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The oil spillover: prospecting for oil in innovation studies and the history of technology

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ABSTRACT
Innovation studies scholars use the concept of 'spillovers' to explain how ideas and people move among firms and industries and how regions form industrial clusters. Historians of technology use different vocabularies, but are interested in similar exchanges. This special issue explores spillovers specifically from (and to) oil firms. Oil touches all of social life, including non-oil technologies, but historians of technology and innovation studies scholars have not grasped its ubiquity. Within history of technology, oil history is a circumscribed subfield that has drawn little attention to non-oil technological activity performed or supported by oil actors, while historians of non-oil and non-energy technologies do not sufficiently acknowledge that the technologies that they write about are shaped by their energetic context. Within innovation studies, meanwhile, oil is also a relatively minor topic, despite substantial R&D within that industry alone. Yet oil was crucial for many canonical technologies of interest to both history of technology and innovation studies, including nuclear power, computing, biotechnology, nanotechnology, and scientific instrumentation. Technological activity within an oil economy/society bears that fuel's mark. More generally, tracing oil and other energetic spillovers shows that different modes of energy production afford different modes of technological activity.

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Energy humanities and history of technology

The purpose of this essay, and the special issue it introduces, is to integrate energy history more firmly with general history of technology, since – as I will argue – different energy regimes afford different modes of technological activity. That is, the dominant ways of producing, consuming, storing, and transporting energy form a defining context for *every* history of technology – a context that is invisible in most contributions to the literature. Granted, histories of energy technologies have long been a staple of this journal and its peers.[1] Yet most energy histories encompass one or perhaps two energy technologies, and say very little about any technologies not directly related to energy. In practice, however, technologies don't exist apart, but rather interact, both directly with each other and indirectly via mutual interactions with other technologies and infrastructures such as

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ports and chemical plants.[2] Conversely, general historians of technology have yet to adequately acknowledge the pervasive importance of energy in *all* technological activity. Thus, the common ground between energy history and general history of technology is largely unoccupied; the urgent need to fill that space is nicely captured by Frederick Buell's trenchant observation that 'nowadays, energy is more than a constraint: it (especially oil) remains an essential (and, to many, *the* essential) prop underneath humanity's material and symbolic cultures', and thus also its technologies.[3]

Extending Buell's point to technology would imply that societies invent, use, maintain, trade, dispose, and do other things with technology differently in a world where windmills dominate the landscape than one where oil derricks and coal mines do. That claim won't surprise scholars in the nascent field of energy humanities, since it is the technological complement to Timothy Mitchell's influential argument that coal affords social democracy while oil fosters neoliberalism.[4] Similarly, economists have long understood 'energy as a factor of production' and thus a determinant of GDP and other measures of economic activity.[5] This special issue simply proposes that we understand energy as a factor also in innovation and other *technological* activities.

For historians of technology, Mitchell's argument might seem to sail dangerously close to technological determinism. Yet it should not be controversial to say that different energy systems afford different ways of organizing technological activity. This claim is illustrated by, for instance, the history of institutions associated with research and development. Early modern academies, universities, botanical gardens, and scientific societies benefited greatly from the motive power of enslaved persons, and ceded influence with the spread of abolition. In the late nineteenth and early twentieth centuries their leading role passed largely to the Humboldtian university and the corporate research lab, which networked and globalized thanks to coal-powered ships and trains. In the interwar period, the institutions most visibly steering science were philanthropic foundations underwritten by oil and automotive fortunes (Nobel, Rockefeller, Ford, Sloan, Macy, etc.). Postwar, the social relations associated with uranium (e.g. a powerful national-security state and society-wide existential risk) gave rise to the think tank, National Laboratory, and science city. And finally, today's emblematic sites of innovation – neoliberal universities and AI and biotech start-ups – were forged in the oil shocks and counter-shocks of the 1970s and 1980s.[6]

Oil 'spillovers' and innovation studies

Thus, the starting point for this special issue is that energy systems and systems for organizing technological activity are, in general, mutually constituted. The articles in the special issue, however, focus more narrowly on one specific energy source – oil – and the systems arrayed around it. My coinage for the link between oil and technological activity is the 'oil spillover'. As this introduction will elaborate, I mean this concept to encompass all the ways in which technological activity draws in (or contributes) people, ideas, money, artifacts, practices, or other resources associated with oil, petrochemical, and oilfield services firms as well as with other oil actors such as trade associations, individual oil company executives, and philanthropic foundations.

The 'spillover' as a generic concept comes from economic geography, innovation studies, and related fields.[7] As originally defined, a spillover is 'the effect of "outside" knowledge capital – outside the firm or industry in question – on the within-industry productivity'.[8] Innovation studies scholars use the concept to, for instance, explain why firms in related industries cluster in the same regions.[9] The concept has also been taken up in other fields, such as the sociological literature on 'social movement spillover', where it refers to 'movement-movement transmission' of membership, leadership, strategy, tactics, etc.[10]

Focusing more narrowly on *oil* spillovers might seem jokey or ultra-specific. The name *is* a pun and provocation. However, there are at least three broad reasons to use the term. First, by invoking this particular spillover I hope to encourage historians of technology to critically engage with the wider spillover literature. Firm-firm, movement-movement, industry-industry spillovers of various resources are common in the history of technology, but historians don't have a good vocabulary for discussing them. We can critique other fields' understanding of spillovers while also (cautiously) applying the concept to technological spillovers to and from universities, firms, states, (quasi-)religious institutions, etc.

Second, oil spillovers could be *methodologically* useful for oil historians. That subfield has long struggled to strike a balance between access to sources and critical distance from the actors who control access to those sources. Oil firms are generally reluctant to make their internal documents public. Thus, some of the most insightful oil histories have been commissioned by firms which allow authors access to internal files in exchange for significant control over what the author publishes.[11] That is a perfectly legitimate arrangement. My suggestion, though, is that by looking at the places where oil firms' activities spill over into non-oil technologies and into seemingly extra-industrial organizations – universities, philanthropic foundations, international organizations, non-oil start-ups, etc. – oil historians may be able to find troves of documents that oil firms won't or can't deny access to, but which nevertheless offer insights into oil actors' strategies, actions, and motivations.

Finally, while the oil spillover might be specific to one industry and energy source, it still has extraordinarily wide application because oil is pervasive in social life. Even for places and activities where oil has not been the predominant energy carrier, the economics and politics of oil have been unavoidable since at least World War Two. Most of the favored industries and technologies of both innovation studies scholars and historians of technology have benefited from oil spillovers – as, indeed, have important innovation studies scholars and historians of technology themselves.[12] Yet those fields have largely neglected the oily underpinnings of their preferred topics. This special issue aims to bring some such underpinnings to light, and to push energy generally and oil specifically toward the center of innovation studies and history of technology.

