Visioning Energy: Science Fiction Author-Energy Researcher Collaboration Workshop Recap

Mark Ruth, Daniella Frank, Emily Mercer, and Elizabeth Doris

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-6A50-91634
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Suggested Citation
Ruth, Mark, Daniella Frank, Emily Mercer, and Elizabeth Doris. 2024. *Visioning Energy: Science Fiction Author-Energy Researcher Collaboration Workshop Recap*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A50-91634. https://www.nrel.gov/docs/fy25osti/91634.pdf.

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National Renewable Energy Laboratory
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Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the National Renewable Energy Laboratory and sponsors of the Joint Institute for Strategic Energy Analysis. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

Acknowledgments

The authors would like to acknowledge the input and support received from the following individuals.

Workshop organizing committee:

- Zia Abdullah, Laboratory Program Manager
- Kim Adams, Corporate Communications Leader
- Jeff Blackburn, Senior Scientist
- Elizabeth Doris, Director, Joint Institute for Strategic Energy Analysis
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- Wil McCarthy
- John Stith
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- Molly Tanzer
- Lauren Teffeau.

Participating NREL staff:

- Birdie Carpenter
- Huyen Dinh

- Bryon Donohoe
- Torie Gaylord
- Susan Habas
- Elaine Hale
- Joey Luther
- Bob McCormick
- Patrick Moriarty
- Matthew Reese.

The development of this report and other communications related to the workshop would not have been possible without the expert editorial contributions of **editors, designers, and others in the Communications Office.**

Executive Summary

In August 2024, the National Renewable Energy Laboratory (NREL) invited speculative fiction authors to collaborate with laboratory researchers on imagining the clean energy future in 2100 in a workshop entitled, "Visioning Energy: Science Fiction Author–Energy Researcher Collaboration." The dual goals of the collaboration workshop were (1) to support out-of-the-box thinking and creative future visioning for the researchers and (2) to provide authors with insights into the latest clean energy technologies and their potential.

The 1-day workshop featured a welcome and 1.5-hour author tour of NREL; a half-day world-building exercise involving 8 authors, 1 guest, and 20 NREL staff members; and a book signing event, open and advertised to all NREL staff. The participants in the world-building exercise developed four scenarios, which the authors of this report titled

1. Utopia on Earth—Not So Much Elsewhere
2. Escape to Polar Confinement
3. Burrowing To Survive
4. Finding Community in Houseboats and Treehouses.

Common research, development, and analysis technologies and themes are found in these scenarios, which could provide ideas for future research, development, and analysis. For example, future work could investigate potential needs for human migration and adaptation and how that could impact urban structures; human, goods, and energy transportation; and tradeoffs between transportation and virtual interactions. The scenarios also predict that future electricity generation located near loads will probably be insufficient; thus, advanced transmission technologies (e.g., superconductivity) could be valuable. Multiple scenarios noted future building advancements, increased efficiency of heating and cooling, and higher population densities with recreational access to nature. Other research, development, and analysis opportunities involve the energy-food-water-land nexus, including carbon dioxide capture for beneficial use and atmospheric water harvesting, and pollution management. Finally, the scenarios identify potential impacts of advancements in nanotechnology and artificial intelligence on the energy system.

This pilot workshop highlighted the potential benefits of researchers and authors meeting for ideation. Future workshops could use alternative methods to develop more detailed and consistent scenarios. Other suggested options to connect these groups for ideation include a resident author program, events that involve junior researchers with authors, and awards programs.

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1 Introduction and Background

In August 2024, the National Renewable Energy Laboratory (NREL) invited speculative fiction authors to collaborate with laboratory researchers on imagining the clean energy future in 2100 in a workshop entitled, "Visioning Energy: Science Fiction Author–Energy Researcher Collaboration." The dual goal of the collaboration workshop was (1) to support out-of-the-box thinking and creative future visioning for the researchers and (2) to provide authors with insights into the latest clean energy technologies and their potential. The workshop was a pilot effort to better outline the opportunities and understand the potential impacts of NREL staff more effectively informing science with a diversity of voices, in this case artists, for the purpose of improving scientific outcomes and progress toward NREL's mission of "Clean Energy for All."

Interactions between science fiction and science reality are well documented, including both bi-directional influence on technology development and more general world-building. Technology developments include the oft-cited Motorola StarTAC flip phone based on the "Star Trek" communicator (Shedroff and Noessel 2012) and even the internet itself (Gutiérrez-Jones 2014). Jordan and Auernheimer (2017) generalize the influence of science fiction through outlining extensive connections in the scientific literature to the technologies used in the fictional "Star Trek" universe. Archibugi's (2016) exploration into whether the cult science fiction film "Blade Runner" could be an experiment in technology forecasting provides an example of connections beyond the "Star Trek" universe, and Bassett (2013) lays out connections between science fiction and innovation generally.

Beyond specific technology influences, more general "world-building," the process of creating a fictional world or a setting for a story, has also illustrated bi-directional influences and expanded opportunities to leverage science fiction and science for the benefit of humanity. In "The First Men in the Moon," H.G. Wells envisions moon-bound space travel influencing generations of scientists for 70 years until the execution of a manned moon landing. Reinsborough (2017) generalizes the research and development benefits of exploring intersections of science fiction in imagining possible futures. Zaidi (2019) explores the science fiction tool of world-building for its scientific creativity implications in driving innovation. Specific to energy systems, Macdonald and Edwards' (2019) special edition journal explores the ways in which fictional future visions provide an increasingly important opportunity for scientists to engage with different concepts for living, dwelling, and powering humanity under increasingly complicated societal, environmental, and scientific circumstances. Robert Heinlein's short story (published under the pseudonym Lyle Monroe) "Let There Be Light" (1940) introduces inventions of low-cost solar photovoltaics and lighting. His subsequent short stories in the "Future History" series explore the social implications of those inventions. Expanding from engagement with concepts, Raven (2017) articulates science fiction as a method to explore, critique, and narrow potential energy future visions and, further, inform technology policies and advancements that could be applicable to a wide variety of futures.

