CEAP | CLEAN ENERGY ACCOUNTING PROJECT

CLEAN FUELS IN THE INDUSTRIAL SECTOR

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Key Takeaways

- Clean fuels are technologically feasible (often with minor changes) for the industrial sector due to their ability to sustain the high temperatures needed for industrial processes.
- Common clean fuels in the industrial sector include renewable hydrogen, geothermal energy, hydrochar/biochar, and renewable methanol.
- There are opportunities within the production and distribution of these fuels to utilize market-based accounting methods. However, such methods have not been historically used for all fuels.
- Despite fewer regulations, there are initiatives aimed at decarbonizing the industrial sector using clean fuel technologies, some governments and industries are joining forces to set common standards, targets, and procurement commitments to meet decarbonization goals.

1. Introduction

As of 2022, the industrial sector accounts for roughly one quarter of energy-related carbon dioxide (CO_2) emissions globally and is still largely dominated by fossil fuels.[1] This sector includes emissions from chemical manufacturing, oil refining, iron and steel, food and beverage, and cement and lime. It is one of the hardest to decarbonize as low-carbon technologies are often underdeveloped or expensive, and because capital assets in these sectors are upgraded infrequently. However, industrial sector emissions have decreased slightly in recent years despite an increase in global emissions, due in part to the uptick in industrial usage of clean fuels such as green hydrogen, sustainable biofuels, and geothermal heat.[2]

When renewable fuels are transported through a network, such as a pipeline, they can be used and tracked by organizations procuring and subsequently retiring a certificate. Certificates for renewable fuel are differentiated by either the type of legislation mandating them or the type of fuel they represent and can function in both regulatory and voluntary contexts.

Market-based accounting uses a book and claim chain of custody model to facilitate fuel procurement from a specified source (i.e. fossil, renewable). The book and claim model ensures that renewable fuel attributes are tracked, documented, and that they are verifiable. This allows renewable fuel buyers to decouple attributes from the physical product and then transfer them, often via a dedicated registry.[3]

This document includes a summary of the industrial sector's key fuel consuming activities, production and distribution characteristics of the clean fuel types available, and examples of relevant regulations and initiatives.

2. Industrial Sector Overview

The industrial sector broadly comprises manufacturing capital goods, such as machinery, chemicals, and construction materials. The sector has seen rapid growth globally over the last two decades, but anticipated demand varies by geography. For example, the demand for delivered renewable energy for the industrial sector in non-OECD countries (such as China) is expected to be significantly higher than that of

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[1] International Energy Agency (IEA). N.d. *Energy system – Industry;* *https://www.iea.org/energy-system/industry*
[2] International Energy Agency (IEA). N.d. *CO2 emissions in 2022*; https://www.iea.org/reports/co2-emissions-in-2022
[3] RSB. N.d., RSB book and claim programme. https://rsb.org/programmes/book-and-claim/

OECD countries by 2040, showcasing where there is more opportunity for uptick of not only clean fuel use but also market-based contractual approaches.

Fuel consumption activities and opportunities to transition to clean fuels also differs by industry. A non-exhaustive list of relevant industries within the industrial sector include:

Aluminum Manufacturing

Aluminum is a heavily versatile material, found in items from soda cans to cell phones. It is also an input to many of the technologies needed to accelerate decarbonization, including light weight vehicles and solar panels.[4] Aluminum production accounts for just 2% of global greenhouse gas (GHG) emissions, but demand for the product is expected to increase by 80% by 2050.[5] Clean fuel sources used in aluminum production are primarily green hydrogen, which reduces emissions by replacing fossil fuel used for high temperature heating processes.[6]

Cement and Lime

Cement and lime are key ingredients in concrete and are the largest source of industrial emissions, accounting for 8% of global CO_2 emissions.[7] Globally, there are several efforts aimed at curtailing cement and lime emissions by replacing conventional fossil fuels with alternative fuels. European Union (EU) policies have targets to reach 60% alternative fuels containing 30% biomass by 2030, and 90% alternative fuels with 50% biomass by 2050.[8] Cement and lime decarbonization can be targeted at various parts of the cement production process. One of the heaviest emitting stages is the creation of the “clinker”, a mix of limestone and minerals that have been heated and transformed in a kiln. This stage requires high temperatures to convert limestone to clinker, and CO_2 is also released as a byproduct.[9] Clinker can be partially decarbonized by replacing fossil fuel with pre-processed waste such as

