Environmental Movements and Scientific, Technological, and Industrial Change

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Abstract

Environmental movements have a diverse set of goals and can have a wide range of outcomes, among which are changes in industry, technology, and science. These changes can involve the sunsetting of industrial sites, technologies, and practices or even entire industries; the redesign of infrastructures, products, and technological systems; and changes in scientific research agendas, methods, and problem areas in response to movement goals. Although state-oriented mobilization with resulting changes in policy or program implementation is important, changes may also take place directly when private-sector firms, consumers, system designers, and scientists alter their preferences, plans, and practices. This chapter argues that attention to the material and epistemic dimensions of environmental movements is central to understanding the problem of outcomes, and it adopts a "sociotechnical perspective" on these dimensions. The perspective involves new analytical categories and research questions, such as the comparative analysis of industrial transition movements, the politics of design, and undone science.

Introduction

The goals of environmental movements frequently include industrial change. At a small scale, local environmental justice struggles often seek to stop an unwanted source of environmental risk, such as pollution from a local industrial site, or to gain some other kind of remediation. Environmental movements can also involve grassroots efforts to build alternative forms of industrial processes, technologies, and organizations. In doing so, they bring together industrial innovation and social movement goals, again often at a local level. At a broader scale, environmental movements can help to motivate more widespread changes in science, technology, and industry (STI) that are guided by public policy and shifts in consumer tastes and organizational strategy. This chapter reviews environmental movements that include among their goals STI change. The review will develop the argument that attention to this topical area has implications not only for the study of environmental movements but also for the study of social movements more generally, and research in this area can help to identify new perspectives that may otherwise tend to receive less attention from theories developed for other types of movements. The new questions and analytical perspectives are broadly "sociotechnical" in the sense that they enable a clearer understanding of ways of thinking

about the material and epistemic dimensions of environmental mobilizations and outcomes. (For a broad overview of sociotechnical perspectives, see Hess and Sovacool 2020.)

Research that focuses on the study of environmentally related changes in STI can be viewed as part of the broader literature on the outcomes of social movements. These outcomes can include state-oriented policy change, but they also include economic outcomes, such as direct effects on markets and consumer preferences, and broader cultural changes in values and identities (Giugni and Grasso 2018, Earl 2004). This chapter focuses on environmentally oriented change and explores the potential of using a sociotechnical perspective that brings attention to technology, products, material culture, and knowledge. The chapter begins with some potential implications for general social movement studies, then it examines three ways of thinking that respectively are related to the three areas of science, technology, and industry.

Definitions and Theoretical Categories

Categories such as "social movements" or "environmental movements" are constructed by researchers to define a terrain of inquiry where results from one study may be helpful for informing research in another study and for developing middle-level, generalizable, social scientific knowledge. Frequently, definitions of social movements and the study of social movements focus on mobilizations that utilize some type of extra-institutional repertoires of action such as street protest and strikes. However, when the focus of attention is on STI change, this definitional scope may become limiting. Frequently, there are mobilizations by coalitions of challengers who either do not rely exclusively on protest and unruly action or who avoid such repertoires in favor of institutionalized approaches. Although many social movements utilize a mixture of extra-institutional and institutional repertoires of action, in the area of STI the emphasis may be on building coalitions for reforming government policies, changing the strategy of corporations, inventing new technologies, designing new organizational forms, creating job opportunities, providing low-income access to industrial goods and avoidance of bads, and bringing about changes in the practices and goals of an occupation (e.g., Frickel and Gross 2005, Hess 2007, Hoffman 1989). Thus, the study of STI and environmental movements requires a broad conceptualization of a social movement as a sustained mobilization by challengers who have met with resistance from incumbents in a social field. If researchers prefer to keep the definition restricted to extra-institutional action, then some other term might be used, such as "mobilized public" or "mobilization."

