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Solar to Fuels

Report on Interdisciplinary Workshop

Arizona State University

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What are the critical societal and policy issues involved in creating fuel from sunlight?

Energy is essential to modern life. None of us could survive without it, but we find it curiously hard to imagine. Despite our constant need for energy as individuals, our access to it is negotiated collectively: beyond turning on a switch or going to a gas station we have little engagement with the larger energy system. However, with the onset of climate change, peak oil, and global energy instabilities it is imperative that our imaginations of energy and our relation to it start to change.

The development of new energy systems involves not only technological innovation - how such new systems could work - but also societal dimensions: how they will impact our lives. Such systems are surrounded by questions of social and behavioral dynamics, ethics and equity, social and cultural geography, economics and public policy. We need to understand these questions in order to ensure that the promises of new energy technologies are realized.

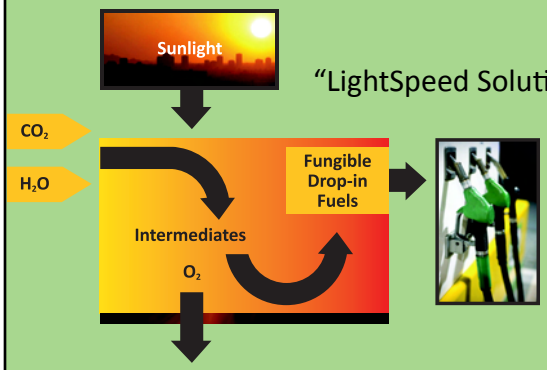
This report describes a workshop which sought to consider some of these questions. The workshop sprang from research being undertaken within Arizona State University on the societal dimensions of emerging technologies. The Solar to Fuels workshop was inspired by the development of LightSpeed Solutions, a proposed research project to create fungible fuels from sunlight. Ultimately, the aim of this effort is to develop a technology which can be deployed at the scale of current oil extraction and which will utilize existing infrastructure (in which the United States has trillions of dollars invested). 'Solar to Fuel' technology will make use of a variety of technological platforms, but is fundamentally about (non-biological) systems which harness energy directly from the sun to create a variety of fungible fuels. Not only will these fuels be carbon neutral and enable the continued use of existing infrastructure (such as cars, gas stations, and pipelines), they can be produced within the USA and will support national energy security.

The LightSpeed Solutions project - currently at the stage of a proposal to the Department of Energy - will create innovative solutions to these challenges. Drawing together expertise from universities and laboratories across the US, it will take an end to end approach to solar to fuels technology with an emphasis not just on cutting edge technology but on workforce development and industrial partnerships.

The Solar to Fuels workshop was an opportunity to consider these emerging energy technologies, their implications for broader society, and the resource, social, and political barriers to their implementation. These are complex and dynamic challenges which lie at the interface of energy technologies and society: they require new combinations of expertise in dealing with them.

"Our energy-producing technology systems, or platforms, will be scalable, energy-efficient, resource- efficient, economical, and practical. These platforms will include bold and innovative advances. They will be flexible in their ability to incorporate new science and breakthrough technologies as they emerge. We will build on and learn from adjacent technologies.

To produce fuel from sunlight, we will draw inspiration from nature's solution: photosynthesis. We will expand the solution space by freeing ourselves of nature's constraints and requirements."

