



WORKSHOP REPORT

NSF Workshop on Advanced Manufacturing for Industrial Decarbonization

August 3-4, 2023

Arlington, Virginia

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1. Introduction

According to a report recently published by the Intergovernmental Panel on Climate Change of the United Nations [1], limiting global warming to 1.5°C and 2°C requires rapid, deep, and in most cases, immediate greenhouse gas emissions reductions. In response to address this grand challenge, the U.S. has set ambitious goals of achieving 100% emissions-free electricity by 2035 and economy-wide net-zero emissions by 2050, as laid out in Executive Order 14008 [2], for which the White House has developed strategies to achieve these goals [3]. Furthermore, the U.S. DOE has published an Industrial Decarbonization Roadmap [4]. Four major pillars are identified in the roadmap:

- 1) Energy efficiency
- 2) Industrial electrification
- 3) Low-carbon fuels, feedstocks, and energy sources (LCFFES)
- 4) Carbon capture, utilization, and storage (CCUS)

Enhancing domestic competitiveness of advanced manufacturing technologies needed for clean energy generation and industrial decarbonization has been emphasized as important priorities in multiple national strategies and technology roadmaps, including the national strategies for global leadership on advanced manufacturing [5] and secured supply chain for a robust clean energy transition [6].

Traditionally, researchers in the manufacturing field have mainly aimed to improve part quality, increase productivity, and reduce cost, with inadequate consideration of manufacturing's carbon footprint. Manufacturing currently contributes to 83% of the energy-related CO₂ emissions in the U.S. industrial sector and 25% of total CO₂ emissions in the U.S. economy [4]. Mitigation of CO₂ emissions from manufacturing is urgently needed. Furthermore, advanced manufacturing can be used to produce novel products that improve energy efficiency or reduce emissions during the usage of these products. Advanced manufacturing can also be used to produce emerging products that aim at mitigating emissions (e.g., sorbents for carbon capture and catalysts for carbon utilization).

To help realize the full potential of advanced manufacturing for industrial decarbonization, the NSF Workshop on Advanced Manufacturing for Industrial Decarbonization was held on August 3-4, 2023, in Arlington, Virginia. The objectives of the workshop included:

- 1) To identify gaps and challenges of advanced manufacturing for industrial decarbonization, including but not limited to technological pathways and their techno-economic analysis
- 2) To share perspectives from federal agencies such as DOE, NIST, and NSF
- 3) To formulate recommendations for research initiatives

The workshop provided an interaction venue for researchers from the communities of advanced manufacturing, energy efficiency, industrial electrification, LCFFES, CCUS, and techno-economics.

A steering committee of 21 members was formed to help recommend and invite speakers, review abstracts for the selection of idea presentations, moderate workshop sessions (invited talks and panel discussions), and provide input to this report. Their brief biographies are provided in Appendix A.

A group of six organizers were responsible for communicating with all the stakeholders (i.e., steering committee members, invited speakers, idea presenters, and participants), coordinating the schedule, working out the logistics, and moderating workshop sessions (invited talks and panel discussions). Their brief biographies are provided in Appendix B.

The workshop lasted for one and a half days. The workshop agenda is provided in Appendix C. It included three types of activities:

- 1) Invited talks. Sixteen invited speakers included experts from industry, national labs, and academia who presented inspiring examples of advanced manufacturing for industrial decarbonization, and representatives from federal agencies who talked about their agencies’ perspectives on advanced manufacturing for industrial decarbonization. These speakers were recommended or invited by workshop steering committee members. Their brief biographies are provided in Appendix D.
- 2) Panel discussions. A group of invited speakers served as panelists for these panel discussions.
- 3) Idea presentations. Ten selected participants presented their ideas about advanced manufacturing for industrial decarbonization. These presenters were selected by the workshop steering committee based on their submitted abstracts. Their brief biographies are provided in Appendix E.

Among the 21 steering committee members, 6 organizers, and 16 invited speakers, there were 12 women or minorities, as illustrated in Figure 1.

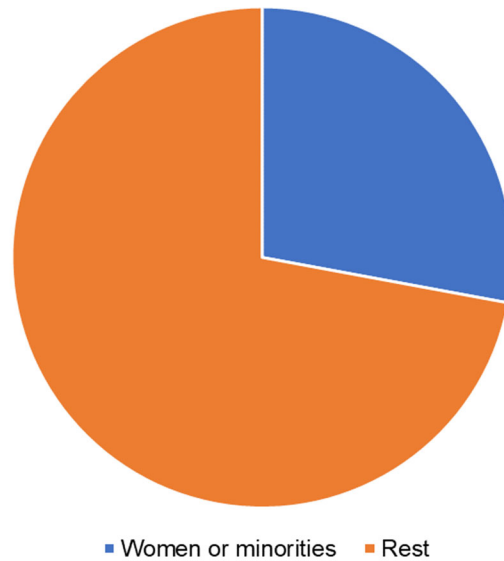


Figure 1: Composition of steering committee members, organizers, and invited speakers

The workshop had more than 100 registered participants, representing academia, industry, national labs, and federal agencies. Their names and affiliations are provided in Appendix F.

The remaining sections of the report are organized as follows. Sections 2 to 5 discuss the four major pillars of industrial decarbonization that were covered by the invited speakers. Section 6 discusses gaps and challenges in advanced manufacturing for industrial decarbonization. Section 7 presents recommendations regarding how to accelerate research and development on advanced manufacturing for industrial decarbonization based on the workshop.

2. Energy efficiency

Sachin Nimbalkar from Oak Ridge National Laboratory gave an invited talk on Energy Efficiency as a Foundational Technology Pillar for Industrial Decarbonization. He highlighted the industry’s significant energy demand and CO₂ emissions, accounting for 33% of the nation’s primary energy use and 30% of the nation’s energy-related CO₂ emissions. Energy efficiency as a foundational technology pillar was emphasized. In the path to net-zero CO₂ emissions per DOE’s Industrial Decarbonization Roadmap [2], efficiency is expected to serve as the dominant pillar by 2040 and remain one of the major pillars by 2050, as shown in Figure 2 [7].

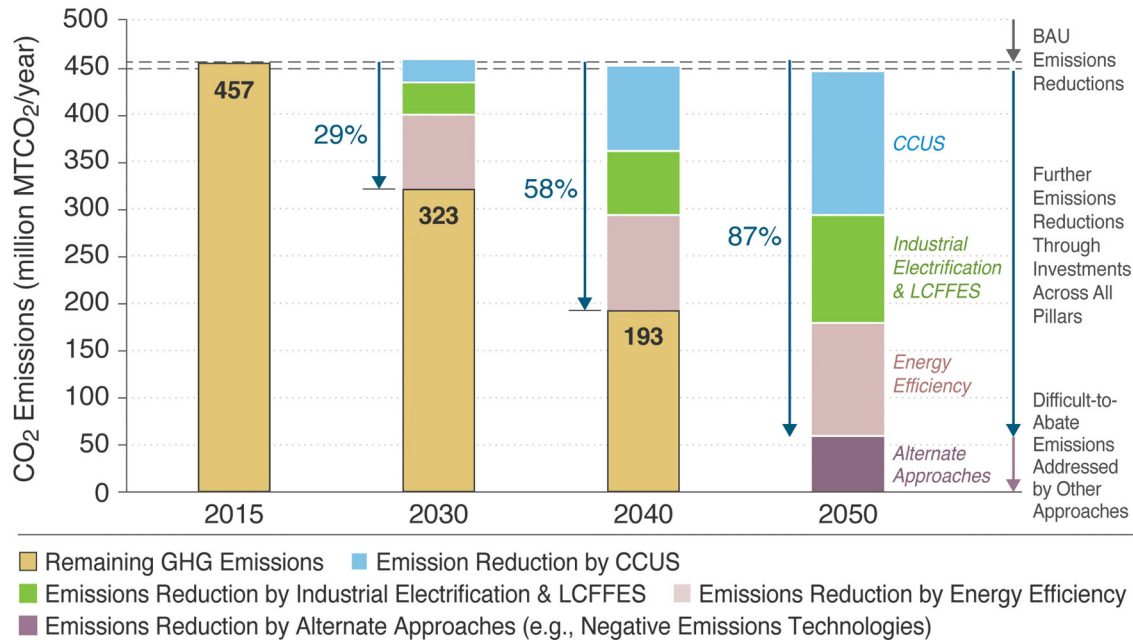


Figure 2: Emissions reductions by different industrial decarbonization pillars and remaining emissions projected in different years [7]

The pathways in the energy efficiency pillar include:

- Strategic energy management
- System efficiency
- Smart manufacturing
- Materials and life cycle efficiency
- Combined heat & power

Specific strategies were provided according to the five pathways above for the six energy-intensive industries, including iron and steel, chemical, food and beverage, petroleum refining, pulp and paper, and cement. For example, smart manufacturing for the iron and steel industry can involve “shortened smelting time and enhanced smelting efficiency using automated detection of molten steel components, blowing controls, and component analysis” or rely on digital twins.

Nilanjan Sarangi from Saint-Gobain Abrasive gave an invited talk on decarbonization from an abrasive manufacturer’s perspective. A case study was presented on their bonded abrasive products. By adopting a net shape processing method, the energy demand is significantly reduced.

Further research for the energy efficiency pillar is recommended by Nimbalkar in the following areas:

- Improving the efficiency of process heating, steam, and motor systems
- Addressing big data challenges related to data quality, storage, and computing
- Advanced data analytics for processing the data and improving cybersecurity
- Data integration for facilitating utility efficiency programs that reward manufacturers for energy saved rather than equipment installed
- Demonstrations of plant automation systems that provide real-time energy performance data

3. Industrial electrification

Cecilia Springer from Global Efficiency Intelligence gave an invited talk on Deep Decarbonization of Industry through Electrification of Process Heating. She highlighted that process heating is the largest contributor to the U.S. manufacturing energy use. She analyzed the temperature levels of the process heat and revealed that two thirds of process heat used in the U.S. industry is below 300 °C. In particular, almost all process heat used in the food industry is below 150 °C.

Furthermore, Springer presented her case study on the electrification of the beer production industry. This study is based on a state-level analysis because different states have different electricity grid emissions factors and industrial energy prices. By replacing a centralized gas boiler system with heat pumps, all process steps of beer production (including mashing, boiling, pasteurization, cleaning, and production support) are expected to save a significant amount of energy. The total energy saved is as large as 69%. CO₂ emissions reductions are also significant, as shown in Figure 3 [8]. For example, the beer industry in California is expected to reduce its CO₂ emissions by more than 100 kt per year in 2030. As the grid electricity becomes cleaner, the CO₂ emissions reductions will be more significant, reaching more than 140 and 160 kt per year in 2040 and 2050, respectively. Other states that expect significant CO₂ emissions reductions by replacing a centralized gas boiler system with heat pumps in beer factories include Colorado, Texas, Ohio, Georgia, Wisconsin, Pennsylvania, Florida, and North Carolina. According to the study, “CO₂ emissions reductions can be achieved even today using grid electricity in most states studied.” In addition, the energy cost was compared between the conventional and electrified processes. The difference is not large. Some states (such as Pennsylvania, Ohio, and Washington) are projected to lower their energy cost while others are to increase it. However, Springer pointed out that “energy cost is only a small portion of total manufacturing cost for many industrial subsectors” and “a moderate increase in energy cost per unit of product resulting from electrification will have a minimal impact on the price of final product and final consumers.”

