UNITED STATES SENATE: COMMITTEE ON ENERGY AND NATURAL RESOURCES

APRIL 22, 2021

HEARING ON: OPPORTUNITIES AND CHALLENGES THAT EXIST FOR ADVANCING AND DEPLOYING CARBON AND CARBON-DIOXIDE (CO_2) UTILIZATION TECHNOLOGIES IN THE UNITED STATES

WRITTEN TESTIMONY:

GAURAV N. SANT, PH.D.

PROFESSOR AND HENRY SAMUELI FELLOW: DEPARTMENTS OF CIVIL AND ENVIRONMENTAL ENGINEERING, MATERIALS SCIENCE AND ENGINEERING, AND THE CALIFORNIA NANOSYSTEMS INSTITUTE; AND, FACULTY DIRECTOR: INSTITUTE FOR CARBON MANAGEMENT
UNIVERSITY OF CALIFORNIA, LOS ANGELES (UCLA)

FOUNDER AND CTO: CARBONBUILT, INC.

INTRODUCTION: Thank you, Chairman Manchin, Ranking Member Barrasso and Members of the Committee, for inviting me to appear before you as you review and examine pathways for carbon dioxide (CO_2) utilization. I would like to start by emphasizing that the views expressed herein are my own.

As requested by the committee, I will focus the first part of my testimony on the need for carbon dioxide utilization. While not a direct solution to climate change in and of itself, carbon dioxide utilization will play a significant role in mitigating emissions from industry and other emissions-intensive sectors. Second, I will highlight pioneering research underway at UCLA's Institute for Carbon Management[1] that seeks to enable large-scale and cost-effective direct utilization (and removal) of carbon dioxide emissions, and thus accelerate our transition to a low-carbon world. In this regard, I focus particularly on the NRG COSIA Carbon XPRIZE-winning Reversa™ technology. This technology that transforms carbon dioxide-into-concrete was recently demonstrated at world-class test-centers in Wyoming and Alabama. Finally, I will elaborate on the support mechanisms that are needed to catalyze and accelerate the deployment of low-carbon technologies in the U.S. and around the world.

As background, I am a professor and Henry Samueli Fellow in the Samueli School of Engineering at the University of California, Los Angeles (UCLA), where I am the Director of our Institute for Carbon Management[1]. I am a civil engineer and a materials scientist by training, with broad competencies in materials synthesis, characterization and processing with special expertise in the materials of modern construction including cement, concrete, steel, glass and ceramics[2]. I am also the Founder and Chief Technology Officer of CarbonBuilt, an early-stage company which is commercializing the pioneering carbon dioxide-to-concrete technology developed at UCLA. Earlier this week, CarbonBuilt was announced as a Grand Prize winner in the NRG COSIA Carbon XPRIZE global competition.

In the testimony that follows, I will elaborate on the multiplicity of actions that are needed to advance and deploy CO_2 utilization (and more broadly, carbon management) technologies in the United States, including:

---

[1] Institute for Carbon Management. UCLA ICM http://icm.ucla.edu/ (accessed April 17, 2021).
[2] Gaurav N. Sant. Google Scholar Profile https://scholar.google.com/citations?user=p_kytiYAAAAJ&hl=en&oi=ao (accessed April 17, 2021).

1) Expanded investments in research, development and demonstration of carbon dioxide management (e.g., including carbon-utilization, -removal, and -sequestration) technologies,
2) Explicit and flexible financial incentives to promote expedient industrial transformations, and
3) Strategic procurement actions which put cost and embodied carbon intensity of materials and products on an equal footing in federal procurement and purchasing decisions.

MOTIVATION: Industrial operations which result in the production of cement, concrete, liquid fuels, chemicals, steel, glass and other such materials, are foundational to the world that we live in. As the sources of materials that make up the automobiles that we drive, the buildings that we live and work in, and even the smart screens of our personal handheld devices, these operations affect and improve the quality of each of our lives, while contributing to the continuous development of our society. While foundational to our world, industrial activities are also a potent contributor to ongoing CO_2 emissions and atmospheric accumulations.

