Efficiency-Optimized Dual Fuel Engine with In-Cylinder Gasoline/CNG Blending

Final CRADA Report

Energy Systems Division

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prepared by
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Energy Systems Division, Argonne National Laboratory

Participants: Ford Motor Company
FCA US LLC

2/21/2019

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Non Proprietary Final CRADA Report

For the Office of Scientific and Technical Information (OSTI)

CRADA Number: 1400901

CRADA Title: Efficiency-Optimized Dual Fuel Engine with In-Cylinder Gasoline/CNG Blending

CRADA Start Date Click or tap here to enter start date – **End Date** Click or tap here to enter end date

DOE Program or Other Government Support

Program office: DOE EERE Vehicle Technologies Office

Program manager name: Kevin Stork

Program manager phone or email: Kevin.Stork@ee.doe.gov

Participant(s)

Participant 1 name: Ford Motor Company

Complete address: 330 Town Center Drive, Dearborn, MI 48126

Participant 2 name: FCA US LLC

Complete address: 1000 Chrysler Drive, Auburn Hills, MI 48326

Participant 3 name: Click or tap here to enter text.

Complete address: Click or tap here to enter text.

Argonne National Laboratory

Argonne PI(s): Thomas Wallner

Funding Table

To add rows, right-click in bottom row and select "Insert" "rows above".

	Planned Funding	Actual Funding	In-Kind
Government	\$ 1,000,000	\$ 1,000,000	
Ford Motor Company	\$ 0	\$ 0	\$ 150,000
FCA US LLC	\$ 0	\$ 0	\$ 100,000
Enter Participant 3 here	\$	\$	\$
Total	\$ 1,000,000	\$ 1,000,000	\$ 250,000

Nature of Work

Describe the research (summary of Scope of Work and principal objectives of the CRADA):

The objective of the proposed project is to demonstrate targeted blending of gasoline and natural gas as a means to reduce petroleum consumption of light-duty spark-ignition engine vehicles by at least 50%. This goal will be achieved through petroleum displacement with natural gas (NG) combined with a relative engine efficiency improvement in excess of 10% while meeting retrofitability requirements with an anticipated payback period of less than 36 months. Further through NG direct injection (DI) a 10% improvement in power density over the PFI baseline will be demonstrated.

The proposed project employs a sound R&D approach and combines experimental work with state-of-the-art computational modeling to be able to demonstrate the ambitious project goals. The project spans a 30 month period and is divided in 3 phases with the initial phase focused on experimental characterization of the gaseous jet structure of the high-pressure NG DI injector which is used to validate the 3D-CFD simulation tool. The phase also includes an experimental demonstration of the fundamental feasibility of the proposed dual-fuel approach on an automotive

single-cylinder research engine. The scope of the second phase includes optimization of the combustion system by means of virtual design combined with 3D-CFD analysis. The resulting optimized combustion system will be built and experimentally evaluated by the end of the 12 month period. The third and final phase expands the scope by integrating the engine results in a vehicle level simulation tool with the objective of developing an optimized engine control strategy that maximizes the efficiency benefits attainable with the limited on-board NG supplies. A detailed cost analysis to verify that the 36 month amortization period requirement is met will conclude the proposed effort.

DOE mission area(s):

Energy and Environmental Science and Technology

Choose an item.

Choose an item.

Conclusions drawn from this CRADA; include any major accomplishments:

A computational fluid dynamics (CFD) approach to model high-pressure gaseous injection was developed and validated against X-ray data from Argonne's Advanced Photon Source. NG side and central DI of various designs and injection strategies were assessed experimentally along with CFD correlation. Significant effects on combustion metrics were quantified and explained via improved understanding of the in-cylinder flow effects due to NG injection. On-demand in-cylinder blending using E10 PFI and NG DI provides an additional lever to adjust in-cylinder turbulence as well as knock resistance across the engine speed and load range. NG DI improves part-load dilution tolerance due to higher in-cylinder turbulence and the high knock resistance of NG compared to E10 improves wide open throttle (WOT) performance while enabling increased compression ratios (CR).

Vehicle level simulations suggest that implementing this strategy on a ½ ton pickup truck with a naturally aspirated engine at 12.5:1 CR improves energy consumption on the aggressive US06 drive cycle by 15.5% compared to E10 operation, and gives a petroleum reduction of 78% over the blended range.

Technology Transfer-Intellectual Property

Argonne National Laboratory background IP:

Click or tap here to enter text.

Participant(s) background IP:

Click or tap here to enter text.