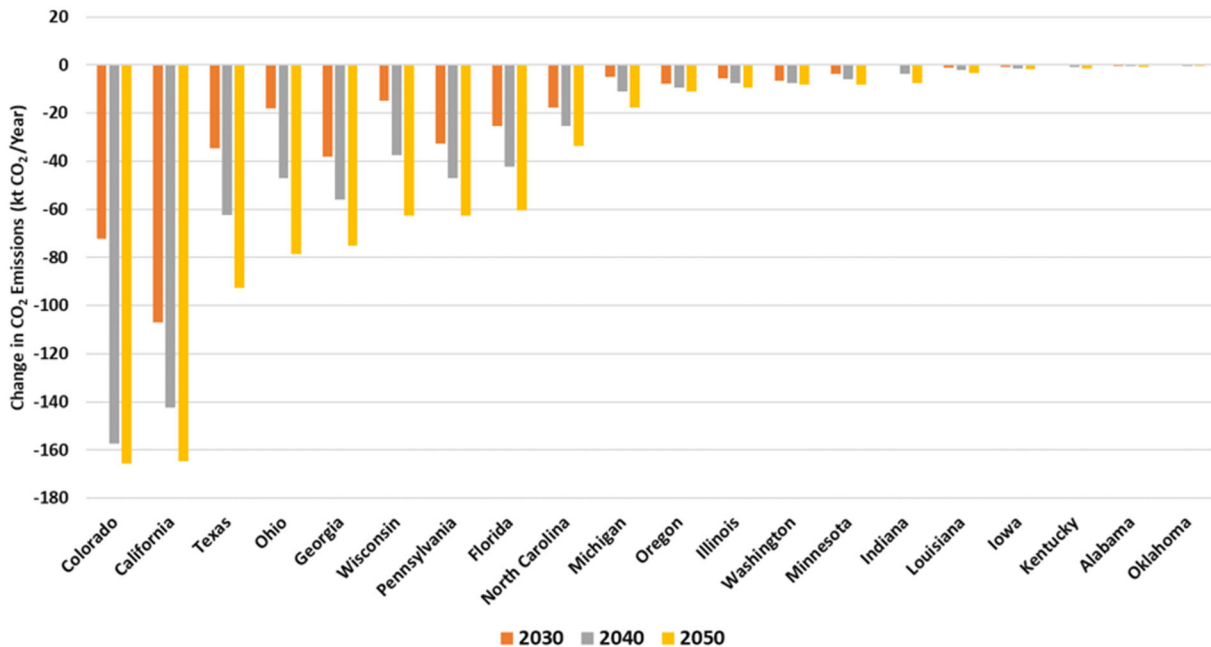


Figure 3: Projected CO₂ emissions reductions in the beer industry across different states in different years [8]

The key takeaways from Springer's talk include:

- There is significant potential to decarbonize the U.S. industry with electrification.
- Using grid electricity, CO₂ emissions reductions from electrification can be achieved in some states with clean electricity supply today and in many more states in 2030.
- Energy cost per unit of production for electrified processes is higher but can be competitive with conventional processes if low-price renewable electricity is available.

Lastly, Springer had the following recommendations on industrial electrification:

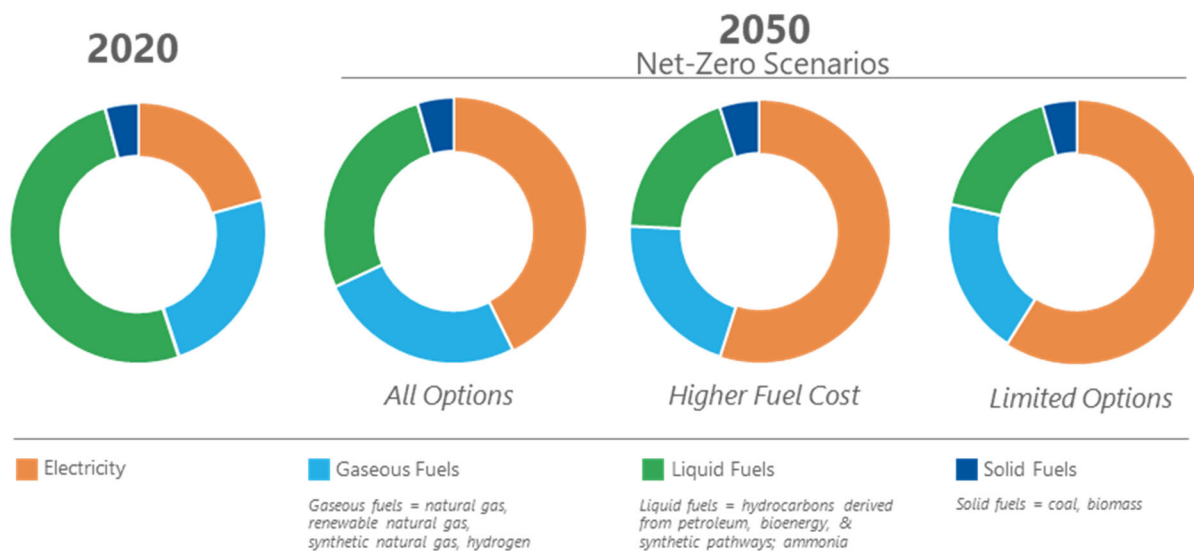
- Identify the sweet spots and start there. Start in states with more favorable conditions (e.g., cleaner grid, lower price ratio of electricity to natural gas, more favorable investment conditions, and local incentives, etc.).
- The industry sector should initiate partnerships with government, academia, think tanks, and other stakeholders to develop and/or scale electrification technologies.
- Six impactful actions that would support increased industrial electrification in the U.S. are:
 - Support demonstration of emerging electrification technologies and new applications of existing technologies
 - Financially incentivize electrification
 - Increase renewable electricity generation capacity
 - Enhance the electricity grid
 - Engage communities
 - Develop the workforce

4. Low-carbon fuels, feedstocks, and energy sources

Eric C.D. Tan from the National Renewable Energy Laboratory gave an invited talk on Energy and Techno-Economic Analysis of Bio-based and Low-carbon Chemicals and Fuels Production Processes. He highlighted two case studies. The first one was on 2,3-butanediol (BDO) separation. BDO is “a biomass-derived intermediate for producing sustainable aviation fuel for commercial aviation decarbonization.” BDO is produced by the fermentation of sugars. The raw broth includes 10 wt.% BDO, 86 wt.% water, and 4 wt.% byproducts. The challenges in BDO separation include low BDO concentration and water being more volatile than BDO. Tan presented analysis results of seven BDO separation processes. The energy consumption and costs of different BDO separation processes vary across one order of magnitude. The second case study was on methanol production. Methanol can serve as an alternative transportation fuel, power generation fuel, and chemical intermediate. There are many methanol production pathways. For example, it can be produced by gasification of mixed plastic waste. It can also be produced by reactive CO₂ capture and conversion. Tan presented analysis results of 12 methanol production pathways. The carbon intensities vary significantly and are dictated by the pathways. These two case studies showed the importance of combined techno-economic analysis and life cycle assessment for emerging technologies.

Don Stevenson from GTI Energy gave an invited talk on gaseous fuels produced from biogenic feedstocks. He first presented a comprehensive U.S. energy system modeling effort conducted in collaboration with EPRI (available at: <https://lcri-netzero.epri.com>). The objective was to evaluate the least-cost pathways to achieve net-zero carbon emissions across the entire U.S. economy by 2050. The modeling shows that, although the share of electricity grows considerably under every scenario, ~50% of all energy is supplied to end-use markets as a fuel, as shown in Figure 4 [9]. Stevenson then highlighted the need for renewable propane, one of the main components of liquefied petroleum gas (LPG). LPG is versatile, being used for industrial, agricultural, residential, transportation, and recreational purposes. However, the availability of LPG is expected to decline with the shrinking fossil fuel industry because LPG is a fossil fuel byproduct. Stevenson shared the related R&D activities at GTI Energy. Furthermore, he shared advanced syngas

manufacturing possibilities. Finally, he concluded that, among many pathways to sustainable products and biofuels, the most scalable route is from cellulosic feedstocks to syngas through processes such as pyrolysis and gasification.



Source: LCRI Net-Zero 2050: U.S. Economy-Wide Deep Decarbonization Scenario Analysis

Figure 4: Projected least-cost pathways to achieve net-zero carbon emissions across the entire U.S. economy by 2050 [9]

Johnathan Scheffe from the University of Florida gave an invited talk on Strategies for Harnessing Solar Thermal Energy for Industrial Decarbonization. He first emphasized that cheap energy storage is key to the renewable energy transition. The variable solar generation within a day can be smoothed by short-term energy storage, for example, Li-ion battery. However, seasonally variable solar generation requires long-term energy storage. He then pointed out that concentrating solar power could be a promising solution. First, it offers cheap thermal energy storage for 24/7 utilization. Second, the high-temperature process heat (up to 1500 °C) can be used for manufacturing (e.g., cement or steel). Third, it allows for the production of energy-dense sustainable fuels, satisfying the transportation sector and enabling seasonal energy storage. Scheffe then introduced a few thermal routes to solar fuel production, including fuel reforming, thermolysis, and redox cycles. Finally, he proposed some research opportunities where advanced manufacturing can help enable the higher temperatures required by solar fuel production. For example, novel design and manufacturing of heliostats is needed to reduce their cost. Furthermore, additive manufacturing may help improve the reactive structures that enable efficient radiative heat transfer.

5. Carbon capture, utilization, and storage

Volker Sick from the University of Michigan gave an invited talk on Market and Climate Opportunities for CO₂ Utilization. He emphasized the importance of CO₂ source and sink combinations of different carbon capture, utilization, and storage (CCUS technologies). The CO₂ sources considered include fossil fuel, fossil carbon (limestone), biomass, and ambient (air and water). The CO₂ sinks considered include processes such as enhanced oil recovery and geological sequestration, and products such as construction materials, chemicals, fuels, and food. Construction materials are considered as Track 1 products that allow for removal/storage of carbon for > 100 years. Fuels and food are considered as Track 2 products that decompose to CO₂ in < 100 years. Chemicals can be either Track 1 or 2 products. The impact of different combinations of these CO₂ sources and sinks is illustrated in Figure 5 [10]. The conversion from ambient

CO₂ to Track 1 products is identified as the sweet spot with negative emissions and economic return. Sick also presented the potential of each type of product in 2050. Construction materials, fuels, and chemicals are projected to be the largest contributors to annual CO₂ consumption, at 1.0-9.5, 0.28-10.80, and 0.26-0.58 gigatonnes, respectively. Their market sizes are estimated to be 800-1000, 21-2060, and 100-180 billion dollars, respectively.

| CO ₂ Source | | Process Type | | Product Type | | | | | |
|------------------------|-------------|--|---|---|---|--|-------------|---------|------|
| | | Enhanced Oil Recovery | Geological Sequestration | Track 1 | | Track 1/2 | | Track 2 | |
| | | | | Construction Materials | Specialty Materials | Chemicals | Agriculture | Fuels | Food |
| Fossil Fuels | Coal | Continues dependence on fossil resources | Net point source reduction of emissions | Profitable Storage - continued dependence on fossil CO ₂ | Modest net impact on emissions - can reduce demand but most fossil carbon is released | Modest net impact on emissions - can reduce demand but all fossil carbon is released | | | |
| | Oil | | | | | | | | |
| | Natural Gas | | | | | | | | |
| Fossil Carbon | Limestone | | | | | | | | |
| Bio-captured | Biomass | Replaces fossil CO ₂ - supports continued fossil fuel use | Permanent storage - no economic return | Sweet Spot - negative emissions - economic return | Potential for permanent storage >100 years | Circular Economy | | | |
| Ambient | Air | | | | | | | | |
| | Water | | | | | | | | |

Figure 5: Impact of different combinations of CO₂ sources and sinks (i.e., process type and product type) [10]

John Shingledecker from EPRI gave an invited talk on Opportunities for Advanced Manufacturing and Materials in Improving Carbon Capture Technology. He first presented the cost breakdown for a carbon capture, transport, and storage system for a prototypical natural gas combined cycle power plant. It turned out that carbon capture contributes to more than 70% of the overall cost. Therefore, it is critical to lower the carbon capture cost, especially its capital cost. He then identified key potential areas for cost reductions, including sorbents and heat exchangers. Afterward, he shared several ongoing R&D activities by different organizations. For example, complex structures produced by additive manufacturing (AM) could improve heat and mass transfer. These structures can be used for sorbents or heat exchangers. It is also possible to use advanced manufacturing to integrate heat and mass exchange to improve the efficiency and thus reduce the size of absorber vessels. Finally, he concluded that applying AM to CCUS systems “is in its infancy with only a limited number of studies being conducted,” suggesting that more research is needed in multiple areas.