The focus on STI and outcomes in the study of social movements has several implications for general social movement theory. For example, the middle-range structural perspective represented by research on the political opportunity structure tends to become broadened by STI questions. (For a background on the political opportunity concept, see McAdam 1996, Meyer and Minkoff 2004.) One example of broadening is the parallel concept of the industry opportunity structure, which can include a range of levels from the firm to global industries (Schurman 2004, Soule 2012). When the goal is regulatory reform or other kinds of policy changes, there is also an epistemic dimension to the opportunity structure because of differences in scientific evaluations of risk and the volume of available scientific research (Hess 2016). In some cases, policy changes must also await the technological dimension of opportunities because new technologies are not yet market ready and require more research and development (Elzen et al. 2011).

Another example of how inquiry into STI-related goals and outcomes may have implications for general social movement theory is research on the strategic symbolic dimensions of mobilizations. Again, there is a long and distinguished tradition of research on collective action frames and the dynamics of framing and counter-framing in social movement studies (Benford and Snow 2000, Esacove 2004). But a subsequent literature suggests that in the context of environmental and STI research, attention needs to be paid to the broader visions and imaginaries of interwoven technological, institutional, and industrial futures (Smith and Tidwell 2016, Zilliox and Smith 2018). Likewise, work on scientization suggests the need to examine how framing activities involve conflicts over defining problems and solutions as merely technical and not political or vice-versa (Kinchy 2012, Levidow 2013).

Even very basic definitional questions such as stratification, agency, and societal inequality may undergo a shift. For example, when defining inequality and actors, should non-human species be included? These questions emerge particularly in the study of animal rights and deep ecology movements, where the study of STI and environmental justice meets challenges of human-centered social theory (Pellow 2014). Sociotechnical perspectives sometimes also examine how human agency becomes delegated to technology within sociomaterial networks or ensembles, thus endowing "things" with a kind of agency, and how scientific theories and models have a "performative" or world-making dimension when used to construct new social institutions such as energy markets (MacKenzie et al. 2007).

In summary, part of the motivation for examining the STI dimensions of environmental movements is that this area of research may have some significant implications for general social movement studies and theory. The remainder of this review will examine three concepts that provide examples of these implications: industrial transition movements, the politics of design, and undone science.

Industrial Transition Movements

Environmental movements can involve some type of STI change as an outcome, but STI change is only one of multiple possible types of outcomes. For example, consumption-oriented environmental movements may involve changes in consumer practices without significant STI outcomes, but they can also become the basis of changes in consumer preferences that have implications for STI. Arguably, some environmental counter-movements do not involve STI change if the primary goal is to maintain the status quo against proposed changes (Hess and Brown 2017, Jacques et al. 2008), and likewise some environmental mobilizations may also attempt to preserve a pro-environmental status quo against roll-back attempts. However, if an environmental movement involves STI change as a goal, it can be considered an industrial transition movement: a type of social movement that has the goal of bringing about a substantial change in an industry, generally with implications for scientific research and technology development (Hess 2016). ITMs do not always have environmental change as a goal; they may instead target other types of industrial change, such as industrial concentration, privacy rights, consumer safety, equitable access, or public health risks.

Social movement researchers have long studied environmentally oriented ITMs that operate in a protest mode, such as the anti-nuclear energy movement of the 1970s and 1980s (Kitschelt 1986). Likewise, researchers have also recognized the generative potential of movements that have helped to spur industrial innovation. Examples include the role of

grassroots mobilizations in the development of the organic foods industry (Obach 2015), the recycling industry (Lounsbury et al. 2003), or the wind industry (Vasi 2011). Although researchers have long studied ITMs, the systematic comparative analysis across industries is much less developed. One of the benefits of using the category of ITMs is that it provides a framework for thinking about the social movement mobilizations that have a goal of STI change.

