DECARBONIZATION

A Bright Future for Energy Engineering

Three often unheralded energy technologies offer hope for decarbonization—and opportunities for mechanical engineers.

ASME
SETTING THE STANDARD



In the face of new technologies, the days may be numbered for petrochemical plants.

ANDY SACKS/GETTY IMAGES

The world needs mechanical engineers. Thousands of them, in fact, partly because three energy technologies—hydrogen production, small modular nuclear reactors, and carbon capture—are emerging as potential solutions to the global challenge of decarbonization.

It's helpful to put these technologies in the context of projected carbon dioxide emissions and energy demand. In its International Energy Outlook 2021, the U.S. Energy Information Administration forecasts that between 2020 and 2050:

- Global CO_2 emissions will grow 24.7%, to 42.8 billion metric tons from 34.3 billion metric tons.
- Global energy consumption will grow 47.3%, to 886.3 quadrillion BTUs from 601.5 quadrillion BTUs.
- The fastest-growing energy source will be renewables (one of which is hydrogen), whose demand will rise at a 3.3% annualized clip to 235.2 quadrillion BTUs—almost the same amount as for liquid (i.e., petroleum-based) fuels.
- Global electricity consumption will grow 55.2%, to 365.9 quadrillion BTUs from 235.8 quadrillion BTUs.
- As with energy, renewables will be the fastest-growing electricity source. Demand for renewables-based electricity will rise at a 3.7% annualized pace, more than double the 1.5% rate for electricity as a whole.

Mechanical engineers will be in the thick of the action for world decarbonization. Companies and governments need them to come up with the engineering breakthroughs and cost efficiencies that will make technologies like hydrogen production, small modular nuclear reactors, and carbon capture ready for widespread commercialization.

But there's more to this than just engineering. Jeffrey Winters, editor-in-chief of *Mechanical Engineering* magazine, notes that "Particularly for mechanical engineers who are early in their careers, decarbonization represents an opportunity to get in on the ground floor of something that will directly affect everyone on the planet. They can truly be part of a huge solution to a huge problem. It's a chance to make the world a better place."

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HYDROGEN PRODUCTION: NO EASY TASK

The good news for hydrogen—which is the most abundant element in the universe—is that it can play a potentially significant role in moving the world to a low- or zero-carbon future. It's a clean fuel source that ultimately could replace the carbon-based gasoline, natural gas, and coal that are responsible for a large chunk of global CO_2 emissions.

The bad news is that hydrogen doesn't occur as a physical form on its own. Instead, it must be extracted from water, organic matter, and hydrocarbons that populate fuels such as gasoline, natural gas, and methanol. Extraction methods include steam methane reforming, carbon capture (more about this later), low-temperature electrolysis with renewable electricity, and eventually, high-temperature electrolysis.

Hydrogen extraction presents big obstacles: It's a technically difficult process and requires massive amounts of energy, often from carbon-based sources. The infrastructure for it doesn't yet exist. Hydrogen itself is highly flammable and potentially explosive. And when the extraction is complete, hydrogen is expensive to produce and store. Large-scale commercial application thus won't happen anytime soon.

All of this bodes well for young mechanical engineers. "The quest for decarbonization through hydrogen is especially exciting for mechanical engineers looking to lay the foundation for their careers," says Jeffrey Goldmeer, emergent technology director for decarbonization at GE Gas Power. "There are so many opportunities to develop technologies for the production, storage, and transmission of hydrogen for everyday use. Engineers can really put their minds and skills to work to develop these new systems."

According to the Hydrogen Council, global demand for hydrogen will skyrocket in the next three decades.

Hydrogen consumption will reach 660 million tons in 2050 from 90 million tons in 2020—a 633% jump with an annualized growth rate of 6.9%.

The following end-use sectors, which are major generators of CO_2 emissions, will account for most of the projected demand (Figure 1):

Mobility. Transportation (on the ground and in the sea and air) should be the single largest consumer of hydrogen going forward. Heavy-duty trucks will need the most hydrogen due to their high mileage and power characteristics, while long-range flights and container shipping will be especially tough to decarbonize.

Feedstocks. Hydrogen already plays an important role in feedstock applications such as ammonia, methanol, and refining. Decarbonizing these applications will require even more.