[4] International Energy Agency (IEA). *Energy system, industry, aluminium;* https://www.iea.org/energy-system/industry/aluminium

[5] Aluminium International Today. September, 2021. *Can hydroghen and the latest burners reduce carbon emissions?* https://www.airproducts.com/-/media/files/external/aluminium-international-today/greener-alu-air-products.pdf

[6] Hydro Media. 2023. *World's first batch of recycled aluminium using hydrogen fueled production*. https://www.hydro.com/en-US/media/news/2023/worlds-first-batch-of-recycled-aluminium-using-hydrogen-fueled-production/

[7] Leilac. N.d. *CO2 Impact*. https://www.leilac.com/co2-impact/#:~:text=The%20cement%20and%20lime%20industries,20%25%20decrease%20in%20CO%E2%82%82%20output.

[8] Cembureau, the European Cement Association. n.d. *Cementing the European Green Deal.* https://cembureau.eu/media/kuxd32gi/cembureau-2050-roadmap_final-version_web.pdf

[9] Cembureau, the European Cement Association. n.d. *Clinker.* https://lowcarboneconomy.cembureau.eu/5-years-on/the-5c-approach/clinker/

biomass. Green hydrogen has also emerged as a plausible alternative fuel to power cement kilns.[10]

Chemical Manufacturing

Chemical manufacturing is a highly complex and dynamic industry which converts raw materials into different products. It is the third most emissions intensive industry within the industrial sector, consuming about 10% of all fossil fuels and generating roughly 3 billion metric tons of carbon dioxide equivalent (CO_2e) annually.[11] Low carbon fuels that are typically available for the chemical manufacturing industry include green hydrogen, renewable natural gas (RNG) and methanol.[11] Green hydrogen and RNG are primarily used when producing ammonia-based fertilizers -- which currently consume about 50% of global hydrogen -- and as an alternative fuel for heating steam crackers. Methanol uses coal as a conventional feedstock, but is also capable of relying on green hydrogen.

Food and Beverage, Agriculture

The food and beverage industry includes agricultural operations, which accounts for 15% of global GHG emissions,[12] but the lifecycle emissions of food production, processing, distribution, and consumption accounts for 30% of global energy consumption.[13] Low carbon fuels that may be used in this industry include biomass (RNG), solar thermal, solar cooling, and geothermal heat pumps.[14] Replacing coal or natural gas with biomass derived from anaerobic digestion can significantly decrease emissions where high heat is needed. Solar is primarily used to produce heating or cooling effects for food processing. Similarly, geothermal heat pumps can be used to provide high enough temperatures to replace traditional fossil fuels in industrial food drying and processing.

Iron and Steel Manufacturing

Iron and steelmaking are highly energy intensive processes that have historically used fossil fuels to reach temperatures suitable to smelt raw iron and carbon into steel.[15] This industry accounts for roughly 7% of global GHG emissions and more than doubled between 2000 and 2020. Emissions from steel production vary by country,

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[10] Specify Concrete. 2022. *Cement kilns in a green hydrogen economy*. https://www.specifyconcrete.org/blog/cement-kilns-in-a-green-hydrogen-economy

[11] S&P Global Ratings. September, 2023. Decarbonizing chemicals part one: sectorwide challenges will intensify beyond 2030. S&P Global

[12] Plunkett Research, Ltd. *Plunkett's food industry market research;* https://www.plunkettresearch.com/industries/food-beverage-grocery-market-research/

[13] Jagtap et al., 2019. *Real-time data collection to improve energy efficiency: A case study of food manufacturer:* https://doi.org/10.1111/jfpp.14338.

[14] Sovacool et al., 2021. Decarbonizing the food and beverages industry: A critical and systematic review of developments, sociotechnical systems and policy options; https://doi.org/10.1016/j.rser.2021.110856

[15] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. N.d. *Iron and steel manufacturing*. https://www.energy.gov/eere/iedo/iron-and-steel-manufacturing

with Italy, U.S., and Turkey producing the least and Ukraine, India, and China producing the most CO_2 in iron and steel manufacturing overall.[16] Steelmaking in China in particular is responsible for 15% of the country's total CO_2 emissions, but several steelmakers in the country have announced plans to invest in hydrogen-fueled blast furnaces and direct-reduction technologies.[17] While some studies have demonstrated that electrification is possible for steelmaking, decarbonization efforts in this industry have mostly focused on fuels rather than electricity.[18] Clean fuels used in iron and steel manufacturing include green hydrogen, used to replace coke,[19] hydrochar made from food waste or other biomass,[20] and RNG which is used where high temperatures are needed with furnaces and kilns.[21]

