Introduction

The 2018-2019 portfolio marks over 16 years of GCEP activities with research programs spanning 12 topic areas. This technical report contains individual reports from approximately 14 funded research activities that will come to an end on or before August 31, 2019. Additionally, reports from eight exploratory programs are provided, as well as descriptions from one cost-shared research program.

Reports from recently completed GCEP funded research activities are described by topic area in Chapter 2 and exploratory projects in Chapter 4. Investigators have provided final reports that include an abstract, introduction, results and progress, publications, and future directions.

A final report from cost-shared research is presented in Chapter 3. Participation in cost-shared research provides funding that leverages other third party contributions and continues the research interests of GCEP-related work. Currently GCEP is affiliated with one membership organization, the Stanford Center for Carbon Storage.

GCEP has now funded research across the following 12 broad topic areas of its portfolio:

1. Hydrogen Impacts, Production and Storage
2. Renewable Energy - Solar
3. Renewable Energy - Biomass
4. Carbon Dioxide Capture and Separation
5. Carbon Dioxide Storage
6. Advanced Combustion
7. Advanced Materials and Catalysts
8. Advanced Transportation
9. Advanced Electric Infrastructure
10. Energy Systems Analysis
11. Carbon Negative Energy
12. Energy for the Developing World

From 2003 to 2019, $165.5 million has been committed to GCEP research. The cumulative distribution of approved funds across the research portfolio is shown in Figure 1. There has been strong support for research in renewable energy sources comprising almost a third of funded projects. The broad categories of carbon-based energy systems, and electrochemistry and electric grid each are almost a quarter of the distribution. The single largest category of funding has been allocated to solar photovoltaics followed by bioenergy and then carbon capture and storage. The allocation of funding has expanded and changed over time as major projects were completed and new funds were targeted towards specific topic areas.