Doug Robinson from Solidia Technologies gave an invited talk on Carbon Utilization in Concrete Manufacturing. He first introduced their cement. Because of a different chemical reaction, the production of their cement generates 30% less CO₂ than ordinary Portland cement (OPC). In addition, their cement reacts with CO₂ instead of H₂O during curing, resulting in additional CO₂ reductions. Furthermore, Robinson introduced their supplementary cementitious materials (SCM). Their SCM can be used to replace OPC, leading to CO₂ reductions. For example, a 35% replacement leads to a 23% CO₂ reduction. Finally, Robinson concluded his talk by providing the techno-economic perspectives of the technologies discussed above. Their cement is market-proven to be profitable, and their SCM are expected to be profitable. In addition, governmental incentives (e.g., tax credits) can make the adoption of their technologies more economical.

Brad Brennan from Dimensional Energy gave an invited talk on Converting CO₂ and Water into Hydrocarbons. He first introduced their process that consists of three steps: 1) electrolysis to convert H₂O to H₂ and O₂; 2) reverse water gas shift to convert CO₂ and H₂ to CO and H₂O; and 3) Fischer-Tropsch

reaction to convert CO and H₂ to fuels. He showed the results of their successful operation. He then pointed out some opportunities where advanced materials and manufacturing can be helpful. First, the reactor should be made of a material without unwanted catalytic properties or hydrogen embrittlement and with sufficient creep strength and corrosion resistance. Second, the heterogeneous catalysts should have sufficient strength, porosity, reaction selectivity, corrosion resistance, and stability (minimal degradation). Currently, the heterogeneous catalysts are manufactured with tableting and extrusion. Alternative routes could be 3D printing, sol-gel, and chemical/physical vapor deposition. Third, heat exchangers serve in harsh environments with high temperature and pressure, large temperature range, corrosion, and fouling. New materials (e.g., ceramics) and manufacturing methods (e.g., coatings) could be pursued. Finally, Brennan concluded his talk by providing some techno-economic perspectives. His analysis showed that the price of their sustainable aviation fuels could be \$3.48 per gallon if the production was scaled up to 10,000 barrels per day.

6. Gaps and challenges

One large gap identified during the workshop is the lack of communications and interactions between the advanced manufacturing community and the industrial decarbonization research community. Most of the invited talks were focused on industrial decarbonization. Most of the workshop participants were from the advanced manufacturing research community. While the workshop was an excellent learning experience for advanced manufacturing researchers, the gap cannot be filled with such a single event. These two research communities need to communicate and interact more frequently in order to identify synergy and conduct convergent research.

One significant challenge in industrial decarbonization is the lack of techno-economic analysis (TEA) and life cycle assessment (LCA) of emerging technologies. Researchers tend to focus on the technical performance of their technologies while omitting TEA and LCA. However, TEA and LCA determine if the technologies will survive the market and create positive environmental impacts from a holistic view. More research on TEA and LCA is urgently needed before governments and private investors can make informed decisions on what technologies to invest in. This challenge is confirmed in one of the latest reports by National Academies of Sciences, Engineering, and Medicine [11].

7. Recommendations

This workshop provided a great opportunity for initiating interactions between the advanced manufacturing and industrial decarbonization communities. The invited speakers were selected to present a high-level overview of ongoing research on industrial decarbonization and examples of how advanced manufacturing could contribute to industrial decarbonization. The primary aim was to enlighten researchers in the advanced manufacturing community and motivate them to formulate their future research plans around industrial decarbonization.

The NSF award provided funds to cover travel expenses of invited speakers. This, together with other NSF resources, helped broaden the participation. The steering committee members, organizers, and invited speakers were purposefully selected to broaden participation. Among the 21 steering committee members, 6 organizers, and 16 invited speakers, there were 12 women or minorities.

Despite the above-mentioned fruitful outcomes from this workshop, a significant amount of future work is needed to continue and augment the momentum generated from this initiative. The following actions are recommended:

- To create funding opportunities that support research on advanced manufacturing for industrial decarbonization, including its techno-economic analysis (TEA) and life cycle assessment (LCA)

- To organize more events (workshops, special sessions, symposia, and conferences) to enable more frequent communications and interactions between the advanced manufacturing community and industrial decarbonization research community
- To organize separate events for each industrial decarbonization pillar to allow for more in-depth discussions on fundamental research areas in which NSF (and other funding agencies) should direct their investments to help grow this field (advanced manufacturing for industrial decarbonization)
- To organize more events for fundamental and applied research focused on techno-economic analysis (TEA) and life cycle assessment (LCA) of emerging industrial decarbonization technologies
- To develop educational programs that produce workforces equipped with both advanced manufacturing and industrial decarbonization knowledge and skills
- To form a national coalition at the intersection of advanced manufacturing and industrial decarbonization, connecting people from industry, national labs, and academia
- To establish an innovation and commercialization ecosystem that supports and incentivizes new and existing companies to adopt emerging technologies

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Appendix A: Brief Biographies of 21 Steering Committee Members

LINKAN BIAN: Dr. Linkan Bian is a program director in the Advanced Manufacturing (AM) cluster of Civil, Mechanical and Manufacturing Innovation division of National Science Foundation (NSF). At his home institute, Mississippi State University, Dr. Bian is the Thomas B. & Terri L. Nusz Endowed Professor in Industrial and Systems Engineering Department. The major themes of Dr. Bian's research focus on understanding the process-structure-property relationships for advanced manufacturing, as well as the investigation of how AI/ML can transform the modeling and experimental approaches. His research has received federal funding from NSF, NIH, DoD, DoE, and industrial companies. Dr. Bian received the Outstanding Young Investigator Award from Institute of Industrial and Systems Engineering (IISE) and serves as Associate Editor for multiple ASME and IISE journals. Dr. Bian received his Ph.D. in Industrial and Systems Engineering from Georgia Institute of Technology, and B.S. in Applied Mathematics from Beijing University.

JIAN CAO: Cardiss Collins Professor Jian Cao (MIT'95, MIT'92, SJTU'89) specialized in innovative manufacturing processes and systems, particularly in the areas of deformation-based processes and laser additive manufacturing processes. She is the Founding Director of the university research center on Manufacturing Science and Innovation at Northwestern. Cao has been the Editor-in-Chief of Journal of Materials Processing Technology since 2018. Cao is an elected member of the National Academy of Engineering (NAE), a Fellow of American Association for the Advancement of Science (AAAS), ASME, the International Academy for Production Engineering (CIRP), and SME. Her major awards include DoD Vannevar Bush Faculty Fellowship, ASME Milton C. Shaw Manufacturing Research Medal, Charles Russ Richards Memorial Award from ASME and Pi Tau Sigma, SME Gold Medal, SME Frederick W. Taylor Research Medal, ASME Blackall Machine Tool and Gage Award (twice), and NSF CAREER Award. She served as President of the SME North America Manufacturing Research Institute, Chair of ASME Manufacturing Engineering Division, and Program Director at the National Science Foundation. Cao now serves on the National Materials and Manufacturing Board of the National Academies, Board of Directors of SME, and Board of mHUB – accelerator for hardtech innovation and manufacturing in Chicago.

ALAA ELWANY: Alaa Elwany is a Science and Technology Policy Fellow at the Advanced Materials and Manufacturing Technologies Office (AMTTO), U.S. Department of Energy. He is currently on detail from Texas A&M University where he is an Associate Professor at the Department of Industrial and Systems Engineering and holder of the Kincaid Professorship. He has also previously served as Assistant Director for Technology at the National Institute of Standards and Technology Office of Advanced Manufacturing (NIST OAM), and Research Scientist at General Motors R&D. His research focuses on modeling, analysis, and control of advanced manufacturing processes and systems, with emphasis on metal additive manufacturing processes, process monitoring, and uncertainty quantification. He has received scholarly recognitions from leading agencies and professional societies including NSF CAREER, SME Outstanding Young Manufacturing Engineer, SME Manufacturing Vision Award, ASME Chao & Trigger Young Manufacturing Engineer, and IBM Faculty Award. Dr. Elwany acquired a PhD in Industrial and Systems Engineering from Georgia Institute of Technology in 2009.

NAKHIAH GOULBOURNE: Dr. Nakhiah Goulbourne is Associate Professor of Aerospace Engineering at the University of Michigan in Ann Arbor. She joined the University of Michigan in 2009 after 3 years as a tenure-track Assistant Professor at Virginia Tech. At UM, she established the Soft Materials Research Lab. From 2018 to 2022, she served as NSF program director for the Mechanics of Materials and Structures program (MoMS) within the Division of Civil, Mechanical, and Manufacturing Innovation. Whilst at NSF, she served on numerous working groups and new solicitations including initiating and leading the EcoManufacturing thrust of the NSF-wide Future Manufacturing Solicitation. She received the NSF CAREER award in 2008, and in 2021, she received the National Science Foundation Director's Award for

Superior Accomplishment. She received her BA degree in Physics from Middlebury College, and M.S. and Ph.D. degrees in Mechanical Engineering from the Pennsylvania State University.

ROBERT W. IVESTER: Robert W. Ivester, PhD, currently serves as the senior advisor for semiconductor engagement at the National Institute of Standards and Technology. Previously, Ivester served as the deputy director of the Hollings Manufacturing Extension Partnership Program. The MEP National Network focuses its expertise and knowledge as well as that of its partners on providing U.S. manufacturers with information and tools they need to improve productivity, assure consistent quality, accelerate the transfer of manufacturing technology and infuse innovation into production processes and new products. Ivester served at the Department of Energy for seven years, most recently as director of the Federal Energy Management Program in the Office of Energy Efficiency and Renewable Energy. FEMP oversees the implementation of policy and actions that result in energy efficiency implementation, renewable energy adoption, and reductions in energy and water use in federal government operations. He also served in the Advanced Manufacturing Office for six years. During that time, AMO launched five Manufacturing USA Institutes, the Critical Materials Hub, and hundreds of small R&D and technical assistance projects across the nation. Ivester also worked at NIST for over 16 years, leading and performing research in advanced manufacturing. Ivester is a fellow of SME and the American Society of Mechanical Engineers. He received his doctorate in engineering, master's degree in manufacturing engineering and a bachelor's degree in mechanical engineering from the University of Massachusetts at Amherst.

