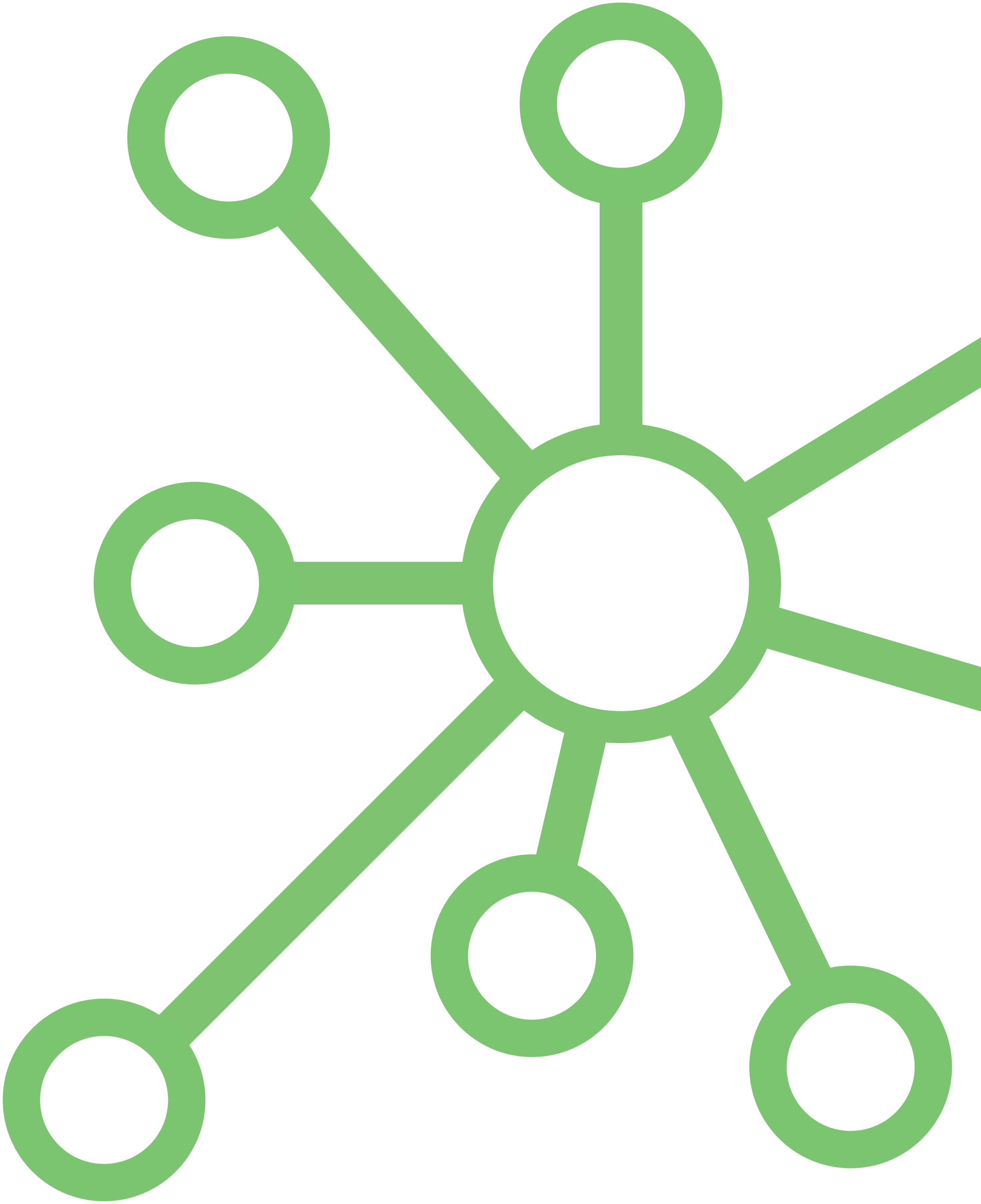

NUCLEAR TECH HUB:

Co-siting cutting-edge nuclear facilities with waste management sites

By Charles Forsberg, Jacopo Buongiorno, and Eric Ingersoll

The organization of the commercial fuel cycle with the geographical separation of waste disposal facilities from other nuclear facilities is a historical artifact. There are large economic and institutional incentives to collocate many fuel cycle facilities with the repository. Similarly, there are large economic and institutional incentives to collocate proposed fission battery factories and nuclear hydrogen/synthetic fuel (synfuel) gigafactories with other waste management facilities (used fuel storage, low-level waste disposal, etc.) to create nuclear technology hubs that create economic savings, generate jobs and tax revenue, and simplify waste management.