Steel. Steelmaking is one of the most difficult processes to decarbonize. There are few alternatives to hydrogen as a method of full decarbonization.

Power generation. While renewable energy represents the primary source of decarbonization for power generation, its volatility means it isn't able to decarbonize an entire power grid. Hydrogen is vital to decarbonizing the grid's final 1% to 2% of power demand.

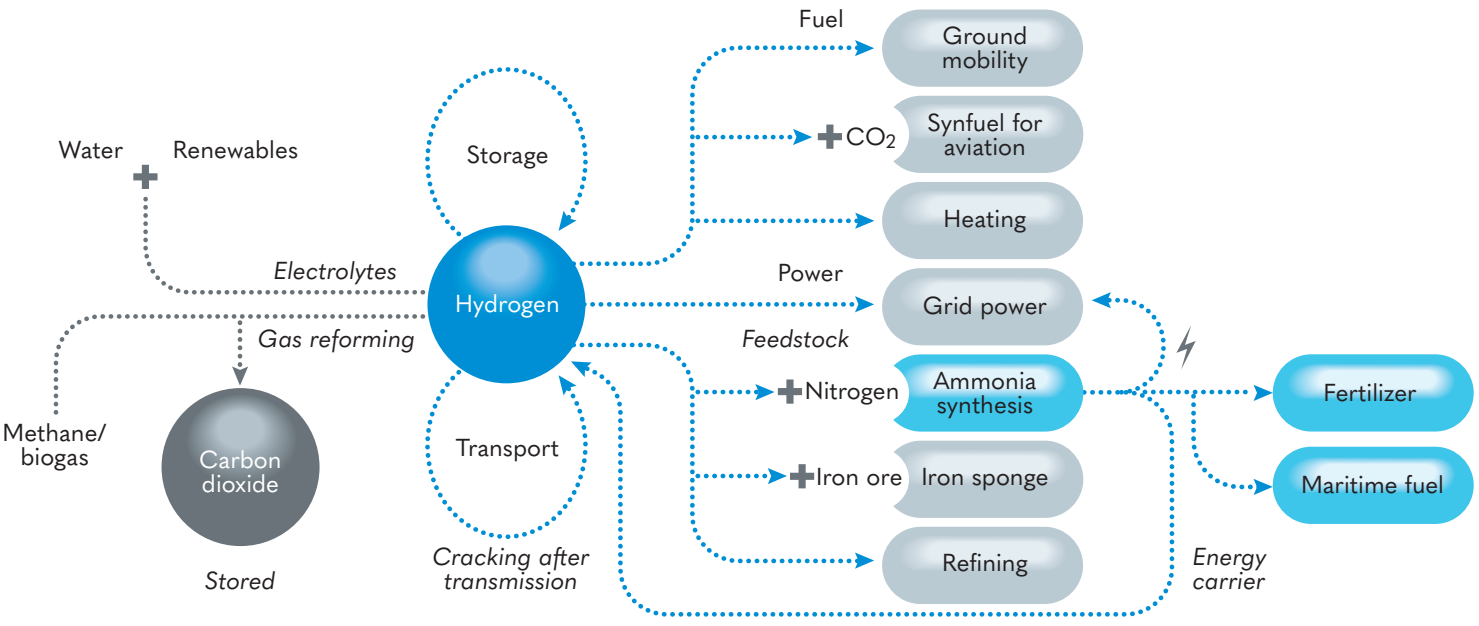
As noted earlier, global electricity demand will keep growing through the next few decades. Goldmeer sees power, industrial processes, heating, and transportation end-use applications as particularly thirsty for electricity and/or hydrogen. "The potential demand from these sectors will require new infrastructure to produce, transport, and store the hydrogen molecule," he says. "The changes in these applications have the potential to transform society while creating all-new industries and great new job opportunities."

Aromatics production. Hydrogen-based decarbonization of the main substances used in producing aromatics (e.g., benzene, toluene, and xylene) is in a very early stage, but industry players

FIGURE 1:

The Many Uses of Hydrogen

SOURCE: HYDROGEN FOR NET-ZERO, HYDROGEN COUNCIL AND MCKINSEY, NOVEMBER 2021



Clean hydrogen produced from "stranded" renewables used as reductant in steel production—or to fuel ships and trucks. Chemicals and energy sectors are coupled—chemicals become energy carriers or fuels. **Note:** Selected examples—not exhaustive.

expect it to accelerate after 2030, when the required technology should reach commercial scale.