Oil Refining

Oil refining is the third-largest source of global GHG emissions from stationary sources, with the sector's average annual emissions increasing at a rate of 0.7% each year from 2000-2021 primarily from the US, EU, UK, and China[22]. The process of refining oil is made up of several steps including distillation, cracking, reforming, and treating, each of which are highly energy intensive and reliant on process heating and steam energy. To decrease emissions from these processes, countries such as the United States have begun requiring refineries to blend in clean fuels such as biofuel.[23] However, biofuel refining can still release many of the emissions associated with the traditional refinery process.[24] Availability of biofuel feedstocks can be dependent on geographic proximity to the supplies needed for those feedstocks, but there is

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[16] Hasanbeigi. April, 2022. *Steel Climate Impact, An International Benchmarking of Energy and CO2 Intensities.* *https://static1.squarespace.com/static/5877e86f9de4bb8bce72105c/t/624ebc5e1f5e2f3078c53a07/1649327229553/Steel+climate+impact-benchmarking+report+7April2022.pdf*
[17] Canary Media. October, 2023., Chart: Here's where the carbon-intensive steel industry is concentrated. https://www.canarymedia.com/articles/clean-industry/chart-heres-where-the-carbon-intensive-steel-industry-is-concentrated?utm_campaign=canary&utm_medium=email&_hsmi=280092330&_hsenc=p2ANqtz-9x_iQrtTbm9nytHOgWK-oQVKSBIt-YCO-rZu_xFec5-1Ub0uUIJDyESNc8sgTBuqZxoWO31HzI2vF6SyjmxL-Y-GiqUP1BG6r5V0XiWepmAfhLA0w
[18] Yale Environment 360. July, 2023. *Steel industry pivoting to electric furnaces, analysis shows.* https://e360.yale.edu/digest/steel-industry-carbon-coal-electric-arc-furnaces
[19] Fuel Cell and Hydrogen Energy Association. November, 2019. *Hydrogen as a clean alternative in the iron and steel industry.* https://www.fchea.org/transitions/2019/11/25/hydrogen-in-the-iron-and-steel-industry
[20] Munir et al., 2023. *Food waste hydrochar: an alternate clean fuel for steel industry.* https://doi.org/10.1016/j.fuel.2023.128395
[21] Renewable Natural Gas Coalition (RNGC) and Guidehouse. 2023. *Using RNG to Meet Voluntary GHG Targets.* https://static1.squarespace.com/static/53a09c47e4b050b5ad5bf4f5/t/646516e4d1613f56a96241ef/1684346603614/RNG+Coalition+Draft+Report_Final_Updated.pdf
[22] Ma et al., 2023. *Global oil refining's contribution to greenhouse gas emissions from 2000-2021.* Volume 4, Issue 1. https://doi.org/10.1016/j.xinn.2022.100361
[23] S&P Global. 2021. *Cleaner refining in the future means biofuels and more efficient conventional fuels*. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/oil/120721-cleaner-refining-in-the-future-means-biofuels-and-more-efficient-conventional-fuels
[24] The National Academies of Sciences. 2011. *Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy.* https://www.ourenergypolicy.org/wp-content/uploads/2012/06/renewablefuel.pdf

evidence suggesting policies advocating for increased blending of biofuels into conventional fuels are part of key strategies to create and expand biofuel markets.[25]

3. Clean Fuels in this Sector

While there are many clean fuels on the market, a select few are most applicable to fuel consuming activities in the industrial sector, due to their ability to enable high temperatures needed for industrial operations. These are renewable hydrogen, geothermal energy, hydrochar/biochar, renewable methanol, and biofuel.

