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Federal Railroad
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Office of Research,
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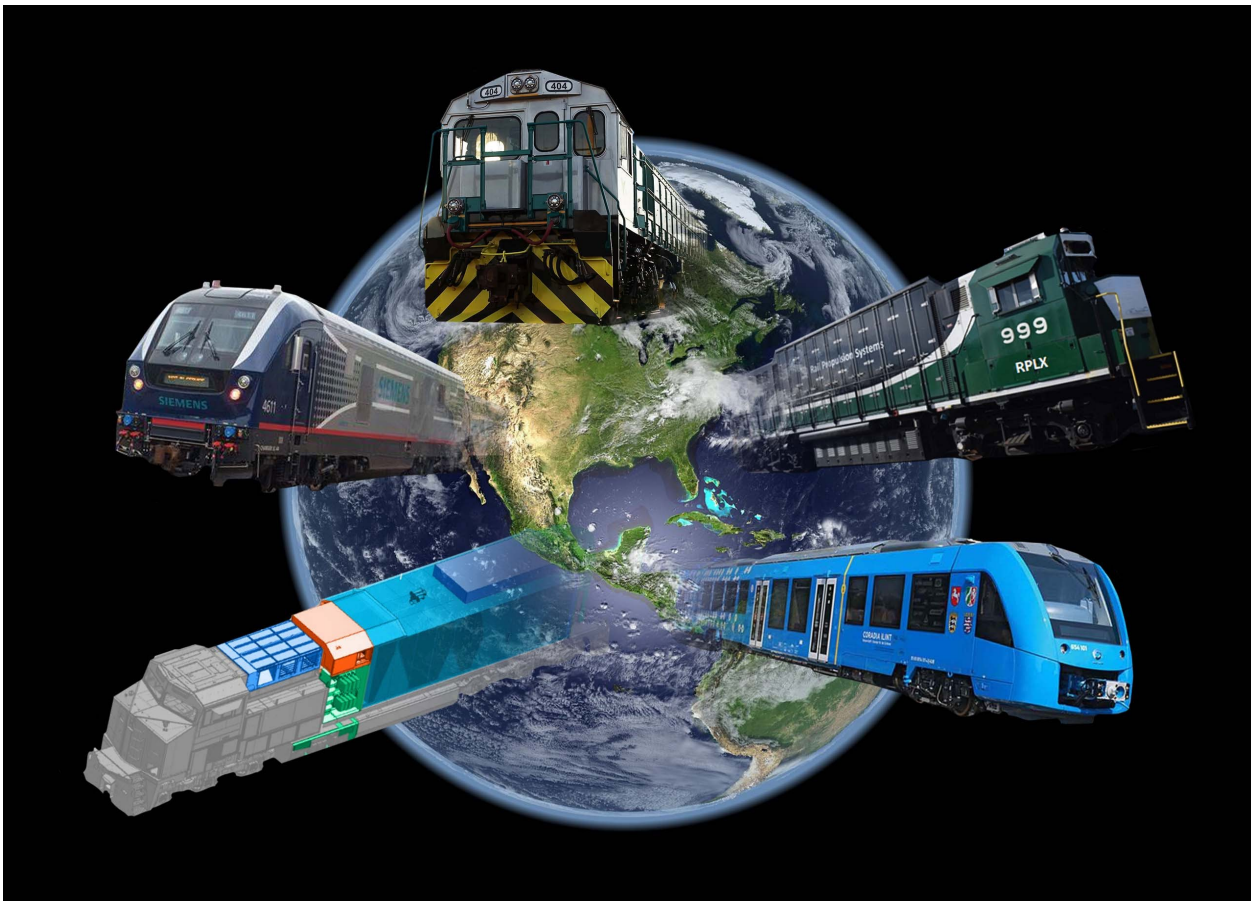
Washington, DC 20590

Proceedings of FRA Workshop on Environmentally Sustainable Energy Technologies Powering Future of Rail



DOT/FRA/ORD-22/06

Final Report | February 2022

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14. ABSTRACT
The transportation sector is seeking to reduce its emissions in a cost-effective and safe manner in response to the climate crisis. The Federal Railroad Administration (FRA) conducted a workshop for domestic and international experts to discuss experiences and challenges regarding alternative fuels, advanced propulsive technology research and implementation. Panelists described varying degrees of success in testing alternatives, with hydrogen fuel cells and hybrid approaches showing the greatest promise.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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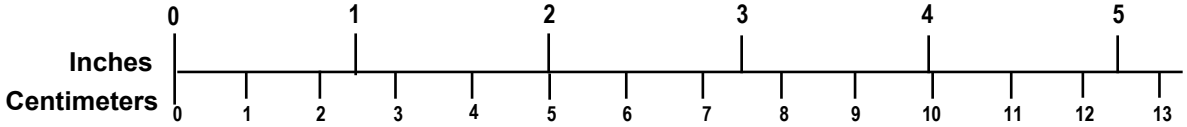
QUICK INCH - CENTIMETER LENGTH CONVERSION



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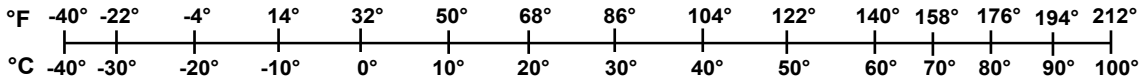

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Contents

Executive Summary

The burgeoning climate crisis is driving alternative fuel and propulsion research as the transportation sector seeks to reduce its emissions in a cost-effective and safe manner. The Federal Railroad Administration (FRA) is expanding its focus from that of a regulatory agency to one more involved in promoting and funding innovative projects for reducing greenhouse gas (GHG) emissions in rail operations. From September 14–15, 2021, FRA conducted a virtual "Environmentally Sustainable Energy Technology Powering Future of Rail" workshop to engage and promote discussions among other Federal agencies, international government agencies, and the rail industry on decarbonization strategies for rail transportation. The workshop presented an opportunity for participants to share technical information on state-of-the-art of technologies, help identifying areas requiring future research and development, and provide various domestic and international perspectives. Recommendations generated throughout this workshop will inform the FRA research agenda on clean energy, emissions, and energy efficiency technology development.

The panels provided a broad overview of domestic and international approaches to alternative fuels, citing various degrees of success.

- Biodiesel and renewable diesel are considered an intermediate step in reducing overall emissions. Biodiesel use in railroad operations has been approved in limited applications by Progress Rail for certain types of locomotives. However, biodiesel is not carbon free. It will not eliminate GHG emissions but can lower net emissions per unit of energy used in railroad operations.
- Liquid or compressed natural gas (CNG) fuels have shown promise, especially with the construction and demonstration of a robust tender. While these fuels are viable and reduce GHGs compared to diesel, the cost of infrastructure required and interference with existing operations may be difficult to overcome. Safety is also a concern with the use of these fuels, though recent railroad pilot projects have shown that CNG and liquefied natural gas (LNG) can be safely used as locomotive fuels. Batteries for railroad applications have advanced beyond traditional lead-acid to lithium-ion chemistries, due to a precipitous drop in cost and increased energy storage density.
- Battery electric technologies have been embraced in Europe, with several hybrid-technology trains in operation, such as the Coradia iLint, which is powered by a combination of battery and hydrogen fuel cell technology.
- Batteries are an attractive option for implementation on passenger routes, yard switching and regional routes as a means of reducing rail transportation emissions and taking steps towards total decarbonization.
- Instituting enhanced safety standards, addressing concerns of, and developing appropriate technology and emergency response to potential fires caused by short-circuits in high energy density batteries will be essential prior to expanding the use of high-wattage batteries in rail services.
- A decade after a successful Burlington Northern Santa Fe Railway (BNSF) demonstration of a hydrogen fuel cell switch engine, this technology has advanced and is

being pursued by passenger rail operators both in the US and Europe. As with batteries, there are safety concerns with hydrogen fuel cell propulsion such as fuel flammability and gas accumulation. Smaller prototype operations of these energy technologies will help improve the technology for rail application and inform future projects, as fuel cells are considered by many as very applicable to long-distance routes.

Technologies of the past and future were also addressed in two presentations: the first discussed revitalizing the electrified Northeast Corridor in the US, while the second introduced a fledgling project working on generating electricity for locomotives via nuclear fuel.

The following topics and research areas were identified as challenges to implementing alternative fuels and energy sources on a larger scale:

- Widespread installation of refueling and recharging infrastructure to support new fuels
- Upfront capital cost for upgrading existing technology
- Establishing regulatory guidelines with greater flexibility for technology in the demonstration phase
- Scaling small demonstrations projects up to test feasibility at a commercial level

The workshop resulted in promising avenues for collaboration between FRA, other governmental US and overseas agencies, and private industry. Utilization of established alternative fuel types will likely vary by application and railroad requirements. Panelists and attendees focused on key areas such as addressing supporting improvements to remanufacturing technologies, increasing demonstration funding, and creating a decarbonization roadmap to guide research undertaken by the Federal government and the railroad industries.

Decarbonizing by 2050 will require extensive research into all alternative fuel options that may be viable for industrial scale applications, a large push towards ensuring proper infrastructure development, picking situation-specific solutions, and balancing environmental and public welfare with economic justice, stability, and growth.

1. Introduction

The Biden Administration has committed to reduce net greenhouse gas (GHG) emissions 50–52 percent below 2,005 levels by 2030**,** and net-zero by 2050. The U.S. Department of Transportation (DOT) is focused on ensuring America has the safest, most efficient, and modern transportation system in the world, which boosts our economic productivity and global competitiveness and enhances the quality of life in communities both rural and urban. The transportation sector is currently responsible for approximately 28 percent of GHG emissions in the United States and is expected to be one of the fastest growing sources of GHG emissions in the foreseeable future due to increased demand for motor gasoline, jet fuel, and diesel fuel. However, rail transportation only accounts for two percent of total GHG emissions (US Environmental Protection Agency, 2021).

In May 1999, DOT formed the Center for Climate Change and Environmental Forecasting (Center) to address issues associated with climate change and variability, and to play a leadership role in meeting these challenges. Through strategic partnerships and outreach, the Center creates comprehensive and multi-modal approaches to reduce transportation-related GHG and to mitigate the effects of global climate change on the transportation network.

The mission of the Federal Railroad Administration (FRA) is to enable the safe, reliable, and efficient movement of people and goods for a strong America, now and in the future. FRA supports research and development (R&D) of technologies that improve the efficiency of rail transportation and reduce emissions. Over the past two decades, FRA has worked with the railroad industry, other Federal agencies, and academia to advance state-of-the-art locomotive technology. Focusing on its core mission and the Biden Administration's goal for reducing GHG by 2050, FRA reached out to experts within the rail industry and energy sector, both nationally and internationally, to discuss current activities, planned future activities and lessons learned from past efforts related to use of alternative fuels and propulsion technologies. FRA held these discussions from September 14–15, 2021, in a virtual workshop.

1.1 Background

FRA convened the workshop to discuss rail application of clean fuel technologies, enhancing environmental protection, and improving environmental justice to affected communities. This workshop presented an opportunity for participants to share information and perspectives relating to the advancement of rail alternative energy technologies and carbon emission reduction.

1.2 Objectives

The workshop's purpose was to:

1. Discuss current knowledge on energy-efficient and alternative fuels, status of research on fuels and associated technologies, and opportunities in, and impediments to, alternative fuel use by the railroads
2. Promote safe, economical, and effective rail technologies for using clean fuels that enhance energy efficiency, reduce climate-harming emissions, minimize the effects on railroad workers and promote environmental justice

3. Develop actionable items for cooperative and non-duplicative technology research and project initiatives with international governmental counterparts and the rail industry

1.3 Overall Approach

The first day of the workshop focused on providing a review current research, sharing updates from recent or ongoing pilot projects, and gaining an international perspective of approaches embraced by rail systems abroad.

The second day focused on lessons learned from previous projects and how they inform the path forward. The second day also provided the perspective of rail operators and communities impacted by regulations and rail infrastructure.

Six technical sessions (24 total presentations) were held over the course of the 2-day workshop. Session topics were:

1. Alternative Fuels for Railroad Applications
2. Logistics of Fuel-Handling, Tankage, Fueling, Safety, Infrastructure, Network Integration and Rail Labor Organizations Concerns
3. Alternative Clean Fuels Technologies in Heavy-duty Transportation Sectors
4. Status of Specific Technologies for Rail Applications
5. Lessons Learned from Pilot Projects
6. Environmental Regulations, Environmental Justice and Related Issues

1.4 Organization of the Report

This report captures the workshop's discussion on current and future energy technologies for rail as it relates to combating climate change in Section 2. Each section includes an overview of presentations, summaries of panel discussions, and ways forward for the FRA in Section 3 and Section 4.

2. Day 1: Environmentally Sustainable Energy Technologies Powering Future of Rail

Day one of the workshop began with the Plenary Session. The Plenary Session featured remarks from the FRA Administrator, Associate Administrator for the FRA Office of Railroad Safety, FRA Directors of the Office of Research, Development and Technology (RD&T), and International Affairs as well as remarks from the Deputy Assistant Secretary of the U.S. Department of Energy (DOE). This session was moderated by Dr. Phani Raj, Engineer and Hazardous Materials Expert within the FRA Office of Railroad Safety, Division of Engineering, Technology & Automation.

2.1 Introductory Remarks

Dr. Phani Raj – Moderator
Dr. Phani Raj is a General Engineer in the Engineering Technology & Automation Division, Office of Railroad Safety at FRA.

The Plenary Session was moderated by Dr. Raj, who welcomed attendees and panelists to the FRA 2021 "Environmentally Sustainable Energy Technologies Powering Future of Rail" workshop. Before introducing the first speaker, Dr. Raj stated the objectives of the workshop as:

- Discuss the state of knowledge on current and future technologies and alternative fuels for use in rail operations
- Highlight opportunities and impediments to their use and research needed to overcome the difficulties
- Develop ideas and a roadmap for utilizing technology and clean fuels to enhance energy efficiency, reduce climate harming emissions, improve the safety of railroad workers, and promote environmental justice

The inaugural address, kicking off the workshop was given by the then FRA Deputy Administrator, Amitabha (Amit Bose), now the present Administrator.

Amit Bose, Administrator, FRA
Amit Bose serves as Administrator FRA (formerly Deputy Administrator). He previously served at FRA during the Obama-Biden Administration as Deputy Administrator, Chief Counsel, Senior Advisor and Director of Governmental Affairs and DOT as Associate General Counsel and Deputy Assistant Secretary for Governmental Affairs. In those positions, he worked on safety, policy, regulatory, and governmental affairs matters, and provided legal counsel, guidance and advice to the Office of the Secretary and DOT's operating administrations.

Mr. Amit Bose thanked the attendees and speakers for their participation in the workshop. He continued by saying this workshop is an effort by FRA to work with the railroad industry to tackle the climate crisis at home and abroad. President Biden issued Executive Order 14008 (Federal Register, 2021), and has resulted in FRA coordination with other government agencies. The railroad industry has already taken steps to address climate change; industry participants such as Wabtec, Cummins, Alstom, and Stadler have reached out to FRA on these issues. The Association of American Railroads (AAR) issued its Freight Railroad and Climate Change Report earlier this year (Association of American Railroads, 2021). Bringing about a rail

revolution of modern, zero emission equipment will allow the US to achieve its goal of net-zero carbon emissions by 2050. The historic Bipartisan Infrastructure Bill (H.R. 3684) will, if passed, make a significant investment in sustainable, resilient, and equitable infrastructure. This has the potential to change the entire transport landscape, spurring rail advancements while President Biden's Build Back Better Agenda will open avenues for job growth and economic expansion. The question of how rail can become the cleanest mode of transportation while further increasing its presence within the transportation sector will be one of the main considerations of this workshop.

Karl Alexy, Associate Administrator, Railroad Safety, FRA
Mr. John (Karl) Alexy is the Associate Administrator for Railroad Safety and Chief Safety Officer of FRA. In this role, Mr. Alexy manages FRA's regulatory oversight of rail safety in the United States and oversees the development and enforcement of regulations and safety programs for the freight and passenger rail industry.

Mr. Alexy stated that the broader mission of FRA is to ensure the safe and reliable movement of people and freight across the US. FRA focuses on ensuring the safety of railroad workers, passengers, and people who live near rail infrastructure. The Office of Railroad Safety supports the current Administration in its initiatives to reduce GHG emissions and minimize or eliminate carbon footprints from all rail operations. Several years ago, the Office of Railroad Safety implemented an alternative fuels program comprised of personnel from multiple safety disciplines, R&D, and the Office of Chief Counsel. Through this program, FRA initiates dialog with the rail industry as they develop, demonstrate, and deploy pilot projects related to alternative fuel technologies. To understand the challenges and risks associated with new technologies, the Office of Railroad Safety works closely with RD&T on research. Any new technology or fuel introduced into the system should not present higher risks to railroad workers or the general population. Full-scale tests of alternative fuel tender cars and tank cars used for transportation of energy commodities improve the design and standards for such equipment and streamline regulations. FRA works closely with the Pipeline and Hazardous Material Safety Administration in the development of regulations related to hazardous materials movement on rail and associated issues. FRA collaborates with the rail industry on development of standards for equipment storing on-board fuel. The Office of Railroad Safety created an Engineering, Technology and Automation division with the mission of working with the industry on the safe introduction of emerging technologies. There are many exciting prospects ahead, but they must be approached with care and consideration of human and environmental safety. This event helps FRA in its collaboration efforts and guide the rail industry safely into the next stage of transportation.

