Overcoming Demand Barriers to Hydrogen Use in Heavy-Duty Trucks and Ports

Aaron Bergman, Alan Krupnick, Katarina Nehrkorn, and Yuqi Zhu

Working Paper 26-03
January 2026

About the Authors

Aaron Bergman is a fellow at Resources for the Future (RFF). Prior to joining RFF, he was the Lead for Macroeconomics and Emissions at the Energy Information Administration (EIA), managing EIA's modeling in those areas. Before working at EIA, Bergman spent almost a decade in the policy office at the Department of Energy, working on a broad array of climate and environmental policies. Bergman has worked in the White House at the Office of Science and Technology Policy, managing the Quadrennial Energy Review and handling the methane measurement portfolio, and at the Council on Environmental Quality, working on carbon regulation. Bergman entered the federal government in 2009 as a Science and Technology Policy Fellow with the American Association for the Advancement of Science, after working in high energy physics.

Alan Krupnick is an RFF senior fellow and director of the Industry and Fuels Program. Krupnick is an expert on the oil and gas sector, reducing greenhouse gas emissions from this and the industrial sectors, and cost-benefit analysis. In particular, Krupnick's recent research focuses on green public procurement, decarbonized hydrogen and tax credits, and developing markets for green natural gas. His portfolio also includes guiding the value of information agenda covered by our VALUABLES initiative with NASA, the valuation of reducing asthma risks, estimating the value of statistical life, and issues of regulatory reform.

Katarina Nehrkorn is a research associate at RFF whose research spans across international climate policy and industrial decarbonization. Nehrkorn earned her BA in economics from the University of Michigan, afterwards working at Deloitte's Risk and Financial Advisory division for two years. In 2023, she completed her MSc in Environmental Economics and Climate Change at the London School of Economics.

Yuqi Zhu is a policy analyst experienced in economics and public policy, with a focus on energy modeling, financial analysis, and industrial decarbonization. He was a senior research associate at RFF. Prior to RFF, he worked in the financial services industry, including roles in corporate development and strategy. He holds bachelor's degrees in computer science and economics from the University of Pennsylvania and a master's degree in public policy from the Harvard Kennedy School of Government.

About RFF

Resources for the Future (RFF) is an independent, nonprofit research institution in Washington, DC. Its mission is to improve environmental, energy, and natural resource decisions through impartial economic research and policy engagement. RFF is committed to being the most widely trusted source of research insights and policy solutions leading to a healthy environment and a thriving economy.

Working papers are research materials circulated by their authors for purposes of information and discussion. They have not necessarily undergone formal peer review. The views expressed here are those of the individual authors and may differ from those of other RFF experts, its officers, or its directors.

Sharing Our Work

Abstract

Hydrogen has the potential to serve as a zero-carbon energy carrier as an element of a zero-carbon economy. But the high cost of clean hydrogen and infrastructure needs for scaling, plus the dismantling of policies to promote its production and use, have hampered its spread. Focusing on the heavy-duty trucking and ports sectors, we review the policy landscape here and abroad and the obstacles faced by clean hydrogen in these sectors. We present potential policies for overcoming the demand-side obstacles in these two sectors, with some focus on the nascent Biden administration's Joint Offtake Producer Auction and its contrast with other policy ideas, such as contracts for differences. The discussion is organized around the obstacles of high cost, uptake of fuel cell vehicles and the construction of a refueling network for heavy-duty trucking. Among several suggestions, we find that hydrogen use in heavy-duty trucking requires more coordinated investment due to the need for extensive refueling infrastructure along transportation corridors.

Contents

1. Introduction

To address the reality of climate change caused by greenhouse gas (GHG) and its threats to our health, economy and environment, decarbonizing our energy use is essential. Some uses are more easily and cheaply decarbonized than others, although even these face many challenges.

The transportation sector, which includes light-, medium-, and heavy-duty vehicles, both on road and off (as well as aircraft, pipelines, ships and boats), is now the biggest US source of anthropogenic GHG emissions, and the medium- and heavy-duty subsector (which makes roughly 23 percent of **this sector's emissions**) is particularly challenging to decarbonize because gasoline and diesel fuel are cheap and ubiquitous and can be rapidly used to refuel vehicles (EPA 2024b).

Given these challenges, particularly for heavy-duty trucking, plans to decarbonize have turned to hydrogen, precisely because of its high energy density, zero direct emissions and ability to rapidly refuel. The Department of Energy's (DOE) roadmaps and pathways to decarbonization reports[1] indicate that in heavy-duty trucking, hydrogen can compete with fossil fuels at the highest hydrogen price of any other sector, making it one of the "low-hanging fruit" sectors for clean hydrogen applications.

These reports have also identified ports as an opportunity for hydrogen because of their motorized equipment and centralization. Forklifts, in particular, are ripe for clean hydrogen use, and more than 95,000 forklifts already use hydrogen. Port opportunities also include trucking and cargo-moving machinery (such as cranes, reach stackers, and straddle carriers).

For all of clean hydrogen's promise (and, in California, use) in these subsectors, realizing its decarbonizing benefits requires producing it with low- or zero-carbon techniques. As of 2019, the United States produced about 10 million metric tonnes per year of hydrogen, primarily in the refinery sector and for ammonia and fertilizer. Almost all of this is gray hydrogen,[2] meaning it has CO_2 emissions as a by-product.

During the Biden administration, a series of incentive programs were enacted to subsidize clean hydrogen production projects, as the current cost is too high to obtain private financing and realize the economies of scale and learning by doing needed to bring production costs down. These incentives included the hydrogen hubs program

1 The DOE Liftoff reports are no longer available on the DOE website. Copies of the hydrogen report are still available on other websites, such as **https://h2fcp.org/content/does-pathways-commercial-liftoff-clean-hydrogen**.

2 The list of hydrogen colors has seemingly grown without bound. We will restrict ourselves to gray hydrogen (from steam methane reforming without carbon capture), blue hydrogen (from reforming, steam methane and otherwise, with carbon capture), and green hydrogen (from electrolysis, usually with some purchase of a **clean electricity attribute** covering the electricity used).

in the Infrastructure Investment and Jobs Act, which was intended to help centralize clean hydrogen's production and use (mitigating distribution concerns) and subsidize production.

It became clear that subsidizing the supply of hydrogen was not sufficient to drive its deployment; demand-side incentives were also needed. Hence, DOE used at least $500 million of a hub program's $8 billion in funding to begin developing a demand-side support mechanism. DOE awarded a contract to a coalition of groups (H2DI) to set it up. However, this movement came to a halt with the second Trump administration.

Even as many of the programs enacted during the Biden administration are being undone,[3] it is likely that any future hydrogen deployment will require demand-side support. Although, as we will describe, the H2DI initiative settled on one such mechanism, a wide array of other options exist, which we will review. We focus on the two promising sectors, ports and heavy-duty trucking, to describe and evaluate demand-side support options that would apply.

We begin in Section 2 by reviewing both sectors, their potential for use of hydrogen, and the barriers to its usage. In Section 3, we review the current policy landscape supporting clean hydrogen use in these sectors, with a focus on policies in the United States and also touching on international policies. In Section 4, we review demand-side policies. Finally, in Section 5, we look at applications of specific demand-side policies to address particular barriers to the use of hydrogen in ports and heavy-duty trucking. We conclude in Section 6.

2. Background

We begin by reviewing the trucking and ports sectors, focusing on the opportunities for and barriers to hydrogen use.

2.1. Trucking

Heavy-duty trucking is a highly fragmented industry, with multiple business models and subsectors, making it difficult to regulate and necessitating tailored solutions for decarbonization.

Trucking as an industry can be broadly split into short- and long-haul segments, using different vehicles, unloading at different frequencies, and covering different distances. Short-haul trucks generally travel within a 200-mile radius, operating within cities or regions, and are lighter-duty vehicles carrying lighter payloads than long-haul trucks

3 The One Big Beautiful Bill Act (OBBBA) sunsets the key clean hydrogen production incentive (Section 45V of the Internal Revenue Code), and the hub program is under review, with support withdrawn from two hubs as of this writing. The status of the demand-side support mechanism is also unclear.

(FHWA 2000). Long-haul trucks often drive more than 200 miles and travel between cities or states. When considering decarbonization solutions, these differences affect whether battery-electric or hydrogen fuel cell trucks are more suitable. Traditionally, battery-electric trucks have been considered better suited for short-haul, lighter-duty vehicles, with hydrogen a potentially better option for longer routes because of its greater energy density and faster refueling times. We focus on long-haul trucking, as this is where hydrogen can play the biggest role.[4]

2.1.1. Long-Haul Trucking

Heavy-duty trucking makes up a significant portion of overall trucking employment and mileage. According to the US Census, in 2022 over 1.1 million people were employed in the general freight trucking industry (NAICS[5] code 4841), with 901,044 in general long-distance trucking (48412) (NCSES et al. 2025).

The sector can be further divided by business model into three broad categories of logistics operations: for-hire carriers, owner-operators (also technically considered for-hire), and in-house/private carriers. For-hire carriers are companies, such as UPS, FedEx, and JB Hunt, that transport goods for other companies. Owner-operators are self-employed individuals with their own trucking business (under their own authority or contracted out to other companies). Finally, private carriers include businesses, such as Amazon, that operate their own logistics and own their trucks.

In 2022, of the 623,108 businesses registered as NAICS 48412 (General Freight Trucking, Long Distance), 91 percent (565,000) were categorized as “nonemployer” firms, representing the largest share of owner-operators in the long-distance trucking industry (NCSES et al. 2025). Larger companies, whether for-hire or private, make up a relatively small share. The top 50 largest companies generate less than 30 percent of overall market revenue (AEO 2024).

These distinctions are important for decarbonization policy because small, owner-operator fleets have limited abilities to obtain capital investment and perform long-term planning. Private carriers may also act more like satisficers, seeking to earn an acceptable amount of profit, as opposed to being profit maximizers. Large companies, on the other hand, often have sophisticated long-term cost modeling and greater ability to make large capital investments.

