Response to U.S. Dept. of Energy RFI- Progression to Net-Zero Emission Propulsion Technologies for the Rail Sector

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The Rail Passenger Association of California and Nevada (RailPAC) is an all-volunteer non-profit passenger rail advocacy group representing the interests of rail passengers since 1978. Thank you for the opportunity to provide comment on the vital issue of zero emission rail technologies.

Responses to RFI Questions

General Questions:

1 **What is your view of zero-emission, or net-zero emission, rail propulsion technologies in the next 5 years? 10 years? 30 years? In your response, please include which rail propulsion technologies for line-haul and railyard operations do you see developing most promisingly. Please provide as many details as possible e.g., battery chemistry for batteries, charger type for electrification, fuel cell vs combustion, feedstock source, etc.**

For the DOE's Office of Energy Efficiency & Renewable Energy, overall energy efficiency is of utmost importance for evaluating and comparing different rail propulsion technology options. Electric trains, powered by overhead catenary wires or third rail, provide the most energy efficient way of rapidly moving large numbers of people or freight over land. A conventional electric train does not have to store its fuel supply onboard or carry its weight. Instead, it takes its energy from an external source, on an as-needed basis where the energy goes straight to the traction motors. In addition, with fewer moving parts, electric trains have proved to be much more dependable and less costly to maintain than diesel powered trains. Electric trains are zero emissions at the point of use and can use power generated from a wide mix of sources including renewables.

Whether for light rail trains, high-speed rail or heavy freight trains, electric rail (using an external power source- overhead wire or third-rail) is the most energy efficient and greenest way of powered transportation over land. The rest of the world knows how to do this well. In terms of overall energy efficiency, conventional electric trains are about three times more efficient than diesel or hydrogen, and about 1.2 times more efficient than battery trains[1]. According to a March

[1] https://www.rssb.co.uk/en/research-catalogue/CatalogueItem/T1145

12, 2023 *Railway Age* article by Mike Iden[2], total 'input-to-wheel' energy conversion locomotive efficiency was calculated to be:

- Catenary wire electric- 90%
- Catenary wire electric with battery tender- 86%
- Battery electric- 77%
- Green hydrogen- 39%
- Diesel with battery tender- 36%

Why is DOE assuming that we have to wait until after 2030 for overhead contact system (OCS), overhead catenary, electrification to be an option? It is available right now. Rail electrification with OCS has been proven for over 100 years for all types of railroad operations. The best bet for many regional rail lines in the metro areas of New York/New Jersey, Chicago, Boston, Philadelphia, Denver and soon San Francisco-San Jose, for example, is to expand existing direct rail electrification w/ overhead wire, before 2030. Ammonia, methanol and hydrogen are very expensive and impractical ways to power most rail operations for the short-, mid- and long-terms, due to the inherent limitations and complexities caused by the laws of physics.

5-Years:

In California, new Caltrain electric Stadler trainsets will start carrying passengers in 2024 under 25 kV catenary wire, and electric rail systems using the same 25 kV technology will soon begin construction on Brightline West (between Southern California and Las Vegas) and California High Speed Rail (in the Central Valley).

More rail operations will use 'renewable' diesel (from plant sources). New Amtrak hybrid locomotives being delivered as part of the Airo trainset procurement. More expansive in-service operations yard and mainline, will occur with the first generation vehicles yielding additional performance and reliability data. The operation of mixed diesel and battery or hydrogen locomotives in power consists will occur more broadly.

Some exploratory financial proposals will be finalized to de-risk the installation of overhead catenary. Combined with lower estimates of OCS per mile construction costs the attractiveness the financial packages and the combining battery locomotives and OCS on high volume mainlines will generate construction proposals.

10-years:

True HSR service utilizing OCS technology in-service between Rancho Cucamonga, CA and Las Vegas and between Merced, CA and Bakersfield, CA. OCS being extended in conjunction with route construction San Jose to Chowchilla, CA, Bakersfield, CA to Palmdale, CA and Rancho Cucamonga to Los Angeles. Full service of discontinuous OCS electrification/hybrid

[2] https://www.railwayage.com/mechanical/locomotives/follow-the-megawatt-hours-hydrogen-fuel-cells-batteries-and-electric-propulsion/

battery service will start (UTA and Caltrain). With OCS expanded from San Jose to Gilroy, Caltrain discontinuous OCS electrification/hybrid BEMU's extended to Salinas, CA.