Relatedly, I hope that this special issue will encourage readers to ask why those oily underpinnings have been so neglected by historians of technology. I have no good answer to that question myself. One reason is surely that oil is so taken-for-granted in daily life, at least in most of the Global North, that it can be difficult to de-naturalize, or even to recognize, how its presence matters. A stronger, but more speculative, version of that claim would be that historians – especially those employed at universities – are so beholden to oil that many of us are not able to achieve critical distance from it. We benefit from the fossil economy; for instance, my own former department at Rice University owned a natural gas well, and before that my postdoctoral fellowship was endowed by an oil industry executive. It's difficult to see how that would *not* affect what we say.

A more charitable interpretation would be that most spillovers either seem so obvious *or* so tenuous that we struggle to derive strong claims from them either way. On the seemingly obvious end, for instance, few would question that the disciplines of geophysics or chemical engineering are suffused with money, personnel, research questions, field sites, and data borrowed from the oil industry.[13] As Beatriz Martínez-Rius's article in this issue shows, however, there are still very interesting things to say about such direct spillovers.[14] Other articles in the issue plumb more distant or convoluted juxtapositions. It's hardly self-evident that art (as in Hannah Star Rogers' article) or music (as in Owen Marshall's) would have benefited so much from oil.[15] It is perhaps more shocking that technologies that ostensibly erode the oil industry's markets – such as geothermal energy (as in Odinn Melsted's article) or solar power and battery-powered vehicles (as in Matthew Eisler's) – are tightly bound to oil.[16] Without prizing these less-obvious oil spillovers more than the direct ones, the surprising spillovers should be an instigation to all historians to prospect for oil in their own fields of expertise. My guess is that most people reading this essay could find oil spillovers in their files.

Energy spillovers up to ~1900

Of course, some readers who work on periods before 'oil firms' existed may rightly doubt that there's much oil in their personal archive. Note, though, that petroleum and its affines have been exploited for millennia; historians of pre-industrial periods cannot claim that oil was entirely absent from the scene.[17] As Amitav Ghosh has argued, there was an oil economy, at least in Asia, centuries before Europeans began trading petroleum.[18] True, the *global* oil industry only emerged in the latter nineteenth century, and grew slowly through the interwar period.[19] As Giuliano Garavini puts it, 'before World War II [f]ew observers would have yet thought to define the twentieth century as the "petroleum century"'.[20] So while I would encourage historians of prewar technology to look for oil's traces even back to the ancient world, I can fully understand why they might not find the oil spillover particularly useful.

For such colleagues I would point to a broader class of *energy* spillovers that run throughout the history of technology. We can, for example, discern *coal* spillovers from the beginnings of industrialization onward.[21] Indeed, some of the earliest and most celebrated artifacts associated with industrialization, such as the steam engine, were coal spillovers. The Newcomen engine, for instance, was introduced in 1712 as a device for pumping water out of coal mines. It was initially only practicable in areas with abundant coal to heat it; as late as 1800 around 40 percent of steam engines were still located in coal mines.[22] Yet extensive use in coal mines allowed steam engines to develop until their efficiency was high enough to attract users outside coal country. Among those users were the railroads, which borrowed another technology from (coal and other) mining: the rails themselves.[23] As we'll see, oil spillovers often worked in the same way, with the oil industry providing an early, protected niche where technologies could mature until they became competitive enough to 'break out' to wider usage.[24]

Leslie Tomory highlights another coal spillover and very early example of a Hughesian Large Technological System: gas lighting.[25] Although there were earlier forms of gas lighting, including ones that didn't burn fossil fuels, industrial-scale gas lighting was made possible by spillovers from coal: namely, the presence of combustible gases in coal mines; coal miners' need for portable lamps; and, from the late eighteenth century onward, the production of such large quantities of coal that gas could be distilled from it for municipal lighting. Later, abundant coal also stimulated the emergence of the chemical and pharmaceutical industries and, with them, the so-called Second Industrial Revolution.[26] In other words, widespread use of coal as a fuel source had spillover effects for technologies not obviously related to coal, including technologies widely seen as foundational for industrialization.

We know this because of the extensive literature on coal. I suspect that we could find spillovers from less-studied pre- and early industrial energy sources such as wood, peat, whale oil, and waterpower if we looked for them. That we haven't looked as closely at them perhaps speaks to the naturalization of fossil fuels – and difficulty obtaining critical distance – that I alluded to earlier.

Midcentury oil spillovers and canonical technologies

In any case, by the beginning of the twentieth century spillovers began to emerge from the growing global petroleum industry. These included technologies that existentially depended on oil, such as aviation; despite many attempts, no other energy source has yet proven practicable for significant heavier-than-air transport. Of course, for some air transport the lighter-than-air option existed but was discarded, and with it the non-oil alternative. The same choice to exclude or minimize non-oil energy sources and feedstocks was taken in many other industries as well, such as automobile or chemical manufacturing.

One inducement to choose the oil pathway was that petroleum is not just a fuel but also a *material*. For instance, even if the gas-powered automobile engine had not become dominant, oil would still have had advantages as a raw material for lubricants, asphalt driving surfaces, synthetic rubber, plastics, and so on – though its utility as a material was clearly multiplied by, and co-evolved with, its use as a fuel.[27] Oil's material properties also encouraged firms that initially specialized in oil production to diversify and integrate into other markets: petrochemical production, gasoline sales, and manufacture of lubricants, asphalt, paraffin, and other oil derivatives. 'Oil' firms' movement into these industries therefore complicates economists' definition of spillovers in terms of a 'within' and an 'outside' of an industry that can be easily demarcated.

Indeed, oil spillovers are so common in part because oil's material and geological properties have offered *many* different types of firms the opportunity to operate both in oil and in other industries. Prospecting for oil, for instance, requires geological knowledge that firms have often translated to and from exploration for, and exploitation of, gold, coal, uranium, and other minerals. Oil exploration also depends on sophisticated instrumentation, which oilfield services firms such as Texas Instruments have then leveraged into applications such as submarine detection or computing. Construction of oil rigs and refineries is often carried out by companies that also build dams and highways. Oil production often entails owning large tracts of land which oil firms have lent to agriculture and other uses. Conversely, large landowners such as the King Ranch in Texas have often increased their rents by leasing parcels to oil firms. And so on; the boundaries of the oil industry have always been highly porous, even if the barriers to entry into the top tier of oil producers are very high. In other words, as Owen Marshall's article in this special issue shows, some 'spillovers' are not transfers so much as traces of commonalities between seemingly distinct domains – such that recognizing the spillover allows us to de-naturalize the distinction and to examine the hard work of giving conjoined domains (e.g., ranching and oil) the appearance of separation.