The economic savings are from shared services (e.g., security and environmental monitoring), a larger infrastructure of local supporting organizations (e.g., consultants, specialty supply companies, and worker training programs), and the elimination of transportation links. The institutional incentives include (1) creating strong local and state support because new business opportunities, high-paying jobs, tax revenue, and waste management are coupled together; and (2) a knowledgeable local and state government in terms of permitting and support, such as local worker training classes and universities.

The start of such technology hubs is becoming visible around existing Department of Energy sites at Savannah River (South Carolina), Oak Ridge (Tennessee), and Hanford (Washington). The Vogtle nuclear plants are next to the Savannah River Site, and the Columbia nuclear plant is next to Hanford. The first Generation IV reactor, the Kairos Power Fluoride Salt-Cooled High Temperature Reactor test reactor, is to be built at Oak Ridge. Each of these sites has a wide array of government and commercial nuclear facilities on government and private lands—along with specialized technical firms that locate nearby to serve multiple government and private customers.

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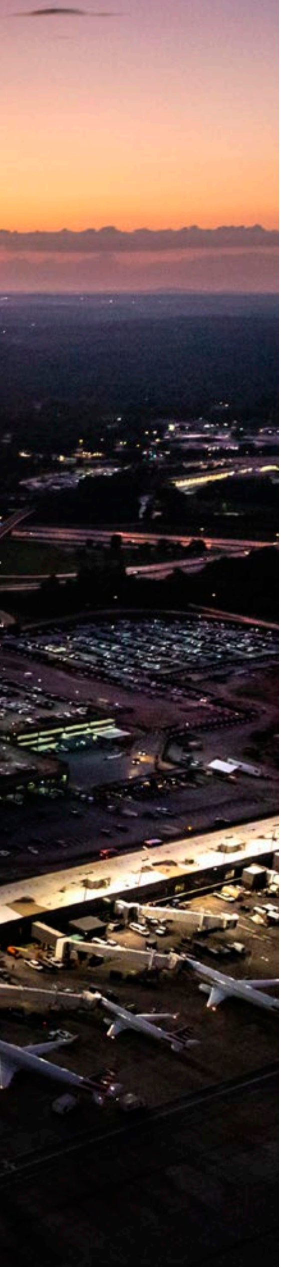
The Hartsfield-Jackson Atlanta International Airport in Georgia. (Photo: @ATLairport)

The nearest nonnuclear analogy to a nuclear technology hub can be found in some airports, such as the Hartsfield-Jackson Atlanta International Airport, Mojave Air and Space Port, and Charleston International Airport. Each of these airports has commercial air flights but also other activities that share taxiways, security, and many other services on public and private land. Atlanta has the massive Delta Airlines operations, aircraft maintenance, and training facilities. Charleston is a joint civilian military airport that includes a Boeing commercial aircraft manufacturing plant and other facilities. Mojave has commercial flight testing, space industry development, heavy aircraft maintenance, and commercial aircraft storage.

One would expect a nuclear technology hub to have many types of facilities, including an industrial park with nonpublic rail and roads connecting facilities to allow the on-site transport of radioactive materials without the requirements for shipping over public highways. That capability enables moving radioactive wastes to central processing and disposal facilities. If there is a low-level waste disposal site, it enables moving large radioactive components used in the hub facilities to the disposal site without cutting components into small pieces to meet over-the-road shipping requirements. The on-site transport of radioactive materials simultaneously reduces costs and risks.

Here we describe three candidate nuclear technology hubs—the repository, the nuclear hydrogen gigafactory, and a fission battery refurbishment facility. The long-term coupling of large numbers of high-paying jobs, tax revenue, and waste management facilities can make such hubs attractive to communities and states, as opposed to isolated waste management facilities, which are typically perceived by the public as "dumps."



GEOLOGICAL REPOSITORIES

If one were designing a nuclear power system for the United States to minimize costs, risks, social opposition, and environmental impact, what facilities would be collocated with the repository? As the U.S. Department of Energy [1] once again attempts to site a spent nuclear fuel storage facility and then a repository, it is an appropriate time to ask that question. One concludes [2, 3, 4] that such a repository would have thousands of high-paying, nonconstruction, long-term jobs, with the majority of those jobs not associated with repository operations. Those jobs would be associated with the following:

International safeguards training and development center. The repository's receiving facilities will have the largest and most varied collection of incoming spent nuclear fuel in the world. That makes it a preferred location for training International Atomic Energy Agency inspectors and testing safeguards systems on multiple types of SNF. Such a center generates large numbers of secondary hotel and restaurant jobs because of the continuous influx of people for training.

SNF and high-activity materials testing and processing. The United States has a large number of facilities that inspect, test, and treat SNF (including failed fuel), highly radiative sources such as cobalt-60 and cesium-137, and high-activity wastes from producing medical and other isotopes. The costs of operating and maintaining these facilities are high for several reasons. First, each facility has its own security, environmental monitoring, and similar overhead functions. Second, these facilities generate complex mixtures of high-level radioactive waste, high-activity wastes, irradiated metals, and other wastes. Collocation with a repository enables (1) sharing of security, environmental monitoring, and other overhead services and (2) lower-cost waste disposal.

The processing and disposal of many nuclear waste streams are expensive because of the conflicting requirements for transportation and disposal. For transport, waste volumes are best minimized to minimize transport costs. Large, contaminated components are size-reduced to fit within transport containers. For disposal, one wants waste forms with good long-term performance. With collocated facilities, one can use alternative lower-cost waste forms, such as special cements that perform better than HLW glass, but are not used today because these waste forms increase final waste volumes and thus shipping costs. (One factor for better waste-form performance is that with lower concentrations of radionuclides in the waste form, there is less radiation damage to the waste form.) With collocation, highway size and weight requirements are eliminated.

The current facilities that treat and package these materials range in size from large facilities, such as the Naval Reactors Facility in Idaho, to smaller facilities with a few tens of employees. In the Navy facility, samples are taken from Navy SNF and destructively tested to determine long-term fuel performance, and thus how long nuclear naval vessels can remain in operation without refueling or decommissioning. Similar types of operations are performed on commercial and research fuels. There is a long list of such facilities that logically belong at the repository site.

Nuclear fuel reprocessing. Collocation of future reprocessing and fuel fabrication facilities at the repository site results in massive reductions in capital and operating costs from front-end receiving facilities to waste management—possibly by a third or more. During the Cold War, the Hanford PUREX plant processed 5,000 to 7,000 tons of short-lived targets and fuel per year to recover weapons plutonium, and yet it was much smaller than the French La Hague commercial facility with a throughput of only 1,600 tons per year. On-site waste disposal was the primary difference.

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For example, chemical de-cladding of fuel (Hanford) is less expensive than mechanical de-cladding but generates much larger waste volumes—volumes that make it expensive to ship such wastes off-site for disposal. The actual separations section of a reprocessing plant that separates fissile and fertile material is less than 10 percent of the total capital cost.

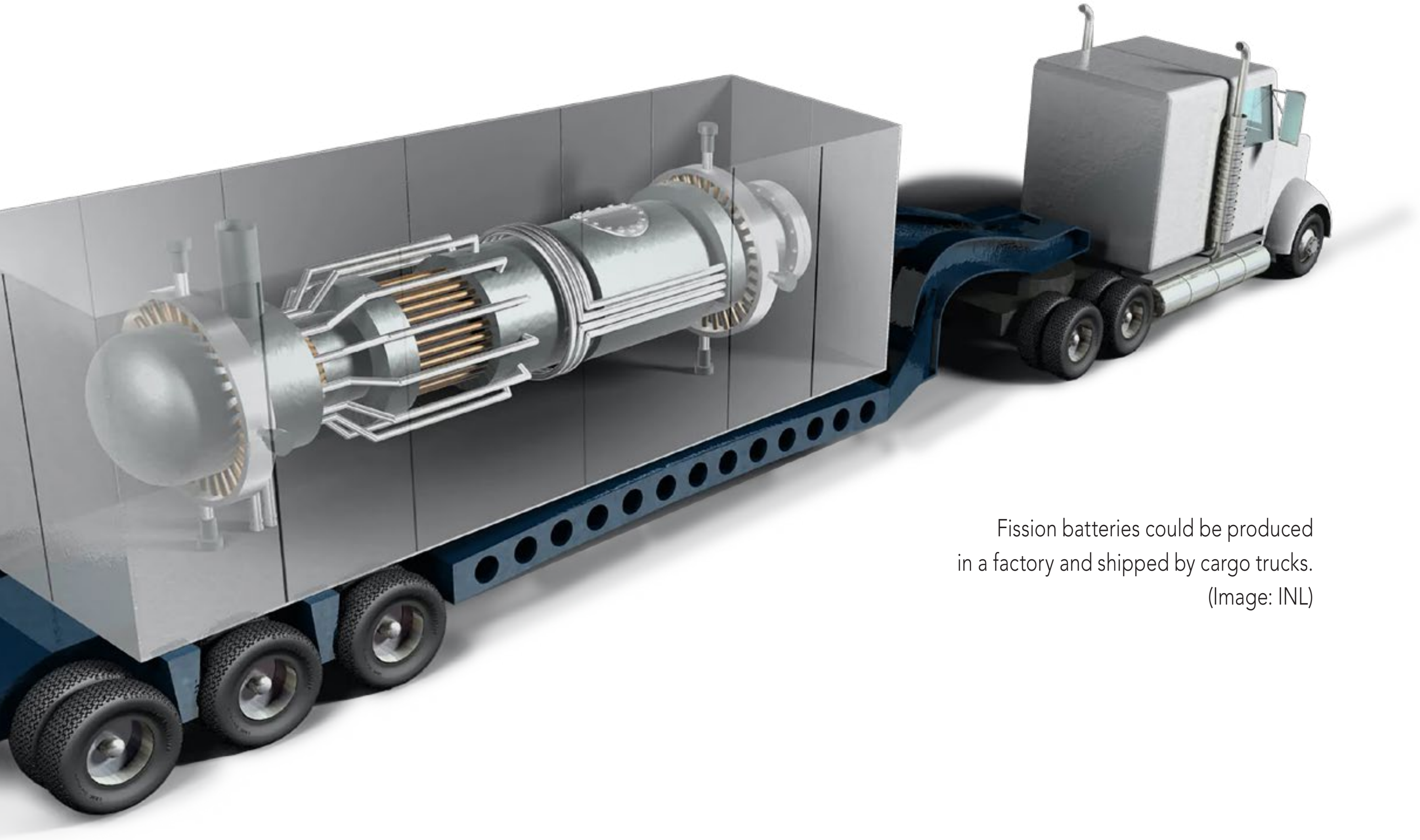
Hanford had many failures in waste management because of the use of shallow-land disposal and tank storage for these long-lived wastes. These challenges, however, are eliminated if the reprocessing plant is collocated with the repository and the use of lower-cost, higher-performance, higher-volume waste forms.

The other area of saving is joint services (security, radiation monitoring, etc.) and facilities such as front-end receiving facilities for SNF and HLW at the repository and reprocessing plant. If economics drives reprocessing decisions, SNF with high fissile content will be reprocessed, but SNF with low fissile content or SNF that is difficult to process will be considered waste. The same front-end facilities can be used for both facilities.

Collocation imposes siting requirements because of the need for good transportation connections and a sufficiently large labor force. In terms of economics, the lowest-cost repositories would be in salt. Salt has also been recognized as a preferred geology for disposal of long-lived radioactive wastes because of its capabilities to assure waste isolation for very long periods of time [5]. The one operating permanent repository in the United States, the Waste Isolation Pilot Plant for defense wastes in New Mexico, is in salt. In Europe, multiple geological repositories for the disposal of toxic heavy-metal wastes exist in salt deposits, including the Herfa-Neurode hazardous waste repository in Germany, which was the first geological repository in the world to be built.

As shown in Fig. 1, salt deposits exist across much of the United States. Other geologies can be used but the disposal costs would be higher. A significant fraction of the United States is suitable for shallow-land and geological disposal of different radioactive wastes. Siting is not limited by geology.

Fig. 1. Rock salt deposits in the United States. (Image: Salt Institute)



Fission batteries could be produced in a factory and shipped by cargo trucks. (Image: INL)

FISSION BATTERIES

Fission batteries (FB), also called nuclear batteries, are a class of advanced nuclear reactors defined by four characteristics [6, 7, 8, 9]: (1) mass-produced in factories in standard sizes to economically compete in major markets, (2) shipped as complete systems to the customer and returned to the factory after use, (3) operate in a secure and unattended manner, and (4) highly reliable. Mass production and transportability enables widespread use and lowers the cost, but this also limits the reactors' physical size and thus their power output. Market, manufacturing costs, and technology limits indicate likely sizes between 5 and 30 MWt.

The markets in a low-carbon world would be for customers using less than 250 MWt for heat and/or electricity production, with many customers having multiple FBs. These batteries would replace oil and natural gas and could be 10 percent of the total energy market—including chemical plants, large institutions (universities, hospitals, etc.), biofuels, industrial customers, data centers, and container ships. Larger energy users in a low-carbon world have other options, such as larger modular reactors and fossil fuels with carbon capture and sequestration—options that may be economically preferred at larger outputs but that require major on-site construction and facilities, and thus likely to be noncompetitive at smaller scales.

The likely business model is the leasing of FBs [7], similar to the practice of leasing commercial jet engines and aircraft. This places the regulatory burden on the lessor and not the customer, who is not in the energy business but needs energy for his own uses. A single supplier would manufacture and lease thousands of FBs and refuel/refurbish them at the factory for reuse. The FB factory/refurbishment facilities would be the largest radioactive waste generators by volume and second to reprocessing plants by radioactivity—far larger than any single nuclear power plant site.

There would be large incentives for access to the sea by barge for receipt and delivery to different customers. SRS/Vogtle, Oak Ridge, and Hanford have barge access. There also would be large incentives for sites with existing local LLW and SNF storage facilities, such as dry cask storage. A key characteristic is the tight coupling of jobs, tax revenue, and multiple waste management facilities.

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NUCLEAR HYDROGEN PRODUCTION SITES

Fig. 2. Hydrogen gigafactory with factory in back, reactor field in the middle, and hydrogen plant in the front. (Image: LucidCatalyst)

Any low-carbon future will require massive quantities of hydrogen; partly for industrial uses (e.g., fertilizer, steel, and biofuels) and potentially as a replacement for natural gas. Recent studies [10, 11] have proposed a new model for nuclear hydrogen production—the gigafactory (Fig. 2). A single site would have manufacturing facilities to build modular reactors and use the heat and electricity from those reactors to produce hydrogen. The hydrogen would be consumed by a downstream process (e.g., synfuel and ammonia) or injected into the gas grid. The reactors would be installed during the multiyear construction process and returned to the collocated factory for refurbishment or decommissioning as appropriate.

There are massive economic gains obtained by serial production, maintenance, operation, and refurbishment of all reactors on a single site, as all the potentially high costs associated with the conventional approach to these activities can be replaced with high-productivity, lower-cost manufacturing processes. Initial studies examined a site with 36 reactors of 600 MWt each for a hydrogen production rate of 2 million tons per year, or equivalent to the output of a medium-size refinery—about 200,000 barrels per day of synfuel. Current U.S. hydrogen production is about 11 million tons per year, but many low-carbon energy futures predict that hydrogen demand will grow to 100 million tons per year.

The gigafactory is made possible by the characteristics of hydrogen/synfuel. The energy output of such a facility would be similar to a large integrated oil refinery. In this context, there is a major difference between the capabilities of large electricity transmission systems and large pipeline systems and their associated storage facilities. Large electricity transmission lines have capacities of 1 to 3 gigawatts and essentially no storage. Pipelines have transmission capacities measured in tens of gigawatts. Hydrogen and synfuels, like natural gas and liquid products, can be stored in underground facilities. Those facilities today store a 30-day supply of natural gas. It is the ability to produce and store hydrogen at scale and transport it to a wide customer base that makes large, centralized facilities like the gigafactory a technical and economically viable option. Synfuels enable even longer-range tanker transport and sales to the global market.

The second factor is the economics of low-carbon hydrogen production. Hydrogen production facilities have high capital costs and must be operated at high capacity factors to be economical, as shown in Fig. 3. That requirement couples well with nuclear plants but makes hydrogen expensive if the energy comes from sources such as solar with low capacity factors. Nuclear plants have capacity factors of about 90 percent, versus wind (about 35 percent) and solar (about 25 percent). Hydrogen plants, like all other chemical plants, have large economics of scale and strongly favor steady-state operation—matching nuclear plant characteristics.

A gigafactory with tens of gigawatts output implies large waste generation rates—larger than any existing nuclear power reactor site. This creates incentives to choose existing sites with existing SNF storage facilities and/or LLW disposal sites.

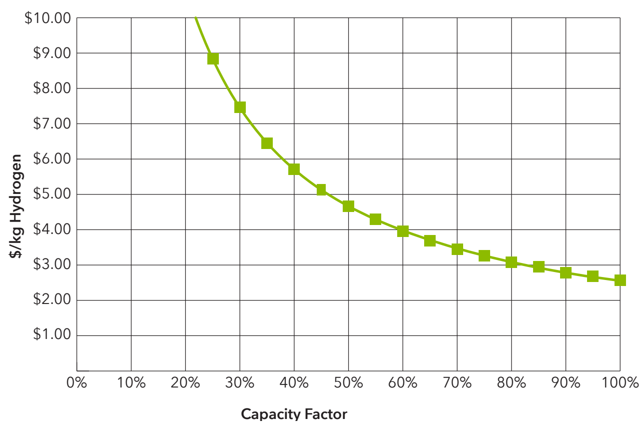

Fig. 3. Illustrative cost of hydrogen vs. capacity factor. (Graph: LucidCatalyst)

INSTITUTIONAL STRUCTURES

Nuclear technology hubs require a different business and institutional structure [2, 4] because the different owners of facilities have different priorities but must cooperate to be successful. As mentioned, a few airports provide models for such nuclear technology hubs. There are different security zones and internal roads or railroads for the transport of materials, including radioactive wastes, between facilities. There also must be sufficient land for expansion and good transportation links. Nuclear technology hubs would be the logical sites for regional SNF storage and other waste management activities because such sites would have lifetimes of many decades or centuries. Such a nuclear technology hub can be primarily private, public, or some combination of private and public partnership.

There are large incentives to work with local and state governments. Nuclear technology hubs can potentially break the deadlock over waste and repository facility siting. Imagine if the federal government promised several thousand long-term nonconstruction jobs within 10 years of opening a repository with massive added tax revenue—rather than designing repositories that minimize local jobs and benefits. This defines a research and development agenda: identify and understand what facilities and functions should be collocated to minimize total economic and societal costs.

The geographical characteristics of the U.S. nuclear fuel cycle system reflects history. The potential deployment of fission batteries, gigafactories for hydrogen production, and a repository system provides incentives to rethink how we should organize the system to reduce costs and environmental impacts while breaking the roadblocks to a fully functional waste management system. There are similar systems in other industries. A few airports have become aircraft technology hubs, where shared facilities and services provide economic benefits to everyone. For a nuclear repository, the burden of rethinking belongs to the government, while for the other nuclear technology hubs, the burden of rethinking belongs to the private sector.

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