Written Testimony of

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My name is Jonathan Lewis. I am Senior Counsel at the Clean Air Task Force, a nonprofit organization that advocates for the change in technologies and policies needed to get to a zero-emissions, high-energy planet at an affordable cost, so that we can meet the world's rising energy demand in a way that is financially, socially and environmentally sustainable.[1] I work on Clean Air Task Force's effort to promote the development and deployment of zero carbon fuels.

I want to thank Chairman Murkowski, Ranking Member Manchin, and the rest of the Energy and Natural Resources Committee for inviting me to testify today, and for holding this hearing on the important topic of emerging offshore energy technologies.

[1] Mitigating climate change requires full decarbonization of major economic sectors

Earth's average surface temperature has increased by about 1°C since 1880.[2] Research strongly indicates that limiting planetary warming to 1.5-2.0°C above preindustrial levels is necessary to avoid the worst impacts of climate change.[3] To stay within the carbon budget implied by the 2°C target, much less a 1.5°C target, annual greenhouse gas emissions must peak soon and then decline rapidly.[4]

To achieve that goal, we need to eliminate greenhouse gas emissions from nearly every major sector of the global economy by 2050. Sectors that cannot fully eliminate their greenhouse gas emissions must reduce those emissions to the fullest extent possible.[5]

The marine shipping sector is one of those sectors. If it were a country, marine shipping would rank sixth on a list of countries with the highest greenhouse gas emissions, behind Japan but ahead of Germany, the United Kingdom, and South Korea.[6] According to the International Maritime Organization (IMO), the sector's greenhouse gas emissions "could grow between 50% and 250% by 2050;"[7] University Maritime Advisory Services (UMAS), a

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1 www.catf.us

2 Rebecca Lindsey and LuAnn Dahlman, National Oceanic and Atmospheric Administration, *Climate Change: Global Temperature* (2020) (https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature).

3 Intergovernmental Panel on Climate Change, *Global Warming of 1.5°C, an IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty* (2018) (https://www.ipcc.ch/sr15/).

4 *Id.*

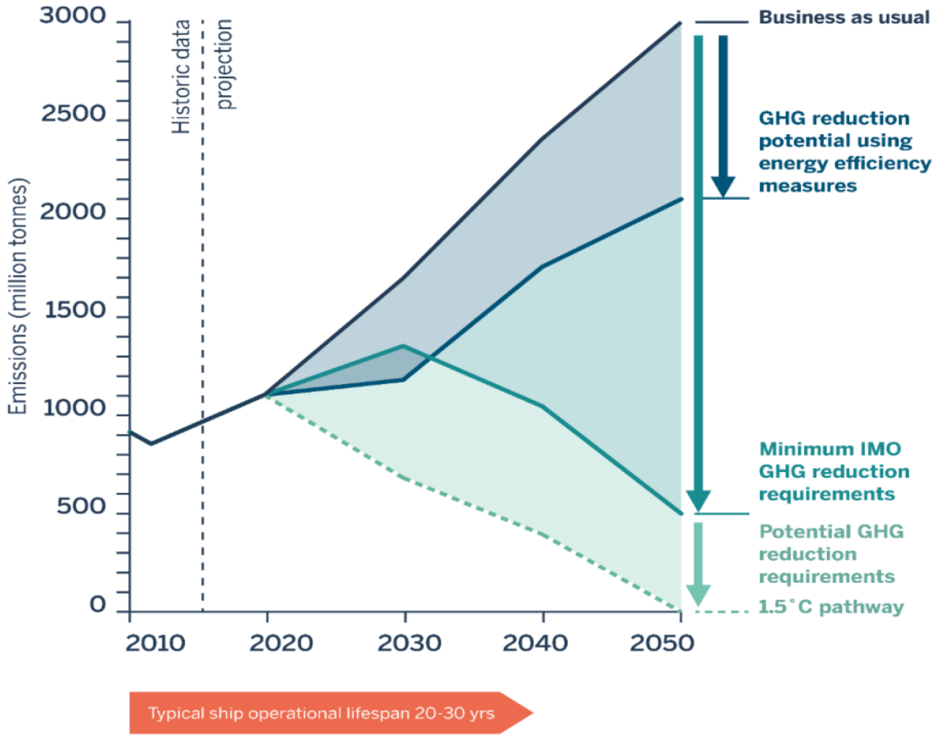
5 See, e.g., David G. Victor, Frank W. Geels, Simon Sharpe, *Accelerating the Low Carbon Transition* (2019) (https://www.brookings.edu/wp-content/uploads/2019/12/Coordinatedactionreport.pdf).

6 International Maritime Organization, *Reduction of GHG Emissions from Ships: Fourth IMO GHG Study*, *MEPC 75/7/15* (2020) (the global shipping sector emitted 1.076 billion tonnes of greenhouse gas in 2018 (a 9.6% increase since 2012), of which 1.056 billion tonnes were carbon dioxide; the sector's emissions account for 2.89% of global anthropogenic GHG emissions in 2018) (https://docs.imo.org/Shared/Download.aspx?did=125134); Union of Concerned Scientists, *Each Country's Share of CO2 Emissions* (2020) (the shipping sector's CO2 emissions in 2018 (1.06 billion tonnes) are lower than the 2018 CO2 emissions from Japan (1.16 billion tonnes) but higher than those from Germany (0.75 billion tonnes)) (https://www.ucsusa.org/resources/each-countrys-share-co2-emissions).