Maryam Allahyar Wyrick, Director, RD&T, FRA
Dr. Maryam Allahyar Wyrick is the Director of RD&T at FRA. Dr. Allahyar Wyrick has nearly 20 years of experience as a research scientist in academia, at the U.S. Department of Defense, the National Transportation Safety Board, and DOT.

Dr. Allahyar Wyrick provided participants a brief history of the FRA's RD&T and its collaboration with the DOE since 2009. As FRA shifts to prioritize funding alternative fuel research, they have strengthened their communication with other departments within DOT. RD&T is mobilizing to address the Administration's priorities and will focus funding on alternative fuels research and energy technologies. FRA has appointed people from the Office of Railroad Safety and the Office of Railroad Policy and Development to DOT Office of the

Secretary as subject matter experts on climate change, decarbonization and resiliency. Dr. Allahyar Wyrick closed by reiterating that RD&T is invested in the success of alternative fuel projects and looks forward to future collaborations.

Barbara Barr, Director, International Division, FRA
Barbara Barr is the Director of International Affairs and Policy at FRA. Her primary duties are to act as primary liaison with FRA international counterparts and is responsible for management of all international-related activities and initiatives while also representing DOT leadership at international forums.

Barbara Barr welcomed all international panelists and participants, emphasized the strong collaborative effort, and anticipated productive discussions. Despite the pandemic, FRA's international cooperation is better than ever. Events like this workshop enables us to share information with our global partners.

Michael Berube, Deputy Assistant Secretary, DOE
Michael Berube is the Deputy Assistant Secretary for Sustainable Transportation in the Office of Energy Efficiency and Renewable Energy (EERE). In this role, he oversees EERE's Sustainable Transportation sector, which includes the Vehicle, Hydrogen and Fuel Cell, and Bioenergy Technologies offices. This portfolio focuses on R&D to increase access to domestic, clean transportation fuels and improve the energy efficiency, convenience, and affordability of transporting people and goods to support U.S. energy security, economic productivity, and competitiveness.

Michael Berube stated that DOE is focusing on how to address the climate crisis upon us. The climate crisis timeline is not set by regulations or any laws, but by the environment. "If we don't take dramatic action now there wouldn't be time later [to act]." DOE manages approximately $1 billion in advanced R&D and deployment, focused on how to decarbonize the transportation sector. DOE has an overarching plan to work with DOT, the U.S. Environmental Protection Agency (EPA), and U.S. Department of Agriculture (USDA) to develop a comprehensive approach for decarbonizing the transportation sector to net zero by 2050. To this end, DOE has three large, focused, R&D programs: battery and electrification, hydrogen fuel cells, and biofuels. These areas show promise and excellent room for growth.

With DOE support over several decades, battery technology has been developed to the current state of the art technology. There has been a dramatic decrease in cost of batteries, increase in energy density of batteries, longevity of life, reduced charging time, etc.; however, there are still many opportunities for further advancement of battery technology. The US issued its first national battery strategy last year (Department of Energy, 2021), creating a roadmap with key R&D target areas to hit 500-Watt hours per kilogram (kg) and cost of $60 per kilowatt-hour (kWh). This density and cost are critically important for rail transportation applications. These goals will be realized through development of new technologies within the latter part of this decade. Steps will include designing batteries made from abundant earth elements and developing large scale lithium-ion recycling facilities. It is possible that advanced batteries will be made of up to 40 percent recycled batteries. This is a critical part of the supply chain strategy. The parts outlined are all needed to support wide-spread deployment of battery technology, especially in the transportation sector, so that reliance on petroleum energy sources is reduced or eliminated.

Hydrogen has gained global attention in the last decade. The field will increase its momentum following the recent announcement of the Energy Earth Shot, challenging researchers to find ways to produce 1 kg H_2 for $1 by the end of the decade. New avenues for the transportation sector's use of hydrogen will open if: 1.) hydrogen can be cheaply made (i.e., cost target of $1 per kg) from renewable/clean energy sources, where less than 1 kg of (carbon dioxide) CO_2 is emitted per kg of hydrogen produced, and 2.) the cost and durability of fuel cell technology advances. When considering the transportation of hydrogen and the associated costs, hydrogen application in the transportation sector makes more sense for centrally fueled vehicles, long-haul heavy-duty trucks, or rail. Utilizing locally generated power sources (e.g., solar or wind) coupled with local electrolyzers would limit or eliminate the need to transport hydrogen long distances. Rail presents an excellent opportunity for such deployment of hydrogen technology. The R&D work in hydrogen at the national labs is in the same state as it was 5–10 years ago on batteries. Many were skeptical about the capability of the battery and its applications. Hydrogen, as with battery, will have the same opportunity for widespread deployment and penetration into many industries.

Finally, DOE is focused on biofuels, high density liquid fuels sourced from renewable or waste carbon resources. DOE has worked on biofuel development and deployment for decades focusing on reducing cost. Steps have been taken to reduce the cost of renewable hydrocarbon fuel, comparable to cost reduction seen in the battery industry over the past decade; however, biofuel is still not competitive against diesel at this time. The US has available approximately one billion ton of waste biomass, municipal solid waste, biosolids from farms, etc. that can be used in economical pathways for conversion to fuel. With these available resources, sufficient fuel can be produced to power the entire aviation sector. DOE, DOT, and others are committed to fueling the aviation sector with 100 percent sustainable fuel. By 2030, the US will be able to produce 3 billion gallons of sustainable aviation fuel, 10 percent of the amount needed for 2050 sustainable goals. This presents a key opportunity for rail transportation because there will be 5-10 percent net-zero or low carbon fuel produced as by-products of the sustainable aviation fuel production. These net-zero or low carbon fuels will have great opportunities for use in sectors that are harder to electrify such as rail or marine. Every aspect of the transportation sector must be included for us to achieve the goals of net-zero by 2050.

Mr. Berube concluded by stating the DOE is eager to partner and collaborate closely with DOT going forward to advance the development and deployment of batteries, hydrogen, and biofuels.

2.2 Alternative Fuels for Railroad Applications

Dr. Phani Raj, FRA, Panel Moderator

The Alternative Fuels for Railroad Applications technical panel was moderated by Dr. Raj. The objectives of this technical panel were to:

1. Discuss, at a policy level, the need for railroads to use clean energy and decarbonization technologies
2. Highlight implementation and technical challenges including logistics, economics, infrastructure build up, public perceptions on safety
3. Identify possible solutions including research, funding sources, public outreach, cooperative ventures

2.2.1 Alternative Fuel Issues, Benefits, Regulations, and Challenges – U.S. Railroads Perspective

Robert Fronczak, AAR

Mr. Robert Fronczak holds the position of Assistant Vice President for Environment & Hazardous Materials at AAR in Washington, DC. His responsibilities include the development and coordination of railroad industry environmental policy.

Robert Fronczak focused on climate change as the driving force behind the exploration of alternative fuel use in rail. To this point, the AAR is investigating the benefits and constraints of using the following fuels: biofuels (i.e., specifically biodiesel and renewable diesel), natural gas (i.e., both liquid and compressed), and hydrogen.

Biofuels appear to be viable, temporary alternatives since switching to them would not require modifying infrastructure and would immediately offset emissions. Current biofuel production lags behind the railroad's fuel consumption, but the National Bio-Diesel Board (NBB) has identified facilities capable of producing an additional 8.3 billion gallons/year. Despite the potential surplus, these alternative biofuels are not as efficient and may require chemical additives to improve the fuel performance. Biodiesel utilization releases increased criteria pollutants, such as NOx. Another difficulty lies in locomotive manufacturers limiting the quantities of biodiesel that can be used at present. While Progress Rail has approved use of 100 percent renewable diesel in its locomotives as well as biodiesel in blends up to 20 percent in certain Union Pacific locomotives, it will take time to implement these changes. Ultimately, using hydrocarbon biofuels still contributes to GHG emissions and is not a permanent solution.

Natural gas, while advantageous for its reduced GHG emissions, also comes with complications. Both compressed natural gas (CNG) and liquefied natural gas (LNG) prove difficult as they require specialized tenders and can pose significant safety hazards to rail workers (e.g., LNG's liquification temperature). Since 2012, the AAR's Natural Gas Fuel Tender Technical Advisory Group has been developing tender specifications and standards that will allow use of CNG and LNG by rail; more data will be acquired following an FRA tender impact test on September 22, 2021. Finally, Burlington Northern Santa Fe Railway's (BNSF) test of a battery-powered line-haul locomotive, in conjunction with Wabtec and the San Joaquin Valley Air Quality Management District, saw decreases in fuel consumption by 11 percent on average.

Using hydrogen fuel cell technology would eliminate all GHG and criteria pollutant emissions, provided the hydrogen comes from a "green" source. As with LNG, there are similar disadvantages to using hydrogen including problems with leak detection, fuel delivery, and storage temperatures. Additionally, the electricity generated by the fuel cell must be stored in on-board batteries. BNSF conducted tests of a hydrogen fuel cell (HFC) locomotive in 2008–2009. Further developments in the field have led to Canada Pacific Railroad (CP) contracting with Ballard Power Systems for six 200-kilowatt fuel cell systems for use of battery-fuel cell hybrid locomotives.

Multiple partnerships (e.g., Wabtec and General Motors [GM]) are expected to further battery and fuel cell advancements. The AAR Locomotive Committee is collaborating with manufacturers, subject matter experts, etc. in developing charging standards for battery powered locomotives. Finally, although the majority of emissions come from locomotives, rail yard

equipment such as cranes and hostlers should also be redesigned (e.g., switched to electric or LNG) to further reduce overall emissions.

2.2.2 Passenger Railroad Perspective on Alternate Fuel Use Alternative propulsion technology in passenger rail (APTA)

Narayana Sundaram, American Public Transportation Association (APTA)

Narayana Sundaram is Senior Director of Engineering and Commuter Rail Operations at APTA. In this role, Narayana's staff advises various commuter rail committees including the commuter rail CEOs Committee. He is also responsible for all regulatory engagement for APTA's commuter and intercity railroads as is the lead for the APTA contingent on FRA's Rail Safety Advisory Committee (RSAC). Narayana led the APTA efforts on the full industry wide implementation of Positive Train Control (PTC) for the commuter rail industry. Narayana manages APTA's Standards program which has developed more than 310 standards and recommended practices.

Narayana focused on the interest of passenger rail industry in terms of alternative energy for propulsion. Currently, batteries and hydrogen fuel cells are the most common alternative propulsion technologies found in passenger rail; alternatives such as hydrogen combustion or natural gas are rare. Passenger rail primarily makes use of lithium-ion (and similar lithium-based chemistries) batteries while continuing to explore advancements in other industries, such as the lithium solid-state battery. Batteries also play a key role in using hydrogen fuel cells by storing and managing the produced energy.

With the wide variety of passenger rail projects underway through Alstom, Siemens, Stadler, etc., APTA is looking towards introducing an industry-wide Alternative Propulsion Safety Standard. This is slated for introduction by mid-2025 and will require multiple steps, beginning with consolidating safety issues on the industry's side as well as leveraging best practices already in place internationally.

Examples of critical safety issues include, but are not limited to:

- Managing uncontrolled combustion (battery-specific)
- Preventing leaks/accumulations of gas (hydrogen-specific)
- Protecting energy systems in case of derailment, fire, etc. (vehicle-specific)
- Maintaining minimum safety operations over the equipment's lifetime
- Proper disposal or recycling of components

Receiving input from stakeholders will allow APTA to continue developing an industry standard for battery- and hydrogen-powered vehicles with the goal of providing Recommended Practices by the third quarter of 2022 and the final Safety Standard in the third quarter of 2025.

2.2.3 Technologies in Use and Public Acceptance in Europe

Carlo Borghini, Shift2Rail/EU

Carlo Borghini was appointed Executive Director of the Shift2Rail Joint Undertaking in February 2016 for a 5-year mandate. He is responsible for the overall management of the

Shift2Rail Joint Undertaking activities and will be entrusted with the new rail research and innovation partnership.

Carlo Borghini presented on Shift2Rail, a program jointly funded by the European Union and rail sector, and its crucial initiatives related to alternative fuels for railroad applications. Shift2Rail is one of the largest programs for rail research and innovation, with €1 billion committed in resources. The second generation of activities will start soon, continuing through 2031 with funding up to €1.2 billion. Despite rail being one of the cleanest modes of transport in Europe, reaching the goal of a carbon neutral continent by 2050 will require reducing transportation emissions by 90 percent through integrating alternative fuel sources and modifying infrastructure. Also, despite high electrification across the European rail network (upwards of 55 percent), further track electrification is not always feasible. New technology innovation that supports smart, sustainable mobility also supports a circular economy via the systems approach that Shift2Rail employs.

Improvements in vehicle consumption, energy storage capacity, low carbon propulsion systems, hydrogen, and batteries are key solutions to replacing diesel engine technology. Hydrogen and battery technologies are deployed when electrification is not possible or when it is not sustainable. There are risks and gaps in these undertakings because Shift2Rail and the future Europe's Rail are focused on the core business of the rail system and are dependent on solutions coming from other sectors and sister agencies—specifically from clean hydrogen and battery alliances currently developing technology that can be applied to rail in the future. Even then, implementation does not always go smoothly as technologies are transferred between sectors.

Shift2Rail sometimes takes a "series approach" to innovation, focusing on demonstration and integration of one piece versus tackling an entire system. This has led to appreciating the practicality of hybrid solutions—that is, combining batteries with electricity or diesel, respectively, in the rail system. Further development is needed at a European level, however, when the cost and competitiveness of hydrogen and batteries (i.e., with or without diesel engines) are considered. Shift2Rail is working to improve the technical, environmental, and circular economy of alternative fuels and energy solutions for rail rolling stock. To this end, Shift2Rail will take a systematic approach to developing and demonstrating more efficient and independently powered vehicle(s), recharging and refueling interfaces, and infrastructure, thereby accelerating the full decarbonization of the rail system. Rail is a key player in reducing Europe's mobility and transportation carbon footprint. Achieving the target reduction in GHG will require a fundamental change to the way rail systems operate. The European Railway Traffic Management System (ERTMS) and second generation ERTMS are key to improving efficiency in rail operations along with alternative fuels and batteries. Additionally, Shift2Rail's sister agency, the Clean Hydrogen Joint Undertaking, is developing the infrastructure and business case for hydrogen while Shift2Rail focuses on developing the demonstration technology.

Engine hybridization (i.e., battery/diesel, battery/electric) will likely play a large role in expanding and providing sufficient coverage across Europe's network—and certainly until hydrogen and battery performance improve and these technologies become more cost-effective. In the interim, automated controls may also help reduce emissions. Finally, decarbonizing and promoting alternative fuels within other transport sectors will be a boon for rail, since rail would not be the only branch investing in recharging/refueling infrastructure.

Pursuing hybrid and alternative fuel options will allow rail to increase its transportation role by reclaiming abandoned track, expanding the overall network, and contributing to a circular economy. To date, only one hydrogen train project has been demonstrated under real-world conditions: the Coradia-iLint trainset operating on a line in Germany. However, this is only a single data point compared to the system-wide change that will be needed. More projects like this will inform the larger changes required for Europe to succeed in becoming a zero-emission continent by 2050.

2.2.4 View from Mexico

David Camacho Alcocer, Agencia Reguladora Del Transporte Ferroviario (ARTF), Mexico

David Camacho Alcocer stated that Mexico's ARTF was created in 2016 to promote and monitor the construction, maintenance, and operation of railway infrastructure and the public railway transport. Simultaneously, the country seeks to optimize its existing railway network without excessively disrupting current freight and passenger operations. To achieve this, a Grand Vision Study of the Mexican Railway System (MRS) has been laid out, methodically creating a 50-year public policy that will guide the analysis and strategic expansion of mixed rail services. The two primary goals are to increase ground freight transportation from 25 to 40 percent in the future, with similar increases in passenger services—both will require carefully considering GHG emissions.

Transportation comprises 25 percent of Mexico's total GHG emissions, of which rail contributes 0.4 percent. Based on road versus rail efficiency comparisons, switching to rail has the benefit of reducing the overall emissions. Huge opportunities exist to increase both freight and passenger rail (e.g., 56.3 percent of freight and 95.4 percent of passengers moved by road in 2019). Strictly examining efficiency, rail in Mexico is already 6.75 times more efficient per ton-kilometer moved, and 4.4 times more efficient per ton than road transport. At this time, road transportation produces 664,000 tons CO_2 per year while rail transportation only emits 18,960 tons CO_2; annually, $89 billion of freight is moved by rail, which comprises 12.8 percent of total freight moved. From a macroeconomic perspective, shifting to rail has additional implications for accident rates, environmental degradation (e.g., soil erosion and deforestation) and ambient noise, as well as fuel efficiency and consumption. The agency's ultimate approach is shifting to rail before addressing technological improvements. At present, it is not economically feasible to electrify most of the rail system, nor will installing catenary result in immediate GHG reduction Therefore, expansion will rely on diesel or diesel-electric hybrid technologies.