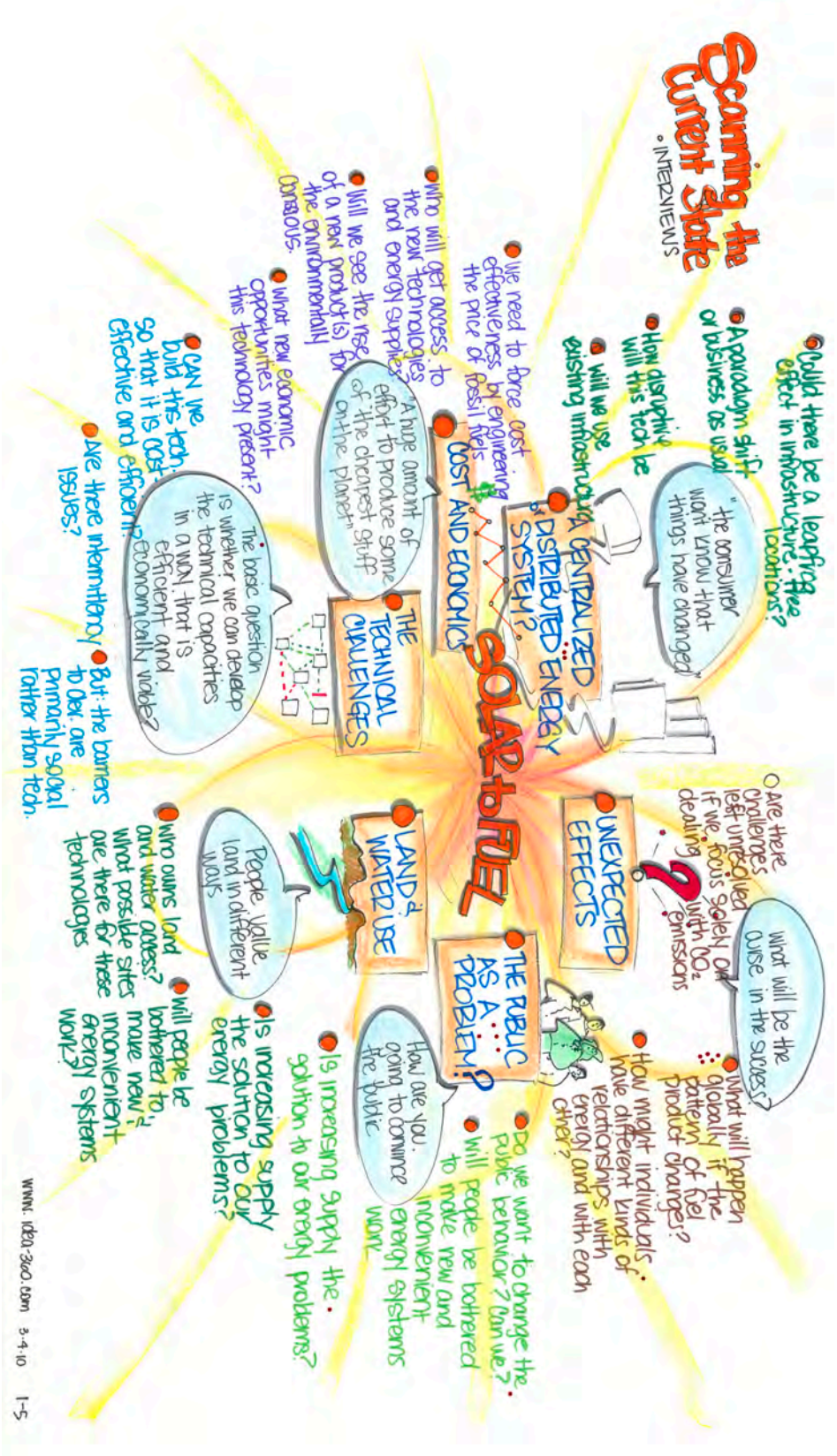


"LightSpeed Solutions will address the technical challenges by developing two complementary and potentially synergistic technologies: a solar thermochemical technology that uses heat from concentrated sunlight to drive a chemical redox cycle and a solar electrochemical technology that uses light ... for reducing carbon dioxide and oxidizing water."

The Solar to Fuels workshop brought together natural scientists with scholars of technology and society, history, political science, and sociology. Their discussion had a number of aims:

- To articulate and clarify current directions and trends in research, in societal issues, and in policy on this technology;
- To map key insights around future visions of this technology and the critical carriers and barriers that will help and hinder its development;
- To generate material for a social science research article on the societal implications of energy technologies and interdisciplinary collaboration on these.

The workshop was led by the NanoFutures project at the Center for Nanotechnology in Society at Arizona State University, and was jointly funded by the Center for Nanotechnology in Society, the Arizona Institute for Renewable Energy, and ASU LightWorks. It took place at Arizona State University over a four hour timeslot. This report summarizes the content of the discussions and of a set of interviews with participants conducted prior to the workshop, highlighting the key themes which emerged. In particular it discusses visions of Solar to Fuel technology in 2025 and issues seen as critical to the technology's development.


