be blended into gasoline or diesel fuel—in tandem with a range of combustion strategies. Researchers from 9 national laboratories discovered ways to boost efficiency and lower emissions using conventional and advanced engines for LD, MD, and HD vehicles that burn petroleum-based fuel blended with up to 30% of components produced from sustainable sources.

Laboratory fuel and engine research was combined with analysis to identify and address economic, environmental, and performance factors for various blendstocks and combustion approaches. Researchers screened more than 1,000 options to pinpoint high-performing blendstocks that can potentially be produced at commercial scale from the estimated billion-ton annual supply of domestic biomass resources.

For LD transportation, Co-Optima examined turbocharged spark-ignition (SI) engines and multimode engines that use different methods of ignition and combustion depending on operational demands. The initiative assessed the potential of conventional diesel combustion and a ducted fuel injection modification, along with other advanced combustion approaches for MD and HD vehicles.

A cross-disciplinary team of scientists, engineers, and analysts applied a wide range of expertise to address challenges. Co-Optima researchers invented scores of new methods and tools to expand understanding of combustion and fuel properties.

More details on Co-Optima findings and impacts can be found on the following pages and on the Co-Optima website.

ENVIRONMENTAL SUSTAINABILITY

Sustainable Domestic Fuel Sources

~25 viable bioblendstocks

GHG Reduction

>50% GHG reduction for LD blendstocks with turbocharged SI combustion

>60% GHG reduction for LD blendstocks with multimode combustion

>60% GHG reduction for MD/HD blendstocks

Blendstock Criteria Pollutant Reduction for MD/HD vehicles

≥99% soot reduction with MCCI

≥80% NO_X reduction with MCCI

NO_X, soot & hydrocarbon reduction with ACI

Co-Optima researchers evaluated over 1,000 molecules and mixtures through tiered screening to discover the 25 most promising bioblendstocks. Renewable, domestic, non-petroleum sources for blendstocks include:

- Energy crops such as switchgrass
- Forestry and agricultural crop waste
- Livestock manure and municipal solid and wet waste
- Waste fat, oil, and grease
- Algae

LD vehicles, including light trucks and passenger vehicles, produce 58% of U.S. transportation-related GHG emissions. Co-Optima researchers identified a set of 12 bioblendstocks compatible with turbocharged SI and multimode combustion strategies that also can reduce life cycle carbon emissions by 50% or more and achieve high market penetration, making up 30% of the fuel mix. Alcohols and olefins appear to be the most promising candidates for both LD combustion approaches.

Diesel-fueled engines typically found in MD and HD commercial freight trucks are powerful and highly efficient. They also produce 24% of U.S. transportation-related GHGs and require costly and complex emissions control systems.

Researchers identified 13 bioblendstocks with the greatest potential to improve MD and HD performance while reducing emissions, with hydrocarbon-based blends presenting the fewest barriers to market entry. The Co-Optima team found MD and HD bioblendstocks that emit 60% less GHG emissions than petroleum-based fuels and can make up 30% of the fuel mix.

Researchers were able to virtually eliminate soot produced by MD and HD diesel engines while making emissions compliance more affordable. An MD and HD multimode strategy that combines diesel-boiling-range fuels with advanced compression ignition (ACI) and mixing-controlled compression ignition (MCCI) reduces nitrogen oxide (NO_X) emissions by a factor of 10. In addition, the ACI strategy delivers hydrocarbon emissions reductions when paired with several bioblendstocks.

A new ducted fuel injection (DFI) engine technology developed by Co-Optima can decrease HD engine-out soot emissions by a factor of 10 compared with those of today's MCCI engines. Combining DFI with a low-sooting blendstock cuts emissions by a total factor of 100.

ENERGY EFFICIENCY

Light Duty

Up to 10% increase in engine efficiency with turbocharged SI combustion

Additional 9%–14% improvement in fuel economy with multimode combustion

Medium & Heavy Duty

Up to 4% increase in engine efficiency with ACI

LD vehicles in the United States consume 57% of all energy used for transportation. Co-Optima research revealed that these vehicles can operate more efficiently by combining optimized engine designs with higher-performing sustainable fuels.

Researchers identified opportunities to increase the efficiency of turbocharged SI engines by up to 10%. The initiative also discovered how even greater efficiencies—as much as an additional 14%—can be delivered with vehicles that use new advanced multimode engines.

MD and HD trucks account for 24% of all energy used for transportation in the United States. The diesel-fueled MCCI engines typically found in commercial freight trucks already supply impressive power and efficiency.

This led Co-Optima researchers to focus on new engine technologies and advanced combustion approaches able to deliver even better performance when combined with lower-GHG bioblendstocks. Potentially transformative ACI approaches can achieve 4% gains in fuel economy plus lower emissions.