In the interim, ARTF's strategy for reducing CO_2 includes shifting to rail transportation, improving existing rail infrastructure, replacing inefficient modes of transport, and optimizing operations (e.g., altering scheduling, and improving signaling and control systems). Projects geared towards reducing CO_2 range from broader cost-benefit analyses of shifting to rail (e.g., incorporating costs of accidents, road maintenance, and automobile emissions) to developing a carbon footprint calculator specifically for rail transport. Advancements in materials and alternative fuel technologies would be monitored and prospectively implemented in the future.

2.2.5 Europe's Approach and Commitments

Peter Mihm, European Union Agency for Railways (ERA)

Peter Mihm is a team leader at the ERA. Mr. Mihm is an engineer and certified railway inspector. He is a project manager of international projects and activities at ERA. Peter has 40 years of railway experience, including 20 years as manager at Deutsch Bahn AG and more than 15 years at the ERA. He is recognized as an expert in various areas of railway technology as well as in railway safety and operations.

Peter Mihm and his colleagues, Idriss Pagand and Sara Bizzotto, discussed the ERA's aims to help establish a single European railway area, guaranteeing operations follow stringent safety protocols and encouraging interoperability across railway systems. Following a European Union white paper published in 2011, rail is expected to aid in the drastic reduction of GHG and criteria pollutant emissions by 2050 (e.g., high-speed rail outpacing aviation for long-distance trips, or shifting over 50 percent of long-distance road-based freight to rail).

In 2019, the European Commission (EC) presented the European Green Deal, which included the following targets for transportation by 2030:

- Reduce GHG emissions by 40 percent (up to 55 percent) when compared to 1990 levels
- Renewable energy should comprise 32 percent of total fuels used
- Energy efficiency should be improved by 32.5 percent

It should be noted that the impact of COVID-19 on freight transport provided valuable insights. Despite an overall drop in GHG emissions across all sectors (6 percent)—which will be needed again in 2022 to limit climate change to 1.5 °C—rail saw an increase in amount of freight moved.

Promoting rail freight will require a multimodal strategy that embraces new technologies and focuses on customers, while presenting a modernized and even playing field between transport sectors. This will allow rail to increase its competitiveness with road transport. Recent innovations that are being pursued are ones involving digitalization (e.g., ERTMS, automated coupling, automatic train operation, etc.), which will help increase rail's capacity and efficiency. Future developments included promoting intermodal transportation, establishing hubs for greater interaction between sea and rail transport, and addressing the "last mile" challenge of transport in places where electrification is not possible. To focus on customers, recommendations for further steps included standardizing timetables and revive single wagonload transport to increase productivity and flexibility in shipping. Finally, the Agency seeks to ensure coordination between stakeholders and monitor the sector's decarbonizing efforts (e.g., publicizing an environmental transport label).

2.2.6 Q&A Panel Discussion

The initial discussion focused on the true emissions of all pollutants in the production of biodiesel and LNG and whether it was the best possible solution. Biodiesel production can potentially have a negative impact on land use and biodiversity. More studies are needed to truly assess the total lifecycle environmental impact of producing biofuels. Safety issues and public perception of other alternative fuels, such as natural gas and hydrogen as well as managing such expectations, were also discussed. The audience discussed strategies railroads could undertake as

they transition to clean energy technologies to ensure continuity of operation. Appropriate tests and demonstrations are needed before widespread implementation of any new technology. A stark difference in approach was seen internationally and domestically, with Mr. Sundaram and Mr. Camacho advocating for an incremental approach towards adopting new technologies and Mr. Borghini calling for quick action. Mr. Sundaram cited public resistance towards certain alternative fuels and technologies as a reason for slower introductions. Mr. Camacho spoke about the lack of electrification of Mexico's network as well as safety concerns. Building out Mexico's rail electrification infrastructure is less feasible than continuing to slowly expand into the alternative fuel realm, and their record of derailments (which is 10 times that of the U.S. in terms of tons/kilometer moved) is also cause for concern if they move too quickly. Mr. Borghini countered, expressing public perceptions can change faster, as was seen within the last 18 months in Europe. He emphasized that moving quickly does not mean failing to comply with safety regulations, but time is of the essence.

2.3 Logistics of Fuel-Handling, Tankage, Fueling, Safety, Infrastructure, Network Integration, and Labor's Concerns

Steve Clay, FRA, Panel Moderator

Steve Clay has worked for FRA since April 2004 and has served in various capacities within the agency. As a key member of the FRA Motive Power & Equipment (MP&E) compliance enforcement team, Steve provides Code of Federal Regulation (CFR) training and guidance to field inspectors and specialists throughout the MP&E discipline workforce. Within the past 8 years, Mr. Clay has been an active member of several newer technology projects to include dual-fuel locomotive (LNG/CNG) implementation, the introduction of battery locomotive technology, and more recently the hydrogen fuel cell technology being implemented in the rail industry.

To begin the technical panel discussion, Mr. Clay stated the objectives:

1. Discuss on board and supply fuel tank sizes, fuel safety to railroad workers and the public in accident conditions and review Labor's concerns on safety and operations
2. Elaborate issues of fuel supply logistics and infrastructure technical challenges, price of fuel and other costs
3. Highlight the challenges of integrating new technologies, and avoiding duplication of efforts, in current operations without disruption

2.3.1 Safety Issues in Handling and Use of Alternative Fuels

Benjamin Schroeder, Sandia National Laboratories (SNL)

Benjamin Schroeder is a staff member at SNL studying verification, validation, and uncertainty quantification topics to improve the underlying credibility of computational simulation-based evidence. Since spring 2021, Ben has been a member of the Fire, Risk, and Transportation Systems department at SNL which has contributed to a variety of hydrogen safety related projects including rail crash risk analyses, designing hydrogen nodes for port applications, and deploying reduced order models for the risk analysis software HyRAM.

Benjamin Schroeder focused on safety issues in handling and use of hydrogen as a fuel. He began by reviewing SNLs' Hydrogen and Fuel Cells Research Program, which provides a

scientific basis for materials needed for the production, storage, and use of hydrogen as well as the development of safety standards surrounding the fuel source.

Sandia's approach for analysis of hydrogen safety is divided into three areas of research activities: behavioral R&D, risk R&D, and the application in Safety Codes and Standards (SCS). The behavioral R&D seeks to find an accurate understanding and modeling of some fundamental physical phenomena such as flames, plumes, and leaks. Risk R&D focuses on the development of models and algorithms for consistent traceable repeatable and rigorous quantitative risk assessments. Tools such as HyRAM were developed as a result of risk R&D activities. Knowledge gained from the behavioral R&D and risk R&D is applied to real applications and SCS are refined. Recent assessments have included quantifying ventilation requirements following a hydrogen leak and a modeled tunnel fire necessary for determining use of hydrogen in road vehicles.

In support of DOE's H2@Scale project, Sandia's studied the rapidly developing hydrogen economy and found that multiple Federal, State, and local entities are interested in regulating aspects of the process, such as transportation, production, storage, and distribution. Stark differences between existing hydrogen regulations were also noted, leading Sandia to identify gaps in jurisdictions and highlight opportunities for Federal agencies to coordinate on future developments of hydrogen regulations, possibly starting with existing natural gas standards as frameworks.

Previous research for FRA reviewed existing codes and standards that may be applicable for hydrogen applications in rail. While a good starting point, AAR's natural gas fuel tender standard is not directly applicable to hydrogen due to differences between the two fuels, such as lower storage temperatures, gaseous escape versus liquid pooling, and densities requiring higher fuel rates for fast-fueling situations. Review of the National Fire Protection Association's (NFPA) Hydrogen Technologies Code, NFPA 2 for application to hydrogen refueling revealed current bulk storage limits are far below the amounts needed to run intensive rail operations in the future, and no outdoor, nonpublic liquid or gaseous refueling standard currently exists.

The program's current projects for FRA are examining these four components pertinent to safety of hydrogen in rail applications:

- Assessing post-crash outcomes in hydrogen locomotives (i.e., both freight and passenger) via data mining of previous locomotive incidents
- Generating emergency response recommendations for potential crash scenarios
- Developing best-practices for human safety during refueling
- Addressing concerns and determining scenarios where hydrogen embrittlement of equipment may occur

2.3.2 New Fuel Risks and Perceptions by Public and Railroad Workers

Michael Fore, AAR

Michael Fore has worked for the AAR for 28 years, starting in 1993 as a mainframe and database programmer working with the ICC Carload Waybill Sample project. Mr. Fore manages the Locomotive Committee and the Locomotive Repair Billing and Interchange Rules Technical Advisory Group.

Michael Fore stated that key aspects of rail infrastructure need to be examined as agencies take steps towards using alternative fuels. With respect to onboard fuel supply, tank size and standards, fuels such as biofuels and natural gas have existing guidelines; battery locomotives and hydrogen, however, are still in developmental stages with multiple organizations (e.g., FRA, AAR, and Transport-Canada) working on joint projects. The AAR expects to receive feedback on standard development from the Locomotive Maintenance Officers Association (LMOA) on renewable fuels. Ongoing projects involving standards development for battery powered locomotives include an AAR/Wabtec task force examining yard and stationary charging, with safety concerns taking priority. The AAR published CNG and LNG fuel tender standards in June 2021 that could be applied to hydrogen once key issues, such as material embrittlement and low liquid temperatures, are addressed (Association of American Railroads, 2021).

While using biofuels presents few infrastructure challenges, their availability can depend on regions or usage restrictions. Usage of CNG/LNG is minimal at this time; more data will become available as more companies consider this fuel. As with biofuels, the total cost of ownership of a battery powered unit varies by region, although innovative charging solutions may increase its viability. Europe has made strides with hydrogen technology while it remains in its infancy in the U.S. Taking the opportunity to learn from these earlier experiments and designs should allow U.S. companies to gain ground and help further the field. For example, using hydrogen in passenger rail could jumpstart the hydrogen economy overall, especially if multimodal recharging stations are introduced.

The common challenge with all renewable energies is ensuring a consistent and on-demand supply. Insufficient production/distribution networks and infrastructure cyber security are large-scale concerns that will need to be addressed while alternative fuels, as well as their effects on engines and equipment, are assessed and standards created. Given the long lifespan of rail equipment, it is likely that renewable fuel demand will exceed supply, and railroads should approach tests and modeling with this gap in mind. This recommendation comes following an LMOA paper for the Canadian National Railway that will be discussed in full during the fall 2021 Convention.

Next steps for the AAR include:

- Work with their members in the recently formed Working Group to coordinate efforts
- Data mine information on current and previous alternative fuels and propulsion technology studies
- Assist in the development of new test plans and initiation of pilot studies where informational gaps exist
- Monitor existing studies related to decarbonization efforts
- Develop standards and best practices related to adoption of new technologies

AAR Locomotive Committee is partnering with the AAR Railroad Electronics Standards Committee and AAR Operating Practices Committee and seeking input from FRA and LMOA on ongoing projects relating to alternative fuels and propulsion technologies.

2.3.3 Q&A Panel Discussion

The question and answer (Q&A) panel discussion started by recognizing that although alternative fuel tests have been successful from a technology standpoint, railroads have not pursued these avenues due to the economic reality (e.g., further electrification of U.S. track is prohibitively expensive). The question is, how can FRA motivate and encourage the transition to clean energy technology without national policies requiring the transition or the possibility of financial assistance? Proactively strategizing to develop standards and best practices, help the industry innovate and get ahead of impending regulations while helping to ensure that rail plays a greater role in shaping its future direction.

In terms of high priority areas where government organizations can collaborate with industry, Mr. Fore suggested taking a close look at hydrogen and long-term energy storage solutions. Current projects will inform the roadmap being drafted by the Locomotive Committee and it is expected that the larger picture will be clearer in the coming year as to which directions railroads will pursue.

Dr. Schroeder stated that the biggest challenge from science's perspective is the lack of data regarding these new systems. Using information gleaned from other fuels is applicable to a point; beyond that, the level of uncertainty becomes too great.

Cooperation between agencies to ensure the applicability of technologies to both freight and passenger rail was welcomed. Although no cooperative agreement is currently planned, past collaborations have included projects like developing LED lighting standards across the industry. APTA in particular is keen on collaborating with other groups on hydrogen research and creating recommended practices.

There was a question on whether the authorization to transport hydrogen by rail could potentially delay the switch to that resource. Mr. Fronczak and Dr. Raj emphasized that although hydrogen is already authorized for transportation, the shift into using it as a fuel source has been slow. This can change once specific technologies are adapted and extensive safety trainings are led for first responders and should lead to greater public acceptance of the fuel source.

2.4 Alternative Clean Fuels Technologies in Heavy-duty Transportation Sectors

Melissa Shurland, FRA, Panel Moderator

This panel was moderated by Melissa Shurland. Ms. Shurland is a Program Manager in FRA RD&T Rolling Stock Research Division. Ms. Shurland's research area focuses on alternative fuels and engine efficiency technologies research.

At the start of the panel, Ms. Shurland outlined the objectives of the technical panel as:

1. Discuss specific characteristics of each mode of transportation, and types of alternative fuels that are suitable
2. Present implementation challenges for each type of application (i.e., technology limitation, fuel & emission reduction costs, on board fuel carriage, etc.)
3. Compare current technology applications in different parts of US, and in other countries

2.4.1 Rail Sector, Global (Europe, Asia, and Australia)

Philippe Stefanos, International Union of Railways (UIC)

Philippe Stefanos is now a Sustainability Advisor in UIC, the International Railway Association. Mr. Stefanos is dedicated to advancing the Energy Efficiency and CO_2 Emissions Sector under UIC's Sustainability Platform. Among these missions and projects, Mr. Stefanos organized "best practice workshops" for railway community stakeholders that develop solutions for energy efficiency improvement and decarbonization.

Philippe Stefanos talked about the outcomes of the latest best practices' workshops related to energy efficiency and emissions. The UIC has 200 members around the world, supporting and driving projects for global cooperation in rail advancement. The following conclusions from three of UIC's yearly workshops are summarized in this section. The workshops specifically covered the decarbonization of freight trains, and the potential of hydrogen and battery trains. A workshop on trackside energy storage is planned for October 7, 2021.

Overall, the freight train workshop called for targeted, efficient monitoring of existing rail infrastructure to ensure updates were appropriate and not redundant. Replacing locomotives will be a long-term process given the equipment's lifespan, although this may allow for in-depth consideration of the units (i.e., hybrid or fully alternative) best suited for specific operators. Furthermore, service providers and suppliers should be incentivized more—an area where policy and enforcement could play a role. The greatest challenge lies in selecting the best technology while crafting standards and technical requirements that are comparable between networks.

With regard to hydrogen fuel cell trains, the consensus remained that further research should be supported, and technical and safety standards will need to be created. Hydrogen fueled trains can become a viable alternative to diesel provided the hydrogen is made through electrolysis and would be well-suited to the US network given the long distances and lack of electrification. Test routes that could further the development and integration of HFC trains should be selected from the following types: rarely used routes, long-distance trips, and routes requiring little downtime for engines. Proof of concept tests have been promising, indicating hydrogen fuel cell systems are capable of operating equally well under the same conditions as diesel engines. Deployment of Alstom's Coradia iLint unit in Germany have led to an anticipated rollout of over 40 trains across Europe by 2022.

As with hydrogen fuel cell trains, the applicability of battery-powered trains will be dependent on battery capacity as well as the range and speeds of routes. There are many options for implementing battery trains, especially in regions where track is electrified and on short-distance routes. Given Europe's established electrified infrastructure, French railway Société Nationale des Chemins de Fer Français (SNCF) estimated over 80 percent of its short-distance lines could be served by battery electric multiple units (EMU). Eaton presented work hybridizing supercapacitors with lithium-ion batteries, improving brake energy recovery and facilitating faster charging. Although energy storage technology improvements are necessary before battery-powered trains become more commonplace, this approach can be cost-effective where electrification or high demand on the energy grid are key considerations.

2.4.2 Commercial Marine Sector

Daniel Yuska, Maritime Administration (MARAD)

Daniel Yuska has served as an Environmental Protection Specialist with the MARAD's Office of Environment since 2002. Mr. Yuska helped to develop the Maritime Environmental and Technical Assistance (META) program and leads environmental research and policy focused on vessel and port emissions reductions, energy efficiency, and alternative fuels and technologies.

Daniel Yuska stated that reducing and mitigating GHG emissions within the maritime transportation sector is exceedingly difficult. Despite being one of the most efficient modes of transport per cargo ton carried, the diversity of vehicles covered by this sector (e.g., oceangoing vessels, harbor craft, and port equipment) requires diligence when selecting an appropriate fuel alternative. The merging of land and sea at ports adds a multimodal aspect, too, since trucks and trains are crucial for transporting cargo inland. As such, MARAD has remained "fuel neutral," recognizing that one fuel type is not suitable for all situations. All current and future fuels MARAD select are or will need to be readily available, safe, cost-effective, and strike an acceptable balance between cargo versus fuel carriage space.

The META program started in 2010 to fill a gap in Federal research into alternative fuels within the maritime sector. This program investigates, demonstrates, and gathers data relating primarily to GHG and criteria pollutant reduction, alternative fuels, and existing energy efficiency. META's work, in collaboration with government agencies, industry shareholders, etc., provides insight into effective technologies/approaches, thereby informing evolving guidelines.

