Natural Gas Vehicle Technology Forum 2020 Meeting Summary

The 2020 Natural Gas Vehicle Technology Forum (NGVTF) was held on February 4 and 5, 2020, in Downey, California. Following is a summary of the meeting. The National Renewable Energy Laboratory (NREL) hosted the forum in partnership with the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy's (EERE) Vehicle Technologies Office (VTO), the California Energy Commission (CEC), South Coast Air Quality Management District (SCAQMD), Southern California Gas Company (SoCalGas), and Natural Gas Vehicles for America (NGVA).

Day One: February 4, 2020

Welcome and Opening Remarks

John Gonzales, NREL

John welcomed forum participants and introduced the NREL, DOE team. He provided an overview of the meeting structure and agenda.

SoCalGas: Who We Are and Our 2020 Initiatives and Vision

Michelle Sim, SoCalGas

Michelle welcomed forum participants to SoCalGas' Energy Resource Center. She discussed natural gas basics and the importance of the fuel, especially for situations like natural disasters, as natural gas vehicles (NGVs) can typically still fuel and be in operation when other transportation services may be compromised. SoCalGas is currently meeting the natural gas needs of their customers and aims to do so for the foreseeable future. Michelle provided an example of one of their customers—a trucking company—who switched from diesel to natural gas and experienced increased reliability and decreased costs. Key factors to natural gas success are affordability, integrated solutions, and working collaboratively as an industry to get where we want to be and to bring new technologies on the market.

CEC Natural Gas Research and Development (R&D) Program Overview

Peter Chen, CEC

Peter discussed the natural gas R&D program, including background on how the program was established in 2004, the budget of $24 million, and the primary research areas which include: energy efficiency, renewable energy and advanced generation, natural gas infrastructure safety and integrity, energy-related environmental research, and transportation research. Research projects are selected through competitive solicitations. Peter elaborated on transportation research goals and presented a timeline of portfolio research and demonstration projects. Currently, CEC is funding about $3.7 million for four projects that are part of the Natural Gas Vehicle Research Consortium. Additional consortium projects are also funded by DOE and SCAQMD and are currently expected to be complete in 2022. Future plans include research into fuel cell technologies, as gas utilities are interested in hydrogen as a

pathway for decarbonizing the natural gas system. Forum participants asked if CEC is working with air districts, and if funding research is aligned with technology advancement goals. Peter indicated that CEC is working with CARB, and that there is sometimes a disconnect between incentive programs and advancement programs.

NGVTF – U.S. Department of Energy Updates

Mike Laughlin, DOE EERE VTO

Mike presented in place of Dennis Smith, who is also with DOE EERE VTO. He discussed VTO funding opportunities and the awards given during the last funding round. A new funding round is underway, with 16 areas of interest covering all VTO program areas. Most notably, NGVTF forum participants should look into areas of interest 5, 12, 13, and 15; concept papers were due February 21, 2020. Mike also reminded participants to sign up for the VTO newsletter.

Natural Gas Pathways, Vehicles, Storage, and Infrastructure Discussion

Rey Gonzalez, CEC, and Mike Laughlin, DOE EERE VTO

Rey and Mike gave an overview of CEC and DOE natural gas projects and opened the forum for discussion about natural gas pathways, vehicles, storage, and infrastructure. Specifically, Ted Barnes, Gas Technology Institute (GTI), was asked what opportunities GTI is thinking about that fit into a national perspective and align with California's goals. He indicated that GTI is listening to the industry and thinking about cost and resiliency of natural gas moving forward. Specific areas of interest include renewable natural gas (RNG), research on engines and components, and rail and marine natural gas applications. Forum participants indicated an interest in RNG but stated that cost is difficult to compete with because of the low cost of fossil gas. SCAQMD is monitoring the inventory of RNG produced in California, which is being more closely tracked through the low carbon fuel standard.

Participants also observed that there is less interest in expanding the use of liquefied natural gas (LNG), as compressed natural gas (CNG) has been the fuel of choice with more fueling stations available. The conversation turned to R&D, where a question was asked about how the political climate is affecting R&D, including how the current focus on electric vehicles may be lessening NGV sales.