On freight lines, depending on the railroad, yard and mainline testing will continue. Mixed consists of diesel and battery units or diesel and hydrogen units will become more common. Railroads exploring battery units will construct segments of catenary on staging tracks and on grades to extend the range of battery units.

15-years:

Overhead wire electrification, combined with battery propulsion, with sections on catenary, comes into widespread use on regional rail networks, intercity, high speed rail and on key high volume freight mainlines. On some of these freight lines the segments of discontinuous catenary is extensive enough allow battery electrics sufficient range to replace the mixed diesel and battery electric locomotives on trains. Some first generation hydrogen units retired and replaced with improved battery electrics now supported by segments of discontinuous catenary.

2 **What efforts are you aware of to decarbonize rail transportation, including ways to reduce diesel fuel use? Are you aware of intermediate decarbonization milestones for rail transportation? Are you aware of longer term decarbonization goals for rail transportation? If so, describe how those goals might be met, including whether low-carbon biofuels will play a role.**

China, Russia, India, Japan, South Africa and other nations in Europe and Asia have extensive electrified rail networks powering the majority of their rail traffic, including on long-distance lines and the heaviest freight trains. The European Union as a whole has electrified over half of total railroad network miles. Switzerland, Laos, Amenia and Ethiopia and Djibouti are nearly entirely electrified. India is on track to complete electrification of 100 percent of all mainline railroad tracks in 2024. India has been steadily electrifying thousands of route miles every year, something which US railroads claim is impossible and prohibitively expensive (though they provide no economic analysis to back up that claim). The International Energy Agency strongly endorses electric rail as a strategy to reduce fossil fuel consumption.

The United States has electrified less than 1% of the nation's rail miles. A wide variety of rail operations around the world have demonstrated that overhead catenary on main lines is overall less expensive than maintaining and operating an all-diesel fleet for an equivalent level of heavy service on main lines. The multi-agency *U.S. National Blueprint for Transportation Decarbonization* was released in January 2023. It overlooked proven rail electrification technology, and did not point out how the US is global outlier in not adopting this technology.

In California, green passenger rail on all commuter and intercity corridors are operated using renewable diesel (from recycled vegetable oil), and the hydrogen multiple unit will start testing in 2024 on service on Metrolink's Arrow Service linking Redlands with San Bernardino. Caltrain electrification is effectively completed between San Francisco and San Jose, with testing underway and full service scheduled to start in the fall of 2024.

3 What are the benefits and challenges of the various rail propulsion technologies as compared to the other alternatives? If possible, please provide a ranking of the alternative technologies starting with the most viable/promising option.

1. Electric rail (external power) Overhead Catenary, or Overhead Contact System (OCS)

Pros:

- Proven technology, off the shelf commercial product in use worldwide in a range of conditions, operating demands, etc.
- Highest efficiency (90% or more), greatly exceeding that of alternative technologies. A conventional electric train does not have to store its fuel supply onboard or carry its weight.
- Lowest operating cost of all alternatives generating significant future savings.
- Cost of 'fuel' (electricity) is much less than equivalent diesel power.
- No investment in fueling or battery charging stations
- Limited or no upgrades to power grid required for implementation
- No out of service time for fueling or battery charging, equals more frequencies.
- High power to weight ratio enables faster acceleration, reduced schedules resulting in higher ridership and ticket revenue.
- Proven resiliency and long-service life.
- With far fewer moving parts, electric trains have proved to be much more dependable than diesel powered trains, with less down time.
- Traction performance and range not impacted by severe heat or cold conditions
- Almost unlimited peak time power available for critical short-time accelleration
- An electric locomotive also can have much greater power per unit than diesel, so fewer locomotives are needed on a multi-locomotive train to do the same job. Far better performance up mountain grades than diesel.
- No refueling or battery charging time means less trainsets required.
- Combination of agency owned behind-the-meter solar and battery storage facilities can provide an opportunity to substantially reduce operating costs (power) along with an upside revenue potential from power sales to the grid during grid peak power demand.
- Lower life cycle costs than other alternative technologies.
- Electric Multiple Units (EMUs) distribute motor power traction along the entire length of the train. EMUs outperform other passenger trains in every respect: speed, acceleration, passenger comfort, energy consumption, O&M costs, reliability, and lower procurement costs.
- Around the world, there is the "sparks effect", a documented increase in passenger train ridership following electrification. This is because electric trains have:
    - Increased train speed and frequency due to better acceleration
    - Passenger comfort (quieter, smoother ride, no smoke)
    - Increased reliability (fewer train breakdowns)
    - Lower equipment, operation and maintenance (O&M) costs means passenger railroads can invest more in frequent service.

