Annex 54: GDI Engines and Alcohol Fuels

Project Duration	April 2016–April 2019
Participants **Task Sharing** **Cost Sharing**	 Canada, Germany, Israel, Switzerland, United States No Cost Sharing
Total Budget	~ €350,000 (~$400,000 US)
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Purpose, Objectives, and Key Question

Under certain conditions, gasoline direct injection (GDI) may increase particle emissions in comparison with port fuel injection (PFI) engine technologies, up to levels that are over the emissions from diesel vehicles equipped with diesel particulate filters (DPFs). Both gasoline particulate filters (GPFs) and alcohol fuel blends, such as E85 (85% ethanol in gasoline fuel), have shown the potential to reduce particulate matter (PM) emissions from GDI vehicles.

The objective of this Annex is to determine the impacts of alcohol fuels on emissions from GDI engines. In addition to information on combustion processes, the focus will be on tailpipe gaseous emissions and PM, along with the potential for secondary organic aerosol (SOA) and genotoxicity formation. The fuels investigated include ethanol blends (E10 to E85, and E100), methanol blends (M56), and butanol blends. The impacts of GPFs and start-stop operation on emissions from GDI vehicles will also be investigated.

Activities

The main activities of this Annex are chassis dynamometer tests of vehicles with GDI engines and comparable counterpart engines. These vehicles will be chassis dynamometer tested over varying drive cycles and ambient temperatures. The vehicles will also be tested with fuels of varying alcohol content (e.g., ethanol, methanol, and butanol) to assess the impact of alcohol fuels on emissions from GDI engines. Some vehicles will be equipped with GPFs in order to determine their efficiency in reducing emissions from GDI engines.

The focus of this project is to obtain detailed information about particulate and particle emissions from GDI technologies. Along with gaseous emissions, fuel economy and efficiency will be quantified. The impact of alcohol fuels and GPFs on PM, particle number (PN), and BC emission rates will be measured. Also, the potential for SOA formation using different vehicle fuel and technology combinations will be assessed.

Experiments were carried out at the Emissions Research and Measurement Section of Environment and Climate Change Canada. Two light-duty vehicles, one GDI and one PFI, were tested on a chassis dynamometer with low-level ethanol blends. The drive cycles used were the Federal Test Procedure (FTP-75) and the Supplemental Federal Test Procedure (US06) at 25°C and −7°C. Tests were also conducted with the GDI vehicle equipped with and without a GPF. Emissions characterization includes carbon monoxide (CO), nitrogen oxide (NO_x), hydrocarbon (HC), gravimetric PM, and PN and BC.

Chile's contribution was led by the Centro Mario Molina (CMMCh). Experiments will be carried out at the Center for Vehicle Control and Certification (3CV) laboratory and photochemical chamber at the Ministry for Transport and Telecommunication (MTT).[1] Chassis dynamometer tests were conducted with light-duty vehicles using the New European Driving Cycle (NEDC) and FTP test cycle, with varying blends of ethanol fuel (e.g., E0, E10, and E85, E22, and E100). In addition to primary gaseous measurements of HC, non-methane hydrocarbon (NMHC), NO_x, and CO, secondary gas formation and particle formation were quantified for ultraviolet irradiation-aged emissions.

Studies conducted at the Institute of Engineering Thermodynamics (LTT) Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) in Germany contain fundamental investigations of mixture formation and soot formation in an optically accessible GDI engine using laser-based diagnostics. Further characterizations of PM are conducted in the exhaust gas duct of a metal GDI engine. Different ethanol-gasoline mixtures (e.g., E20, E85) and other model fuel mixtures (including iso-octane and toluene) as well as butanol mixtures (e.g., Bu20) were studied in a wide range of operating points.

[1] Gramsch, E., Papapostolou, V., Reyes, F., Vásquez, Y., Castillo, M., Oyola, P., López, G., Cádiz, A., Ferguson, S., Wolfson, M., Lawrence, J., and Koutrakis, P., 2018, "Variability in the Primary Emissions and Secondary Gas and Particle Formation from Vehicles Using Bioethanol Mixtures," *Journal of the Air & Waste Management Association*, 68:4, 329-346, DOI: 10.1080/10962247.2017.1386600.