Scanning the Current State
• INTERVIEWS
SOLAR-to-FUEL
Could there be a leapfrog effect in infrastructure locations?
A paradigm shift or business as usual
"the consumer won't know that things have changed"
How disruptive will this tech be
Will we use existing infrastructure
A CENTRALIZED DISTRIBUTED ENERGY SYSTEM?
We need to force cost effectiveness by engineering the price of fossil fuels
COST AND ECONOMICS
Who will get access to the new technologies and energy supplies?
Will we see the rise of a new product(s) for the environmentally conscious.
"A huge amount of effort to produce some of the cheapest stuff on the planet"
THE TECHNICAL CHALLENGES
What new economic opportunities might this technology present?
CAN we build this tech so that it is cost effective and efficient?
The basic question is whether we can develop the technical capacities in a WAY that is efficient and economically viable?
Are there intermittency issues?
But the barriers to deal are primarily social rather than tech.
UNEXPECTED EFFECTS
Are there challenges left unresolved if we focus solely on dealing with CO_2 emissions
What will be the curse in the success?
What will happen globally if the fuel product changes?
How might individuals have different kinds of relationships with energy and with each other?
THE PUBLIC AS A ... PROBLEM?
Do we want to change the Public behavior? Can we?
Will people be bothered to make new and inconvenient energy systems work
How are you going to convince the public
LAND & WATER USE
Is increasing supply the solution to our energy problems?
People value land in different ways
Who owns land and water access? What possible sites are there for these technologies
Will people be bothered to make new & inconvenient energy systems work?
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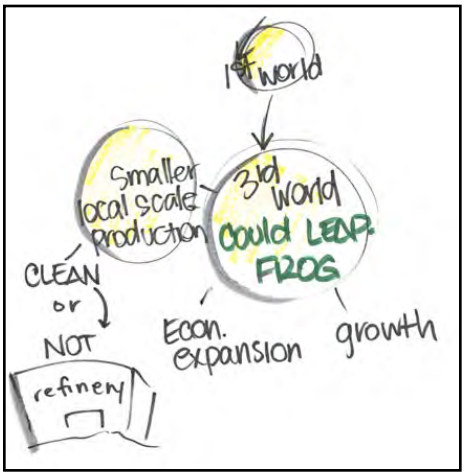
Plausible Futures: Key themes from visioning activity

The future is uncertain. Even in the 15 year time-frame the visioning stage focused on, it was clear that there are many unknowns and that there would be **surprises** in how the technology develops and is both integrated into and shaped by society. What will the oil industry's role be? How controversial will finding a site for centralized plants be? Will sustainability priorities influence financial incentives? How much refining will the new fuel need? The answers to these and many other questions are still unclear.

However, many people felt that, in practice, **2025 is unlikely to look or feel very different to society today.** At best, Solar to Fuels technology will have reached proof of concept deployment, with a small unit producing fuel. Even as the technology is deployed further - and though there are uncertainties around the way that it will be refined and the type of fuel that will be produced - the technology will be designed to fit into existing infrastructure, and individuals will therefore still use fuel in the same way. "The consumer won't know that things have changed." However, significant differences are likely to be upstream in fuel production and use: while end users have the same experience, refiners and distributors may have their practices and procedures disrupted. Energy security is a key driver, and, at this upstream level, there may be global effects as patterns of production and distribution change. International as well as national politics (for example around pricing, incentives, and land use) will thus be a significant feature of the technology's development and could very well **change the international energy economy**.

Solar to Fuel technology will therefore play out on a global stage and may be adopted in different ways in different locations. One potential impact of the emphasis on using the United State's existing infrastructure, for example, might be **a leapfrog effect in the global South.** Countries without networks of refineries, pipelines, and point of sale facilities may develop this technology in different ways and - perhaps - more quickly. They may make different choices - to immediately focus on distributed rather than centralized fuel production, for example - and take different technological pathways. For them, the future could look different both to their experience today and to the patterns of fuel production and use that countries such as the US have.