Cons:

- Large upfront capital cost (though much lower in other countries than recent US projects).
- Service cannot begin until the entire route including ancillary tracks is electrified.
- Requires change in operations. Electrified service limited to electrified lines, locomotive changes required.
- Opposition from lineside stakeholders (usually only for aesthetic reasons) can delay the entire project for years.
- All costs are borne within an agency's budget (for public projects).
- Limited manufacturer/promotion by industry in the U.S.
- One reason OCS is avoided by freight railroads is that if they acknowledge its potential they would have to start implementing near-term this available technology.

2. Battery-OCS hybrid or "Discontinuous Electrification":

Battery combined with sections of overhead catenary. Using battery power on an electric locomotive or multiple-unit in a hybrid combination with an overhead pantograph enables it to move between sections of overhead wire. This eliminates the need to electrify each mile of track no matter whether it's a terminal service track, low volume connecting track or siding, etc., It also allows select sections to be bypassed where there is opposition to catenary through historic neighborhoods, scenic line segments, etc. While there is often a comparison between the flexibility of battery electric propulsion vs. the operational efficiency of complete OCS electrification, with discontinuous electrification is a blended alternative that combines the advantages of both while at the same time mitigating many of the challenges involved with each technology.

Pros:

- Addresses the range limitation of batteries and the high upfront costs of overhead catenary electrification
- Incremental phase-in; vehicle battery investment and catenary investment can be balanced to produce the optimum performance.
- Avoids the high cost of grid upgrades for central battery charging facilities.
- Avoids conflicts with lineside stakeholders with concerns over catenary.
- High efficiency levels ~80 – 85% energy efficiency depending on the percentage of track miles with catenary.
- Among the lowest long-term operating costs.
- During transition can integrate with existing equipment and power consists.
- Investment timeline for further catenary investments can match service requirements and the level of grant awards.
- Can be incremental first step to full overhead catenary electrification.
- Several Europe-based manufacturers already offer OCS-battery hybrid streetcars, light rail, trainsets and locomotives.

-The first OCS-battery hybrid locomotives were built over a century ago, so the technology is well-established compared to other technologies.

Cons:

- Lack of economies of scale in the cost per mile for segments of overhead catenary.
- Complexity and costs of the mix of technologies.
- Other technologies benefit from compete vendor packages and promotion and is an unknown concept not well understood by grant awarding entities.
- Early phase-in pairing with diesel locomotives for reliability/range during testing may create a challenge with some stakeholders.
- Weight of batteries will have an impact on passenger train performance.

3. Battery (only) power

Pros:

- Less technologically complex than hydrogen
- Benefiting from auto experience, a more fully developed technology; less risk
- ~75%-80% overall energy efficiency, more than double that of hydrogen
- No fundamental operational changes required
- Potentially lower upfront costs or costs borne by others (power companies)
- One-for-one unit replacement
- Heavy weight of batteries can be an advantage for freight locomotives.
- A benefit for battery technology is the ongoing battery research and development by the automobile companies.

Cons:

- Battery technology with the capability to deliver range and schedule turn times still under development, increased risk.
- Cost of batteries required leads to much higher rolling stock cost compared to OCS.
- Battery trains have higher O&M costs compared to straight-electric trains.
- Cost of grid improvements to support high power demand central charging facilities.
- Unit range and recharging time lower than alternative technologies.
- Weight of batteries reduces power to weight ratio negatively impacting acceleration/schedule performance of passenger trains.
- If charging time is required during the daily schedule cycle then equipment utilization is negatively impacted and additional trainsets are required to maintain published schedules.
- Cost of grid improvements provided by others reflected in electricity costs, as battery trains are less energy efficient than OCS electric trains.
- Battery performance/range negatively impacted by high heat or severe cold conditions.
- Safety hazards of battery fires and chemical spills in a derailment

- Environmental impacts of mining and processing battery materials, including GHG emissions.
- Disposal of used batteries, recycling/toxic waste disposal adds costs and risks.