ERICK JONES: Dr. Erick C. Jones is dean of the College of Engineering at the University of Nevada, Reno. He currently is serving a three-year term on the National Science Foundation Directorate for STEM Education Advisory Committee. He has served as a program director for the NSF Engineering Directorate for Engineering Research Centers Program and for the Education Directorate for Division of Graduate Education. He also has been a program director for the prestigious Graduate Research Fellowship (GRF) Program. Jones is a former senior science advisor in the Office of the Chief Economist at the U.S. State Department. He also is a former professor and Associate Dean for Graduate Studies at the College of Engineering at The University of Texas at Arlington, and a former professor at the University of Nebraska Lincoln. Prior to his academic career, Jones held engineering, management and executive management positions in industry. Jones is an internationally recognized researcher in industrial manufacturing and systems engineering, with an expertise in supply chains. He is known for his pioneering work with Radio Frequency Identification (RFID) technologies, Lean Six Sigma Quality Management and autonomous inventory control. He has published more than 243 manuscripts and three textbooks and has garnered more than \$10 million in grants and contracts. Additionally, Jones was a National Academies Jefferson Science Fellow from 2021 to 2022. He received his M.S. and Ph.D. degrees from University of Houston, and B.S. degree from Texas A&M University, all in Industrial Engineering.

THOMAS R. KURFESS: Thomas R. Kurfess is the Chief Manufacturing Officer of the Georgia Institute of Technology, and the Executive Director of the Georgia Tech Manufacturing Institute. He is also the HUSCO/Ramirez Distinguished Chair in Fluid Power and Motion Control and Professor of Mechanical Engineering at Georgia Tech. He is also the Chief Technology Officer to the National Center for Manufacturing Sciences (NCMS). During 2019-2021 he was on leave serving as the Chief Manufacturing Officer and the Founding Director for the Manufacturing Science Division at Oak Ridge National Laboratory, where he was responsible for strategic planning in advanced manufacturing. During 2012-2013 he was on leave serving as the Assistant Director for Advanced Manufacturing at the Office of Science and Technology Policy in the Executive Office of the President of the United States of America. In this position he had responsibility for engaging the Federal sector and the greater scientific community to identify possible areas for policy actions related to manufacturing. He was President of the Society of Manufacturing Engineers in 2018, and currently serves on the Board of Governors of the ASME. His research focuses on the design and development of advanced manufacturing systems targeting secure digital manufacturing, additive and subtractive processes, and large-scale production enterprises. Kurfess is an elected member of

the National Academy of Engineering and is a Fellow of ASME, AAAS, and SME. He received his S.B., S.M. and Ph.D. degrees in mechanical engineering from M.I.T. in 1986, 1987 and 1989, respectively.

AJAY "AJ" P. MALSHE: Ajay “AJ” P. Malshe is currently R. Eugene and Susie E. Goodson Distinguished Professor of Mechanical Engineering at Purdue University. He is the Co-Director of Purdue’s Engineering Initiative (PEI) for Manufacturing. He has a collective professional experience of 40 years, partly overlapping, in industries (as a Board Member, CTO, and entrepreneur) and academia. He has gained a national and international reputation in advanced manufacturing, multifunctional-resilient-sustainable bio-inspired designing, functional multi-materials, and system integration and productization. Over the decades, application areas of his interest and contributions are heterogeneous microelectronics for high-density systems, nanomanufacturing for extreme machines, in-space servicing, assembly, and manufacturing (ISAM) at the point of need, and biomanufacturing for food proteins. Malshe has published over 225 peer-reviewed manuscripts. He has received over 27 patents and his patent/product conversion rate is more than 70% resulting in more than 20 award-winning engineered products applied by leading corporations in energy, defense and aerospace, transportation, EV, die casting, high-performance racing, and other key industrial sectors. In 2018, he was elected to the National Academy of Engineering (NAE) “for innovations in nanomanufacturing with impact in multiple industry sectors”, the highest award an engineer can receive. He is also a Fellow of leading professional societies including the American Association for Advancement of Science (AAAS), American Society of Materials (ASM), American Society of Mechanical Engineers (ASME), Institute of Physics (InstP), International Academy for Production Engineering (CIRP), National Academy of Inventors (NAI) and recipient of engineering translation awards including R&D 100 and Edison Awards.

SUZY MARZANO: Suzy Marzano is currently the Sr. Manager of Industry Development and Technical Activities at SME. Ms. Marzano joined SME in 2015 and has taken on numerous roles and responsibilities including the lead interface with SME Committees and Technical Communities targeted to different domains: Manufacturing Research and Education, Accreditation, SME Journals, and Technical networks and communities. Marzano is the SME liaison for ABET and oversees the program evaluation process for Accredited programs in Manufacturing Engineering and Manufacturing Engineering Technology. Marzano leads Competitions and Recognition programs, Career Development Forums, and experiential activities designed to inspire and attract the next generation of Manufacturing professionals.

KC MORRIS: KC Morris is an internationally recognized researcher and leader at the National Institute of Standards and Technology (NIST). She applies her background in computer science, information modeling, and knowledge representation to solve industrial challenges in the manufacturing sector while ensuring that new practices lead to more competitive and sustainable manufacturing. Building on a 30+ year career contributing to research and standards for manufacturing systems integration, she currently leads the effort towards standards for transitioning manufacturing to a circular economy. KC’s earlier work contributed foundational standards for sharing product designs followed by leadership in smart and sustainable manufacturing. She serves on the executive committee of ASTM International’s E60 Committee on Sustainability, as vice-chair of ASTM E60.13 on Sustainable Manufacturing, member of the US TAG for ISO 323 on Circular Economy, a technical expert to ISO TC 184 on Automation systems and integration, and President-Elect for SME’s North American Manufacturing Research Institute (NAMRI). KC served as an ASME Congressional Fellow during the 116th Congress (2018-2020) where she focused on US manufacturing policy while supporting the US Congressional House Manufacturing Caucus. KC is a Fellow of SME and AAAS.

BRIGID MULLANY: Brigid Mullany is a professor in the Department of Mechanical Engineering and Engineering Science at the University of North Carolina at Charlotte. In 2021 she became the Associate Dean for Research for The William States Lee College of Engineering at UNC Charlotte. From January 2017 to November 2019, she was a program director in the Advanced Manufacturing Program at the

National Science Foundation (NSF) in Alexandria, VA. She is currently working in the area of additive manufacturing (metal and ceramic), surface finishing, and robust multi-class surface discrimination machine learning frameworks. Mullany received in the SME Kuo K. Wang Outstanding Young Manufacturing Engineer Award in 2007, and the NSF CAREER Award in 2008. She is the Past President for SME's North American Manufacturing Research Institute (NAMRI), a fellow of the International Academy of Production Engineering (CIRP), and is currently the Chair of CIRP's Scientific Technical Committee on Surfaces (STC-S). She received her bachelor's degree and doctorate in mechanical engineering from the University College Dublin in Ireland. After graduation, she received a two-year EU Marie Curie postdoctoral research position at Carl Zeiss in Germany.

STRATOS PISTIKOPOULOS: Stratos Pistikopoulos is the Director of the Texas A&M Energy Institute and holds the Dow Chemical Chair Professorship in the Artie McFerrin Department of Chemical Engineering at Texas A&M University. He was a Professor of Chemical Engineering at Imperial College London, UK (1991-2015) and the Director of its Centre for Process Systems Engineering (2002-2009). He worked with Shell Chemicals in Amsterdam before joining Imperial. He has authored or co-authored over 550 major research publications in the areas of modelling, control and optimization of process, energy and systems engineering applications, 15 books and 4 patents. He was a co-founder of Process Systems Enterprise (PSE) Ltd, a Fellow of AIChE and IChemE, and the current Editor-in-Chief of Computers & Chemical Engineering. He is a past Chair of the Computing and Systems Technology (CAST) Division of AIChE and served as a trustee of the Computer Aids for Chemical Engineering (CACHE) Organization (2014-2019). Prof. Pistikopoulos was a co-recipient of the prestigious MacRobert Award from the Royal Academy of Engineering in 2007, the recipient of the Computing in Chemical Engineering Award of CAST/AIChE in 2013, the IChemE's Sargent Medal in 2020, and the AIChE's Sustainable Engineering Forum Award in 2021. He holds a Ph.D. degree from Carnegie Mellon University.

STEVEN R. SCHMID: Steven R. Schmid is currently the Belk-Woodward Distinguished Professor at the University of North Carolina at Charlotte. He conducts research and teaches courses in the general fields of manufacturing, metal forming, tribology, and design. Of his textbooks, Manufacturing Engineering and Technology (with S. Kalpakjian) is the world's most popular manufacturing textbook. Dr. Schmid was a professor for over 25 years at the University of Notre Dame. From 2016-2019 he served as Program Director for the Advanced Manufacturing Program at the National Science Foundation. In 2012-2013, Dr. Schmid was the first Faculty Fellow at the Advanced Manufacturing National Program Office, and served as the Associate Director for Research Partnerships. Dr. Schmid has served as an International Delegate for SME (equivalent to Board member), and as President of the North American Manufacturing Research Institute. He is a Fellow of the American Society of Mechanical Engineers and the Society of Manufacturing Engineers. He was awarded the SME Gold Medal in 2019 and the Award of Merit (a lifetime achievement award) by the Manufacturing Engineering Society of Spain in 2020. Dr. Schmid received his Bachelor of Science Degree in Mechanical Engineering at the Illinois Institute of Technology; Master of Science and Ph.D. degrees at Northwestern University.

TIM SHINBARA: Tim Shinbara is Chief Technology Officer for AMT – The Association for Manufacturing Technology where he is responsible for delivering market intelligence, compiling industrial research and development trends, and conducting manufacturing technology discovery. Mr. Shinbara is concurrently serving as a Guest Researcher at the National Institute of Standards and Technology (NIST) supporting the Engineering Laboratory. His expertise spans applied R&D in additive manufacturing, composite fabrication, and technology transition experience at Northrop Grumman Corporation, including supporting IT/OT data interoperability and information modeling. He currently serves as a Board Officer of the MTConnect Institute, an Advisory Commissioner to the Loudoun County (Virginia) Board of Supervisors supporting economic development, and Board Chairman of Ambleside School (private K-8 school). Tim previously participated as a member of the Leadership Council for MForesight (U.S. government-funded think tank responding to advanced manufacturing inquiries). Mr. Shinbara further

supports international manufacturing initiatives through participating in advisory councils for Canada's Natural Science and Engineering Research Council of Canada (NSERC) and as a Corporate Member in the International Academy of Production Engineering (CIRP). Mr. Shinbara is a U.S. Navy veteran and has earned BS and MS degrees from Purdue University and an MBA from Pepperdine University.

DILEEP SINGH: Dileep Singh is an Argonne Distinguished Fellow, Senior Scientist and the Group Leader for Thermal and Structural Materials. He has over thirty years of experience and outstanding contributions in the area of science of ceramic and composite materials. He is internationally recognized for pioneering work in the low-temperature phosphate ceramics for structural and nuclear waste disposition applications. He has demonstrated strong technical leadership and program development skills in the areas of thermal energy storage, materials for extreme environments, advanced characterizations, and innovative manufacturing. He is a winner of several awards, including three R&D 100 awards, James Mueller award (American Ceramic Society, ACerS), the Federal Laboratory Consortium award for technology transfer, Argonne's Director's award for Outstanding Achievement. He is a Fellow of the ASM International and American Ceramic Society, and is an Academician of the World Academy of Ceramics. He has over 175 publications and 28 US and international patents. He has served as the Chair of the Engineering Ceramics Division of the ACeRS and on the editorial board of several journals, including International Materials Reviews. He received his Ph. D. in Materials Science and Engineering from the University of Utah and has completed the Strategic Laboratory Leadership Program from the University of Chicago.