3.1. Renewable and Low-Carbon Hydrogen

Production Process and Feedstocks

Hydrogen is categorized by various colors that represent the type of energy source used to produce the hydrogen, with colors varying from green (cleanest) to black (dirtiest). The two most common methods for producing hydrogen are natural gas reforming (also known as steam methane reforming or SMR) and electrolysis.[26] Natural gas reforming is currently used to produce approximately 95% of the hydrogen in the world.[27] For hydrogen to be considered "renewable", the production process must be powered by renewable resources (green hydrogen).[28]
Green hydrogen refers to hydrogen that is created when an electrolizer uses zero-emissions renewable energy such as wind or solar power to split water molecules into water and hydrogen. As such, the physical feedstocks for green hydrogen are just water, air, Nitrogen (N), and CO_2.[29]

Distribution Networks

Hydrogen is typically produced in close proximity to where it is used, as distribution network infrastructure is not widely deployed. Given this restriction, hydrogen is currently distributed through three main methods: pipeline, high pressure tube

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[25] Ebadian et al., *December 2020. Biofuels policies that have encouraged their production and use: an international perspective.* https://doi.org/10.1016/j.enpol.2020.111906
[26] U.S. DOE. (n.d.). Hydrogen Basics. Alternative Fuels Data Center: Hydrogen Basics. https://afdc.energy.gov/fuels/hydrogen_basics.html
[27] ScienceDirect Topics. (n.d.). Methane steam reforming. Methane Steam Reforming - an overview. https://www.sciencedirect.com/topics/engineering/methane-steam-reforming#:~:text=Steam%20methane%20reforming%20(SMR)%20is,produce%20hydrogen%20and%20carbon%20monoxide
[28] Electrolysis using renewable electricity demonstrated through the retirement of renewable energy certificates (RECs) is the primary method for producing renewable hydrogen.
[29] Decarbonization technology. May, 2023. *Feedstocks and utilities for green hydrogen and e-fuels.* https://decarbonisationtechnology.com/article/163/feedstocks-and-utilities-for-green-hydrogen-and-e-fuels#:~:text=Water%2C%20air%2C%20nitrogen%2C%20and,operations%20(see%20Figure%201).&text=Pure%20water%20supply%20to%20an,molecules%20into%20oxygen%20and%20hydrogen.

trailers, and liquefied hydrogen tankers.[30] The U.S. currently has the most miles of hydrogen pipelines, followed by Belgium and Germany. High pressure tube trailers allow hydrogen to be transported in a gaseous state for under 200 miles. For longer distances, tankers can be used to transport liquified hydrogen. This method may be more efficient and can transport a far higher quantity of hydrogen compared to other methods, but is significantly more expensive due to the liquification process.

Other Key Facts

Hydrogen is a fuel derived from other energy sources, as can be derived from the color spectrum of different hydrogen types. The "cleanness" of hydrogen is determined by those feedstocks. For example, green hydrogen is produced using electricity generated from renewable sources (solar, wind) and creates zero emissions, but hydrogen produced with electricity generated from coal, gas, etc. produce emissions and is thus not considered renewable even if hydrogen itself has no emissions. The exact feedstock used should be considered when determining best practices for emissions accounting.

Recent legislations such as the United States Inflation Reduction Act (IRA) Section 45v and the European Union Hydrogen Directive have a more robust three-pronged approach for determining the "cleanness" of hydrogen production. These three pillars are Incrementality/Additionality (is the clean energy used for hydrogen production new, or would it have gone online without this incentive); temporal matching (matching the hour of generation of the renewable source to the hour of hydrogen production); and deliverability/geographical correlation (how close the renewable source is to the hydrogen facility).

3.2. Geothermal Energy

Production Process and Feedstocks

Geothermal power plants utilize three key processes: dry steam, flashed, and binary cycle, each of which pull hot water and steam from the ground and then return it after use to prolong the heat source itself.[31]The dry steam process is the simplest design option, but it is also the least deployed. It involves hydrothermal fluids (essentially steam) directly entering a turbine, which in turn drives a generator that produces electricity. The flashed process is most common and involves using electricity to pump water from deep underground at high pressure to a lower pressure above-ground tank. The change in pressure creates steam/vapor which

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[30] U.S. Department of Energy, Alternative Fuels Data Center. N.d. *Hydrogen production and distribution.* https://afdc.energy.gov/fuels/hydrogen_production.html

[31] Union of Concerned Scientists. December, 2014. *How geothermal energy works.* https://www.ucsusa.org/resources/how-geothermal-energy-works

drives the turbine to generate electricity. In a binary cycle system, boiling water is used to heat a second liquid in a closed loop. The second liquid typically will boil at a lower temperature than water, making it easier to convert to steam and thus run the turbine.[32]

Feedstocks for geothermal energy generated using any of these processes are primarily water and/or steam.