4. Hydrogen

Pros:

- Incremental phase-in of technology and hydrogen powered units
- Longer range than battery(only) trains
- Promise of minimal required operational changes, due to shorter fueling time
- Potentially lower upfront costs or costs borne by others (fuel companies, government agencies)
- A lot of support and investment by cash-rich major oil and gas companies.

Cons:

- Lowest overall energy efficiency of any of the alternatives (less than 40%). Even if the hydrogen comes from green sources, it would require three times the amount of overall energy compared to an electric train connected directly to the grid.
  More costly and complex technology than other technologies. High costs of hydrogen production, cost of carbon capture, cost of fuel transport and storage and cost of fueling facilities. High upfront cost of hydrogen infrastructure and supply chain.
- Sources of hydrogen are still overwhelming from fossil fuels, risk of “greenwashed” hydrogen
- Cost of carbon capture (grey hydrogen) and risk of leakage from carbon capture facilities
- Water supply an issue in the Western U.S. for “green hydrogen” sourced from electrolysis, due to common drought conditions.
- Cost of hydrogen fuel is uncertain, and has recent jumps in price. Many potential external costs which will be reflected in fuel costs.
- Price of non-green hydrogen fuel subject to subject to market forces and international political tensions.
- Weight of fuel cell, hydrogen storage containers and batteries negatively impacting acceleration and schedule performance, along with taking up space on passenger trains.
- Low energy density compared to other fuels, and poor energy efficiency and risks of storing it energy-intensive compression or cooling.
- Range, while better than that of battery-only trains, is only a fraction of that of diesel
- Poor performance in cold weather (as in the case of Alstom units in Germany).
- Technology and its capabilities still under development, high number of unknowns
- Battery development running apace with hydrogen improvements yielding little net gain for hydrogen.
- Safety risks of hydrogen leakage and fire danger.

4. **What obstacles to rail decarbonization is the industry facing? What plans can be put in place to overcome these challenges?**

Macro Issues:

For OCS it is clearly financing and upfront costs before service can start. This proven technology is also often prematurely dismissed out of hand by US railroads and government agencies.

For hydrogen clearly cost; upfront capital costs of the technology (rolling stock, fueling stations and infrastructure), higher maintenance and operations costs, and the potentially volatile cost of fuel. Then there is the issue of energy efficiency and impact on the grid, dirty grey hydrogen and carbon storage, along with possible safety risks of leaking hydrogen.

For batteries cost of batteries and range issues even assuming major improvements in battery technology.

Fleet management:

For the freight railroads it is extra complication of managing and distributing various types of locomotives. They do this already to a degree distributing newer locomotives for mainline use, older locomotives for secondary trains and locals and yard locomotives. Having a mainline fleet of pure electric locomotives and pantograph- -equipped battery hybrid electric locomotives adds a layer of complexity. A challenge, but one that is not an impossible task.

Capital costs and financing:

The main obstacle to OCS electrification is the upfront capital cost of overhead wire and supporting electrical infrastructure. In the case of the recent Caltrain electrification project between San Francisco and San Jose, the cost was about $14 million/route mile, much higher than the world average. However, many of the reasons for this include limited experience in the US with electric mainline rail technology and its construction. In Germany, for example, the labor pay scales, material costs and environmental regulations are not much different from the US, yet the cost of overhead wire catenary and supporting infrastructure is much less (as low as $2 million/route mile). The high upfront capital costs for rail electrification need to be viewed in the context of the several-decade lifespan of the infrastructure investment, the cumulative avoided cost of diesel fuel, locomotive maintenance and the pollution impacts of diesel locomotives over the same period. The experience of railroads around the world has shown that the lower operating and maintenance costs of electric trains will result in lower costs over the long run.