As Solar to Fuels and related technology progress, energy capture and use may gradually change. We will move from using energy dense fossil fuels, which are often extracted and refined in ways and places that are invisible to us, to diffuse energy sources such as the sun. These will change our lives by being **a much greater part of the landscape**: it is estimated that solar to fuel technology would require x square miles of concentrated solar mirrors in order to replace the oil currently imported in the USA. Land is therefore going to be an important issue which has the potential to become a new political hot potato. Locations

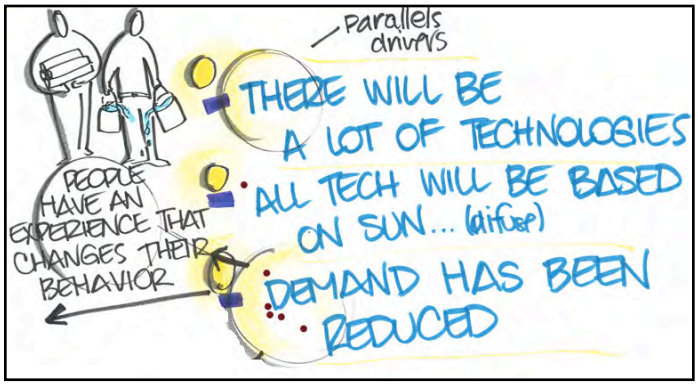
water (whether purified or brackish may depend on how the technology develops); whether land is currently used for food production. How such decisions will be made is as yet unclear. To what extent will the public buy in to difficult land use choices? Will they be driven through by the 'brute force' of government and industry? What role will lobbying and environmental groups have?

Indeed, concerns were voiced as to **whether the US political system will be able to keep pace** with technological progress and the urgency of climate change. There may be ready technological solutions, but without political will and robust policy instruments, change could be slow. Revising the energy system requires the creation of new kinds of incentives, from capital investments for production and demand reduction incentives on the consumption side. New regulatory models and market rules will need to be crafted in alignment with the specificities of some of the new energy technologies. Who will lead this development? Can we fast-track the policy changes required? What role will global competition - for instance with China - play? Many in the workshop felt that, at the moment, the political framework of the US energy system is not developing quickly enough or in the right directions. More research on the complex interactions between people, science and policy in the context of energy is urgently required in order to enable these changes to take place.

One change that could drive political reorganization is if energy becomes a more obvious part of our lives. This awareness may shift as energy begins to dominate our landscape in new ways and programs for reducing **demand take hold**. Publics will be increasingly aware of global climate change and have a greater appreciation of the ways in which their actions and choices use energy. In particular, many in the workshop expect **higher prices** of fuel and energy. Solar to Fuel technology, for example, is estimated to have an end-use price of $6-8 per gallon. Workshop participants were agreed that price linked directly to demand and use: raising prices will therefore reduce energy consumption, shift patterns of transportation use, and increase energy efficiency. Raising prices artificially - through taxation or 'clean up' costs - might be one way of enhancing public understanding of energy use and of achieving the reduction in demand that is necessary for sustainable technologies such as Solar to Fuel to supply our energy needs. At the same time, rising prices could also **aggravate inequality** (nationally and internationally), with particular communities being over-burdened by the costs of cleaner fuel or losing access to cheaper energy sources.

"Per capita we're the largest carbon producer on the planet - we could cut that in half without changing our lifestyle a lot."

While the workshop focused on Solar to Fuel technology, it was emphasized that there is no one solution to our energy needs. It is more likely that we will experience **a suite of new technologies** - based directly or indirectly on the sun - which will develop in a number of different directions. Such technologies will ideally be used as a portfolio, in combination with one another, but are also likely to compete with each other. This is particularly significant for as yet untested Solar to Fuel technology, which may appear as a competitor to more established technologies. This diversity will mean that everyday energy experiences are likely to vary from place to place within the US. Solar to fuel technology may eventually evolve into more distributed models of fuel production and distribution, as well as the centralized route it will initially take. Cheaper, more efficient photovoltaics will mean that it is easy for homeowners to produce their own electricity and to live off the grid (such as in more remote areas) if they wish. Such changes could alter contemporary urban and living environments both aesthetically and spatially, creating new kinds of homes, communities and cities. It is these kinds of choices - and the different ways that different public groups make them - that are likely to drive the direction of technological innovation in the coming years.