The use of the concept of goals, which are understood here as articulated and intended outcomes of a mobilization, is difficult but necessary to define the category of ITMs. For example, goals are not always congruent with outcomes, movements can have multiple and not always coherent sets of goals, and outcomes can be unintended and unanticipated (Giugni 1998). There are often disagreements within the movement over goals, and internal divisions can affect the likelihood of achieving the goals. However, thinking about movements in terms of goals can facilitate an analysis that examines movement strategy in relationship to consequences. Advocates and activists in movements often seek to answer this question; however, with a few exceptions (Jasper 2008), researchers in social movement studies have not explored the topic with the same attention that is found for other research questions in the field.

A synthesis of previous work on ITMs (Hess 2016) has identified two main types of goals: sociotechnical or design goals, which focus more on the material and organizational dimensions of industrial sectors (with the understanding that design changes may require policy or political change in additional to scientific and technological change and changes in industrial strategy); and societal changes, which focus more on the connections between industrial change and broader agendas of societal reform. Within each of these two broad categories are two subcategories:

1. Sociotechnical or design change
   a. Sunsetting or opposing unwanted industrial processes, technologies, side effects, or technological systems (industrial opposition).
   b. Supporting alternative industrial processes, technologies, or technological system (alternative industrial development).
2. Societal change
   a. Addressing problems of equality such as access to material products and safe employment.
   b. Changing the organizational form of industrial production and the governance of industry and technology in more democratic directions.

In some cases, it is possible to demarcate a movement that focuses on one aspect of industrial change, such as a green jobs equity movement, which can be studied apart from other movements occurring in the same social and political space at the same time. In other cases, the movement or mobilization of interest is an amalgam of various types.

This approach helps with the problem of classifying the vast research on social movements and industrial change in order to compare studies across industries and sectors. Among the most salient industrial sectors for environmental movements are the built environment and transportation, energy, finance, food and agriculture, the media, waste and materials, and water. Examples of research from the substantial literature for four broad industrial sectors are provided in Table 1. For example, oppositional movements include

mobilizations against highways and land development; fossil fuels and nuclear energy; pesticides, genetically modified food, and confined animal feeding; and chemical toxicity and landfills. But these movements have a "pro" counterpart, sometimes in the form of occupational reform movements. Corresponding examples include support for human-powered transportation and urban density; renewable energy and energy efficiency; organic food and plant-based diets; and green chemistry, recycling, zero waste. Moreover, movements can also address sector-specific inequality: affordable housing and transportation; affordable electricity and heating; hunger and food deserts; and unequal access to clean or nontoxic air, land, products, and water. These movements may also be connected with demands for access to green jobs. Finally, movements can attempt to build alternative organizations and institutions or advocate for more democratic governance processes. Examples include public transit and vehicle-sharing programs; community-controlled or publicly owned energy; food cooperatives and community gardens; and eco-parks and industrial ecology. The last category can include both the development of new organizational forms (public agencies, cooperatives, B corporations, local ownership and control, etc.) and new processes of governance (public oversight, transparency improvements, public engagement mechanisms, etc.).

Table 1. Examples of Industrial Transition Movements for Specified Sectors and Goals

	Built Environment and Transportation	**Energy**	**Food and Agriculture**	**Waste and Chemicals**
Industrial opposition (sunsetting)	Infrastructure (Mohl 2014)	Infrastructure and fossil fuels (McAdam and Boudet 2012, Vasi et al. 2015)	Industrial agriculture (Ansell et al. 2006, Schurman 2004)	Waste and toxics (Pellow 2007, Sherman 2011)
Alternative industrial development	Sustainable transportation (Golub et al. 2016, Hess 2007). Urban design reform (Bullard et al. 2007, Talen 2005)	Wind energy development (Mey and Diesendorf 2018, Vasi 2011)	Sustainable food (Cherry 2006, Jaffee and Howard 2010, Obach 2015)	Recycling (Lounsbury et al. 2003). Green chemistry (Iles 2013, Woodhouse and Breyman 2005)
Inequality remediation, distributive justice	Transit access (Bullard et al. 2004)	Energy access (Fuller and McCauley 2016), green jobs (Nugent 2011)	Food access (Alkon and Agyeman 2011, Sbicca 2013)	Clean water access (Krings et al. 2019)
Democracy, procedural justice	Urban planning reform (Bailey et al. 2011, Gengs 2002)	Energy governance reform (e.g., Hess and Lee 2020)	Food governance reform (Andrée et al. 2019, Goodman et al. 2012, Schneiberg et al. 2008)	Toxics governance reform (Chilvers and Burgess 2008, Howell et al. 2019)