Having previously considered LNG, MARAD has since rejected this fuel due to total lifecycle emissions. Future projects include researching methanol and ammonia, the latter requiring rigorous safety protocols. MARAD has also partnered with the DOE to examine the feasibility of fuel cells and hydrogen aboard ships. While it is unlikely that main onboard propulsion will come from hydrogen, trials with small fuel cells have been successful in providing shore power and could be applied to other port operations. Also, changes need not be solely focused on fuel type when thinking about emissions. Hull design and vessel routes alone can impact energy efficiency, which can reduce overall emissions, regardless of switching fuels. A multi-pronged approach incorporating fuel types, new technologies, and energy-efficient plans will be best.

The future challenges include fuel energy density (i.e., currently less than half the energy density of diesel) and the ability to refuel/recharge at all ports. Notably, electrifying ports is as important as it is challenging considering the involvement of port authorities and utility companies, the local grid's capabilities, and higher costs during peak hours.

Moving forward, the U.S. aims to decarbonize; to do so effectively *all* transportation sectors should be considered. Ports are multimodal by design and the interaction between surface transport modes at these hubs makes further collaborations between MARAD, FRA, and other DOT departments.

2.4.3 Development of International Standards for Shipboard Hydrogen Fuel Cell Powered Systems

Timothy Meyers, U.S. Coast Guard (USCG)

Timothy Meyers is part of the USCG Office of Design and Engineering Standards group. Mr. Meyers' duties are focused on development of policy standards and regulations for the safety and safe design of commercial vessel systems.

Timothy Meyers focused on development of international standards for shipboard hydrogen fuel cell power systems. Mr. Meyers stated that while hydrogen and fuel cells are gaining momentum as alternative fuel sources able to meet maritime emission control requirements, one hurdle to their acceptance lies in securing regulatory approval. The framework provided by international standards for ships powered (in part or wholly) by gases, such as LNG, may lead to faster implementation of the technology. Using this framework, the USCG Design Standards Office aims to move forward with creating guidelines for hydrogen fuel cell vessels. The International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF) was finalized and adopted in June of 2015 and went into force on the first of January 2017. It is an international standard prescriptively written for safety design of natural gas fueled vessels. The IGF scope has broader application than natural gas; it is applicable to other low flashpoint fuels, alternative fuels that have been discussed thus far: hydrogen, methanol, as well as ammonia. For natural gas-fueled vessels, it is prescriptive but for other low-flashpoint fuels there are other ways to address safety and safe design of vessels using these other fuels.

The USCG intends to use the IGF framework and apply it to U.S. hydrogen vessel projects. They propose adapting the existing code, exchanging requirements written for natural gas with those specific to hydrogen—for example, substituting the American Society of Mechanical Engineers' (ASME) hydrogen piping standard 831.12 into the guidelines. Although current Federal regulations do not address hydrogen or hydrogen fuel cell vessels, the framework can be used to establish an equivalency to design standards described in Title 46 of the CFR. This could then be applied to vessels on a case-by-case basis, guiding the USCG's approval process and vessel inspections. To date, the USCG has taken this approach with one HFC passenger vessel under final construction on the west coast.

2.4.4 Rail (Freight and Passenger) in Canada

Ben Chursinoff, Railroad Association of Canada (RAC)

Ben Chursinoff is a Policy Analyst and Program Coordinator with RAC. Mr. Chursinoff works to advance RAC members' needs and concerns with Federal officials at all levels and across departments. He coordinates the RAC's environment committee, safety culture improvement initiative and works closely with the Federation of Canadian Municipalities on the Proximity Initiative.

The RAC advocates on behalf of industry to ensure safe working and transportation environments. Rail contributes significantly to Canada's overall economy, moving approximately 100 million passengers and $320 billion in goods annually. Approximately 30 percent of Canada's 2019 GHG emissions came from transportation; rail contributed 3.5 percent to this total, despite moving 44 percent of the country's freight. It is anticipated that freight will outpace passenger transportation by 2030, but this increased shift to rail will result in reduced

emissions overall due to rail's higher efficiency. Since 1990, freight GHG emission intensity has been reduced by 45 percent, and passenger by 37 percent, through consistent locomotive upgrades and improving technology. Further reductions will require significant measures. In response, the government is implementing a clean fuel standard to assist in transitioning to low carbon and eventually net zero options.

In partnership with the government, the RAC has launched the Rail Pathways Initiative. This two-phase program aims to guide the future decarbonization of the rail sector. The Phase I initiative was undertaken by RAC, its members, Transport Canada, Environment and Climate Change Canada, and Natural Resources Canada. The specific objectives were:

- Develop a common understanding of the current state of rail sector decarbonization in Canada, which can be used as a tool for collaboration between industry and government
- Create a repository for current Federal, provincial and territorial GHG reduction legislative instruments and activities impacting the rail sector
- Contribute to the next-phase work on a roadmap to achieving future GHG reductions in Canada's rail sector

This Phase I report, Rail Pathways Initiatives, Phase I: Landscape Document, has been instrumental in mapping next steps for GHG reduction (Delphi Group & Pollution Probe, 2020). The RAC determined true decarbonization will occur in waves, with short-term improvements in efficiency, followed by further integration of biofuel blends (i.e., medium-term), and finally, increasing electrification (i.e., long-term). As with the maritime sector, solutions will be unique to different railroads. The Phase II effort, a rail decarbonization roadmap, is underway and will include surveying the technical, social, and economic factors linked with decarbonization options. The data gathered will inform industry direction and government policy by educating legislators. An assessment tool that evaluates cost, decarbonization potential, commercial readiness, challenges of potential technology has been created to compare alternative fuels more easily within similar stages of development. Assessments were conducted on B20 biodiesel, hydrogen, battery electric, catenary electric and hydrogenation derived renewable diesel. Natural gas was not included because the focus is to move away from petroleum fuels. Assessments will be done frequently using the most up-to-date information to inform stakeholder strategy and rapidly introduce industry and government initiatives.

Mr. Chursinoff concluded by reviewing ongoing projects including CP's retrofitted line haul hydrogen-powered locomotive scheduled to test in 2022, and the joint Southern Railway of British Columbia/University of British Columbia's School of Engineering venture converting a switcher locomotive to run as a hydrogen-electric unit. These pilot projects may have a social impact as well by reducing GHGs and criteria pollutants in residential areas. Transport Canada has modeled the transition from diesel to hydrogen, emphasizing cost estimates based on aggressive rollout timelines. Given the continental integration of rail between the U.S. and Canada, a joint initiative between the countries may help advance this transition. These new partnership opportunities deviate from the typical development pathway between OEM and railways and could be key in achieving these emission goals.

2.4.5 Q&A Panel Discussion

Initial questions and discussion focused on USCG involvement in hydrogen vessel construction. Timothy Meyers clarified that the USCG regulates safety from both an operational and design point; for vessels with innovative technologies not addressed by the CFR, the USCG works with applicants to create equivalent safety standards for certification. The IGF code's framework has been beneficial in this regard. As further technology improvements are made, it is likely that the IGF code will also begin addressing fuel cells and accompanying feed fuels.

Multiple panelists addressed how the lifespan of locomotives impact emission reduction strategies. Some railways will have the capital to repeatedly invest in new locomotives, while others will opt for retrofitting one engine at a time based on financial constraints. With locomotives operating between 30–50 years, there are also opportunities for Class I railroads to upgrade and pass older units to lower-tiered operators who can retrofit them.

2.5 Status of Specific Technologies for Rail Application

Steve Clay, FRA, Panel Moderator

Mr. Steve Clay moderated this technical panel discussion and outlined the objectives of the discussions as:

1) Discuss current different applicable technologies, their current state of readiness for revenue application, impediments, resource limitations, etc.
2) Highlight research activities and time horizons for industrial scale implementation
3) Compare and contrast between new and mature technologies, their advantages, limitations, applicable geographical areas, public acceptance, etc.

2.5.1 Hydrogen Fuel Cell

Pete Devlin, DOE

Pete Devlin is the Technology Development and Intergovernmental Coordination Manager for the DOE Hydrogen and Fuel Cell Technologies Office (HFCTO) and works on hydrogen and fuel cell technology research and provides support to government agencies in their technology development and deployment activities. Specific areas of focus recently include rail, marine and aviation applications.

Pete Devlin gave DOE's perspective and activities on hydrogen and fuel cells. DOE's H2@Scale research activities are focused on decarbonization and economic growth surrounding hydrogen and fuel cell technologies. H2@Scale explores avenues best suited for hydrogen fuel applications, primarily focusing on areas where decarbonization is difficult, e.g., transportation (i.e., rail, marine, heavy-duty trucks) and industrial processes (i.e., steelmaking, power grid support, etc.). The U.S. produces 10 million metric tons (MMT) of hydrogen per year; the sector could increase two-to five-fold in the future. Provided such growth can be achieved, it could generate approximately $140 billion in revenue, support 700 thousand jobs, and reduce in GHG emissions by 16 percent by 2030.

The HFCTO's mission is to research, develop, and demonstrate (RD&D) hydrogen and fuel cell technologies that support clean energy, reduce emissions, create jobs, and ensure a sustainable and equitable future. They are achieving this through three main focus areas: fuel cells,

hydrogen, and system integration. Cost reduction is a challenge in fuel cell RD&D; current production prices will need to drop from $323 per kW to a 2030 target of $80 per kW for this technology to be applied in multiple areas. For hydrolytic hydrogen, reductions are needed across all stages: production, dispensing, and storage. To meet these targets, Secretary Granholm (Secretary of Energy) issued the following *Hydrogen Shot "1-1-1"* challenge in July 2021: produce 1 kg of clean hydrogen for $1 by the next decade. To achieve this, the cost of electricity needs to be reduced, lower equipment/capital costs by 80 percent, and cut operating/maintenance costs by 90 percent.

With the amount of hydrogen produced annually, existing distribution pipelines, and the number of planned or built polymer electrolyte membrane (PEM) electrolyzers, there are many successful applications for hydrogen (e.g., fuel cell cars and buses, forklifts, and backup energy storage). Similar projects are appearing internationally as well. It is expected that more fuel cell demonstrations will take place in North America following recent Wabtec and GM announcements. In addition to existing production areas, a hydrogen plant dedicated to producing fuel for transportation will be brought online in Nevada in 2022.

The 2019 FRA/HFTO H2@Rail workshop called for more RD&D in equipment durability, safety standards, advanced infrastructure, as well as increasing hydrogen's competitiveness with diesel. Since then, an analysis of total cost of ownership of a passenger rail system suggests that a hydrogen EMU could compete with a diesel engine in the coming years as technology improves. To that point, a joint Sierra Northern Railway (SNR)/GTI hydrogen fuel cell switcher locomotive project is underway collecting data to inform future deployments. HFTO sponsored Sandia National Laboratory to explore refueling station infrastructure and identify the challenges. For rail applications, current refueling technology flow rates at 10 kg per minute is insufficient; further R&D is needed in this area. The published report detailing the study and results is expected next year.

2.5.2 Nuclear Energy Based Electrification

Claudio Filippone, Thermadynamics Rail, LLC

Dr. Filippone is the founder of F&A Technologies, an engineering firm dedicated to the development of an array of pollutant reduction technologies for, amongst others, the nuclear and rail industries. Dr. Filippone is an expert in electrical and nuclear engineering.

Claudio Filippone's presentation focused on two technologies with the potential for broader implementation: locomotive waste-heat recovery and nuclear microreactors. Through FRA sponsorship, ThermaDynamics has designed a Locomotive Waste Heat Recovery System (L-WHRS) that can be installed on various locomotive engines in three components. A high-pressure heat exchanger (HiP-HEX) is attached to the locomotive exhaust stack using the unit's frame with the purpose of extracting heat out of the exhaust. The HiP-HEX is then connected to a microturbo-generator that will convert the heat energy into electricity. The entire system can be installed within 8 hours and removed within 3 hours and has been shown to reduce fuel consumption by 7–12 percent in road tests. ThermaDynamics is currently focused on determining the efficacy of the L-WHRS to charge a high-cycling battery array that will work to supplement the OEM battery to help with engine restarting post-idling. Recovered energy could also power a trainset's hotel loads, or supplement onboard pollution reduction technologies.

The second technology from HolosGen is a "portable" nuclear microreactor sponsored by DOE Advanced Research Projects Agency-Energy (ARPA-E). Subscale prototype tests have demonstrated this as a feasible technology for decarbonizing rail, but it will require scaling up. In the proposed full-scale unit, multiple, independent, "all-in-one" microreactor blocks create a coupled core that fits within an ISO shipping container. It utilizes tri-structural isotropic particle fuel (TRISO), which has a lifespan of approximately 8.5 years and a high melting point (2,300 °C or 4,172 °F) that would not be reached even following total coolant loss. The unit is capable of producing 10 megawatt energy over its lifespan if run continuously and can be mounted and integrated with a battery-powered locomotive or installed as an adjacent substation to supply energy for catenary or third rail power systems. The amount of fuel in these reactors is equal to the amount of spent nuclear fuel currently transported by rail from nuclear facilities. Before expanding this technology, analysis is needed to compare a locomotive's lifetime pollutants from conventional fuels versus the amount of nuclear waste generated.

2.5.3 Batteries – High Power and Large Power Density

Russell Kubycheck, Progress Rail

Russell Kubycheck works for Progress Rail. Mr. Kubycheck has over 30 years of engineering experience. Mr. Kubycheck has worked in the following industries: telecom, aerospace, healthcare, and rail. During that time Russell has focused on defining customer requirements for the development of safety critical systems.

Russell Kubycheck's talk focused on Progress Rail's activities surrounding high power and large density batteries. Mr. Kubycheck gave an overview of recharging locomotive batteries. He stated that recharging of locomotive batteries is similar to plug in electric vehicles, but given the size differences, the amount of energy drawn can tax power grids in the short-term. An AAR Task Force is developing standards for charging interface for a battery powered locomotive that would allow for better interchange of these types of equipment across North America. Another option for recharging is regenerative dynamic braking, which captures and converts kinetic energy from locomotive braking into power for batteries.

Batteries are evolving, moving from typical lead-acid to lithium-ion and lithium-polymer chemistries and beyond. Each chemistry type has compromises in lifespan, thermal stability, safety, cost, and specific energy versus density. The diverse environments locomotives encounter (i.e., ranging from deserts to polar conditions), recharging safety, and high power for long duration are all factors into battery selection for rail applications. Battery types also have tendencies to respond differently in terms of power supplied following recharging (e.g., sub-optimal power output when not fully charged or after priorly having been fully depleted).

Lithium-sulfur and lithium-air batteries are currently in R&D phases; both have shown promising high-energy outputs although there are concerns surrounding their lifespans. In addition to the BNSF Battery Electric Locomotive (BEL) pilot, Vale Railroad in Brazil is operating a 2.4 megawatt hour (MWh) battery powered switcher. As the automotive industry continues to advance battery technology development, rail will likely look to these technologies and adapt them to the sector's requirements.

2.5.4 Electrification Technologies

Derek Maier, Amtrak

Derek Maier is responsible for leading the brand-new trainset acquisition as well as the maintenance, diagnostics, and technical support changes necessary to support the new fleet at Amtrak.

Derek Maier provided an overview of Amtrak's catenary power infrastructure as well as insights into decisions surrounding technology investments the company is making. Of the 1,500 miles of catenary owned and maintained by Amtrak along the Northeast Corridor, many portions are outdated, having been installed from 1915–1937. Two major upgrades include modernizing the New Jersey rail corridor and the stretch from New Haven, CT, to Boston, MA, in 1999. Routes are good candidates for electrification if they are frequently used, support a high volume of traffic, and run shorter distances per tonnage moved. Terrain, space, and climate also affect the decision to electrify. Despite the space-intensive requirements of overhead catenary, it offers many paths for "green" adaptability as well as a high return on investment (ROI) when applied to dense operating corridors.

Amtrak has opted for the following approaches that may be applicable to other railroads considering electrification in the US:

- Capital *improvement* (i.e., acquiring better technology)
- Capital *replacement* (i.e., switching older units with newer ones of the same tier)
- Capital *maintenance* (i.e., maintaining operations without additional improvements)

Costs significantly impact the selected approach. As the catenary system ages, maintenance will become more expensive to improve when moderate to major work needs to be done every effort should be made to upgrade and future proof the system. Mr. Maier emphasized "future proofing" with regard to any capital investment—that is, anticipating developments that could positively or negatively affect the acquired technology to better forecast total costs. Advancements in other fields, like computer modeling and simulations, will allow for more effective catenary installation planning, while automated inspection (e.g., via drone) will more efficiently find areas for preventative maintenance or upgrading.

Regarding future investments in rolling stock, Amtrak has ordered over 70 new trainsets from Siemens in 3 configurations. They include diesel locomotive trainsets to replace the Pacific Northwest's Cascades fleet, dual mode diesel/auxiliary catenary trainsets with power trucks for greater horsepower (HP) in high-speed corridors, and dual mode diesel/battery sets. Despite the weight and space sacrificed for the dual mode technologies, Amtrak has balanced this against increased reliability and easier transitioning between areas of non-electrification and catenary. The company is also looking at prototypes solely powered by batteries, which will allow them to further research passenger rail options.

2.5.5 Q&A Panel Discussion

The discussion followed addressing concerns over microreactor safety, costs associated with catenary, and battery issues.