SCOTT SMITH: Scott Smith is the Section Head for Precision Manufacturing and Machining at Oak Ridge National Laboratory. Prior to joining ORNL in 2019, Smith was a Professor and the Chair of Mechanical Engineering at the University of North Carolina at Charlotte. During 2012-13, he served as the Assistant Director for Technology at the US Advanced Manufacturing National Program Office in Washington DC. His research areas include high-speed machining, process optimization, and machine dynamics. Smith is a Fellow of the International Academy for Production Engineering (CIRP), and he is a Fellow of both ASME and SME. Smith served as the Chair of the Manufacturing Engineering Division of ASME, and as the President of the North American Manufacturing Research Institute of SME. He is an author of more than 100 technical papers. He holds 14 patents. Smith has received numerous awards including the ASME/SME M. Eugene Merchant Manufacturing Medal, the ASME William T. Ennor Manufacturing Technology Award, the ASME Blackall Machine Tool and Gage Award, the NAMRI/SME S.M. Wu Research Implementation Award, the SME Education Award, the AMT Charles F. Carter Advancing Manufacturing Award, the American Helicopter Society Pinckney Award, and the NAMRI/SME Lifetime Service Award.

JOHN W. SUTHERLAND: Dr. John W. Sutherland is Professor and Fehsenfeld Family Head of Environmental and Ecological Engineering (EEE) at Purdue University. As the first permanent Head of Purdue EEE, he has led the development of the department's undergraduate and graduate (M.S. and Ph.D.) degree programs and growth in terms of students, staff, and faculty into one of the largest environmental engineering programs in the U.S. He is one of the world's leading authorities on the application of sustainability principles to industrial issues. He has mentored over 100 students to the completion of their graduate degrees, including 33 Ph.D. students. He has published more than 400 papers in various journals and conference proceedings and is co-author of the textbook: Statistical Quality Design and Control: Contemporary Concepts and Methods. Sutherland is a Fellow of the Society of Mechanical Engineers (ASME), International Academy for Production Engineering or College International pour la Recherche en Productique (CIRP), and American Association for the Advancement of Science (AAAS). He was elected to the National Academy of Engineering (NAE) in 2023. Sutherland received his B.S., M.S., and Ph.D. degrees from the University of Illinois at Urbana-Champaign.

ANAND TANIKELLA: Anand Tanikella is currently the worldwide Vice President of R&D for Saint-Gobain Surface Solutions based in Massachusetts, USA. He manages teams in over 30 locations worldwide with several hundred team members. Anand joined Saint-Gobain in 1996 in USA as a Senior Research

Engineer in Saint-Gobain's North American R&D Center in Northborough, MA in the Boston area. He held various positions with increasing responsibilities during the past 26 years, conducting breakthrough R&D in technologies related to Ceramics, Abrasives, Plastics and various Construction materials. He is experienced in technology management, bringing out profitable innovations and passionate about influencing the impact of engineering education on industrial innovation. Anand has authored numerous international journal publications and holds over 18 patent families with several in process. Anand received a Ph.D. in Materials Science & Engineering and Precision Engineering from North Carolina State University in 1996 and a B.S. in Mechanical Engineering from SRKR Engineering College, Andhra University, India and was the university gold medalist (1st Rank). Anand is also an honoree of NC State University College of Engineering Hall of Fame.

JOHN VICKERS: Mr. Vickers concurrently serves as the principal technologist for advanced manufacturing in the Space Technology Mission Directorate at NASA Headquarters and as the senior leader for advanced manufacturing at the NASA Marshall Space Flight Center. He also serves as the associate director of the Marshall Materials and Processes Laboratory and as the director of NASA's National Center for Advanced Manufacturing. The National Center for Advanced Manufacturing has been in operation for more than 20 years and is home to a partnership between NASA's Michoud Assembly Facility, the State of Louisiana, Louisiana State University, and the University of New Orleans. In these positions, he provides agency-wide leadership responsible for the formulation of technology investment strategies and is the principal steward of the agency's advanced manufacturing technical capabilities to meet long-term needs and achieve NASA's challenging goals. He is the NASA representative on the National Science and Technology Council's Subcommittee on Advanced Manufacturing and on the Subcommittee on Critical Minerals. He has over 40 years of experience in materials and manufacturing, including research and development, engineering, and production operations for propulsion, spacecraft, and scientific systems. He received a Bachelor of Science degree in Industrial and Systems Engineering from the University of Alabama in Huntsville. He is a fellow of SME and an associate fellow of AIAA.

JOHN WILCZYNSKI: As the Executive Director of America Makes, John is responsible for the leadership and strategic vision of the Institute. Through his national outreach, sustainment efforts, and management of membership and stakeholders, he drives the mission and vision for the nation's leading public-private partnership for additive manufacturing (AM) technology and education. In 2009, John joined the National Center for Defense Manufacturing and Machining (NCDMM) and, in 2012, transitioned to the America Makes program, which is driven by NCDMM. He continues to play an instrumental role in the amplification of the additive manufacturing industry.

HITOMI YAMAGUCHI: Dr. Yamaguchi is a professor and the graduate coordinator in the Department of Mechanical and Aerospace Engineering at the University of Florida. Her research interests have evolved throughout her career and now include ultra-precision finishing, magnetic field-assisted finishing, surface functionalization, and medical-device development. Her work has been published in over 100 refereed journal papers, and she has been granted 13 patents. She has received many awards, including Outstanding Young Engineer awards from Japan Society of Mechanical Engineers (JSME) in 1995, Society of Manufacturing Engineers (SME) in 2000, and Japan Society for Abrasive Technology (JSAT) in 2003. In 2018-2019, she served as the President of the North American Manufacturing Research Institute of SME. She is currently the Chair of the Scientific Technical Committee for Abrasive Processes (STC-G) of CIRP (International Academy for Production Engineering). In recognition of her contributions, she has been elected a fellow of both ASME and SME.

Appendix B: Brief Biographies of Six Organizers

FARUQUE HASAN: Dr. Faruque Hasan is an Associate Professor and the Kim and Phillip McDivitt Faculty Fellow in the Artie McFerrin Department of Chemical Engineering at Texas A&M University. He also serves as an Assistant Director of Decarbonization at the Texas A&M Energy Institute. His research group develops multiscale methods, tools, and techniques for process systems engineering, design, analysis, and optimization with direct applications to decarbonization of the energy and industrial sectors. Specific technological interests include carbon capture, utilization and storage, methane separation, sustainable hydrogen economy, and resilient supply chains. He is the recipient of a National Science Foundation CAREER award, American Chemical Society Petroleum Research Fund New Doctoral Investigator award, and Outstanding Young Researcher award from the Computing & Systems Technology Division of the American Institute of Chemical Engineers (AIChE). He received a Ph.D. in chemical engineering from National University of Singapore and completed his postdoctoral training at Princeton University.

MICHAEL D. JOHNSON: Dr. Michael D. Johnson is a professor in the Department of Engineering Technology and Industrial Distribution at Texas A&M University. He also serves as interim associate provost for faculty success and interim associate vice president for faculty affairs. Prior to joining the faculty at Texas A&M, he was a senior product development engineer at the 3M Corporate Research Laboratory in St. Paul, Minnesota. His research focuses on production economics, engineering education, and design tools. He has over 100 peer reviewed publications and several patents. His research has been funded by the National Science Foundation, the Department of Energy, and industry. He is an ASEE National Engineering Technology Teaching Award and Fredrick J. Berger Award winner. He has served as the chair of the ASME Mechanical Engineering Technology Leadership Committee. He received his S.M. and Ph.D. from the Massachusetts Institute of Technology. He received his B.S. from Michigan State University.

CHAO MA: Dr. Chao Ma is an Associate Professor for the Department of Engineering Technology and Industrial Distribution at Texas A&M University. He was a senior mechanical engineer at ASML from 2015 to 2016. His expertise covers additive manufacturing, laser manufacturing, and metal matrix nanocomposites. He has published nearly 50 journal papers in these areas. His research, teaching, and service have been recognized by multiple awards, such as the NSF CAREER Award, the SME Outstanding Young Manufacturing Engineer Award, the Outstanding Paper Award at the International Conference on MicroManufacturing, the Best Paper Award of Manufacturing Division at the ASEE Annual Conference and Exposition, and the ASME Best Organizer of Symposium and Session Award. He received his Ph.D. degree from University of California, Los Angeles in 2015, M.S. degree from University of Wisconsin–Madison in 2012, and B.E. degree from Tsinghua University in 2010, all in Mechanical Engineering.

NIKOLAOS MICHAILIDIS: Dr. Nikolaos Michailidis is a Research Professor in the Department of Materials Science and Engineering at Texas A&M University, and a Professor and the Director of the Physical Metallurgy Laboratory in Department of Mechanical Engineering at Aristotle University of Thessaloniki (AUTH), Greece. He is also the Chair of the Centre for Research & Development on Advanced Materials – a Joint initiative between Texas A&M Engineering Experiment Station and AUTH. He is a Fellow of the International Academy for Production Engineering (CIRP) and the Editor-in-Chief of the European Journal of Materials. He served as the President of the Hellenic Metallurgical Society (2016-2022) and the Chair of the Scientific Committee of EUROMAT 2019. He served as a Visiting Professor at Fraunhofer Institute for Production Technology (IPT), Aachen-Germany (2008-2009). He is an author of 151 journal publications, 291 publications in International Conferences, 4 Book Chapters, 4 articles in International Encyclopaedias, 132 publications in Greek language in National Conferences, and holds 14 Patents.

ZHIJIAN (ZJ) PEI: Dr. ZJ Pei is a professor in the Department of Industrial and Systems Engineering at Texas A&M University (TAMU), and the holder of the Mike and Sugar Barnes Professorship II. He is also the Director of Engineering Research Development Services. From November 2016 to November 2017, he was an ASME Foundation Swanson Fellow, serving as the Assistant Director for Research Partnerships at the Advanced Manufacturing National Program Office hosted by NIST. From August 2012 to August 2016, he served as the Program Director of the Manufacturing Machines and Equipment program at NSF. He has served as an associate editor for four journals and an editorial board member for seven journals. He has published about 200 journal papers and more than 160 conference papers. He is a fellow of ASME, SME, and IISE. He received his PhD degree in Mechanical Engineering from University of Illinois at Urbana-Champaign.

EMILY PENTZER: Dr. Emily Pentzer is an Associate Professor in the Department of Chemistry and the Department of Materials Science and Engineering at Texas A&M University. Her research centers on developing new polymeric materials and assemblies as a route to understand structure-property-application relationships and access functions not possible with current state-of-the-art systems. Her group works on the encapsulation of “active” liquids and gases, designing and synthesizing new polymer chemistries, and developing feedstocks for additive manufacturing to produce multifunctional materials, and these materials have applications in thermal energy management, electrochemical energy storage, and carbon capture. She has received several awards including the NSF CAREER award (2016), PMSE Young Investigator Award (2017), ACS WCC Rising Star Award (2021). She serves as Editor in Chief of RSC Applied Polymers. She received a BS in chemistry from Butler University (2005) and PhD in chemistry from Northwestern University (2010).

Appendix C: Workshop Agenda

Thursday, August 3, 2023

| Time | Event |
|---------------|--|
| 8:00 - 8:20 | Introduction and Opening Remarks (Moderator: Michael D. Johnson) <ul style="list-style-type: none"> Alexis Lewis: NSF Workshop on Advanced Manufacturing for Industrial Decarbonization |
| 8:20 - 9:20 | Invited Talks on Industrial Electrification and Energy Efficiency (Moderator: Hitomi Yamaguchi) <ul style="list-style-type: none"> Cecilia Springer: Deep Decarbonization of Industry Through Electrification of Process Heating Nilanjan Sarangi: Decarbonization – An Abrasive Manufacturer’s Perspective Sachin Nimbalkar: Energy Efficiency as a Foundational Technology Pillar for Industrial Decarbonization |
| 9:20 - 10:10 | Panel Discussion on Industrial Electrification and Energy Efficiency (Moderator: Thomas R. Kurfess) <ul style="list-style-type: none"> Panelists: Cecilia Springer, Nilanjan Sarangi, and Sachin Nimbalkar |
| 10:10 - 10:30 | Coffee Break |
| 10:30 - 11:30 | Invited Talks on Low-Carbon Fuels, Feedstocks, and Energy Sources (Moderator: Nikolaos Michailidis) <ul style="list-style-type: none"> Eric C.D. Tan: Energy and Techno-Economic Analysis of Bio-based and Low-carbon Chemicals and Fuels Production Processes Don Stevenson: Potential Contributions of Advanced Manufacturing toward Industrial Decarbonization Jonathan Scheffe: Strategies for Harnessing Solar Thermal Energy for Industrial Decarbonization |
| 11:30 - 12:20 | Panel Discussion on Low-Carbon Fuels, Feedstocks, and Energy Sources (Moderator: Tim Shinbara) <ul style="list-style-type: none"> Eric C.D. Tan, Don Stevenson, and Jonathan Scheffe |
| 12:20 - 13:30 | Lunch Break |
| 13:30 - 14:50 | Invited Talks on Carbon Capture, Utilization, and Storage (Moderator: Faruque Hasan) <ul style="list-style-type: none"> Volker Sick: Market and Climate Opportunities for CO₂ Utilization John Shingledecker: Opportunities for Advanced Manufacturing and Materials in Improving Carbon Capture Technology Doug Robinson: Carbon Utilization in Concrete Manufacturing Brad Brennan: Converting CO₂ and Water into Hydrocarbons |
| 14:50 - 15:40 | Panel Discussion on Carbon Capture, Utilization, and Storage (Moderator: Emily Pentzer) <ul style="list-style-type: none"> Panelists: Volker Sick, John Shingledecker, Doug Robinson, and Brad Brennan |
| 15:40 - 16:00 | Coffee Break |
| 16:00 - 17:10 | Idea Presentations (Moderator: Steven R. Schmid) <ul style="list-style-type: none"> Lei Chen: Resonant Acoustics-Assisted Mechanochemistry Method for Li-ion Battery Recycling Pei Dong: Manufacturing Porous Carbon Structures at Multiple Scales for Sustainability Ping Guo: Solid-State Powder Generation for Circular Economy in Additive Manufacturing |

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| | <ul style="list-style-type: none"> • Zhe Qiang: Plastic Wastes Enabling Decarbonized Chemical Manufacturing • John Schueller: Internal Surface Treatments to Help Decarbonize Industrial Cleaning Processes • Xuan Song: Nature-inspired Additive Manufacturing of Ceramics with Significantly Reduced Carbon Emissions • Qiang Xu: Novel Natural Gas Monetization Method for Simultaneous Production of Electricity, Fertilizer, and Salicylic Acid with Inherent CO₂ Sequestration and Utilization • Cheryl Xu: Additive Manufacturing of Functionally-Graded Refractory Metal-Ceramic Structures using the Electron Beam Sintering (EBS) Process • Meng Zhang: Exploring How Biomass Can Help on the Path to Industrial Decarbonization • Jingzhou Zhao: Continuous Casting of High-Temperature Micro-encapsulated Phase Change Materials for Industrial Decarbonization |
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Friday, August 4, 2023

| Time | Event |
|---------------|---|
| 8:30 - 8:40 | Introduction and Announcements |
| 8:40 - 9:40 | Invited Talks on Federal Agencies' Perspectives (Moderator: Brigid Mullany) <ul style="list-style-type: none"> • Avi Shultz: Overview of DOE Research, Development & Demonstration of Industrial Efficiency and Decarbonization Technologies • Philseok Kim: Opportunities with ARPA-E to Advance and Decarbonize Manufacturing and Industrial Processes • KC Morris: Standards Needs for Industrial Decarbonization through Circularity |
| 9:40 - 10:10 | Panel Discussion on Federal Agencies' Perspectives (Moderator: John Vickers) <ul style="list-style-type: none"> • Panelists: Avi Shultz, Philseok Kim, and KC Morris |
| 10:10 - 10:30 | Coffee Break |
| 10:30 - 11:10 | Invited Talks on Federal Agencies' Perspectives (Moderator: Erick Jones) <ul style="list-style-type: none"> • Cliff Ho: Federal Legislation and Incentives for Clean-Energy Manufacturing and Industrial Decarbonization • Khershed Cooper: NSF Advanced Manufacturing Program and Funding Opportunities |
| 11:10 - 11:40 | Panel Discussion on Federal Agencies' Perspectives (Moderator: Alaa Elwany) <ul style="list-style-type: none"> • Panelists: Cliff Ho and Khershed P. Cooper |
| 11:40 - 12:00 | Summarizing Key Workshop Findings |

Appendix D: Brief Biographies of 16 Invited Speakers

BRAD BRENNAN: Dr. Brad Brennan is the Chief Science Officer at Dimensional Energy, a startup company converting carbon dioxide back into hydrocarbons. There, he leads the development of catalyst and thermocatalytic reactors for converting carbon dioxide and green hydrogen into syngas for downstream conversion into chemicals and fuels. This was showcased during the finals of the NRG COSIA Carbon XPrize in 2020 with a successful pilot of a solar thermal driven system. Dimensional Energy currently utilizes funding from DOE's ARPA-E and Solar Energy Technologies Office for advanced manufacturing of corrosion-resistant ultra-high temperature materials for chemical reactors and solar thermal applications. Dr. Brennan obtained his Doctoral Degree from Arizona State University with subsequent post-doctoral experiences at Yale University and Caltech.

KHERSHED COOPER: Dr. Khershed P. Cooper is a Program Director for Advanced Manufacturing in the Civil, Mechanical and Manufacturing Innovation (CMMI) Division of the Engineering (ENG) Directorate at National Science Foundation (NSF). He directs basic research activities in advanced manufacturing, nanomanufacturing and associated Manufacturing USA Institutes and NSF-DFG (Deutsche Forschungsgemeinschaft) collaborations. He is a disciplinary program officer for the Engineering Research Centers (ERCs), and a co-program officer for cross-cutting programs – Critical Aspects of Sustainability (CAS), CAS: Climate Change, Civil Infrastructure research for climate change Mitigation and Adaptation (CLIMA), Emerging Frontiers in Research and Innovation (EFRI), Network for Computational Nanotechnology (NCN), National Nanotechnology Coordinated Infrastructure (NNCI), NSF Directorate for Engineering - UKRI Engineering and Physical Sciences Research Council Lead Agency Opportunity (ENG-EPSRC) and Accelerating Research through International Network-to-Network Collaborations (AccelNet). Dr. Cooper is an NSF representative for the National Science and Technology Council (NSTC)'s Nano Science Engineering and Technology (NSET) Sub-committee, which frames the National Nanotechnology Initiative (NNI) Strategic Plan. He represents NSF for NextFlex (flexible hybrid electronics) and REMADE (circular economy) Manufacturing USA Institutes. He has nearly 150 publications, edited one book and holds one patent. He is a Fellow of SME and ASM International and a recipient of ASM International's Burgess Memorial Award. He received his MS and PhD from University of Wisconsin–Madison and his BTech from IIT—Bombay.

CLIFF HO: Dr. Cliff Ho is serving as a legislative fellow in Senator Heinrich's office advising on energy and climate issues. He is a senior scientist at Sandia National Laboratories, where he has worked since 1993 on problems involving solar energy, energy storage, water safety and sustainability, heat- and mass-transfer processes in porous media, microchemical sensor systems for environmental monitoring, nuclear waste management, modeling of airborne pathogen transport and exposure-risk mitigations, and industrial decarbonization. Dr. Ho has authored over 300 scientific papers, holds over 20 patents, and is author and co-editor of three books. He received an Outstanding Professor Award at the University of New Mexico in 1997, and he received the national Asian American Engineer of the Year Award in 2010. Dr. Ho received an R&D 100 Award in 2013 for his development of the Solar Glare Hazard Analysis Tool, and an R&D 100 Award in 2016 for the development of the Falling Particle Receiver for Concentrating Solar Energy. In 2008, he won Discover magazine's "The Future of Energy in Two-Minutes-or Less" video contest. Dr. Ho is a Fellow of the American Society of Mechanical Engineers.

PHILSEOK KIM: Dr. Philseok Kim is a Program Director at the Advanced Research Projects Agency - Energy (ARPA-E), where he leads research efforts aimed at accelerating the electrification and decarbonization of energy infrastructure through the development of functional materials and composites, engineered surfaces, and structures with high energy efficiency, resilience, and low carbon emissions. Dr. Kim has a wealth of experience in both academia and industry. Before joining ARPA-E, he co-founded Adaptive Surface Technologies, Inc. and leveraged ARPA-E-funded SLIPS projects to develop fouling-resistant and fuel-saving ship hull coatings and additives. He also co-led pre-commercial development

projects at Harvard University aimed at improving the energy efficiency of refrigerators by reducing frost formation and defrost time. Dr. Kim holds a Ph.D. in chemistry from the Georgia Institute of Technology and received his B.S. and M.S. from Seoul National University. He has 12 years of industrial experience in the petrochemicals, polymers, and coatings products sectors.

ALEXIS LEWIS: Alexis Lewis is the Deputy Division Director for Civil, Mechanical and Manufacturing Innovation in NSF's Directorate for Engineering. She joined NSF in 2014 as a Program Director for Materials Engineering and Processing, which later became part of the Advanced Manufacturing Program. A Metallurgist by training, Dr. Lewis has worked across NSF on the Designing Materials to Revolutionize and Engineer our Future (DMREF) program, and in support of computation and data-driven activities including Cyberinfrastructure for Sustained Scientific Innovation (CSSI) and Harnessing the Data Revolution (HDR). She currently serves on NSF's Public Access and Open Science Working Group, on the Board of Directors for the Minerals, Metals and Materials Society (TMS), and is a member of the White House Subcommittee on the Materials Genome Initiative (SMGI). Prior to joining NSF, Dr. Lewis was a staff scientist at the Naval Research Laboratory in Washington DC. She holds an SB, MSE and PhD in Materials Science and Engineering.

KC MORRIS: KC Morris is an internationally recognized researcher and leader at the National Institute of Standards and Technology (NIST). She applies her background in computer science, information modeling, and knowledge representation to solve industrial challenges in the manufacturing sector while ensuring that new practices lead to more competitive and sustainable manufacturing. Building on a 30+ year career contributing to research and standards for manufacturing systems integration, she currently leads the effort towards standards for transitioning manufacturing to a circular economy. KC's earlier work contributed foundational standards for sharing product designs followed by leadership in smart and sustainable manufacturing. She serves on the executive committee of ASTM International's E60 Committee on Sustainability, as vice-chair of ASTM E60.13 on Sustainable Manufacturing, member of the US TAG for ISO 323 on Circular Economy, a technical expert to ISO TC 184 on Automation systems and integration, and President-Elect for SME's North American Manufacturing Research Institute (NAMRI). KC served as an ASME Congressional Fellow during the 116th Congress (2018-2020) where she focused on US manufacturing policy while supporting the US Congressional House Manufacturing Caucus. KC is a Fellow of SME and AAAS.