DOT Fuel Tank Integrity Codes and Standards

Lou Browning, ICF

Lou presented on a project evaluating alternative fuel systems and container safety standards. Federal Motor Vehicle Safety Standards (FMVSS) specify requirements for integrity of the fuel system and fuel container on CNG-fueled vehicles. Despite the increasing number of CNG heavy-duty vehicles on the road, there are no federal fuel system integrity requirements for CNG (or LNG) heavy-duty vehicles. The National Highway Traffic Safety Administration (NHTSA) is considering fuel system integrity requirements for medium- and heavy-duty NGVs to update FMVSS No. 303. NHTSA is also considering updates to FMVSS No. 304 to address safety issues and better reflect current best practices and existing standards for high pressure fuel tanks in motor vehicles. NREL is conducting a study to provide applicable and accurate recommendations to ensure the standards address relevant safety issues, are practical, and do not produce future barriers. ICF will work with NREL to provide recommendations on performance requirements and specifications for natural gas fuel systems and fuel containers.

Lou described both FMVSS codes (303 and 304), including labeling requirements and gaps, fuel system testing gaps, vehicle inspections and inspection labels, burst and hydrostatic pressure gaps, fuel container integrity and recommendations for improvements. Lou provided next steps, which include sharing a summary of the discussion with NHTSA. A discussion with forum participants followed, including the differences between U.S. and European codes, the preferred situation for regulations common across the globe, what the future of standards holds, and container recommendations.

DOE Funding Opportunity Announcement Awards

Margo Melendez, NREL

Margo presented an update on the NGV Research Consortium project, which includes eight projects totaling about $17 million in funds from DOE, CEC, SCAQMD, and about $14 million in matching funds from awardees, totaling about $36 million. Most projects kicked off in 2019 and will extend through 2022. Projects include engine development, vehicle demonstration, hybridization, smart fueling, combustion research, and emissions control research. The Consortium funding partners are meeting regularly to discuss project progress. As these projects progress, teams will present at future NGVTF meetings to provide updates.

Multi-Laboratory Natural Gas Research

Brad Zigler, NREL

Brad discussed a multi-laboratory natural gas research project underway with NREL, Argonne, Oak Ridge, and Sandia National Laboratories. The project focuses on early stage research on pre-chamber spark-ignition design and aims to address key barriers. These include an inadequate science base and simulation tools to describe and predict the fluid-mechanical and chemical-kinetic processes. Brad went into detail on each research area, such as pre-chamber spark ignition, unfueled pre-chamber spark-ignition simulations, analysis of pre-chamber ignition processes, advanced fuel ignition delay analysis, and computational fluid dynamics simulations. The key focus of this research is to identify, understand, and simulate fundamental natural gas combustion phenomena.

Cummins Heavy-Duty Engine Update

Yemane Gessesse, Cummins Westport

Yemane presented on Cummins Westport's 2019-20 products. Specifically, the Cummins Westport natural gas engines, including their architecture. For 2020, Cummins Westport has three new engines certified to near zero. Cummins Westport also received an award as part of the NGV Research Consortium project and will be designing a natural gas-specific engine that will improve efficiency and provide diesel-like torque.

Advanced Ultra-Low Emission Natural Gas Engines in Port Yard Trucks

Patrick Couch, Gladstein, Neandross, and Associates (GNA)

Patrick discussed a project funded by CEC focused on development, demonstration, and testing of low-NO_x NGVs in port yards, and the development of innovative gas composition sensors. For this project, GNA works with a subcontractor, the University of California Riverside (UCR), Center for Environmental Research and Technology. Project objectives are to develop and demonstrate two LNG yard hostlers with right-sized low-NO_x engines, conduct comparative emissions testing, and develop and bench-test

innovative composition sensor technology. One activity, started in May 2019, was a data collection focus on portable activity monitoring systems (PAMS) to collect data on LNG yard tractors at CalCartage (interim site). This activity had positive results. From there, the tractors moved to their permanent home at Everport Terminals, where GNA provided host site training. There were some issues with crankcase filter clogging, though the natural gas engines were well received.

Preliminary analysis from data collection shows that diesel and natural gas operations may not be identical on the same day. In addition, duty cycles vary based on the work conducted on the terminal. Chassis dynamometer testing at UCR is expected to begin in February. Finally, Patrick presented on the UCR Gas Composition Sensor and wrapped up with project accomplishments to date.