In that broader evolutionary context of the relationship between science fiction and science and in keeping with NREL's mission, the pilot "Visioning Energy" workshop created a forum of bi-directional collaborations between renewable energy researchers and speculative fiction authors

to explore a broader array of renewable energy futures than those bound by traditional technological research. This report presents

1. A summary of the approach and implementation
2. The individual scenarios built by participants as well as an exploration of synthesized common themes
3. A set of themes identified across the scenarios and possible subsequent research, development, and analysis opportunities
4. Future opportunities both for better understanding the benefits of researcher-author relationships toward impact in science and science fiction and for developing relationships within those processes.

Understanding the long-term implications of such interactions would involve a comprehensive research approach including considering the time and complexity of inputs required to bring both works of fiction and works of clean energy research to completion, as well as longitudinal relationship studies. This report catalogues this pilot effort as an exploratory step, resulting in an experience for researchers and authors (as well as researcher-authors) and an output of collaborative world-building, exploring the creative bounds of possible clean energy futures.

1.1 Description of the Event

In August 2024, NREL brought together senior researchers and speculative fiction writers for a 1-day workshop to co-explore world-building toward a clean energy future in 2100.

1.1.1 Structure of the Workshop.

The 1-day workshop began with a welcome and 1.5-hour author tour of NREL; a half-day world-building exercise, including a lunch provided by Joint Institute for Strategic Energy Analysis (JISEA) sponsors; and a book signing event, open and advertised to all NREL staff. A full agenda is provided in Appendix A.

1.1.2 Invitations and Attendees.

The organizing committee invited 29 authors to the workshop: 11 accepted and 8 attended. Also in attendance were 20 NREL staff members of the 21 that responded in the affirmative. More than 75 were invited from the list of Distinguished Members of Research Staff and Research Fellows, representing NREL's most senior subject matter experts, who inform large work portfolios.

The organizing committee used creative means to recruit diverse voices from various genres and disciplines for this workshop, including extensive internet searches and network leveraging, with varying levels of success:

- All attendees came from within driving distance. Rocky Mountain region-based authors and on-site employees were given priority for invitations because of lack of resources to cover travel expenses for participants.
- All but one NREL participant reported being at NREL for more than 15 years. (NREL staff invitations were limited to senior members). In addition to outsized influence in

research direction relative to junior staff, senior staff have more flexibility to prioritize their own professional time.
- Review of submitted biographies from authors indicated at least three different subgenres represented, in addition to a wide variety of publishing media.
- Of 32 registrants, 30 answered an optional gender identification question: 15 identified as male, 14 as female, and 1 as nonbinary.
- To an optional question about race, 30 responded: 26 identified as white.
- When asked whether participants favored "Star Trek" or "Star Wars" (in an optional question), 31 answered: 12 reported "Star Trek," 8 reported "Star Wars," and 11 reported "other" with 10 unique answers.

1.1.3 World-Building Exercise.

The 3-hour exercise used a collaborative, sequential writing approach to enable broad input and encourage expansive thinking. The method increased interaction among different participatory styles, providing increased likelihood of participation by all attendees.

The method included five rounds of review by four different groups: each group consisting of two or three NREL staff members and two authors, joined by a facilitator and notetaker (both from NREL). In the first round, the groups developed scenarios describing the world in 2100, with the following guardrails:

- Neither utopian nor dystopian viewpoints are desired; an achievable, believable, and understandable scenario is sought.
- The global economy is net zero in carbon emissions, but effects of climate change and/or solution(s) to climate issues may remain.
- Global population has stabilized and is similar to today's global population (8–10 billion people).

On completion of the first round, the notetakers traveled with the scenarios developed in their original group to the next group, and the rotation repeated five total times, with a focus topic for each rotation:

1. Base vision for the future in 2100
2. Technologies that would need development in that scenario
3. Societal developments that would likely accompany the scenario
4. Unexpected and unintentional consequences within the scenario.

The completed scenarios were returned to the original group for a final session—a scenario review. In those reviews, the groups were asked to identify surprises and possible additions and to start thinking about types of characters and stories that might fit into their scenario.

In each rotation, the participants reviewed the existing information from the notetaker (the original scenario and subsequently added information) and discussed the topic for the round, while the notetaker recorded the participants' ideas.

To enable rapid development, the notetakers leveraged an artificial intelligence (AI) method to rapidly synthesize the notes into narratives. Between rounds, the bulleted notes were submitted to a Microsoft Azure AI environment to be converted into short narrative summaries of the bullets for provision to the next group. The Microsoft Azure environment was closed, meaning that the system did not interact with any services operating outside of NREL.

After the workshop, the individual outputs of the rotations were synthesized by this report's authors into the singular scenario narratives in Section 2.

A full overview of the exercise is provided in Appendix B.

2 Scenarios

Summaries of the four scenarios developed in the world-building exercise are provided in this section. The authors of the report developed the summaries by reviewing the notetakers' original notes and synthesizing them into narratives. The authors did not use AI to develop these summaries—it was used only the day of the workshop to provide short narratives to the next group with a fast turnaround.