7 International Maritime Organization, *Greenhouse Gas Emissions* (2020) (http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/GHG-Emissions.aspx).

marine sector consultancy affiliated with University College London, projects that the sector's emissions will grow 200% by midcentury under a business-as-usual scenario.[8]

Fig. 1. Actual and Projected Emission Trajectories for Marine Shipping, 2010-2050 (UMAS)



Given typical ship operational lifespans and midcentury net-zero carbon targets, investments in zero-carbon fuel infrastructure that can be applied in current ship designs need to be a policy priority.

Marine shipping is one of several segments of the global economy frequently referred to in climate change mitigation discussions as a "hard to abate" sector—a designation typically applied to sectors that cannot be readily electrified and therefore decarbonized through carbon-free electricity. Eliminating greenhouse gas emissions from the marine shipping sector will indeed be difficult, but it can be done. Moreover, it can be done over the next few decades, through the deployment of known technologies. By supporting the commercialization of those technologies, the United States, Congress, and this Committee can play a leading role in helping the marine sector decarbonize.

Zero carbon fuels and the engines, turbines, boilers, and fuel cells that can run on zero carbon fuels are at the center of this effort.

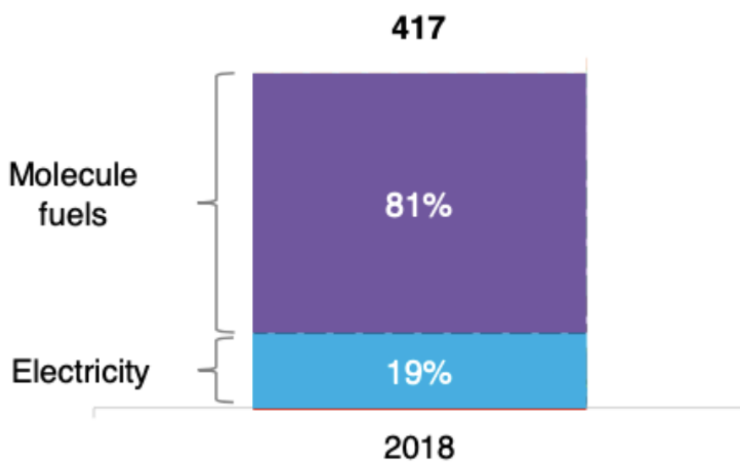
8 UMAS, *How Can Shipping Decarbonise?* (2019) (https://www.u-mas.co.uk/Latest/Post/411/How-can-shipping-decarbonise-A-new-infographic-highlights-what-it-d-take-to-decarbonise-shipping-by-2050).

[2] What are zero-carbon fuels?

Zero carbon fuels are fuels which emit no carbon dioxide when consumed, and for which lifecycle greenhouse gas emissions are minimized. In practice this is likely to mean hydrogen (H_2) and ammonia (NH_3)—which can be converted to energy in compatible fuel cells, reciprocating engines, turbines, and other machines—when the hydrogen or ammonia is the result of certain production pathways. The concept of minimal lifecycle greenhouse gas emissions is likely to evolve over time but in any event means a significant reduction when compared to the fossil fuels being displaced. There are other fuels that offer potentially significant reductions in lifecycle greenhouse emissions, such as synfuels made from hydrogen and carbon removed from air, however these may present different infrastructure challenges and reflect different issues related to scale up and economics.

The world currently uses carbon-containing fossil fuels (oil, gas, coal) to power approximately 90% of transportation,[9] 65% of electricity generation,[10] and 76% of industrial energy consumption.[11] Liquid and gaseous fuels are especially convenient, and account for the bulk of US and global energy end-use (see Fig. 2).

Fig. 2. Global Final Energy Consumption in 2018 (EJ)



Much of our carbon emissions come from use of fossil fuels. Replacement of those high-carbon emitting fuels with zero-carbon emitting alternatives is an essential pathway to deep decarbonization. (Data: IEA via BNEF12)

The International Energy Agency (IEA), US Energy Information Administration (EIA), and other analysts project that oil will continue to power a significant portion of the transportation sector for decades, even when high rates of future electrification are

9 BP, *Energy Outlook: Transport* (2018) (https://www.bp.com/en/global/corporate/energy-economics/energy-outlook/demand-by-sector/transport.htm).

10 BP, *Statistical Review of World Energy*, at 48 (2018) (https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-electricity.pdf).

11 US Energy Information Administration, *International Energy Outlook 2019*—Table: Delivered energy consumption by end-use sector and fuel (https://www.eia.gov/outlooks/aeo/data/browser/#/?id=15-IEO2019&region=4-0&cases=Reference&f=A).

12 Koban Bhavnagri, BNEF, *Hydrogen Economy Outlook* (2020) (presentation on file with CATF).

assumed. Even if *all* light duty vehicles are electrified by 2040, demand from the rest of the transportation sector (comprised of harder-to-electrify vehicles like trucks, trains, ships and aircraft) would still exceed 35 million barrels of oil per day, per IEA data.[13]

Safeguarding against the worst impacts of climate change will likely require a near-total reduction in carbon emissions from the transportation, power, and industrial sectors. Doing so requires a wholesale shift away from carbon-intensive fuels, and points to the urgent need to develop and deploy alternative fuels that offer the benefits of oil, gas, and coal—but without the carbon. Two of the most promising options are hydrogen and ammonia.