Distribution Networks

Geothermal energy is distributed via geothermal heat pumps and district heating systems.[33] A geothermal power plant uses heat to produce steam. The generated steam is either directly used in various industrial sectors for heating or is used to fuel the turbine. Steam from geothermal power plants can only be used near its source, as steam dissipates over long distances. The resulting energy is most often transported via wire in the form of electricity.[34]

Other Key Facts

Geothermal energy can be bought and sold by a Geothermal Power Purchase Agreement (PPA). Geothermal PPA's differ from those for wind and solar, so the agreements may require significant station service requirements for extracting, re-injecting, processing, or otherwise using geothermal energy. A seller should always clarify that it is retaining the RECs associated with the station service in the event that there is an imbalance between RECs procured and delivered.[35]

3.3. Hydrochar and Biochar

Production Process and Feedstocks

Hydrochar and biochar both use various biomasses (ex: agricultural residue, forestry waste, and organic industrial by-products) as feedstock to create clean fuels through two pathways: hydrothermal carbonization and slow pyrolysis. Hydrochar is produced by processing biomass via hydrothermal carbonization (HTC), which is a much faster

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[32] Department of Energy, Office of Energy Efficiency and Renewable Energy. N.d. *Electricity generation; geothermal technologies office.* https://www.energy.gov/eere/geothermal/electricity-generation#:~:text=Binary%2Dcycle%20geothermal%20power%20plants%20differ%20from%20dry%20steam%20and,or%20%22binary%2C%22%20fluid.

[33] Resources for the Future (RFF). September, 2020. *Geothermal Energy 101.* https://www.rff.org/publications/explainers/geothermal-energy-101/?gclid=CjwKCAiAmsurBhBvEiwA6e-WPIVJOUfZIjFclU5EnyKJMuFUbEN8QsAaNY-4xBnYLS8DEi_j6pJ_2RoCp2UQAvD_BwE

[34] Institute for Energy Research (IER). N.d. *Geothermal.* https://www.instituteforenergyresearch.org/?encyclopedia=geothermal#:~:text=Also%2C%20steam%20from%20geothermal%20plants,site%20of%20the%20geothermal%20activity.

[35] Stoel Rives, LLP. 2008. *Brief anatomy of a geothermal Power Purchase Agreement.* https://www.stoel.com/brief-anatomy-of-a-geothermal-power-purchase-agreement

process than the aptly named slow pyrolysis, which produces biochar.[36] The largest difference between the two pathways is that, in HTC, the biomass feedstock is treated with hot compressed water as opposed to drying.[37]

Distribution Networks
Hydrochar and biochar are physical products which can be blended into fossil-based fuels to reduce emissions associated with production. In the industrial sector, this is conducted during blast furnace iron and steel production, where hydrochar and biochar are used to partially replace fossil-based coals to sinter iron ore.[38]

3.4. Renewable Methanol

Production Process and Feedstocks
Methanol is a colorless liquid that can be used as a clean fuel source when generated from low- or no- carbon feedstocks. Although typically deployed in the transportation sector, renewable methanol can be used in the industrial sector as well, specifically in chemical manufacturing. There are two main ways to produce renewable methanol which produce two distinct "types" of methanol: bio-methane and e-methanol. The former is produced through sustainable biomass such as forestry and agricultural waste, while the latter is obtained through capturing CO_2 from renewable sources and hydrogen.[39]

Distribution Networks
Distribution of renewable methanol is typically done through existing infrastructure and/or blending with conventional fuels. Production of methanol from biomass or captured CO_2/green H_2 does not involve experimental technologies, making it more easily utilized in its biomethane/e-methanol forms.

Other Key Facts
Methanol is often traded via contractual instruments according to the International Methanol Producers and Consumers Association (IMPCA) specifications. The International Sustainability and Carbon Certification (ISCC) has developed a methodology for transacting certificates for renewable methanol, specifically in the EU. Although certification of any methanol for both fuel and material use are not yet

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[36] Masoumi et al., 2021. *Hydrochar: a review on its production technologies and applications.* https://doi.org/10.3390/catal11080939
[37] Kambo & Dutta, 2015. *A comparative review of biochar and hydrochar in terms of production, physico-chemical properties and applications.* https://doi.org/10.1016/j.rser.2015.01.050
[38] Khanna et al., 2019. *Biochars in iron and steel industries.* https://doi.org/10.1016/B978-0-12-814893-8.00011-0
[39] International Renewable Energy Agency (IRENA). 2021. *Innovation outlook: Renewable Methanol.* *https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jan/IRENA_Innovation_Renewable_Methanol_2021.pdf?rev=ca7ec52e824041e8b20407ab2e6c7341*

standard, it may be made possible with ISCC certification. The ISCC requires every step in the methanol supply chain to have an individual certification for traceability[40].