The world-building exercise focused on generating ideas instead of developing internally consistent scenarios, so some scenarios contained internal inconsistencies. Not all those inconsistencies were resolved in the scenario summaries. As a result, the scenarios reported here are not entirely internally consistent.

2.1 Scenario 1: Utopia on Earth—Not So Much Elsewhere

By 2100, technological advancements and the pursuit of scarce terrestrial natural resources have led humankind to establish colonies on the moon and Mars. Society, culture, and economics across these three locations have diverged because of differences in resources and developmental priorities between Earth and the space colonies, but similarities remain as both civilizations contend with the consequences of a world that has evolved rapidly.

On Earth, society has followed an overall pattern of urbanization. The cities are practically designed according to the 15-minute city concept—where residents can access all essential life needs within 15 minutes (Moreno 2016)—and boast a combination of aesthetically pleasing and energy-efficient architecture. These cities are supported by strong local economies, which can provide for the needs of each community more efficiently than previous large-scale economies. This localization has also contributed to the growth of close-knit community culture, which is seen in the increase of community activities and festivals.

Along with the growth of energy-efficient cities, Earth has seen the popularization of sea steading—these permanent settlements in international waters are a result of land scarcity and rising sea levels. The expansion into sea-based territories has sparked increased international collaboration as countries work to adapt international legal frameworks to these new societies. These international efforts include both residential development and regulation of ocean-based industries such as fisheries. This ocean-based development has also motivated the development of more efficient depollution processes, with scientists able to clean up and perform complete mineralization of both dissolved and solid pollutants. This notable improvement also brings with it risks, as these relatively new processes can introduce the development of new toxins and still require improvement.

Scientific breakthroughs in nuclear fusion, superconductivity, and direct air capture of both carbon dioxide and water have made resources such as carbon, hydrogen, and oxygen readily available—these processes have even become commercialized—but global treaties are necessary to allocate other resources. Efforts to find and economically extract extraterrestrial resources are ongoing, including platinum from the moon and iron from Mars.

The societies both operate in a post-scarcity energy environment resulting from several scientific inventions and investments – i.e., energy scarcity is no longer a concern impacting policies and

government decisions. Governments have invested in the space power concept of large collectors in geospatial orbit that provide dedicated power to a specific terrestrial or lunar location. With so much electricity available and storage eliminating timing constraints, energy-intensive processes that were previously deemed wasteful have now resurfaced. The combination of AI-managed energy systems and increased and modernized transmission infrastructure meets generation growth and ensures reliability and resilience.

Thanks to years of scientific progress in sustainable aviation, sustainable supersonic air travel has become a significant and affordable transportation option on Earth. This includes the subcategory of drone aviation technology. Along with aviation, electrical high-speed rail is a popular transportation option, because of a shift in political favor throughout the 21st century. The optimization of transportation options has boosted the amount of tourism in the world, elevating tourism's status to one of the most profitable industries and putting a strain on popular locations.

In contrast to society on Earth, society on the moon and on Mars faces more constraints. Even though each society is energy independent, transportation options are limited. For most people, space travel is a once-in-a-lifetime opportunity. Thus, communities are isolated from each other and develop their own structures, cultures, and customs. Those differences lead to occasional conflicts, but they are mostly "cold conflicts" because of the challenges of space travel. Additionally, there is more economic inequality as space mining has benefited investors and owners and burdened laborers and locals. Because the colonies are dependent on trade with Earth for much of their carbon-based materials (the moon and Mars are carbon poor), they are vulnerable to economic and interplanetary instability.

Another notable advancement is the evolution of the agriculture industry. Food scientists are easily able to isolate amino acids and other molecules and create them when necessary, using the abundant energy. They use those molecules to create food with 3D printers. These advancements, in combination with ones that allow humans to communicate with fellow mammals, have put an end to animal husbandry practices and relegated traditional agriculture processes to leisure-based activities and luxury items such as raw apples. The agricultural industry is replaced with the synthetic carbohydrate and protein industry. The Earth enjoys these capabilities—the Moon and Mars have ability to produce food, provided carbon is available from Earth but, because interplanetary carbon transport is still limited, there are occasional food and material shortages in those locations.

With a reduced threat of energy and food shortages on Earth, universal basic income is a reality. This era of energy and food abundance has increased individual free time, leading to more travel, leisure activities, and altruistic work. Vacations to desirable destinations and festivals are abundant. There is a very small percentage of people who are content to live a life of leisure, which has resulted in an increase of self-driven pursuits such as artistic productivity and scientific advancement. The abundance of energy has also changed the political landscape by allowing humanity to minimize international competition resulting in larger governing entities and coalitions with broader visions and goals.

On the other hand, the removal of conflict results in an Earth population with a lack of purpose and initiative. Risk-takers and strivers self-select to migrate off planet, increasing the societal

ennui. There are resulting divisions between people who appreciate education and scientific discovery and those who are content living an indolent lifestyle of leisure. There is also a rise in cults as people seek to find meaning and new purpose in their way of life. Overall, society's elimination of many current-day problems has led to a state of existential questioning.

On the other hand, the Moon- and Mars-based populations struggle to resolve economic and scarcity issues. They continue to address problems such as resource ownership, compensation for mining risk, and food shortages. Universal basic income is not available for them, and life can be challenging. However, they can develop and discover new opportunities changing their social status.