Put yet another way, the 'oil industry' is a social construct; the term refers not to a set of firms but to a set of activities spread across a wide range of organizations. Many of the most important organizations pursuing those activities have also (or even primarily) been involved in other fields or industries. The oil industry is hardly unique in that. Indeed, all industries are social constructs which their associated firms inevitably spill over. That is one reason that historians of technology should more often invoke the spillover concept. Yet the size, wealth, influence, and technical capacity of those organizations that primarily deal with oil mean that spillovers from those organizations are particularly numerous, consequential, and worthy of historical attention.

Let me illustrate the pervasiveness of oil spillovers with three examples drawn mainly from the interwar and early postwar periods: scientific instrumentation; nuclear energy; and biotechnology. All three are technologies that figure disproportionately in the history of technology and innovation studies literatures – and yet, in all three cases, the debt to oil has been largely obscured. Take scientific instrumentation, for instance. That topic has figured prominently in economists' studies of user innovation and university-industry relationships.[28] Historians and historically-minded philosophers, meanwhile, have used instruments as illustrations of the evolving phenomenology, epistemology, and disciplinary structure of science.[29] Historians of chemistry, in particular, have argued that an 'instrumental revolution' accelerated the postwar rise to prominence of physical and analytic chemistry and of academic chemistry in the US.[30] Almost no studies in any of these literatures mention oil firms, however – other than to note *in passing* that one company or another contributed to the early development of these tools and/or was the lead customer for the first commercial version of some important class of instruments.[31]

Yet if we reread those literatures and highlight the few mentions of oil, a new picture emerges that might resolve some historiographic riddles. For instance, the historians of chemistry who put forward the 'instrumental revolution' thesis seem rather puzzled as to why that revolution started in the US. Consider, though, that when the instrumental revolution began, the global oil industry was dominated by the so-called 'Seven Sisters', *five* of which were headquartered in the US; a sixth, Shell, had a large and relatively independent US subsidiary that played a significant role in scientific instrumentation R&D.[32] Thanks to the breakup of Standard Oil and other antitrust and (regional) protectionist policies and agreements, the US oil industry was also much more fragmented than other countries', and thus featured a vast number of firms willing to buy instruments or even capable of developing their own instruments. Thus, the mid-century dominance and complex structure of the US oil industry surely helps explain the mid-century global prominence of US scientific instrumentation firms that served or were even spun off from the oil industry.

Similarly, nuclear topics are a perennial obsession for historians of technology, yet usually with hardly any mention of oil except as nuclear power's dominant rival.[33] Admittedly, innovation studies scholars have been less interested in the topic, perhaps because of the global slowdown in construction of nuclear power plants since 1980.[34] That slowdown was, of course, driven largely by growing public opposition to, and fear of, nuclear power. Thus, the gap left by the absence of innovation studies research on nuclear topics has been filled by studies of technological *risk*. In those studies nuclear power has usually served as the canonical example of a risky technology.[35] A few prominent contributions to the risk literature also examine risks posed by the production and transport of oil and the manufacture of petrochemicals. Strangely, though, the risk literature takes the nuclear and oil industries as two entirely separate entities. Charles Perrow's classic, *Normal Accidents*, for instance, has two chapters on nuclear technology, one on petrochemical plants, and one on marine accidents (in which oil tankers feature prominently); yet Perrow offers no sense that nuclear and oil technology were both part of an integrated system.[36]

In fact, in the 1970s and 1980s – i.e. the era when Perrow (and peers such as Paul Slovic and Ulrich Beck) first began writing about risk – the oil industry controlled most of the United States' (and much of the world's) uranium supply, and oil firms were major players in uranium refining, nuclear power plant construction and operation, and nuclear waste processing.[37] The two technologies – and the risks they pose – were thus utterly entangled at the time that the field of risk studies came into being. It's strange that risk scholars spilled so much ink on oil and nuclear separately and not together. One reason might be that conjoining oil and nuclear would complicate their arguments. The novelty of nuclear power and its attendant risks is central to Beck's claim of a newly emergent risk society, for instance; that novelty attenuates somewhat if nuclear power is simply the oil industry by other means. Probably there are other, less apparent reasons, though – such that rereading the risk studies literature with an eye to the technological entanglements that it misses might lead to both new critiques of, and avenues for, risk research.

In any case, oil firms were central to nuclear technology from the very beginning. During World War Two, the companies that built most of the infrastructure and employed most of the personnel involved in the US atomic bomb program were largely oil producers, oilfield services firms, and petrochemical manufacturers (or companies that would soon transition from coal to petroleum as their main feedstock). Those firms were drawn into the Manhattan Project not just because of their deep expertise in rapid construction and operation of continuous-production manufacturing facilities (rigs, refineries, and chemical plants), but also because the technologies for finding and analyzing oil were *the same* as those for finding and enriching uranium.[38]

Take isotope separation – perhaps *the* biggest challenge to building an atomic bomb. Of the main routes the Manhattan Project pursued, one (electromagnetic separation) depended on scientific instrumentation – mass spectroscopy – that Humble Oil and Phillips Petroleum helped develop in the 1930s.[39] Stone & Webster and Tennessee Eastman were the main organizations implementing electromagnetic separation. A Standard Oil executive, Eger Murphree, led development of a second route – centrifugal separation – that was also based on a laboratory technology used in the oil and petrochemical industries.[40] Finally, the third and most successful route – gaseous diffusion – was largely entrusted to Kellex, a spin-off of MW Kellogg (an oilfield services firm) and Union Carbide (one of the first chemical manufacturers to adopt oil and natural gas feedstocks).[41]

After the war, many oil producers and oilfield services companies joined or stayed in the nuclear game. Kerr-McGee, for instance, became an important uranium exploration, mining, and processing company.[42] Phillips Petroleum ran the Atomic Energy Commission's Materials Testing Reactor for most of the 1950s and 1960s.[43] Shell advised the Dutch government and Dutch nuclear scientists on that country's foray into nuclear power; later Shell made important contributions to centrifuge technology and jointly owned General Atomics with Gulf Oil.[44] Brown & Root, Bechtel, and Chicago Bridge & Iron all joined Kellogg in adding nuclear plants to their portfolios of construction projects alongside pipelines, drilling platforms, refineries, and other oil infrastructure.[45] Oil firms were also important early corporate funders of academic nuclear research, for instance at MIT and the University of Chicago.[46] And those are just a few examples of *firms* that bridge the oil and nuclear domains. *Individual* executives and scientists also moved smoothly between the petroleum industry and the nuclear weapons complex/nuclear energy industry. Those are also just *early* postwar examples; as I'll elaborate later, the oil-nuclear nexus grew substantially from the late 1960s to the early 1980s.

