U.S. Department of Energy DE-FOA-0003186: Request for Information on Progression to Net-Zero Emission Propulsion Technologies for The Rail Sector

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The American National Rail Network, covering freight, commuter, and passenger services, spans over 160,000 miles (260,000 kilometers) of track, making it the world's longest and most interconnected rail system. By comparison, the European rail network, with 94,000 miles (151,000 kilometers) of track, is more than 40% smaller. The larger loading gauge of American railways allows for bigger and heavier trains, resulting in significantly higher efficiency for American freight railways, which transport nearly three times more cargo per mile of track compared to European counterparts. Additionally, the adoption of a uniform, single track gauge across all classes of railroads (Classes 1, 2, and 3), along with standardized rail equipment, ensures interoperability and seamless operations across the entire U.S. rail network.

These factors are essential considerations when evaluating power options for U.S. rail, and in determining which implementation strategies can safeguard the integrity of the critical U.S. rail supply chain while transitioning it to a more sustainable future. Central to this transition is not only the speed at which new locomotives can be introduced but also the seamless integration of new fleet assets into existing operations.

In the United States, over 38,000 freight locomotives are in operation, burning over 3.5 billion gallons of diesel fuel annually. This usage results in the emission of 925,000 short tons of nitrous oxide (NOx) and particulate matter (PM) emissions, and 43 million metric tons (MMT) of CO2eq. This extensive pollution has significant implications for public health, resulting in higher rates of acute and chronic health issues, including exacerbated respiratory and cardiovascular ailments affecting nearly 40% of the U.S. population. Over 122 million people residing in counties designated as "nonattainment" areas by the EPA suffer from unhealthy levels of air pollution attributed to locomotives, with over 1,000 railyards in densely populated urban areas failing to meet EPA air quality standards.

Although these unhealthy levels of air pollution are largely attributed to locomotives, the rail sector is the only transportation mode lacking significant emissions policies, innovation support, or feasible plans in place to eliminate ozone, smog, and greenhouse gas (GHG) emissions. While the California Air Resources Board (CARB) has made commendable efforts to accelerate the transition of locomotive fleets to zero-emission, there are notable shortcomings in their approach leading to dangerous misinterpretation at the federal policy-making level.

Specifically, CARB's In-Use Locomotive Regulation restricts locomotive power options to battery-electric and hydrogen, influencing federal policy discussions. Over the past three years, the Federal Railroad Administration (FRA), Environmental Protection Agency (EPA), and CARB have conveyed to Class 1, 2, and 3 railroads, as well as the public, that only battery-electric or hydrogen solutions are acceptable. This approach, however, is dubious, as it inadvertently suggests that battery-electric and hydrogen locomotives are adequate solutions, overlooking the inherent limitations of these technologies.

While these options may appear reasonable, they are inherently flawed solutions. Battery-electric and hydrogen locomotives are only viable for a small subset of the U.S. locomotive fleet—specifically, low horsepower, low duty cycle locomotives rated under 2200 hp, known as "switchers." Unfortunately, neither battery-electric nor hydrogen power can be scaled up to meet the power requirements for line haul locomotives, even under optimal conditions. **This fundamental limitation presents a significant obstacle to achieving emissions reductions in the rail sector, given that line haul locomotives contribute 85% to 90% of all criteria and greenhouse gas emissions.**

To effectively decarbonize U.S. rail, federal and state governments must address the 25,000 line haul locomotives responsible for the most of emissions. **The resolution lies in developing line haul power solutions that can be scaled down for switcher applications, ensuring interoperability across locomotives, railcars, and infrastructure. This approach will facilitate seamless operations throughout the entire U.S. rail network, preserving the efficiencies that have long distinguished U.S. rail as the world's most efficient supply chain.**

The three tenured U.S. manufacturers of line haul locomotive engines (Wabtec, Progress Rail, and Cummins) remain focused on selling diesel engines and diesel locomotives, rather than investing in the development of zero-emission line haul locomotives. There is a notable "Green Washing" of environmental focus from these manufacturers, with a lack of serious efforts to develop or advance near-zero or zero-emission technologies for line haul locomotives.

Unfortunately, there are line haul programs that are not real line haul programs. As an example, the hydrogen-powered "Line Haul" locomotives deployed by Canadian Pacific offer only 1600 hp of continuous power and can carry only 150 kg of hydrogen, while a true line haul locomotive requires a minimum of 4600 hp of continuous power for sustained operation over extended periods and the ability to carry the equivalent 5,000 gallons of diesel fuel.

Regrettably, neither the federal government nor CARB has demonstrated substantial progress in supporting viable research and development (R&D) efforts for line haul locomotives either. Over the past decade, only one zero-emission line haul program has been initiated by either entity—the Department of Energy's partnership with OptiFuel Systems to develop zero-emission locomotives, as outlined below:

OptiFuel's Total-Zero™ 6,100 hp RNG-Electric Line Haul Locomotive and 9,00 DGE, 3,000 hp RNG Powered Tender Will Begin Testing in 2025 at FRA's TTC

Further hindering progress, the Federal government is actively promoting the use of more diesel locomotives instead of near-zero or zero emission solutions.

Federal initiatives, such as the Consolidated Rail Infrastructure and Safety Improvements (CRISI) R&D funding opportunity, fail to require near-zero or zero-emission solutions, permitting diesel locomotive projects. Despite the presence of four or five small business providers offering affordable electric, hydrogen, or RNG switcher locomotives that are near-zero or zero emission, most of the locomotives funded under CRISI are Tier 3 or Tier 4 diesel models from the three major engine manufacturers and not zero-emission R&D projects. Through R&D oversights like this, the Department of Transportation (DOT) and Federal Railroad Administration (FRA) continue to miss a significant opportunity to advance zero-emission solutions and deploy advanced locomotive technology in the field.

Similarly, in a recent environmental settlement with Cummins, authorities perpetuated diesel locomotives in their decision, disregarding the potential for zero-emission alternatives. Despite Cummins' capability to repower switchers and line haul locomotives to zero-emission standards, authorities required Cummins to repower 27 locomotives to Tier 4 diesel standards – a solution that achieves minimal NOx reduction. It is astounding that neither the U.S. Justice Department nor the State of California mandated Cummins to allocate even a part of the millions in fines towards zero-emission line haul solutions.

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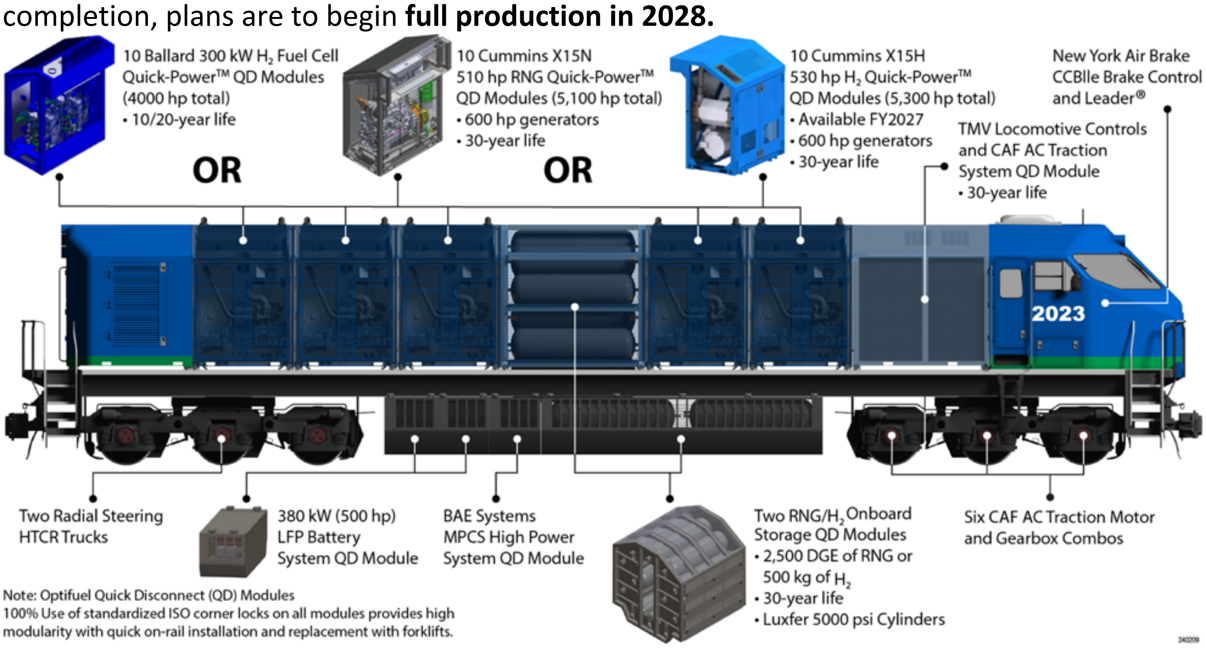
Of the Four US Manufacturers of Line Haul Locomotives, OptiFuel Systems is the Only One Focused 100% on Zero Criteria and ZERO GHG Emission Solutions. OptiFuel Systems is a solution provider designing and manufacturing **Total-Zero™** emission products and services in the hard-to-abate transportation and industrial markets, specifically in rail, marine and power generation. OptiFuel works as a systems integrator with strategic partners to engineer innovative technology that is low-risk and modular with flexible fuel options consisting of affordable renewable natural gas (RNG) and hydrogen fuels. Products include switcher and line haul freight locomotives, RNG and hydrogen tenders, stationary and mobile refueling systems, and mobile and stationary standby and emergency generators. Services include sales, leasing, long-term maintenance, and refueling services. Customers are expected to achieve increased reliability, reduced lifetime maintenance costs, minimized downtime, greater sustainability, and an impressive up to 30% enhancement in fuel economy.