2.2 Scenario 2: Escape to Polar Confinement

By 2100, the emissions crisis has been resolved, but there is still irreparable damage to the Earth, leading to a cascade of consequences. Much of the population has moved inland and toward the poles to escape the increased temperatures and rising sea levels. Because of the reduced availability of livable land, the population has transitioned to more condensed housing in the form of large towers.

Energy generation develops where land is inexpensive—unlivable, equatorial areas. Electricity transmission has increased, creating further blights on the land. The most unfortunate people need to live in unlivable locations because they manage the energy systems.

The large housing towers surround stackable, communal hydroponic hubs. Aridification has impacted agriculture and, as a result, people's diets have shifted to food that can be readily produced via hydroponics. Some land is still used for agriculture and produces maize, potatoes, and nuts. Meat is an expensive option, but synthetic meat is affordable for limited occasions. Eating natural meat is a status symbol. The saturation of urban infrastructure makes travel physically difficult and isolates cultures.

The effort to mitigate the impact of decades of climate damage has motivated a generation of technological innovation. Photovoltaics, wind power, and geothermal energy have been established around the poles, but that supply is insufficient and is supplemented by photovoltaic energy generated near the equator and transmitted long distances. Energy storage with higher-energy-density materials is standard and addresses most resource adequacy issues. Pipelines and pumps are used to cool glaciers and mitigate sea level rise. However, these systematic changes disrupt animal life and migratory patterns.

Artificial intelligence continues to evolve, and its role in society has become refined. Society has identified professions that are better served by AI, including medicine. Artificial intelligence techniques combined with a holistic focus and additional knowledge of the human genome result in medicine being more accurate and customizable.

Artificial intelligence also provides waste management intelligence, sorting waste streams early and reducing cross-contamination, thus reducing the cost of recycling. The human genome replaces social security numbers as the primary method of identifying people. Combined with AI data, analysis improves national security and local safety but increases state intelligence and oversight. Artificial intelligence has relieved humans of time-consuming, tedious tasks.

Population redistribution has forced government restructuring. More localized governments with large regional unions have become the norm. They will manage (and fight for) limited resources such as rare earth metals and water resources (e.g., aquifers). Geographically dispersed enclaves of cultural identity (e.g., religious identity) are a second government structure that provides many services that we currently think of as a governmental role (e.g., education, insurance, health care). These enclaves are made up of multigenerational families that offer each other mutual aid rather than depending on government support, as was the practice in the 20th century. These enclaves are insular, with some developing unique dialects, and the quantity of subcultures multiplies. They interact virtually but few meet physically because travel is limited due to conflicts between regional governments.

Although there have been many beneficial technological advances by this year, shrinking of livable land and the cultural, environmental, and political changes over the 21st century have also led to conflict and unrest. Water and critical material scarcity has led to the need for increased government regulation. The shrinkage of available livable land and the uneven distribution of natural resources has put local governments in more direct conflict with each other. Integrated data centers and other smart technology have created a new vulnerability that opens the possibility for bad actors to impact the entire world. Property value is at the mercy of the climate, as only wealthier classes can afford safer locations.

These issues and others have impacted the way people reflect upon and live their lives. People use art to express their trauma from the impacts on the environment, the loss of traditional homes, the impacts of immigrating climate refugees, and the changes to societal structure.

A schism has emerged between people who want to participate in society and those who reject it for the new burdens it has brought. Nostalgia for open spaces and simpler lifestyles drive small communities to separately live off grid in the wild spaces outside cities. Many of those communities are migratory, following the seasons and weather. These communities accept the dangers of less-livable land and fewer medical and economic resources. Regional governments provide some emergency support such as grids they can tap into during extreme weather events, but life can still be challenging and short.

2.3 Scenario 3: Burrowing To Survive

In the year 2100, the world has undergone significant changes resulting from climate change and technological advancements. Worldwide, many previously habitable places have become uninhabitable because of an increase in average temperature and extreme weather events. This has caused large populations of people to either choose to migrate seasonally or live in underground housing developments that offer protection from the heat. Some of the people who migrate seasonally live in advanced mobile homes. Others have winter locations and summer locations and can use underground high-speed rail to migrate between them. Additionally, in some places, people's daily routines have shifted, with many becoming nocturnal to avoid the heat. They work and recreate during the night and sleep during the hottest parts of the day.

Large-scale efforts have been made to combat the effects of climate change. For example, electricity is generated through a combination of wind, solar, and geothermal technologies. Because many of the buildings are underground, direct geothermal cooling and heating are common. Highly efficient ventilation technology provides clean air. Bioengineered synthetic

moss and algae are used for carbon capture and energy sources. The captured carbon is used to produce organic chemicals as well as for sequestration. Additional bioengineered sequestration techniques, including those that increase soil carbon, have been developed.

Bioengineered trees that can act as fire breaks limit forest fire impacts, and rehabilitation of topsoil for agriculture has become a priority. Vertical farming has become much more common, and many places co-crop energy and food. Overall agriculture has become more efficient, with vertical farming, automation, and large-scale, indoor hydroponics reducing the need for flatland farming and long-distance food transportation. The desire to reduce impact on resources has led to a predominantly vegetarian society and has also helped solve social justice issues surrounding people working in hot, inhumane conditions.

Because in many places people spend most of their time inside and underground to avoid heat, there have been many inventions aimed at helping people cope with this changing lifestyle. For example, underground gardens, rainforest walls, and nature-based holograms have become common in many houses. Virtual communication has become highly efficient (with hyperloops as the underground communication backbone). Holograms enable people to feel that they are in the same room as others who are miles away, and chips implanted in human brains allow direct connections beyond our physical senses. Some people have been able to form strong virtual communities thanks to this technology. Artificial intelligence technology has advanced to a point where others would rather interact with AI avatars than real people, creating virtual echo chambers and isolation.