The global marine shipping sector consumed 222 Mtoe of residual oil, marine diesel oil, and LNG in 2019 (containing approximately 9 quadrillion btu of energy).[14] Shifting that consumption in its entirety to zero carbon fuels—which are currently not used at all to power marine shipping—will require significant effort from both the private and public sectors. According to an analysis by the Global Marine Forum (GMF), fully decarbonizing the shipping sector by 2050 through a transition to hydrogen and ammonia fuels will cost between USD $1.4-1.9 trillion.[15] The bulk of these investments (87%) would be for fuel production; GMF estimates that only 12% of the investment would go toward to propulsion systems and fuel storage and another 1% would go to energy efficiency upgrades.[16]

The shift to zero carbon marine fuels will take place within the context of other decarbonization initiatives throughout the broader economy—and other demands for hydrogen and ammonia. As discussed in Part 4, below, hydrogen and ammonia fuel could play important roles in the elimination of greenhouse gas emissions from several economic sectors, including other types of heavy-duty freight transport, industrial processes, commercial and residential space heating, and power (by providing long-duration storage).

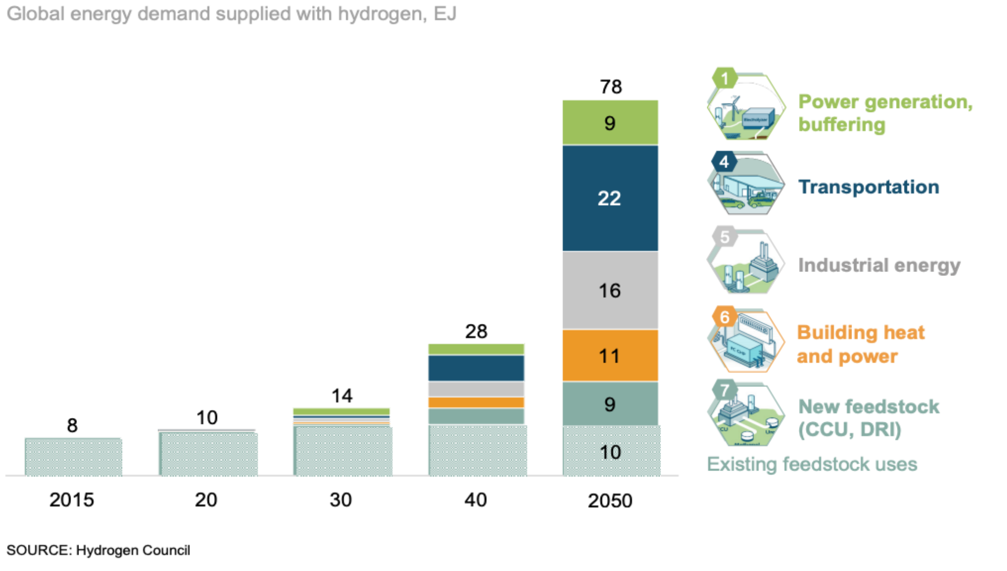
13 International Energy Agency, *World Energy Outlook 2016* —Table 3.3: World oil demand by sector in the New Policies Scenario (2016).

14 International Energy Agency, *International Shipping* (2020) (https://www.iea.org/reports/international-shipping).

15 Global Maritime Forum, *Getting to Zero Coalition Insight Series: The scale of investment needed to decarbonize international shipping* (2020) (the level of investment depends on the production method(s) used to make the hydrogen and the ammonia, with an approach that depends fully on SMR+CCS representing the low-end cost estimate and an approach that depends fully on pure electrolysis production representing the high-end) (https://www.globalmaritimeforum.org/content/2020/01/Getting-to-Zero-Coalition_Insight-brief_Scale-of-investment.pdf).