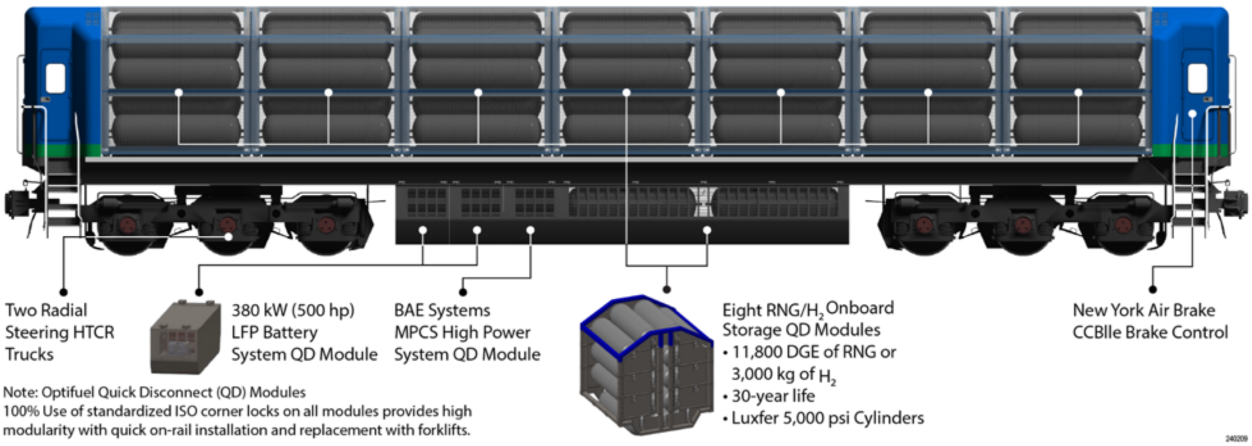
In 2013, OptiFuel was awarded a contract with Indiana Harbor Belt railroad to develop four CNG Tier 4 dual fuel switcher locomotives and integrate CNG refueling systems into the existing diesel refueling station. The project was highly successful, with the locomotives achieving EPA approval & FRA concurrence, operating without failures for over five years. Refueling is seamless at the on-site CNG locomotive refueling station engineered and built by OptiFuel. Railroad employees received training and have managed all refueling with zero safety incidents. OptiFuel's initial contracts for zero emission technology were with Sierra Northern Railway (SNR) to supply hydrogen fuel cell modules, hydrogen storage modules, and battery modules for four 1500 and 2000 hp hydrogen switcher locomotives for CEC and CalSTA.

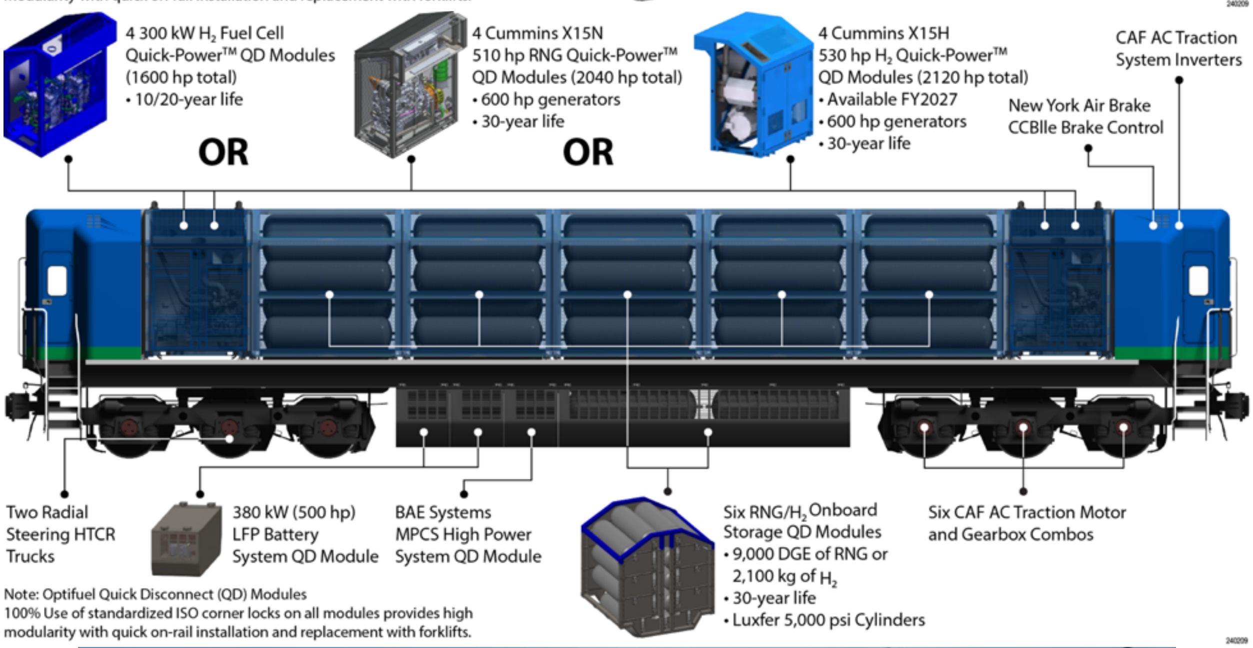
OptiFuel is committed to spearheading the sustainable revolution with locomotives and refueling solutions that make fleet transitions smooth and affordable. Unique to OptiFuel's locomotive designs is the **use of modularity** consisting of standard Quick Disconnect (QD) modules using standardized ISO corner locks (see graphic below). About 90% of the same components are used for OptiFuel's 1000 hp to 5600 hp RNG or hydrogen switchers and line haul locomotives and our RNG standard and powered tenders.

By integrating off-the-shelf components with proprietary technologies, OptiFuel delivers cutting-edge locomotives at an affordable price, reducing the cost to decarbonize all 38,000 US freight locomotives to approximately $150 billion in CAPEX. This upfront cost will be further offset by reduced annual operating costs, including lower fuel and maintenance expenses (see figure below), heightened reliability, and enhanced system automation, empowering railroads to expand market share in national freight transportation.

With support from the Department of Energy, in 2025, OptiFuel will begin testing a prototype 5600 hp **Total-Zero™ Renewable Natural Gas (RNG) Line Haul Locomotive**, a **2500 hp, 9,000 DGE Total-Zero™ Powered Tender, and a standard 11,800 DGE RNG tender** (see the three figures below). Focused on sustainability, OptiFuel's **near-term, low risk, affordable** Total-Zero™ RNG-Electric Line Haul Locomotive will have **ZERO** Well-to-Wheel (WTW) nitrogen oxides (NOx) and particulate matter (PM) criteria emissions and **Negative Carbon Intensity** (CI) while simultaneously improving fuel cost and operating range by 25%. **In 2026, OptiFuel will start a 1-million-mile test program with twenty pre-production 5600 hp, 2,500 DGE RNG line haul locomotives and five 11,800 DGE RNG tenders operating around the US.** Upon successful completion, plans are to begin **full production in 2028.**




Two Radial Steering HTCR Trucks
380 kW (500 hp) LFP Battery System QD Module
BAE Systems MPCS High Power System QD Module
Eight RNG/H_2 Onboard Storage QD Modules
• 11,800 DGE of RNG or 3,000 kg of H_2
• 30-year life
• Luxfer 5,000 psi Cylinders
New York Air Brake CCBIIe Brake Control
Note: Optifuel Quick Disconnect (QD) Modules
100% Use of standardized ISO corner locks on all modules provides high modularity with quick on-rail installation and replacement with forklifts.


4 300 kW H_2 Fuel Cell Quick-Power™ QD Modules (1600 hp total)
• 10/20-year life
OR
4 Cummins X15N 510 hp RNG Quick-Power™ QD Modules (2040 hp total)
• 600 hp generators
• 30-year life
OR
4 Cummins X15H 530 hp H_2 Quick-Power™ QD Modules (2120 hp total)
• Available FY2027
• 600 hp generators
• 30-year life
CAF AC Traction System Inverters
New York Air Brake CCBIIe Brake Control
Two Radial Steering HTCR Trucks
380 kW (500 hp) LFP Battery System QD Module
BAE Systems MPCS High Power System QD Module
Six RNG/H_2 Onboard Storage QD Modules
• 9,000 DGE of RNG or 2,100 kg of H_2
• 30-year life
• Luxfer 5,000 psi Cylinders
Six CAF AC Traction Motor and Gearbox Combos
Note: Optifuel Quick Disconnect (QD) Modules
100% Use of standardized ISO corner locks on all modules provides high modularity with quick on-rail installation and replacement with forklifts.