Thinking about environmental movements and industrial change in this way opens up the possibility of comparative social science analysis that seeks to find patterns in strategies and outcomes across movements. For example, consistent with the broad sociological literature on routinization and cooptation, the industrial opposition movements frequently begin with a goal of a full moratorium on a technology or industrial process, but the outcomes are often modified to involve STI design changes and a partial moratorium on some aspects of the industrial technology. Likewise, alternative industrial movements often end up losing the original aspirations of local ownership and community control as the technologies (e.g., solar, organic agriculture, recycling) are scaled up and incorporated into industrial regimes, which nevertheless undergo changes in response to the absorption process. Equity-oriented movements sometimes become routinized as organizations gain acceptance for their demands and shift into a service-provisioning, nonprofit model. The comparative analysis of the movements can point to common pitfalls and challenges that movements face as they gain partial concessions from the state and industrial incumbents (Hess 2007).

Another way to use this approach is to develop a "multi-coalition perspective" on environmental social movements. Unlike the broad comparative project outlined in the previous paragraph, this approach studies the divergences and convergences of related forms of mobilization in a demarcated space and time. For example, energy-related environmental mobilizations in New York State during the first two decades of the twenty-first century were diverse but also interconnected (Hess 2018). For example, with respect to the goal of industrial opposition, the most salient industrial opposition movement related to energy transitions was the statewide movement against natural gas fracturing (fracking) technologies (Dodge and Lee 2017). The extensive movement ultimately led to a positive outcome (for the movement) of a state government decision not to proceed with fracking, and the movement subsequently moved on to opposition to natural-gas pipelines and liquid natural-gas terminals.

This more visible and classic type of oppositional, protest-based environmental movement is not the only type that was active in New York State during the two-decade period. With respect to the goal of alternative industrial development, a group of mostly different environmental organizations played a significant role, along with partners from the private sector, in building support for the policy framework for a statewide energy transition (Raymond 2016). In the first decade, they helped to build support for the state government's decision to embrace the Regional Greenhouse-gas Initiative, which put in place a cap-and-trade system in the region, and they were active in subsequent policy reforms. With respect to the goal of equity, another group of organizations, located more in community-based organizations and the labor movement, advocated successfully for a green jobs law that was also connected with low-income weatherization and energy affordability (Hess 2018). With respect to the goal of democratizing energy governance, as the energy-transition and energy-equity policies became institutionalized, another mobilization emerged to promote a more just and democratic energy transition in the state, with goals that included those of the other three mobilizations but also procedural changes in the state government's decision-making process and support for community-based and community-controlled renewable energy. The energy-democracy coalitions could count some significant, albeit partial victories, such as a climate justice component of a law approved in 2019 (Assembly Bill 1564, Senate Bill 2385; NYRenews 2019).

In summary, with either a cross-industry perspective or a multi-coalition perspective within a region, the comparative analysis of ITMs helps to identify research questions and new perspectives with respect to the study of outcomes and consequences of environmental movements:

1. From a comparative perspective, what are the general tendencies for industries to adopt, transform, and deflect proposals for the sunsetting of some technologies and organizational forms and the sunrising of others?
2. When goals are broadened from sociotechnical change (e.g., ending nuclear power or fossil fuels for electricity) to societal change (e.g., improved equity or democracy), under what conditions does this broadening improve or worsen the achievement of goals?
3. What is the structure of coalitions or networks for a range of related environmental ITM mobilizations in a demarcated space and time? Under what conditions do the mobilizations occur as silos, and under what conditions are broad coalitions formed? How does the organizational composition and framing change as broader coalitions are formed?
4. What is the role of private- and public-sector actors in these different mobilizations, and where are the divisions within private-sector, public-sector, and civil society actors? How are the mobilizations connected with internal conflicts within companies and industries over strategy and change?