16 *Id.*

Fig. 3: Hydrogen demand could increase 10-fold by 2050

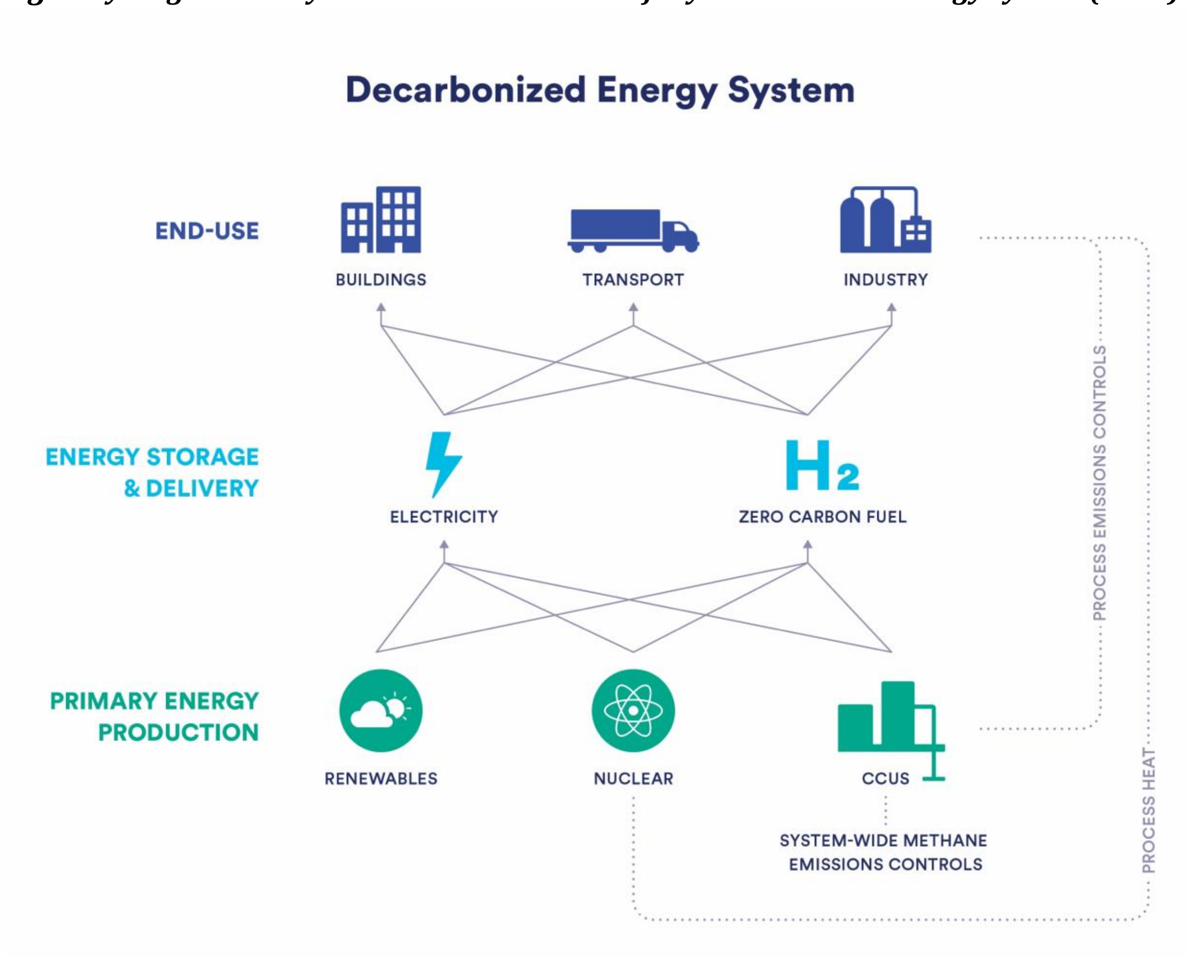


Energy-related demand for hydrogen from power generation, transportation, and other economic sectors could grow from 8 exajoules in 2015 to 78 exagjoules in 2050.

McKinsey & Company has estimated that a ten-fold scale-up in hydrogen production could be needed to meet future demand for hydrogen in a 2050 global economy that uses to hydrogen-based fuels to meet 18% of final energy demand.[17]

17 McKinsey & Co. for the Hydrogen Council, *Hydrogen Scaling Up: A sustainable pathway for the global energy transition* (2017) at 20 (https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf).

Fig 4. Hydrogen is likely to be critical vector in a fully decarbonized energy system (CATF)



Hydrogen (as well as ammonia made from hydrogen) can be produced from multiple zero- and low-carbon technologies and processes (e.g., electrolysis using renewable or nuclear energy, gas reforming with carbon capture), and can power a wide variety end-uses--particularly those that may prove difficult to electrify.

Although the vast majority of the hydrogen and ammonia currently produced is made through processes that emit significant volumes of carbon dioxide (CO_2), both molecules—hydrogen and ammonia—can be produced and used to carry energy through processes that emit little or no greenhouse gas.

Gas reforming with carbon capture and storage is one such process. Steam methane reformers (SMR) and similar technology decompose methane (CH_4) into hydrogen and carbon monoxide (CO) at high temperatures over a catalyst. A water-gas shift process then converts the CO into a stream of CO_2 and additional hydrogen. CO_2 generated in a process can be captured by a variety of commercial technologies, and geologically sequestered (CCS). The hydrogen or ammonia production would be low-to zero-carbon—assuming effective emission controls are put in place to significantly reduce methane leakage throughout the natural gas production, transport, and distribution system. Two commercial projects in North America already each capture more than one million tons of CO_2 per year from natural gas reforming hydrogen production, and additional projects are under consideration.[18] By adding CCS technology to gas reformers and gradually increasing the capture rate, ammonia production can meet increasingly stringent greenhouse gas limits by incrementally reducing its carbon intensity.[19]

Electrolysis of water with zero-carbon electricity is another method for producing hydrogen without associated carbon dioxide emissions. Electrolysis uses electricity to split water (H_2O) into hydrogen and oxygen. If a zero-carbon power source is used to generate the electricity (*e.g*., nuclear, wind, solar), the production of the hydrogen results in zero lifecycle carbon emissions. It currently costs more to make hydrogen with zero-carbon electrolysis than with SMR+CCS;[20] reducing that cost gap will require a significant global R&D effort aimed at making electrolysis less expensive. Furthermore, electrolytic production of hydrogen can be carried out at a range of different plant scales and is amenable to modularization. Reductions in the cost of zero-carbon electricity and thermal energy—for example, through advancements in nuclear power technologies[21]—could also play an important role in dropping the cost of electrolytic hydrogen production.