The research conducted under Israeli-European cooperation between the Technion – Israel Institute of Technology and the Joint Research Centre of the European Commission (JRC) was commissioned by the Ministry of Energy, State of Israel. Emissions tests were conducted with three vehicles: two GDI and one PFI, fueled with gasoline, methanol, and ethanol gasoline fuel mixtures (RON95, E85, M56) over the New European Driving Cycle (NEDC). Emissions characterization includes NO_x, HC, CO, PM, PN, and formaldehyde.

Switzerland's contribution was provided by the following organizations:

- Paul Scherrer Institute
- University of Applied Sciences Northwestern Switzerland
- University of Applied Sciences Bern
- Swiss Federal Laboratories for Materials Science and Technology (Empa)

GDI vehicles were tested with ethanol gasoline blends (E0, E10, E85) and butanol blends (E10/Bu15 and Bu30). The drive cycles included the Worldwide Harmonized Light Vehicles Test Cycle, NEDC, and steady-state cycle. Some of the vehicles were equipped with GPFs and compared to a diesel vehicle. Regulated gaseous emissions, along with formaldehyde, polycyclic aromatic hydrocarbon, ammonia, and metals, were quantified along with nanoparticles. Testing in a smog chamber allowed for a comparison of the particle burden and the genotoxic potential and the SOA formation potential of GDI and diesel vehicles.[2,3]

Through the U.S. Department of Energy's Oak Ridge National Laboratory, a light-duty vehicle equipped with a GDI engine and start-stop operation was chassis dynamometer tested with the FTP-75 drive cycle. Many manufacturers are implementing start-stop operation to enhance vehicle fuel economy. During start-stop operation, the engine shuts off when the vehicle is stationary for more than a few seconds. When the driver releases the brake, the engine restarts. Three fuels were evaluated: an 87 AKI gasoline (E0), a 21% splash blend of ethanol and the 87 AKI gasoline (E21), and a 12% splash blend of iso-butanol and the 87 AKI gasoline (iBu12). PM mass,

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[2] EmGasCars, Research of Nanoparticles and of Non-Legislated Emissions from GDI Cars in the Primary Emissions and Secondary Gas and Particle Formation from Vehicles Using Bioethanol Mixtures.

[3] Comte, P., Czerwinski, J., Keller, A., Kumar, N., Muñoz, M., Pieber, S., Prévôt, A., Wichser, A., and Heeb, N., "GASOMEP: Current Status and New Concepts of Gasoline Vehicle Emission Control for Organic, Metallic and Particulate Non-Legislative Pollutants," Final Scientific Report of the CCEM-Mobility Project 807.

transient PN concentration and size distribution, and soot mass concentration were evaluated for both start-stop operation and *no start-stop* operation on each fuel.[4]

Main Conclusions

The overall outcome will focus on the impacts of alcohol fuels and varying technologies on emissions from GDI and comparable technology vehicles.

This Annex will result in the following:

- Information of fundamental processes of combustion and pollutant formation in a GDI engine;
- Data on the impacts of alcohol fuel blends on both gaseous PM and PN emission rates from GDI vehicles operated under varying conditions;
- The effect of start-stop operation on emissions;
- The effects of GPF on emissions from GDI vehicles;
- Provision of information on the SOA forming potential; and
- Information on the genotoxicity of emissions from GDI vehicles.

Initial results clearly show that using alcohol fuels can decrease PM and PN emissions from GDI vehicles. The use of GPFs also resulted in a significant decrease in PM and PN emissions. The type of catalyst coating and filter technology impacted both PM and gaseous emissions.

Publications

The work performed under Annex 54 will result in a final report, "GDI Engines and Alcohol Fuel."

[4] Storey, J., Moses-DeBusk, M., Huff, S., and Thomas, J., et al., "Characterization of GDI PM during Vehicle Start-Stop Operation," SAE Technical Paper 2019-01-0050, 2019, https://doi.org/10.4271/2019-01-0050.