Natural Gas Heavy-Duty In-Use Emissions Study

Sam Cao, South Coast Air Quality Management District

Sam presented on a vehicle in-use emissions testing program that aims to identify technology benefits and shortfalls, inform future research and development opportunities and regulation development, and improve emissions inventory estimates. The study uses portable activity measurement system (PAMS), portable emissions measurement systems (PEMS), chassis dynamometers, and real-world in-use trailers to test for emissions, with a target completion of May 2020. Sam discussed the preliminary key findings for PAMS, PEMS, and chassis data. He also presented a summary of low NO_x regulations and the need to control in-use emissions.

Following the presentation, a participant asked if the study could incorporate additional data that fleets are willing to provide. Sam indicated that this would warrant an additional discussion offline. Another participant asked why battery electric vehicles were not included in the study, which Sam indicated was because the availability of vehicles was limited when the study kicked off. Finally, Sam stated that seasonal impacts of emissions are not covered in the study.

DOE is Listening – DOE Listening Feedback Session

Mike Laughlin, DOE EERE VTO and John Gonzales, NREL

Mike and John updated forum participants on the Clean Cities Coalition Network listening sessions and the feedback they received on natural gas. First, they provided background, stating that 35 coalitions have held 47 listening sessions to discuss the pros and cons of NGVs. The primary issues raised were technical barriers around fuel gauge inaccuracy, tank issues (packaging, payload, and life expectancy), and maintenance costs and frequency. Other challenges that rose to the surface included lack of training for technicians, drivers, and emergency responders; lack of competent repair facilities; supply chain challenges; lack of original equipment manufacturer product options; and range anxiety.

Day Two: February 5, 2020

Introduction and Agenda Review

Jeff Clarke, NGVAmerica

Jeff welcomed forum participants to day two of the forum and provided an overview of the day's agenda.

Introduction to End of Life Natural Gas Tank Testing

Aaron Williams, NREL

Aaron presented on CNG fuel tank end of life testing, which is the condition of fuel tanks at the end of their service life. The industry challenge with natural gas tanks is that the vehicles can last longer than tanks are currently certified for use. Aaron discussed the current tank design and safety standards, which include manufacturing, inspection, and labeling requirements and state that at the end of the life of the tank it should be destroyed. There are also safety challenges to be aware of with visual tank inspections, when replacing tanks, and with expired tanks.

The project objectives were to characterize tank conditions and the remaining functional life of expired tanks, to determine how fuel tanks might fail under routing conditions, and to develop better methods of evaluating tanks. One test method used was modal acoustic emission (MAE), which is a non-destructive and non-visual evaluation technique. In 2012, Digital Wave conducted a MAE study on self-contained breathing apparatus tanks and evaluated carbon fiber composite overwrapped cylinders with a 15-year service life. They found MAE could detect burst strength within 10%. Aaron wrapped up his presentation with a project outline, stating that 101 tanks, sourced from Los Angeles Metro, were visually inspected, artificially damaged, fatigued cycled, burst tested, and evaluated using MAE.

Natural Gas Tank Testing and Results

Brian Burks, Digital Wave

Brian presented in more depth on the project background for end of life natural gas tank testing. He covered types of testing and inspections done on the tanks and provided project results. Specifically, Brian described the test methods as visual inspection, MAE, burst pressure, hydrostatic pressure cycle, notch tolerance, and impact tolerance. For burst tests, the tanks were visually inspected, proof pressure tested, and MAE inspected prior to the burst testing. Prior to these evaluations, all tanks had passed each test. For hydraulic fatigue cycle testing, 20 tanks were visually inspected, proof pressure tested, and MAE inspected, and burst tests were conducted after the hydraulic fatigue testing. Prior to testing, all tanks passed visual inspection, proof testing, and MAE inspection. For notch tolerance testing, two notches were machined into each cylinder sidewall, and then all cylinders were MAE inspected. Notches did affect strength. Finally, impact testing was conducted, and tanks were inspected after each test. Tanks passed visual inspection test and proof pressure test, but failed MAE inspection.

Testing results showed that Type 3 and Type 4 tanks met all performance and testing requirements at the end of their useful life, localized impact damage can be highly deleterious to tank performance, and MAE testing successfully identified compromised tanks where traditional methods could not.