2.1.2. Current Use of Hydrogen in Trucking

Although hydrogen has been identified as a potential decarbonization solution for long-haul trucking, its current use in the United State is limited. Total cost of ownership (TCO) modeling comparing hydrogen trucks to potential alternatives has found that

4 See Nehrkorn et al. (2024) for an overview of the issues associated with hydrogen-fueled heavy-duty trucking and comparisons to using batteries for power.

5 NAICS refers to the North American Industrial Classification System.

the TCO of fuel cell electric vehicles (FCEVs) is much higher than diesel, but parity could be reached over time. With the Inflation Reduction Act (IRA) incentives and cost projections, FCEVs could have reached parity as early as 2034 (Ledna et al. 2024). However, other estimates put that at 2050 (Burnham et al. 2021) or beyond. When compared to electric options, studies find conflicting answers as to which applications will have a lower TCO (Hunter et al. 2021; Ledna et al. 2024; Burnham et al. 2021).

Hydrogen fuel cell trucks are still in the demonstration and early commercialization phases, and their availability is very limited. Several start-up manufacturers, such as Nikola and Hyzon, have focused specifically on building them; however, both of these firms have recently gone bankrupt. Legacy manufacturers continue to invest in hydrogen vehicles, with Daimler, Volvo, PACCAR, Toyota, Honda, and Hyundai all involved in manufacturing FCEVs to some extent. This includes a **joint venture between PACCAR and Toyota** where Toyota supplies the fuel cell modules to PACCAR, which inserts them and related equipment into Kenworth and Peterbilt truck bodies with non-hydrogen-related equipment. According to interviews, Toyota has the capacity to produce 30,000 fuel cell stacks per year, which combine individual fuel cells to form the heart of the **fuel cell power system**, and has completed successful pilots at the Port of LA.

The other fundamental requirement for widespread, scaled hydrogen use is infrastructure availability. In the United States, hydrogen infrastructure is limited and almost exclusively in California. According to DOE's Alternative Fueling Station Locator, 72 public or private US refueling stations are available (55 in California), with five accessible to heavy-duty vehicles and only two open to the public (DOE 2025). Both of the available public heavy-duty refueling stations are in California.

2.1.3. Challenges to Hydrogen Use in Trucking

To better understand the barriers to hydrogen adoption in heavy-duty trucking, we interviewed stakeholders across the value chain, including a supplier of fuel cell systems, a diesel original equipment manufacturer piloting FCEVs, and a company developing fuel cells for port equipment and stationary/mobile power. Across these conversations, three consistent barriers emerged: lack of fueling infrastructure, high hydrogen costs, and the high upfront cost of hydrogen trucks.

Infrastructure limitations remain a key challenge for large-scale deployment. Although hydrogen fuel cell trucks offer a key advantage over battery-electric models with their rapid refueling time, the refueling network is extremely limited and heavily concentrated in California. These stations require large capital investments, which carry significant risk without dedicated demand. DOE (2021) found that the average hydrogen station requires $1.9 million in capital. These costs increase as the capacity does, with the AFLEET model assuming station costs of $1,892,967–3,448,461, depending on the dispensing rate (Burnham 2023). This can be compared to modeled costs for diesel stations of about $172,000. One interviewee estimated that a 300–400 mile route would require at least 2–3 stations to be suitable for long-haul trucking. This raises the question of how infrastructure is coordinated, where it is placed (e.g., along major truck routes connecting two or more major cities—termed by some a "hydrogen corridor" approach), and who is responsible for building it.

Another major barrier to wide-scale deployment is the cost of hydrogen. One interviewee suggested that the highest price that could make hydrogen feasible for trucking end uses is $8–9/kg. As of this writing, California stations have prices **as high as $36/kg**, but this would come down with a higher rate of capacity use. Because of fuel cells' greater efficiency compared to diesel, transportation applications have a higher willingness to pay than other end uses and can accept a slightly higher price, but current prices are still far from economically feasible. A different interviewee expressed that parity with diesel could be reached at around $6–7/kg or preferably $4–5/kg.

Beyond the cost of hydrogen, fuel cell vehicles remain much costlier than diesel. Existing voucher programs help significantly close this gap, and long-term economies of scale could bring FCEV costs down significantly. Nonetheless, the high price of hydrogen fuel cell trucks still creates problems for insurability and financing. On paper, a hydrogen truck can cost over $600,000 at small production volumes and around $350,000 at full production levels (compared to a **diesel truck at around $117,000**) (Nehrkorn et al. 2024), requiring insurance companies to take on more risk. Additionally, technological uncertainties still surround FCEVs, further increasing insurance risk. Although insurers can charge more, this creates additional costs for owners.

The resale market is another critical issue for the cost of FCEVs. The long-haul trucking industry relies heavily on resale, with diesel trucks often logging 750,000 miles or more and changing hands several times over their life cycle. The opportunity to resell the vehicle decreases the effective cost, and it is often owner-operators who buy used vehicles from larger fleets. As their fuel efficiency decays over time, long-haul trucks are often shifted to more regional routes that can require a vastly different refueling structure than the corridor model. More technological uncertainty arises over the trucks' useful life, adding more risk to secondary purchasers. With an unknown resale pathway, fleet owners may be even more reluctant to commit to hydrogen.

2.2. Ports

The United States has more than 300 ports, managed under a mix of governance models that include states, counties, municipalities, and private companies (DOT 2025). Ports employ over 2.5 million workers, with the largest concentrations of jobs and GDP contributions in California, Texas, Florida, Louisiana, and New Jersey (American Association of Port Authorities 2024).

Ports are major sources of energy demand and production. They host facilities for electricity generation and petroleum refining, with multiple stationary and mobile sources of diesel consumption. This includes diesel-powered equipment, such as forklifts, yard tractors, and cargo handlers, and electric generators ranging from 5 kW to 10 MW. Mobile sources span ocean-going vessels, harbor craft, drayage trucks (used for hauling shipping containers relatively short distances from the port), long-haul trucking, and rail.

2.2.1. Governance of US Ports

The governance of US ports is important to understand because these entities are the key (if not only) targets for hydrogen incentives. Such governance generally operates under three main models: public service (also referred to as “operational ports”), landlord, and corporate/private ports. For a public service port, a government entity (the port authority) performs the whole range of services, including ownership, administration, and cargo handling. Under a landlord port, the most common US structure, port authorities lease infrastructure to private operators while retaining ownership of the land. This is commonly done through a concession agreement, where a private company is granted a long-term lease in exchange for rent; the terminal operators typically invest in cargo-handling equipment and manage operational decisions. Finally, a corporate/private port has almost all services under private control, with the public sector only serving as a regulator (US EPA 2024a).

This diversity of governance structures presents challenges for policy implementation. Decarbonization initiatives must be designed to target the relevant decisionmaking bodies, whether public authorities, private operators, or a combination of both. For example, in landlord ports, both the port authority and private tenants must coordinate to deploy hydrogen infrastructure, but it may be easier for a public service port to unilaterally do so.

2.2.2. Potential Uses of Hydrogen in Ports

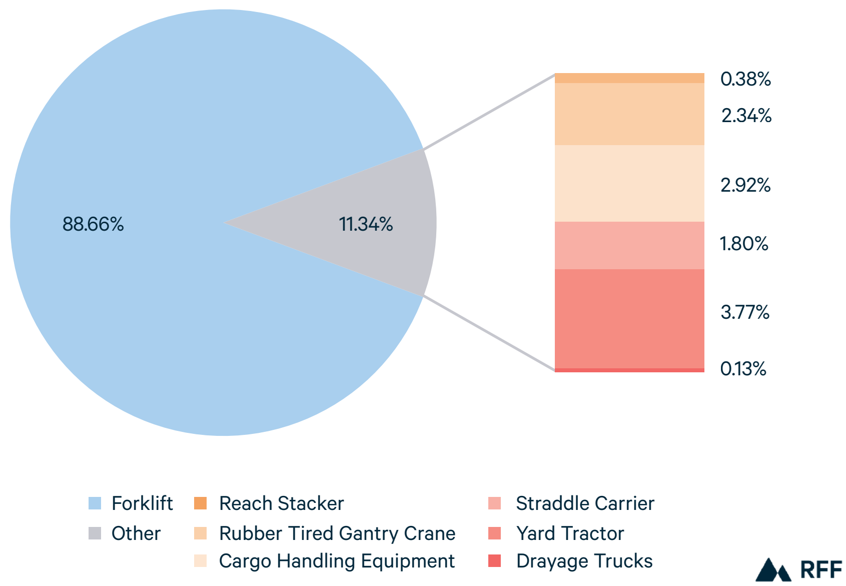
Ports are particularly well suited for hydrogen deployment due to their high energy demand and variety of energy needs. The EU estimates that up to 42 percent of total EU hydrogen demand could be concentrated in port areas by 2050, an indicator of their strategic importance (Clean Hydrogen Partnership 2023). In this section, we outline the use of hydrogen in US ports in port equipment, trucking, and drayage. (It can also be used in colocated industries and as ship fuel.)

2.2.3. Port Equipment

Ports rely on a wide array of cargo-handling equipment, including forklifts, yard tractors, reach stackers, and cranes, to keep goods moving. The majority of this machinery runs on diesel fuel, which generates both high GHG emissions and localized air pollution. A DOE feasibility study estimated that cargo-handling equipment at the Ports of Seattle and Tacoma produce over 44,000 tonnes of CO_2 emissions annually (Steele and Myers 2019).

Full electrification of this equipment faces barriers, as heavy payloads and high duty cycles make battery-powered options difficult to scale. Hydrogen fuel cells offer a potential solution, refueling quickly and operating with zero tailpipe emissions. Many of these technologies are already commercially available or are close to being commercially available. Figure 1 shows the DOE estimate for hydrogen demand across cargo-handling equipment (and drayage) for 19 US ports.

Figure 1. Potential Daily Hydrogen Demand Percentage for US Ports, by Cargo-Handling Equipment



Source: Steele and Meyers 2019.

Companies such as Plug Power have already deployed thousands of fuel cell forklifts, providing a proof of concept for applications in port terminals. According to Plug Power, hydrogen forklifts require just two minutes for refueling per shift compared to 15 minutes for battery forklifts.