Reducing the cost of OCS infrastructure:

- Reducing costs related to obstacles encountered along a railroad track, such as bridge and tunnels, are key. Bridge and structure clearance innovations such as under-cable support

structures, conductor bars, insulating covers/coatings, surge arresters, and use of neutral sections under bridges.
- Electric trains can also just ‘ride through’ short segments without an overhead wire, and this is done around the world.
- Composite masts, with lighter weight so can enable smaller foundations, reducing installation costs. Wider spacing between masts can also reduce costs of OCS installation.
- Thorough review of current state of the art international best practices. Standardization, mass production, modularity can also be based on established international standards.
- Use of proven, reliable systems is key to reducing costs.

Entrenched institutional bias against rail electrification:

Perhaps the biggest obstacles to rail electrification in North America are not technical, but more financial, political, and even cultural/ideological. There is a longstanding institutional opposition in the US to rail electrification, despite the technology being proven and economically viable for all types of rail operations around the world.

In discussion about rail electrification in North America, private track ownership is assumed to automatically nix electrification. Typical objections raised by the US railroads against electrification include legitimate concerns about employee safety, clearances, and potential electromagnetic interference with signal and communication systems. These are all valid concerns, but whatever technical/safety issues that the Class Is bring up can be resolved, as these issues have already been resolved in electric rail operations worldwide. Overcoming the Class I resistance is possible because it has already happened. US Class I railroads have long operated freight under electrified wire, even if the locomotives themselves are diesel (the last Conrail electric train ran in 1981). Freight trains regularly run on the Northeast Corridor and several of its branches, including double-stacked container trains in Pennsylvania. Between Los Angeles and Fullerton (22 miles), BNSF Railway has agreed to California High Speed Rail Authority installed over tracks on the busy Southern Transcon mainline it owns, with overhead catenary wires high enough for double-stacked container freight trains to run under them.

The planning of a proposed passenger or freight rail route or service should strive to minimize adverse impact on affected communities, with full consideration of mitigation measures such as electrification. A handful of trackside residents in affluent communities have filed lawsuits against construction of electrification infrastructure along a rail corridor merely on aesthetic grounds. Such unreasonable opposition to infrastructure development harms both the environment and mobility for society at large. To meet the challenge of climate change and many other environmental and societal problems related to transportation, this tension between local and macro priorities needs to be addressed.

5. **For direct electrification of rail, how do you foresee the infrastructure (such as overhead catenary) being built? Who should own and operate the infrastructure?**

Infrastructure is often the “weakest link” in adopting a new technology. However, rail electrification infrastructure is a well-understood technology. There are many models from around the world for how electric rail infrastructure is built, owned and operated. Railroads, but also public agencies and electric utilities could be owners of rail electrification infrastructure.

Multiple financial strategies are the key goal. The construction of OCS needs to be de-risked to protect the freight railroads against bankruptcy in case an economic downturn occurs during OCS construction before it is completed and its benefits can accrue to the finances of the railroad. One option from the financial perspective, is to structure any construction loans for catenary construction be “off the books” until construction is completed. This would avoid the railroads facing a short-term negative impact to their quarterly earnings reports.

One key factor that can influence the structure of financial packages is that fact the traditional overhead catenary and electrification generates substantial operating and maintenance cost savings and productivity. These will allow the financial packages to include internal railroad capital and specifically designed loans ones with long repayment terms and forgiveness guarantees in case of economic downturn before construction is completed.

OCS can be owned by the railroads, utility companies or private sector investment funds that invest in green technology. Because OCS electrification generates major cost savings, investment firms looking for long-term stable income – strong income with bond type safety would find this project attractive. The investor would finance and build the catenary based on a long-term agreement with the railroad to buy the electricity. One option would be tax credits utilized to create a very attractive investment for the railroads or private investors to decarbonization of the rail industry. Another option would be tax free Private Activity Bonds as part of an investment strategy to allow investors an attractive tax-free investment.

6. **What collaboration with any other entities do you think will be necessary to support the decarbonization of rail transportation?**

Electric utilities will be key for the decarbonization of rail transportation, and must be involved in planning for rail electrification from the outset. While there would be a need to construct new electric power infrastructure to serve electrified freight rail lines, electric utilities could see the new loads from freight trains as a business opportunity. Energy storage connected to electric rail catenary, and wayside energy storage systems (WESS) could be located at passenger train stations and along freight railroads. Under utility control, these distributed energy storage systems could be charged at off-peak hours, provide power to the local distribution grid during periods of peak power grid demand, and provide ancillary services such as voltage and frequency support, reactive power, or aid integration of distributed solar energy systems. A sufficient level of energy storage along a rail line could provide backup power in case of a local or regional power outage.