Industrial decarbonization is prerequisite to mitigating the ongoing accumulation and release of CO_2 into the atmosphere [N.B.: anthropogenic CO_2 emissions globally distribute in approximately equal thirds among heavy industry, transportation and the built environment]. However, such decarbonization on account of both being technically challenging and our societal dependence on these industries, needs to be implemented without disrupting the material contributions of these sectors to our way of life, or our cost- or standard-of-living. To meet these challenges, CO_2 utilization is expected to be the catalyst, and in other cases perhaps the only approach for achieving cost-effective decarbonization in the near-term. Therefore, it is important to stage, support and incentivize the deployment of CO_2 utilization technologies to help industry to transition from being a valuable contributor, but also a major CO_2 emitter, to only a valuable contributor (to society, and to our way or life) by 2050; if not sooner.

Compared to power generation and transportation, where the rapid worldwide deployment of renewable energy generation and storage assets is enabling emissions reductions, the decarbonization of heavy industry, which constitutes over a third of total emissions[3], is proceeding at a much slower rate. As a result, industry operations are emitting, and will continue to emit, substantial amounts of carbon dioxide into the atmosphere on account of their processing energy demands and the nature of chemical separations, modifications and transformations that they carry out. For context, chemical production, the production of ordinary Portland cement (OPC), and iron and steel production result in the emission of around 5 %[4], 10 %[4], and 9 %[4] of anthropogenic carbon dioxide emissions, respectively.

Heavy industry's reliance on fossil fuels is based on its need for high temperatures, high energy density[5], and/or predictable and continuous power[6] — requirements that cannot be met by renewable energy. While energy storage would help to address the latter issues, its substantial cost remains a significant barrier to adoption. Furthermore, in processes such as oil refining, cement production and others, feedstocks are broken down into simpler components before being re-composed into more chemically, and commercially desirable products such as gasoline and OPC. As a result, in such operations, a majority of the carbon burden is associated with the chemical route that is required/used. For example, in the case of OPC production[7] the thermal decomposition of limestone ($CaCO_3$) and the

[3] International Energy Agency. CO_2 Emissions Statistics https://www.iea.org/subscribe-to-data-services/co2-emissions-statistics/ (accessed April 17, 2021).
[4] International Energy Agency. Tracking Clean Energy Progress: Industry https://www.iea.org/topics/tracking-clean-energy-progress/ (accessed April 17, 2021).
[5] de Pee, A.; Pinner, D.; Roelofsen, O.; Somers, K.; Speelman, E.; Witteveen, M. *Decarbonization of Industrial Sectors: The Next Frontier*; McKinsey & Company, 2018; p 63.
[6] International Energy Agency; Cement Sustainability Initiative. *Technology Roadmap: Low-Carbon Transition in the Cement Industry*; World Business Council for Sustainable Development, 2018; p 66
[7] The production of ordinary portland cement (OPC) – the primary binding agent used in traditional concrete – accounts for nearly 9% of global CO_2 emissions with 0.9 t of CO_2 being emitted per ton of OPC produced. Therefore, the development of new cementation agents that take-up CO_2 is critical to reduce the CO_2 emissions associated with cement/concrete production,

associated release of CO_2 (~65% of CO_2 emissions) is a far more significant contributor to emissions of the process than the combustion of fossil-fuels to heat the cement kiln (~35% of CO_2 emissions)[8].

Construction of industrial manufacturing facilities requires substantial capital expenditures and demands long capital-amortization periods. Since new capital investments may be difficult to justify in the absence of proven profitability, or the need to ensure regulatory compliance, it is critical that CO_2 utilization technologies readily integrate with existing processes, are energy efficient, and are subjected to transparent and time-bound permitting processes, if needed. Beyond the financial considerations, these additional issues are important to consider in terms of what is needed to accelerate the deployment of CO_2 utilization technologies.