Although many new technologies have been developed, many societies have also leaned on older, indigenous methods to address the effects of climate change. This has resulted in holistic solutions to issues such as land and forest fire management. Rewilding is a priority, and, by 2100, people use only approximately 20% of the planet to support themselves. People enjoy many ecosystems, biodiversity, and natural spaces more than they once could. The Japanese concept of forest bathing (spending time immersed in nature to connect to the natural world through sensory engagement) is used to make underground living more tolerable, and doctors often “prescribe” spending time in nature when people do not feel well.

Many workforce needs have disappeared because of automation, which has allowed people to have a lot more free time to recreate and spend time with friends and family. The most social recreation opportunities involve festivals, but they differ from those in 2024. For example, springtime festivals celebrating survival of the winter are replaced with autumn festivals celebrating survival of the summer. Crop timing also reflects climatological changes, so harvest festivals are in early summer instead of in autumn.

The largest growth in work opportunities is in ecological restoration. Nanotechnology developments accelerate ecological restoration efforts, and related nanotechnologies have advanced medicine.

Some unintentional and unexpected societal consequences have resulted because of a rapid transition to a new way of living. A minority of people are unwilling to change their lifestyles and have the resources to maintain a lifestyle similar to U.S. residents in 2024. Some have the means to bioengineer their bodies to make them more heat tolerant. They still rely on expensive,

energy-intensive technology such as fashionable climate-adapting bodysuits that use nanotechnology to provide cooling when they go outside as does everyone who does not have the bioengineered adaptation. Fashion has evolved to cover more of the body to protect from heat and provide cooling. Additionally, many wealthy people have not adapted to the new ways of living and continue to use limited resources such as fossil fuel as a "luxury" to support their lavish and convenient lifestyles. Wood is seldom burned because of its lack of availability and is not readily available for building products, furniture, and other early 21st century uses. Artisanal wood is a luxury item and acts as a status symbol. As these decisions worsen environmental problems, the divide between the "haves" and the "have nots" widens.

Another big issue is the spread of misinformation through AI and the internet. Because people feel like they are spending time with other real people when using AI, fewer human-human interactions occur and are available for AI training. Thus, the technology gets worse at training itself to sound and act like real people, creating a negative feedback loop.

Overall, society is focused on adapting to Earth's changing environment by avoiding the times and locations where conditions are unlivable instead of exploring other options, such as emigration to another planet. However, future interplanetary emigration is more possible because people are used to living in enclosed and confined spaces and using privacy technologies.

2.4 Scenario 4: Finding Community in Houseboats and Treehouses

In the year 2100, people have been forced to move to cities that are inland and upland—and closer to the poles—to adapt to a warmer climate and rising sea levels. Those who want to live near water reside in floatable homes that are tethered with chains to accommodate for weather and energy needs. Although inland urban living is similar to that of the 20th century, rural homes also look different. Many people swap large estates for smaller homes or living in "treehouses" powered by solar energy and cooled efficiently. Walkable and paddle-distance communities in the "village model" have become more popular as people have become less attached to material possessions and focus on community interaction.

Energy efficiency measures such as ultra-efficient light-emitting diodes and improved space and water heating and cooling reduce energy demands enabling most energy generation to be local using solar and wind power to generate hydrogen fuel. When distant sources of energy are needed, hydrogen pipelines enable the necessary transmission and efficient hydrogen storage makes energy available during the winters when solar energy production is limited. Urban nature becomes carefully planned, so limited human interactions with plants are available to urban dwellers while still minimizing energy and water requirements. However, species continue to diminish because of the lack of native plants and differing sun cycles.

People seek deep human interaction and connection in the digital age, which has led to the rise of new spiritual communities and religious groups. As the value of time and money change, society grapples with the inevitability of pandemics and the potential for uploading human consciousness to the cloud. Education and socialization struggle to keep up with technological advancements, leading to calls for greater focus on civic-mindedness and societal impacts. That focus leads to communal child-rearing.

The changing world has also given rise to many new technological developments. Food production has largely shifted to urban indoor environments—with hydroponics and artificial soil used to grow a variety of crops—and most of society has adopted a plant-based diet. Water scarcity has become a major issue, with desalination and advanced water conservation technologies playing a crucial role in shaping the landscape. The issue of water conservation leads to debates on the efficiency and nutrition of lab-grown meat versus traditional livestock farming. Improved livestock management, regenerative agriculture, and agrivoltaics arise as solutions for promoting ecological health. Landowners with access to water resources hold significant power, and the value of land is largely determined by its ability to produce resources.

Geoengineering is explored as a means to manipulate nature and prevent natural disasters, and biodomes and AI-driven models are used as ways to test and understand the potential impacts of this technology. Waste reclamation has become more advanced, with molecular sorting used to separate and repurpose waste materials, including landfill mining.

Advancements in health care have allowed for the replacement of failing organs and longer life spans, but society faces ethical dilemmas as gene modification and targeting become commonplace. People must decide the limits of these advancements, such as whether to enhance their children's abilities or physical traits. As longevity increases, questions arise about family planning and the right to die. Although amazing health treatments are now available, there are major issues surrounding accessibility to these treatments because of wealth inequality. Wealth inequality is obvious because of the freedom to self-determine one's appearance being limited only by cost.