Some ports are also moving beyond forklifts to heavier equipment. In May 2024, the Port of Los Angeles put the world's first hydrogen fuel cell–powered rubber-tired gantry crane into commercial operation (Blekhman 2024). Internationally, the Port of Valencia has tested hydrogen-powered reach stackers and yard tractors (Port Authority of Valencia 2023). These demonstrations show that hydrogen can deliver the operational characteristics needed for cargo handling while avoiding the operational constraints of full electrification.

Ports also require reliable electric power for a range of operations. This demand has historically been met by diesel generators, further increasing carbon emissions and local air pollution. Hydrogen offers a cleaner alternative for power generation by delivering steady output without on-site emissions. Unlike batteries, which have short active periods and long recharge times, hydrogen systems can provide continuous backup power as long as fuel is supplied. Portable hydrogen units can also be deployed across port facilities.

Hitachi Energy, for example, has developed hydrogen-powered stationary systems designed to provide both grid stability and resilient backup power. These systems integrate electrolyzers, hydrogen storage, and fuel cells, enabling ports and other industrial hubs to generate electricity using hydrogen. **The Port of Gothenburg** has connected its hydrogen electric generation system directly to the local power grid to demonstrate its capabilities in port operations. The concept allows ports to reduce reliance on diesel and also enhance resilience in areas vulnerable to grid disruptions.

2.2.4. Trucking and Drayage

Trucking, particularly drayage, which shuttles containers between terminals, warehouses, and rail yards, is a promising application for hydrogen at ports. These trucks operate with heavy payloads on predictable routes, making them an ideal use case. The predictability and limited mileage of drayage routes also mitigates difficulty with refueling infrastructure.

Several ports are investing in this area, with the Port of Houston receiving $25 million in federal grants to construct a hydrogen refueling station at its Bayport Terminal. This is a public–private partnership with Linde and will be designed to serve heavy-duty trucks (Port Houston 2025). In addition, at the Ports of Los Angeles and Long Beach and with support from Toyota and Kenworth, multiple fuel cell Class 8 trucks have been tested in live drayage service, moving containers between the ports and local distribution hubs (FCHEA 2023).

2.3. Challenges to Use of Hydrogen in Ports

Although hydrogen has many potential use cases in ports, several challenges remain.

First, given the unique and varied management structure of ports throughout the United States, it can be difficult to coordinate decarbonization plans across all actors. The Environmental Defense Fund identifies several key players for decarbonization—port landlords, port authorities, and port terminal operators (Nasser et al. 2024). Structures with more divided authority may pose an extra challenge in approving and coordinating the infrastructure. Some ports, such as LA and Long Beach, have decarbonization plans that encompass the whole port, but many do not.

Second, delivery and cost pose challenges for widespread use of hydrogen. It is estimated that green hydrogen costs $3–7/kg to produce (Shafiee and Schrag 2024). However, this is only a portion of its overall cost. When it must be transported in, the costs are material, adding significantly to the overall price. Storage costs bring this number even higher, with estimates that green hydrogen can be delivered at $7.01–15.25/kg depending on end use (Shafiee and Schrag 2024).

When demand is sufficient, on-site production of hydrogen becomes more economical. This might be feasible, given the many potential use cases in ports. However, it requires significant coordination between landlords and tenants (who will also face significant capital costs) to build generation stations.

Finally, policy specifically targeting hydrogen's use at ports is lacking. For example, very few projects from the Environmental Protection Agency (EPA) Clean Ports Program involve hydrogen. Most focus on electrification, which may be a better option for some decarbonization challenges. However, stakeholders have expressed that certain heavy machinery cannot easily be electrified. One stakeholder noted the usefulness of even small hydrogen programs, such as a $9.7 million program under the American Recovery and Reinvestment Act for deploying fuel cells in forklifts. Targeted demand-side support could help provide needed certainty to obtain large-scale infrastructure investment.

3. Current Policy Landscape for Hydrogen

3.1. General Hydrogen Policy

Next, we turn to the hydrogen policy landscape in the United States and internationally. This has shifted considerably in the United States under the second Trump administration. Under the Biden administration, the Infrastructure Investment and Jobs Act (IIJA) and IRA included many incentives for hydrogen, primarily as grants, such as the Hydrogen Hub program, and tax credits, such as the 45V Hydrogen Production Tax Credit (United States 2021; United States 2022). These are primarily on the supply side. At the state level, both supply-side and demand-side incentives exist, with the latter being primarily regulatory, either efficiency standards or clean vehicle mandates. However, the status of many of these policies is in flux or unclear, introducing new uncertainties into the clean hydrogen market. We review the policies as of the time of this writing. We start by looking at federal policies that target hydrogen broadly and then specific federal and state policies that target it in the trucking and ports sectors. We also review some international policies to support hydrogen.

3.1.1. Broad Federal Policies

The Regional Clean Hydrogen Hubs (H2Hubs) program committed $7 billion across seven hubs to create a national network of hydrogen producers, consumers, and infrastructure. A complementary demand-side initiative was announced with an additional $1 billion (reduced to around $500 million) to support offtake of hydrogen produced at the hubs. The status of these initiatives is unclear, with the announcement of funding being withdrawn from at least two hubs. The DOE has stated that the program is under review. In addition, people with firsthand knowledge told us, "H2DI completed its phase one work in January 2025, including drafting complete terms and conditions for JOPA and designing the structure for an implementing entity. As of October 2025, it is unknown if DOE plans to implement." The IIJA also included an additional $1.5B in support for clean hydrogen, with $750M of grants announced in 2024. It appears that these grants remain active, with the first round of funding outlaid for most grants (Atlas Public Policy n.d.).

The IRA included or modified several federal tax credits to incentivize clean hydrogen production, carbon capture (necessary for blue hydrogen), and zero-emission vehicles. Although many clean energy provisions were repealed or scaled back under OBBBA, hydrogen-related credits were less affected than some other tax credits:

- **45V (Clean Hydrogen Production Credit)**: Provides up to $3/kg of clean hydrogen, with the exact value determined by the carbon intensity of production. Under OBBBA, this tax credit is preserved for facilities that begin construction on or before December 31, 2027. This credit is relevant for both blue and green hydrogen, although IRS guidance could change under the Trump administration.
- **45Q (Carbon Capture Credit)**: Offers credits for capturing and storing or using carbon oxides, with the value depending on whether the carbon is captured from anthropogenic sources or from the air. Although the prior version of the tax credit had different values depending on whether the carbon was stored geologically or used, OBBBA equalized these values. This credit is relevant for blue hydrogen production.
- **45W (Clean Commercial Vehicles Credit)**: Originally offered a credit for purchasing clean commercial vehicles (up to $40,000 for medium-/heavy-duty vehicles). OBBBA repealed this credit entirely, eliminating a driver for purchasing hydrogen trucks.
- **30C (Alternative Fuel Vehicle Refueling Property Credit)**: Offers credits for clean refueling infrastructure in eligible locations. OBBA sunset this for facilities that come into service after June 30, 2026.

3.2. Hydrogen Trucking Policy

The policy environment for hydrogen in heavy-duty trucking is a patchwork of state and federal approaches to encourage transportation decarbonization. Generally, these are not targeted at hydrogen specifically but rather vehicle decarbonization more broadly. These policies also suffer from significant uncertainty at both the state and federal level. Policies and regulations typically target one of three areas: truck demand and cost, infrastructure buildout, and fuel costs.

3.2.1. Federal Policy

The main federal regulation affecting heavy-duty trucking decarbonization is EPA's Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles. Under the Biden administration, EPA announced Phase 3, which set stronger GHG standards beginning in model year 2027, building on Phase 2 standards from 2016. Hydrogen fuel cell trucks were explicitly modeled as a compliance option, particularly in long-haul and drayage applications. The rule also requires emissions control components to carry warranties of five years or 100,000 miles, which interviewees have stated increases compliance costs for low-emission vehicles (EPA 2024c). However, the Trump administration is seeking to terminate these standards.

Multiple federal incentives focus on refueling infrastructure. The Alternative Fuel Vehicle Refueling Property Credit (26 USC 30C) provides up to 30 percent of the cost of hydrogen refueling property, capped at $100,000 per installation. This is a relatively small amount compared to the price of heavy-duty refueling stations and will sunset in 2026. Additionally, the Charging and Fuel Infrastructure grant program allocated $2.5 billion for zero-emission refueling. However, in its first round, only 16 percent of funding went to (three) hydrogen infrastructure projects (Atlas Public Policy 2024).

The Biden administration also attempted to coordinate the buildout of refueling infrastructure. The Joint Office of Energy and Transportation, a collaboration between the Departments of Energy and Transportation, worked on a National Zero-Emission Freight Corridor Strategy to begin to tackle this challenge and outline a strategy for building networks of hydrogen refueling and electric vehicle charging stations (Chu et al. 2024). The status of this effort is unknown, with **no full-time federal employees** remaining in this office.

3.2.2. State Policy

At the state level, California has led on zero-emission truck policy through the Advanced Clean Truck (ACT) and Advanced Clean Fleets (ACF) regulations. ACT requires manufacturers to sell an increasing share of zero-emission medium- and heavy-duty trucks 2024–2035, and, at its peak, 11 other states adopted its rules. However, its legal status is contested. In May 2025, Congress passed a Congressional Review Act (CRA) resolution to rescind California's Clean Air Act waiver, and President Trump signed it into effect on June 12. This action is disputed: both the Senate Parliamentarian and Government Accountability Office have held that waivers are not "rules" subject to CRA. California continues to treat ACT as active, with the California Air Resources Board (CARB) adopting amendments to provide more compliance flexibility (CARB 2021a).

ACF, by contrast, targeted demand by requiring drayage, government, and federal fleets to purchase increasing numbers of zero-emission trucks beginning in 2024 (CARB 2023). The drayage provision mandated all new port drayage trucks be zero-emission starting in 2024, with a full fleet turnover by 2035. However, CARB withdrew its waiver request in January 2025. California has since agreed to repeal or revise provisions related to private fleets after legal challenges, though the state and local government fleet requirements remain in effect.