DECARBONIZING HEAVY INDUSTRY AND THE BUILT ENVIRONMENT: Industrial decarbonization often implies carbon capture and storage (CCS)[9]. While CCS is expected to remain our primary path to address carbon dioxide emissions because of the potential scale it offers, its implementation is challenged by: (i) the high cost of capturing and concentrating carbon dioxide from flue gas streams, (ii) the potential uncertainty associated with the permanence of sequestration, (iii) the lack of reservoirs near current sources of carbon dioxide emissions, (iv) the absence, and cost of pipelines to transport carbon dioxide from sources to viable reservoirs**Error! Bookmark not defined.**, [10], [11], and (iv) a lack of a clear liability-release or -cap, in jurisdictions where Sovereign guarantees have not been offered, that would limit the liability of project developers in the event of unexpected carbon dioxide release. This is especially relevant for the low-margin industrial sector, which is not well-equipped, financially or otherwise, to implement capital intensive transformations in an accelerated manner.

In contrast, carbon dioxide utilization can play an important, and immediate role in mitigating emissions, albeit in part, because of the absolute amount of CO_2 (on the order of a few gigatonnes) that could be utilized[12]. This is because the sale of products made using CO_2 has the potential to produce revenue, and conceivably yield a profit unlike typical carbon management solutions which imply an increase in cost, and hence reduction in profit. Timely action to mitigate the effects of climate change requires the rapid deployment of technologies for carbon dioxide utilization. The deployment of such technologies, like many nascent industries, will initially require government support to facilitate first-of-a-kind, commercial-scale demonstration projects that will inform our learning curves, demonstrate the commercial value-proposition, drive cost-reductions, and thus hasten follow-on deployments and adoption. Today, support for such demonstration projects, e.g., via grant-making mechanisms, is unfortunately very limited; but it is absolutely necessary. Industry has little ability to deploy unproven technologies at scale due to uncertainty in revenue and profit, substantial regulatory and compliance burdens, and the very high costs associated with emplacing greenfield facilities with long operating horizons. Therefore, it is necessary for the government to help mature, and de-risk technologies at large-enough scales to help heavy industry to reduce their carbon emissions (i.e., the embodied carbon intensity: eCI) of their products and processes. Combined with streamlined permitting processes, industry is expected to adopt change once they are assured of the commercial viability and scalability of new technologies. This will facilitate and simplify the market penetration, and widespread adoption of novel CO_2 utilization technologies.

---

[8] International Energy Agency; Cement Sustainability Initiative. *Technology Roadmap: Low-Carbon Transition in the Cement Industry*; World Business Council for Sustainable Development, 2018; p 66.

[9] In traditional carbon capture and storage (CCS), CO_2 emitted from industrial processes or from the combustion of fossil fuels is first concentrated to >95 % purity, following which it is transported by pipelines to locations that it can be geologically disposed, e.g., in hydrocarbon depleted reservoirs, saline aquifers, etc.

[10] Kulichenko, N.; Ereira, E. *Carbon Capture and Storage in Developing Countries: A Perspective on Barriers to Deployment*; Energy and Mining Sector Board Discussion Paper, No. 25; World Bank Publications, 2012.

[11] Bachu, S. *Energ. Convers. Manage.* **2000**, *41* (9), 953–970.

Furthermore, it is critical that the government greatly and systematically expand and harmonize basic and applied research, development and demonstration (RD&D) funding — within a unified framework instead of across disconnected programs and agencies (e.g., recent reports developed by the National Academies[12],[13]). With the ability to accept both successes and failure, harmonized support is needed to develop new technologies, and to scale-up and scale-out existing technologies for carbon emissions mitigation — the need for which becomes ever more significant with the passage of time[14]. Major programs for the development, de-risking and deployment of CCUS (carbon capture, utilization, and storage) technologies supported by the Departments of Energy, Defense, Transportation, Housing and Urban Development, and the National Science Foundation are critical in this regard. Such support is needed to: (a) maintain and expand the U.S.'s intellectual leadership in carbon management, (b) ensure that U.S. corporations, big and small, are able to diffuse and monetize their spirit of creativity, innovation and societal welfare globally, (c) ensure that U.S. corporations are able to diminish the carbon-intensity of their operations, thereby enabling them to operate – without constraint – across global jurisdictions in a low-carbon world, and (d) ensure that the U.S.'s deep intellectual reservoir housed within its universities, national laboratories and corporate R&D organizations continues to train, sustain, support and grow the talented scientists, engineers and subject matter experts that have ensured the U.S.'s global technological leadership and spirit of innovation over the last century.