Technological Change and the Politics of Design

Environmentally-related industrial change involves the complex interweaving and co-construction of cultural, organizational, political, and material dimensions. The sociotechnical perspective views these dimensions as connected and mutually constituting, but it also views the design of the material dimensions of social life as a site for politics. A broad term for this approach is the "politics of design." Long used in the design professions, the first use of the term in the science and technology studies (STS) literature is probably by Donald MacKenzie in his essay "Marx and the Machine" (MacKenzie 1984). In the essay, MacKenzie rejected a technological determinist reading of Marx and instead argued that Marx viewed technological changes and social changes as deeply interconnected. MacKenzie then shifted from the discussion of technology in Marx to the politics of design, that is, the idea that technological design "reflects the social relations within which it develops" (1984: 499). Although he argued that Marx equivocated on the issue, MacKenzie turned to work in the history and philosophy of technology that pointed to how the design of technological systems could reflect social and political choices. The view has become much more widely accepted during the decades after the publication of his essay, but it has also clarified the sociotechnical approach to focus more on how the material and social worlds are coconstituted.

Other researchers were also developing this perspective. For example, Noble (1978) showed how choices over machine tool design emerged in the context of the labor movement and labor-capital struggles, and the decisions reflected the desire of industry owners and managers to wrest control of the machine from workers and shift it to management. Winner (1986) discussed how decisions about highway design reflected racist values, and he drew Mumford's analysis of democratic and authoritarian technics to argue that artifacts have

politics (Mumford 1934, 1964). Similarly, Wajcman (1991) and other feminist technology researchers pointed to the political implications of design choices for gender relations in the workplace, domestic, and reproductive technologies (Layne et al. 2010).

Much of this research recognizes the role of social movements (labor, civil rights, environmental, feminist) in developing alternative views or frames for understanding design choices. Thus, the politics of design perspective does not just explain design outcomes as the result of structural conflicts in society; it also draws attention to how the design of technological systems and material culture more generally can change as the result of political contestation. To broaden MacKenzie's analysis somewhat, the "politics of design" perspective includes how the political and technical orders (or the social and material orders) are coconstituted through relations of cooperation and conflict. The design of technological systems is constantly modified, reproduced, and contested, and at any given point in time the design represents a sociomaterial settlement (such as an imposition or compromise). Technology, especially at the scale of large technological systems such as infrastructure, is coconstituted with social structures, fields, and networks. In Winner's phrase, "technology is legislation" (2007).

From this perspective, technology is not merely a black-boxed prop or instrument in movement struggles, such as the study of how activists use information technologies to support mobilizations. Likewise, technology is not only a black-boxed object of contestation (e.g., movements that advocate for or against some kind of material change, such as a ban on natural-gas fracking or tuna fishing with nets). These approaches to technology should be considered in an analysis, but a sociotechnical perspective also views the design of the material world as a complicated negotiation with multiple possibilities and positions. The design focus implies that choices, options, or alternatives are both imaginable and possible. Technology is not a diversion from politics but a site for political contestation and mobilization, which often does involve mobilizations in the political field and may also involve changes focused on industrial innovation, consumer use and redesign, and upstream scientific research.

Design conflicts can be broken down into various subtypes. "Object conflicts" are a subset that focus on existential questions (Should the pipeline be built? Can we close the landfill?) or more complex questions of remediation (Can we reroute the powerline or put it underground? What are the political implications of gas, clean diesel, or electric buses for our city?). But design conflicts can also erupt over large-scale technological systems, such as the restructuring of a country's power grid. These conflicts can include the design of the technological governance, that is, the procedures by which decisions are made and public accountability is strengthened, and the design of systems of remediation or resettlement (such as for hydroelectric dams). In turn, the politics of design shades into the more general politics of democratic accountability and power. Easily misconstrued to mean that the focus on STI involves acceptance of private-sector governance and becomes compromised by an implicit neoliberalism, instead the "politics of design" perspective suggests continuity with questions raised by Marx. The design of sociotechnical systems is politics by other means, just as the development of technology policy is engineering by other means. One of the tasks of researchers is to show how the framing of technological, scientific, industrial, and infrastructure policy as guided merely by technical criteria (cost, efficacy, efficiency) can itself be a maneuver to shift power to more easily controlled, scientized, technocratic, decision-making fora.