California has also adopted the Heavy-Duty Omnibus regulation, which seeks to reduce NO_x emissions from medium- and heavy-duty vehicles beginning with the 2024 model year (CARB 2021b). It tightens allowable NO_x emissions for diesel engines and imposes enhanced warranty requirements.

With ACT and the omnibus regulation, the stricter standards in California (and other states implementing ACT) have created a tension for manufacturers as they must decide whether to align with EPA rules or California's stricter standards. Manufacturers have expressed that they are left in a holding pattern as some legacy models cannot be sold in states with California's standards. This leads to increased truck costs and decreased volumes in California. At the same time, states must decide whether to harmonize with California's standards or maintain EPA's standards. With the uncertainty of California's standards under the Trump administration, this is exacerbated, complicating long-term planning for hydrogen adoption.

California has also paired its regulations with incentives. The Hybrid and Zero-Emission Truck and Bus Voucher Incentive Program offers up to $240,000 per truck purchase, depending on class and application, helping hydrogen trucks approach cost parity with diesel (California HVIP 2024). The state's Low Carbon Fuel Standard requires fuel suppliers to reduce the carbon intensity of transportation fuels by setting a declining carbon intensity benchmark for fuels; credits are generated by fuels below the benchmark and deficits by fuels above (CARB 2010). Opportunities also exist for those who own hydrogen dispensing equipment to generate credits. Finally, the California Energy Commission has invested about $1.4 billion in zero-emission infrastructure. This is part of the Clean Transportation Program, which has allocated funding for 96 public hydrogen fueling stations, of which 44 are open (though a limited number cater to medium- and heavy-duty vehicles) (CEC 2024).

3.3. Ports

Unlike trucking, ports do not have equivalent regulations mandating decarbonization. Instead, ports generally rely on incentives and voluntary targets.

On the federal level, EPA's Clean Ports Program, created under the IRA, funded over $3 billion in decarbonization projects (EPA 2022). The program has announced 54 awarded grants, with 25 focused on zero emissions technologies. Only 3 of the 25 involve hydrogen: the Port of Oakland for electric and hydrogen cargo-handling equipment, railcar movers, and drayage trucks; Hawaii for hydrogen cargo-handling equipment and storage and fueling infrastructure; and Illinois for hydrogen locomotives and fueling infrastructure. Although these grants still may be active, the projects in Hawaii and Illinois have not yet had any funding outlaid (Atlas Public Policy n.d.). Several Climate and Air Quality Planning grants also include planning activities related to hydrogen. These grants are also assumed active, with some receiving the first round of money.

At the state and local levels, many ports have their own decarbonization plans. The Ports of Long Beach and LA have a Clean Air Action Plan (n.d.) strategy that identifies strategies to reduce pollution from ships, trucks, trains, harbor craft, and cargo-handling equipment. Both ports implemented a goal of zero-emission container-handling equipment by 2030.

Overall, the US port policy environment favors electrification decarbonization pathways, but several federal grants have begun to include hydrogen. Given that multiple awarded hydrogen hubs are located near ports, if the hub program continues, it would add additional support to integrating hydrogen in port environments.

3.4. International Hydrogen Policy

A variety of demand-side policies to stimulate clean hydrogen heavy-duty trucks and build up hydrogen use in ports have been implemented outside the United States.

3.4.1. Trucks

The European Union has the most comprehensive set of demand-side policies, following a fairly traditional subsidization and standard-setting strategy.

Already ambitious CO_2 emissions standards for heavy-duty trucks were revised in 2024, with additional target years and tighter targets. The standards require a fleet-averaged 15 percent reduction against 2019 levels in 2025, increasing to 45 percent in 2030, 65 percent in 2035, and 90 percent by 2040 (Mulholland 2024).

These standards create an incentive to switch to alternative fuels, with clean hydrogen being most likely in this sector. The European Union also has a variety of additional incentives to move hydrogen into heavy-duty trucking. Research on and the manufacturing of fuel cells and high-pressure tanks is supported by state-aid waivers through the Important Projects of Common European Interest. Truck building is supported through the Clean Hydrogen Partnership, which allocated 30 million euros to cofund the H2Accelerate Trucks project (a consortium of truck-building companies, Daimler, IVECO, and Volvo). It targets deployment of 150 fuel cell trucks and eight heavy-duty hydrogen refueling stations for demonstration by 2029. Shell, TotalEnergies and Everfuel are building the stations (H2Accelerate TRUCKS 2024).

To address refueling issues, the European Union has designated a very extensive network of major roads along which hydrogen refueling stations are to be built (European Commission 2025) and is subsidizing their construction through the Connecting Europe Facility and the Clean Hydrogen Partnership. The Alternative Fuels Infrastructure Regulation mandates a minimum number of refueling stations, liquid natural gas refueling stations, and a light duty vehicle electric vehicle network and requires member states to develop deployment plans (European Commission 2024). Stations must be no more than 200 km apart, and at least one has to be in each urban “node.”

The focus of the refueling plan appears to be truck-supplied green hydrogen to eight stations presumably along a 1,600 km route where the 150 trucks would operate. No trucking transport companies are involved, although one or more could sign on to have goods delivered.

The Japanese government has a very ambitious goal of 17,000 hydrogen trucks and buses on the road by 2030. The major trucking companies have been collaborating with the government to develop fuel and engine systems and the trucks themselves. To address the lack of competitiveness of green hydrogen with diesel, the government has implemented a subsidy of almost $5/kg. To address refueling infrastructure, the government designated six priority regions for hydrogen truck and bus deployment and is subsidizing refueling station building in those areas through support for eight hubs. The Green Innovation Fund is providing subsidies along the supply chain worth 12 billion euros (GR Japan 2024).

3.4.2. Ports

Many of the same subsidy and grant demonstration programs apply to decarbonizing port operations. EU-wide regulations, guidelines, and technical standards are in the works for hydrogen in port areas. The EU defines demonstration projects for ports as encompassing the full supply and demand chain for hydrogen. In addition , the European Clean Hydrogen Alliance has built an investment agenda for government support. The EU also has an “investment window” (InvestEU) to support hydrogen supply and demand among many priorities. This fund of 26 billion euros offers loan guarantees to leverage up to 372 billion euros in investment.

In Japan, hydrogen in ports is being promoted through (indirect) regulations and funding for infrastructure and demonstration projects. These efforts feed into a government policy to make ports carbon neutral. In response, specific ports are planning to use hydrogen. Japan is also implementing a $20 billion contract for difference (CfD) for clean hydrogen (and ammonia) production projects. Twenty-seven bids were received, adding up to more than the available funding.

4. Demand-Side Support

Without any policy rewarding low carbon fuels and uses, any cost differential with fossil fuels will discourage production and uptake of hydrogen. These cost differences are substantial. More specific market failures also exist. For example, trucking has the chicken-and-egg problem with getting refueling networks built. More generally, a relatively high risk is associated with clean hydrogen technologies, and a lack of demand inhibits private capital markets from providing financing (the “valley of death”). Due to the spillovers from innovation and demonstration, in addition to the uninternalized externality of GHG emissions, the social benefits from pursuing these technologies exceed the private benefits, motivating government intervention.

To incentivize clean hydrogen use in heavy-duty trucking and ports, both supply-push and demand-pull policies are important.[6] The former increase the supply of clean hydrogen, meaning that at a given price, more hydrogen would be produced. The latter augment the demand for clean hydrogen so that more would be demanded at any price. These policies complement one another to increase clean hydrogen trade and lower its price.

However, this distinction can be artificial, as supply and demand are inextricably linked. For example, to achieve financing for a new facility, investors will often want to see a binding offtake contract; policies that motivate the offtake also subsidize the supply

6 See Bergman et al. (2023) for more detail on demand-pull innovation policies.

by derisking the project. Other policies, such as the Joint Offtake Producer Auction (JOPA), discussed later, may target both supply and demand at the same time. We will focus on policies that are inherently linked to demand. Policies that purely focus on supply, such as production tax credits or performance insurance that derisks the performance of a new technology, are out of scope.

In this section, we will review potential demand-side support policies that can apply to the heavy-duty trucking and ports sectors.

4.1. Subsidies

Many of the instruments we discuss in this paper can be termed "subsidies," in that the government provides funds on the demand side to reduce the cost of clean hydrogen, increasing the demand at a given unsubsidized price. These subsidy-like instruments include less common mechanisms, such as CfDs and advanced market commitments (AMCs), in addition to more traditional instruments, such as tax credits or direct grants, although the latter are usually used for improving technologies rather than to support uptake. One example of a direct grant program is the hydrogen hub program.

4.2. Public Procurement

Government procurement programs can be designed for cleaner products, such as heavy-duty trucks. Federal procurement of trucks for mail delivery and military use, among other uses, can be a significant share of demand and could shape and even create markets for clean products. Medium- and heavy-duty vehicles accounted for **more than 115,000 units** in the federal fleet in 2021, and in 2023, the Postal Service announced plans to purchase **66,000 electric delivery vehicles** by 2028 as part of its fleet-modernization program. To do so, the government would need to define specifications for clean products and be able to appropriately incentivize bidders. A drawback is that for the immediate needs to be met, the clean technology must be available more or less off the shelf.

As an example, the government could specify that purchases of heavy-duty trucks as part of its procurement activities be zero emitting, thereby setting up competition between battery and fuel cells. Refueling networks would be needed and would complicate using this instrument, although they would be necessary to support any demand-side policy.

4.3. AMCs

AMCs, sometimes called "advance purchase commitments," are a form of demand guarantee for yet-to-be-developed technologies or products. Recently, AMCs have shown notable success for vaccines (Sivaram, et al. 2021).

AMCs guarantee the sale of a given amount of clean hydrogen heavy-duty trucks (and/or clean hydrogen fuel) at an agreed-upon price, sufficient to make it worthwhile for the producers to make the needed investments to produce the trucks. Those committing to future purchases are not limited to governments. Several instances exist of major AMCs being underwritten by private sector companies seeking CO_2 reduction credits toward their net zero goals.