Comprehensive actions to reduce CO_2 emissions from industry will require capital spending — by governments and corporations. For corporations however, a commitment to making capital expenditures, requires policy- and regulatory-certainty. Our current state of regulatory (and policy) uncertainty hinders our collective capability to limit the emissions of CO_2 into the atmosphere. The reasoning is simple: first, corporations which are required to create value for shareholders are only going to make decisions that ensure a competitive advantage in the marketplace in order to enhance shareholder value. Therefore, unless CO_2 emissions are constrained, penalized, or reductions thereof incentivized (e.g., via tax-credit, grant-, or cash-payment programs or a carbon emissions cap[15]; a penalty on unbounded excess; and/or limits on the embodied CO_2 footprint of manufactured products); there exists no driver, regulatory-, or compliance-based to make capital investments that would reduce carbon emissions. While consumer demand and investor pressures are forcing companies to make emissions reduction (and carbon-neutrality) pledges, often these pledges are a target rather than a binding commitment. To address this inertia, government purchasing decisions that prefer low-carbon products can catalyze market demand, especially for concrete, steel and other construction materials for which public entities are major purchasers. Such low-carbon procurement ("Buy-Clean") actions should be implemented promptly to affect supply chains both upstream and downstream, from the points of raw material procurement and manufacturing to the point of consumption.

All of us, i.e., society in general, are consumers of the products that industry manufactures. As such, an important aspect of carbon management involves affecting consumer choices, selections and awareness regarding the products that we seek to consume. As evidenced by our implementations of building energy-efficiency programs, this requires us to develop a national basis of measuring, affecting and incentivizing carbon-efficiency, and lowering carbon-intensity and -footprint via robust, progressive and transparent methods of data reporting and analysis, e.g., within national and sub-national databases. Why? Small, although quantifiable changes made by and demanded by 330 million consumers in the U.S. and 7 billion consumers globally could result in vast emissions reductions that are motivated by a combination of "industry-push" and "market-pull." Therefore, data disclosure and reporting initiated by

---

[12] National Academies of Sciences, Engineering, and Medicine. *Gaseous Carbon Waste Streams Utilization: Status and Research Needs*; The National Academies Press: Washington, DC, 2018; p 254.
[13] National Research Council. *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration*; The National Academies Press: Washington, DC, 2015; p 154.
[14] Mercator Research Institute on Global Commons and Climate Change (MCC). Remaining carbon budget https://www.mcc-berlin.net/en/research/co2-budget.html (accessed April 17, 2021).
[15] Nunez, F.; Pavley, F. *Assembly Bill 32 - California Global Warming Solutions Act of 2006*; 2006.

governments that creates consumer awareness is foundational to effecting broad-based industrial transformations, i.e., a market-driven basis of change. At this point, it should be highlighted that low-carbon products and construction materials can particularly play a major role in the American Jobs Plan, which heavily focuses on the built environment and U.S. infrastructure. For this reason, a federal "Buy Clean" procurement policy focused on reducing the embodied carbon footprint of our buildings and infrastructure would be catalytic in creating market demand for low-carbon concrete and construction materials, in general.

It is particularly important to highlight that issues related to carbon management are based on the premise of ensuring societal good. This is an outcome in which, the government, more than any other actor has a vested interest. Therefore, it is necessary that governments take the foremost actions. In this regard, the U.S. plays a special role in the international arena. This is because over the last century, the U.S. has come to be regarded as the bellwether for the world; such that actions implemented by the U.S. are examined closely and often followed by other governments. Of interest, the U.S. contributes nearly 15 % of global CO_2 emissions, while hosting only 5 % of the world's population[16]. For reasons of leading by example, it is essential that we place an emphasis on robustly maximizing our carbon efficiency, and in turn, diminishing our CO_2 emissions.