Then my third example, molecular biology and agricultural biotechnology. In innovation studies, molecular biology figures somewhat prominently as the scientific field from which biotechnology emerged.[47] In the field's flagship journal, *Research Policy*, 'molecular biology' is mentioned in around 200 articles, and 'biotechnology' in more than a thousand! Historians have also written extensively about molecular biology and biotechnology, and have placed agricultural biotechnology in the larger context of the technological intensification of agriculture in the Global North and the attempted 'transfer' of that form of agriculture to the Global South.[48]

For historians and for a few innovation studies scholars, an unavoidable actor in this story is the Rockefeller Foundation, which stimulated both the emergence of molecular biology in the interwar period and the Green Revolution, starting in Mexico, in the 1940s.[49] There is, of course, an extensive literature on the Rockefeller Foundation's activities across many domains: malaria eradication, the social sciences, development aid, higher education, etc.[50] Much of that literature links the Foundation's aims and practices to the belief systems of Rockefeller family members and/or Foundation officials – particularly John D. Rockefeller's Baptist faith and eugenic predilections. Little of that literature, however, connects the Foundation specifically to the oil empire that funded it. Perhaps the most perceptive exception is Philip Mirowski and Esther-Mirjam Sent's argument that interwar philanthropies borrowed the organizational template of the M-form corporation in order to run science along industrial lines.[51] But even Mirowski and Sent don't say whether (and, if so, how) it mattered that the corporate model for the Rockefeller Foundation – by far the most influential philanthropic funder of mid-century science – was specifically borrowed from the *oil* industry.

What might an argument about the influence of Standard Oil on the Rockefeller Foundation's scientific patronage look like? A helpful comparison comes from Bernard Dionysius Geoghegan; he posits that it was no accident that early cybernetics was fostered by a foundation with oil roots (the Macy Foundation) because there are affinities between a cybernetic systems perspective and the systems thinking on which an oil economy is based.[52] I'm somewhat skeptical of that particular case, since the oil entrepreneur Josiah Macy had been dead for several decades before his daughter set up the Foundation;

Standard Oil shares did provide its seed capital but as far as I can tell the Macy family had long lost frequent contact with the oil industry. We therefore need to be careful about drawing straight lines between the oil business and the activities of oil actors' personal and family philanthropies. In a more diffuse sense, though, Geoghegan's argument is plausible: after all, not just Macy but also the Rockefeller, Ford, Sloan, Volkswagen, and other foundations with ties to oil and related businesses were important early promoters of cybernetics.[53]

We can discern similar indirect affinities between the oil business and philanthropic strategy in the Rockefeller Foundation's sponsorship of the Green Revolution. The form of agriculture that the Foundation supported in Mexico and later elsewhere – consciously chosen at the expense of other forms of agriculture – was extraordinarily oil-intensive. The Foundation encouraged greater use of heavy tractors and other motorized vehicles/machines; petrochemical pesticides, herbicides, fertilizers; and irrigated water transported long distances by motorized pumps. Thus, the Rockefeller Foundation's agricultural programs stimulated new markets for oil companies; I'm *not* claiming that the Foundation's officers were motivated by Standard Oil's business strategy, however. After all, the point of the Foundation was to redeem the family's name by *dissociating* it from John D. Rockefeller's corporate predations. Rather, I'm saying that running an oil business and/or inheriting an oil fortune seemingly predisposed the Rockefellers and the Foundation's employees to believe that oil-intensive activities make the world a better place. Finding concrete evidence for such a predisposition, and especially explaining how it emerged and was enacted, might be difficult; we might need to look to *cultural* histories of oil to make that connection. Energy humanities scholars such as Stephanie LeMenager and Matthew Huber, for instance, have shown how living in an oil-filled world shapes its consumers' understandings of themselves and their relationship to the state, and both constrains and enables their conceptions of what counts as a good life.[54]

Indeed, especially in the 1960s and 1970s oil firms contributed to reimagining life itself while attempting to turn much of the world, especially in the Global South, into literal – literally literal! – consumers of oil. Robert Bud and Douglas Rogers, for instance, have investigated the 'petroprotein' efforts that started at BP in the late 1950s and rapidly spread to other oil multinationals as well as to national oil firms and ministries in the Soviet Union, Kuwait, Venezuela, and elsewhere.[55] In the 1970s, oil firms also invested heavily in most of the major early biotechnology companies, such as Amgen and Cetus. In that period, oil firms such as Atlantic Richfield and Occidental Petroleum also bought up seed, meat, and other agribusiness companies, seemingly in conjunction with their investments in agricultural biotech start-ups that were working on engineered tomatoes and onions. In other words, the history of biotech – just like the history of nuclear technology and scientific instrumentation – is saturated with oil, even though oil is barely acknowledged in the historical literature on any of these technologies.

From abundance to scarcity

To recapitulate: I'm arguing that modes of energy production that predominate in a society afford particular modes of technological activity; that we can discern energy spillovers going back at least to the earliest stages of industrialization; that we can discern *oil* spillovers from at least the early twentieth century onward; and that those oil spillovers fostered some of the canonical technologies of interest to historians and innovation studies scholars. Note, though, that the oil spillovers in the articles in this special issue mostly took place later than the ones so far mentioned in this introduction. That's no accident, as events conspired to make oil spillovers more common from the mid-1960s to the mid-1980s. The rest of this introduction therefore surveys that period and the spillovers it stimulated.

Most of those spillovers emerged from the frantic reordering of the postwar oil industry at the end of the 1960s. The immediately preceding period from 1945 onward had seen extraordinary increases in demand for oil on both sides of the Iron Curtain – but also even faster increases in production in both the Soviet and US spheres of influence.[56] Although one could identify technological oil spillovers from this era, cultural spillovers were perhaps more common. Both firms and 'oilmen' – a term that, like 'Seven Sisters', reflects the industry's gender norms – splashed money on art, opera, literary erotica, architectural landmarks, and so on.[57] Hannah Star Rogers' article in this special issue takes a nuanced look at artists' and the cultural industries' ambivalent relationship to oil patronage from the 1960s onward.

The stability of the postwar 'free world' oil industry (i.e., outside the sphere of Soviet influence) depended on the ability of Western oil firms to ramp up production if any country in the Global South attempted to nationalize its oil assets or demand a larger share of revenue from oil produced in its territory. That option started to disappear in 1969–1970, however, when US domestic oil production peaked (not to be exceeded again for another half century) at the same time that Libya and Iran began pushing for a greater share of oil revenues.[58] Since US firms were now unable to make up the shortfall if those countries took their oil off the market, industry leaders felt they had little choice but to accede. Seeing that such tactics were suddenly effective – unlike in earlier periods – the other members of OPEC soon followed suit.

Thus, 1970 marked the start of what many industry insiders believed would be an era of permanently rising oil prices. Most ordinary citizens were probably not very aware of that new era until late 1973, when the Organization of Arab Petroleum Exporting Countries (OAPEC, not OPEC!) declared an embargo, oil prices skyrocketed, and gas lines and 'car-free Sundays' dominated headlines.[59] The 1973 crisis led to a panicked scramble by many governments; but oil firms were able to take advantage of that scramble because they had foreseen some kind of crisis coming from several years away.[60]

Thus, even before 1973 oil firms invested heavily – both in money and their own resources and time – in other energy technologies that could complement oil and thus alleviate the price shock. For instance, in the 1960s oil firms started to seize control of much of the US coal industry. The oil industry complemented that takeover by sponsoring research into ways to make coal more oil-like, such as coal gasification and liquefaction and solid-liquid coal 'slurries' that could be pipelined.[61] Similarly, many of the big national and multinational oil firms waded deeper into nuclear energy in the late 1960s and 1970s.[62]

The oil industry also invested in, took over, and/or spun off many of the leading companies of the 1970s solar boom.[63] Many oil firms set up in-house solar research units in the 1970s as well. Indeed, several companies – particularly Exxon, Shell, and Atlantic Richfield – pursued multiple solar pathways simultaneously: in-house R&D and spin-offs from in-house units; take-over of external firms; investment in academic researchers and their start-up companies; and partnership with government agencies. Oil firms were so dominant in 1970s solar that when the boom collapsed in the early 1980s and other firms tried to liquidate their solar assets, the consulting company Booz Allen Hamilton advised them that oil firms and members of the Saudi royal family were the most promising buyers.[64]

Solar wasn't the only renewable energy technology to attract oil industry attention. As Odinn Melsted's article in this special issue shows, there were also crucial spillovers (moving in both directions) between oil and geothermal energy that predated – but were intensified by – the 1973 crisis.[65] Similarly, Matt Eisler's article in this special issue details oil firms' long attachment to electric vehicles, advanced batteries, and fuel cells that would complement and facilitate large-scale roll-out of renewables.

Oil spillovers to alternative – and seemingly competing – energy technologies highlight the difficulty of interpreting oil actors' motivations. Did oil company executives in the 1970s invest in solar or geothermal firms based on a sincere belief that those energy sources would eventually become one of their employer's core businesses? At the time, a widely held view – reinforced by politicians such as US Senator James Abourezk – was that oil firms invested in competing technologies solely in order to *prevent* their adoption.[66] This view has held on in popular culture – e.g. David Mitchell's *Cloud Atlas* features an oil executive scheming to blow up his company's nuclear plant – and even in academic work such as Timothy Mitchell's *Carbon Democracy*.[67]

We should, of course, be wary of oil firms' claims that they are investing in a green transition even as their own internal forecasts call for continued reliance on fossil fuels for many decades to come. That said, viewing this question through the lens of oil spillovers shows that there is little evidence for conspiratorial explanations for the investments of the 1970s, and indeed much evidence that oil firms' ventures into alternative energy were, at that time, sincere. For instance, in this special issue Odinn Melsted shows that exchanges and overlaps between the oil and geothermal industries were so numerous and longstanding that oil firms' geothermal plays were simply a natural extension of their core operations. Also in this issue, Matt Eisler views Exxon and its peers' forays into electronic materials as defensive and ultimately misguided but not deceitful. Elsewhere, Jelena Stankovic and I have both found little evidence that solar entrepreneurs who worked with oil firms believed that they were being cynically used (though some solar entrepreneurs did criticize the arrogance and incompetence of their oil partners).[68] Michiel Bron, too, has argued that nuclear fission was so entangled with oil that the conspiracy theories are simply untenable.[69]

Harvesting the windfalls

The other main academic explanation for post-embargo oil spillovers into alternative energy is that 'oil companies had become interested in solar energy [and other alternatives] during the 1970s as they pursued the then fashionable strategy of diversification'.[70] That explanation does hold some water. Many postwar executives believed that diversification far outside their core markets was the best way for large conglomerates to grow. Oil executives were no exception.[71] Especially after 1973, the price of oil was so high that the big multinational oil firms enjoyed enormous windfalls, which they invested in part in businesses outside of the oil industry.

One symptom of the need to park their windfall profits was that many oil firms formed or expanded their corporate venture capital units in this era, some of which made successful bets on non-oil tech companies such as Amgen and Iomega.[72] Oil firms also simply added new subsidiaries, sometimes seemingly without rhyme or reason. For instance, Getty, Texaco, and Tenneco all ventured into selling insurance. Sunoco and Atlantic Richfield bought medical equipment manufacturers, and Mobil took over Montgomery Ward.[73] Exxon Enterprises put money into a couple dozen start-ups selling chips, computers, software, displays, and other peripherals, and briefly tried to bundle their products as the Exxon Information Systems office computing suite.[74] Gulf Oil, for reasons that are hard to fathom, almost bought Ringling Brothers-Barnum & Bailey Circus, while Getty became 72 percent owner of the ESPN cable sports network![75] And beyond these colorful oddities, oil firms also bought their way into more mundane firms: almond ranches, trucking companies, newspapers, rivet manufacturers, candle makers, etc.[76]

Solid evidence to explain these buying sprees is hard to come by. Possibly we should see them as rooted in the same motivations as oil firms' patronage of cultural institutions – especially those from the same era, such as iconic television shows like *Cosmos* and *Undersea World of Jacques Cousteau*. However, many of these purchases were not very visible, and some of those that were (e.g., Mobil's purchase of Montgomery Ward) were highly controversial. So they were not very successful at promoting the oil industry's good name, if that was the intention. More likely, in my view, is that the motivation was personal: top executives wanted to get their names in the financial pages of the newspaper and compete with the heads of other companies; while more junior executives wanted to demonstrate their chops by taking charge of wayward subsidiaries.

Some of these investments were more instrumental and thus rather easier to explain in terms of business strategy, though. Exxon Enterprises' interest in a graphite golf club manufacturer, for instance, was related to Exxon's longer-term plans for electric cars and perhaps nuclear power (both of which require high-quality graphite).[77] Amoco and Schlumberger's investments in a prominent artificial intelligence start-up, Intelligenetics – and Schlumberger's establishment of an AI lab in Silicon Valley – were even more closely linked to the need for automated interpretation of seismic and borehole data.[78] Thus, even if 'diversification' was a popular business strategy among large conglomerates in this era, that strategy alone doesn't fully explain why oil firms invested in some directions and not others. Rather, those diversification investments took place in a context - one in which oil executives thought that their main product was becoming less abundant and more expensive, which certain diversification plays might help them alleviate.