AMCs provide incentives for successfully bringing to market a desired technology or product, based on a contract between the buyer (or offtaker) and the producer. The government or private offtaker guarantees their purchase, subject to performance by the product. This arrangement is like government procurement, but the demand can be far into the future rather than to meet immediate needs, so the technologies can be less mature when the commitment is made.

First proposed by Kremer and Glennerster (2004), these purchases only take place when the technical requirements of the new product and deadlines for delivery are met. Additionally, contracts can be written with added flexibility. For instance, purchasers could agree to pay more than the contracted price, or producers could agree to cap their price and the licensing of their intellectual property to others (Kremer and Williams 2010).

AMCs, like procurement, are not necessarily a substitute for broad market development, as just a handful of winning companies might be selected. Also, an AMC recipient can fail to meet their contract requirements, although penalties for nonperformance could be built into the contract.

Whether the success with vaccines can be replicated in other sectors is an open question. It would depend on maturity of the technology, its profitability, the number of competitors engaged in the contracts, and many other factors.

Optimal AMC design also depends on the technological maturity of the desired innovation. These may be more feasible for more mature technologies because of lower risk of failure to commercialize, but targeting promising and highly disruptive earlier-stage technologies could be more efficient in the long run.

4.4. Milestone Payments

Milestone payments are funds received by developers as they reach various stages in the demonstration or commercialization process. They can start early on or be meted out in a complex process involving, say, just the demonstration phase. Nemet et al. (2018) note that as the milestone payments come after a stage is reached, they support learning by doing and more general knowledge creation. They can make R&D contracts more efficient by addressing several problems in R&D funding, such as asymmetric information (one party has more information than the other, which could lead to underinvestment), investor risk aversion (which can be lessened knowing that milestone payments are coming), hold-up (investors underinvest because they fear their rate of return will be too low), and moral hazard (one party is overly incentivized to take risks, as it does not fully bear the downside consequences). The requirements for milestone payments involve precommitment from developers, which should reduce hold-up concerns. Finally, milestone payments can reduce moral hazard.

Milestone payments can be and have been incorporated into many different policies. For example, the hydrogen hub program featured four phases of funding, each based, in part, on performance in the previous phase. Milestone payments are also used in private R&D partnership contracts and the projects of ARPA-type agencies (Azoulay, et al. 2019).

4.5. Regulation

Subsidies are considered “carrot-based” approaches, and regulations are considered “stick-based” policies. One form of regulation is mandates. For hydrogen trucking, this could be a requirement that a given percentage of a company’s fleet be hydrogen powered or have zero emissions (a more technology-neutral alternative).

Another form of regulation is standards. The federal Corporate Average Fuel Economy standards have tightened over time, providing incentives for truck manufacturers and owners to switch to low-emissions trucks.

Standards can contribute to additional product choices for users, reduce transaction costs, and facilitate the trade of complex products. For established technologies, standards can help scale technologies and move through the “valley of death.” Moreover, Blind (2016) argued that standards can increase profits for firms that already meet them.

Standards also have some potential challenges and downsides. They need to be set for product classes rather than an entire sector. Carbon intensity standards on Class 8 trucks would need to be different than for Class 6, for instance. This issue, although recognized and acted upon by some regulatory bodies, such as California’s Buy Clean Program for diverse steel products, is highly contentious and requires good communications between regulators and the regulated.

Some other downsides are mentioned by Blind (2016) and Swann (2000). One concern is a tendency for standards to increase market concentration, which can stifle innovation. This effect is strongest when standards are set at the level of the best technology, giving firms that already use it an edge. Patent protections can, for a time, make this situation worse. However, setting standards tighter than what technologies can deliver has its own issues, such as prohibitive costs and a disincentive to new entrants. A related issue is technology lock-in. Standards based on certain technologies can result in those crowding out others that are newer but have not been “endorsed” through the standard-setting process. Standards directed to new sources of emissions can result in “new source bias”: firms not retiring older technologies when they would otherwise do so, to avoid the higher costs of meeting standards on new sources. Frequent interactions between regulator and regulated and frequent updating of standards can help mitigate these issues. One idea for application to using standards in green procurement processes, suggested by Krupnick (2020), is to create multiple standards of ever more "greenness" and provide project scoring systems that award more points for meeting tighter standards in the bidding process.

4.6. CfDs

A CfD can take many forms, but the most important for our purposes is a financial subsidy from a government to a producer that is designed to derisk the commodity's price. Eliminating or reducing price risk can result in more investor confidence and greater private funding. If the commodity is green hydrogen, for instance, the contract determines a "strike price," which is the price set through auction or administratively, and the market price, such as the price of gray hydrogen, which is sold in a market. The difference between the two prices is the subsidy (assuming the strike price exceeds the market price).[7] A useful feature of CfDs is that the strike price doesn't need to be fixed throughout the contract's duration but can be modified for changes in economic conditions outside of the seller's control.[8]

5. Application of Demand-Side Supports to Hydrogen in Ports and Trucking

In the remainder of this paper, we focus on potential additional policies to support the demand for hydrogen, building on the demand-side policies described. Part of our motivation is that most of the federal support (such as the 45V tax credit and the Hydrogen Hubs) is on the supply side. However, even without this support, it is still vital to understand the role of demand-side support in engendering a hydrogen ecosystem.

The reason for this focus is that the hydrogen currently produced and used (almost entirely in refineries and ammonia production) does not function as a (zero-carbon) energy carrier. Its use as an energy carrier to enable decarbonization has negligible demand absent policies to support it or disadvantage its fossil fuel competitors.

We will divide the discussion into policies that address hydrogen cost broadly and policies that specifically target uptake of fuel cell vehicles and the construction of a refueling network for heavy-duty trucking. The reason to start with cost is that it is the primary barrier to the uptake of clean hydrogen on the demand side, even as replacing diesel fuel is one area where hydrogen can be competitive at a relatively higher cost compared to other sectors. In addition to production, transportation is a component of cost, whether via pipelines or truck.

7 CfDs can be designed to be symmetric—the seller would pay the government if the strike price is lower than the market price.

8 For greater detail on CfDs, see Look et al. (2025).

We next focus on policies to support fuel cells, as they are the primary technology that can be used in both transportation and most or all port equipment. The barriers to uptake are twofold. First, even as fuel cell vehicles are more energy efficient than diesel-fueled vehicles, they have higher capital costs. Second, although fuel cells are already in use, they still have significant room to improve. This presents a barrier to uptake, as the vehicles will have limited resale value (as the technology will likely have improved in the interim). Additionally, because these technologies are relatively new, warranties will be expensive or unavailable.

Finally, we look at policies to support refueling networks. One advantage of the use of hydrogen in ports is that they are relatively centralized, and the fueling can be done at a single location. However, this is not possible in heavy-duty trucking, particularly for long-haul trucking. Instead, the need for refueling infrastructure is a significant barrier, where companies may be unwilling to invest in infrastructure without assurance of demand, but long-distance heavy-duty hydrogen trucking is not viable without it.

In the remainder of this section, we examine potential demand-side policies to address these areas in turn.

5.1. Hydrogen Cost

5.1.1. General Considerations

The 45V Hydrogen Production Tax Credit was a major effort to reduce the cost of hydrogen, but, as mentioned, its lifetime has been significantly shortened by OBBBA. However, the experience with the DOE Hydrogen Hub program indicates that participants thought this tax credit was insufficient to bring about the needed hydrogen demand.

One challenge with a production subsidy, such as the 45V tax credit, is that the needed markets do not exist (other than for ammonia and fertilizers). Although presumably a subsidy level exists at which new or existing hydrogen consumers would be willing to purchase clean hydrogen, that level may be prohibitively high. In addition, those consumers would likely not want to enter into long-term contracts, as the price would likely decline with increased volumes and improved technologies. This lack of long-term contracts makes it hard for hydrogen producers to receive financing.

Because of the challenges the hydrogen hubs had with finding committed users, DOE allocated a portion of the money in the program to set up a demand initiative, as discussed. The awards were intended to involve users in addition to producers. Similarly, in this section, we will look at subsidies that inherently involve the offtakers for the hydrogen. However, we first discuss some general principles for demand-side policies in these sectors before turning to specific policies.

5.1.2. Offtakers in Ports and Heavy-Duty Trucks

A common question for all these demand policies is the identity of the offtaker. Although these questions can apply to many sectors, we focus on ports and heavy-duty trucks. For the latter (including the trucks used in drayage), the individual owners or fleet operators may be too numerous and small to be parties to a subsidy program. The same likely holds for individual refueling stations, which, although not end users, could serve as a party to a subsidy. Similarly, the ownership structure for ports varies, and certain policies may be more or less suited to a given structure. Any policy must address this diversity of potential offtakers.

5.1.3. Structures for Offtaker Involvement

In many of the demand incentives described next, the subsidy would involve both a hydrogen producer and an offtaker, along with a contractual relationship to purchase the subsidized amount of hydrogen. Such a contractual relationship involves several risks. Primarily, the production may never materialize at a (subsidized) price that is profitable for the producer or offtaker. Offtakers, by signing a binding contract, additionally lose some option value, as hydrogen may be available at a lower price at the time of production.

The risks can be allocated among the producer and offtakers in varying ways, such as by including in the contract that the offtaker pay a prespecified price for the hydrogen. However, such a contractual relationship may be too high a barrier for the parties, and weaker forms of relationships may ultimately be necessary.

Irrespective of the risk, it may also be a burden for small, multitudinous offtakers to enter into contractual relationships. Even weaker forms of relationships may present difficulty in aggregating the needed amount of demand for a large production facility. One might consider having the producer only demonstrate the willingness of offtakers to pay a specified price, such as through a survey or other market research.

5.1.4. Auction Design

A common way to award a fixed amount of subsidy is through a reverse auction. Although the details will differ among the various policies, several important questions arise relating to auction design that are broadly applicable.[9] We will give an overview of the relevant issues here. For more information, see, for example, Look et al. (2025).