UTILIZATION – TURNING CARBON DIOXIDE INTO CONCRETE: Earlier this week, the UCLA CarbonBuilt team was selected as one of two Grand Prize winners of the NRG COSIA Carbon XPRIZE. This accomplishment, the first XPRIZE won by a university team, is a testament to: 1) the talent hosted within, and the spirit of innovation that is foundational to, U.S. universities, 2) the sustained support of our sponsors and partners, and 3) the potential of the concrete construction sector to serve as an enormous sink for carbon dioxide emissions. While multiple pathways exist for transforming carbon dioxide into products such as plastics, fuels, chemicals, concrete emerges as the foremost choice on account of both its large market size which translates into an enormous capacity to serve as a permanent carbon dioxide "sink" and the simplicity of the chemical conversion, or "mineralization", of carbon dioxide into concrete.

Even before the start of the NRG COSIA Carbon XPRIZE competition, our research at UCLA has been focused on developing cost-effective technologies that can directly transform dilute-state CO_2 (as borne in the flue gases of cement plants, power plants, etc.) into construction materials and products. Now being commercialized by CarbonBuilt Inc., a company spun out of UCLA, the Reversa™ technology avoids the need for "carbon capture" step, resulting in the lowest-cost pathway for scalable CO_2 utilization, while creating construction materials that are cost-, performance and function-equivalent to traditional concrete. Significantly, CarbonBuilt's solution produces concrete materials and products with an embodied carbon intensity (eCI) that is up to 75 % lower than the incumbents[17],[18],[19],[20],[21]. Furthermore, the low-carbon concrete products produced using CarbonBuilt's Reversa™ process are compliant with existing construction codes and standards and so are immediately suitable for use in construction projects. At this time, the Eastern Shoshone Tribe of the Wind River Reservation in Wyoming, and UCLA, among others, are in the midst of using CarbonBuilt's concrete masonry units in their construction projects.

---

[16] Our World in Data. CO_2 emissions per capita vs GDP per capita https://ourworldindata.org/grapher/co-emissions-per-capita-vs-gdp-per-capita-international- (accessed April 17, 2021).
[17] Vance, K.; Falzone, G.; Pignatelli, I.; Bauchy, M.; Balonis, M.; Sant, G. *Ind. Eng. Chem. Res.* **2015**, *54* (36), 8908–8918.
[18] Wei, Z.; Wang, B.; Falzone, G.; La Plante, E. C.; Okoronkwo, M. U.; She, Z.; Oey, T.; Balonis, M.; Neithalath, N.; Pilon, L.; et al. *J. CO_2 Util.* **2018**, *23*, 117–127.
[19] Mehdipour, I.; Falzone, G.; La Plante, E. C.; Simonetti, D.; Neithalath, N.; Sant, G. *ACS Sustain. Chem. Eng.* **2019**, *7* (15), 13053–13061.
[20] CarbonBuilt Inc.: https://www.carbonbuilt.com/ (accessed April 17, 2021)
[21] The production of solid carbonates including calcite and magnesite exploits favorable thermodynamics and produces stable mineral reaction products that are known to persist at ambient temperature and pressure, without risk of CO_2 leakage, or release over billions of years. Furthermore, the handling of solid mineral carbonates, i.e., as compared to fluid-state CO_2 is simpler and therefore presents distinct advantages.

The development of CarbonBuilt's Reversa™ technology would not have been possible without the longstanding support of the U.S. Department of Energy's Office of Fossil Energy (and our philanthropic, and corporate partners), particularly its Carbon Capture and Carbon Utilization Programs. This support, which was provisioned to UCLA via the National Energy Technology Laboratory allowed us to demonstrate the technology at the Integrated Test Center in Gillette, Wyoming in 2020 and the National Carbon Capture Center in Wilsonville, Alabama in 2021. While these pilot-demonstrations have de-risked our solution from a technical standpoint, and helped ascertain the favorable unit economics of production, more work remains. Particularly, what remains now is to demonstrate our technology at commercial scale, a throughput level that is nearly 20 times higher than our current scale. Such commercial demonstration is needed to develop industrial comfort and experience in operating, maintaining and managing new technological processes that are somewhat different from those in use today. These are key activities for the broader industrial sector to gain confidence in low-carbon technologies. Given industry and investors' traditional reticence to participate in first-of-a-kind projects, strategic government support of initial commercial-scale projects can very significantly accelerate commercialization of promising carbon utilization solutions. Beyond just enabling the first deployments of new technological solutions, early-stage support could also involve direct incentives in the form of tax credits related to carbon dioxide utilization (and reduction), grants for energy efficiency improvements for plants that integrate CO_2 utilization technologies, or even penalties for ongoing, long-unabated and 'far-above-average' CO_2 emissions. These approaches, collectively, will serve to create both a domestic manufacturing base and a market for low-carbon products and processes.