3.5. Renewable Natural Gas (RNG)

Production Process and Feedstocks

Renewable natural gas (RNG), or biomethane, can be substituted for fossil natural gas. RNG is produced by putting biowaste (from landfills, livestock operations, wastewater treatment, etc.) through an anaerobic digestion process, where microorganisms break down biodegradable material in the absence of oxygen.[41]

Distribution Networks

RNG can replace conventional fossil natural gas for many industrial processes with limited infrastructure change. It can be used onsite or injected into natural gas transmission or distribution pipelines. In the U.S., slightly fewer projects utilize pipeline injection than on-site delivery of RNG.[42]

Other Key Facts

RNG can be procured through several market-based methods, including through long term contracts, energy brokers, self-sourcing, or by using spot markets.

4. Regulations and Initiatives

Global economies such as the United States, Canada, Singapore, and several EU countries are actively researching the use of clean fuel technologies to advance decarbonization. However, implementation to date has been focused on easier to abate sectors, like residential or transportation. Although fewer regulations exist for employing clean fuel technologies in the industrial sector, two examples are described below.

4.1. U.S. Industrial Heat Shot™[43]

The U.S. Department of Energy has launched an initiative called Energy Earthshot™ to accelerate breakthroughs for clean energy within the next decade. Among these

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[40] IMPCA. N.d. https://www.impca.eu/IMPCA/Technical/IMPCA-Documents
[41] U.S. Department of Energy (DOE), Alternative Fuels Data Center. N.d. *Renewable Natural Gas Production*. https://afdc.energy.gov/fuels/natural-gas-renewable#:~:text=Animal%20manure%20is%20collected%20and,gas%20vehicles%20or%20produce%20electricity.
[42] U.S. Environmental Protection Agency (EPA). 2011. *An Introduction to Renewable Natural Gas*. https://www.epa.gov/system/files/documents/2022-11/RNG_Intro_Guide.pdf
[43] U.S. Department of Energy (DOE) Industrial Heat Shot. N.d. https://www.energy.gov/eere/industrial-heat-shot

Earthshots™ are seven individual initiatives targeted at specific sectors, including the Industrial Heat Shot™, which aims to develop cost-competitive industrial heat decarbonization technologies with at least 85% lower GHG emissions by 2035. This initiative refers specifically to decarbonizing sources of industrial heat, which can be done through various clean fuel technologies.

4.2. Clean Energy Ministrerial – Industrial Deep Decarbonization Initiative[44]

The Clean Energy Ministerial is a high-level global forum to promote policies and programs to advance clean energy technology. It has developed an initiative to decarbonize the industrial sector and stimulate global demand for low carbon industrial materials by 1) encouraging governments and the sector to purchase low carbon industrial materials (steel and cement) which are produced when manufacturers purchase low- or no-carbon fuels to power their production and 2) sourcing and sharing data for common standards and targets. By 2025, a minimum of ten governments are targeted to make green public procurement commitments to buy low or zero emission steel, cement, and concrete, including Canada, Germany, and the United Kingdom.

5. Summary

The industrial sector is one of the most difficult to abate sectors due to its resource and energy intensive activities. Decarbonizing this sector will require rapid deployment and adoption of new clean fuel technologies. Clean fuels such as green hydrogen, hydrochar and biochar, geothermal energy, and renewable methanol can be deployed to fuel various industrial activities. Market-based accounting may be an effective strategy to not only ensure proper tracking of clean fuels, but also stimulate innovation and drive demand for these fuels. Initiatives in the United States and around the world are working to aid in decarbonizing the industrial sector in part through advancing the use of clean fuels. While there are some market-based approaches to contracting clean fuel certificates, particularly hydrogen, geothermal, and methanol, there is still a gap in robust market-based accounting guidance for clean fuels across the industrial sector. Finally, the industrial sector currently lacks regulations and structure to facilitate abatement through clean fuels, but there is potential for market-based accounting in the clean fuels landscape to create opportunities for additional policy requiring the industrial sector to transition away from high-carbon fuels and feedstocks.

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[44] Clean Energy Ministerial. N.d. Industrial Deep Decarbonization Initiative (IDDI). https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf