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The Future of Houston as Energy Transitions

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This report is a collection of thoughts on Houston's future from the fellows and scholars at the Baker Institute's Center for Energy Studies.

Houston has long been referred to as the "energy capital of the world," a title derived from its prowess in petroleum and the dominance petroleum has held in global energy markets. Now, however, the global energy landscape is evolving in the direction of lower-carbon energy sources. For Houston to retain the energy capital moniker as markets transition, the city (and region) will need a strategy that adapts its extensive infrastructure, technology base, and highly educated workforce to the temper of the times.

Houston, and Texas more generally, is not starting behind the proverbial eight ball with regard to energy transitions. Rather, it has a substantial comparative advantage that it can leverage in finding and developing low-carbon solutions and creating opportunities to efficiently and effectively deploy the region's vast resources to produce and deliver cleaner, greener fuels to the nation and the world. This comparative advantage derives from the region's engineering talent, subsurface expertise, depth of knowledge in the chemical and conversion industries, significant experience in logistics and supply chain management, and favorable business environment. Indeed, each of these factors, in addition to the state's tremendous energy resource wealth, have already placed Texas in a leading position nationally in several different areas. In particular,

- Texas is the 2nd largest state in the U.S. in terms of GDP (behind California), and it would have the 10th largest GDP in the world if it were a sovereign nation;[1]
- Texas accounts for about 11% of all power demand and 12% of all power generation in the U.S., making it the largest single state in both categories;[2]
- Texas has the largest natural gas power generation fleet in the U.S. (almost 15% of the nation's operating capacity), the largest wind power generation fleet in the U.S. (over 26% of the nation's operating capacity), and the largest coal power generation fleet in the U.S. (almost 8% of the nation's operating capacity);[3]
- The Texas industrial footprint is huge, accounting for about 46.9% of all extractive industry output, 10.3% of manufacturing output, and 10.8% of construction output in the U.S. in 2019, with a heavy concentration of activity along the Gulf Coast;[4]
- Texas produces over 40% of U.S. crude oil, over 25% of U.S. marketed natural gas production, and accounts for roughly 25% of national refined product output;[5]
- Texas has the largest transportation network (roads and rail) of any state;[6] and
- The port system in Texas is massive, and in terms of tonnage in the U.S., Houston

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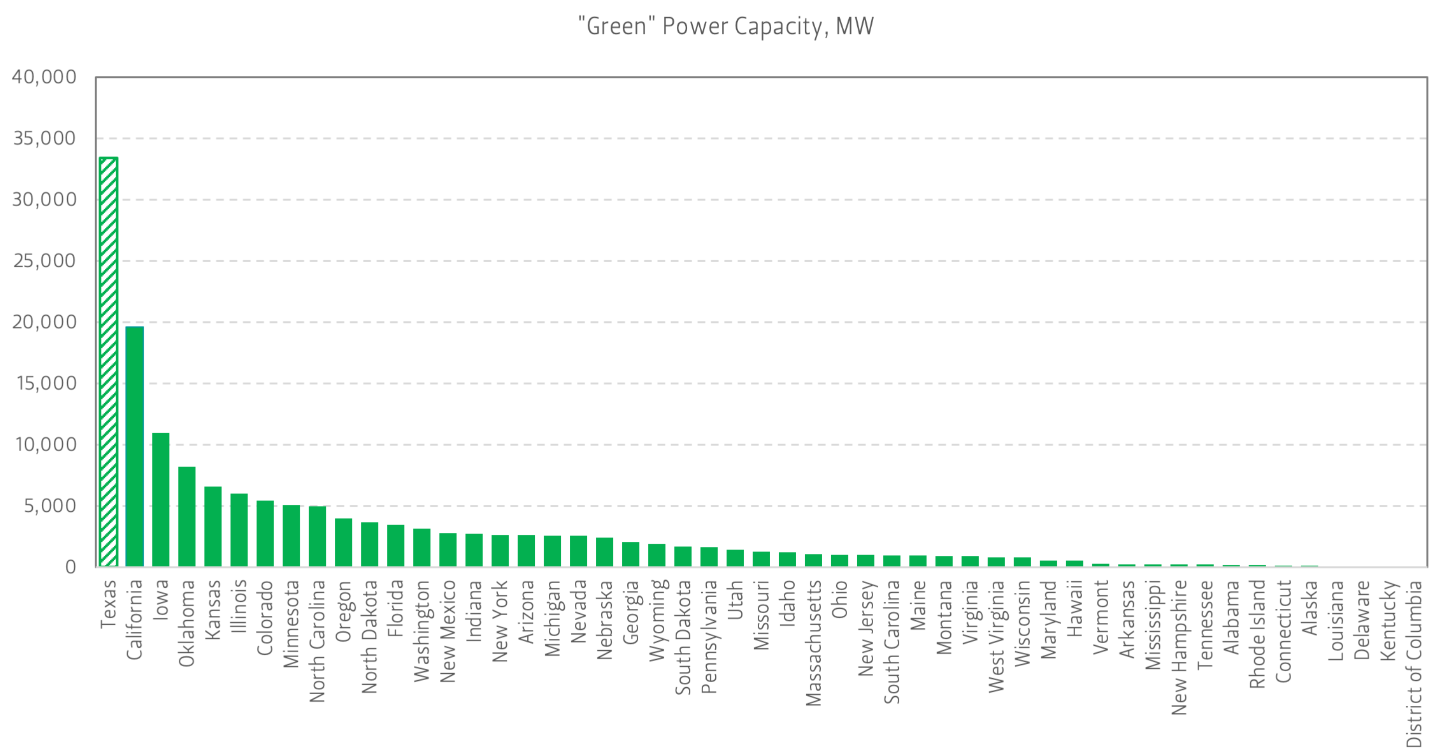
is #1, Corpus Christi is #4, Beaumont is #5, Texas City is #16, Port Arthur is #19, and Freeport is #23, meaning six of the top 25 U.S. ports are in Texas.[7]

Of course, this also means the industrial CO_2 footprint in Texas is large, representing about 23% of national industrial sector emissions and 12% of national power generation sector emissions.[8]

Houston's regional workforce includes nearly 57,000 engineers, making it home to one of the highest concentrations of engineering talent in the nation.[9] Applying that talent to all parts of the energy value chain will be vital to Houston's ability to retain its foothold as a leader in the energy business, no matter how energy transitions unfold. Houston can lead energy transitions by promoting more environmentally responsible natural gas and crude oil production and distribution, low-carbon LNG options, continued expansion of renewables in a fully integrated power market, carbon capture and utilization/sequestration (CCUS) deployment, energy storage options, hydrogen opportunities, and carbon-neutral fuels such as biomethane and biodiesel that can be blended with traditional fuels. Moreover, leading in this manner would have a dramatic impact on CO_2 emissions in the state, thereby impacting national CO_2 emissions. As the virtual center of America's energy ecosystem and the nation's undisputed leader in oil and gas, petrochemicals, and wind-based renewable electricity, Houston is uniquely positioned to become a pioneer of the emerging energy future.

FIGURE 1A — INSTALLED "GREEN" POWER CAPACITY BY STATE AS OF OCTOBER 2020



SOURCE Data sourced from EIA, Preliminary Monthly Electric Generator Inventory (based on Form EIA-860M as a supplement to Form EIA-860).

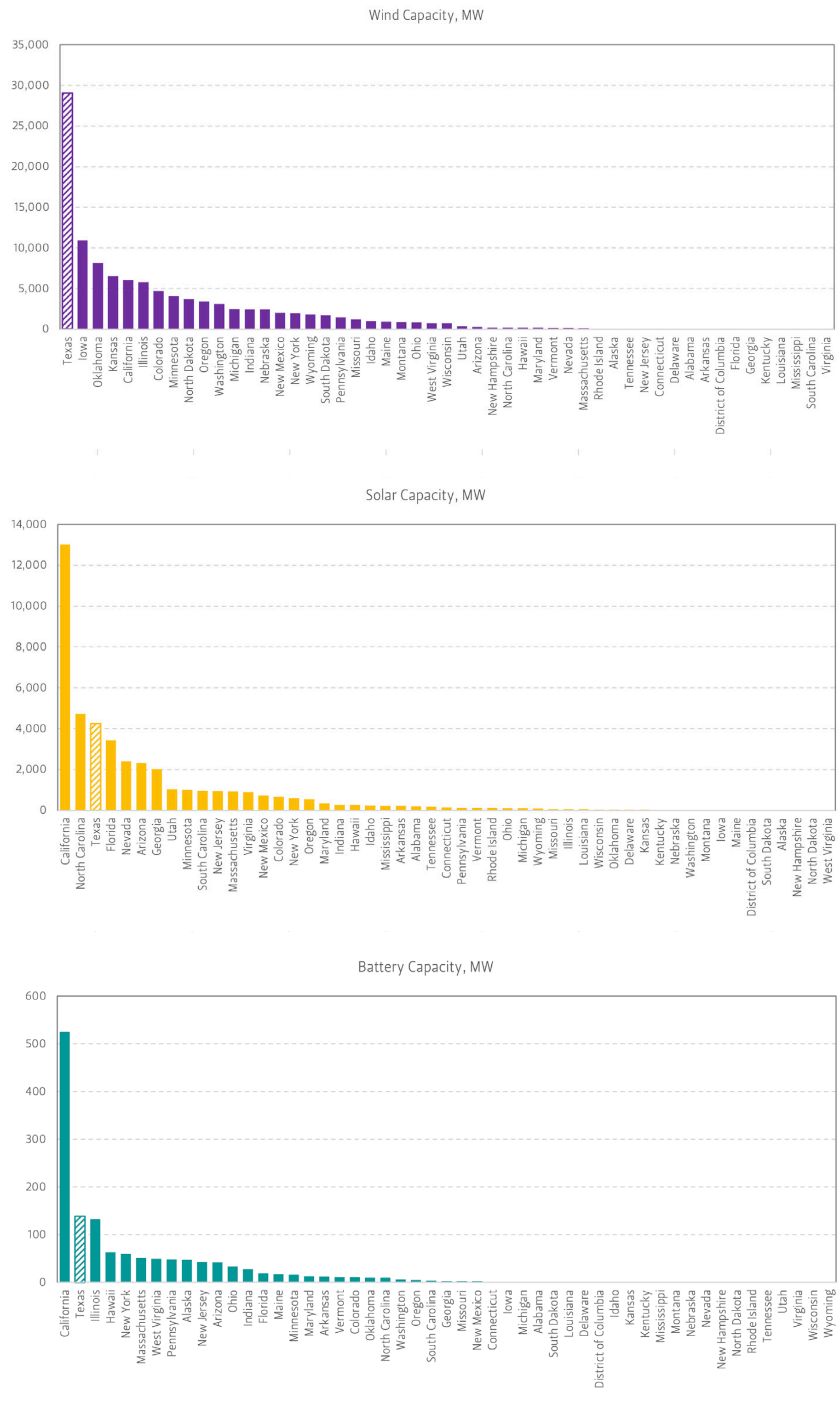
PERCEPTION VS. REALITY AND A ROLE FOR LEADERSHIP

There a few striking facts regarding green energy technology deployment that bear mentioning, and they may run counter to public perception. Texas already has more wind capacity than any other state (more than 26% of the entire U.S., in fact). Texas is home to almost 10% of the nation's installed solar capacity, and 10% of the nation's installed battery capacity. So, Texas currently accounts for 20% of the nation's total non-hydro renewable power capacity, despite the fact that it accounts for only 11% of the nation's total installed generation capacity.[10] This means Texas is ranked #1 in wind capacity, #2 in battery capacity, and #3 in solar capacity among every state in the U.S., which puts Texas at the top of all states in terms of installed green power technology capacity (see Figure 1). Moreover, in terms of planned capacity additions, Texas currently ranks #1 in both wind and solar capacity, and #2 in battery capacity (not pictured).

Nevertheless, Texas is rarely associated with being a leader in renewable energy, even though the data reveal a different truth. It is worth noting that this leadership position in renewable energy capacity has largely occurred without levels of support comparable to other states (i.e., portfolio standards, carbon markets, or carbon intensity provisions). Much of the observed growth in renewables can be attributed to the competitive market structure, the existence of significant natural gas generating capacity to serve as flexible support to counter intermittency, and adequate investment in transmission capacity through the creation of the CREZ (competitive renewable energy zones). This directly highlights a substantial strength of the Texas economy.

In addition, Houston has the 12th largest tech sector in the U.S., with more than 235,000 tech jobs and 8,800 tech-related firms.[11] Altogether, these facts alone should be sufficient attraction for investment and funding for new energy technologies. While green tech is currently a small part of the energy sector, it is growing rapidly. Indeed, the development of Rice University's Ion, a

FIGURE 1B — INSTALLED "GREEN" POWER CAPACITY BY STATE AND TYPE AS OF OCTOBER 2020



SOURCE Data sourced from EIA, Preliminary Monthly Electric Generator Inventory (based on Form EIA-860M as a supplement to Form EIA-860).

$100 million innovation hub, and the entry of Greentown Labs just south of downtown could be a harbinger of things to come.[12] Despite the large and growing footprint of renewable energy and batteries in power generation, energy from fossil fuels maintains the largest footprint in Texas, especially in its large industrial sector. Industrial CO_2 emissions in Texas are largely located near the Houston area. This is where CCUS and hydrogen could play a very important role and have a massive impact, firmly entrenching the region as a leader in low-carbon energy solutions.[13] Houston can use its human capital comparative advantages to lead by example and singlehandedly alter the trajectory of America's industrial emissions footprint. Of course, leading by example only works if policymakers and the general public are aware of the facts and their implications. Public awareness can be substantially elevated if state leaders provide political and economic support for Houston companies, entrepreneurs, and innovators as they transition toward low-carbon energy services, alternative energy technologies, and advanced chemical and industrial processes.

DECARBONIZING THE HYDROCARBON SUPPLY CHAIN

Houston's proximity to major carbon dioxide emissions sources, subsurface sequestration locations, and resident engineering and geological expertise make it a natural leader for next-generation carbon solutions. Indeed, Houston has an important role to play in advancing efforts to decarbonize the hydrocarbon supply chain by taking steps to restrict methane emissions and flaring, promote LNG exports, and advance the development of the CCUS supply chain.

The consensus in much of the OECD world outside of Texas is that controlling CO_2 emissions means severe restrictions and outright reductions. Less attention has been given to a future of carbon neutrality where consumers can continue to access thermodynamically (and economically) advantaged oil and gas-derived fuel sources, but where the sector also incorporates CCUS technologies, perhaps even including "carbon-to-value" technologies, to offset existing emissions and reach a point of net rollback in atmospheric CO_2 levels one day. This is key to making traditional fuels cleaner while leveraging existing legacy infrastructures, thus supporting the world's twin goals of universal energy access and environmental sustainability.

Reduce Methane Emissions and Flaring

Restricting methane emissions and eliminating routine flaring is an important step toward decarbonizing the oil value chain while, at the same time, adding low-carbon natural gas supplies to the energy mix. The International Energy Agency (IEA) has stated that "even with an over-supplied gas market, reducing methane emissions from oil and gas operations is amongst the lowest of low-hanging fruit for mitigating climate change."[14] The Environmental Defense Fund is already working with oil companies to reduce emissions, and several aerial survey initiatives and satellite monitoring efforts are tracking methane emissions in places such as the Permian Basin. So transparency, it seems, is emerging in the upstream sector. The Oil and Gas Climate Initiative (OGCI) has announced a collective average methane intensity target as a share of marketed natural gas of 0.25% by 2025, which applies globally.[15] This target, if achieved, will amount to an estimated 350,000-ton reduction per year in the total upstream methane emissions of all operated gas and oil assets across all OGCI member companies since 2017.[16] In Texas, the Texas Oil and Gas Association (TXOGA) and other members of the Texas Methane & Flaring Coalition have announced a commitment to end routine flaring.[17]

Reducing methane emissions and eliminating routine flaring in the Permian Basin will be critical for the ability of Texas oil and gas producers to market their production, and organizations such as TXOGA and the Greater Houston Partnership can play a pivotal role in advocating for stricter regulation, transparency, and enforcement. It is worth noting that flaring is an oil production activity, and venting can occur when flares are unlit. Flaring and venting has been a noted and well-publicized issue affecting the Permian Basin. So reduction of flaring is an important step to reducing the environmental footprint of oil-directed upstream activity, especially in regions like the Permian Basin. Of course, flaring and venting is not a practice deployed during gas-directed upstream activities. Nevertheless, U.S. LNG exports have been undermined by the extent of flaring and venting activity in the Texas upstream. Thus, reductions in flaring and venting would not only lower GHG emissions in Texas, they would also support LNG exports. In turn, this could promote greater use of natural gas over coal abroad, thereby allowing a Texas export to materially impact CO_2 emissions in foreign markets.

LNG Exports

When gas supply is increased by adding associated gas volumes that otherwise would have been flared, the opportunities for expanding natural gas exports increase. European energy buyers in France, Germany, and Ireland have recently pulled back from supporting the import of LNG from Texas because of their concerns about flaring, particularly in the Permian, and uncapped methane emissions. European consumers represent approximately half of worldwide consumption of internationally traded natural gas.[18] Whether or not the actions taken by potential buyers have a direct impact on the emissions footprint of marketed natural gas produced in Texas, their message is clear. Houston-area companies can enhance the marketability of their energy exports by reducing their own GHG footprints. Such steps could include supporting the World Bank's Zero Routine Flaring by 2030 Initiative and supporting reasonable, technically feasible restrictions on methane emissions.

Engineered and Nature-based Carbon Reduction Solutions

CCUS is a key element of any realistic portfolio of solutions for achieving net-zero emissions. It represents an engineering-focused solution to decarbonization that relies on tremendous technological depth, a strong knowledge of geology and the subsurface, and the ability to leverage economies of scale in the capture phase. As such, Houston is in a strong position with regard to CCUS, and has a distinct comparative advantage in the advancement of CCUS technologies.[19]

Similarly, the are decarbonization solutions that leverage nature's carbon removal technology: photosynthesis. So-called "natural solutions" require large swaths of land that can be managed in different ways to maximize their carbon removal potential.[20] Texas has a significant endowment of prairie, agricultural and timber lands, thus placing it in a prime position to expand potential nature-based solutions.

Clear and sustained commitment from regulators and elected officials to resolve legal and regulatory uncertainties and provide supportive commercial frameworks will determine the extent to which Texas will capture a leadership position in both engineered and natural carbon reduction solutions.

In terms of planned capacity additions, Texas currently ranks #1 in both wind and solar capacity, and #2 in battery capacity.

ADVANCING ALTERNATIVE ENERGY TECHNOLOGIES

There is ample precedent for the role of policy in accelerating new energy value chains. Given the importance of hydrocarbons to Houston's economy, strong policy and commercial frameworks to support the development and advancement of new combustion processes, expanded uses of hydrogen produced from hydrocarbon feedstocks, next-generation biofuels, and low-carbon feedstock solutions in industrial processes and power generation will help to secure Houston's role as an alternative energy technology leader in the future.

Advancing the Hydrogen Economy

"Grey" hydrogen is either produced via steam methane reformers (SMR) that use natural gas as a feedstock, or else it is obtained as a by-product of other chemical processes. In 2019, the net hydrogen demand at Texas Gulf Coast refineries totaled 68 thousand barrels per day (kbd)—roughly one third of the U.S. total.[21]

The hydrogen solution today faces constraints that demand dedicated R&D efforts, which is an area where Houston has a potentially transformative role to play.

In 2020, the "grey" hydrogen production capacity of Texas refineries totaled an estimated 291 million cubic feet per day (mmcfd), the majority of which was located in the Texas Gulf Coast.[22]

Industrial gas producers, in particular, are well-positioned to supply refineries with by-product hydrogen from nearby chemical plants. Houston is home to more than 44% of total base petrochemical manufacturing capacity in the U.S.,[23] and these "merchant suppliers" can take advantage of the growing network of hydrogen gas pipelines located in the Gulf Coast. Leveraging the expertise in the chemical and conversion industries that exist in Houston can enable the advancement of a hydrogen economy that moves toward cleaner, less carbon-intensive forms of hydrogen.

Hydrogen classified as either "green" (produced from water using wind and solar power), or "blue" (produced from natural gas with much of the carbon removed through CCUS) has substantially lower carbon content than most other fuels. "Turquoise" hydrogen—which, like "blue" and "green" forms of hydrogen, circumvents the problem of atmospheric CO_2 emissions—is an area of opportunity for Houston and Texas more generally. Unconventional processes that eliminate the production of CO_2 entirely, such as the direct conversion of methane in natural gas to hydrogen and value-added carbon materials such as carbon nanotubes or CNTs (i.e., methane pyrolysis), have gained traction among major oil and gas companies. "Yellow" hydrogen is produced as a result of biomass conversion with CO_2 capture.

Hydrogen can be used either on its own or as a "drop-in fuel" that can be blended with natural gas to lower the carbon content of the natural gas. SoCalGas has recently announced plans to blend hydrogen with its natural gas, with up to 20% of the gas stream consisting of hydrogen. Natural gas producers and pipeline companies based in the Houston area can step in and lead this transition. Hydrogen can be exported blended with natural gas in an LNG cargo, or together with ammonia, another cooled liquid.

Some railways including Canadian Pacific are already testing hydrogen as a fuel for locomotives. The U.S. Gulf Coast, and the Houston Ship Channel area in particular, are replete with facilities for liquefying, storing, and loading gases onto vessels, though siting and financing new hydrogen interstate and export facilities would benefit from clarification of licensing and regulatory authority. Houston and its surroundings also hold advantageous physical assets, starting with the huge pipeline network and prolific access to geological storage, which bodes well for carbon sequestration and hydrogen transport.

Green hydrogen at utility scale requires access to vast supplies of renewable electricity and the infrastructure to transport the gas itself. As a national leader in renewables and gas pipelines, Houston has access to both and a competitive advantage in creating a new paradigm in energy storage and transport. The hydrogen solution today faces constraints that demand dedicated R&D efforts, which is an area where Houston has a potentially transformative role to play.

Next-Generation Biofuels

Houston's human and capital infrastructure bases for producing liquid fuels and getting them to markets worldwide at competitive cost are world-class. Much of this "installed base" positions the city well for leading in next generation biofuels—and potentially, also the development of hydrogen-oriented energy supply activities.

Sustainable aviation fuel is already being produced from waste and residues. Much of the feedstock comes from the U.S., but the refining is done in Singapore. Converting refining capacity from fossil to biofuel in the Houston area makes sense. Additionally, renewable diesel from plant and animal oils has huge potential in the trucking and rail industries as a blend stock for existing fuels.

Biodiesel fuels can be produced from biomass, and can be blended with other fuels for transportation and heating. By using feedstock that would otherwise be wasted, both biomethane and biodiesel lower the net carbon content of the fuels with which they are blended. In the U.S., biodiesel is derived mainly from soybean oil and has a composition different than diesel fuel.

Another example is incorporating in natural gas streams biomethane (or renewable gas) from organic waste or landfills. The feedstock is fed into an anaerobic digestion reactor that produces biogas, which is then upgraded to biomethane and can be injected into the natural gas grid. SoCalGas has announced plans to deliver renewable gas as 5% of its natural gas stream in 2022, increasing to 30% by 2030. Houston-based energy companies could do likewise.

Process Emissions: Low-Carbon Feedstock Solutions

In parallel, Houston should position itself as a center for research into synthetic liquid fuels and use of nuclear energy to produce such fuels as inputs to the chemical industry. The chemical and the refining sectors, in particular, could see significant reductions in process emissions through the use of biomethanol, bioethanol, nuclear, and hydrogen-based feedstocks during chemical production. Process emissions in the industrial sector result from the chemical transformation of materials or feedstocks, and are among the most difficult to abate. Switching to a low-carbon feedstock—either biomass or hydrogen-based—can substantially alter the process emissions profiles of key industrial sectors.

ELECTRICITY MARKET DESIGN AND TECHNOLOGIES

The Texas electricity market was transformed through Senate Bill 7 more than 20 years ago. The resulting competitive market landscape coupled with public infrastructure support has engendered significant opportunities for new energy technologies, and transformed the Texas grid. Houston is home to much of the underlying activity, with firms such as Sunnova and EDP Renewables managing a sizeable presence. As such, Houston is poised to play a significant role in advancing new technologies in the power market.

Development of Advanced Nuclear Technologies

Nuclear energy offers a major advantage for any decarbonization strategy due to its high energy density. Moreover, nuclear offers opportunities to complement energy storage options at a relatively low cost.[24] But new large-scale nuclear power plants are expensive to build and existing plants present proliferation and waste disposal risks. Developments in nuclear technology may offer a variety of possible solutions by lowering costs, increasing safety (e.g., through passive control), and eliminating waste (including plutonium by-products). Cutting-edge nuclear research is notably absent in Houston today, despite the nearby South Texas nuclear project and the employment opportunities that nuclear technology could afford in port and medical applications.

Some of the most promising technological development opportunities include small-scale modular nuclear technology, thorium-based reactors, ITER or other (private) controlled hydrogen fusion efforts, fusion of boron or other elements higher up the periodic table, and laser separation of isotopes. Among the firms looking at smal-scale reactors, molten-salt reactors, thorium reactors, or different types of fusion, none have any presence in Houston. This could present a serious threat to Houston's energy leadership if such technologies take off.

Renewable Generation and Energy Storage

With an electricity transmission network that already leads the nation in wind-powered generation, Texas can leverage its dominant position in wind. Texas wind turbines have steadily increased production over the last two decades, and in 2020 surpassed coal generation.[25] In fact, the abundance of low-cost natural gas and substantial natural gas-fired generation capacity to serve as a flexible, competitive power generation market has supported the growth of renewable generation without compromising grid stability. Indeed, building on critical features of the region that already exist—the strength of electricity aggregators

Managing supply chains, handling materials, and deep expertise in chemistry and engineering are all skillsets that drive the oil and gas industry, and they form the basis of Houston's comparative advantage. All are transferable, and will remain important for the development and delivery of all energy services.

and distributors well-versed in the logistics and scheduling challenges of the sector and a port (Port of Houston) that is already integral for the wind industry—Houston is primed to take the lead in areas, such as batteries and advanced materials, that are deemed important for even greater expansion of renewables.

In general, battery development/deployment is an energy storage challenge involving engineering, chemistry, logistics and supply chain management. Expanding the energy storage context to include hydrogen opens additional pathways that could leverage existing infrastructure and know-how. Hydrogen, regardless of how it is produced, can be stored and used as needed to help address the intermittency challenges inherent in renewable power generation. As long as the stored hydrogen is accessible to the grid, it does not need to be co-located with renewable assets. Hence, energy storage assets can be deployed to balance grid demands as needed.

ADVANCED CARBON-BASED MATERIALS

Hydrogen production from methane pyrolysis results in solid carbon by-product that is a substitute for carbon black. Enhancing the value proposition for this carbon by-product as an intermediate input into advanced materials improves the commercial prospects for hydrogen by supporting a range of "carbon-to-value" possibilities. At present, the carbon to-value opportunities are largely limited to substitution for carbon black. But the market for carbon black is currently limited to a handful of uses, such as an additive in rubber for tires, paints, and in select chemical processes. Therefore, if methane pyrolysis is to expand, there will be accompanying logistical and commercial considerations regarding the transport, storage, and use of solid carbon.

One area of potential promise that has gained traction among researchers involves the production of high value-added carbon materials based on carbon nanotubes (CNTs). CNTs, a family of carbon-based hollow cylindrical structures, have distinctive electrical, thermal, and mechanical properties that hold promise in advancing leadership in innovative materials, energy, and environment. CNTs are critical components to future decarbonization strategies. With Houston serving as the headquarters and the intellectual capital for virtually every segment of the energy industry including exploration, production, transmission, marketing, supply, and technology, CNT advancements present an opportunity for Houston to break new ground in the global economic, energy, environment, and geopolitical arenas and in building a stronger, more resilient nation. By fostering and cultivating research hubs to advance CNT development, Houston can establish itself as a trailblazer in the field of nanotechnology.

Along this pathway, due consideration must be paid to addressing and ensuring their safe manufacturing, handling, use, transportation, and disposal. Taking these steps creates untapped opportunities to advance a world-class research portfolio, expedite commercialization of nanotechnology-enabled applications, support a dynamic and skilled workforce, and ensure responsible development from lab to market.

CIRCULAR ECONOMY: LIFE-CYCLE OBLIGATIONS, PLASTICS, AND CHEMICALS

There is a growing awareness that circularity can lead to sustainability. The innovations and scientific advancements required for the clean energy revolution all come with social, economic, and environmental impacts that arise throughout a product's life cycle. Yet the ESG impacts of new energy technologies and related innovations from cradle to grave and across global supply chains are too often ignored, seldom quantified and rarely understood in their entirety. Take some of the most common examples: import-reliant minerals that are mined, processed, smelted, and traded overseas in countries with weak governance institutions or environment, health, safety, and labor laws; obscure trading and waste disposal practices; underdeveloped or nonexistent waste management technologies at the end-of-life; or transportation between each segment of this complex global supply chain network that supports renewable and low-carbon energy technologies. If Houston wants to lead the energy transition and retain global energy leadership, sustainability and environmental stewardship should assume its rightful place at the top of corporate priorities.

With global demand for plastics projected to triple by 2050, the overall contribution of plastics waste to this supply chain must change dramatically. The recycling and petrochemical industries can play an important role in improving waste management, enhancing sustainability, and transitioning to a circular economy by converting polymeric waste into virgin-grade feedstock that can then be used to produce new materials and chemicals of virgin-grade quality. Chemical recycling transforms polymers back into their original monomers and purifies them for repolymerization to make new materials and other valuable liquids such as lubricants or fuels. Research is needed in this area to help shepherd advanced chemical recycling toward successful commercialization.

Texas is the largest chemical-producing state, generating $172 billion in annual revenue.[26] Houston is a global leader in manufacturing petrochemicals, with the Houston Ship Channel recognized as the largest petrochemical complex in the U.S. Houston alone accounts for nearly half of the nation's base petrochemical capacity.[27] The critical mass created by such a high concentration of companies and thought leaders in one geographic area yields opportunities for all sectors of the energy industry to adopt transformational and disruptive chemical recycling technologies. Houston has a real and pressing opportunity to lead the way in plastics sustainability and to become the world leader in producing circular polymers from recycled-mixed-waste plastics.

CONCLUDING REMARKS

Houston is widely known as the energy capital of the world. This has manifested from its dominant position in oil and gas, but the moniker is actually derived from the skillsets and expertise that make up the region's workforce. With the Port of Houston consistently ranked the nation's largest for waterborne tonnage, foreign imports, and vessel transits, Houston has earned its stripes as a global epicenter for logistics and complex supply chain operations. Managing supply chains, handling materials, and deep expertise in chemistry and engineering are all skillsets that drive the oil and gas industry, and they form the basis of Houston's comparative advantage. All are transferable, and will remain important for the development and delivery of all energy services.

Will Houston flex with a transitioning energy system? First, it must be recognized that energy always transitions, and there is no single dimension that characterizes how things will unfold. The energy world looks very different today than it did 30 years ago (in 1990), and it looked far more different 30 years prior to that (in 1960). It will look different 30 years from now (in 2050). In the past, Houston has flexed successfully to meet the changing energy landscape, and there is no reason to believe that Houston cannot successfully rise to future challenges. Houston has the talent pool, the tax advantages, and the business-friendly environment to lead in energy transitions. Thousands of energy-related firms are located within the Houston metro area, including a third of the country's 25 largest oil & gas E&Ps, two-thirds of the world's global integrated oil companies, a fifth of the world's national oil companies, two-thirds of the country's largest pipeline operators, and more than four-fifths of the nation's largest gas transmission companies.[28] Moreover, despite factors that make other states (such as California) desirable for the high-tech industry, the decision by companies such as Tesla, Oracle, and Hewlett Packard to join Dell in Texas is a signal of the attractive business environment in Texas. Houston is well-positioned to pioneer the continuing evolution of the global energy system.

ENDNOTES

1. U.S. Bureau of Economic Analysis (BEA), GDP by State, https://www.bea.gov/data/gdp/gdp-state.

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7. Data from U.S. Department of Transportation, Bureau of Transportation Statistics, Tonnage of Top 50 U.S. Water Ports, Ranked by Total Tons, https://www.bts.gov/content/tonnage-top-50-us-water-ports-ranked-total-tons. Port rankings are typically done in two ways: (1) Container traffic (measured as TEUs – or Twenty Foot Equivalent Units) and (2) gross tonnage. Shanghai is #1 in both, but the Shanghai port is also expansive, covering 3619.9 square km, which is more than an order of magnitude larger than the area of all Texas ports combined. The total tonnage moved through all Texas ports is about 614 million tons, which puts the region on par with Shanghai. The Port of Houston alone is 285 million short tons.

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