SACHIN NIMBALKAR: Dr. Sachin Nimbalkar is the Group Leader of the Oak Ridge National Laboratory's (ORNL) Manufacturing Energy Efficiency Research & Analysis Group. Dr. Nimbalkar and his group conduct research; analyze and disseminate knowledge on energy, carbon, water, and material efficiency in the manufacturing sector; and develop, deploy, and promote impactful practices, tools, and technologies in the field of energy efficiency and decarbonization. Dr. Nimbalkar provides technical support to U.S. Department of Energy's Better Plants and Better Climate Challenge partners through energy roadmap development, baselining analyses, in-plant trainings, and field visits to investigate feasible measures to reduce process energy requirements. Dr. Nimbalkar conducts life-cycle assessment and techno-economic analysis in the areas of energy efficiency, decarbonization, sustainable manufacturing, smart manufacturing, and water-energy nexus. He has contributed to the U.S. DOE's high impact publications on energy efficiency and decarbonization such as Industrial Decarbonization Roadmap in 2022 and Quadrennial Technology Review in 2015. Dr. Nimbalkar has held several training workshops and webinars throughout Brazil, China, Costa Rica, India, Turkey, and Ukraine, covering energy efficiency in process heating systems and waste heat recovery from industrial process heating equipment and DOE's Process Heating Assessment and Survey Tool.

DOUG ROBINSON: Dr. Doug Robinson is the Senior Director of Performance at Solidia Technologies, a leading provider of decarbonization technologies and sustainable solutions to the construction and building materials industries. Solidia Cement® is produced with less limestone and at lower temperatures than

Portland cement. Solidia Cement carbonates in the production of final products, further reducing the carbon intensity of concrete applications. Solidia is the third cleantech startup that Dr. Robinson has worked for. Most of his career was in investment banking, having worked for Deutsche Bank and Merrill Lynch. His career started as a reservoir engineer with Shell. Dr. Robinson obtained his doctorate from the Engineering-Economic Systems Department of Stanford University and his B.S. in Chemical Engineering from the University of Virginia.

NILANJAN SARANGI: Nilanjan Sarangi is a Global R&D Director at Saint Gobain Abrasives. Nilanjan is responsible for product and process development for Vitrified Bonded Abrasive and coordinating abrasive grains activities across all regions. Nilanjan's role includes developing and delivering innovations that lower carbon footprint for the end customers' processes as well as improving internal processes to enable Saint-Gobain's journey to a low-carbon manufacturing and use of products. Nilanjan's background is in Glass and Ceramic Engineering, and he has long and varied multinational and multi-disciplinary background. He has worked in manufacturing, process control, and quality assurance among other plant functions before his current assignment as the Global R&D Director. He has over 20 patents in his field of work, many of those improving carbon footprint of both manufacturing and end use.

JONATHAN SCHEFFE: Jonathan Scheffe is an Associate Professor in the Department of Mechanical and Aerospace Engineering at the University of Florida. Prof. Scheffe is Principle Investigator of the Renewable Energy Conversion Laboratory that is focused on research in the area of energy conversion and storage. Applications include the production of renewable fuels/electricity, H₂ production and fuel reforming. He is the former chair of the American Society of Mechanical Engineers (ASME) Solar Energy Division and has co-authored more than 40 peer reviewed publications in the field of solar thermal energy conversion. Prof. Scheffe has received research funding from the U.S. Department of Energy, Duke Energy, Synhelion SA, Florida Department of Transportation, and Qatar National Research Foundation.

JOHN SHINGLEDECKER: Dr. John Shingledecker is a Principal Technical Executive in the Electric Power Research Institute (EPRI). As a recognized technical expert and thought leader for the Generation Sector, his activities include leading key technical projects in advanced manufacturing methods and materials for new generation technologies, strategic leadership in EPRI Technology Innovation programs, and collaboration with governmental and international research organizations. Prior to his current role, Dr. Shingledecker led EPRI's Cross Sector Technologies research area focused on chemistry, water, materials and NDE as well as leading EPRI's Materials and Repair Program. He was the technical leader for the DOE/OCDO Advanced Ultrasupercritical (A-USC) Steam Boiler and Turbine Consortia. His current research focuses on nickel-based structural alloys for future gas turbines, concentrating solar power plants, and advanced nuclear technologies. Prior to joining EPRI in 2008, he held various positions at Oak Ridge National Laboratory (ORNL). He is a Fellow of the American Society for Materials (ASM), serves on the editorial committee for Advanced Materials & Processes and International Materials Review. He has published more than 200 papers, proceedings, and reports on the metallurgy and behavior of engineering alloys. He has given over 20 invited lectures/seminars/keynote presentations. His accomplishments include ORNL's highest award for technology transfer, EPRI's Chauncey Starr award for research (2009, 2011, 2014, 2016), two best-paper awards, and most recently the 2021 Carl-von-Bach Medal from the Materials Testing Institute from the University of Stuttgart, Germany. He holds B.S. and M.S. degrees in materials science and engineering from Michigan Technological University and a Ph.D. in materials science and engineering from the University of Tennessee Knoxville.

AVI SHULTZ: Dr. Avi Shultz is the Deputy Director of the U.S. Department of Energy's Industrial Efficiency and Decarbonization Office, which supports innovation in technologies and the adoption of practices to enable the industrial sector to cost-effectively reduce greenhouse gas emissions. Previously, he was the Program Manager for concentrating solar-thermal power (CSP) for DOE's Solar Energy Technologies Office (SETO). Dr. Shultz has been with DOE since 2013, where he started as a science and

technology policy fellow. Before joining DOE, Dr. Shultz was a post-doctoral fellow at the University of Amsterdam, after getting his Bachelor and Doctoral degrees in Chemistry, from Columbia University and Northwestern University, respectively.

VOLKER SICK: Volker Sick, Arthur F. Thurnau Professor of Mechanical Engineering and DTE Energy Professor of Advanced Energy Research, is the Director of the Global CO₂ Initiative and Faculty Director of the Center for Entrepreneurship at the University of Michigan College of Engineering. His research focuses on accelerating deployments of CO₂-utilization technologies for decarbonization solutions and continued access to required carbon-based products to help address the climate crisis. His most recent awards and honors include the ASME Edwin F. Church Medal, the Royal Society of Chemistry Spiers Memorial Medal, and the President's Award for Distinguished Service in International Education. He is a Fellow of SAE International and Fellow of The Combustion Institute. He joined the University of Michigan as a Professor of Mechanical Engineering in 1997. He received his Doctorate in Chemistry and Habilitation in Physical Chemistry from the University of Heidelberg, Germany.

CECILIA SPRINGER: Cecilia Springer is a Senior Research Manager at Global Efficiency Intelligence. Her interdisciplinary research background spans the economics and policy of international low-carbon transition and industrial decarbonization. She has extensive experience in conducting techno-economic analysis on industrial energy efficiency and decarbonization and working on industrial policy analysis. Previously, she was a Research Affiliate at the Lawrence Berkeley National Laboratory and a postdoctoral fellow at the Harvard Kennedy School. She earned a M.S. and Ph.D. from the Energy and Resources Group at the University of California, Berkeley and a B.S. in Environmental Science from Brown University.

DON STEVENSON: As Vice President of Energy Supply & Conversion, Don Stevenson leads GTI Energy's research, development and demonstration projects focused on increasing the affordability and improving the environmental performance of our energy resources through environmentally responsible energy production, application of energy conversion processes such as gasification, partial oxidation, reforming and advanced power cycles, and development of bioenergy and CO₂ capture and utilization processes. He has served in leadership roles at Rockwell International, The Boeing Company, and United Technologies Corporation. Don earned a B.S. degree in Aeronautical & Astronautical Engineering from the University of Washington and an MBA from Pepperdine University.

ERIC C.D. TAN: Dr. Eric Tan is a senior research engineer and sustainability analyst at the National Renewable Energy Laboratory (NREL). He specializes in biomass conversion pathways for low-carbon fuel and chemical production. Dr. Tan has extensive industry R&D experience, including fuel processing technology, hydrogen production processes, and commercial fuel cell systems. He is a senior member of the American Institute of Chemical Engineers (AIChE), chair and technical advisor of the AIChE's Sustainable Engineering Forum Leadership Team, and an American Center for Life Cycle Assessment (ACLCA) certified LCA Professional. Dr. Tan has made significant contributions to the fields of heterogeneous catalysis, biorefinery, process intensification, decarbonization, circular economy, and sustainability, as reflected in his numerous publications. He received his Ph.D. degree in Chemical Engineering from the University of Akron and master's degree (ALM) in Sustainability from Harvard University.

Appendix E: Brief Biographies of 10 Idea Presenters

LEI CHEN: Dr. Lei Chen is currently an assistant professor in Department of Mechanical Engineering, University of Michigan-Dearborn and affiliated with Michigan Institute for Data Science and Graham Sustainability Institute. Chen's research interest is in the broad area of advanced manufacturing, particularly on clean energy. The research in Chen's group is supported by NSF, ORAU, ARL, ONR-SBIR, MIDAS and automobile industries. Chen has published over 100 authored and co-authored papers in top international journals, with > 5500 citations to date, such as, Nature, Nature Communications, npj Computational Materials, Advanced Materials, Advanced Energy Materials, Acta Materialia, International Journal of Plasticity, ASME Journal of Manufacturing Science and Engineering, Additive Manufacturing, etc. Chen is in close collaboration with automobile industries in Detroit. He has received several awards from universities and organizations. Recent awards include the prestigious ASEE Southeastern Section New Researcher Award (2018), ORAU Ralph E. Powe Junior Faculty Enhancement Award (2017), Chinese Excellent Self-Financed Student Abroad Award (2012), and President Graduate Fellowship Award at National University of Singapore (2009).

PEI DONG: Pei Dong is an assistant professor in the Department of Mechanical Engineering at George Mason University. Her current research interests include the design and manufacturing of advanced materials, as well as their applications in energy, water, and biomedical fields. She is the recipient of the Franz and Frances Brotzen Fellowship Award, Best Thesis Award, and Materials Today Energy Promising Early Career Scientists Award. She then did her postdoctoral research in the Department of Materials Science and NanoEngineering at Rice University. She obtained her Ph.D. in Mechanical Engineering from Rice University and her B.S. in Microelectronics from Nankai University.

PING GUO: Dr. Ping Guo is an Assistant Professor at the Department of Mechanical Engineering, Northwestern University. Dr. Guo's research interests center on the paradigm of micro/meso-scale manufacturing, including precision surface texturing, process micro-mechanics, miniature machine tools, metrology, micro-additive manufacturing, etc. He currently serves as the Associate Editor of the Journal of Manufacturing Processes. He is the recipient of Kornel F. Ehmann Manufacturing Medal from ASME 2021, Outstanding Young Manufacturing Engineer Award from SME 2020, Young Investigator Award from International Symposium on Flexible Automation 2018, Hong Kong Research Grants Council Early Career Award 2016. He is elected as the Associate Member of the International Academy for Production Engineering (CIRP) in 2022. Before joining Northwestern University in September 2018, he spent four years at the Chinese University of Hong Kong as an Assistant Professor. He received his B.S. degree in Automotive Engineering from Tsinghua University in 2009 and his Ph.D. degree in Mechanical Engineering from Northwestern University in 2014.