2013

OptiFuel SYSTEMS

Question 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.

To effectively eliminate railroad emissions, **solutions MUST focus on technologies suitable for the LINE HAUL LOCOMOTIVES that emit 85% Of all Criteria and GHG emissions**. The chart below underscores the emissions footprint of line haul locomotives and our critical reliance on their extensive lifespan. Tier 1 line haul locomotives, averaging 21 years in age, handle over 60% of line haul rail transport and an estimated 197.4 million tons of US exports[1], operating about 5 million miles over a 30-year span before being repurposed for an extended life in less stringent operations. Safeguarding the integrity of the US supply chain requires locomotive technologies capable of high-performance operations for 30+ years.

Current US Locmotive Fleet Estimated Emission in Tons Annually

Line Haul Locos (Mostly Class 1)	BSFC		Emission Factors (gm/bhp-hr)[1]				Calculated Annual Emissions (tons/yr)						Calculated Annual Emissions (tons/yr)					
	(bhp-hr/gal)	Activity Factor (gal/yr)[3]	NOx	PM	CO	HC/NMHC	NOx	PM	CO	HC/NMHC	TOTAL EMISSIONS	Number Locmotives	NOx	PM	CO	HC/NMHC	TOTAL CRITERIA EMISSIONS	TOTAL CO2 EMISSIONS
Tier <0	20.8	175,000	13	0.44	5	1	52.16	1.77	20.06	4.01	78	0	-	-	-	-	-	-
Tier 0	20.8	175,000	8	0.22	5	1	32.10	0.88	20.06	4.01	57	0	-	-	-	-	-	-
Tier 1	20.8	175,000	7.4	0.22	2.2	0.55	29.69	0.88	8.83	2.21	42	12706	377,265	11,216	112,160	28,040	528,680.30	22,673,231
Tier 2	20.8	175,000	5.5	0.1	1.5	0.3	22.07	0.40	6.02	1.20	30	3602	79,490	1,445	21,679	4,336	106,950.04	6,427,591
Tier 3	20.8	175,000	5.5	0.1	1.5	0.3	22.07	0.40	6.02	1.20	30	2949	65,079	1,183	17,749	3,550	87,561.26	5,262,345
Tier 4	20.8	175,000	1.30	0.03	1.5	0.14	5.22	0.12	6.02	0.56	12	1518	7,918	183	9,136	853	18,089.80	2,708,796
							163.31	**4.45**	**67.01**	**13.20**	**247.97**	**20,775**	**529,752**	**14,027**	**160,724**	**36,778**	**741,281**	**37,071,963**
	SUBTOTAL GAL.	**3,635,625,000**										**Average**	**25.50**	**0.68**	**7.74**	**1.77**	**35.68**	
Switcher Locos (Mostly Class 2&3)	**BSFC**		**Emission Factors (gm/bhp-hr)[1]**				**Calculated Annual Emissions (tons/yr)**						**Calculated Annual Emissions (tons/yr)**					
	(bhp-hr/gal)	Activity Factor (gal/yr)[3]	NOx	PM	CO	HC/NMHC	NOx	PM	CO	HC/NMHC	TOTAL EMISSIONS	Number Locmotives	NOx	PM	CO	HC/NMHC	TOTAL CRITERIA EMISSIONS	TOTAL CO2 EMISSIONS
Tier <0	15.2	40,000	17.4	0.44	8	2.1	11.66	0.29	5.36	1.41	19	3116	36,337	919	16,707	4,386	58,348.75	1,270,937
Tier 0	15.2	40,000	11.8	0.26	8	2.1	7.91	0.17	5.36	1.41	15	4879	38,585	850	26,159	6,867	72,461.66	1,990,019
Tier 1	15.2	40,000	11	0.26	2.5	1.2	7.37	0.17	1.68	0.80	10	3116	22,972	543	5,221	2,506	31,241.85	1,270,937
Tier 2	15.2	40,000	8.1	0.13	2.4	0.6	5.43	0.09	1.61	0.40	8	3116	16,916	271	5,012	1,253	23,452.27	1,270,937
Tier 3	15.2	40,000	5	0.1	2.4	0.6	3.35	0.07	1.61	0.40	5	0	-	-	-	-	-	-
Tier 4	15.2	40,000	1.30	0.03	2.4	0.14	0.87	0.02	1.61	0.09	3	0	-	-	-	-	-	-
							36.59	**0.82**	**17.22**	**4.52**	**59.15**	**14,227**	**114,810**	**2,584**	**53,099**	**15,011**	**185,505**	**5,802,830**
	SUBTOTAL GAL.	**569,080,000**																
	TOTAL GAL.	**4,204,705,000**									**Total Line Haul & Switcher**	**35,002**	**644,562**	**16,611**	**213,823**	**51,790**	**926,786**	**42,874,793**

To assess which rail propulsion technologies are most promising, it is important to align the capabilities and constraints of each technology with the requirements of line haul and railyard, or "switcher" operations, as they differ significantly.

SWITCHER LOCOMOTIVES: Switcher locomotives typically have the following operational and technical requirements:

- Average operational horsepower: 200 to 300 hp
- Maximum horsepower: 1000 to 2000 hp
- Diesel consumption: 30 to 60 gallons per day
- Refueling frequency: every 5 to 7 days, typically when fuel levels are 25% to 50%
- Daily operating hours: 2 to 24 hours a day depending on operational schedule – there is

[1] Joint Economic Committee Report: January 2018

not a "standard" switcher schedule.

When developing a new switcher locomotive, one starts with the EPA standard switcher duty cycle and the expected maximum operating hours annually – around 6,000 hours. This is shown in the table below. Subsequently, the aim is to reduce IDLING hours by up to 80%, resulting in operating hours of around 3,500 annually and updated duty cycles, as indicated in the orange columns 4 and 5 in the table. The average 1500 hp switcher locomotive operates on 25% or less power for 95% of its operating time, resulting in average horsepower utilization under a standard EPA duty cycle of around 200 hp.

Hours in a day	24.00					
Day of week	5					
# Weeks	50					
% Availability	1					
Total Annual Hou	6,000					
1,500 HP SWITCHER LOCOMOTIVE	**EPA Switcher Duty Cycle (Time)**	**Total Annual Hours With No ESS System**	**Total Annual Hours With ESS System**	**Percentage Total Annual Hours With With ESS System**	EPA - Percentage Power Notches Schedule	**Total Horsepower Notch Schedule**
			0.8			1,500
Normal Idle	52.73%	3,164	633	18.24%	1%	75
Dynamic Brake	0.00%	-	-	0.00%	0%	-
Notch 1	14.58%	875	875	25.22%	5%	68
Notch 2	14.46%	868	868	25.02%	12%	173
Notch 3	6.82%	409	409	11.80%	24%	353
Notch 4	4.23%	254	254	7.32%	35%	525
Notch 5	4.23%	254	254	7.32%	49%	728
Notch 6	1.76%	106	106	3.05%	64%	960
Notch 7	0.24%	14	14	0.41%	85%	1,275
Notch 8	0.94%	56	56	1.63%	100%	1,500
Total	100.00%	6,000	3,469	100.00%		

What this tells us is that it's crucial to consider both **average power** and **peak power** requirements when evaluating alternative power solutions for switcher locomotives. Average power dictates the primary power source (RNG, batteries, hydrogen, etc.) and the necessary storage space for fuel or batteries to meet operating needs (8 hours, 24 hours, 48 hours, 5 days, etc.). Peak power combines average power with the additional power needed for tasks like ascending hills or assembling trains, often supplemented by an ancillary power source. For instance, OptiFuel's zero emission switchers for Sierra Northern Railway employ hydrogen fuel cells for average power and LFP batteries in a hybrid configuration for peak power.

LINE HAUL LOCOMOTIVES: Line haul locomotives operate in stark contrast to switcher operations. Typically, two to eight locomotives collaborate to transport 150 rail cars over long distances, reaching speeds of up to 70 miles per hours for extended periods. Line haul locomotives and rail cars MUST be fully interchangeable between Class 1, 2 and 3 railroads, refueling sites, and functionalities. Failure to achieve this interoperability risks undermining the critical efficiencies that have defined the US freight railway system for the past century. This is the primary reason that locomotive technologies – even those used in switcher operations – must first be capable of meeting the demands of line haul operations.

Line haul requirements are outlined below, followed by a duty cycle table.