Of great significance in the twenty-first century environmental politics is the politics of design of the electricity system and increasingly the electrified transportation system. These industrial transitions involve myriad sites of political conflict that include how organizations, practices, devices, and infrastructure are configured. Does solar take the form of large-scale, utility-controlled energy, or can it be reimagined as enabling greater local control and democratic accountability? Are smart meters configured in wireless or wired mode, with detailed monitoring of real-time household energy use or with aggregated data that offers better privacy protections? Do utility programs that require time-of-use pricing have negative implications (by gender, race, and class) for households with second- and third-shift workers? These conflicts take place in the political field and can be conceptualized in traditional ways, but they also take place in the guise of politically neutral, "technical" choices that may require the mobilization of counter-expertise even to identify the political valences and societal implications of emergent forms of design.

In summary, the "politics of design" perspective opens up the study of environmental movements and industrial change to a series of questions, such as the following:

1. What is the material and technological dimension of the environmental movement's goals, and what is the range of design changes that are at play?
2. What are the political valences of the various design proposals at play in the field of contention? What groups benefit or lose from the proposals, and how are the proposals related to coalition composition and framing?
3. How are the object conflicts (the materially focused design conflicts) connected with the design conflicts over arrangements of governance and remediation?

Epistemic Change and Undone Science

Scientific research and environmental movements come together in various ways, and the mutual shaping of the two can be classified using the different goal types outlined above. Where the goal is industrial opposition, the movement often needs research that documents risk or harm. Such research can be used to expand frames to include public health concerns and to build coalitions between environmentalists, public health leaders, and community groups. The frame expansion can contribute to improved chances of a mitigation outcome. Where the goal is building alternative industrial technologies or industries, the focus is more on innovation and the role of scientific research in contribution to developing new technologies or to making existing ones more economically and environmentally viable. Social science research can also be valuable for documenting unequal distributions of goods and bads and for developing a better understanding of new modes of governance and industrial organization.

Again, the epistemic dimensions of social movements have long been recognized, but the sociotechnical perspective adopted here argues for a more systematic approach to the topic. Previous research has recognized how scientists play a role in shaping social movements, such as opposition to wars and weapons research (Moore 2013). Scientists can also embrace the goals of social movements by altering their research agendas, such as by working with social movements in an advisory capacity or by providing research in citizen-science alliances and shadow mobilizations (Brown 2007; Frickel et al. 2015; Lubitow 2013; McCormick 2006, 2007), but they can also develop new research fields in response to articulations of research needs by social movements, such as environmental toxicology (Frickel 2004). Scientists also

sometimes engage in participatory and community-based research, where there research programs are more directly an outcome of social negotiation with publics (Allen 2018, Cordner et al. 2019). The relationships between, on the one hand, activists, advocates, and communities and, on the other hand, scientists and scientific research are not always easy and smooth. Scientists have their own priorities and may negotiate with the activists and advocates, and likewise participatory, community-based research can be associated with projects that lack symbolic capital in the scientific field. Sometimes the resulting research does not always document the effects that activists and advocates wanted to have demonstrated (Yearley 1992, 2005).