Dr. Filippone further explained the air- and water-cooling options for the microreactor. He emphasized that, should a catastrophic failure occur, the reactor would spike to 1,300 °C

(2,372 °F)—well short of TRISO's melting point. Railroad workers potentially encountering heat and radiation from the unit also raised safety concerns. Dr. Filippone stated that air temperatures from the system would reach 60 °C (140 °F) unless a larger radiator unit is installed. The unit would be shielded, but having railroad workers in close contact with the reactor would not be permissible for safety reasons.

Mr. Maier elaborated on the variable costs of catenary in the U.S. and offered that future Federal and State government partnerships, along with increased efficiency, could drive costs down. He also briefly touched on safety protocols in dual mode locomotives regarding battery discharge in tunnels. Catenary solutions are not being looked at; a diesel component would allow the train to "limp home" instead.

A question was posed about the possibility of batteries alone being a zero-emissions solution for rail, or if achieving zero-emissions would require adding electrification or hydrogen sources as support. Mr. Kubycheck and Mr. Maier both stated that a battery-only zero emissions rail solution is unlikely. It is possible for lightweight trainsets to run short distances on battery power only, as have been demonstrated in Europe on a 200-mile route. Freight and passenger rail in the US will require external energy input for their battery powered locomotives. External energy can come from the hydrogen fuel cell system, regenerative braking, etc. Recycling batteries requires further investigation to understand the total lifecycle costs and emissions of the technology.

3. Day 2: Environmentally Sustainable Energy Technologies Powering Future of Rail

The agenda for the second day of the workshop focused on the historical perspective of alternative fuels and propulsion technologies, lessons learned from past projects and the status of planned future ventures and emissions, and environmental justice issues surrounding rail transportation.

3.1 Lessons Learned from Pilot Projects

Michael Iden, Independent, Panel Moderator

Mike Iden is a consultant focusing on new railroad propulsion technology, with an emphasis on successful technological change, minimizing project risks, and maximizing locomotive operability, maintainability, and reliability. Mr. Iden has 48 years of experience in railroad operations and locomotive design, manufacturing, maintenance, and operation, having been employed by three Class I railroads and a major locomotive manufacturer. Mike Iden opened the discussion by reiterating the objectives of this technical panel:

1) Discuss past, current and future pilot projects. Present their objectives, types of data collected, and results expected
2) Highlight technical issues faced and how they were mitigated
3) Identify lessons learned and any policy decisions related to technology implementation based on pilot project data

3.1.1 Historical Perspective on Pilot Projects

Michael Iden, Independent

He has 48 years of experience in railroad operations and locomotive design, manufacturing, maintenance, and operation, having been employed by three Class I railroads and a major locomotive manufacturer.

Michael Iden's talk focused on the historical perspective of alternative fuel and propulsion technologies piloted in the rail industry over the past three decades. Mr. Iden stated that the increasingly visible effects of climate change challenge the rail industry to reduce its emissions. Emissions reductions will help alleviate stress on the environment but will also allow rail to remain competitive as a mode of transport. The time frame in which to develop and implement changes is short, however, with a mere 9 years to show readiness for addressing climate change and net-zero by 2050. The amount of work ahead coupled with an urgency to act may result in increased risks.

It took 25 years for US, Canadian, and Mexican railroads to convert from steam to diesel; now is the time for experimentation with technologies. The most unique feature of North American rail is our continental interoperability and connectedness. North America has the largest single integrated rail system serving an entire continent. Dieselization of rail transportation allowed the railroads to improve efficiency by openly exchanging locomotives with trains, instead of each railroad using only its own locomotives. As various propulsion alternatives are considered in the future, two key questions must be addressed: 1) will there be an expectation of interoperability of

locomotives between railroads in the future, and 2) what are the benefits and costs of deviating from the current approach of interoperability?

Learning from past experiences and changes within the rail sector, Mr. Iden offered the following recommendations:

1. To experiment with multiple solutions, but recognize limitations between test fleets and the potential for commercialization.
2. The ability to select technology should not be rushed—they may not be applicable to all situations.
3. Despite heavy emphasis on experimental locomotives, little has been discussed about the upgrades to present railroad infrastructure that these locomotives may need.
4. Diesel-electric locomotives have become compatible across individual providers in the larger North American rail network; newer fuel technologies may not be. The distinct infrastructure demands for batteries versus hydrogen will result in a different breakdown of costs and benefits.
5. To manage successful technological change will require small steps, recognizing an option must be sufficient (i.e., not always the best possible), and keeping in mind the goal is to move people and goods—not only locomotives.
6. Reliability Growth Testing (RGT) is crucial. Too often experimental designs have been pushed through to production only to fall into a continual redesign loop. Rigorous RGT should involve field-tested, pre-production fleets by railroad workers long before heading to commercial production.
7. Regulatory action should be thorough and *prompt*.
8. FRA, Transfer Canada, etc. should participate in economic analyses now, which will further guide the ARPA-E LOCOMOTIVES project as more data helps refine the framework and direction (Ledoux, B., n.d.).

3.1.2 Lessons Learned from LNG Fuel-in-tender Pilot Projects

Michael Cleveland, BNSF

Michael is the lead for BNSF's battery electrification and energy storage initiative. Michael has over 10 years of experience with BNSF working in the locomotive department as a technology subject matter expert and project leader. He has successfully implemented projects ranging from EPA engine certifications to BEL equipment.

Michael Cleveland discussed the extensive testing of LNG locomotives from 2013–2017 by BNSF. The railroad exposed four locomotives and two tender cars to various conditions, ranging from cold winter temperatures to long-distance hauling to rugged duty cycles. GE and EMD modified 4,400/4,300 hp locomotive engines, respectively to burn both natural gas and diesel. The dual fuel engine consumed a 60 percent natural gas to 40 percent diesel blend. The locomotive covered over 100,000 miles and consumed over 300,000 diesel gallons equivalent of LNG. It is possible to run a locomotive on natural gas. However, the next phase of reliability, growth testing and integrating this into the rail network is still unknown. Legacy tenders from a previous trial were refurbished; while not the optimal tenders, these modifications and final

design helped inform the AAR's M-1004 tender standard. The insurmountable hurdle to this project was ultimately infrastructure.

As the LNG program was progressing, battery-electric technologies were also advancing, giving rail additional ways in which to achieve zero-carbon emissions throughout the sector. Battery electric options can be applied for reducing emission from locomotives but are also applicable to many yard-based vehicles, provided they are safe, suited to the operations, and provide a ROI. Batteries also provide a hybrid option, which has merit as it allows railroads to adjust their trajectory towards cleaner fuels and zero-emissions without requiring drastic adjustments the industry is incapable of applying.

Mr. Cleveland also touched on BNFS's 3-month partnership with Wabtec testing a BEL in a hybrid train consist. This project is summarized in greater detail in Section 3.1.6.

3.1.3 Lessons Learned from LNG Fuel-in-tender Pilot Projects

Rod Keefe, Florida East Coast Railway (FEC)

Rod Keefe is Vice President, Advanced Technology at FEC, a Grupo Mexico Transportes company. At FEC, Rod is responsible for pursuing projects serving Train Operations including the installation of PTC, the implementation of a new Computer-Aided Train Dispatching System (CAD), LNG revenue shipment management, and the conversion of the FEC mainline locomotive fleet to utilize LNG as a locomotive fuel for revenue service.

Rod Keefe talked about activities at FEC related to environmental sustainability. FEC launched an environmentally driven plan in 2013 to convert its main line fleet to dual fuel based on a natural gas-diesel fuel blend. Like BNSF, FEC's dual fuel locomotives were 4,400 hp that had a minimum substitution rate of 60 percent natural gas to 40 percent diesel fuel. Currently, the locomotives are configured for an 80 percent natural gas to 20 percent diesel fuel blend. This less than 100 percent natural gas fueling approach provides a safety net in the event of a natural gas issue, where the engine would shift to diesel consumption and not interrupt the service operation schedule. The FEC fleet now consists of twenty-four 4,400 hp dual fuel locomotives and 13 LNG UNT-75 double-walled ISO cryogenic tanks on purpose-built well cars. AAR, through the development of M-1004, AAR MSRP Interoperable Fuel Tenders for Locomotives, had set requirements for accident scenarios which included the tender surviving a perpendicular impact by an 80,000-pound vehicle traveling at 40 mph without releasing LNG. Tenders were also equipped with remote monitoring technology that were set to provide continual status updates and communicate with operators in case of malfunction.

FEC's goal was to design fail-safe methodologies by identifying hazards in advance. Communicating with the labor unions proved invaluable in this regard, since their mechanics and workers had experience with many unforeseen scenarios. This dialogue also helped establish trust between the railroad, the labor unions, and the communities the railroad passed through. By proactively holding safety trainings for rail workers and emergency responders, FEC had an easier transition when the time came to expand their service area. Remote monitoring of the LNG tender helped to ensure safety of the operations.

The first locomotives began running on limited routes in 2015; by 2016 the FEC petitioned FRA to allow for expansion of their pilot program to cover their entire 350-mile network. Since then, the locomotives have completed nearly 14,800 trips covering 4.7 million miles and consuming approximately 17 million diesel gallons equivalent of LNG and are viewed as a great success.

3.1.4 H2 – Fuel Cell Use in U.S.

Carrie Schindler, San Bernadino County Transit Authority (SBCTA)/Stadler

Carrie Schindler is Director of Transit and Rail Programs for the SBCTA. Ms. Schindler is responsible for delivering the promises of Measure I, San Bernardino County's half-cent transportation sales tax as it relates to transit and rail efforts.

Carrie Schindler gave an overview of the SBCTA project to extend the Metrolink system about 9 miles and introduce new equipment for passenger service. SBTCA contracted with Stadler to provide diesel multiple units (DMUs)—Fast Light Intercity and Regional Train (FLIRT) for the new service. This FLIRT DMU platform's specifications made it ideal for modification to meet SBCTA's environmental air quality requirements. The Tier 4 diesel generators could be replaced to transition the DMU into a zero-emission multiple unit (ZEMU). The 9-mile corridor is 95 percent constructed and will start service with three DMUs in 2022, connecting Redlands, California to San Bernardino, CA. A more expansive vision includes the ZEMU service spreading further onto the existing Metrolink lines or converting the entire fleet. A timeline for this, however, is unclear.

After an initial review of appropriate technologies, SBCTA determined battery and hydrogen hybrids were feasible options. A second analysis considered range, costs of manufacturing and expansion, as well as the ease of applying the technology to other portions of the corridor. The hydrogen hybrid was ultimately selected for its expandability.

Little guidance existed for the nation's first hydrogen hybrid passenger vehicle in terms of fueling logistics, maintenance buildings, or handling of emergency response. SBCTA, at the direction of FRA, used guidance for natural gas fuel in development of the design and approach for the ZEMU. SBCTA has requested proposals for a future fuel provider, as gaseous vs. liquid hydrogen refueling has not yet been decided due to space constraints. Until then, the prototype will be supplied from a temporary delivery/storage solution. As mentioned by Mr. Keefe, early outreach with the community and emergency responders has been positive, which should ease the introduction of this locomotive. The final ZEMU is scheduled for delivery in 2023 with testing in 2024 hopefully leading to commercial operations soon after.

3.1.5 H2 – Fuel Cell Use Overseas

Noah Heulitt, Alstom

Noah Heulitt is Regional Lead for Alstom's Rolling Stock Sales, Business Development and Rolling Stock Commercial Strategy and Capture Planning. In his role with Alstom, Mr. Heulitt is responsible for coordination with Alstom's global engineering and product management teams to set product strategy for the North American market.

Noah Heulitt's presentation focused on Battery and Hydrogen Fuel Cell Technology for Rail. Mr. Heulitt stated the primary goal of his presentation was to address diesel fuel replacement and whether to pursue a reduced or emission-free path. New technology needs to be introduced, regardless of the path, whether bi-mode electric multiple unit (MU) - diesel and hybrid diesel engines with an energy storage component for the reduced emissions route, or battery electric MU and fuel cell MU for the emission-free path. Of note, the fuel cell MU setup specifically requires a hydrogen refueling station which will factor into infrastructure costs later on.

Mr. Heulitt provided a brief overview of reduced and emission-free units currently being tested, converted, or coming into service soon in the US and Europe. They include the Coradia Stream fuel cell MU—entering Italy's service in 2023—and a project with the Long Island Railroad for the conversion of a M-7 EMU to a battery electric MU. Two Coradia iLint trainsets powered primarily by battery and hydrogen fuel cell are touring Europe and may be brought to the U.S. and Canada for further demonstration of their feasibility in replacing small commuter diesel powered units. Alstom is also working on a conversion of the United Kingdom Breeze 321; this is a conversion of an old 321 electric MU into fuel cell MU. At the time of this workshop, revenue service demonstration began later in 2021. Alstom is studying various technological combinations for reduced emissions or zero emissions rail yard operations, assessing their range of autonomy under various power options before needing to be recharged or refueled.

Mr. Heulitt concluded by reviewing the following three points:

1. For providers considering battery versus fuel cell options, Alstom provides individualized solutions based on a number of parameters. Battery electric MUs are better suited for short-range stretches with portions of non-electrified track while fuel cell MUs are more applicable for long-range routes.
2. Regarding hydrogen trains, regional rail transport is most easily adapted when DMUs are replaced. If hydrogen production and storage were ensured, the main infrastructure investment in this case would be the hydrogen refueling station. Therefore, the operation should plan to run longer than 10–15 years to allow for a ROI.
3. Both hydrogen and battery units can be emission-free. The biggest challenge is obtaining renewable and greenly sourced hydrogen. North America's geographical diversity has the greatest impact on cost of energy per kilometer, which requires communicating with partners and other organizations to determine strategic locations for installing infrastructure and factoring these components into the total cost of ownership calculations.

3.1.6 Battery Use in Locomotives

Greg Wright, Wabtec

Greg Wright is Senior Engineer at Wabtec Corporation within the Advanced Technology Group. Mr. Wright has more than 13 years of experience in the rail industry, working in various roles spanning from engine, cooling, and systems to product management. In his current role, he is helping lead the decarbonization efforts for future products within Wabtec.

Greg Wright's talk focused on Wabtec's FLXdrive BEL. Wabtec began examining powering locomotives by battery in the early 2000s, with further strides made in the late 2010s once battery energy density had improved and it was less cost prohibitive. The BEL locomotive Wabtec has developed in partnership with BNSF started out with a 10 percent targeted reduction of GHGs. The ultimate goal is to reach zero emissions with the locomotive, and reduced emissions for the entire train once the BEL is introduced to the consist.

Testing commenced with this goal in mind; the locomotive was subjected to the real-world conditions a typical diesel engine would experience, running along a 350-mile stretch (i.e., between Barstow and Stockton, CA) and reaching 75 mph. Additionally, situating the 2.4 MWh FLXdrive BEL unit between two Tier 4 locomotives allowed the team to optimize and maximize

dynamic braking energy by increasing FLXdrive's effort and reducing the propulsive requirement of the other units. The batteries were charged from the wayside charging station in Stockton, CA, and through regenerative dynamic braking while underway. Following a 3-month testing period, the FLXdrive has been a success, having had *no* major failures, saved over 6,000 gallons of diesel fuel, and travelled over 13,000 miles.

Wabtec considers the importance of quality control and the Failure Reporting, Analysis and Corrective Action System to the demonstration's success. Range improvements, liquid cooling, and adapting future auto industry fuel cells to suit rail's needs will help the FLXdrive succeed at a commercial level, provided this progression is accompanied by proper infrastructure and safety procedures.

Wabtec is now collaborating with GM to customize batteries as well as fuel cells for locomotives. These advancements should assist in the stepwise reduction of GHGs as locomotives are switched over from Tier 4 diesel to battery hybrid consists (e.g., FLXdrive). This will extend the lead time for further battery hybrid testing and fuel cell design as the industry works to eliminate 60 MMT of CO_2 per year. Infrastructure needs to be at the forefront of the ecosystem of any new technology that is being considered.

3.1.7 Q&A Panel Discussion

A lengthier discussion followed touching on topics of safety and the lessons learned and foreseen problems after conducting pilot programs with these newer fuels.

With respect to safety, Mr. Cleveland addressed the risks of using LNG versus diesel. No fuel is without risk but setting rigorous safety standards and preparing workers and emergency responders well ahead of time can mitigate these. In BNSF's recent LNG locomotive tests, gaseous natural gas was transferred across couplers, which alleviated issues with pressure differentials seen with LNG transfer. Mr. Cleveland outlined some safety specifications and requirements from the AAR M-1004 standards related to LNG fuel tender.

Ms. Schindler responded to questions on the safety of hydrogen passenger trains as well as changes to maintenance building design, stating that the Stadler powerpack has been fully revamped and the SBCTA is ensuring maintenance buildings meet the NFPA standard to address such concerns. Mr. Heulitt agreed, mentioning the iLint's certification process through internationally recognized safety standards and its subsequent acceptance by German and French railways.

Mr. Wright touched on how battery capacity varies with route or propulsion demand, recognizing that harder duty cycles will result in less assistance from the battery due to current capacity limitations. Routes may allow for increased energy recapture if the terrain is ideal, but if recapture energy exceeds the battery storage capacity, the remaining energy must be dumped to the environment as heat and is lost. Wabtec has taken the step towards liquid cooling, which will increase the number of batteries packaged onboard significantly and achieve 6 MWh of energy—three times what Wabtec demonstrated with BNSF in 2020. This increase has the potential to strain energy grids when recharging, so it will be essential to factor in future infrastructure.