- Operational horsepower ranges from 2000 to 3000 hp, with max horsepower of 4500 hp.
- 35% of the time, line haul locomotives operate at 50% to 100% of their fuel power.
- To traverse steep mountain ranges, locomotives must be capable of operating at 100% power for two to three continuous hours (referred to as "continuous power").
- Each locomotive carries approximately 4700 to 5100 gallons of diesel fuel.
- Locomotives must be capable of 1,500 miles and/or 50 hours between refueling.

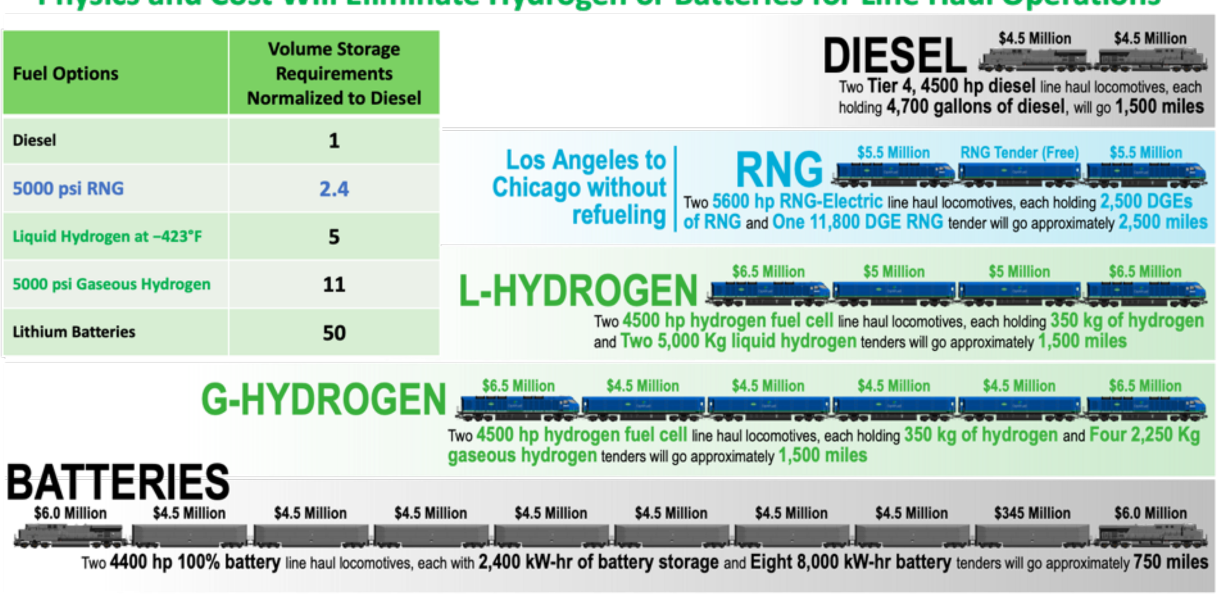
Hours in a day	24.00					
Day of week	5					
# Weeks	50					
% Availability	1					
Total Annual Hou	**6,000**					
5,100 HP LOCOMOTIVE Ten X15N Engines	**EPA Line Haul Duty Cycle (Time)**	**Total Annual Hours With No ESS System**	**Total Annual Hours With ESS System**	**Percentage Total Annual Hours With With ESS System**	EPA - Percentage Power Notches Schedule	**10 X15N Total Horsepower Notch Schedule**
			0.8			5,100
Normal Idle	38.00%	2,280	456	10.92%	1%	75
Dynamic Brake	12.50%	750	750	17.96%	0%	125
Notch 1	6.50%	390	390	9.34%	5%	330
Notch 2	6.50%	390	390	9.34%	12%	687
Notch 3	5.20%	312	312	7.47%	24%	1,299
Notch 4	4.40%	264	264	6.32%	35%	1,885
Notch 5	3.80%	228	228	5.46%	49%	2,574
Notch 6	3.90%	234	234	5.60%	64%	3,364
Notch 7	3.00%	180	180	4.31%	85%	4,435
Notch 8	16.20%	972	972	23.28%	100%	5,100
Total	100.00%	100.00%	**4176**	100.00%		

POWER: Therefore, to achieve sustainable success with line haul locomotives, it is imperative to ensure that designing line haul locomotive, any solution must be capable of meeting the **continuous power** requirement **100% of operating time**.

FUEL/BATTERY STORAGE: Given the extended duration of full-power operation for line haul locomotives, the **onboard energy storage design is paramount**, as is the design of associated tenders. **Discussions with Class 1 railroads indicate their acceptance of fuel tenders, provided there is no more than 1 tender for every 2 line haul locomotives and that the overall range matches or exceeds current diesel range**. Considering these criteria, the physics associated with storing hydrogen and batteries would eliminate them as viable options for line haul locomotive operations. This storage constraint is expressed in the figure below.

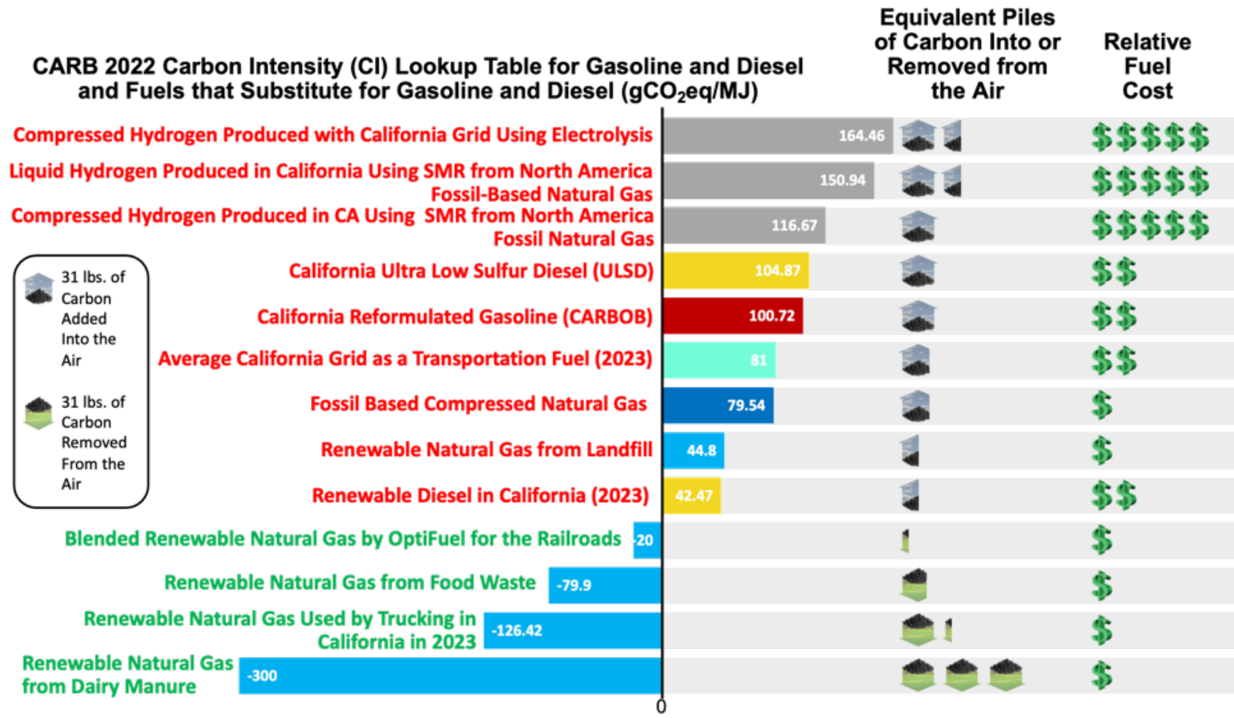
The volume density of gaseous RNG, gaseous hydrogen, liquid hydrogen and lithium batteries compared to diesel varies from 2.4 to 50. RNG at 5000 psi requires **2.4** times the volume to store energy, Green Hydrogen at 5,000 psi requires **10** times the volume to store energy, Green Hydrogen at -423 ℉ (-252.8 ℃) requires **4** times the volume to store energy and lithium batteries require **50** times the volume to store energy compared to diesel. As shown in the same figure, RNG is the only sustainable power source that can meet the required operating distance of Class 1 railroads with a limit of **1 tender per every two line haul locomotives and the required operating range. Overall range for two 6100 hp RNG line haul locomotives carrying 2,500 diesel gallon equivalent (DGE) each and a single 11,800 DGE RNG tender will have a range 1.7 times more than with two 4,700 hp diesel locomotive alone.** RNG can be conveniently accessed through existing natural gas pipeline infrastructure running along US railroad rights-of-way. Transporting the 10 million kg of highly explosive liquid hydrogen daily would necessitate thousands of Class 8 trucks and impart unnecessary risk to the US public.