7. **What are the most critical gaps (e.g., with respect to standards, regulations, supply chain, labor) that need to be filled to support acceptance of and markets for alternative rail propulsion technologies?**

The biggest barriers to achieving decarbonization of rail are the intransigence of the rail industry and public perceptions that new and different is always better. The public is always gravitates to the something new, especially if it constantly promoted as the "future". This is fundamentally a gap in understanding. The rail industry wants to delay change from diesel operations and their focus on generating maximum return from existing assets with minimum capital investment. Adding additional assets - catenary, charging stations or hydrogen fueling supply chain undermines their prime focus. As a result there are tremendous gaps in understanding about OCS in the North America rail industry, along with industry intransigence and government inaction on rail electrification.

Taking a global perspective, the term "alternative rail propulsion technology" is not very descriptive or useful. It is implied that "alternative" means near-zero or zero-emissions technologies. However, all-electric, zero-emissions trains that most Americans would consider 'alternative' or even 'exotic' have been an everyday experience in many other countries for decades. For example, in Switzerland a polluting diesel locomotive would be considered 'exotic' because they are so rarely used- the Swiss rail network's mainlines have been completed electrified since 1967.

There is a wealth of global experience and proven "off the shelf" technology that the U.S. can utilize to address its transportation issues, particularly for rail electrification. Manufacturing capacity needs to be developed for U.S rail electrification, not just for locomotives and EMU rolling stock, but also OCS infrastructure (masts, insulators, etc.). Construction contractor experience and skills need to be developed.

8. **What infrastructure is required to support promising alternative rail propulsion technology? Are there specific routes, railyards, or network segments that would be a good candidate for alternative propulsion technologies (e.g., catenary, hydrogen fuel cells, or batteries)?**

Overhead catenary is needed on the core high traffic volume mainlines with traction substations, switching and paralleling stations along railroad tracks. The combination of discontinuous catenary and battery electric pantograph equipped electric locomotives can allow an incremental start to mainline electrification. After core mainlines are electrified with OCS, these pantograph equipped battery electric locomotives can shift to secondary routes equipped with discontinuous catenary. Yard locomotives would be pantograph equipped battery with key yard tracks seeing high power loads having catenary to increase hours of daily service and for recharging.

One factor that must be considered is that OCS trains pull their power load balanced across the utility's multiple power grid circuits as the train travels along its route. Battery electric trains would pull a high power load at specific terminal endpoint charging stations in the range of several megawatts (MW). This would require a substantial investment in utility electrical infrastructure beyond the rail line. Current technology requires at least several hours for a battery train to be fully recharged. Battery-powered trains have lower overall energy efficiency than

OCS electric trains, so more electrical energy from the grid would be required for the same level of train service.

For battery locomotives there must be strategically located charging facilities. Given range issues, even with battery improvements, one solution to the range issue might be to change battery locomotive consists for new fully charged battery locomotive consists at key enroute intermediate facilities.

For hydrogen technology there will be fueling stations, fuel storage facilities, electrolyzers, grid improvements, water supply infrastructure (including purification and treatemen), and power generation to support these electrolyzers. If fuel is delivered there will be the off-site facilities to produce, store and transport hydrogen fuel.

9. What type of service testing, or derisking, of these propulsion technologies do you think are necessary for each alternative rail propulsion technology?

Test sites for different rail propulsion technologies need to be set up around the U.S., to test a variety of rail applications and operating conditions, in different types of weather, etc. In addition, real railroad revenue operation of pre-production locomotives is needed to truly identify design or component issues and correct them. One critical need is to address the objections to operating freight trains, most specifically double stack container trains under catenary. This would be done with a specific program testing clearances and any electrical issues these higher loads might create. In addition, there needs to be a test to develop the parameters of discontinuous catenary paired with battery locomotives. Compared to hydrogen and battery, conventional OCS carries virtually no technological risk due to extensive operational experience around the world, along with a large global pool of established manufacturers, vendors, suppliers and contractors. The only risk for OCS is the potential financial risk during construction before the cost savings from the efficiency of OCS can accrue to the railroad.