ZHE QIANG: Dr. Zhe Qiang is an Assistant Professor of Polymer Science and Engineering at the University of Southern Mississippi (USM). His group's current research interests include materials and manufacturing science of polymers and their derived functional materials for the sustainable development of environment and society, including pioneering the additive manufacturing of functional carbons using plastic waste materials. Since the start of his independent career in 2019, Dr. Qiang has received many awards and honors, including an ACS PRF Doctoral New Investigator (2021), NSF EPSCoR Fellow (2022), Forbes 30 under 30 in Science (2022), USM College of Arts and Science Junior Faculty of the Year (2022), ACS PMSE Early Career Investigator (2023), SAMPE Emerging Leadership Award and Young Professional of the Year (2023), USM Basic Research Award (2023), and NSF CAREER Award (2023). He also received an NASA-MSSGC STEM Enhancement Award in 2019, recognizing his contributions and efforts in STEM education and outreach. He received his M.S. and Ph.D. degrees in Polymer Engineering from the University of Akron, and was a postdoc fellow at Northwestern University.

JOHN SCHUELLER: John K. Schueller is a professor in mechanical and aerospace engineering at the University of Florida. Prof. Schueller is currently leading the University of Florida's efforts within the multi-institution NSF ENGINES Development Grant project on Advancing Additive Manufacturing Technologies. He has served on supervisory committees for almost five hundred graduate students in a dozen majors. Among other previous employers are a lawn and garden equipment manufacturer, Texas A&M, Caterpillar, Kyoto University, and Universiti Putra Malaysia.

XUAN SONG: Dr. Xuan Song is an Associate Professor and James A. Chisman Faculty Fellow in the Department of Industrial and Systems Engineering at the University of Iowa (UIowa). His research focuses on studying how material forming processes existing in nature can be utilized to enable next-generation additive manufacturing (AM) technologies for ceramics and composites. He has received several awards including the NSF CAREER award, the SME Outstanding Young Manufacturing Engineer award, College of Engineering Early Career Faculty Excellence award at UIowa, and the Best Paper award in the QSR track of INFORMS. He received his bachelor's degree in Mechanical Engineering from Wuhan University, master's degree in Mechanical Engineering from Zhejiang University, and PhD degree in Industrial Engineering from the University of Southern California.

QIANG XU: Dr. Qiang Xu is the Full Professor of Dan F. Smith Department of Chemical & Biomolecular Engineering at Lamar University in Beaumont, Texas, USA. His main research areas include process synthesis, production scheduling, dynamic simulation and optimization with particular applications in chemical/petrochemical/midstream industrial emissions reductions, energy saving, process safety, and regional air-quality analysis. He has published 169 peer-reviewed papers and given over 300 invited talks and conference presentations. He is the recipient of 2016 Excellence in Process Development Research Award from AIChE, University Professor Award in 2020, University Scholar Award in 2012, and University Merit Award in 2010. He is also the holder of Anita Riddle Faculty Fellow in 2017 and Distinguished Faculty Research Fellow during 2015~2021 from Lamar University. He is currently the Chair of the AIChE Process Development Division. Dr. Xu obtained his B.S. degrees in chemical engineering and environmental engineering respectively, both in 1998; Ph.D. degree in 2003 in chemical engineering, all from Tsinghua University in Beijing, China.

CHERYL XU: Dr. Cheryl Xu is a Professor of Mechanical and Aerospace Engineering at North Carolina State University. She is an expert with 20+ years of experience in multifunctional ceramic materials, high-temperature wireless sensing, and artificial intelligence (AI) for process modeling and real-time control. Her research work has been supported by both government agencies and large defense companies that include and are not limited to the Office of Naval Research (ONR), Army Research Office (ARO), Air Force Office of Scientific Research (AFOSR), National Science Foundation (NSF), Department of Energy (DOE), National Aeronautics and Space Administration (NASA), and General Dynamics, etc. She has graduated 8 Ph.D. and 7 M.S. students. She has co-authored 1 textbook and has written 7 book chapters. She has published ~70 peer-reviewed journal articles and ~40 refereed conference proceedings. She has 15 US and international patents and patent applications. Dr. Xu is a Fellow of the American Society of Mechanical Engineers (ASME). She won the Office of Naval Research (ONR) Young Investigator Award and was awarded the Society of Manufacturing Engineering (SME) Outstanding Young Manufacturing Engineer Award in 2011.

MENG ZHANG: Dr. Meng Zhang is an associate professor and a Steve Hsu Keystone research faculty scholar in the Department of Industrial and Manufacturing Systems Engineering at Kansas State University (K-State). Zhang's research is centered on advanced manufacturing. He is specifically interested in field-assisted manufacturing (ultrasonic and laser) and carbon-neutral manufacturing. Current research topics include: ultrasonic-assisted cutting of construction materials for silica dust reduction, abrasive machining of semiconductor and composite materials, high throughput multiphoton polymerization of functional structures, and hydrothermal carbonization of organic wastes for energy and environment applications. His

research has been supported by fundings from NSF and USDA. Research discoveries from Zhang's team have led to more than 50 publications in peer-reviewed journals, over 40 conference papers, and 2 book chapters. He organizes symposiums on "Nontraditional, Assisted, and Augmented Manufacturing Processes" for ASME Manufacturing Science and Engineering Conference every year since 2018. Zhang was a recipient of the "SME Outstanding Young Manufacturing Engineer" award in 2018. He received a bachelor's degree in Mechanical Engineering from Dalian University of Technology, China, in 2009, and a doctorate degree in Industrial Engineering from K-State in 2014.

JINGZHOU ZHAO: Jingzhou (Frank) Zhao is an assistant professor at Binghamton University. Before joining Binghamton University, he was an assistant professor at Western New England University and directed the Advanced Manufacturing and Materials Processing Laboratory, which conducts basic and applied research in solidification nanomanufacturing for energy and sustainability applications. He received his BS (2011) in Mechanical Engineering from Shanghai Jiao Tong University in China with emphases in Mechatronics and Automation, his MS (2013) from University of Wisconsin-Madison in manufacturing and energy applications of microsensors for in-situ sensing systems, and Ph.D. degree (2017) from University of California, Los Angeles, with a focus on scalable manufacturing of metal nanomaterials using thermal drawing.

Appendix F: Names and Affiliations of Registered Participants

| First Name | Last Name | Affiliation |
|------------|---------------|--|
| Guillermo | Aguilar | Texas A&M University |
| Alauddin | Ahmed | University of Michigan |
| Mohammad | Albakri | Texas A&M University at Qatar |
| Mark | Atwater | Liberty University |
| Bruno | Azeredo | Arizona State University |
| Mostafa | Bedewy | University of Pittsburgh |
| Debangsu | Bhattacharyya | West Virginia University |
| Linkan | Bian | NSF |
| Sandra | Boetcher | Embry-Riddle Aeronautical University |
| Brad | Brennan | Dimensional Energy |
| Lei | Chen | University of Michigan-Dearborn |
| Xiangfan | Chen | Arizona State University |
| Gary | Cheng | Purdue University |
| Harish | Cherukuri | UNC Charlotte |
| Ciera | Cipriani | Texas A&M University |
| Sesh | Commuri | University of Nevada at Reno |
| DANIEL | COOPER | University of Michigan |
| Khershed | Cooper | NSF |
| Hongtao | Dang | Washington State University |
| Hongtao | Ding | University of Iowa |
| Fatih | Dogan | Missouri University of Science and Technology |
| Pei | Dong | George Mason University |
| Nandika | DSouza | University of North Texas |
| Alaa | Elwany | U.S. Department of Energy |
| Zhaoyan | Fan | Oregon State University |
| Robert | Gao | Case Western Reserve University |
| Ping | Guo | Northwestern University |
| Rajeev | Gupta | North Carolina State University |
| Azadeh | Haghighi | University of Illinois Chicago |
| Ashley | Hartwell | NIST |
| Faruque | Hasan | Texas A&M University |
| Cliff | Ho | Office of U.S. Senator Martin Heinrich of New Mexico |
| David | Hoelzle | Ohio State University |
| Jida | Huang | University of Illinois at Chicago |
| Mo | Jiang | VCU |
| Michael | Johnson | Texas A&M University |
| Erick | Jones | University of Nevada, Reno |
| Ibrahim | Karaman | Texas A&M University |
| Marwan | Khraisheh | Texas A&M University at Qatar |
| Philseok | Kim | ARPA-E, Department of Energy |
| Tom | Kurfess | Georgia Tech Manufacturing Institute |
| Saniya | LeBlanc | The George Washington University |
| Jaesung | Lee | Texas A&M University |
| Markus | Lesemann | GTI Energy |
| Alexis | Lewis | National Science Foundation |
| Ying | Li | Texas A&M University |

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|-----------|---------------|--|
| Wei | Li | The University of Texas at Austin |
| Hongfei | Lin | Washington State University |
| Dong | Lin | Oregon State University |
| Xingbo | Liu | West Virginia University |
| Shunyu | Liu | Clemson University |
| Jeff | Ma | Saint Louis University |
| Chao | Ma | Texas A&M University |
| Rajiv | Malhotra | Rutgers The State University of New Jersey |
| Guha | Manogharan | Penn State University |
| Nikolaos | Michailidis | Texas A&M University |
| Amin | Mirkouei | University of Idaho |
| Reza | Moini | Princeton University |
| Katherine | Morris | NIST |
| Brigid | Mullany | UNC Charlotte |
| Sachin | Nimbalkar | Oak Ridge National Laboratory |
| Albert | Patterson | Texas A&M University |
| Zhijian | Pei | Texas A&M University |
| Emily | Pentzer | Texas A&M University |
| Adam | Powell | Worcester Polytechnic Institute |
| Zhe | Qiang | University of Southern Mississippi |
| Hongmin | Qin | Texas A&M University |
| Hantang | Qin | University of Wisconsin - Madison |
| Doug | Robinson | Solidia Technologies |
| Nilanjan | Sarangi | Saint-Gobain |
| Jonathan | Scheffe | University of Florida |
| Steve | Schmid | UNC Charlotte |
| John | Schueller | University of Florida |
| Chenhui | Shao | University of Illinois at Urbana-Champaign |
| Tim | Shinbara | AMT - The Association For Manufacturing Technology |
| John | Shingledecker | EPRI |
| Avi | Shultz | DOE - IEDO |
| Volker | Sick | University of Michigan |
| Xuan | Song | University of Iowa |
| Cecilia | Springer | Global Efficiency Intelligence |
| Don | Stevenson | Gas Technology Institute |
| Ying | Sun | University of Cincinnati |
| Murali | Sundaram | University of Cincinnati |
| Bruce L | TAI | Texas A&M University |
| Eric | Tan | National Renewable Energy Laboratory |
| George | Tan | Texas Tech University |
| Matt | Triebe | National Institute of Standards and Technology |
| John | Vickers | NASA |
| Zimo | Wang | SUNY Binghamton |
| Hui | Wang | Florida State University |
| Peng | Wang | University of Kentucky |
| Joerg | Werner | Boston University |
| Sarah | Wolff | The Ohio State University |
| Wenzhuo | Wu | Purdue University |
| Hao | Xu | University of Nevada, Reno |

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|----------|-----------|---------------------------------|
| Cheryl | Xu | North Carolina State Universty |
| Qiang | Xu | Lamar University |
| Baoxing | Xu | University of Virginia |
| Vikram | Yadama | Washington State University |
| Hhitomi | Yamaguchi | University of Florida |
| Rong | Yang | Cornell University |
| Wayne | Yuan | North Carolina State University |
| Dianyun | Zhang | Purdue University |
| Meng | Zhang | Kansas State University |
| Jingzhou | Zhao | Binghamton University |

Appendix G: A Group Photo at the Workshop