Physics and Cost Will Eliminate Hydrogen or Batteries for Line Haul Operations



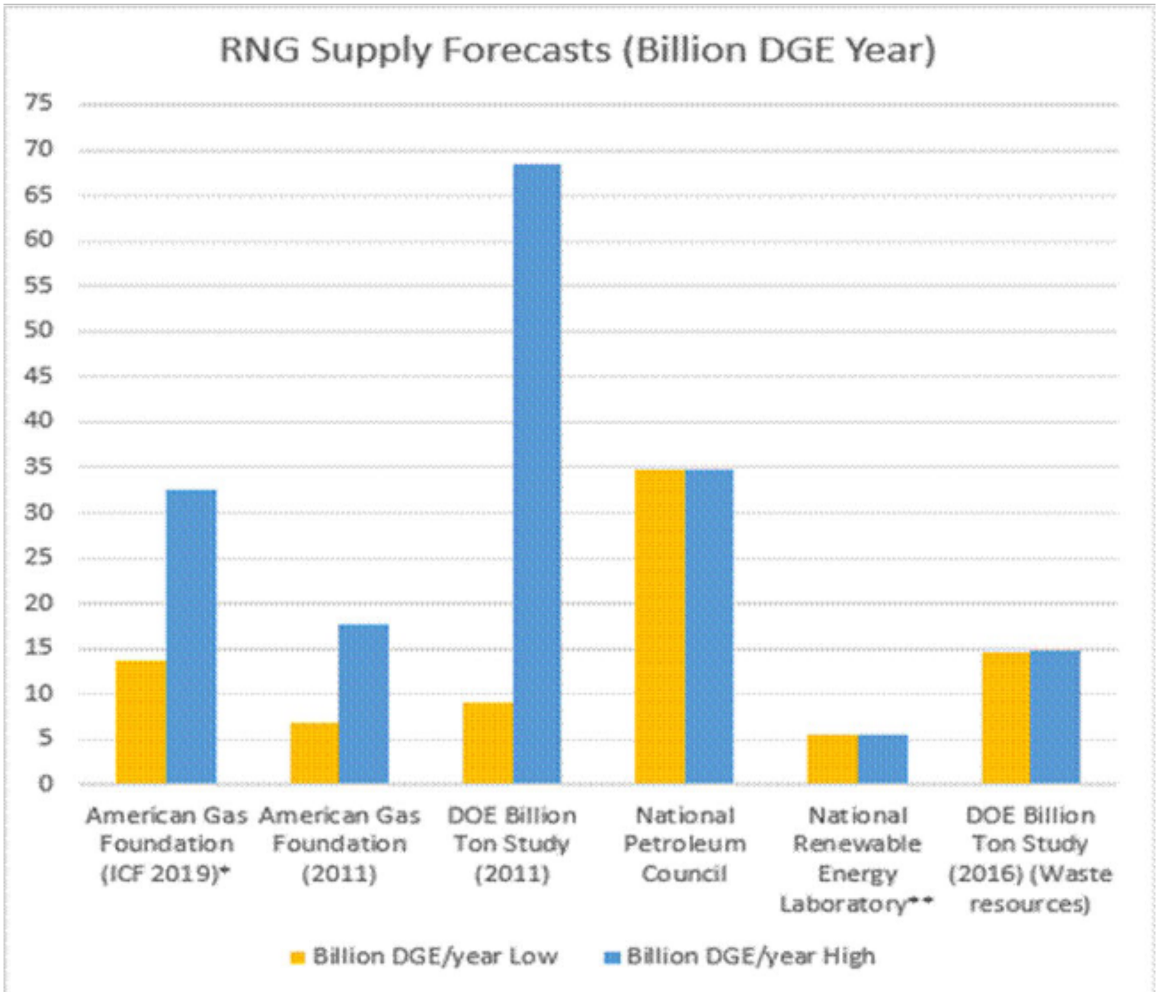
Fuel Options	Volume Storage Requirements Normalized to Diesel
Diesel	1
5000 psi RNG	2.4
Liquid Hydrogen at -423°F	5
5000 psi Gaseous Hydrogen	11
Lithium Batteries	50

REAL WELL-to-WHEEL (WTW) CARBON INTENSITY OF FUEL OPTIONS: There is a large amount of "Greenwashing" with relative to real availability of low or zero CI fuels for locomotives. As you can see from the chart "CARB 2022 Carbon Intensity (CI) Lookup Table" inserted below, battery-electric locomotives using the California grid have a CI of 81, providing only marginal benefit over diesel locomotives. Efficiency of using battery vs IC engines improved the CI, but the manufacturing of batteries and disposing of them every 10 years increases the actual CI back up to the CI of diesel. Grey liquid hydrogen is even worse than diesel with a CI of 164. Using RNG instead of fossil based CNG can reduce the CI, but the idea of using low CI hydrogen instead of using the RNG directly in a locomotive is financially, environmentally, and operational imprudent.



Only 0.5% of all hydrogen in the world is “Green” hydrogen and what is manufactured in the US over the next 30 years will go to markets other than rail.

The only available biofuel with a NEGATIVE CI is RNG. The graph below shows the results of several research studies that have been conducted in recent years to estimate the total RNG production potential in the U.S. To put this in perspective, the rail sector consumed 3.4 billion gallons of diesel in 2023, according to U.S. EIA estimates. That represents 7 percent of the 47 billion gallons of diesel fuel consumed by the transportation sector in 2023. Considering 29 billion DGE/year as the average high resource potential of all studies in the figure and 47 billion DGE/year as the estimated total diesel fuel consumption per EIA, this means that RNG production can potentially displace up to 62 percent of all diesel fuel consumption for transportation applications today. Considering diesel consumption by the rail sector alone, the **RNG production potential is 13 times the amount of fuel needed to fuel every locomotive application in the U.S.**



COST OF CONVERSION: The next table shows an estimate of the cost to convert all 38,000 locomotives to zero NOx, PM and GHG emissions using different energy sources. The cost is based on ZERO Well-to-Wheel (WTW) emissions with the energy sources aligned to zero CI.

Cost to the Railroads to Decarbonize the US Locomotive Fleet Over 30 Years Using 100% Renewable Electricity

Cost ($B)	RNG	Hydrogen Fuel Cells + Liquid Green H2	Hydrogen Fuel Cells + Gas Green H2	Green Battery-Electric	Green Electric Catenary
140k miles of track Infrastructure Modifications	$ 0	$ 0	$ 0	$ 0	$ 1,167
Additional US Renewable Power Stations to Power the Electric Grid or Make Green Liquid Hydrogen	$ 0	$ 1,468	$ 1,468	$ 248	$ 248
Update US Grid	$ 0	$ 0	$ 0	$ 186	$ 186
Fixed & Mobile Refueling Stations Around the US	$ 0	$ 20	$ 20	$ 20	$ 0
Cost for 25,000 Line Haul Locomotives for 30 yrs	$ 138	$ 163	$ 163	$ 300	$ 113
Cost for 13,000 Switcher Locomotives for 30 yrs	$ 33	$ 46	$ 46	$ 85	$ 33
Tender Cost to Support 18,700 Line Haul Locomotives Daily	$ 0	$ 168	$ 94	$ 1,346	$ 0
Cost for 3,500 New Hydrogen Trucks and Liquid Hydrogen Trailers to Move the H2 to Refueling Sites	$ 0	$ 9	$ 9	$ 0	$ 0
Total CAPEX Required by the Railroads Over 30 yrs	**$ 170**	**$ 1,798**	**$ 1,873**	**$ 2,184**	**$ 1,745**
Annual Energy Cost to Railroads Based on 4 Billion Diesel Equivalent Gallons (DGE)	**$ 8**	**$ 40**	**$ 40**	**$10 to 16**	**$10 to 16**

NOTE: Does not include the additional cost and GHG emissions to manufacture and dispose of batteries every 10 years