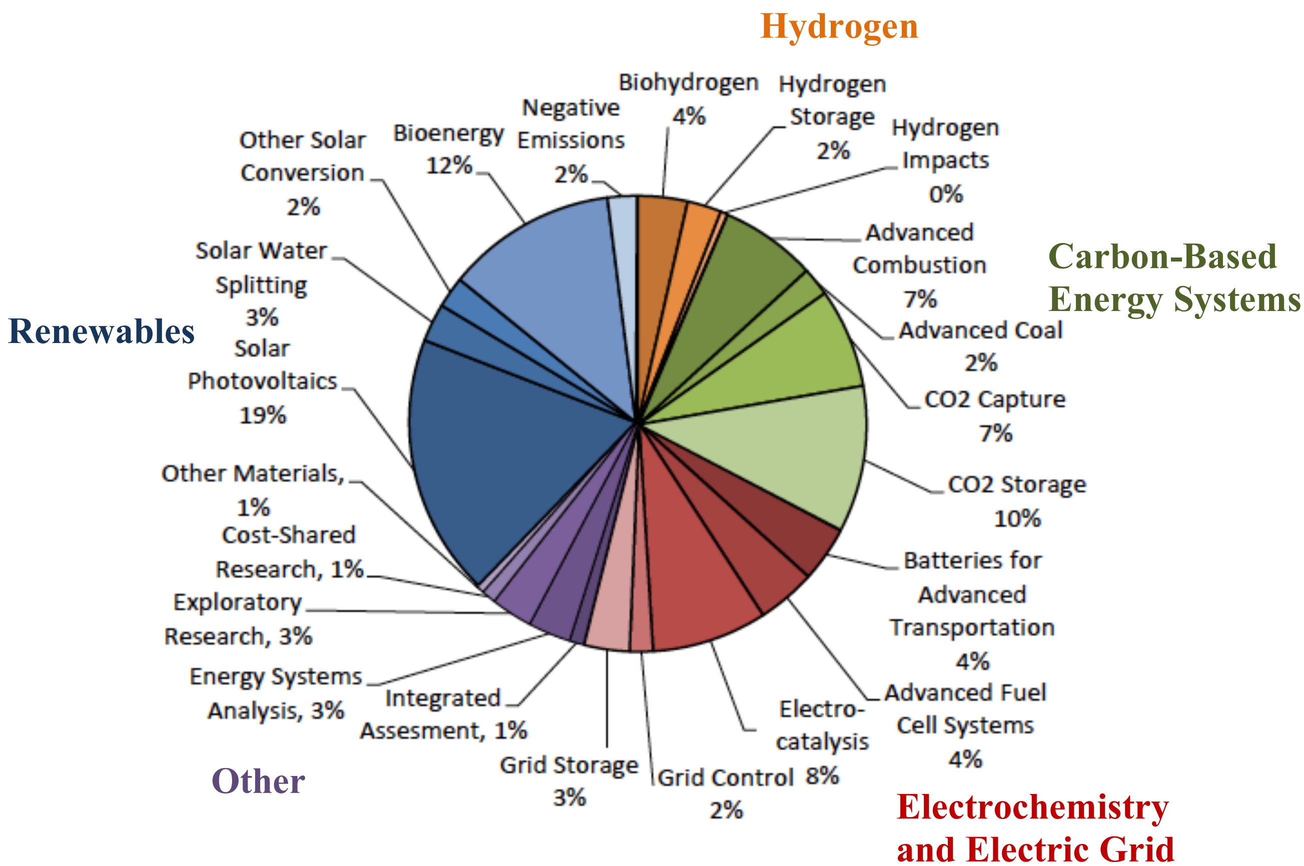

Figure 1. Cumulative GCEP Portfolio 2003-2019

While not an exhaustive list, each of these areas is expected to play an important and interconnected role in future energy systems and the reduction of greenhouse gas emissions (GHG). For example, hydrogen has been identified as a potential energy carrier in some energy scenarios. The research portfolio described here includes programs where the hydrogen is produced by microbes. Currently hydrogen is produced primarily from fossil fuels. Reduction of GHG emissions from that method of producing hydrogen would also require CO_2 capture and storage, another topic considered in this report.

One option for carbon mitigation is through carbon capture and storage (CCS). While there are many elements to the CCS chain, capture and separation technologies dominate upwards of 80% of the total CCS costs. There is significant opportunity to exploit fundamental advances in chemistry, materials science and engineering to drive down the penalties that CO_2 capture and separation technologies impose. There are also opportunities that reduce the CO_2 generated or emitted through overall system optimization and process alternatives. For carbon storage, better understanding of the subsurface reactions is needed to gain confidence in full-scale technology and system deployment.

Solar radiation is the largest energy flow entering the ecosystem, representing an enormous resource of renewable energy that could potentially meet a large fraction of global energy needs. Several solar programs are focused on developing innovative materials for high-performance photovoltaic solar cells to improve efficiency, reduce cost, and increase durability. This field has many researchers pursuing similar means, and GCEP has focused on solar technologies that are not only efficient and inexpensive at the cell or module level, but also those which can be durable in the field, easily manufactured, and cost-effectively integrated at scale at the system level.

Biomass energy is another renewable energy option that has the potential of low net emissions of CO_2 or even net negative carbon emissions. Biomass resources are being considered as a potential alternative to transportation fuels. Biomass research, like other renewable energy technologies, still needs to address issues of cost, conversion efficiency, energy density, and sustainability.

Combustion is currently, by far, the most common first step in converting the energy stored in chemical bonds to energy services for humankind. Because of its ubiquitous nature and its intimate coupling with carbon-based fuels, even small improvements to combustion technology can have significant impact on total greenhouse gas emissions whether they are from biomass or fossil resources.

The development and advancement of materials is an encompassing need in systems that extract, distribute, store or use energy. The performance of these systems depends on materials. Plastics, coatings, alloys and catalysts are some of the broad classes of materials used in current energy products. Advancements in these materials improve system efficiency and energy conversion processes, extend lifetime, and reduce CO_2 emissions.

To allow integration of renewable sources of electricity onto the electric grid and to achieve displacement of base load electricity supplied from fossil fuel sources, research aimed at understanding the grid operation and needs for storage is essential. The GCEP portfolio includes studies on grid controls and large-scale storage to examine the control of the electricity network in a condition where there is a high penetration of renewables and to develop technology so that supply does not have to equal demand at all times.

Energy systems analysis involving net energy analysis and life-cycle assessment is emerging as an important research area for long-term, energy economic and policy planning. Fundamental analysis of energy and material flows in technology development and deployment provides a perspective grounded in first-order laws of physics and thermodynamics.

Many scenarios that project global CO_2 emissions over the coming decades show that levels of CO_2 in the atmosphere and oceans may rise to values that affect the ecological infrastructure on which we depend for food and water resources. Options to realize primary energy production with a net removal of CO_2 from the atmosphere could be a critical part of a future energy portfolio. Low cost, sustainable ways to achieve net negative carbon emissions from a segment of the primary energy sector will have the additional benefit of allowing continued use of fossil-based energy sources in a portfolio by offsetting them with negative emissions.

The opportunity to provide low cost, high quality, and environmentally sustainable energy technologies for developing and emerging markets is enormous. Over the coming decades, billions of people will for the first time have access to modern energy technologies. Currently the world population is over 7 billion people of which approximately 1.4 billion people live without electricity and 3 billion people rely on solid biomass for heating and cooking. More than half the world population lacks modern access to energy and its services, either because it costs too much or is simply unavailable. Bearing in mind that energy and income poverty are tightly coupled, a major challenge is the need for relevant ideas to be extremely affordable without compromising the quality of the energy service or technology.