To conclude, Mr. Cleveland spoke about the challenges of gaseous alternative fuels and the problems he anticipates in the future. Safety hazards associated with hydrogen are exponentially higher than those with LNG. Reiterating that infrastructure is the largest hurdle, he also raised the concern of energy-intensive compressing or liquefying hydrogen. The differences in cost, as

well as the potential for "green" energies to come from non-green sources, make starting the transition difficult. However, it is unrealistic to think the existing grid will not make similar strides towards green energy as transportation sectors push in the same direction.

3.2 Environmental Regulations, Environmental Justice, and Related Issues

Melissa Shurland, FRA, Panel Moderator

This panel was moderated by Melissa Shurland of FRARD&T as discussed in Section 2.4. Ms. Shurland stated the objectives of this technical panel at the start of the discussion, which were:

1) Discuss the current environmental regulations, impact of new technologies on environmental justice, and specific applicability to railroad operations
2) Indicate target emission requirements and the schedule for compliance/deadlines, if any, in both State and Federal regulations
3) Identify resources, incentives, grants, implementation incentives, public support for demonstration projects and environmental justice issues

3.2.1 Emission Standards and Regulations for Rail Operations

Francisco Dóñez, EPA

Francisco Dóñez works for the EPA and leads the Ports and Railroad sector work groups for the West Coast Collaborative, a public-private partnership to reduce air pollution from heavy duty diesel engines. He also spearheaded agency outreach to regional environmental justice communities affected by diesel pollution.

Francisco Dóñez identified available funding opportunities that railroads can access to replace or upgrade older, less efficient equipment. One such funding opportunity, the Diesel Emission Reduction Act (DERA), aims to reduce diesel air emissions from medium- and heavy-duty vehicles by eliminating old diesel engines and replacing them with upgraded equipment. Eligible transportation entities from multiple sectors can receive funding to replace these vehicles through DERA's National Grant Program, which emphasizes environmental justice. Numerous rail and rail yard engines are eligible for upgrading, including Tier 3 and below locomotive engines; these lower tiers may also have options to retrofit or install certified remanufacture systems. Tier 4 engines can only be replaced with zero emissions options, as they are currently the cleanest diesel engines available.

Another funding opportunity for equipment upgrade is the Targeted Airshed Funding Program, geared towards reducing pollutants in nonattainment areas—that is, areas where pollutant levels consistently remain above the primary and secondary air quality standard. Many projects funded by this grand program are similar to those supported by DERA; for example, a recent 2020 project involved replacing an unregulated locomotive in the Mojave Desert region. Overall, the Targeted Airshed Funding Program has awarded nearly $205 million over the last 5 years.

Sharing the allotted time with Francisco Donez was Peter Smith. Mr. Smith works as an engineer at the EPA in the Diesel Engine Compliance Center. The Diesel Engine Compliance Center is part of the Office of Transportation & Air Quality.

Peter Smith's contribution to the discussion focused on current locomotive regulations (40 CFR Part 1033) for emissions limits. He outlined the historical perspective of the law and discussed its

application. While regulation 40 CFR Part 1033 applies to all railroad classes, there are some opportunities for relief for small operators that maintain a fleet, like short line railroads. There is also a degree of flexibility for certifying equipment with non-OEM components. The standards applied to different engines will be based on the original manufacturing year and the vehicle's power rating.

To provide clarity in definitions, a *remanufactured* engine is considered one where all parts have been inspected and replaced within a 5-year period or the locomotive had its engine replaced with a newly manufactured one. *Refurbishment* applies to a locomotive that has more new parts than used parts. This involves more in-depth changes and is more like an overhaul. Typically, railroads will stay away from this option because this path tend to trigger a more stringent emissions tier classification for the locomotive.

Finally, *upgraded* refers to three types of remanufacturing done to pre-1973 engines: repowering, refurbishing without newly manufactured parts, or modifying one to comply with Tier 0 standards. When remanufacturing, a kit could be needed. Such kits can be purchased from an OEM. Non-certified parts can also be used if they do not adversely affect emissions. Provided the operator/owner adheres to the maintenance schedule set down by the kit manufacturer and keeps detailed records, compliance is easily verified.

3.2.2 California Regulations and Technology Advancement Initiatives

Justin Hwang, California Air Research Board (CARB)

Justin Hwang is part of the CARB Locomotive Group. His focus is primarily on analyzing and reducing emissions from locomotives and rail yards in California. He is part of the team that is working on CARB's latest efforts on developing In-Use Locomotive Regulations. His current and previous work includes locomotive emissions verification, development of a Draft Truck vs Train Emissions Analysis. Mr. Hwang supports CARB's Class I Locomotive Emissions Inventory update; and analysis of annual data provided by Union Pacific and BNSF in the South Coast Air Basin was possible by the 1998 Locomotive NOx Fleet Average Emissions Agreement.

Justin Hwang gave the audience an overview of CARB's mission to promote and protect public health, welfare, and ecological resources. CARB adopts regulations that curb criteria pollutants and GHGs. California has made progress in addressing poor air quality; still, the only two extreme air quality nonattainment areas in the US are located in California. These areas are in regions of the State's main freight corridor. CARB published the draft truck versus train emissions analysis report that shows a high-level comparison of exhaust emissions from average trucks and trains operating in California. With current Tier 4 technology trains are emitting less particulate matter (PM) 2.5 and NOx emissions than trucks but this will change as truck transitions to clean energy technologies to meet 2050 zero emissions target.

In conjunction with stakeholders and agencies, CARB is applying a large program of policies, regulations, and incentives to decrease emissions and associated health impacts while moving towards a more sustainable system. New zero emissions and cleaner combustion requirements for locomotives are slated for implementation in 2022.

Assembly Bill 617 was passed to protect local communities from air pollutants emitted by the State's 100+ rail yards in close proximity to residential communities. The accelerating transition of rail yard vehicles to zero emissions will require locomotives to switch over as soon as possible. Although trains are considered the cleaner transport mode to trucks, trucks will emit

significantly less PM2.5 and NOx compared to trains after 2023 when updated regulations go into effect. To remain competitive, trains will need to transition to zero emissions technologies. Despite the South Coast's 1998 memorandum of understanding (MOU) designed to encourage deploying more efficient locomotives, there has only been an incremental increase in Tier 4 engine activity, with larger usage of Tier 0+ and 1/1+ locomotives in the last decade by railroads in the region. Railroads cannot continue using lower tier engines to meet increased demand; as such, new strategies are needed.

CARB is focusing on two strategic fronts: partnerships and technology. With respect to partnerships, the Zero Emission Heavy Transport (ZEHTRANS) working group lets multiple agencies interact, which then allows CARB to connect and coordinate with stakeholders and key organizations. CARB is also incentivizing zero emissions technology, like the BEL demonstrated by BNSF/Wabtec. Funding for locomotive improvement is also available through their Low Carbon Transportation Investments and Air Quality Improvement Program. For in-use locomotives, CARB has also drafted regulatory language to guide improvements.

CARB aims to reduce emissions in communities disproportionately impacted by locomotive pollution; the adoption and turnover to cleaner technologies such as Tier 4 locomotives, however, has been slow. CARB is therefore encouraging a faster transition by creating a spending account credit for those operators switching early. The 2020 "Zero Emissions by 2035" Executive Order N-7920 will help expedite the zero-emission transition.

3.2.3 Short line Railroads' Perspectives on Clean Fuels

Jo Strang, American Short Line and Regional Rail Association (ASLRRA)

Jo Strang is Senior Vice President at the ASLRRA. Ms. Strang advises and represents the Association's members nationally in regulatory matters.

Jo Strang emphasized the importance of the short line and regional railroad industry. Short line railroads are critical to freight transportation in the US. Despite primarily covering short distances, these 600 small businesses and operators are critical for distributing goods from hubs to final destinations, mostly in rural areas and to small businesses. A typical short line railroad has 6 locomotives, 22 employees, and serves 15 or fewer customers. With over 40 percent of U.S. freight moved by rail equaling 2.0 percent of transportation related GHG emissions, trains are significantly more environmentally friendly than trucks. Rail is also safer for the motoring public, accounting for a fraction of injuries and deaths within the broader transportation sector.

Short line railroads typically operate using older locomotives with an average fleet age of 45 years, with nearly half of all engines dating to pre-1973, 24 percent have been rebuilt. Replacing older locomotives or upgrading them via EPA kits can be cost-prohibitive for these small businesses. Therefore, ASLRRA is exploring decreasing emissions through non-traditional, cost-effective technologies, including fuel additives, and injector sets. Cleaner fuels, such as biodiesel and other renewable fuels that are compatible with older engines will be key for this sector. Such fuels will allow short lines to continue operating until a more tenable solution becomes available, thereby keeping more freight on rail and off roads.

ASLRRA members are engaged in emission reduction projects such as Pacific Harbor Line's demonstration of Progress Rail's Joule battery electric locomotive, or the joint SNR/GTI partnership to convert a retired Tier 0 locomotive to zero emission hydrogen switcher unit. The association has also joined the EPA's SmartWay and encourages FRA to do so as well, as this

may help increase their environmental leverage. ASLRRA plans on testing non-traditional technologies to reduce emissions; these non-traditional technologies are typically used by short line such as injector sets, additives, etc. The purpose is to quantify how these non-traditional technologies affect emissions and engine efficiency.

3.2.4 Environmental Justice Issues

Angelo Logan, Moving Forward Network

Angelo Logan is the Policy and Campaign Director for the Moving Forward Network and co-founder of East Yard Communities for Environmental Justice. Angelo Logan has been advocating for his community and communities across the country impacted by industrial and transportation pollution. Angelo serves on the White House Environmental Justice Advisory Council, Harbor Community Benefit Foundation, Board of Directors, Social and Environmental Entrepreneurs Board of Directors, and Co-Chair of California EV Charging Infrastructure Strike Force.

Angelo Logan talked about the Moving Forward Network, which is a coalition of more than 50 organizations with the common mission of addressing social and environmental justice issues tied to ports, warehousing, and freight corridors. They comprised of 58 organizations and are located in 20 cities across the US.

The transport, storage, and distribution of goods do not occur in an isolated system, separate from other human activities. A community's close proximity to such industrial hubs is linked with a higher incidence of health issues. In 2007, California conducted a health risk assessment of four major rail yards that showed higher risks of cancer occurred in neighborhoods adjacent to the freight corridor and rail yards. In many cases, the neighborhoods located near such industrial sites are also comprised of low-income communities of color, leading to disproportionate representation by these groups within total high-risk populations.

As transportation networks continue expanding and increasing in capacity, rail yard emissions are and remain an issue. For example, a proposed BNSF rail yard in Los Angeles, CA, would be placed next to community facilities such as schools, recreation parks, and homeless shelters. With these facilities, it is no longer a matter of mitigating the emissions from a single engine, rather those from hundreds of locomotives, trucks, and yard vehicles. The rail industry and land use decision makers should consider the ramifications of increased, local pollution and avoid subjecting these communities to it, which are disproportionally communities of color.

The Moving Forward Network believes environmental justice concerns can be addressed while also requiring stringent emission controls. The Moving Forward Network advocates for the introduction of a Tier 5 locomotive standard that would require all new switcher locomotives to be zero emissions by 2025 and all new line-haul locomotives by 2030. Remanufactured switcher locomotives should all meet Tier 4 emissions standards by 2025 all remanufactured line haul locomotives should be Tier 4 quality by 2027. Finally, those units not meeting Tier 4 standards should be removed from service no later than 2045. Though they recognize a transition of this scale will be financially costly, the Moving Forward Network sees it as railroads internalizing the cost that would otherwise be placed on the public's shoulders. There needs to be a better balance between the impact on public welfare and the cost of rail operations.

3.2.5 Q&A Panel Discussion

The final panel Q&A discussion began with considering the feasibility of the Moving Forward Network's proposal. EPA and CARB panelists expressed interest in taking an in-depth look at the proposals and support for the ideas. Mr. Logan recommended local and Federal agencies collaborate and use their own authority to impose regulations and recognized the increased burden such a zero-emission transition would have on short line operators. Here, he suggested seeking ways to increase capital.

Ms. Strang pointed out that, broadly, short line operators do face a financial hurdle, both from a small business and an external funding perspective. The SNR and Pacific Harbor Line's tests were made possible by securing grants like DERA, which are competitive and few and far between. She cautioned that the transition to zero emissions is harder for short line operators since they also pay to maintain rail infrastructure; the trucking industry, however, is not financially responsible for highway maintenance.

The discussion also touched on the different approaches to emission reduction. CARB's position is to reduce emissions overall, so operators can select natural gas, as well as hydrogen or battery hybrid options. Mr. Hwang then stated CARB is also looking at methods to decrease idling time and cut emissions. Mr. Logan expressed the Moving Forward Network's opposition to natural gas as it is not a zero emissions fuel and emits toxic, ultrafine particles. He supports interim mitigation technologies like diesel exhaust fluid filters, seeing them as an important step, although an audience member cautioned these technologies are not always compatible with all locomotive engine types.

CARB and the Moving Forward Network have both collaborated with railroads to address the slow transition from older locomotives to cleaner technology with mixed results. The combined cost of operating and investing in these new units seems to be the biggest problem. Ms. Strang concurred. It was also pointed out that with efficiency gains—and a decrease in freight move due to COVID-19—many Class I operators have no need to purchase more locomotives. If the modal shift from truck to rail is achieved in California, these older engines will need replacing, as they will become the larger emitters once zero emissions truck regulations are enforced. A modal shift to rail across the US, however, could see greater emission reduction immediately; however, as further NO_x and PM2.5 emission restrictions for trucks are rolled out by the EPA, the lower emissions advantages of rail over trucks will be eliminated. Railroads need to embrace newer clean energy to stay competitive.

The panel concluded recognizing many agencies have the common goal of addressing climate change and that a path can be found that addresses the needs of all industries and communities.

3.3 General Discussions and Research Priorities

Phani, Raj, Barbara Barr, Melissa Shurland, and Steve Clay, Panelists, FRA

The workshop was capped by an open discussion on what actions are needed to advance technologies for safe, clean rail transportation. It was moderated by Dr. Phani Raj, Melissa Shurland, Steve Clay, and Barbara Barr of FRA. The specific objectives of the discussion were to:

1. Develop a list of research priorities based on the panel discussions and audience questions and suggestions

2. Identify resources for funding and cooperative ventures to maximize the technology ROI
3. Discuss incentives for research, achievement goals, commercialization of results, and implementation into railroad revenue service operations

Melissa Shurland opened the discussion by summarizing rail's contributions to the transportation sector as well as to overall emissions; these emissions are regionally concentrated and pose risks to public health and welfare, especially for low-income communities of color in urban areas. GHG reduction approaches are diverse. One of FRA's goal in this workshop was to learn about the experiences of national and international entities on their efforts to address climate change and clean energy technologies. FRA seeks feedback on which steps to take as it researches, promotes, and oversees introduction of future decarbonization technologies.

Many panelists agreed that small steps are warranted. As infrastructure is a significant barrier to introduction of alternative fuels, Michael Cleveland (BNSF) encouraged identifying pieces of an operation that could be converted to reduce or zero emissions units now, thereby chipping away at the larger issue of emissions. Justin Hwang agreed, citing success with CARB's battery-electric rail car movers. Frank Maldari of Long Island Railroad asked if anyone had experience with using wayside energy storage for recaptured dynamic braking energy. Energy captured from a train braking can be stored by on-board batteries or by a wayside energy storage system. Wayside energy storage systems allow already electrified trains to capture and reuse energy that would otherwise be loss to the environment. Advancement in this type of technology for passenger rail operations could further improve efficiency and reduce emissions associated with electricity production. Mike Iden recalled that FRA funded a similar project in 1979. Mr. Cleveland suggested research on possible solutions for extending end-of-use battery life while cutting peak costs for recharging a battery electric locomotive.

When asked how FRA can work with the industry in the future to address their concerns, attendants and panelists offered many suggestions, including:

- Assist with renewable- and biodiesel roll outs as a cost-effective way of immediately drawing down emissions, especially for short line operators
- Draw up a roadmap for decarbonization that can be followed by all railroads with timelines for sequentially phasing out old technology
- Increase funding for improvement technologies and work with the EPA to address the aging legacy fleet and operating functions (e.g., compressed air leaks)
- Make more funds/resources available for demonstrations, as well as RGT projects that could inform future commercial-scaling efforts

With respect to the final point, Mr. Cleveland added that overall, discussions of new technologies should be reframed to provide railroads with a clearer picture of the final gains the company can expect by transitioning. Mr. Iden was adamant there should be increased subsidizing of pre-production projects that had shown promise for scaling to a larger test fleet.

It was broadly agreed that battery safety testing was a primary concern. Anil Kapahi of Jensen Hughes suggested that FRA should look to the NFPA 855 Standard for a lithium-ion storage system that could be applicable when creating a battery safety standard.

Dr. Raj then addressed the changing role of FRA, having originally focused on regulatory aspects, and now faced with pursuing new technology research. He posed the larger question of whether FRA should involve itself in the market, promoting technologies, or if it should take a more regulatory stance. A request went out to all attendees to supply FRA with the four main priorities they felt the administration should consider. Ms. Shurland also called for ideas about engaging additional international and national agencies for future collaborations.