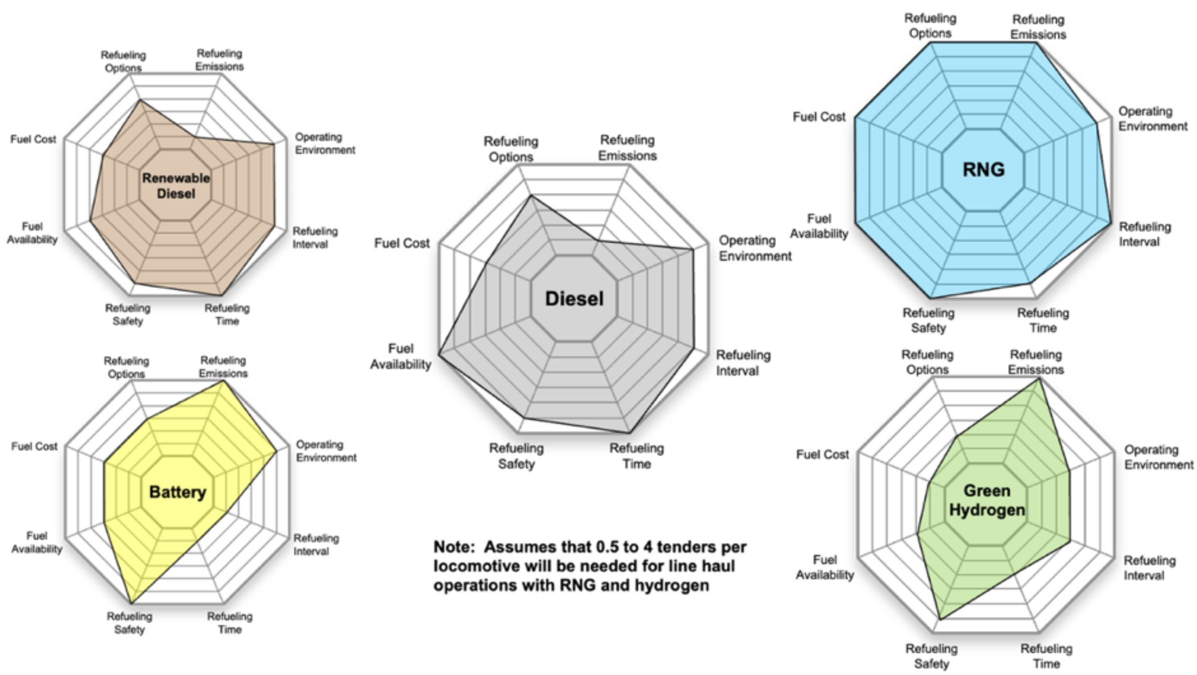
CATENARY: Converting the US freight network to overhead catenary comes with an estimated $2 trillion price tag, covering new power stations, grid expansions, and associated infrastructure. This approach, however, proves significantly less efficient than a track-only system. While Class I Railroads already invest billions annually in track maintenance, the upkeep of a catenary system would parallel these costs initially but escalate over time due to climate-related damage. Furthermore, catenary systems lack reliability and cannot ensure continuous operations, making them unsustainable without nationalizing the tracks.

BATTERY-ELECTRIC: Battery power imposes the most significant operational constraints, requiring 8 tender cars of battery storage for every 2 locomotives. This power source also has the highest implementation cost.

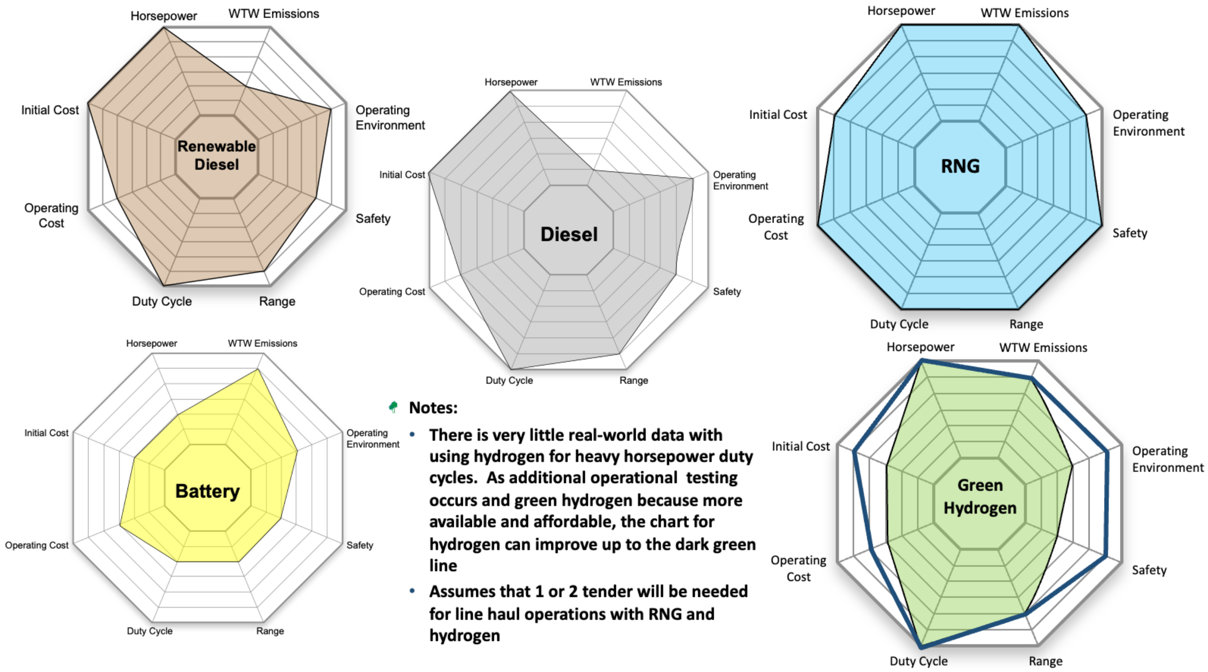
GREEN HYDROGEN: The assessment of hydrogen reveals a stark reality: less than 0.5% of all global hydrogen derived from solar or wind can be considered truly "green" with zero carbon intensity. Further limiting its use is cost. To establish the infrastructure necessary for producing and transporting sufficient green liquid hydrogen to meet the demands of rail would require an estimated $2 trillion investment.

RNG: RNG stands out as the most economical and technically favorable choice. The best technical solution is the one that minimizes current changes to line haul operations. As shown on the two spider charts that compare locomotive power options and fuel refueling options, the RNG implementation requires minimal alterations to current line haul operations, allowing for trains to operate in a consist with both old (diesel) locomotives alongside new (RNG) locomotives without changes to routes, distance between stops, refueling time, or capital expense budgets.

Fuel Cost, Refueling Options, Refueling Emission, Operating Environment, Refueling Intervals, Refueling Time, Refueling Safety, and Fuel Availability Will Drive Fuel Choices for the Railroads



Horsepower, Fuel Range, Duty Cycle, Operating Cost, Operating Environment, Emission, Refueling Intervals, Fuel Availability, and Refueling Options Will Drive Locomotive Power Choices for Railroads



Question 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?

There are no gaps with respect to standards, regulations, supply chain, labor for RNG or hydrogen locomotives. Between the RNG and Hydrogen technical standards that exist that are being used for Class 8 trucks and the available line haul locomotive and tender commonality standards that AAR, supporting by FRA, have produced including M-1004 that defines RNG and hydrogen tenders and interfaces to the locomotives.

Question 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)?

Infrastructure supporting RNG-powered locomotives is cost-effective and scalable, primarily requiring the addition of RNG dispensers to existing diesel refueling islands. This infrastructure is already being implemented, as seen at the Indian Harbor Belt railroad in Chicago. During the fleet scaling process, fuel can be delivered by truck, and locomotives can be refueled via mobile refueling stations.

Question 10:

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

To encourage the Class 1,2 and 3 railroads to expend effort or funds to reduce the emissions of the 38,000 locomotives, a combination of new regulations, fines, and financial benefits to reduce the cost of the fuel and initial/operating cost could prove highly effective. The federal and state governments may want to consider expanding the use of the "CARROT and STICK" approach used for on-road vehicles.

For the regulatory "**STICK**" aspect:

- Create a new Federal EPA Tier 5 locomotive standard for all new locomotives (line haul and switchers), effective in 2028 with:
    - NOx: 0.02 g/bhp-hr
    - PM: 0.005 g/bhp-hr
    - Carbon Intensity: 0 gCO2e/MJ
- Allow for the adoption of any alternative fuel technologies that meet the Tier 5

standard. Specifically include RNG and Hydrogen IC engines along with battery and fuel cell solutions.

- Set an initial mandate requiring Class 1 locomotive fleet owners to start replacing or repower 7.5% of their line haul, road switcher, and switcher locomotive fleet older than 2013 by 2030 with Tier 5-compliant models. Each year thereafter, increase the model year requirement by one year until 2029. This schedule ensures that the 25,000 Class 1 locomotives that produce 90% of all locomotive criteria and GHG emissions in the US are updated to Tier 5 by FY 2045.
- Set an initial mandate requiring Class 2 and 3 locomotive fleet owners to replace or repower 7.5% of their line haul, road switcher, and switcher locomotive fleet older than 2018 by 2035 with Tier 5-compliant models. Each year thereafter, increase the model year requirement by one year until 2034. This schedule ensures that the 13,000 Class 2 and 3 locomotives that produce 10% of all locomotive criteria and GHG emissions in the US are updated to Tier 5 by FY2050.
- Exempt any Class 2, Class 3, historical, industrial, or military locomotive that annually uses 10,000 diesel gallons or less.

For the regulatory "**CARROT**" aspect:

- Provide open-ended federal and state grants that encourage early adoption, with incentives that decrease by a set percentage each year, with the net effect that the earliest adopters receive the highest benefit.
- Expand the existing on-road vehicle incentives used by the federal and state governments to the off-road locomotive market. Currently, the cost of diesel fuel to locomotive fleet owners is 20% to 30% of the operating cost of a locomotive. By providing a lower-then-diesel fuel cost for early adopters of RNG locomotives, rapid adoption is incentivized.
    - By 2026, modify the Federal RINS Credits to include all classes of locomotives.
    - By 2026, modify the Federal Alternative Fuel Tax Credit (AFTC) Program (26 USC 6426 and 6427) to include all classes of locomotives, increase the credit to $1.00 per DGE, and extend the program until 2050.
    - Request that any State specific RNG subsidies/credits from the Low Carbon Fuel Standard (LCFS) include all classes of locomotives staring in 2025 until 2050.