Or to put it another way: the metaphor of the oil 'spillover' implies sloppy randomness; and indeed, many spillovers seem unpredictable, surprising, and even counterintuitive. But oil spillovers – just like oil spills – aren't entirely random either: they happen along a deliberately chosen line of travel. By looking at where the oil industry put its money and where spillovers occurred, we can learn something about oil actors' priorities. Attention to oil spillovers could thus be a methodological aid to oil historians, who might otherwise ignore firms' activities that are seemingly unrelated to oil. The oil industry is notoriously secretive, but firms may be less protective of sources stemming from their non-oil ventures, even as those sources offer insights into the industry's better-guarded core.

In the aftermath

We can see how oil spillovers offer insights into the oil industry's strategies by, for instance, noting the difference between the spillovers of the 1970s and those of the 1980s. In the 1970s, spillovers were stimulated by the high price and perceived scarcity of oil. With the 1980s 'counter-shock', however, the price of oil gradually returned to almost its 1973 level.[79] The resulting collapse in oil firms' profits meant they no longer had enormous cash reserves to spend on side-projects. At the same time, activist investors started to demand faster return on their investments, forcing oil firms to retreat to their 'core competence', which both oil executives and investors believed was the production of fossil fuels.[80] External investments in spillover technologies were pulled, while in-house units directed at innovation in non-oil technologies were spun out, sold off, or closed down. Scientists and engineers left the industry in the thousands, some of whom – such as Auto-Tune inventor Andy Hildebrand in Owen Marshall's article in this special issue or Nobel laureate chemist M. Stanley Whittingham in Matt Eisler's – went on to greater fame in their post-oil careers.

In retreating to their core business of hydrocarbon production, oil firms now had to deal with the threat posed by climate science. In the 1970s, firms such as Exxon and Atlantic Richfield had been major sponsors of cutting-edge climate science and had emphasized the dangers of global warming to policymakers and to executives in their own industry.[81] As we've seen, at that point the oil industry could claim that by the time climate change became a significant problem they would be able to offer commercially competitive nuclear energy and renewables. That claim became harder to defend once oil firms retreated from alternative energy and focused on fossil fuel production in the 1980s. Thus, oil money began spilling over to physicists (the famed 'merchants of doubt') and economists such as Julian Simon as part of a larger program of undermining mainstream climate science.[82]

As a result, since the mid-1980s an ever-greater proportion of oil spillovers have been *negative* – that is, they have contributed more and more error and confusion to the scientific record and the policy debate. This outcome is nicely captured by the double entendre of 'oil spillover'. Innovation studies scholars tend to think of spillovers as a good thing, while most people would view oil spills negatively; the combination of the two is therefore ambivalent. With oil, one person's spillover is often another's externality!

That's not to say that arguably-positive oil spillovers have vanished completely. The oil industry still creates extraordinarily wealthy people and organizations that need somewhere to put their money. Witness, for instance, the innovation – but also hype as well as political and economic dislocations – attending the Saudi royal family's investments in companies like Uber in recent years, or the techno-ecological innovations sprouting from the United Arab Emirates' 'spaceship in the desert'.[83] Oil firms have also long needed to publicly affirm their support for a transition to an energy economy that includes more renewables, even as they were – both publicly and privately – undermining those renewables. Thus, many of the big multinationals resumed their involvement in solar energy and other renewables in the 1990s – though always at a scale dwarfed by their fossil fuel business.[84]

Here we come to the contemporary relevance of investigating historical oil spillovers. One motivation for this special issue is that oil companies have a long history of involvement with technologies that we will need in order to address climate change. Studying the history of oil spillovers could show us the conditions under which the oil industry moves both *toward* and *away from* renewables (as well as auxiliary technologies that are relevant for reducing greenhouse emissions, such as semiconductors and computing). Historical research on oil spillovers can also help us understand the factors that affect the ratio of cynicism to sincerity in oil firms' investments in renewables. As I have argued above, the widely-held view that oil firms *only* invest in alternative energy in order to undermine those technologies and prolong the use of fossil fuels is untenable; but the opposite view, i.e., that oil industry interest in alternative energy was sincere, is also not the whole story.

Sincere or not, the existence of 'oil spillovers' shows that the oil industry has made technological contributions to a variety of other industries, including ones that are today seen as its competitors. Thus, the oil spillover presents grounds for both pessimism and optimism going forward. Firms that today primarily produce oil need to quickly and radically reduce that part of their business. They *could* do so by simply liquidating their assets and going out of business entirely; but few large organizations are capable of such autolysis. Instead, the more likely scenario is for oil firms to become less oily by enlarging their involvement with non-oil, or even non-energy, technologies. The oil industry's long history of spillovers to such technologies could provide a pathway for such a transition.

Yet, by the same token, the past development of technologies that will be needed in order to reduce carbon emissions – such as solar energy – has been driven to a significant extent by investments from firms that primarily specialize in oil production. We cannot be certain that those investments will continue, or be taken up by someone else, as the oil industry shrinks. That is, oil firms are an integral part of the innovation system; to achieve a world where those firms are less important we need contributions from that same innovation system. Unfortunately, our capacity to solve the problem of oil could potentially diminish as and because the problem is being solved! There's no easy way out of that paradox, but it would probably help if we had a better baseline historical understanding of how the oil industry has contributed to innovations that are seemingly unrelated to oil. This special issue is intended to contribute to that baseline, though much other research will be needed to complete the picture. More fundamentally, we need a better recognition not just of how the oil industry shapes the innovation system, but also of how inhabiting an oil-filled world constrains and enables researchers' – historians' of technology and innovation studies and STS scholars' in particular – conceptual categories, such as 'innovation', 'system', 'industry', or 'oil' in the first place.

Conclusion and summary of special issue contributions

In summary, this special issue offers a response to recent calls for the fields of innovation studies and history of technology to make energy central to every story about technology.[85] Naturally, making energy 'central' does not necessarily mean making energy the determining factor, nor making actors associated with energy technologies the only actors with agency. Indeed, oil spillovers are often driven by, and benefit, actors who operate mainly outside of the oil industry. For example, in Beatriz Martínez-Rius's article, 'An open secret: Marine geosciences, offshore oil exploration and industrial secrecy in the Mediterranean seafloor', we see how the decolonizing French state's tendrils into both academic institutions and the oil industry created the conditions for young, entrepreneurial geologists to act as couriers between their academic discipline and oil firms prospecting in the Western Mediterranean. The oil never materialized; but the geologists' embrace of both plate tectonic theory and university-industry-government collaboration had long-lasting implications, both for their own careers and their discipline.