The panel and workshop concluded with Dr. Raj, Ms. Shurland, and Ms. Barr thanking all panelists and attendees before speaking about next steps, which could be a 2022 an in-person conference—COVID-19 permitting.

4. Conclusion

The workshop garnered diverse perspectives on future approaches to alternative fuels and technological advancements that can be expected in the rail (and broader transportation) sector. It is clear there are local, national, and international challenges to improving or changing existing rail vehicles and infrastructure, as described by the varied array of panelists. However, this diversity also allows for multiple, innovative approaches as the sector strives to decarbonize by 2050.

The avenues that have shown exciting progress and promise for continued growth include biofuels, electrification and batteries, and hydrogen fuel cell development. Of these, hydrogen fuel cells are of great interest as they would eliminate GHG and pollutant emissions provided the hydrogen is cleanly sourced. A broadly achievable path, certainly in the shorter term, lies with hybrid technologies due to the flexibility they offer; international rail agencies have greater experience with this option. This provides ample opportunity for US operations to determine which hybrid technologies (e.g., battery electric and battery diesel) could be applied based on regional logistics and fuel source availability. The rail sector can also learn from other facets of global transportation—the multimodal nature of ports, for example, has required the maritime sector to adopt a "fuel neutral" stance as it has recognized a patchwork approach will be necessary to reduce GHG emissions across their operations.

Another clear step forward is the large-scale improvement of infrastructure and vehicles/engines. Given the long lifespan of locomotives and the increased cost of continually maintaining aging infrastructure, efforts should be made to "future proof" operations. This is a complicated matter, in part because it will require more technologies to advance beyond the demonstration phase before being reliably deployed on a large scale. It can also be cost-prohibitive, especially for smaller operators that are better equipped to making incremental improvements. Regardless of the type of improvement, such progress is also critical to addressing another aspect of passenger and freight transport: environmental justice concerns. GHG and pollutant emissions affect not only the climate and regional environment, but also the health and wellbeing of those living or working in close proximity to rail yards, transport hubs, etc.

FRA, in its endeavor to research, promote, and oversee the implementation of future decarbonization technologies, has opened a dialogue for feedback. Given the scale of the global rail community, there are many opportunities for collaborations and ways in which FRA can aid in bringing about expedient changes in the future.

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Appendix A.
Speakers' Biographies

Dr. Phani Raj, Moderator (Plenary Session, Technical Session 1A), General Engineer, FRA

Dr. Phani Raj is a General Engineer in the Engineering Technology & Automation Division in the Office of Railroad Safety at FRA. He has been at FRA for 8 years. Before joining FRA, he headed a Safety and Risk Analysis consulting company in Boston for over 30 years.

Amit Bose, Administrator, FRA

Amit Bose serves as the Administrator (former Deputy Administrator) of FRA. Previously, Mr. Bose worked at HNTB, an architectural and engineering firm, where he also served as board chair of the Coalition for the Northeast Corridor and on the New Jersey Restart and Recovery Advisory Council. He previously served at FRA during the Obama-Biden Administration as Deputy Administrator, Chief Counsel, Senior Advisor and Director of Governmental Affairs, and at DOT as Associate General Counsel and Deputy Assistant Secretary for Governmental Affairs. In those positions, he worked on safety, policy, regulatory, and governmental affairs matters, and provided legal counsel, guidance and advice to the Office of the Secretary and DOT's operating administrations. Before joining DOT, Mr. Bose also worked for New Jersey Transit, the New Jersey Department of Transportation, and as a transportation staffer in the U.S. Congress.

John "Karl" Alexy, Associate Administrator and Chief Safety Officer, FRA

Mr. Alexy joined FRA in 2009 as a General Engineer in the Hazardous Materials Division. In 2015, Mr. Alexy became Director of the Office of Safety Analysis, which is comprised of seven divisions: Economic and Regulatory Analysis, Passenger Rail, Human Performance, Data and Information Management, Risk Reduction, Security, and the Highway-Rail Grade Crossing and Trespasser Prevention Program.

In July 2019, Mr. Alexy became the Associate Administrator for Railroad Safety and Chief Safety Officer of FRA. In this role, Mr. Alexy manages FRA's regulatory oversight of rail safety in the United States and oversees the development and enforcement of regulations and safety programs for the freight and passenger rail industry. Mr. Alexy previously served as FRA's Deputy Associate Administrator for Railroad Safety supervising the Office of Safety Analysis, the Office of Technical Oversight, and the Office of Regional Operations.

Before joining FRA, Mr. Alexy worked for DuPont de Nemours in Wilmington, DE. At DuPont, he served as the Senior Engineer in DuPont's Logistics Group where he oversaw the design, construction, and modification of tank cars used to transport hazardous materials. He also was a Fleet Manager responsible for overseeing the maintenance of the owned and leased vehicles.

Mr. Alexy earned degrees in Biology from Bloomsburg University in Bloomsburg, PA, and Civil Engineering from Drexel University in Philadelphia. He graduated Summa Cum Laude and first in his class at Drexel. He earned a professional engineering license from the State of Maryland.

Barbara Barr, Director of International Program, FRA

Ms. Barr is the primary liaison with international counterparts for FRA and is responsible for management of all international-related activities and initiatives while also representing DOT leadership at international forums. Barbara has been with FRA since 2009 and previously was responsible for the overall management of the Railroad Rehabilitation and Improvement

Financing Program (RRIF) that offers financial assistance of up to $35 billion for rail related projects.

Prior to joining Federal service, Ms. Barr held various leadership positions in the private industry. Most recently, she served as the head of Credit & Risk Management at Sallie Mae in Reston, VA. She has a Master's Degree of Business Administration from George Washington University with a concentration in Finance & Investments and a Bachelor's Degree in Business Administration from Coe College in Cedar Rapids, IA.

Michael Berube, Deputy Assistant Secretary, Sustainable Transportation in the EERE, DOE

Michael Berube is the Deputy Assistant Secretary for Sustainable Transportation in the EERE Office. Prior to joining EERE, Michael spent more than 25 years in the transportation sector and automotive industry, specifically in the areas of environmental, energy and safety policy, and product development and marketing.

Robert Fronczak, Assistant Vice President Environment & Hazardous Materials, AAR in Washington, DC

His responsibilities include the development and coordination of railroad industry environmental policy. Before joining AAR, he was a Senior Program Manager with Radian Corporation in Milwaukee, WI. He spent 6 years with the Milwaukee Road Railroad in Chicago, IL, as Director of Environmental Engineering. Robert has a Bachelor of Science in Civil Engineering from Valparaiso, University, and a Master's Degree in Business Administration from DePaul University. He is a registered professional engineer in the State of Illinois.

Narayana Sundaram, Senior Director of Engineering and Commuter Rail Operations, APTA

In this role, Narayana Sundaram's staff advises various commuter rail committees including the commuter rail CEO's committee. He is also responsible for all regulatory engagement for APTA's commuter and intercity railroads as the lead for the APTA contingent on FRA's RSAC. Mr. Sundaram led the APTA efforts on the full industry wide implementation of PTC for the commuter rail industry. Mr. Sundaram manages APTA's Standards program which has developed more than 310 standards and recommended practices.

Prior to joining APTA, he held several positions with ENSCO, a technology provider in the rail industry. He spent 13 years at ENSCO holding several positions last of which was Business Area Manager for the Vehicle/Track Interaction Consulting Services. Mr. Sundaram conducted about 13 years of research for FRA for passenger and freight rail operations. He holds a Master's Degree in Mechanical Engineering from the University of Maryland and a Bachelor of Science Degree in Mechanical Engineering from India. He lives in Centreville, VA, and chairs the Math Club at Greenbriar West Elementary School.

Carlo Borghini*, Shift2Rail *Joint Undertaking

Carlo Borghini was appointed Executive Director of the Shift2Rail Joint Undertaking in February 2016 for a 5-year mandate. He is responsible for the overall management of the S2R JU activities. His mandate has been extended till May 2026 and he will be entrusted with the new rail research and innovation partnership. Previously, Mr. Borghini held different senior

management positions in private and international organizations. Mr. Borghini holds a master's degree equivalent in Business Economics.

Dr. David Camacho Alcocer, Head of Rail Transportation Regulatory Agency

Dr. Alcocer is a Civil and Environmental Engineer from the University of Massachusetts, Amherst. He has a Master's Degree in Infrastructure Planning from the University of Stuttgart, Germany and a PhD in Railway Engineering from the University of Stuttgart, Germany. Dr. Alcocer's doctoral research topic focused on the maintenance of the railways of light rail systems by means of signal processing of the different geometric parameters of the track and modelling in multibody systems. He has directed more than 25 master's theses in various topics focused on track maintenance and planning of light rail systems for Mexico. From December 2018 to March 2021, he served as General Director of Studies, Statistics and Mexican Railway Registry in the Rail Transportation Regulatory Agency of Mexico, a decentralized agency of the Ministry of Communications and Transportation of the Mexican government. Since April 1, 2021, he was appointed by the President of México as Head of Rail Transportation Regulatory Agency.

Peter Mihm, Team Leader for International Relations, ERA

Mr. Mihm is an engineer and certified railway inspector. He is a project manager of international projects and activities at ERA. Peter has 40 years of railway experience, including 20 years as manager at Deutsch Bahn AG and more than 15 years at the ERA. He is a recognized expert in various areas of railway technology as well as in railway safety and operations. Peter has authored many different decisions and regulations adopted later by the EC as well as author of railway related articles and publications including presentations and speeches in international and worldwide conferences. Peter is always willing to share his experiences with others and to learn from others.

Steve Clay (Moderator Technical Panel 1B, 1D), MP&E Specialist, FRA

Steve Clay has been with FRA since April 2004 and has served in various capacities within the agency. As a key member of the FRA/MP&E compliance enforcement team, Mr. Clay provides CFR training and guidance to Field Inspectors and Specialists throughout the MP&E discipline workforce. Within the past 8 years, Steve has been an active member of several newer technology projects to include dual-fuel locomotive (i.e., LNG/CNG) implementation, the introduction of battery locomotive technology and more recently the hydrogen fuel cell technology being implemented in the rail industry.

Mr. Clay has extensive experience in rail accident investigations, leads and conducts special audits and equipment inspections, and special investigations. He prepares technical reports, narratives, and correspondence that are reviewed and endorsed by FRA's counsel and senior management in Washington, DC. He effectively interacts with labor unions, the general public, State, and local governments on matters relating to MP&E safety oversight within the U.S. rail industry.

Prior to FRA, Mr. Clay has worked several years in locomotive rebuild and maintenance management with the Union Pacific Railroad, and he is a retiree of the USCG after 23 years of service in a mechanical and engineering discipline.

Formal Education: Dale Carnegie Training, North Little Rock, AR; University of Houston, Houston, TX; and American History San Jacinto College, Pasadena, TX, where he received a Certificate of Technology in Automotive and Diesel Technology

Dr. Benjamin Schroeder, R&D S&E Chemical Engineering, SNL

Dr. Ben Schroeder obtained his Bachelor's Degree of Science in Bioproducts and Biosystems Engineering at the University of Minnesota in 2010. Thereafter he attended the University of Utah studying Chemical Engineering and received a Ph.D. in 2015. Upon graduation he became a postdoctoral researcher and then staff member at SNL studying verification, validation, and uncertainty quantification topics to improve the underlying credibility of computational simulation-based evidence. Since spring 2021, Dr. Schroeder has been a member of the Fire, Risk, and Transportation Systems department at SNL where he has contributed to a variety of hydrogen safety related projects including rail crash risk analyses, designing hydrogen nodes for port applications, and deploying reduced order models for the risk analysis software HyRAM.

Michael Fore, Director of Technical Services, AAR

In 1993, Michael Fore started as a mainframe and database programmer working with the ICC Carload Waybill Sample project with AAR. Mr. Fore has generated and published various industry Tariffs and the Freight Commodity Statistics while working in the Economics and Finance Department of the AAR. Mr. Fore has managed Industry Reference Files and its associated User Fees program while working briefly for Railinc. After transferring back to the AAR, Mr. Fore worked with various AAR departments to develop and manage an AAR User Fees program. Mr. Fore managed the Equipment Health Monitoring Committee (EHMC) from 2009–2016 and currently manages the Locomotive Committee and the Locomotive Repair Billing and Interchange Rules Technical Advisory Group (2013–present). Mr. Fore also provides support and oversite to the Mechanical Inspection Department (MID) by generating, distributing, and reviewing the MID inspection reports notifications and the corrective action responses to those reports, on behalf of the AAR's Executive Director of Rules and Standards.

Melissa Shurland (Moderator Technical Sessions 1C, 2B), Program Manager, FRA RD&T

Melissa Shurland's research focus is on alternative fuels and motive power technologies for improved efficiency and reduced emission of rail propulsion equipment. Ms. Shurland also manages a portfolio of projects that focuses on issues related to train occupant protection, specifically fire safety, emergency preparedness and accessibility of passenger trains. Ms. Shurland joined FRA in 2007 following a 6-year career as a Car Equipment Engineer at MTA New York City Transit. She obtained a Bachelor of Science Degree in Mechanical Engineering from New York University Tandon School of Engineering (formerly Polytechnic Institute) in 2001.

Philippe Stefanos, Sustainability Advisor, UIC

Philippe Stefanos is a Sustainability Advisor in UIC. Mr. Stefanos is dedicated to the energy efficiency and GHG emissions topics related to the UIC sector that goes by the same name: Energy efficiency and CO_2 emissions Sector, under UIC's Sustainability Platform. Among these missions and projects, Mr. Stefanos take care of organising "best practice workshops," for which are invited railway community actors that develop solutions for energy efficiency improvement and decarbonisation.

Daniel Yuska, Environmental Protection Specialist, MARAD

Daniel Yuska has served as an Environmental Protection Specialist with the MARAD's Office of Environment since 2002. Mr. Yuska helped to develop the META program and leads environmental research and policy focused on vessel and port emissions reductions, energy efficiency, and alternative fuels and technologies. In addition, he has also been a member of the U.S. Delegation to the International Maritime Organization, serving as a technical advisor for air emissions and GHG reduction.

Prior to development of the META program, Mr. Yuska spent several years leading agency environmental planning efforts for major port and intermodal infrastructure projects. He holds Master and Bachelor of Science Degrees in environmental and ecological science disciplines. Mr. Yuska also served as Marine Science Technician in the USCG.

Ben Chursinoff, Program Coordinator/Analysts, RAC

Ben Chursinoff studied political science, economics, and public administration at the undergraduate and graduate levels, his early work with the Saskatchewan Association of Rural Municipalities gave him frontline exposure to how government decision-making is improved with the right inputs from external stakeholders. Since becoming a Policy Analyst and Program Coordinator with the RAC in October 2019, he has worked to advance RAC members' needs and concerns with Federal officials at all levels and across departments. He coordinates the RAC's environment committee, safety culture improvement initiative, and works closely with the Federation of Canadian Municipalities on the Proximity Initiative.

Pete Devlin, Technology Development & Intergovernmental Coordination Manager, DOE Hydrogen & Fuel Cell Technologies Office

As Technology Development and Intergovernmental Coordination Manager for DOE HFCTO, Pete Devlin works on hydrogen and fuel cell technology research and provides support to government agencies in their technology development and deployment activities. Mr. Devlin is responsible for managing DOE research and demonstration projects for hydrogen and fuel cell technologies for transportation and stationary applications. Specific areas of focus recently include rail, marine, and aviation applications.

Prior to his current work, Mr. Devlin was responsible for advanced technology development for fuel cell vehicles, hydrogen production R&D, and advanced combustion engine and fuels for a total of 19 years at DOE. Pete spent the first 12 years of his career in private industry developing advanced propulsion and power generation systems from alternative fuel sources. Trained and educated as an industrial engineer, Mr. Devlin received a Bachelor of Science from Virginia Polytechnic Institute and State University in 1979.

Dr. Claudio Filippone, President, F&A Technologies

Dr. Filippone is the founder of F&A Technologies, an engineering firm dedicated to the development of an array of pollutant reduction technologies for, amongst others, the nuclear and rail industries. Dr. Filippone is an expert in electrical and nuclear engineering. During his career, he has worked on power systems utilized to produce electricity from conventional and advanced nuclear, fossil-fueled and renewable energy sources. His expertise is based on activities dedicated to design, manufacturing and testing of thermal-hydraulic systems to recover and convert waste thermal energy to increase power plant thermodynamic efficiency, while reducing operating cost and pollutant emissions.

Dr. Filippone is currently the technical lead on several multi-million dollar government funded projects granted to F&A Technologies' affiliate companies, including a DOE ARPA-E award to HolosGen LLC to demonstrate the viability of its HOLOS™ transportable gas-cooled micro-reactor concept through the use of multi-physics modeling and simulation tools, as well as a multi-phase grant awarded by FRA to ThermaDynamics Rail LLC for the development of its THERMARAIL™ technology for non-invasive retrofitting waste thermal-energy recovery from diesel-electric locomotives.

Dr. Filippone holds Ph.D. and Master's Degree in Nuclear Engineering from the University of Maryland in College Park, and an Electrical Engineering degree from the Industrial Technical Institute G. Marconi in Verona, Italy.