Expected Benefits of Total-Zero™ RNG-Powered Line Haul Locomotives:

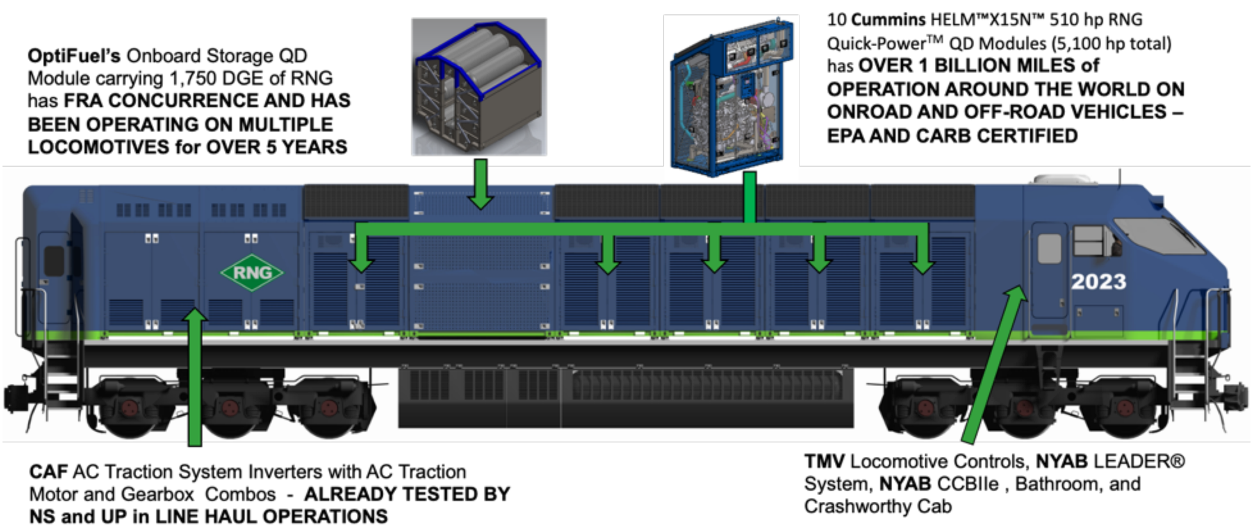
- Zero NOx and PM emissions
- Zero greenhouse gas (GHG) emissions
- Zero Scope 1, Scope 2, and Scope 3 emissions
- Capability to travel from the Port of LA or Long Beach to Chicago with no refueling stops (1500 miles) using only a single RNG tender with two RNG-Hybrid Line Haul Locomotives.
- Fixed-rate fuel pricing for 20 years (with an optional extension to 30 years)
- Lower lifetime operating expense
- Up to 25% reduced fuel usage compared to Tier 4 diesel locomotives.

- Expected 95% operating uptime, surpassing the industry average of 81% for diesel locomotives.
- On-track maintenance and 1-hour module replacement minimizes disruptions and out-of-order assets

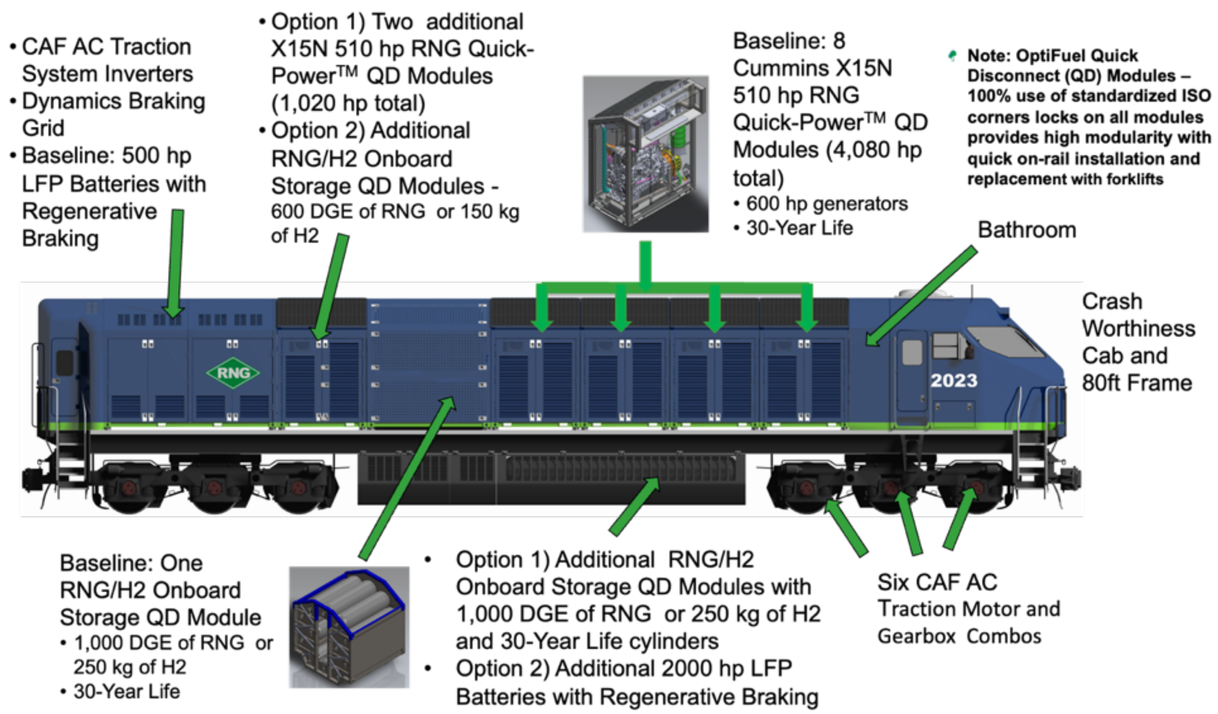
OptiFuel Readiness

From a technical, programmatic, and financial perspective, we are confident that OptiFuel will be capable of producing 2,000 Total-Zero™ RNG-powered line haul locomotives per year beginning in 2028. All necessary US-based components are already in production, including the components required to produce RNG tenders that can meet the existing AAR/FRA M-1004 standards. (See Figure below)

OptiFuel's line haul locomotives will use OptiFuel's 510 hp RNG Quick-Power™ QD Modules using Cummins HELM™X15N™ RNG engines. These engines have over 1 billion miles of operation around the world on on-road and off-road vehicles and are EPA and CARB certified. Over the last two years, Cummins will have spent over $500 Million for supporting the production of the X15N in their Jamestown facility with the ability to produce 25,000 X15N engines annually. OptiFuel's Onboard Storage QD Modules carrying 1,750 DGE of RNG already have **FRA concurrence and has been operating on multiple locomotives for over 5 years for both switcher operations and on main track operations.** Already approved by DOT for rail usage, the Type 4 natural gas storage cylinders used in our fuel module have been in production over 20 years, millions are produced every year on the US, and they are designed to operate up to 30 years before replacing.



OptiFuel's only remaining readiness benchmarks include completing the required FRA crashworthiness testing, which is scheduled to begin in 2025, and conducting one million miles of operational testing with a minimum of 10 locomotives over a two-year period. The proposed program will facilitate achieving these critical milestones.



OptiFuel Total-Zero RNG-Hybrid Line Haul Locomotive Specifications and Options

Sole Technology Ready for Near-Term Demonstration in Line Haul Operations

This initiative not only supports the elimination of US locomotive emissions by 2045 but also positions OptiFuel to demonstrate the operational viability and safety of RNG-powered locomotives for both switcher and line haul applications. We have developed the only zero emission locomotive technology that is ready for near-term demonstration in line haul operations, coupled with a comprehensive and sustainable system-wide refueling strategy. Furthermore, with our latest strategic plan, we are confident in our ability to achieve this milestone well ahead of the specified target date.

Plan for Transitioning US Line Haul Locomotive Fleets to Zero Emission by 2040

Here is an outline of our five-step plan from 2024 to 2029 reflecting a comprehensive and ambitious strategy for advancing RNG-powered locomotives and transitioning the US fleet to zero emissions 10 years ahead of the 2050 target:

1. **Demonstration and FRA Testing (2024-2025)**

- Utilize a $2.5 million DOE grant and additional $8 million of OptiFuel investment funds to build a Total-Zero™ 5600 hp RNG Hybrid Line Haul Locomotive and a 9,000 DGE, 2,500 hp RNG Powered Tender.
- Conduct year-long testing in 2025 at the Federal Railroad Administration's Transportation Technology Center to obtain full FRA concurrence for the locomotives and RNG/Hydrogen standard and powered tenders.