As the world adapts to these changes, the wealthy enjoy vacation homes on both poles, showcasing the stark contrast between the challenges faced by the majority and the luxuries afforded to the few. "Secret billionaires" have been able to take advantage of the rapidly changing world, thanks to massive hacking opportunities for a single person or group to manipulate it all. These ultra-wealthy people do not fully understand the consequences of their innovative ideas and inadvertently create dystopian pockets. For example, bioengineered "purple forests" and plastic-eating bacteria cause more problems than they solve because researchers did not identify potential consequences of these new technologies.

There is a newfound focus on balancing technological development with social wellness and justice to ensure a sustainable future for all. However, it is a conformist culture—there is a lot of cultural pressures to not be different—balancing technological advancements and societal and cultural responsibilities. Those that split off can discover and provide new opportunities, but it takes more energy to do so than in 2024.

3 Scenario Themes and Research, Development, and Analysis Opportunities

The participants developed a broad range of future scenarios indicating that the future is unknowable and there are no single solutions. However, a number of common research, development, and analysis technologies and themes are found in the scenarios. The scenarios focus on societal changes, especially those that may be caused by climate change. They all consider potential needs for human migration and adaptation and how that could impact urban structures; human, goods, and energy transportation; and tradeoffs between transportation and virtual interactions. Researchers and analysts could benefit from considering these themes as they identify future opportunities.

Overall, the scenarios are optimistic regarding energy generation. Most assume solar photovoltaics, wind, and geothermal generation technologies will drop in cost by 2100, and some identify other technologies that will be developed, including fusion and space power. Generation near the loads (where people live) is identified as a key opportunity, but the scenarios indicate that resources are probably insufficient. Thus, superconductivity could be an important technology for transmission over long distances.

The scenarios expect buildings will adapt to address the impacts of climate change. Ultraefficient buildings, including geothermal heating and cooling systems, will reduce energy loads. Large towers, possibly also at higher latitudes, can reduce the overall load by reducing exposure to the elements while increasing availability of unused land and reducing the need for people to travel far. One scenario proposes underground dwellings with architectural features such as underground gardens, rainforest walls, and nature-based holograms to overcome psychological challenges. Biodomes are a related above-ground option. Another scenario identifies sea steading as an option to address changes to shorelines. Yet another scenario identifies the opportunity for fashionable bodysuits that can provide comfort even at hot and cold ambient temperatures. Urban planning analysis and technologies could provide insight into how these could develop and what might be optimal development.

The scenarios also identify transportation technology improvements. Interregional transportation could include supersonic air travel and high-speed rail. Transport could be unmanned with drones delivering goods. People could live in advanced mobile homes that allow seasonal migration and are energy autonomous and manage all their waste efficiently.

The energy-food-water-land nexus and challenges therein identify additional technology development opportunities. The scenarios all identify the likelihood of regions without human habitation either intentionally (rewilding) or unintentionally (unlivable because of climate issues). Land improvement opportunities include topsoil regeneration and engineered trees that can act as firebreaks. To enable sufficient food supplies, the scenarios all identify options for concentrated agricultural practices. These include advanced greenhouses, hydroponics, bioengineered food, and printed food.

Technologies that could help meet resource requirements include carbon dioxide capture and reduction to form organic chemicals; atmospheric water harvesting to provide both water for

human and agricultural use and hydrogen for chemical processing; and material sourced from the moon, asteroids, and Mars.

Pollution management is a key need. Scenarios identify the potential to develop technologies that address issues with waste both absorbed in water and plastics (and other materials) in bodies of water as technology opportunities. Carbon capture and sequestration is discussed as an opportunity, including options such as bioengineered synthetic moss that can synthesize carbon dioxide rapidly and efficiently. The scenarios also identify geoengineering as an option to reduce the impacts of climate change.

Advancements in nanotechnology could radically impact medicine by providing synthetic organs, agriculture by increasing water and energy efficiency and managing pests and weeds, and environmental restoration by, for example, making soil amenable to reclamation.

The scenarios all include increased use of AI, noting that it would benefit from the availability of inexpensive, clean energy. Artificial intelligence could eliminate the need for people to perform mundane tasks. It could provide advanced systems management that, for example, increases reliability and resilience of the energy system or sorts waste for reuse and recycling. AI could support security and medicine needs more efficiently than people could. It could also potentially provide translation services, which could be important if the number of dialects increases, as identified in one scenario.

4 Conclusion and Future Efforts

The pilot workshop provided, in a very compressed time frame, four scenarios and a variety of themes and opportunities for research, development, and analysis tasks. Researchers and authors experienced several hours of exposure to a related but very different field and carried away experiences that will inform work in both reality and fiction. The pilot workshop illustrated the potential expansive impact of a very small, low-resource effort to engage with the science fiction author community. The results indicate that expanded efforts, supported through both traditional and nontraditional sponsors, could increase the quality, creativity, and impact of NREL relative to its mission for clean energy for the world.

However, these impacts are most likely to be internalized by the participants; a goal of this report is to expand the impact of the limited group. Two categories of expansions could increase the impact of collaborations and peer-to-peer learning: incremental changes to enable more information out of similarly designed workshops (i.e., how we would improve what we did the first time) and wholesale different approaches for achieving the goals from different directions. Incremental improvements to the existing workshop style could include increased remunerated planning and structure input from authors, broader geographic or subgenre input, or regional workshops to identify regional or subgenre differences, increasing engagement support funds for authors and researchers to participate (very likely improving participation from underserved communities and improving diversity of inputs).