Industrial heating. Hydrogen can be a key ingredient in decarbonizing industrial structures, notably for high-grade heat applications such as glassmaking, aluminum remelting, and cement manufacturing.

Where Progress Is Happening Now

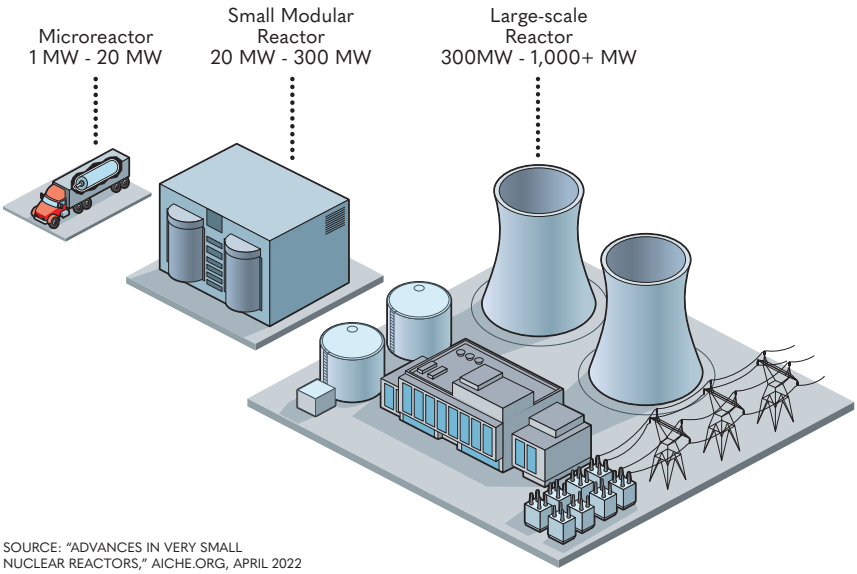
The processes and facilities for extracting hydrogen and decarbonizing are in their infancy. For hydrogen to function as a power source currently, it can only be used in combination with natural gas.

According to Goldmeer, the lone place where this is happening now is at a GE power plant in Hannibal, Ohio, which has conducted tests using hydrogen and gas to generate power. The tests' success demonstrates that power plants can use hydrogen to reduce their carbon footprint. Other hydrogen-based works in progress include a New York Power Authority project to convert an airplane gas turbine into a stationary engine to produce power; an Airbus program to develop a jet engine exclusively fueled by hydrogen; and Plug Power's efforts to create hydrogen-powered fuel cells for use in certain applications.

The System of Systems: Engineers Needed

Significant technological issues must be addressed for hydrogen production to reach the critical mass for large-scale commercialization. Such issues also apply to the numerous systems to be created in order for commercialization to be possible in the first place. This "system of systems," as Goldmeer calls it, will require the vast deployment of mechanical engineers not only to create but also to fit the smaller systems together so that they run smoothly and efficiently.

Think about it. Engineers will have to imagine the infrastructure for hydrogen production and break through previously impenetrable barriers to build it. They'll have to understand the properties of metals used in carbon capture as well as the plastics and other materials needed to construct turbines and solar panels. They'll have to create new materials to design processes that never existed before. The list goes on.



SOURCE: "ADVANCES IN VERY SMALL NUCLEAR REACTORS," AICHE.ORG, APRIL 2022

SMRs: SMALLER IS BETTER

Small modular nuclear reactors (SMRs) present an innovative way to generate carbon-free power and, in the process, help decarbonize the world. Multiple SMRs are active or in the planning stages—and providing opportunities for mechanical engineers—in the U.S., Europe, Canada, Russia, and China.

A key reason SMRs are so appealing is that many large Western countries have lost the ability to build traditional, gigawatt-scale nuclear reactors on time and on budget. In the U.S., for example, the Tennessee Valley Authority started construction on its Watts Bar 2 plant in 1973, halted work in 1985 as projected demand for its power declined, resumed work in 2007, and finally finished in 2016.