Summary of Natural Gas Tank Testing and Recommendations

Aaron Williams, NREL and Brian Burks, Digital Wave

Aaron and Brian discussed findings and next steps for the natural gas tank testing. Specifically, they found that end of life tanks passed burst requirements, visual inspection results were non-conservative, and MAE testing showed promise. The remaining question is whether MAE can be used to improve visual inspections and if it can help recertify tanks instead of replacing them when they're operating correctly.

A discussion with forum participants followed. One participant suggested that cracks should be considered in testing as well. Another participant asked about the timing of the technical report. Aaron indicated that it is planned for June 2020. The report should help determine whether tanks manufacturers are being held to higher standards than necessary. Another participant pointed out a study with NHTSA and NASA that showed that there was no reduction in tank strength at all over a tank lifetime of 15 years.

Foothill Transit Study – Battery Electric Bus (BEB) Evaluation Results

Leslie Eudy, NREL

Leslie presented on the BEB evaluation, which was a third-party evaluation of advanced technology in real-word service, working with transit agencies, governments, and original equipment manufacturers. Researchers collected data on a variety of topics, including fleet experiences, charging and maintenance records, utility information, and others. Leslie provided detailed information on each transit evaluation, such as the number of buses and service and evaluation dates. The fleets evaluated in the study include: Foothill Transit, West Covina California; County Connection, Concord California; Long Beach Transit, Long Beach California; and King County Metro, Seattle Washington.

Leslie then discussed the successes for BEBs, including dropping costs, more model availability, and an increase in bus orders across the country. In addition, BEBs have proved to be up to five times more efficient than conventional technology, including natural gas, diesel, and hybrid technology. Challenges with BEBs include high variability in efficiency as a result of duty cycle, operator driving style, and HVAC use. Further, utility rates vary greatly by provider, whereas natural gas costs are typically more stable. Maintenance costs can also be high for BEBs, especially around propulsion because of issues with low-voltage batteries and tires.

The discussion following Leslie's presentation included a question about user guides for buses and transit agencies that provide an overview of each application and fuel type. Leslie indicated that the Transit Cooperative Research Program has a relevant report. Participants also asked several questions about charging infrastructure costs and reliability of infrastructure, as well as driver feedback.

Trends and Issues Associated with Renewable Natural Gas

Marianne Mintz, Argonne National Laboratory

Marianne presented on RNG, including information about what it is, emissions benefits, and national and regional trends and issues. She explained that RNG is essentially upgraded biogas and can be used without modification in natural gas engines, be injected into natural gas pipelines, and help meet environmental, economic, and energy goals. The Clean Cities Coalition Network supports RNG and currently has a variety of RNG initiatives underway, including an RNG working group. It is important to note that many RNG pathways have reduced well-to-wheel emissions when compared with diesel and natural gas.

The Renewable Fuel Standard has boosted the use of RNG. The U.S. Environmental Protection Agency has reduced cellulosic fuel requirements because of technical constraints and expanded eligibility to RNG. Today, RNG accounts for about 97% of D3 renewable identification numbers. In addition, the low carbon fuel standard credit values are rising.

Marianne provided information on an Argonne database that provides a comprehensive list of biogas projects that are upgrading gas for pipeline injection or for use as vehicle fuel (whether locally or at the

end of a pipeline). As of March 2019, there are 220 verified RNG projects, with landfills accounting for 87%. And capacity of operational RNG projects is growing. To conclude, Marianne provided some trends and issues affecting RNG projects, including: major shifts in the market, more interest in RNG because of renewable identification numbers (for which values are highly uncertain and variable), mandated renewable portfolio standards at the state level, and a bright outlook for the market.

Discussion followed, where a participant asked about the cost effectiveness of different feedstocks for RNG. Marianne indicated that she hasn't seen any comparisons on this, but that the yields will be different. Another participant asked how much potential RNG is available, and the answer is that it is debated, though it depends some on the available technology.

Vehicle Incidents and Lessons Learned

Jeff Clarke, NGVAmerica

Jeff presented on an incident investigation and root cause analysis working group. The working group's goal is to educate the NGV industry on the root cause of safety incidents, and to communicate incident investigations as well as codes and standard development organizations. One outcome of the working group was to propose changing the inspection period for Class 8 trucks from 36 months or 36,000 miles, to 12 months, as multiple annual inspections for high mileage vehicles can cause problems. In addition, NGVA published several maintenance facility modification documents, one in collaboration with NREL. Jeff also pointed out that the National Fire Protection Association offers free alternative fuel vehicle safety training and pointed out that NGVA has a number of additional training options available. Finally, NGVA issued a cold weather advisory press release about how to handle cold weather with NGVs, but it received negative feedback from stakeholders concerned that it wasn't well balanced.