Social movements themselves can also be sources of grassroots research and innovation. The topic of citizen science has gained popularity in recent years, partly in response to the failure of governments to address research needs that social movements and public-interest civil-society organizations have identified (Jalbert et al. 2017, Kimura and Kinchy 2019, Ottinger 2017). When movements are institutionalized and have large organizations, sometimes the organizations have the means to hire scientists or otherwise to fund scientific research directly, as occurs with some of the large environmental organizations (Hess 2009). Social movements and civil society organizations can also provide laboratories of grassroots innovation, where ideas for new technologies are translated into prototypes and tested (Smith et al. 2016). The early history of the Danish wind industry or the organic food industry in the northeastern U.S. are examples (Mey and Diesendorf 2018, Obach 2015). These experiments can also be sites for the development of new organizational forms (e.g., community renewable energy and community-supported agriculture) and for political organizing for "stretch and transform" policy changes (Smith and Raven 2012).

By developing a politics of knowledge similar to and in parallel with the politics of design, social movements participate in the social shaping of science, but at a level quite different from the processes of social construction identified in the STS programs of the 1980s, which focused on how networks of scientists negotiated the transformation of knowledge claims into consensus knowledge in their specialty fields (Knorr-Cetina and Mulkay 1983). Instead, the focus is less on the construction of credibility for scientific claims within research fields and more on the political valences of choices between research agendas and priorities.

Attention to the construction of research agendas and priorities also entails identifying areas where research is needed and not yet completed. In other words, the science aspect of STI outcomes involves identifying areas of scientific ignorance. The study of scientific ignorance—both within the scientific field and in the broader social spaces in which scientific knowledge is valued, rejected, vetted, and interpreted—has become a topic of growing interest (Gross and McGoey 2015). Within the broad range of interdisciplinary inquiries and conceptualizations of ignorance, one type that is especially relevant to social movements and especially the concerns with health and environmental in environmental movements is undone science (Hess 2016). This type of scientific ignorance focuses on non-knowledge specified from the standpoint of a social movement, public interest group, or community that is mobilizing to protect its health, welfare, and environment. These mobilizations identify not only goals of political, technological, and industrial change but often the need for new or different types of research, and they identify the knowledge that is missing, in insufficient quantity, or inconclusive. The absence or low volume of research is defined oppositionally, especially in

contrast with research that is conducted or funded by industry. Often industry can produce research at a higher level of volume and visibility in the public sphere to support its view that an industrial site, technology, process, or infrastructure does not present a public risk and that regulation is not needed (Frickel et al. 2010, Hess 2016).

Undone science is systematically produced because the lack of knowledge is beneficial to powerful actors such as industries that generate risk from toxic exposure and pollution. (Again, it is helpful to remember Marx, whose development of an alternative political economy was also a kind of sociology of scientific ignorance.) Dominant actors in industrial and political fields can exert systematic influence on funding flows to tilt the contours of research agendas in directions favorable to the more environmentally harmful industrial processes and technologies so that the relevant research remains in an ongoing state of doubt and inconclusiveness. In turn, the funding agendas send signals of what is valued to research fields, and these signals become internalized as "habitus" (Jeon 2019). When scientists set out to address undone science, and especially when they have results that are unfavorable to industry and they circulate the results in the media, then industry (and sometimes government) has a range of techniques of suppression that it can use to maintain doubt and ignorance in the public. The suppression of environmental science is widespread, and the exemplary tales can cause other scientists to think twice before entering the fray (Kempner et al. 2011, Martin 2007, Oreskes and Conway 2010). Likewise, if industry funds research that ends up documenting unwanted health or environmental risk, it will engage in internal processes of suppression that lead to the "sequestering" of knowledge to keep it hidden from the public (Richter et al. 2018).

The situation of undone science is not necessarily a permanent condition, and thus one of the outcomes of a social movement can be to get the undone science done, as some of the studies mentioned above recognized. However, often the project of getting undone science done is challenging, and this outcome, like other outcomes of environmental movements, can become ambiguous. For example, even if advocates and activists are successful in convincing funding agencies to support the research or in convincing scientists to take on such research projects as pro-bono work, undone science can re-emerge in a second-order form. This situation occurs when research is conducted to address the undone science, but it is configured methodologically in ways that the original research questions are not answered directly or fully, or the methods are set up in ways that bias results toward inconclusiveness that legitimates further policy inaction (Allen et al. 2017, Kleinman and Suryanarayanan 2013).