Watts Bar 2's total cost is thought to be $6.1 billion, nearly 150% more than the initial $2.5 billion estimate. The American Society of Mechanical Engineers estimates that construction of a traditional plant today could cost between $8 billion and $10 billion.

SMRs offer substantial advantages over traditional reactors, all of which make them far less expensive:

- They're much smaller and produce less wattage (typically 100 megawatts or less), meaning that they can be sited in far more locations and can service areas of lower demand (see illustration).
- They're built in a factory using standardized modular designs instead of on a one-off basis, and transported to their site rather than built there.
- Their production is cheaper and faster and requires a much shorter learning curve.
- They can be purchased individually or in bunches, providing the flexibility to add generation capacity.

Jacopo Buongiorno, a professor of nuclear science and engineering at MIT and director of its Center for Advanced Nuclear Energy Systems, considers SMRs a great decarbonization solution. "It starts with nuclear power itself," says Buongiorno. "Nuclear is low in carbon, very compact, and easily transmissible. These benefits are magnified when reactors are smaller because costs fall significantly, much less space is needed, and location becomes much more convenient for providers as well as consumers."

SMR Engineering Challenges

Not surprisingly, new mechanical engineering challenges arise when a nuclear power plant is miniaturized. Buongiorno cites the design of an ultra-compact heat exchanger, the creation of new materials that can handle high radiation levels, and the automation of an SMR's operations as particularly noteworthy in this context.

He also points to the needs that SMRs can address, each of which will require engineers to come up with fresh ideas that they'll have to translate into new devices, processes, and materials. Among these needs are heating for chemical and manufacturing processes, the creation of hydrogen for use in transportation, and the desalination of seawater for agriculture.

The State of SMRs Today

Currently, there is one active SMR in the world: a Russian-built pair of 35-megawatt (MW) reactors on a barge floating in the Arctic Ocean off Siberia. There are a number of others in various stages of construction or design in the U.S., Canada, China, Poland, and Romania.

United States. The Department of Energy is supporting three active SMR projects. These are a 345 MW TerraPower reactor in Kemmerer, Wyoming, expected to go online in 2027-2028; a 77 MW NuScale Power reactor for Utah Associated Mountain Power Systems, scheduled to go online in 2028-2029; and the Tennessee Valley Authority's commitment to explore the construction of multiple SMRs at Clinch River, Tennessee.

Other U.S. projects include an X-energy fabrication facility for SMR fuel in Oak Ridge, Tennessee, scheduled to start up as early as 2025; and a joint TerraPower/GE Hitachi (GEH) plant at PacifiCorp's Naughton Power Plant site in Wyoming, congressionally mandated to go online by 2028. The Department of Defense is working on a transportable reactor that can fit on a truck, with testing expected in 2024-2025.

Canada. Ontario Power Generation is working with GEH on Canada's first commercial, grid-scale SMR, to be located in Darlington, Ontario. Construction could be completed as early as 2028.

China. A Chinese consortium expects to start operating two high-temperature gas-cooled modular pebble bed reactors later this year.

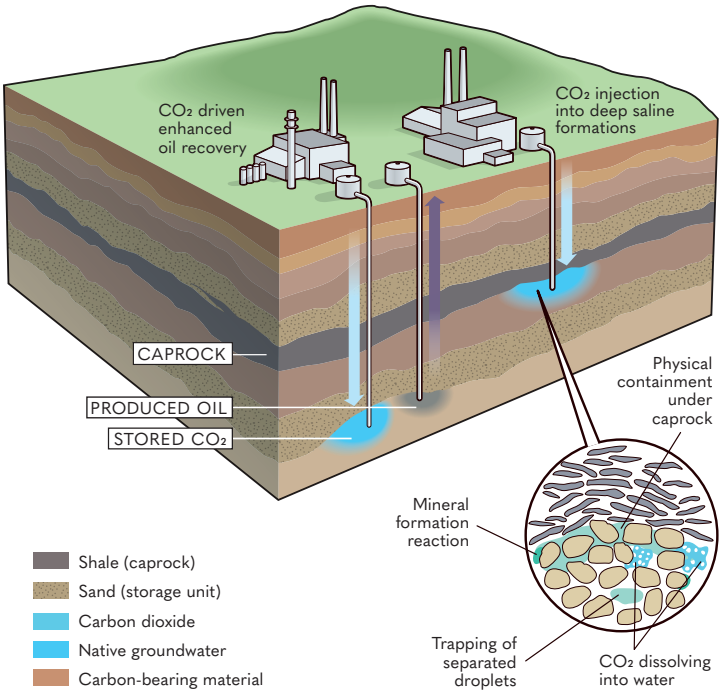
Poland. In February, NuScale Power and Polish metals producer KGHM Polska Miedź signed an agreement for the two companies to collaborate on Poland's first SMR. The reactor should go online by 2029.