Using the Haber-Bosch process, hydrogen acquired through gas reforming or electrolysis can be combined with nitrogen (from ambient air, sometimes through air separation units) to make ammonia. This is a fully commercial process used at very large scale in the fertilizer industry today While hydrogen itself works well in some energy applications (*e.g.,* as fuel for on-road fuel cell vehicles), there are several energy sector-relevant applications where taking the extra step to make ammonia from hydrogen is beneficial. For example, ammonia is easier to store, especially in large quantities (it can be held and transported in modestly refrigerated tanks, whereas hydrogen storage requires deep refrigeration or significant pressurization). One practical implication of ammonia's advantage with respect to storability is that may make economic sense to move hydrogen energy across long distances (*e.g.,* from the US Gulf Coast to Japan) in the form of ammonia. Also, as discussed below, ammonia can be burned in modified or purpose-built internal combustion engines, which might limit the extent to which existing energy systems need to be wholly replaced.

Further deployment of low- and zero-carbon production of hydrogen and ammonia will likely require cost reductions in gas reformers, capture and sequester CO_2 equipment (including CO_2 transport infrastructure), and electrolyzers.

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18 Air Products, *News Release: Air Products Signs Agreements to Acquire Five Operating Hydrogen Plants for $530 Million and Long-Term Hydrogen Supply to PBF Energy* (2020) (http://www.airproducts.com/Company/news-center/2020/03/0330-air-products-to-acquire-hydrogen-plants-and-provide-long-term-supply-to-pbf-energy.aspx); Shell, Quest CCS Facility Captures and Stores Five Million Tonnes of CO2 Ahead of Fifth Anniversary (2020) (https://www.shell.ca/en_ca/media/news-and-media-releases/news-releases-2020/quest-ccs-facility-captures-and-stores-five-million-tonnes.html).

19 New ammonia plants can potentially reduce their CO2 capture costs by using oxy-fuel combustion to power their reformers. In an oxy-fuel combustion process, the fuel—in this case methane—is mixed with pure oxygen (rather than with air, which is mostly nitrogen). The result is a relatively rich and easier-to-capture stream of CO2. See CATF, Oxy-Combustion Capture http://www.fossiltransition.org/pages/oxy_combustion/113.php.

20 Cedric Philibert, International Energy Agency, *Electro fuels: An introduction*, at slide 8 (2018) (http://ieahydrogen.org/pdfs/1CedricPhilibert.aspx).

21 Lucid Catalyst, *Missing Link to a Livable Climate: How Hydrogen-Enable Synthetic Fuels Can Help Deliver the Paris Goals* (2020) (https://85583087-f90f-41ea-bc21-bf855ee12b35.filesusr.com/ugd/2fed7a_0d2e1cc06bff412cb3031fd4bdf93cb0.pdf); Energy Options Network, *Zero Carbon Hydrogen: An Essential Climate Mitigation Option-Nuclear Energy's Potential Role* (2020) (https://d1qmdf3vop2l07.cloudfront.net/fresh-locust.cloudvent.net/hash-store/45b2875b85350c341a53d50425c4e3a9.pdf).

[3] Zero-carbon fuels can play a central role in the decarbonization of marine shipping

In 2018, the IMO adopted an initial greenhouse gas emissions reduction strategy that requires the marine shipping industry to reduce its greenhouse gas emissions at least 50% by 2050.[22] Although the IMO target falls far short of the obligation facing the shipping sector and other major economic sectors to fully decarbonize by mid-century, it nonetheless confirms the necessity of developing and deploying zero carbon fuels.

As an initial matter, the IMO 2050 target demonstrates the inadequacy of carbon reduction strategies that depend exclusively on efficiency improvements. According to the International Council on Clean Transportation (ICCT), "CO_2 intensity of many major ship classes decreased (i.e., they became more efficient)" during the two-year review period (2013-2015), but "total CO_2 and CO_2-eq emissions from ships increased."[23] Meeting even the IMO's 50% reduction target will require a shift to lower-carbon fuels.

But which fuels? Although liquified natural gas (LNG) provides some tangible environmental benefits such as lower emissions of sulfur oxides and particulate matter when compared to conventional marine fuel oil, it falls well short of the IMO mark for greenhouse gas reductions. The natural gas supply chain, as currently constructed and operated, emits substantial volumes of methane, a potent contributor to climate change.[24] Recent analyses by the ICCT and SINTEF Ocean AS have found lifecycle GHG emissions rates from LNG-fueled shipping to be as high or higher than the emissions rates associated with fuel oil and marine gasoil (MGO), respectively.[25]

Marine biofuels pose intertwined challenges of sustainability and scalability. If an energy source is going to play a leading role in the transition to zero-carbon energy, it must be massively scalable—but scale presents a unique set of problems for bioenergy. Even at its current size (approximately 3.5 quadrillion btu (quads) per year[26]), the global production of biofuel for transportation markets poses significant sustainability challenges, including significant lifecycle greenhouse gas emission from conventional biofuels; scaling up biofuel production to meet the projected energy demand from just the global marine freight sector

22 International Maritime Organization, *UN Body Adopts Climate Change Strategy for Shipping* (2018) (http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx).

23 Naya Olmer et al., International Council on Clean Transportation, *Greenhouse Gas Emissions from Global Shipping*, 2013-2015 (2017) (https://theicct.org/publications/GHG-emissions-global-shipping-2013-2015).