Barriers and carriers: Key dynamics around the technology's development

In addition to the visions of the future of Solar to Fuel technology, the workshop- and the interviews carried out beforehand- threw up a range of broader issues seen as critical to the ways that this - and related - technologies will develop. These, for example, include the public and policy context of new energy systems, decisions to be made between centralized and more distributed energy systems, and the sense of urgency created by global climate change: such issues are not necessarily specific to Solar to Fuels technology, though they will shape its trajectory. These broader dynamics are detailed below.

New energy systems - not just technologies

New energy technologies will require new ways of thinking about science, technology, and society. Not only are new, interdisciplinary forms of working required, but the technologies need to be understood '**end to end**', within a context of policy, usage, and technological life cycles. This means that targeted, science-only calls and proposals are no longer effective means of development. New ways of developing human capital - to create a body of workers who are able to integrate different natural and social science perspectives into their thinking - are required to deal with the business, public and policy contexts of energy systems. Similarly, research on and implementation of policy innovation is required. Regulatory and incentive schemes need to develop in ways that keep pace with new technological development but which also manage the timing of this development in ways that acknowledge the urgent need for change in US energy use.

Research therefore needs to understand not just how a technology might work, but what the industrial ecosystem around it might look like.

Understanding scaling up is also essential: building new power plants and factories can take decades and relies on complex sets of supply chains. If solar to fuels technology is to be rolled out on a large scale, the ability to meet this production capacity - in terms of, for example, materials for mirrors or human capital in the form of engineers - needs to be planned in advance. Research therefore needs to understand not just how a technology might work, but what the **industrial ecosystem** around it might look like.

The public as a problem?

The public are often seen as a challenge to change in energy systems: they are perceived as energy-hungry, energy-inefficient, and unwilling to change their behavior. "Solar has always had to address some kind of public perception of a problem." Negative or overly pessimistic

public perceptions of emerging energy technologies do exist. But to emphasize this is perhaps to take an overly simplistic view: while education programs are certainly necessary, public responses to technology are informed by a wide variety of concerns and experiences as well as an appreciation of scientific facts. Indeed, **public understandings of energy technologies are likely to vary widely**. More research is needed on the ways in which different public groups will consume, perceive, and make choices about emerging energy technologies such as Solar to Fuel. What kinds of behaviors - from having to go to the gas station to paying more for fair trade or organic food - are likely to be carried over from existing experience, and in what ways will radical new ways of using energy come about?

Workshop participants thus felt that more humility in meeting people where they are at is required in order to enable the co-evolution of energy transitions between producers and consumers. Public engagement with new energy technologies needs to be seen as an opportunity, rather than a problem, and participation should be built into scientific research on these areas. Diverse public groups - legislators, activists, 'NIMBY'ers - should be brought together with those involved in developing new energy technologies in order to understand the ways that these technologies will be used - or not - in practice.

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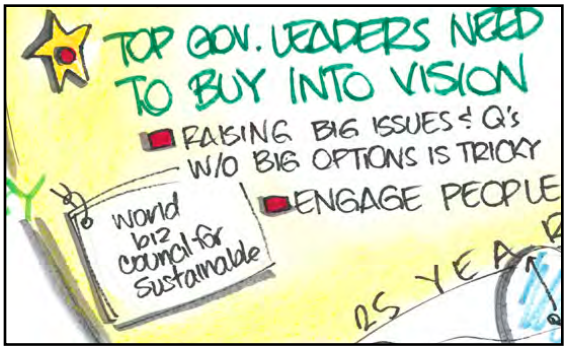
Finding political (and corporate) will