Moreover, the epistemic battles also involve the interpretation of scientific knowledge in the public sphere. The public relations machinery that industry has developed and the rise of right-wing populism, fake news, and political polarization can make it difficult for independent scientists to maintain credibility and visibility in the public sphere and likewise for social movements to get the knowledge to the public (Bray 2017, Cordner 2015, Dunlap and McCright 2011). Thus, a third order of undone science emerges in the public sphere, where even a consensus around "done science" may be undone by the mechanisms of politicized attacks and the circulation of claims on social media without vetting.

In summary, just as the politics of design leads to a conceptualization of environmental movements as sociotechnical projects with sociotechnical outcomes, so the focus on epistemic politics and undone science leads to a conceptualization of sociotechnical change as also epistemic change. A set of corresponding research questions then emerges:

1. What are the mechanisms by which undone science is produced and maintained, and likewise what are the mechanisms by which this form of scientific ignorance is addressed?
2. Under what conditions do the second- and third-order forms of undone science occur, and again through what mechanism, and how are they combatted?
3. Under what conditions is scientific research and the epistemic dimension of environmental movements important to outcomes (such as achieving an environmental justice remediation or gaining broad policy support for industrial transition policies), and under what conditions is this dimension relatively unimportant in comparison with other forms of mobilization and contestation (e.g., protest, litigation, coalition expansion)?

Conclusion

The study of STI outcomes and environmental movements can be more than a small subfield that is in turn positioned in the subfield of research on environmental movements. Rather, as this chapter has argued, research on STI outcomes requires a sociotechnical perspective that can contribute to thinking about fundamental concepts in social movement studies.

Longstanding definitions and understandings in social movement theory may come to be viewed in a new light that emerges at the nexus of science and technology studies (STS) and social movement studies (reviewed in Hess 2016). For example, the concept of political opportunity structures becomes broadened to opportunity structures in other social fields (industry, research), but even the concept of political opportunities takes on a new, epistemic hue. The concept of a frame becomes broadened to include sociotechnical visions and the ways in which technological systems and the criteria upon which they are evaluated come to frame the limits of the imaginable. The concept of agency may be extended to include nonhuman agency such as animals, delegations of agency to objects, and the world-making capacity of scientific knowledge. The concept of mobilizing structures is broadened to include scientific and intellectual movements, scientist activists, citizen-science alliances, and citizen science.

Moreover, the nexus of STS and social movement studies may help to open up new kinds of empirical research problems and questions. The nexus contributes to ongoing thinking in social movement studies that has diversified the understanding of the target of social change from the state to industry and cultural practices. In doing so, new categories such as the industrial transition movement may be helpful for establishing an object of comparative or quantitative analysis that can be the source of new generalizations. Attention to the politics of design may help to sharpen thinking about the political effects of technical decisions and choices but also how existing systems frame and limit the imagination. Likewise, concepts such as undone science point to the important role of systematic absences of knowledge and to the increasingly important role of the construction of ignorance, disinformation, and science denialism. The sections above ended with lists of more specific questions that can emerge from a sociotechnical perspective.

Finally, the sociotechnical perspective may help activists and advocates find new sites for political contestation. Where political opportunities are partially or highly closed, they may find that targeting other sites such as research fields, industrial innovation, and consumer practices may help to create broader awareness that can reopen political opportunities. Attention to the ways in which technological design choices and the prioritization of research

agendas are a form of politics by other means may help to avoid lock-in when new projects are under development and to find ways to integrate technical, epistemic, and political change. In a world that is increasingly mediated by technology and cyber-infrastructure, it will be increasingly important to pay attention to how the patterns of the co-constitution of the material and symbolic orders are themselves crucial to the generation, maintenance, and transformation of what Bourdieu (1991) termed "symbolic power."

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