Romania. In May, NuScale Power signed a memorandum of understanding (MOU) with Nuclearelectrica, the Romanian state-owned nuclear

FIGURE 2

CO_2 Is Used and Sequestered Underground

SOURCE: "CARBON CAPTURE," CENTER FOR CLIMATE AND ENERGY SOLUTIONS.



power corporation. NuScale and Nuclearelectrica will jointly conduct engineering studies, technical reviews, and licensing and permitting activities for the deployment of a NuScale SMR.

CARBON CAPTURE: HERE TO STAY

By definition, carbon capture is a means of decarbonization. Processes either capture CO_2 from fuel before the fuel is used to generate power or scrub it from the gas that results from fossil fuel combustion. In the latter case, the scrubbed CO_2 must be sequestered—stored onsite where it's scrubbed or injected in liquid form into underground geologic formations such as oil and gas reservoirs, deep saline formations, coal beds, basalt formations, or shale basins (Figure 2).

Unlike hydrogen production or SMRs, carbon capture dates back to the 1970s, when it was first used in industrial projects or to provide CO_2 for use in helping to recover oil and gas from underground. The world's largest commercial carbon capture facility, ExxonMobil's Shute Creek plant in Wyoming, opened in 1986.

The Center for Climate and Energy Solutions reports that as of 2020, there were at least 26 commercial-scale carbon capture projects in operation globally, with another 21 projects in early development and 13 in advanced development. Industrial processes where large-scale carbon capture was in commercial operation included fertilizer production, coal gasification, ethanol production, natural gas processing, refinery hydrogen production, and coal-fired power generation.

Carbon capture in electricity generation is comparatively recent. As with hydrogen production, much of the technology for it doesn't yet exist, and it's thus not yet economically feasible on a large scale—which is where mechanical engineers come into the picture.

Guy DeLeonardo, executive product manager at GE Gas Power, sees this as a tremendous opportunity for engineers early in their careers: "The need for electricity will keep growing, and that electricity will have to be decarbonized. Not only that, but carbon capture will have to be retrofitted into many existing gas- and coal-fired power plants and industrial facilities. We can't meet these challenges without the imagination and skills that young engineers can bring. They're vital to making carbon capture a reality for power providers, their customers, and investors."

DeLeonardo agrees with the system-of-systems concept espoused by his GE colleague Goldmeer and notes that it's as relevant to carbon capture as it is to producing and using hydrogen for power generation. "There are about 96 different systems in a typical power plant," DeLeonardo says. "Mechanical, electrical, control, and chemical, to name a few. That's a lot for any team of engineers to maintain and coordinate for reliable operation. When you add the systems needed to capture, liquify, and sequester CO_2, that means even more integration and oversight. Mechanical engineers are primarily the ones who have to make this happen."

HELP WANTED: MEETING THE GOALS OF DECARBONIZATION

Whether it's by producing hydrogen, building small modular nuclear reactors, or capturing carbon, the need for decarbonization solutions is huge and will only grow. As Goldmeer puts it, "There are three goals for decarbonization. The first is to create everything that's needed for it—the science, materials, processes, systems, all of it. The second is to do it. And the third is to get to the point where it's so common and normal that we don't even have to think about it."

It will take a vast army of mechanical engineers to realize these goals. The U.S. government (most notably the Department of Energy), as well as companies across many industries, are actively looking for engineers to help make the world a cleaner place—and create a brighter future for everyone.

About the American Society of Mechanical Engineers (ASME)

Founded in 1880, ASME has a long history of helping engineers connect with colleagues and resources throughout the engineering industry. Our mission is to promote the vital role of engineers in society. ASME enables collaboration, knowledge sharing, and skill development across all engineering disciplines. Explore networking opportunities and become part of our worldwide community through an ASME membership.

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