24 See CATF, Oil and Gas Methane Mitigation Program (https://www.catf.us/educational/mitigation-program/).

25 Per ICCT, "Using a 20-year GWP … and factoring in higher upstream emissions for all systems and crankcase emissions for low-pressure systems, there is no climate benefit from using LNG [in place of residual fuel oil], regardless of the engine technology." Nikita Pavlenko et al., International Council on Clean Transportation, The climate implications of using LNG as a marine fuel (2020) (https://theicct.org/publications/climate-impacts-LNG-marine-fuel-2020). SINTEF Ocean AS analysis reached a similar conclusion when it reviewed a 2020 study by Thinkstep, finding that greenhouse gas emissions from LNG-fueled low-pressure dual fuel engines exceed those from marine gas oil-fueled engines. Elizabeth Lindstad, *Increased use of LNG might not reduce maritime GHG emissions at all* (2019) (https://www.transportenvironment.org/sites/te/files/publications/2019_06_Dr_Elizabeth_Lindstad_commentary_LNG_maritime_GHG_emissions.pdf).

26 International Energy Agency, *World Energy Outlook 2019*—Fig. 2-6.

in 2050 (approximately 13 quads per year[27]) could dangerously exacerbate those problems.[28] Waste-based biofuels present fewer sustainability problems, but aggregating highly dispersed waste feedstocks is complicated and expensive, and the shipping sector would have to outcompete the aviation industry (which has fewer decarbonization options than the shipping sector) for whatever volume of waste-based biofuel becomes available.

Ammonia is a particularly compelling candidate for fuel-shifting in the marine shipping sector because production of hydrogen and ammonia is massively scalable, in part because the ingredients for making the two fuels are readily obtainable and nearly inexhaustible; and because ammonia could be used as fuel in both purpose-designed and modified internal combustion engines (ICEs),[29] either neat or in a blend with petroleum fuel. Marine vessels are especially well-positioned to use ammonia-fueled ICEs because they can accommodate heavier engines and larger fuel tanks more easily; ports already site and build ammonia storage and handling equipment, thereby avoiding the chicken-or-egg problem that sometimes confounds the transition to alternative fuels in light-duty personal vehicles; and, unlike most light-duty vehicles, marine vessels are already fueled by professionals who can be trained to safely manage ammonia.

Numerous recent academic studies and industry reports confirm ammonia's potential as a key energy option for a decarbonizing marine shipping, including the following analyses:

- *Lloyd's Register & UMAS* (2020): "[A]mmonia produced from hydrogen, where the hydrogen is produced from NG [natural gas] with CCS, … becomes the lowest cost zero-carbon option out to the 2050s. Furthermore, over time, the production and supply of ammonia can transition from NG to hydrogen produced from renewable energy, providing a more resilient long-term transition pathway."[30]
- *Alfa Laval, Hafnia, Haldor Topsoe, Vesta, Siemens Gamesa* (2020): "[A]mmonia is not only an attractive long-term solution for carbon neutrality but also can have a strategic role in the transition phase. By shifting gradually from fossil-fuel based ammonia to green ammonia, the CO2 footprint can be progressively lowered at low risk for the shipowner…."[31]
- *Shell* (2020): "Interviewees consider hydrogen and ammonia to be the most promising long-term fuel alternatives for shipping…."[32]

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27 US Energy Information Administration, International Energy Outlook 2019, *Transportation Sector: Freight Sector Energy Consumption by Region and Mode* (https://www.eia.gov/outlooks/aeo/data/browser/#/?id=51-IEO2019&cases=Reference).

28 See Reid WV, Ali MK, Field CB. The future of bioenergy. Global Change Biology (2019) 00:1–13 (https://doi.org/10.1111/gcb.14883).

29 See Agustin Valera-Medina et al.,, *Ammonia for Power, Progress* in Energy and Combustion Science (2018) 63-102 (https://www.sciencedirect.com/science/article/pii/S0360128517302320); MAN Energy Solutions, *Engineering the Future Two-Stroke Green-Ammonia Engine* (2019) at 5 (https://www.man-es.com/docs/default-source/marine/tools/engineering-the-future-two-stroke-green-ammonia-engine.pdf?sfvrsn=2b4d9d8a_10).

30 Lloyd's Register & UMAS, *Techno-Economic Assessment of Zero-Carbon Fuels* (2020) at 4 (https://www.lr.org/en/insights/global-marine-trends-2030/techno-economic-assessment-of-zero-carbon-fuels/).

31 Alfa Laval, Hafnia, Haldor Topsoe, Vesta, Siemens Gamesa, *Ammonfuel--An Industrial View of Ammonia as a Marine Fuel* (2020) at 6 (https://hafniabw.com/wp-content/uploads/2020/08/Ammonfuel-Report-an-industrial-view-of-ammonia-as-a-marine-fuel.pdf).

32 Shell, *Decarbonising Shipping: All Hands on Deck* (2020) at 19 (https://www.shell.com/energy-and-innovation/the-energy-future/decarbonising-shipping/_jcr_content/par/toptasks.stream/1594141914406/b4878c899602611f78d36655ebff06307e49d0f8/decarbonising-shipping-report.pdf).