First, there are at least two different auction formats to consider. Many government auctions are sealed bid, where bids are reviewed at the same time to make the award. Each bid includes a strike price and, often, a quantity of hydrogen. Winners are based on the lowest strike price, until all the subsidy is exhausted. Auctions can be uniform

9 We would like to thank Bill Shobe for many conversations on the issues in this section, which also draws on the discussion in Look et al. (2025).

or discriminatory price. In the former, all winning bidders receive the same strike price as the accepted bid with the highest strike price. In the latter, each winner instead receives its bid strike price. Uniform price auctions incentivize bidders to bid their actual price; bidders in a discriminatory price auction may tend to shade their bids. On the other hand, if the pool of money is finite, more bidders can receive the subsidy in a discriminatory price auction.

Auctions must also have a sufficient number of bidders to be effective. More bidders can help with price discovery and also reduce the possibility of collusion among participants. It can be beneficial to set a minimum number of participants to make an award, although it may not be politically feasible to withhold the award. Another challenge with auctions is that bidders may bid unreasonably low to receive the subsidy but be unable to deliver. In addition to the harm in not delivering the desired product and associated decarbonization, this behavior can harm other bidders by pushing out bids that are more likely to deliver and depressing the strike price of the final accepted bid. Some ways to address this include restrictions on bidders that decrease the risk of nondelivery and ensuring that contracts with winners contain significant penalties for nonperformance. However, these restrictions may reduce bidders, decreasing the competitiveness of the auction. Regulators may also want to set maximum and minimum prices for the auction.

The choice of bid price is also important for policies designed to improve environmental outcomes. It is generally simpler to rank bids based on the price of the subsidy bid. However, different bidders may have different values of reduced emissions per dollar subsidy. To ensure the least cost per unit abatement, winners could instead be ranked based on the dollar per emissions reduction; these incentives are more unclear and likely require additional research.

Additionally, the goal of these subsidies may go beyond immediate emissions reductions. They may also try to drive down the cost of technologies, generating spillover benefits. Simply taking the lowest bids may exclude more costly technologies that could yield higher cost declines. One way to address this is to subdivide the auction to ensure that less mature technologies receive subsidies. However, this also reduces participants in the auction, with the associated challenges.

5.1.5. Demand-Side Policies to Address Hydrogen Cost

5.1.5.1. JOPA

One of the ideas arising from the H2DI program was a nascent proposal for a JOPA. Although auctioned subsidies for production have been long considered, the potential novelty in JOPA is that the bids are submitted jointly by a producer and an offtaker. The details of this mechanism were never formalized, but we can describe the broad outlines. Each bid comprises a value for the dollars per kilogram subsidy requested and total quantity of hydrogen to be subsidized. Bids are ranked in increasing value of the subsidy, with the lowest subsidy being awarded first, and then in increasing levels of subsidy until the supply of funding is exhausted, with some restrictions. An example of such a restriction is putting a limit on the percentage of total funds available to any one hub to ensure that multiple hubs receive awards. Another restriction was on the percentage of total funds available to any one project. Even with these and other restrictions, the JOPA organizers expected quite a large number of bidders across the seven funded hubs—around 100—from which the available $500 million was expected to fund 5–10 projects. Implicitly, this means that projects were expected to average $50–100 million each.

To actually implement this mechanism requires a set of practical choices, some of which have no clear best answer. Although the details of the choices in the JOPA program remain confidential, we can list the types. Many of them involve consequences for non- or less-than-promised performance by the producer in delivering the hydrogen to the offtaker, such as permitting the funder to adjust agreed-upon subsidy amounts. Performance assurance equal to some percentage of the expected subsidy is also needed to provide an incentive to perform. Typical ways to design such guarantees are with letters of credit, bonds, or cash in escrow. There may also be requirements for prior documentation of the ability of a bidder pair to fulfill project outcomes are related.

Other choices include the following:

- Bid price minimums and maximums. Too small a winning bid risks producers walking away from an unrealistic and, ultimately, unprofitable situation. Too large a winning bid risks the same on the offtaker's part.
- The delivery date as measured from the award date in years. Having different delivery dates from different bids complicates the award identification process. Thus, JOPA standardized the delivery date for all bidders.
- Whether end-use diversity or production pathway diversity is to be given weight in the selection process. As the original directive from Congress to create hubs called for such diversity, these factors could be included, or not, impacting the simplicity of the auction design and process.
- Requirements for data disclosure, such as on costs and on bids. Many reasons argue for more over less disclosure, such as to better evaluate program success and enhance knowledge spillovers. The usual reason for less disclosure is to protect confidential business information and, thus, profitability. Disclosure only to the government could be a compromise position.
- When an auction would be terminated. For instance, this may occur because of too few bidders, on the grounds that auction may not be sufficiently competitive.

Focusing on the main innovation of this mechanism (the producer/offtaker bidder pair), this type of subsidy has several advantages over one that only involves producers, such as the 45V tax credit. Most important is that each bid must entail some sort of agreement, the exact details of which would need to be specified as part of the mechanism design, that the offtaker would purchase the hydrogen produced. This ensures that the subsidy is not a bridge to nowhere—the offtake agreement ensures demand at the subsidized price. This arrangement also can lead to discovering the amount of subsidy necessary to stimulate demand in a given sector.

5.1.5.2. CfDs

CfDs also provide a subsidy to hydrogen cost, but instead of being set at a fixed value, the payment is the difference between a fixed strike price and market-determined commodity price. A CfD simulates a fixed price offtake agreement, partially derisking the project. In addition, the strike price can provide an embedded subsidy to motivate demand. The adjusting nature of the CfD payment can mitigate the cost to the government of the hydrogen subsidy.

However, no market price exists for clean hydrogen to compare with the strike price. Basing the CfD on the price charged by the producer introduces the risk that it could artificially increase the price to receive a larger subsidy. Along the theme of demand-side policies, one could instead target the offtaker with a CfD based on its purchase price. However, for ports and heavy-duty trucking, the product is transportation services. One possible way to price (marginal) transportation services is to proxy with the price of diesel, as almost all transportation in these sectors uses diesel as a fuel. Hydrogen is not priced in units of diesel fuel, however, so some conversion factor would be necessary. The intent is to capture the price of transportation services, so a simple conversion in energy units is not sufficient, as fuel cells are more efficient than diesel engines. An appropriate sector-specific conversion factor taking this into account could be set in legislation or regulation.

This sort of subsidy is somewhat removed from a direct subsidy for hydrogen production. Instead, the CfD mitigates the price risk by allowing the sale of hydrogen at a price competitive with diesel fuel. This mitigation is because, for each kilogram of hydrogen sold, the offtaker will have to pay the diesel price times the diesel-to-hydrogen conversion factor, a fixed value that is the price necessary to sell hydrogen so that it produces the same amount of transportation services as diesel fuel. In return, the offtaker will receive the strike price times the quantity of hydrogen purchased. The strike price will be higher than the cost of hydrogen to embed a subsidy that offsets the marginal cost difference between hydrogen-powered services and diesel-fueled services. As the price of diesel fuel increases, the CfD payment will decline.

This design can be represented by the following formula for the marginal cost of hydrogen sales by the refueling station:

$$[(p_s - \gamma p_d) + (p_f - p_h)]$$

where p_s is the strike price, p_d is the diesel price, γ is the conversion factor, p_f is the sale price for the hydrogen, and p_h is the purchased price of the hydrogen. The first term in parentheses represents the impact of the CfD, and the second is the ordinary revenue. The refueling station can set $p_f = \gamma p_d$ to ensure that the hydrogen is sold at a viable price. Then, the strike price will be p_h plus an additional subsidy to recover capital expenses.

As the award is based on the lowest strike price, this creates an incentive to have the price be as low as possible. A joint offtaker/producer auction makes sense as a mechanism to ensure that both supply and demand exist. Instead of the level of subsidy being bid, bidders will propose a strike price in dollars per kilogram of hydrogen and a quantity of hydrogen production.

5.1.5.3. AMCs and Government Procurement

AMCs and government procurement share the challenge of very little demand for hydrogen as an energy carrier, particularly by the government. However, either could be applicable should the government build out a fleet of fuel cell vehicles. The government (or a private entity for an AMC) may want to prescribe the particular form of hydrogen production, such as to support a more nascent technology. The government could also demand a ceiling for the carbon intensity of production. The level of the AMC or purchase price can be set through a government procurement process, which can share many of the same characteristics as an auction.

AMCs and government procurement also apply to the vehicles themselves, discussed next.

5.2. Fuel Cell Vehicle Costs

Another source of increased costs for hydrogen use in the ports and heavy-duty trucking sectors is the cost of fuel cells and the associated engines. Many subsidies and mandates exist for fuel cell vehicles at the state level, particularly in California. Even if hydrogen is sufficiently inexpensive that it is competitive with diesel fuel in its ability to provide transportation services, the high capital costs for fuel cells may still render them uncompetitive on a levelized cost basis.

5.2.1. Direct Subsidy

One straightforward option already in use is for the government to directly provide a subsidy to the purchaser to offset the cost of the trucks and port equipment. If an auction were used to allocate the subsidy, it would need a subdivision in terms of the type of equipment. For the ports sector, this might be challenging, given the variety of equipment, although a subset of it could be selected for funding. As fuel cells are inherently a part of hydrogen demand, subsidizing them means that the need for offtake is already addressed by the subsidy, and the structure of a JOPA is not applicable; the auction would only apply to the purchaser. However, the auction design considerations would still apply.

5.2.2. CfDs

The lack of a commodity price on which to base a CfD makes CfDs hard to apply in this area. One could consider an adjusting subsidy akin to a CfD, where the subsidy for fuel cell vehicles adjusts based on the cost of a comparable diesel engine.

5.2.3. AMCs and Government Procurement

Government procurement and AMCs are applicable anywhere the government is involved in ports and heavy-duty trucking. If the goal of the policy is to drive down costs for fuel cells, it may be worthwhile to focus on more advanced technologies using an advanced market commitment rather than procurement of more broadly available technologies, which may not have as much opportunity for cost reductions.

5.2.4. Other Demand Incentives

Demand-side incentives can also address the barriers due to the relative novelty of fuel cells in trucking and port equipment. For example, heavy-duty trucks are often resold. However, as fuel cell technology improves, the value of less advanced fuel cells will decline, driving down the resale price. This increases the effective amount of investment for a new truck. The government can address this issue with subsidies, as earlier, but could also repurchase trucks, reselling them at lower costs and absorbing the difference.