10. What government actions do you think are necessary to help move the rail sector towards net-zero emissions?

The Federally-regulated nature of U.S. railroads means that leadership of the Federal government is essential for rail decarbonization. The Federal government should establish a program with the nation's electric utilities and railroads to implement rail electrification nationwide. Electrification of high-volume rail lines through heavily-polluted 'non-attainment' areas where trackside communities have been most heavily affected by diesel locomotives, should be a priority for a national rail electrification program.

The US based offices of worldwide engineering and construction firms should tap the in-depth knowledge of their worldwide associates to achieve electrification at low costs. There simply has not been enough mainline electrification projects undertaken in the North America to yield this level of expertise. To facilitate this, the FRA and DOE need to develop in-house electric rail engineering expertise.

Government support of electric rail financing:

Different models of ownership (such as publicly-owned electrification infrastructure over tracks that are privately-owned per the LA-Fullerton electrification proposed by CHSRA on the BNSF-owned section of LOSSAN) and capital project financing need to be explored. Most critical, reducing the financial risks and upfront costs (i.e. engineering) for freight railroads with publicly-backed financing (grants, loans, bonds, etc.) will expedite much needed mainline rail electrification.

Property taxes for private railroad companies could be abated for, say, 20 years for any rail improvement that expands track capacity, increases speed or electrifies operations. Legislation in Congress has been introduced in recent years to create a long-discussed National Infrastructure Bank. This new financial institution could be a steady funding source for rail capital projects, to complement funding from other Federal, state and local sources.

Discontinuous electrification, a strategy for limiting lawsuits:

One benefit of Discontinuous Electrification is that it can reduce the risk of lawsuits from lineside stakeholders over catenary construction. These lawsuits have been a major barrier to rail electrification projects in the past. With traditional electrification a lawsuit delays the entire project, costs rising, until the lawsuit is settled. With the incremental staging of electrification and the flexibility of battery operation, the remainder of the project can continue and service begun while the lawsuits are resolved. However, in addition to battery-hybrid technology there needs to be new policies or laws which mitigate NIMBY lawsuits against rail electrification. In California's case, an exemption to the California Environmental Quality Act (CEQA) for overhead catenary wire rail electrification infrastructure is long overdue.

11. **Other than tax credits, what opportunities are there to incentivize transition to clean fuels, recognizing that costs are likely to be higher in the near to mid-term? (For example, vehicle consumer incentives in the on-road sector include the use of high- occupancy vehicle (HOV) lanes, free workplace charging, etc.).**

The Federal government can invest in electric rail infrastructure, and subsidize innovative financing packages involving loans and bonds. Tax credits, grants and government guaranteed loans can by utilized by all the technologies and is a key early investment strategy in the move toward decarbonization. However, because of its efficiency, OCS electrification generates substantial savings in operating; maintenance costs and productivity improvements OCS can be attractive as a private investment because there is little or no technological risk. Financial packages for OCS construction could come in the form of internal railroad capital, loan guarantees or loans with long repayment terms reflecting the long-term climate and economic benefits, financed by power producers in return for a long-term power purchase agreement, investment funds that invest in green technology or investors looking for long-term stable income with bond type safety. Finally, Private Activity Bonds to construct OCS would allow investors an attractive tax-free investment.

12. What type of workforce challenges are present? Are you aware of any workforce development programs that are relevant to the clean energy transition in the rail sector?

The DOE, in collaboration with FRA and other departments, should fund and support sites for Electrical and railroad employee technical training programs, which could also host zero-emissions electric railroad technology demonstrations. The U.S. electric utility and railroad industries need to train electrical line workers in OCS installation and maintenance, and collaborate on building these skills.

13. Are you aware of any goals for Total Cost of Ownership (TCO) willingness to pay for advanced technologies? Recognizing that DOE and industry are driving to cost parity with diesel in the long term, what do you think the goals should be regarding reasonable extra costs over the diesel baseline in the near term?