- *MAN Energy Solutions* (2019): "Considering that the goal of IMO is to reduce the total annual GHG emission by at least 50% by 2050 compared to 2008 and, eventually, fully eliminate harmful emissions, the global maritime industry has to look into carbon-free fuels like hydrogen and ammonia … Ammonia constitutes a disruptive energy storage solution that can be produced using existing synthesis methods and storage solutions, and therefore has the potential to enter the market relatively quickly."[33]

Hydrogen itself could also play an important role in marine shipping decarbonization, especially for ferries and other near-shore vessels. Hydrogen fuel cell-powered ferries, cruise ships, and tugs are under development in California,[34] Norway,[35] Japan,[36] and elsewhere, and a recent study suggests that hydrogen fuel cell-powered vessels could be used for transoceanic shipping.[37]

Full decarbonization of the shipping sector requires not only ships that can run on zero carbon fuels, but also massive volumes of hydrogen and ammonia to be produced and supplied to ports around the world. In a report produced for CATF in Spring 2020, a team from Columbia University School of International and Public Affairs (SIPA) interviewed dozens of industry stakeholders and conducted detailed assessments of the capacity for zero carbon fuels storage at major port systems in the United States (New York/New Jersey, Houston, and Los Angeles), the Netherlands (Rotterdam), the United Arab Emirates (Jebel Ali), Japan (Keihin/Tokyo Bay), China (Hong Kong and Shanghai), and Australia (Fremantle, Darwin, others), and Singapore.[38]

The SIPA report outlines five "actionable steps that major market movers – shipping companies, oil and gas, policymakers, etc. – could take" to improve ports' capacity to deliver ZCF to the global fleet of transoceanic tankers, container ships, and bulk carriers:

Recommendation 1: Shipping regions, such as Europe, Southeast Asia, Asia-Pacific, or Northeast Americas, should establish trans-oceanic coalitions between government, energy industry companies, shipping companies, and financial institutions.

Recommendation 2: Shipping companies must partner with fuel suppliers aligned with the most relevant trade lanes through first-mover ports.

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33 MAN Energy Solutions, *Engineering the Future Two-Stroke Green-Ammonia Engine* (2019) at 5 (https://www.man-es.com/docs/default-source/marine/tools/engineering-the-future-two-stroke-green-ammonia-engine.pdf?sfvrsn=2b4d9d8a_10).

34 Sandia National Laboratories, *SF-BREEZE* (2020) (https://energy.sandia.gov/programs/sustainable-transportation/hydrogen/market-transformation/maritime-fuel-cells/sf-breeze/).

35 *Norway plans hydrogen network for ships*, The Motorship (2020) (https://www.motorship.com/news101/alternative-fuels/norway-plans-hydrogen-network-for-ships)

36 Martyn Wingrove, *Japan takes leap into hydrogen fuel*, Riviera (2019) (https://www.rivieramm.com/news-content-hub/news-content-hub/japan-takes-a-leap-into-hydrogen-fuel-56658).

37 Xiaoli Mao, et al., International Council for Clean Transportation, *Refueling Assessment of a Zero-Emission Container Corridor Between China and the United States: Could Hydrogen Replace Fossil Fuels?* (2020) (https://theicct.org/publications/zero-emission-container-corridor-hydrogen-2020).

38 Columbia University School of International and Public Affairs, *Zero-Carbon Fuels for Marine Shipping* (2020) (https://www.catf.us/wp-content/uploads/2020/06/2020_SIPA_Zero-Carbon-Shipping.pdf).

Recommendation 3: First-mover ports must work within their country or region to aggregate economy-wide demand for hydrogen fuels.

Recommendation 4: Fuel producers must coalesce around standard production methods for green hydrogen/ammonia while continuing to innovate.

Recommendation 5: Private and public capital must work with fuel producers to de-risk investments and lower the cost of capital for new fuel production and infrastructure.

Some of these recommendations—in particular, Recommendation 5—can be pursued in part by Congress and this Committee, and are aligned with the policies proposals described below in part 5 of this testimony.

[4] Zero carbon fuels can support decarbonization in a range of economic sectors

Zero carbon fuels can be used to accelerate the process and/or reduce the cost of decarbonizing a wide range of energy applications in addition to marine shipping. These applications include:

- Long-haul heavy trucking: Preliminary analysis by the National Renewable Energy Laboratory suggests that heavy-duty freight trucks could have a lower total cost of ownership when powered by hydrogen fuel cells rather than an electric battery alone.[39]
- Long-duration energy storage for electric grids with high penetration of variable renewable energy systems. Atmospheric pressure ammonia tanks (see Fig. 4) could promote grid stability by storing weeks' worth of zero-carbon energy, for use during dips in wind- or solar-based power generation or to meet demand peaks.
- Some industrial processes, *e.g.*, ironmaking, high temperature heating.
- Some medium transport, *e.g.*, long-distance buses, SUVs.
- Residential and commercial space heating: The use of hydrogen for space heating is currently limited by natural gas-hydrogen blend walls, but work is being conducted internationally to address these constraints.[40]

39 Chad Hunter and Michael Penev, National Renewable Energy Laboratory, *Market Segmentation Analysis of Medium and Heavy Duty Trucks with a Fuel Cell Emphasis* (2019) (https://www.nrel.gov/docs/fy19osti/73491.pdf).