Studies such as Martínez-Rius's – where the conceptual distance traversed by the spillover is relatively small – are a good place to begin integrating energy history and general history of technology. Another tactic to begin building those bridges would be to take lessons from the literature on oil spillovers in *cultural* arenas such as film and visual art.[86] For example, Hannah Rogers' contribution to this special issue, 'What art can show STS about oil: Engaging oil spillover's anthropocene landscapes', examines the complex dance of cultural actors whose institutions are dependent on oil but whose own attitude toward oil is ambivalent or critical. She looks at artists; but her observations could easily be transferred to other ambivalent oil industry partners such as solar power entrepreneurs, conservation biologists, nuclear engineers, or Microsoft programmers.[87] Indeed, Rogers could make much the same arguments about academics who study technology – and in her article she does draw usable parallels between science and technology studies (STS) scholars and artists who are critical of oil. She does so by examining works of 'oil art' that acknowledge but also critique the pervasiveness of oil and hence the mutuality of 'natural' and 'built' environments.

Next, Odinn Melsted's 'Geoscience Spillover: Gunnar Böðvarsson and the Adoption of Petroleum Technologies in Iceland's Geothermal Industry, 1940s-1970s', explores a kind of spillover-at-a-distance. Oil firms themselves had virtually no involvement with Iceland's successful postwar exploitation of geothermal energy. Yet Iceland's geothermal venture would have failed without oil drilling equipment *and* the textbook geoscience knowledge used in oil exploration and production. Moreover, even though oil firms were not themselves present in Iceland, they were keenly interested in what was going on there. The same institutions – e.g. geoscience professional societies and their conferences – that transmitted geoscience knowledge from the oil industry to Iceland's geothermal pioneers allowed companies like Chevron and Union to incorporate Iceland's experiences into their own geothermal projects.

Matt Eisler's article, 'From petrochemicals to power sources: Big Oil and the technopolitics of energy conversion' perhaps comes closest to the ideal type of the oil spillover. Eisler shows that oil companies' knowledge of and innovation in materials and chemicals is baked into all kinds of advanced electronics that we don't associate with oil today: lithium-ion batteries, fuel cells, solar panels, etc. He argues that the oil industry was one of the few places where that knowledge existed and thus where those sophisticated materials could originate. But he also shows that oil executives didn't really understand the materials business, and thus could not commercialize their firms' own advances.

By contrast, Owen Marshall's 'The Oleaginous Voice: Auto-Tune, Linear Predictive Coding, and the Security-Petroleum Complex', offers a kind of anti-spillover. For

Marshall, tales of spillovers from the oil industry to voice technology – most notably Auto-Tuned pop music – are all too common and largely miss the point. For him, connections between oil and voice technologies don't represent spillovers from one to the other; rather, the commonalities between oil and voice technologies reflect a common lineage in, and patronage from, the national-security complex. Oil and voice were multiply-connected nodes in a Cold War spiderweb, where vibrations in one part of the web were always felt at the other. Combating the Soviets was the common goal; and the same algorithms and circuits were pressed into that project whether in analyzing seismic data or encrypting voice communications.

All of these articles will, I hope, instigate readers to examine their own work and the topics with which they are most familiar. Once you start to look for oil spillovers, you will see them everywhere and not be able to unsee them. We don't just burn oil: it's in our bodies, in the air we breathe, the food we eat, in our habits of thought, our ways of organizing science, industry, the state, education, and the arts, and it is therefore in our technologies and the activities surrounding them. We have only to look for it; and looking for it provides real insights into technology's place in history and in society today.

Notes

1. Examples just from this journal include: Carson, "Nuclear Energy Development"; Shulman, "Science Can Never Demobilize"; and Schröter, "Strategic R&D."
2. Some energy histories that do take a wider view include Priest, "Seismic Innovations"; Fressoz, *Sans Transition*; Jones, *Routes of Power*; and Lu, "Carbon Continuity."
3. Buell, "A Short History," 274.
4. Mitchell, *Carbon Democracy*. For energy humanities more generally, see Szeman and Boyer, *Energy Humanities*; Mišík and Kujundžić, *Energy Humanities*.
5. Missemer and Nadaud, "Energy as a Factor of Production."
6. Mody, "Taking the Marks to the Market."
7. Tom Turnbull (personal communication) suggests the term specifically comes out of economic studies (conducted at places like RAND) of spillovers from defense R&D to the civilian economy. See Nelson, Peck, and Kalachek, *Technology Economic Growth and Public Policy*, which cites a 1959 study to claim that "unintended spread of benefits [from military R&D] has beentermed 'spillover'."
8. Griliches, "Issues in Assessing," 102.
9. Feldman, "The New Economics of Innovation."
10. Meyer and Whittier, "Social Movement Spillover."
11. E.g. Sluyterman, *Keeping Competitive*; Bamberg, *British Petroleum*; and Pratt, Priest, and Castaneda, *Offshore Pioneers*.
12. The clearest example is Robert Jacobus Forbes, first winner of the Society for the History of Technology's Da Vinci Medal for lifetime achievement, as well as a prominent chemist at Royal Dutch Shell. I cite Forbes' histories of pre-industrial oil below. My thanks to Tom Turnbull for conversations about the influence of oil on academic understandings of technology and innovation; I hope that those conversations will eventually lead Tom and me to write a more in-depth study.
13. Rosenberg, *Studies on Science*, ch. 15–16; and Anduaga, *Geophysics, Realism, and Industry*.
14. Martínez-Rius, "An open secret."
15. Rogers, 'What art can show STS'; and Marshall, "The Oleaginous Voice."
16. Eisler, "From Petrochemicals to Power Sources"; and Melsted, "Geoscience Spillover."
17. Forbes, *Bitumen and Petroleum in Antiquity*.