Electric locomotives, with energy (fuel costs), decreased mechanical complexity, longer service lives and maintenance costs 40%-50% lower than those of a comparable diesel locomotives. They also have on average one-third of the down time. As a result, OCS locomotives have long-term TCO below that of diesel locomotives. The key to leveraging these cost savings are financial packages to de-risk the OCS decarbonization initiative during construction.

14. In your opinion, how do certain technologies (e.g. battery) compare for different use cases (e.g. line haul, switching)?

Overhead catenary wire, or overhead contact system (OCS) is the best overall zero-emissions rail propulsion technology, for the widest variety of use cases, including very heavy freight trains. A 50 kV AC overhead wire, would be the most economic and practical way to power very heavy electric freight trains, such as 15,000 to 20,000 ton freight train up Cajon Pass that use up to 30 MW of continuous power for over an hour. The Deseret Power Railway operates 50 kV electric heavy coal trains between Colorado and Utah. This is a real working example of heavy freight rail electrification that one can actually go see in operation in the US. Similar 50 kV electric coal trains ran in Arizona until 2019, and in British Columbia until 2000. 50 kV electric iron-ore trains weighing over 40,000 tons have been in operation in South Africa for decades.
Direct electrification with overhead wire is the most energy efficient and economic means of achieving zero emission rail propulsion for high and medium density rail lines. Battery and hydrogen are only practical for light density routes and yard/industrial switching operations. As concluded by the 2021 *Why Rail Electrification?* report by the UK Railway Industry Association:

> Evidence does not support the view that electrification is unnecessary, thanks to hydrogen and battery systems improving rapidly: hydrogen trains are inherently less efficient than electric trains, due to the physical properties of the gas. Expert opinion predicts that battery capability might double by 2035. *Yet, whilst this might affect the hydrogen / battery traction mix required for decarbonisation, it is unlikely to change significantly the requirement for electrification.*

> The laws of nature make electrification a future-proofed technology that is a good investment, offering large passenger, freight, and operational benefits. Furthermore, railways cannot achieve net-zero carbon emissions without a large-scale electrification programme.

In a 2020 analysis of technical abilities of non-diesel rail traction technologies, from "Traction Decarbonization Network Strategy – Interim Programme Business Case –Executive Summary"[3] report by UK Network Rail, electric with OCS was the only zero-emissions propulsion mode viable for all speeds of passenger and freight service. Hydrogen was only determined to be 'good' for passenger trains under 75 mph, fair for 100-125 mph, and poor for freight and passenger over 125 mph. Battery was judged to be 'fair' at best for passenger trains up to 100 mph, and poor for all other applications except certain freight (yard switching and short distances). The report concluded that, for the currently unelectrified lines in the UK, rail decarbonization requires electric, hydrogen and battery traction operating on respectively 86%, 9% and 5% of the rail network.

15. In your opinion, what percentage of overall locomotives could reasonably be expected to be zero-emission locomotives between now and 2050? How do you think production might scale up over time?

Full electrification by 2050 is not only feasible; it has already been done in other countries. Switzerland effectively electrified all of its railways back in 1967. Laos, Armenia, Ethiopia and Djibouti also have achieved this milestone in the decades since. Other countries are mass-producing electric locomotives right now at a very large scale. India and China are each manufacturing hundreds of electric locomotives and multiple-unit trains per year.

16. How do you think power needs should be estimated for the rail industry over time? E.g. number of locomotives or switchers?

There is a lot of precedent and well-established practice around the world on assigning electric locomotive power to all variety of railroad applications. Consulting with international expertise is therefore vital.

17. What do you think should be the estimated global market size for net-zero emission locomotives or retrofitting technologies?

Zero-emissions, electric locomotives (and multiple-units) have had a well-established and huge market around the world for many decades. Electric rail propulsion has long been a significant portion of the world's railroad industry, and is becoming an even larger portion. The International Union of Railways (UIC), the global locomotive manufacturers (Siemens and Alstom) would be a good source of data. Also US locomotive manufacturers, which sell locomotives worldwide who have produced electric locomotives and are involved in the US ZEV initiative, would be another source of estimates.

[3] https://www.networkrail.co.uk/wp-content/uploads/2020/09/Traction-Decarbonisation-Network-Strategy-Interim-Programme-Business-Case.pdf