2. **Reliability Testing and Data Collection (2025-2028)**
    - Allocate $350 million to establish testing sites across four locations in the US over a three-year period.
    - Build 20 Total-Zero™ 5600 hp RNG Hybrid Line Haul Locomotives, 10 RNG tenders, and 4 RNG refueling stations, each capable of refueling 260,000 diesel gallon equivalents (DGE) of RNG per day.
    - Each locomotive will carry 2,000 DGEs of RNG, with RNG fuel stations capable of refueling two locomotives per hour. (Note: The proposed stations are larger versions of the CNG refueling station that OptiFuel built for the Indiana Harbor Belt Railroad.)

3. **RNG Production and Expansion (2026-2028)**

- Invest $30 million to construct a 5 million DGE RNG production site adjacent to the natural gas pipeline.
- Utilize these pilots to evaluate the feasibility of establishing an additional 90 RNG production sites across the US. Each site would have the capacity to produce 5 million DGE of RNG annually with a -300 carbon intensity (CI). The overall initiative aims to generate 450 million DGEs of RNG per year, with an estimated infrastructure capital expenditure (capex) of approximately $3 billion.
- Blend 450 million DGEs of -300 CI RNG with 3.2 billion DGEs of +40 CI Landfill Gas to achieve 3.6 billion DGEs of RNG with zero CI, which is the volume sufficient to replace diesel with RNG for all 38,000 freight locomotives in the US.
- The RNG production sites can be located anywhere in the US, provided there is a nearby natural gas pipeline, as refueling stations for the locomotives must be in proximity to existing natural gas infrastructure. Fortunately, most of the current Class 1 railroad refueling stations are situated near such pipelines. For instance, the BNSF refueling station in Barstow benefits from proximity to the PG&E pipeline, facilitating efficient and sustainable refueling operations for RNG-powered locomotives. This strategic alignment between production sites and refueling infrastructure ensures optimal deployment and utilization of renewable natural gas resources in the transportation sector.

4. **Full Scale Production Starting (2028-2029)**
   - Aim to commence full-scale production of line haul locomotives in 2028 or 2029, building 2,000 units annually.
   - Cummins to manufacture the 20,000 X15N engines required annually, supported by the recent $452 million upgrade to their New York factory.
   - Target price is $5.5 million per locomotive.

5. **Accessible Financing Option for Locomotive Replacement:**
   OptiFuel Locomotive-as-a-Service (LAAS™) Program (2029-2045)
   - OptiFuel’s straightforward LAAS™ program option aims to ease the burden of replacing line haul locomotive fleets. This program ensures railroads can transition to zero emission technology with manageable upfront costs and predictable long-term fuel pricing.
   - The key components of the LAAS™ program include:
     a. Initiation Payment:
        a. An initial payment of approximately $1.1 million per line haul locomotive, equivalent to ~20% of the retail price of a 5600 hp OptiFuel Total-Zero™ RNG-Powered Line Haul Locomotive.
     b. Comprehensive Equipment, Infrastructure, & Fuel:
        a. The program covers use of the locomotive, tender and refueling infrastructure equipment for up to 30 years.

   b. RNG is provided at an expected 20-year fixed-rate price of $3.00 per diesel gallon equivalent (DGE), with an option to extend to 30 years. This rate is equivalent to the average cost currently paid for diesel.
c. Railroad extends a 30-year ground lease to OptiFuel for the RNG refueling station.
d. OptiFuel takes ownership, operation, and maintenance responsibility for the fuel station infrastructure and equipment.
e. Railroad and OptiFuel share the cost of accessing the nearby natural gas pipeline to facilitate efficient refueling operations.

- Standard upfront locomotive purchase options are also available, where railroads can contract with OptiFuel for fuel, infrastructure, and other services.

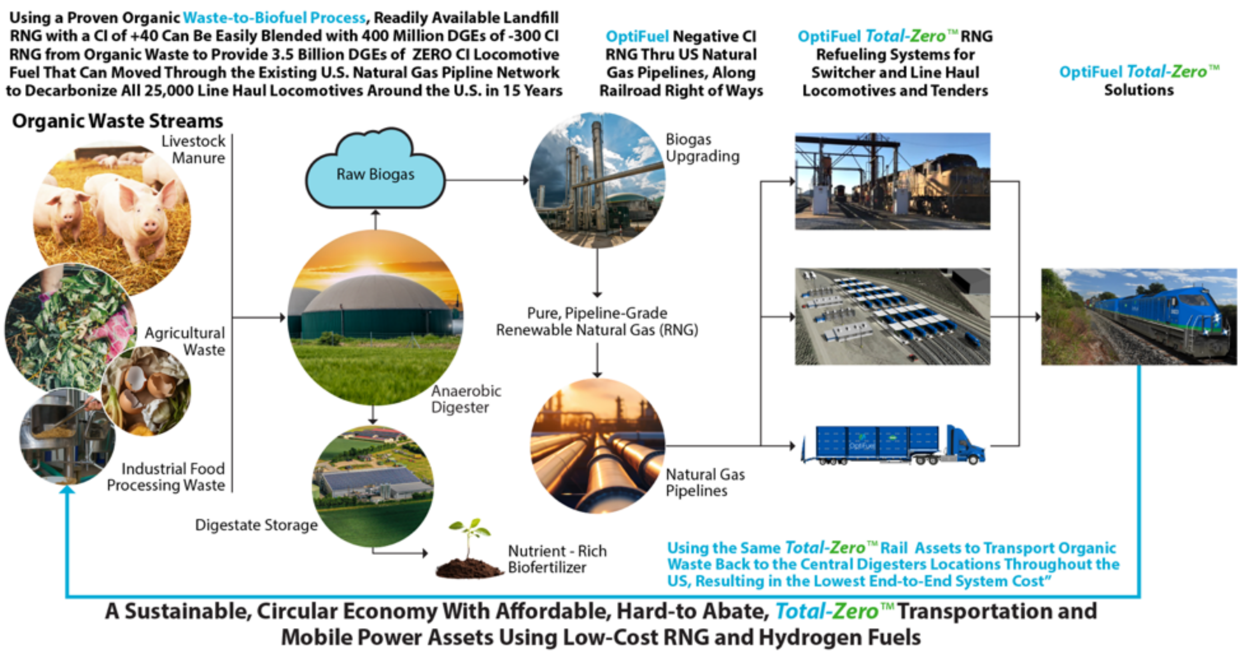
This timeline underscores the scale and scope of the transformational effort required to achieve widespread adoption of sustainable locomotive technology and achieve significant reductions in emissions across the rail transportation sector.

OptiFuel's Projected Infrastructure Costs per Station and Overall Investment Breakdown:

a. Installing Refueling Station, Maintenance, and Operation:
   a. Estimated investment per refueling station (260,000 DGE/day): $45 million
   b. Total investment (covers 100% of U.S. line haul track):
      i. 60 refueling stations: $2.7 billion
      ii. (cost recovered from the per-DGE fixed cost of RNG of $3.00)
b. Mobile Refueling Equipment:
   a. Total investment for mobile refueling equipment: $250 million
   b. (cost recovered from the per-DGE fixed cost of RNG of $3.00)
c. Warranty and Maintenance:
   a. 5-year warranty and 5 years of 6-month maintenance included in LAAS™
d. Standard Tenders (1,500 units x 11,800 DGE):
   a. Total investment for standard tenders: $5 billion
   b. (cost recovered from the per-DGE fixed cost of RNG of $3.00)
e. Powered Tenders (1,500 units x 9,000 DGE, 2,500 hp)
   a. Total investment for powered tenders: $5.5 billion
   b. (cost recovered from the per-DGE fixed cost of RNG of $3.00)
f. RNG Production Sites (90 sites x 5 million DGE):
   a. Estimated cost per RNG production site: $30 million.
   b. Total investment for 90 RNG production sites: $3 billion
   c. (cost recovered from Federal D3 RIN credits)
   d. See Figure below
g. Total-Zero™ 5600 hp RNG Hybrid Line Haul Locomotives
   a. Estimated cost per locomotive: $5.5 million.
   b. Total investment (covers 100% of the US line haul fleet: 25,000 locomotives): $130 billion
   c. (cost recovered from Federal D3 RIN credits)

d. Locomotive Production Capacity: 2,000 units per year

Through this proposed plan, it would take approximately in 13 years to complete the transition and replace the 25,000 haul locomotive fleet with Total-Zero™ 5600 hp RNG hybrid locomotives. OptiFuel plans to leverage use of Federal D3 RIN credits to effectively offset equipment costs over a ten-year period, making the transition financially viable for railroads ***to pay $3 per DGE, inclusive of the locomotive and fuel, with only a single $1.1 million down payment.***



The substantial investment commitment by OptiFuel's reflects the long-term vision and commitment of OptiFuel towards revolutionizing the industry and advancing environmental sustainability.