The novelty of fuel cells also makes it harder for manufacturers to provide a warranty, increasing the risk of equipment ownership. The government could step in to provide warranties or backstop manufacturer warranties, mitigating this risk.

5.3. Building Refueling Infrastructure

Although the infrastructure for refueling in ports is relatively localized, using hydrogen for long-distance heavy-duty shipping requires a network of refueling stations. However, constructing them presents a “chicken-and-egg” problem. Without a guarantee of demand for the hydrogen along the shipping route, the stations risk sitting idle, providing little value, but without them, no one will invest in the vehicles needed for shipping along the route. In some ways, this is akin to a network externality, where the system of refueling stations along a corridor is worth more than the sum of what each station is worth individually. It follows that value does not increase smoothly as the number of refueling stations increases; instead, the value is only realized when a threshold density of refueling stations is reached that enables long-distance shipping.

5.3.1. Corridor Designations

One straightforward action the government can take is to select a small number of refueling corridors to focus efforts. This mitigates the risk of diffusing the impact of a given policy over too many regions, such that no one region receives the support necessary for success. It may also serve to focus private sector efforts and allow the network externality to have a multiplying effect on investments. The EU corridor policy could be a template.

5.3.2. Subsidies and CfDs

Direct subsidies and CfDs can address refueling infrastructure as well, by raising the revenue per kilogram of hydrogen sold. These policies may benefit from being paired with a corridor designation, as earlier, to capture the coordination benefits. This approach could be in addition to or in lieu of a broader subsidy open to all applicants.

One challenge with subsidies targeted at hydrogen sales for enabling refueling infrastructure is that the refueling station still has significant risk with respect to the volume of hydrogen sold. Given that the volume will largely depend on whether a full network of stations exists, this risk is likely determinative in the ability for stations to recover their capital expenses.

Fixed subsidies per refueling station (as opposed to subsidies that depend on the amount of hydrogen sold) can address the volume risk. The subsidies could also be based on station capacity, either the total hydrogen storage capacity or volume of hydrogen that can be pumped at a given time. However, a fixed subsidy does not address the marginal cost of the fuel. As hydrogen will be more expensive than diesel for transportation services, some policy is necessary to offset that. The fixed subsidy could be paired with a variable one to address this issue.

One can also address volume risk in the context of a CfD. However, the challenge of the differential between a viable sale price of hydrogen and its purchase price by the refueling station remains. A pure exchange of a fixed for a variable payment will leave the station with an incentive to either use an unviable price or lose money on every transaction. A hybrid CfD consisting of both a fixed and variable payment to the station based on set strike prices (in exchange for a variable payment to the government based on the price of diesel) can both offset the need for a subsidy and mitigate the volume risk with respect to recovering capital expenditures (capex). Without the fixed component, the strike price must be above the price of the hydrogen to recover the capex. In this hybrid structure, instead, the refueling station is able to bid a lower strike price equal to the price of hydrogen and separately bid its capex.

One challenge with this structure is how to rank the bids. By setting an assumed volume, v, the bids could be ranked as $\mathrm{p_s v + c_s}$, where $\mathrm{p_s}$ is the strike price and $\mathrm{c_s}$ is the capacity cost bid. However, the incentives for bidding are not clear and likely depend on the choice of assumed volume. For example, a refueling station could trade off the strike price and bid capacity cost to attempt to lower the overall bid price. However, having separate auctions for the CfD and capacity subsidy has similar challenges with the bidding incentives. Devising an appropriate CfD for refueling stations that addresses volume risk is a subject for future research.

6. Conclusion

Preliminary experience with the hydrogen hubs program at DOE has shown that solely supporting the production of clean hydrogen is likely not sufficient to motivate its use. Its cost is too high to compete with existing fuels. Demand-side incentives can work in concert with supply-side supports to help incubate a clean hydrogen ecosystem. We identify heavy-duty trucking and ports as two sectors where demand-side supports can have a significant impact.

The impact can be significant because, in these sectors, (1) hydrogen replaces diesel fuel, which is relatively expensive, and (2) electric vehicles may not be a viable option because of the long-haul nature of heavy-duty truck driving and need for quick refueling. For ports, uses of hydrogen are also generally colocated, which reduces the need for extensive refueling infrastructure. However, that is a significant barrier for heavy-duty trucking, which needs multiple fueling stations along a long-distance corridor. This barrier, separate from the cost barriers to the use of hydrogen, can also be addressed through demand-side support.

We identify several demand-side policies to address the most prominent barriers in these sectors: the cost of hydrogen, cost of fuel cell vehicles, and need for extensive refueling infrastructure for heavy-duty shipping. For cost barriers, these policies include subsidies that target hydrogen consumption and AMCs or government procurement of hydrogen and fuel cell vehicles.

Looking at CfDs, the lack of a standard commodity price for clean hydrogen makes implementation difficult. We propose instead to base the CfD on the cost of transportation services, with the price of diesel fuel as a proxy. However, this suggestion adds significant complexity and likely requires further research.

With respect to refueling infrastructure, the government can designate certain corridors for subsidization to focus investment and enable the benefits from a sufficiently dense set of refueling stations. Subsidies and CfDs can also benefit refueling networks, but the coordination challenge means that basing these subsidies on the amount of sales presents an additional risk where the subsidized amount depends on having a viable transportation corridor. This problem can be addressed by capacity-based subsidies, or, for a CfD, a fixed subsidy added to the variable one. As before, the CfD presents novel challenges and again would benefit from further research.

The exact role that hydrogen can play as a zero-carbon energy carrier in a decarbonizing economy is not clear. Even without prescribing particular outcomes for technology deployment, known market inefficiencies, such as the valley of death in moving to demonstrate innovation and network externalities for refueling infrastructure, mean that a role for government in bringing new technologies to market can be justified. Particularly for an intermediate good, such as hydrogen, with few current uses, we find that demand-side supports can play a synergistic role with supply subsidies to achieve this goal. Multiple policy options exist for each market, each with their individual pluses and minuses. Detailed analysis of these markets, alongside further research, will inform future policymakers in implementing these policies.

The subsidies are of course all what economists would call second-best approaches. The first-best approach to address climate change is to price the climate externality appropriately, through a carbon tax or cap-and-trade program. Clean hydrogen production, trucks, and refueling stations would all become more competitive against their diesel counterparts, leaving electricity and clean hydrogen to fight it out for market share.

References

American Association of Port Authorities. 2024. *2024 Economic Impact Report*. **https://www.aapa-ports.org/files/2024%20Economic%20Impact%20Report.pdf** (accessed October 17, 2025).

Atlas Public Policy. n.d. *Climate Program Portal*. **https://climateprogramportal.org/** (accessed October 17, 2025).

————. 2024. "A Look at Charging Infrastructure Funding Awards." *Climate Program Portal*. **https://climateprogramportal.org/2024/02/21/full-charge-a-look-at-charging-infrastructure-funding-awards/** (accessed October 17, 2025).

Azoulay, Pierre, Erica Fuchs, Anna Goldstein, and Michael Kearney. 2018. "Funding Breakthrough Research: Promises and Challenges of the 'ARPA Model.'" National Bureau of Economic Research Working Paper No. 24674. **https://doi.org/10.3386/w24674** (accessed October 17, 2025).

Bergman, Aaron, Alan Krupnick, Daniel Haerle, Lucie Bioret, Yuqi Zhu, and Jhih-Shyang Shih. 2023. "Demand-Pull Tools for Innovation in the Cement and Iron and Steel Sectors." RFF Reports 23-01. March 1, 2023. **https://www.rff.org/publications/reports/demand-pull-tools-for-innovation-in-the-cement-and-iron-and-steel-sectors/** (accessed October 17, 2025).

Blekhman, David. 2024. "Hydrogen Crane Deployment at the Port of Los Angeles." *Forbes*, June 11, 2024. **https://www.forbes.com/sites/davidblekhman/2024/06/11/hydrogen-crane-deployment-at-the-port-of-los-angeles/** (accessed October 17, 2025).

Blind, K. 2016. The Impact of Standardisation and Standards on Innovation. In *Handbook of Innovation Policy Impact*, by K. Blind. Edward Elgar Publishing.

Burnham, Andrew, David Gohlke, Luke Rush, Thomas Stephens, Yan Zhou, Mark Delucchi, Alicia Birkey, Chad Hunter, Zhenhong Lin, Shiqi Ou, Feix Xie, Camron Proctor, Steven Wiryadinata, Nawei Liu, and Madhur Boloor. 2021. *Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains*. ANL/ESD-21/4. Lemont, Illinois: Argonne National Laboratory. **https://publications.anl.gov/anlpubs/2021/05/167399.pdf**.

CARB (California Air Resources Board). 2010. Low Carbon Fuel Standard Regulation (17 CCR §§ 95480–95503). Effective April 15, 2010. **https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard/lcfs-regulation** (accessed October 17, 2025).

————. 2021a. Advanced Clean Trucks Regulation. OAL approved and filed with the Secretary of State March 15, 2021. **https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks** (accessed October 17, 2025).

————. 2021b. Heavy-Duty Engine and Vehicle Omnibus Regulation. Effective December 22, 2021. **https://ww2.arb.ca.gov/rulemaking/2020/hdomnibuslownox** (accessed October 23, 2025).

————. 2023. Advanced Clean Fleets Regulation. Effective October 1, 2023. **https://ww2.arb.ca.gov/our-working/programs/advanced-clean-fleets. California Air Resources Board+5California Air Resources Board+5California Air Resources Board+5** (accessed October 17, 2025).

CEC (California Energy Commission). 2024. CEC Approves $1.4 Billion Plan to Expand Zero-Emission Transportation Infrastructure. December 11, 2024. **https://www.energy.ca.gov/news/2024-12/cec-approves-14-billion-plan-expand-zero-emission-transportation-infrastructure** (accessed October 17, 2025).