40 See various publications from Hy4heat (https://www.hy4heat.info/reports).

Fig. 5. QAFCO Ammonia Storage Tanks - Messaieed, Qatar

Two 50,000 metric tons net capacity single-wall refrigerated ammonia storage tanks built by McDermott in Messaieed, Qatar[41]*; these tanks hold ammonia with an energy content of around 2 million MBtu. (Picture: HansonDoha)*

[5] Policy proposals and ideas for advancing the production and use of zero carbon fuels to decarbonize marine shipping

To address the massive scale-up challenge for zero-carbon fuels that is outlined in this testimony, Clean Air Task Force would like to submit the following federal policy proposals.

Clean Air Task Force recommends that the Senate immediately pass the American Energy Innovation Act of 2020. This package contains important provisions that would begin to expand research and development for zero-carbon fuels. In particular, the Clean Industrial Technology Act of 2019, which was cosponsored by the Chair of this committee which requires the Department of Energy (DOE) to establish an industrial emissions reduction technology research, development, demonstration, and commercial application program would make important strides for zero-carbon fuels, which have application in both shipping and industrial sectors. The technical assistance program to achieve emission reductions in nonpower industrial sectors could successfully pair with future additional federal policies and funding to support the development of zero carbon fuels in coastal states and municipalities around the country.

41 McDermott, *QAFCO Ammonia Storage Tanks* (https://www.mcdermott.com/What-We-Do/Project-Profiles/QAFCO-Ammonia-Storage-Tanks).

Beyond legislation currently under consideration in the full Senate, the Committee on Energy and Natural Resources can advance the production and use of zero carbon fuel in the marine shipping sector through measures that:

- Reduce technology costs by sponsoring research, development, and deployment (RD&D);
- Support markets with infrastructure and deployment policy; and
- Kick-start early projects with stimulus funding.

Research, development, and deployment. RD&D activity at the US DOE related to zero carbon fuel technologies could be greatly expanded. Several technologies relevant to marine shipping decarbonization deserve additional support, including: ammonia solid oxide fuel cells, ammonia reciprocating engines, large-scale ammonia cracking, high-temperature electrolysis, and advanced methane reforming.

Support for zero carbon fuel infrastructure and markets. Shifting the marine shipping sector (and other fuel-intensive sectors of the economies) to zero carbon fuels will require a systems approach involving federal support for fuel production, infrastructure build-out, and end-use technology adoption.

Fuel production and utilization support

Because zero carbon fuels are likely to cost more than incumbent high-carbon fuels at least for some time in many applications, policies should help catalyze market development through procurement incentives for zero carbon fuel-compatible energy and industrial end-use systems (e.g., dual-fuel marine engines that can utilize ammonia or fuel oil).

Production tax credits and/or 45Q-type policies should be created to mitigate the difference between market rates and production costs for zero carbon fuels.

Infrastructure build-out support

Policies need to help connect key production areas (*e.g.*, fossil, renewable, and nuclear resources in the Gulf Coast, the Marcellus region, the central Midwest, etc.) with ports and other demand centers such as Los Angeles and Long Beach, the Houston Shipping Channel, Chicago, and New York/New Jersey.

Infrastructure investments could include new dedicated pipelines, zero carbon fuel terminals, storage, etc., and repurposed existing fossil infrastructure.

The private sector alone is unlikely to invest ahead of need. Federal government could incentivize construction through measures such as tax credits pegged to the amount of zero carbon fuel moved through a new or repurposed pipeline (in which the value of the credit would be determined by the mass or energy value of the fuel moved divided by the fuel's carbon intensity).

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End-use technology support

Zero carbon fuel end-use technologies will need supportive policies to help drive their adoption as production and infrastructure is developed. This could include, for example, rebates and incentives for appliances and vehicles, including marine vessels, trucks, and trains that utilize fuel cells, internal combustion engines, or turbines fueled by hydrogen or ammonia.

Kick-start zero carbon fuels and transportation. Stimulus funding should promote zero carbon fuel for marine shipping through the following initiatives, which could also open up new job sectors in the United States:

In order to build out a zero carbon fuels system, we need to develop the key interconnected components of production, transport and end-use at the same time. Therefore, policy should focus on catalyzing zero carbon fuels regional hubs.

Ammonia Hub

Hubs could include a combination of production, transport and endues technology options. A hypothetical hub in the Gulf Coast region could have the following characteristics on the ammonia supply chain:

- Production: methane reformer and ammonia synthesis loop; >90% carbon capture and sequestration across system; ammonia output: 1 million MT per year[42].
- Transport: Five-mile ammonia pipeline from production site to portside storage, loading, and fueling terminals.
- Use: Decarbonized ammonia, in the form of fertilizer or marine fuel, would be delivered to agricultural sector consumers willing to pay a premium to reduce carbon intensity of fertilizer, and to ammonia fuel-compatible marine vessels.

To catalyze the development of these types of hubs, federal support could cover low-interest development loans and cost-share grants to build help build initial infrastructure and end-use transport vehicle fleets. Production tax incentives, or other types of deployment incentives could mitigate the difference between production costs for the fuel and the market rate.

42 Hubs could be used to promote the development of multiple hydrogen and ammonia production pathways (e.g., electrolysis using variable renewable energy, electrolysis using nuclear power and thermal energy).