All in the workshop were agreed that there is a profound urgency around the development of new energy systems. Climate change is real and will have significant impacts: indeed, the time for action to mitigate its worst effects is probably over. "It is now too late. We are now going to be faced with catastrophic draconian action. … The time frames to evolve the energy industry are simply too long to deal with the problem that's ahead of us." Dealing with these effects would necessitate putting the world's production systems on a "wartime footing" - converting all automobile production plants, for example, into wind turbine factories. Such a conversion will simply not happen, however, given that public and political will is not committed to this sense of urgency. Our current systems have a limited capacity to deal with the unprecedented challenges the world is facing. Changing this may require shifts in government - one somewhat tongue in cheek suggestion was to switch to a socialist or monarchical system in which something other than money and pricing will drive development - as well as forcing corporations to act as 'citizens' and, potentially, draconian policy measures. If we are to avoid the consequences of failing energy and climate systems, the timescales of technological development need to move forward by decades. Doing this will require decisions made at the highest levels of government and radical new ways of pricing energy - carbon taxing, for example, may become necessary.



"It's a political issue. A policy issue. We could build these [technologies] but we don't do it because we don't have the policy in place to drive it and because we've got so much fossil fuel that we don't need it."

Who is 'we'?

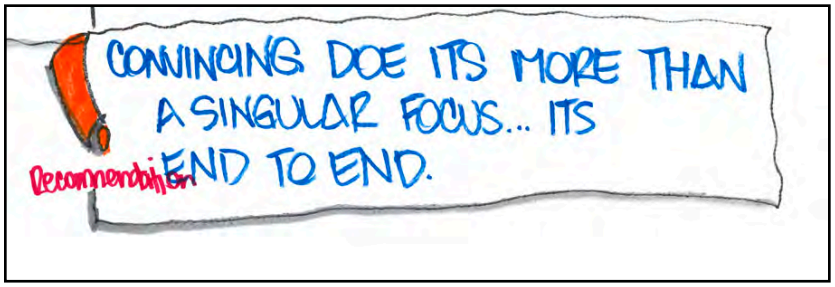
These issues are important to think about at this early stage of solar to fuels technology's development. It is also important to recognize, however, that as this and other technologies develop, they will affect different groups of people (and countries) and that they will unfold in a changing public and political context. While 'we' - those in the workshop - may be relevant decision-makers today, the decision-makers of the future are likely to come from different countries, socioeconomic backgrounds, and ethnic groups. As with the technology's engagement with the broader public, then, there is a need for considering multiple vantage points and agendas. The perspectives of diverse public groups and of international partners should be incorporated as solar to fuels technology is developed and deployed.

Next steps

It is worth emphasizing again the complexity of the systems being shaped by new energy technologies. We cannot fully predict the ways that Solar to Fuel technology will be taken up by publics or the ways that it will shape global energy use and sale. "Will there be a 'curse in the success'?" Are there challenges around equity, democracy and resource use that are being left unresolved by focusing on CO_2 emissions and climate change? How might individuals have new kinds of relationships with energy and with each other? These kinds of questions should now be considered as part of the process of normal technological research and development, in which social and natural science expertise are used in tandem to deal with the complexity of energy transitions. We should also, however, not expect research to give us all the answers. These will be understood in full only as the technology unfolds into everyday experience.

What are the geographies, economic and environmental impacts, distributions of risks and benefits, opportunity costs, aesthetics, and long-term societal implications of existing energy systems, and how will these change in the coming years?

This document has presented the key themes which emerged from an innovative discussion between scholars from a range of disciplines with interests in energy and society and which took Solar to Fuels technology as its focus. It has described the key features of these scholars' vision of a 'Solar to Fuels' future, in which the technology has started to be rolled out. It has also raised a set of broader dynamics which are likely to shape changes in energy systems. In doing this, this Report presents questions which were raised at the workshop and not answered - which, indeed, cannot be answered without further study. What are the geographies, economic and environmental impacts, distributions of risks and benefits, opportunity costs, aesthetics, and long-term societal implications of existing energy systems, and how will these change in the coming years? What are the meanings people attach to novel technological infrastructures and patterns of land use and water consumption, and what will the long-term impacts of these be for people's lives and the lives of their neighbors and communities?



This Report therefore represents a starting point for continued conversation. The questions and themes it describes call for further research - and for a continuation of interdisciplinary forms of collaboration and discussion.

Participant research interests

A section of the graphic notetaking for the workshop showing participant research interests.

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