Russell Kubycheck, ***Manager of the Product Compliance Group at Progress Rail, a Caterpillar Company***

Russell Kubycheck graduated from the University of Illinois with bachelor's degrees in computer engineering. With over 30 years of engineering experience Mr. Kubycheck has worked in the following industries: telecom, aerospace, healthcare, and rail. During that time Russell has focused on defining customer requirements for the development of safety critical systems. Mr. Kubycheck currently holds certifications from TUV-SUD for Functional Safety Expert and from International Council on Systems Engineering (INCOSE) as a Certified System Engineering Professional. Specific to the AAR, Mr. Kubycheck has participated in a few AAR efforts including Locomotive Committee as Vice Chair, and 49 CFR Part 229 Subpart E Task Force as Vice Chair.

Derek Maier, PE, Senior Director - Intercity Trainsets at Amtrak

Derek Maier is responsible for leading the brand-new trainset acquisition as well as the maintenance, diagnostics, and technical support changes necessary to support the new fleet. Prior to this role, Mr. Maier was the Fleet Director for the east coast passenger fleets, some of which will now be replaced by the new trainsets. While with Amtrak, he has led various engineering teams to implement programs for everything from ride quality and wheel wear improvements to onboard and wayside diagnostics programs to major aesthetic refreshes. He has been with Amtrak for over 9 years and previously graduated from the University of Delaware with Master's and Bachelor's degrees in Mechanical Engineering.

Michael Iden (Moderator Technical Session 2A), Consultant focusing on new railroad propulsion technology, with an emphasis on successful technological change, minimizing project risks, and maximizing locomotive operability, maintainability, and reliability

Michael Iden has 48 years of experience in railroad operations and locomotive design, manufacturing, maintenance, and operation, having been employed by three Class I railroads and a major locomotive manufacturer. He is a registered Professional Engineer in three states and was formerly licensed by FRA as a Class I locomotive engineer. As a consultant Mr. Iden has advised railroad and supplier clients internationally and is currently involved in projects involving diesel-electric, fuel cell/battery and all-battery propulsion. He has a Bachelor of Science Degree in Mechanical Engineering from MSE University and a Master of Management degree from Northwestern University.

Michael Cleveland, Senior Manager Emerging Technologies, BNSF

Michael Cleveland is the lead for BNSF's battery electrification and energy storage initiative. Mr. Cleveland has over 10 years of experience with BNSF working in the locomotive department as a technology subject matter expert and project leader. He has successfully implemented projects ranging from EPA engine certifications to battery electric locomotive equipment. Mr. Cleveland formed and led BNSF's battery electrification team, which aims to reduce the environmental footprint and costs through the implementation of vehicle technology projects leveraging emerging energy storage technologies. Throughout this initiative BNSF has implemented battery electric yard tractors, side-loaders, hybrid rubber tire gantry cranes, and battery electric locomotives. He led BNSF's partnership with Wabtec in the development, manufacturing, and demonstration of the first linehaul battery electric locomotive. This locomotive operates within a consist of other conventional diesels to form a hybrid consist. He has a Master's Degree in Mechanical Engineering from Texas A&M University and a Bachelor of Science degree in Physics from Austin College in Sherman, TX.

Rod Keefe, Vice President, Advanced Technology, Grupo Mexico Transportes, FEC

Rod Keefe joined the FEC, now owned by Grupo Mexico Transportes (GMXT), in 2013 as Vice President of Advanced Technology following an extensive career with another Class I railroad. At FEC, Mr. Keefe is responsible for pursuing projects serving train operations including the installation of PTC, the implementation of a new CAD, LNG revenue shipment management, and the conversion of the FEC mainline locomotive fleet to utilize LNG as a locomotive fuel for revenue service. Mr. Keefe is also responsible for the Information Technology team and functionality at FEC. Mr. Keefe attended the Purdue School of Engineering at Indiana University–Purdue University Indianapolis and holds a Master of Business from Jacksonville University.

Carrie Schindler, Director of Transit and Rail Programs for the SBCTA

Since 2015, Carrie Schindler has been responsible for delivering the promises of Measure I, San Bernardino County's half-cent transportation sales tax as it relates to transit and rail efforts. She joined SBCTA in 2012 as Chief of Fund Administration after spending 10 years with the County of San Bernardino where she served in many capacities including Resident Engineer and Chief of Transportation Planning. Prior to joining the public sector, she worked in the private sector on transit related efforts in the San Diego area. Ms. Schindler is a graduate of San Diego State University in Civil Engineering and a registered Professional Engineer in California.

Noah Heulitt, Regional Lead for Alstom's Rolling Stock Sales, Business Development and Rolling Stock Commercial Strategy and Capture Planning

Noah Heulitt has over 14 years of experience in increasingly responsible roles at several companies with a focus on services and rolling stock, including Bombardier Transportation and Arcelor Mittal. In his role with Alstom, Mr. Heulitt is responsible for coordination with Alstom's global engineering and product management teams to set product strategy for the North American market.

Mr. Heulitt is a recognized executive with heavy equipment, operations, and industrial systems experience in the Transportation and Steel Sectors. He has extensive experience in project delivery with profit and loss accountability, client relationship management, business development, and line leadership of both professional and union employees in an industrial

setting. He also holds a Bachelor's in Science in Mechanical Engineering from Temple University.

Greg Wright, Senior Engineer at Wabtec Corporation Within the Advanced Technology Group

Greg Wright has more than 13 years of experience in the rail industry, working in various roles spanning from engine, cooling, systems to product management. In his current role, he is helping lead the decarbonization efforts for future products within Wabtec.

Francisco Dóñez, Air and Radiation Division at the EPA Pacific Southwest Regional Office (Region 9)

Francisco Dóñez leads the Ports and Railroad sector workgroups for the West Coast Collaborative, a public-private partnership to reduce air pollution from heavy duty diesel engines. He also spearheaded agency outreach to regional environmental justice communities affected by diesel pollution. Dr. Dóñez completed his Ph.D. in Energy and Resources at the University of California, Berkeley. His prior academic training includes a Bachelor of Science Degree in Mechanical Engineering from Massachusetts Institute of Technology, and a Master's Degree in Public Policy from Georgia Institute of Technology.

Justin Hwang, Air Resources Engineer, California Air Resources Board

Justin Hwang has been working in the CARB's locomotive group since 2017. He and his team work primarily on analyzing and reducing emissions from locomotives and railyards in California, and their latest efforts are focused on developing the CARB In-Use Locomotive Regulations. He provides essential analyses and has helped shape the current regulation in development. He provides key support on railroad operations, emissions estimates, locomotive technologies, and more for the technical feasibility and economic analysis of the regulation. His current and previous work includes locomotive emissions verification, development of a Draft Truck vs Train Emissions Analysis; coordinating and presenting CARB's In-Use Locomotive Regulation workshop Technology Day; is a key member of the Zero-Emission Heavy Transport Group that is a California interagency workgroup that focuses on prioritizing zero emission rail; supporting CARB's Class 1 Locomotive Emissions Inventory update; and analysis of annual data provided by Union Pacific and BNSF in the South Coast Air Basin made possible by the 1998 Locomotive NOx Fleet Average Emissions Agreement.

Mr. Hwang received his PhD in Mechanical and Aerospace Engineering at the University of California Davis with a focus on hydrogen and natural gas combustion, after serving in the U.S. Army Transportation Corps.

Angelo Logan, Policy and Campaign Director for the Moving Forward Network and Co-founder of East Yard Communities for Environmental Justice

For 20 years, Angelo Logan has been advocating for his community and communities across the country impacted by industrial and transportation pollution. Mr. Logan's life experience allows him to provide his perspective through an environmental justice and equity lens.

Angelo serves on the White House Environmental Justice Advisory Council- Member, Harbor Community Benefit Foundation Board of Directors, Social and Environmental Entrepreneurs Board of Directors, California EV Charging Infrastructure Strike Force Co-Chair.

Appendix B.
Workshop Registration

First Name	Last Name	Affiliation
Adair	Fleming	US DOT
Adam	Klingbeil	Wabtec
Ajay	Mangat	California State Government
Allen	Doyel	Burlington Northern Santa Fe Railway
Allen	Meek	Cummins
Allison	Glass	US DOT
Alyson	Azzara	US DOT
Amgad	Elgowainy	Argonne National Laboratory
Angelo	Logan	Academia
Anil	Kapahi	Jensen Hughes
Arash	Shahabi	Union Pacific
Barbara	Klein Barr	US DOT
Bart	Sowa	GTI
Ben	Chursinoff	Railroad Association of Canada
Benjamin	Schroeder	Sandia National Laboratories
Brian	Ehrhart	US DOE
Carlo M	Borghini	Shift2Rail
Carolyn	Hayward-Williams	US DOT
Charles	Myers	US DOE
Charles	King	US DOT
Charlotte	Thalhammer	Stadler
Chris	LaFleur	Sandia National Laboratories
Chris	Miller	Canadian National
Cynthia	Woodlock	US Coast Guard
Daniel	Yuska	US DOT
Daniel	McNair	Wabtec
Daniel	Blais	Transport Canada
David	Reeves	KCS Southern Railroad
David	Valenstein	US DOT
David	Scott	CNG Motive
Dilani	Abeywickrama	Canadian National
Elena	Merritt	Funds for Railway Accidents Involving Designated Goods, Canada
Elizabeth	Carper	Washington State Government
Emily	Mak	Southern Railway of British Columbia
Eric	Dillen	Stadler
Eric	Banghart	Mott MacDonald
Eric	Feeley	Oregon State Government
Francisco	Gonzalez	US DOT
Francisco	Donez	US EPA
Francois	Belanger	Canadian National
Frank	Maldari	Long Island Railroad

First Name	Last Name	Affiliation
Fred	Mottley	US DOT
Genevieve	Saur	NREL
Greg	Moreland	US DOE
Greg	Wright	Wabtec
Guadalupe	Contreras	US DOT
Gurpreet	Singh	US DOE
Harold	Weisinger	US DOT
Jackson	Xue	American Public Transportation Association
Jacob	McBane	Transport Canada
Jason	Hill	US DOT
Jeffrey	Gordon	US DOT
Jerainne	Heywood	Wabtec
Jeremy	McGarry	Wabtec
Jo	Strang	American Short Line & Regional Railroad Association
Joe	Viscek	Foreign Government Agency
Johannes	Lorenz	Stadler
John	Mikulin	US EPA
John	Kopasz	US DOE
Jonathan	Boese	Ontario Northland Railroad
Jonathan	Brodkin	KCS Southern Railroad
Joseph	Lopat	California State Government
Joy	Buenaflor	California State Government
Justin	Hwang	California State Government
Kari	Jacobsen	US DOT
Keith	Nordin	Southern Railway of British Columbia
Kennan	Beard	Sierra Railroad
Kerri	Swail-Born	Transport Canada
Kevin	Bailey	Wabtec
Kyle	Beauliua	Transport Canada
Laszlo	Czihaly	Southern Railway of British Columbia
Laura	Sullivan	US DOT

First Name	Last Name	Affiliation
Leonard	Evans	US DOT
Leonardo	Dongiovanni	ERA
Lijin	Sun	California State Government
Lisa	Colicchio	Southern California Railroad Authority
Lisa	Matta	Wi-tronix
Lucie	Anderton	UIC
Lynn	Harris	Deutsch Bahn
Marie	Plaud-Lombard	UIC
Mark	Maday	US DOT
Mark	Duve	Rail industry manufacturer/supplier
Mark	Schulze	Burlington Northern Santa Fe Railway
Markus	Spillmann	Stadler
Matt	Krech	Transport Canada
Matthew	Brewer	US DOT
Matthew	Findlay	Canadian Pacific Railroad
Matthew	Bogden	US DOT
Melissa	Shurland	US DOT
Michael	Cleveland	Burlington Northern Santa Fe Railway
Michael	Faust	Railroad
Michael	Iden	Independent
Michael	Weismiller	US DOE
Michael	Cleary	Alstom
Michael	Faust	Railroad
Michael	Fore	Association of American Railroads
Mike	Morris	California State Government
Monique	Stewart	US DOT
Murray	MacBeth	Genesee & Wyoming Railroad
Narayana	Sundaram	American Public Transportation Association
Nazib	Siddique	Argonne National Laboratory
Nick	Laverick	Mott MacDonald

First Name	Last Name	Affiliation
Nirwair	Bajwa	Canadian Pacific Railroad
Noah	Heulitt	Alstom
Oscar	Delgado	International Council on Clean Transportation
Patrick	Jacob	Alstom
Patrick	Student	Independent
Paul	Nissenbaum	US DOT
Paul	Izdebski	Transport Canada
Pedro	Santos	CNG Motive
Pete	Devlin	US DOE
Peter	Chen	California State Government
Peter	Smith	US EPA
Philippe	Stefanos	UIC
Raghu	Chatrathi	CSX Railroad
Raphael	Isaac	US DOE
Richard	Zavergiu	Transport Canada
Robert	Fronczak	Association of American Railroads
Robert	Ledoux	US DOE
Robert	Jones	Stadler
Robert	Bouffard	Ontario Northland Railroad
Rodney	Keefe	Florida East Coast Railway
Roozbeh	Hosseini	Transport Canada
Roy	Chen	US DOT
Ryan	Steinbach	US DOT
Ryan	Sharpe	State Government
Samir	Mulgaonkar	California State Government
Scott	Chart	Chart Industries
Scott	Myers	Optifuel Systems
Sean	Cronin	Metra Railroad
Shawn	Wang	California State Government
Sidarta	Beltramin	Progress Rail

First Name	Last Name	Affiliation
Stan	Thompson	Independent
Stefan	Bernsdorf	Stadler
Steve	Griffith	National Electrical Manufacturers Association
Steve	Fritz	Southwest Research Institute
Stan	Thompson	Independent
Stefan	Bernsdorf	Stadler
Steve	Griffith	National Electrical Manufacturers Association
Steve	Fritz	Southwest Research Institute
Tamer	Yassa	Transport Canada
Tarek	Omar	US DOT
Tarek	Elkhatib	Union Pacific
Ted	Barnes	GTI
Theodore	Krause	Argonne National Laboratory
Theresa	Romanosky	Association of American Railroads
Timothy	Meyers	US Coast Guard
Tony	Roberts	KCS Southern Railroad
Troy	Johnson	US DOT
Ursula	Green	Transport Canada
Vishal	Kochar	Wabtec
Wes	Swift	Sierra Railroad
Wolfgang	Fengler	FMW Solutions
Yan	Zhou	Argonne National Laboratory
Yunnie	Osias	California State Government

Abbreviations and Acronyms

ACRONYMS	EXPLANATION
ARPA-E	Advanced Research Projects Agency-Energy
APTA	American Public Transportation Association
ASLRRA	American Short Line and Regional Rail Association
ASME	American Society of Mechanical Engineers
AAR	Association of American Railroads
BEL	Battery-Electric Locomotive
BNSF	Burlington Northern Santa Fe Railway
CARB	California Air Research Board
CP	Canadian Pacific Railroad
CO_2	Carbon Dioxide
CFR	Code of Federal Regulations
CNG	Compressed Natural Gas
CAD	Computer-Aided Train Dispatching System
DERA	Diesel Emission Reduction Act
DMU	Diesel Multiple Unit
EMU	Electric Multiple Unit
EC	European Commission
ERTMS	European Railway Traffic Management System
ERA	European Union Agency for Railways
FLIRT	Fast Light Intercity and Regional Train
FRA	Federal Railroad Administration
FEC	Florida East Coast Railway
GM	General Motors
GHG	Greenhouse Gases
HiP-HEX	High-Pressure Heat Exchanger
HFTO	Hydrogen and Fuel Cell Technologies Office
HP	Horsepower
IGF	International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels
UIC	International Union of Railways

ACRONYMS	EXPLANATION
kg	Kilogram
kWh	Kilowatt-hour
LNG	Liquefied Natural Gas
LMOA	Locomotive Maintenance Officers Association
L-WHRS	Locomotive Waste Heat Recovery System
MARAD	Maritime Administration
META	Maritime Environmental and Technical Assistance
MOU	Memorandum of Understanding
MWh	Megawatt Hour
MRS	Mexican Railway System
MMT	Million Metric Tons
MP&E	Motive Power & Equipment
MU	Multiple Unit
NBB	National Bio-Diesel Board
NFPA	National Fire Protection Agency
EERE	Office of Energy Efficiency and Renewable Energy
RD&T	Office of Research, Development and Technology
PM	Particulate Matter
PEM	Polymer Electrolyte Membrane
PTC	Positive Train Control
Q&A	Question & Answer
RSAC	Rail Safety Advisory Committee
RAC	Railway Association of Canada
ARTF	Regulatory Agency for Rail Transport
RGT	Reliability Growth Testing
R&D	Research & Development
RD&D	Research, Development and Demonstrate
ROI	Return on Investment
SCS	Safety Codes and Standards
SBCTA	San Bernadino County Transit Authority
SNL	Sandia National Laboratories

ACRONYMS	EXPLANATION
SNR	Sierra Northern Railway
SNCF	Société Nationale des Chemins de Fer Français
TRISO	Tri-Structural Isotropic Particle
USDA	U.S. Department of Agriculture
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
USCG	U.S. Coast Guard
EPA	U.S. Environmental Protection Agency
ZEHTRANS	Zero Emission Heavy Transport
ZEMU	Zero-emission Multiple Unit