THE ROLE OF SUPPORTIVE INCENTIVES AND MARKET MECHANISMS: It is necessary to develop structures and systems that incentivize CO_2 emissions mitigation by both early-stage companies, who seek to transform the industrial sector, and by established corporations. In this regard, reducing and reversing carbon dioxide emissions requires the development and broad-based deployment of technology-neutral incentives. Examples of current incentive mechanisms include the 45-Q tax credit[22], California's low-carbon fuel standard (LCFS)[23] and the Buy Clean California Act. These mechanisms, which offer incentives/credits up to \$50 per ton (45-Q[22]), or up to \$180 per ton (LCFS)[23] offer a means to offset the cost of CO_2 abatement technologies. On the other hand, Buy Clean mandates create a means for public works and other government agencies to incentivize (select or limit) the purchase of materials and products based in part on their embodied carbon intensity. While these are unquestionably steps in the right direction; more inclusive incentives are needed. For example, tax credits are valuable only if the developer has a tax-liability that can be offset. This advantages large established corporations over innovative start-up companies. Offering cash payments in lieu of tax credits, either for the construction of production capacity, or the production of products, would resolve this issue. In addition, even with the reductions enacted in 2018, 45-Q still requires 25,000 tonnes of CO_2 to be sequestered or utilized per year at a given site. This level is far too high for many of the most promising CO_2 utilization technologies, particularly those that are decentralized in nature. Reducing the cap to 2,000 tonnes per year, for example, while enhancing the value of the tax credit/cash payment for initial demonstrations of a particular category of utilization solution, could go a long way towards facilitating new decentralized approaches, i.e., which require proximity to markets rather than to simply large point-sources of carbon dioxide. As a prominent example, these types of progressive actions helped to ensure the success of both community and grid-scale solar power generation in the U.S.

Expansive thinking, in terms of incentive mechanisms and the consequent market forces that they could unleash, is needed to support the creation, adoption and diffusion of new carbon dioxide utilization technologies and the economic opportunities that are prerequisite to achieve rapid CO_2 mitigation. But

---

[22] Office of the Law Revision Council. 26 USC 45Q: Credit for carbon dioxide sequestration https://uscode.house.gov/view.xhtml?req=(title:26%20section:45Q%20edition:prelim) (accessed April 17, 2021).
[23] California Air Resources Board. Low Carbon Fuel Standard Program https://www.arb.ca.gov/fuels/lcfs/lcfs.htm (accessed April 17, 2021).

this requires credible, unbiased, and defensible publicly available data related to the (embodied) carbon intensity of products, services and processes that are sold in the marketplace. Thus, and in closing, it is critical to establish a national database that quantifies and tabulates the “carbon intensity” of both raw materials and finished products, e.g., for cement, steel, concrete, concrete products, insulation materials, glass, etc. This nature of database which does not currently exist would offer a credible, technology-neutral and unbiased basis to compare and incent carbon efficiency, intensity and improvements thereof, to develop low-carbon product standards (e.g., for concrete, and other construction materials) and to assess and accrue incentives in a transparent manner. Having such a basis of comparison would allow us to rank and order materials, products and services and create a means by which consumers and purchasers, i.e., the market could make informed product selections; thereby favoring the widespread adoption of CO_2 utilization technologies, and the low-carbon products that they are used to create.

Thank you again for the opportunity to testify on this important topic.