ECONOMIC VIABILITY

Fuels with cost-competitive prices of **$2.50–$4/GGE**

Up to 500,000 new biorefinery jobs

Maximum potential use of **1 billion tons of domestic biomass**

Lower emissions compliance costs for MD/HD diesel trucks

Making sure new fuels and engines can be scaled up for commercial production, will be compatible with fueling infrastructure and auto components, and can be produced at competitive cost are all vital factors in bringing cleaner, more efficient transportation solutions to market.

Co-Optima techno-economic and life cycle analyses determined key marketplace drivers for new fuel and engine technologies, identifying which bioblendstocks can reduce GHG emissions the most while meeting production cost targets. Blendstock candidates produced from corn stover, woody biomass, and used cooking oil show potential to be produced at commercial scale and deliver prices at the pump below $4 per gasoline gallon equivalent (GGE).

Research also indicated that certain bioblendstocks with improved properties could provide refineries and automotive manufacturers with additional economic benefits, including a breakeven blendstock value as high as $110 per barrel of oil equivalent under some conditions. Plus, the blendstocks have the potential to decrease the need for HD engine aftertreatment, reducing lifetime operating costs.

The Bioenergy Technologies Office's Billion-Ton Study revealed the potential to convert 1 billion tons of sustainable domestic waste and biomass feedstocks into 60 billion gallons of fuel per year. Bioblendstocks identified by Co-Optima researchers can help maximize the use of these sustainable domestic resources, decrease reliance on imports, strengthen U.S. energy security, and keep fuel prices affordable.

Biofuel production can also positively affect the American workforce, with potential to create up to 500,000 new biorefinery jobs and bolster the economy in rural areas.

SCIENTIFIC PROCESS

>30 new tools for property prediction and simulation

New methods to more quickly & accurately assess **1,000s of blendstocks**

Co-Optima researchers applied fundamental principles to fuel and engine research for LD, MD, and HD vehicles. These core scientific approaches steered the entire initiative, spanning multiple disciplines to identify the most promising fuel and combustion options and provide a foundation for future research.

The initiative led to a deeper understanding of the relationships between molecular, fuel, and engine properties. New engine and fuel hypotheses, along with a formula called a merit function, related fuel properties to performance to determine the interplay between fuel property values and combustion, guide research activity, and make it possible to rapidly and accurately identify promising solutions.

Simulations can evaluate fuel blend performance much faster than testing in actual engines. New insights dramatically improved the scope and fidelity of combustion kinetic simulations that are critical for predicting fuel behavior.

The Co-Optima team developed a wide range of robust, validated tools to capture fuel-engine interactions with greater accuracy, improve the efficacy of predictions, and speed up computations. The fast solvers, lower-order models, and algorithms make it possible to evaluate an unprecedented number of fuel blends and combustion approaches in a fraction of the time required for bench testing.

BRIDGING FROM LOW-CARBON TO NO-CARBON TRANSPORTATION

Co-Optima solutions provide a bridge from today's petroleum-dependent transportation system to cleaner bio-based fuels and an emissions-free tomorrow.

Even as more electric cars are introduced and charging infrastructure is expanded, it will still take decades to turn over the entire LD vehicle fleet. Due to weight and operational patterns, trucks are tougher to electrify and will continue to run on liquid fuels longer.

More sustainable, low-emission, high-efficiency vehicles using ICEs and liquid fuels such as those identified by Co-Optima will play an important role in reducing GHG emissions during that transition—with many of the identified blendstocks having potential to be used at levels well above 30%.

Beyond on-road transportation, approaches pioneered by Co-Optima point the way to sustainable fuels, improved efficiency, and reduced GHG emissions for other transportation modes. Studies show that biomass-derived fuels could eventually meet 100% of future demand for air, marine, and rail fuel while still leaving a supply of feedstock to produce automotive fuel.

Environmental justice considerations are beginning to play a larger role in research, development, and deployment decisions. Co-Optima reveals ways to reduce vehicle criteria pollutants, GHG emissions, and related poor air quality often concentrated near underserved populations and help limit the impact of climate change on vulnerable communities.

Cutting GHG emissions is more urgent than ever. It is not an option to delay smaller-scale, near-term reductions while the search continues for a perfect solution—it is critical to begin reducing carbon emissions today.

Ultimately, the new fuels and engines identified through Co-Optima research will be cleaner, produce fewer life cycle GHG emissions, and make important contributions in the nation's transition to a net-zero-carbon-emissions energy future.

A WIDE-REACHING COLLABORATION

Co-Optima leverages synergies across DOE's Office of Energy Efficiency and Renewable Energy (EERE). Led by EERE's Vehicle Technologies Office and Bioenergy Technologies Office, partners include:

- Argonne National Laboratory
- Idaho National Laboratory
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- National Renewable Energy Laboratory
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory
- Sandia National Laboratories
- More than 40 industry and university partners

Bio-based blends identified by Co-Optima could eventually provide 100% of air, marine, and rail fuel while still leaving enough feedstock to produce automotive fuel. Photos from Getty Images

U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

For more information on the Co-Optimization of Fuels & Engines initiative, visit: **energy.gov/fuel-engine-co-optimization.**

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