18. Ghosh, *The Great Derangement*.
19. Forbes, *More Studies in Early Petroleum History*.
20. Garavini, *The Rise and Fall of OPEC*, 16.
21. Nef, “An Early Energy Crisis.”
22. Kanefsky and Robey, “Steam Engines in 18th-Century Britain.”
23. Smith, “England’s First Rails.”
24. I’m drawing here on the vocabulary (niches, regimes, breakout) of the Multi-Level Perspective. See Geels, “Technological Transitions.”
25. Tomory, *Progressive Enlightenment*.
26. Travis, “Perkin’s Mauve.”
27. Examples of oil’s importance to automobility far beyond just gasoline figure prominently in Grace, *African Motors*.
28. Rosenberg, *Studies on Science*, ch. 4; and Von Hippel, “The Dominant Role of Users.”
29. Rasmussen, *Picture Control*; Wilson, *The Invisible World*; Baird, *Thing Knowledge*; Chang, *Inventing Temperature*; and Mody, *Instrumental Community*.
30. Morris, “Laboratories and Technology.”
31. Examples include chromatography, nuclear magnetic resonance spectroscopy, mass spectrometry, IR spectroscopy, and UV spectroscopy. Gerontas, “Reforming Separation”; Reinhardt, *Shifting and Rearranging*; Grayson, *Measuring Mass*; Morris, “Laboratories and Technology”; and Bertomeu-Sánchez and García-Belmar, “Practice and Experiment.”
32. Yergin, *The Prize*.
33. There’s a large literature on nuclear technology, but let me sample some works that nicely focus on (quasi)*commercial* aspects of fission energy – i.e. where attention to oil interests would most readily extend the analysis: Hecht, *Being Nuclear*; Wellerstein, “Patenting the Bomb”; Johnston, *The Neutron’s Children*; and Balogh, *Chain Reaction*.
34. I take *Research Policy* as the flagship journal of innovation studies; there has not been an article in that journal with ‘nuclear’ in the title since 1979! There has *never* been an article with ‘nuclear’ in the title in the *International Journal of Innovation Studies*. Notably, there are a few recent innovation studies on phase-out of and/or opposition to nuclear technology: e.g. Kungl and Geels, “Sequence and Alignment.”
35. Most notably Beck, *Risk Society*.
36. Perrow, *Normal Accidents*.
37. I’ll elaborate on specific ties later, but a good overview can be found in Cohen, “Firm Heterogeneity.”
38. Bron and Mody, “Scientific Instruments.”
39. Grayson, *Measuring Mass*, 33–40.
40. Reed, “Centrifugation during the Manhattan Project.”
41. Rhodes, *The Making of the Atomic Bomb*, 494–6.
42. McGee, “The Kerr-McGee Story.”
43. Holl, “The National Testing Reactor Station.”
44. Streefland, “Jaap Kistemaker”; and Seidel, *Technology Transfer*.
45. Walker, *The Lone Star and the Atom*.
46. Martin, “The Simple and Courageous Course.” Martin lists Standard Oil of New Jersey, Standard Oil of Indiana, Shell, and Sun Oil, plus petrochemical firms Dupont, Union Carbide, and Celanese as patrons of the University of Chicago’s nuclear research circa 1950. MIT’s plans to raise funds from oil firms for the Institute’s nuclear research are outlined in Compton, *Nuclear Science*; the archival folder in which those plans can be found also contains letters to several oil companies such as Atlantic Refining and Cities Service.
47. E.g. Jong, “Academic Organizations and New Industrial Fields”; Murray, “The Role of Academic Inventors”; and Kenney, *Bio-Technology*.
48. E.g. Cullather, “Miracles of Modernization.” I cite several histories of biotechnology *per se* below.
49. Kay, *The Molecular Vision of Life*; Fitzgerald, “Exporting American Agriculture”; and Smith, “Imaginaries of Development.”

50. E.g. Kohler, "A Policy"; Mueller, "The Rockefeller Foundation"; and Farley, *To Cast out Disease*.
51. Mirowski and Sent, "The Commercialization of Science."
52. Bernard Dionysius Geoghegan, Twitter post (no longer extant) and ensuing personal communication with the author, February 14, 2020 and after.
53. The Macy, Ford, and Rockefeller Foundations as well as the Sloan Business School [endowed by a General Motors CEO] all figure in Kline, *The Cybernetics Moment*.
54. LeMenager, *Living Oil*; and Huber, *Lifeblood*.
55. Bud, *The Uses of Life*; and Rogers, "Petroprotein Dreams."
56. Perovič, "The Soviet Union's Rise"; and Yergin, *The Prize*, Part IV.
57. Attwood and Reay, "The Syndicates"; Petersen-Perlman, "Opera for the People"; and Villota Peña, The Hyper Americans!
58. Petrini, "Eight Squeezed Sisters"; and Garavini, *The Rise and Fall of OPEC*.
59. Jacobs, *Panic at the Pump*; and Bini, Garavini, and Romer, *Oil Shock*.
60. Turnbull, "No Solution"; Lifset, "A New Understanding."
61. Wasp, "Slurry Pipelines."
62. Bron, "The Uranium Club."
63. Stankovic, "History of Oil and Solar."
64. Mody, "After the IC."
65. See Department of Energy, *Geothermal Progress Monitor*.
66. Abourezk, *Advise and Dissent*; and Jacobs, *Panic at the Pump*.
67. Mitchell, *Cloud Atlas;* and Mitchell, *Carbon Democracy*.
68. Stankovic, "History of Oil and Solar"; and Mody, "After the IC."
69. Bron, "The Uranium Club."
70. The quote is Jones and Bouamane, *"Power from Sunshine."* Lojek, *History of Semiconductor Engineering*, makes a similar claim for oil investments in computing and electronics.
71. Ollinger, "The Limits of Growth."
72. Mody, "Spillovers from Oil Firms."
73. "The New Diversification Oil Game"; and Arco Medical Products Company, *Radioisotope-Powered Cardiac Pacemaker Program*.
74. Byrne, "When Exxon Wanted to Be the Next Apple."
75. Hammer, "Gulf Oil Drops Bid"; and Kleinfield, "ABC to Acquire ESPN."
76. "The New Oil Diversification Game."
77. "The New Diversification Oil Game."
78. Smith, Schoen, and Tenenbaum, "Early AI."
79. Basosi, Garavini, and Trentin, *Counter-Shock*.
80. On the general retreat to core competences in the face of investor pressure, see Shin, "The Corporate Restructuring Imperative."
81. Supran, Rahmstorf, and Oreskes, "Assessing ExxonMobil's Global Warming Projections"; and Roberts, "An Inquiry."
82. Oreskes and Conway, *Merchants of Doubt*; and Sabin, *The Bet*.
83. Isaac and de la Merced, "Uber Turns to Saudi Arabia"; and Günel, *Spaceship in the Desert*.
84. Tensions within the oil industry over how much (and how sincerely) to invest in alternative energy appear in Coll, *Private Empire*. For more on Shell specifically, and the role of long-range forecasts in shaping its investments in alternative energy, see Verbong et al., *Een kwestie van lange adem*.
85. E.g. the conclusion to Kranakis, "Writing Technology into History."
86. E.g. some of the essays in Barret and Worden, *Oil Culture*; Lutz, Lifset, and Stanford-McIntyre, *American Energy Cinema*; and Appel, Mason, and Watts, *Subterranean Estates*.
87. On oil firms' sponsorship of conservation biology research, see Schleper, "Caribou Crossings." For a critical insider's appraisal of the tech industry's oil contracts see Cool, "Oil Is the New Data."

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