Wholesale different approaches could also effectively develop bi-directional information exchanges between the science fiction community and scientific clean energy researcher communities. These could include the following:

- More individualized or internally consistent scenarios
- The presentation of preformed scenarios to enable more depth, description, and discussion within a short period of time
- Groups focusing on specific sectors, such as transportation, social systems, or electricity sector
- Author review of analysis model operations and results presentations and providing inputs or asking questions from their perspective.

Beyond similar or different world-building workshops, science and, more broadly, speculative fiction, could be more institutionalized to inform NREL staff creativity and inform research agendas to create the following:

- A resident author program, empowering an author to interact with research staff for a period of time, with bi-directional informing. This effort could be modeled on the National Science Foundation (NSF) Antarctic Artists and Writers program (U.S. National Science Foundation 2019), which similarly provides input to the broader NSF mission from the art community.
- A program that supports senior or junior researchers to attend science fiction events with a specific priority on sharing recent NREL learning to inform the science fiction community and to expand NREL thinking about research possibilities and possible future needs.

- An award for researchers that illustrates connections to creativity and the artistic fields to inform their research questions, methodological approaches, and interpretation of results.
- An award for speculative fiction authors that addresses clean energy technologies and potential social impacts of those technologies to further motivate energy researchers and analysts to identify and consider opportunities.

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Appendix A. Agenda

Agenda

All times shown in Mountain Time (MT)

TIME	DESCRIPTION/LOCATION	PRESENTER/HOST
8 a.m.	Arrive at NREL; check-in; get coffee if desired; proceed to conference room *(RSF X344 – San Juan)*	
8:30 a.m.	***Opening*** • Welcome • Introductions • Review of the Day • NREL Overview	Mark Ruth
9–10:45 a.m.	***NREL South Table Mountain Campus Tour*** • Energy Systems Integration Facility, Science & Technology Facility, Solar Energy Research Facility, Agrivoltaics	Jim Bosch
10:45 a.m.	Break	
11 a.m.	***Icebreaker and introduction to collaborative activity*** *(RSF X344 – San Juan)*	Jeff Blackburn & Jill Engel-Cox Mark Ruth
11:20 a.m.	***Collaborative World-Building Activity – Phases 1 and 2*** *(RSF X344 – San Juan)* • Break into 4 small groups and introductions (10 minutes) • Phase 1: Develop vision of the world in 2100 (30 minutes) • Transition: 5 minutes • Phase 2: Technologies that need development (30 minutes)	**Group facilitators:** Jeff Blackburn Jill Engel-Cox Sheila Hayter Ling Tao / Kim Adams
12:35 p.m.	Lunch and informal discussions *(RSF X344 – San Juan)* Food catered to conference room	
1:20 p.m.	***Collaborative World-Building Activity – Phases 3, 4, and closeout*** *(RSF X344 – San Juan)* • Phase 3: Societal developments (30 minutes) • Transition (5 minutes) • Phase 4: Unexpected and unintentional consequences (30 minutes) • Transition (5 minutes) • Scenario Review **(**30 minutes)	**Group facilitators:** Jeff Blackburn Jill Engel-Cox Sheila Hayter Ling Tao / Kim Adams
3 p.m.	Break and Set Up for Author Panel / Signing *(RSF X344 – San Juan)*	

TIME	DESCRIPTION/LOCATION	PRESENTER/HOST
3:30 p.m.	***Author Panel*** *(RSF X344 – San Juan)*	Moderator: Mark Ruth
4:15 p.m.	***Book Signing*** *(RSF X344 – San Juan)*	
5 p.m.	***Soft Dismissal*** Optional happy hour at Barrels and Bottles 1055 Orchard St, Golden, CO 80401	

Appendix B. The Collaborative Activity

Background

At its best, science fiction

- Generates new viewpoints of technology needs and opportunities
- Impacts and interacts with the cultural zeitgeist

Historically, NREL's input has provided value to authors

- John Turner, Jim Bosch, & Doug Arent were acknowledged in Ian McEwan's *Solar*)
- *The Weight of Light* (https://www.nrel.gov/news/program/2020/urban-electrification-and-the-future-of-cities.html)

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Objective:

Develop new scenarios of the future of energy and its effects on human and natural systems to envision innovative NREL research programs and inform science fiction, inspiring energy researchers and writers.

Product: An NREL report with a 2-4 page summaries of each of the four scenarios

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Scenario Guardrails

- Neither utopian or dystopian but rather achievable, believable, and understandable.
- Global economy is net-zero in carbon emissions but effects of the problem and/or solution may remain
- Population has stabilized and is similar to today's global population (8-10 Billion people)

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Process & Logistics

- Four small groups – each with 2-3 authors, 3-4 researchers, facilitator, corner table
- Notetakers: will rotate between groups at the end of each phase
- Five 30-minute phases
  - Prompt questions to help guide discussions (you don't have to answer all)
  - Notetakers will take notes & record discussion to inform the summary report
  - Working summaries will be created and distributed at the end of each phase
  - Notes and recording will be used in writing the scenarios for the final report
  - Each group will build upon another group's summary in the following phase

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Notetakers

Claire Bolyard

Maggie Ryan

Emily Mercer

Jason Youngstrom

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Phases:

30 minutes planned for each

1. Develop vision of the world in 2100
2. Technologies that need development
3. Societal developments
4. Unexpected and unintentional consequences
5. Scenario Review

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Prompt Questions & Working Summaries

- Printouts provided to each table at the beginning of each phase
- Working summaries
  - Notes input into a Microsoft Azure Generative AI system;
  - Azure creates a ≈300 word summary;
  - Printed and passed out at the beginning of Phases 2-5

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Microsoft Azure Privacy Statement

Your prompts (inputs) and completions (outputs), your embeddings, and your training data:

- are NOT available to other customers.
- are NOT available to OpenAI.
- are NOT used to improve OpenAI models.
- are NOT used to improve any Microsoft or 3rd party products or services.
- are NOT used for automatically improving Azure OpenAI models for your use in your resource (The models are stateless, unless you explicitly fine-tune models with your training data).
- Your fine-tuned Azure OpenAI models are available exclusively for your use.