ISX12 G to Dedicated Exhaust Gas Recirculation (D-EGR)

Michael Kocsis, Southwest Research Institute (SwRI)

Michael presented on achieving efficiency improvement in heavy-duty natural gas engines. For background, he provided information on U.S. emissions regulations. A demonstration using an ISX12 G achieved lox NO_x (with some CO_2 penalty), and Michael outlined keys to success including how to recover the CO_2 penalty. SwRI proposed D-EGR on a Cummins Westport ISX12 G engine combined with an advanced ignition system, charge motion development, and high efficiency turbo, as a potential solution for efficiency gains. SwRI's two main goals were to improve natural gas engine efficiency by 10% and achieve low NO_x emissions. At the end of the project, they were able to improve ISX12 G efficiency by 12% and concluded that stoichiometric with EGR is a preferred technology path through 2020 for heavy-duty on-highway engines.

Natural Gas Fueling, Gas Expanding Technology

Ted Barnes, Gas Technology Institute

Ted presented on gas expanding technology for natural gas fueling. He first provided background information on GTI and gave an overview of several ongoing projects. The smart station expander development project is funded through the NGV Research Consortium. This project will develop CNG full fills using smart vehicles and dispensers, advanced full fill algorithms, and cost-effective pre-cooling, and will test and demonstrate full fills (improvement of up to 25%) using an expander to pre-cool gas. Through another project with DOE, GTI is working to develop an NGV driver information system that

predicts miles-to-empty within 5% or 25 miles to reduce range anxiety. From there, Ted went into more detail on the smart station expander development, including designing of prototypes, testing, and an economic analysis. Participants asked about the proprietary nature of the technology, and Ted indicated that they are looking into commercial development of the product.

Validation of Natural Gas Models used in AltRAM

Myra Blaylock, Sandia National Laboratory

Myra presented on a project that used AltRAM; an integration platform for state-of-the-art alternative fuel safety models and data. AltRAM can provide a quantitative risk assessment for specific alternative fuels; frequency and probability data for fueling component failures; and fast-running, validated plume, flame, and overpressure models. AltRAM also has a number of physics models available. Myra provided a summary of a literature review of published experiments on CNG plume and flame models for sub-sonic flow and choked flow. Conclusions from the literature review included thoughts on each flow, and showed confidence in the models for use in quantitative risk assessment. During the discussion, Myra indicated that the final information should be ready by the end of the 2020 fiscal year.

Adsorbed Natural Gas Technology Discussion

Billy-Paul Holbrook and Peter Barber, Ingevity

Billy presented on adsorbed natural gas (ANG) technology, field tests, and where it fits in the vehicle market. ANG is the reversible binding of molecules to a surface, and is a process used to store natural gas. Activated carbon is used for pore size distribution control, performance, cost, and the ability to create different forms, shapes, and sizes. Ingevity has an ANG bi-fuel Ford F-150 available, which is a plug-in hybrid ANG vehicle. Key components include a system integrator, engine calibrator, vehicle outfitter, shape-specific activated carbon monoliths, low-pressure natural gas tanks, and off-board natural gas fueling appliances. The truck was tested on-road and was found to displace 600 gallons of gasoline. It also has fuel economy similar to a rented gasoline truck, though the fuel economy for natural gas is slightly higher. ANG also has an emissions benefit of about 19% compared to gasoline. Additionally, Ingevity manufacturers low-pressure private refueling appliances. To date, Ingevity's ANG products are operating in five states.

Following the presentation, participants discussed the relative fueling station storage size compared to conventional stations, and Billy indicated the storage size is about half the amount of gas you would store at 3,600 psi—when you drop the psi you lose capacity.

Issues, Key Points, Next Steps, and Priorities for Next Meeting

John Gonzales and Margo Melendez, NREL

John and Margo wrapped up the forum and let participants know that they can reach out to the NREL or DOE team at any time for assistance.