California HVIP. 2024. Implementation Manual for the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP). October 31, 2024. **https://californiahvip.org/wp-content/uploads/2024/10/FY23-24-HVIP-Implementation-Manual-103124.pdf** (accessed October 17, 2025).

Chu, Kang-Ching (Jean), Kevin George Miller, Alex Schroeder, Alycia Gilde, and Michael Laughlin. 2024. *National Zero-Emission Freight Corridor Strategy*. DOE/EE-2816. Joint Office of Energy and Transportation, US Department of Energy/Department of Transportation. **https://driveelectric.gov/files/zef-corridor-strategy.pdf** (accessed October 17, 2025).

Clean Air Action Plan (Ports of Los Angeles & Long Beach). n.d. Clean Air Action Plan: Strategies. **https://cleanairactionplan.org/strategies/** (accessed October 17, 2025).

Clean Hydrogen Partnership. 2023. Study on Hydrogen in Ports and Industrial Coastal Areas. **https://www.clean-hydrogen.europa.eu/document/download/9fef29ac-6f95-465b-bb6e-1365526f43c4_en?filename=Study%20on%20hydrogen%20in%20ports%20and%20industrial%20coastal%20areas.pdf** (accessed October 17, 2025).

DOE (US Department of Energy), Office of Energy Efficiency & Renewable Energy. 2025. Alternative Fueling Station Locator: Hydrogen, Heavy-Duty (Nonretail), US. **https://afdc.energy.gov/stations#/analyze?tab=station&fuel=HY&hy_nonretail=true&country=US&maximum_vehicle_class=HD&show_map=true** (accessed October 17, 2025).

——————. 2021. *Hydrogen Fueling Station Cost*. DOE Report No. 21002. **https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/21002-hydrogen-fueling-station-cost.pdf?Status=Master** (accessed October 17, 2025).

——————. 2024. *Pathways to Commercial Liftoff: Clean Hydrogen (December 2024 Update)*. Washington, DC: US Department of Energy. **https://liftoff.energy.gov/wp-content/uploads/2024/12/Clean-Hydrogen.pdf** (accessed October 23, 2025).

DOT, Maritime Administration. 2025. Ports—The Gateway to American Waters. **https://www.maritime.dot.gov/ports/ports** (accessed October 17, 2025).

EPA (US Environmental Protection Agency). 2022. Clean Ports Program. **https://www.epa.gov/ports-initiative/cleanports** (accessed October 17, 2025).

——————. 2024a . Ports Primer: 3.1 Port Operations. Last updated December 10, 2024. **https://www.epa.gov/ports-initiative/ports-primer-31-port-operations** (accessed October 17, 2025).

——————. 2024b. Fast Facts: US Transportation Sector Greenhouse Gas Emissions 1990–2022. EPA Publication No. EPA-430-R-24-001. **https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P101AKR0.pdf** (accessed October 17, 2025).

——————. 2024c. Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles—Phase 3 Final Rule. Effective June 21, 2024. **https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-greenhouse-gas-emissions-standards-heavy-duty**.

European Commission. 2024. Alternative Fuels Infrastructure—Clean Transport—Alternative Fuels & Sustainable Mobility in Europe. **https://transport.ec.europa.eu/transport-themes/clean-transport/alternative-fuels-sustainable-mobility-europe/alternative-fuels-infrastructure_en** (accessed October 17, 2025).

——————. 2025. Trans-European Transport Network. **https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en. transport.ec.europa.eu** (accessed October 23, 2025).

FHWA. 2000. Chapter 3 Truck Fleet and Operations Introduction. **https://www.fhwa.dot.gov/reports/tswstudy/vol2-chapter3.pdf**.

FCHEA (Fuel Cell & Hydrogen Energy Association). 2023. Hydrogen Driving Port Commercialization. June 12, 2023. **https://fchea.org/wp-content/uploads/2025/03/Hydrogen-Driving-Port-Commercialization.pdf** (accessed October 17, 2025).

GR Japan. 2024. Japan's Hydrogen and Ammonia Policy—Overview and Key Developments (Final). March 12, 2024. **https://grjapan.com/sites/default/files/content/articles/files/Japan%27s%20hydrogen%20and%20ammonia%20policy%20-%20overview%20and%20key%20developments%20%28final%29_1.pdf** (accessed October 23, 2025).

H2Accelerate TRUCKS. 2024. H2AccT Flyer (2-page English version). November 2024. **https://h2accelerate.eu/wp-content/uploads/2024/11/H2AccT_Flyer_2pages_vEN.pdf** (accessed October 23, 2025).

AEO (Association for Enterprise Opportunity). (2024, October 4). *Industry Analysis*. **https://resili.aeoworks.org/industry-analysis/** (accessed October 17, 2025).

Kremer, Michael, and Rachel Glennerster. 2004. *Strong Medicine: Creating Incentives for Pharmaceutical Research on Neglected Diseases*. Princeton, NJ: Princeton University Press.

Kremer, M., and H. Williams. 2010. Incentivizing Innovation: Adding to the Tool Kit. *Innovation Policy and the Economy* 10(1), 1–17.

Krupnick, Alan. 2020. "Green Public Procurement for Natural Gas, Cement, and Steel." RFF Reports 20-17. November 2020. **https://media.rff.org/documents/RFF_WP_20-17_Green_Public_Procurement_for_Natural_Gas_Cement_and_Steel.pdf** (accessed October 17, 2025).

Ledna, Catherine, Matteo Muratori, Arthur Yip, Paige Jadun, Christopher Hoehne, and Kara Podkaminer. 2024. "Assessing total cost of driving competitiveness of zero-emission trucks," *IScience* 27(24): 109385. **https://doi.org/10.1016/j.isci.2024.109385**.

Look, Wesley, Seton Stiebert, Yuqi Zhu, William Shobe, Benjamin Longstreth, Alan Krupnick, Aaron Bergman, Chris Bataille, and Pavitra Srinivasan. 2025. *Contracts for Difference to Spur Clean and Competitive Industry: Options for Federal Policymakers*. Washington, DC: American Council for an Energy-Efficient Economy. **https://www.aceee.org/sites/default/files/pdfs/i2501.pdf**.

Mulholland, Eamonn. 2024. *Policy Update: The Revised CO_2 Standards for Heavy-Duty Vehicles in the European Union*. ID 130. Cambridge, MA: International Council on Clean Transportation. **https://theicct.org/wp-content/uploads/2024/05/ID-130-%E2%80%93-EU-CO2_policy_update_final.pdf**.

Nasser, Ellu, Dana Rodriguez, Fern Uennatornwaranggoon, Ken Adler, Mark Button, Amy Leitch, Elizabeth Joyce, and Hannah Wilson. 2024. *Practical Pathways for Port Decarbonization and Environmental Justice: Guidance for US Ports and Their Partners. Environmental Defense Fund and Arup*. **https://www.edf.org/sites/default/files/documents/2024-EDF_Port_Decarb_EJ_Report_0.pdf**.

NCSES (National Center for Science and Engineering Statistics), US National Science Foundation, and US Census Bureau. 2025. Nonemployer Statistics by Demographics Series (NES-D): Statistics for Employer and Nonemployer Firms by Industry and Sex for the US, States, Metro Areas, Counties, and Places: 2022. Economic Surveys, ECNSVY Nonemployer Statistics by Demographics Company Summary, Table AB00MYNESD01A. **https://data.census.gov/table/ABSNESD2022.AB00MYNESD01A** (accessed October 17, 2025).

Nehrkorn, Katarina, Beia Spiller, and Alan Krupnick. 2024. *Exploring Hydrogen's Role in Heavy-Duty Trucking*. Washington, DC: Resources for the Future. **https://media.rff.org/documents/Report_24-11_xxQBjTI.pdf**.

Nemet, G. F., V. Zipperer, and M. Kraus. 2018. The Valley of Death, the Technology Pork Barrel, and Public Support for Large Demonstration Projects. *Energy Policy* 154–67.

Port Authority of Valencia. 2023. The First Hydrogen Powered Container Stacker Arrives at the Port of Valencia, as Part of the H2PORTS Project. August 30, 2023. **https://www.valenciaport.com/en/the-first-hydrogen-powered-container-stacker-arrives-at-the-port-of-valencia-as-part-of-the-h2ports-project/** (accessed October 17, 2025).

Port Houston. 2025. Port Houston Receives $25 Million Grant: Pipeline-Based Hydrogen Refueling Station of the Future. January 17, 2025. **https://porthouston.com/wp-content/uploads/2025/01/Port-Houston-Receives-25-Million-Grant_-Final-Jan-17-2025.pdf** (accessed October 17, 2025).

Shafiee, Roxana T., and Daniel P. Schrag. 2024. Carbon Abatement Costs of Green Hydrogen Across End-Use Sectors. *Joule* 8(12): 3281–89. **https://doi.org/10.1016/j.joule.2024.09.003**.

Sivaram, Varun, Matt Bowen, Noah Kaufman, and Doug Rand. 2021. "To Bring Emissions-Slashing Technologies to Market, the United States Needs Targeted Demand-Pull Innovation Policies." *Commentary*, January 20, 2021. Center on Global Energy Policy, Columbia University. **https://www.energypolicy.columbia.edu/publications/bring-emissions-slashing-technologies-market-united-states-needs-targeted-demand-pull-innovation/** (accessed October 17, 2025).

Steele, Lindsay M., and Charlie Myers. 2019. Hydrogen Fuel Cell Applications in Ports: Feasibility Study at Multiple US Ports. PNNL-SA-147032. Presented at the H2@Ports International Workshop, September 2019, San Francisco. **https://www.energy.gov/sites/default/files/2019/10/f68/fcto-h2-at-ports-workshop-2019-viii3-steele.pdf** (accessed October 17, 2025).

Sivaram, V., Bowen, M., Kaufman, N., and Rand, D. (2021). *To Bring Emissions-Slashing Technologies to Market, the United States Needs Targeted Demand-Pull Innovation Policies*. Center on Global Energy Policy, Columbia University

United States. 2021. *Infrastructure Investment and Jobs Act*, Public Law No. 117-58, 135 Stat. 429 (November 15, 2021).

United States. 2022. Inflation Reduction Act of 2022, Public Law No. 117-169.