The Azure OpenAI Service is fully controlled by Microsoft; Microsoft hosts the OpenAI models in Microsoft's Azure environment and the Service does NOT interact with any services operated by OpenAI (e.g. ChatGPT, or the OpenAI API).

https://learn.microsoft.com/en-us/legal/cognitive-services/openai/data-privacy

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Groups

Southeast	Southwest	Northwest	Northeast
Jill Engel-Cox	*Sheila Hayter*	*Jeff Blackburn*	*Ling Tao*
Molly Tanzer	**Marie DesJardin**	**Rachel Kuintzle**	*Kim Adams*
Stant Litore	**Glen Engel-Cox**	**Wil McCarthy**	**Lauren Teffeau**
Grant Buster	**Karen Stith**	Elaine Hale	**John Stith**
Birdie Carpenter	Matthew Reese	Torie Gaylord	Huyen Dinh
Bob McCormick	Patrick Moriarty	Joey Luther	Bryon Donohoe
			Susan Habas

Notetakers

Claire Bolyard	Maggie Ryan	Jason Youngstrom	Emily Mercer

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Phase #1: Develop vision of the world in 2100
11:30 – 12:00

As traditionally trained scientists and engineers, we are often limited by real world constraints to think beyond the dogma in our fields. Science fiction writers, in contrast, live in a world where plausible imagination is key. Their bravery to explore this boundary pulls our collective intelligence ahead.

Mike Himmel – NREL Senior Research Fellow

Guardrails:

- Neither utopian or dystopian but rather achievable, believable, and understandable.
- Global economy is net-zero in carbon emissions but effects of the problem and/or solution may remain
- Population has stabilized and is similar to today's global population (8-10 Billion people)

Phase #2: Technologies that need development
12:05 – 12:35

Science fiction, unlike fantasy, is speculation about how changes in circumstances will affect the human condition, and science (and particularly technology, which is the application of scientific understanding to human affairs) is one of the major influences on change. So science fiction is shaped by the reality we share.

James Gunn*

* *Fafnir – Nordic Journal of Science Fiction and Fantasy Research*, Volume 4, Issue 1, pages 31–35.

Phase #3: Societal developments
1:20 – 1:50

I like to describe science fiction as 'the literature of the human species.' It's about humanity, not about individual humans, and so it tells us about our mutual survival or destruction. Science fiction can be about disaster (Brian Aldiss' short definition is 'hubris clobbered by nemesis') but it doesn't have to be. There are lots of stories that tell us how to survive in changing times.

James Gunn*

- In what ways have most peoples' lives become easier and what new challenges have emerged?
- What new ethical dilemmas have emerged due to advancements in technology and science?
- How do societies address issues of privacy, data security, and surveillance?
- What role does bioethics play in decisions about genetic engineering and AI?
- In what ways do education and learning methods evolve?
- How have relationships and family structures evolved?
- In what ways do people find community and connection in a digital age?
- How has the notion of love and friendship changed in the context of technological advancements?
- Do technological advancements change the way groups of people resolve conflicts?

* *Fafnir – Nordic Journal of Science Fiction and Fantasy Research*, Volume 4, Issue 1, pages 31–35.

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Phase #4: Unexpected and unintentional consequences
1:55 – 2:25

There is a fine line between engineering a solution and creating a new problem. Scientists and technologists can be addicted to their research processes.

Olivia Chadha – *Rise of the Red Hand*

- How do these changes affect the environment? The landscape?
- What might be challenges in the political landscape? Domestic? Global?
- How might the culture be impacted negatively?
- Who might be left behind in the cultural structure?
- What economic challenges might arise?
- What is lost from our current society?

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Scenario Review
2:30 – 3:00

The origin of this quote is unclear; it may have been Isaac Asimov, Robert A. Heinlein, Frederik Pohl, or James E. Gunn who first said it or wrote it down, but Connie Willis expressed it this way, attributing the particular phrasing to Colorado writer Ed Bryant: "The job of a science fiction writer is to look for the unforeseen consequences, the problems and kinks and side effects that nobody has really thought about. Ed Bryant said it best. He said that if this were 1890, it would take an inventor to predict the automobile, and it would take a real visionary to predict highways and gas stations. But it would take a science fiction writer to predict the traffic jam."

James Gunn*

- What surprised you about the resulting scenario?
- What did you expect?
- How would you add to the scenario / setting?
- What technologies / advances are missing that might improve the scenario?
- What type of story would interest you in this setting?
- What type of characters might you consider in this setting?

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Thank you!

- **Planning team:** Kim Adams, Jeff Blackburn, Jill Engel-Cox, Ling Tao, Liz Doris, Zia Abdullah, Sheila Hayter
- **Prompt questions:** Glen Engel-Cox
- **Communications & Notetakers:** Emily Mercer, Claire Bolyard, Maggie Ryan, Jason Youngstrom, Daniella Frank
- **Azure Interface:** Grant Buster
- **Logistics:** Nicole Simões, Lisa Cramer

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