Identify any new Subject Inventions as a result of this CRADA:

IN-16-008 Gaseous direct injection to improve combustion in internal combustion engines

Summary of technology transfer benefits to industry and, if applicable, path forward/anticipated next steps towards commercialization:

The outcome of the proposed project is a proof-of-concept that includes the demonstration of the technology on a single-cylinder research engine platform using prototype DI NG hardware combined with vehicle level fuel economy and cost predictions. Developing a technology from this proof-of-concept level to a production stage involves several additional steps. The target market for this technology could include one or more of the respective OEM partners' range of light, medium, and heavy duty vehicles. The OEM partners compete globally with all other major OEMs in the different vehicle segments and could potentially leverage their extensive distribution channels which include their respective manufacturing plants and broad dealer networks.

Other information/results (papers, inventions, software, etc.):

Sevik, J., Pamminger, M., Wallner, T., Scarcelli, R. et al., "Performance, Efficiency and Emissions Assessment of Natural Gas Direct Injection compared to Gasoline and Natural Gas Port-Fuel Injection in an Automotive Engine," SAE Int. J. Engines 9(2):2016, doi:10.4271/2016-01-0806.

Bartolucci, L., Scarcelli, R., Wallner, T., Swantek, A. et al., "CFD and X-Ray Analysis of Gaseous Direct Injection from an Outward Opening Injector," SAE Technical Paper 2016-01-0850, 2016, doi:10.4271/2016-01-0850.

Wallner, T.; Pamminger, M.; Sevik, J.; Scarcelli, R.; Wooldridge, S.; Boyer, B.: 'Performance and Efficiency Potential of an Engine Concept employing NG Direct Injection and In Cylinder Fuel Blending with Gasoline.' 11th Conference on Gas-Powered Vehicles: Gaseous-Fuel Drives and Climate Protection Targets: The Right Path. Potsdam / Germany. 2016.

Pamminger M, Wallner T, Sevik J, et al. Performance, Efficiency and Emissions Evaluation of Gasoline Port-Fuel Injection, Natural Gas Direct Injection and Blended Operation. ASME. Internal Combustion Engine Division Fall Technical Conference, ASME 2016 Internal Combustion Engine Division Fall Technical Conference ():V001T03A008. doi:10.1115/ICEF2016-9370.

Sevik, J., Pamminger, M., Wallner, T., Scarcelli, R. et al., "Influence of Injector Location on Part-Load Performance Characteristics of Natural Gas Direct-Injection in a Spark Ignition Engine," SAE Int. J. Engines 9(4):2016, doi:10.4271/2016-01-2364.

Pamminger, M., Sevik, J., Scarcelli, R., Wallner, T. et al., "Evaluation of Knock Behavior for Natural Gas - Gasoline Blends in a Light Duty Spark Ignited Engine," SAE Int. J. Engines 9(4):2016, doi:10.4271/2016-01-2293.

Hall, C., Sevik, J., Pamminger, M., and Wallner, T., "Hydrocarbon Speciation in Blended Gasoline-Natural Gas Operation on a Spark-Ignition Engine," SAE Technical Paper 2016-01-2169, 2016, doi:10.4271/2016-01-2169.

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Pamminger, M., Sevik, J., Scarcelli, R., Wallner, T. et al., "Influence of Compression Ratio on High Load Performance and Knock Behavior for Gasoline Port-Fuel Injection, Natural Gas Direct Injection and Blended Operation in a Spark Ignition Engine," SAE Technical Paper 2017-01-0661, 2017, doi:10.4271/2017-01-0661.

**"Hall, C.; Pamminger, M.; Sevik, J.; Wallner, T.: 'Optimal Energy Control of a Dual Fuel Vehicle Fuelled by Natural Gas and E10
' The 20th World Congress of the International Federation of Automatic Control. Toulouse/France. 2017."**

Hall, C.; Pamminger, M.; Sevik, J.; Wallner, T.: 'Instantaneous and cycle optimization of fuel usage on a dual fuel vehicle leveraging gasoline and natural gas .' Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. <https://doi.org/10.1177/0954407017743159> . 2017.

Sevik, J.; Pamminger, M.; Scarcelli, R.; Wallner, T.; Wooldridge, S.; Boyer, B.; Miers, S.: 'Influence of charge motion and compression ratio on the performance of a combustion concept employing in-cylinder gasoline
ANL-1060 (06/07/2018)

and natural gas blending.' J. Eng. Gas Turbines Power. 2018;140(12):121501-121501-10.
doi:10.1115/1.4040090

Wallner, T.; Pamminger, M.; Scarcelli, R.; Powell, C.; Kamguia Simeu, S.; Iqbal, A.; Reese, R.; Wooldridge, S.; Boyer, B.: 'Performance, Fuel Economy and Economic Assessment of a Combustion Concept Employing In-Cylinder Gasoline/NG Blending for Light-Duty Vehicle Applications.' SAE Journal of Engines. Under review.

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