1. Introduction: geography, technology, society

Barney Warf

Any technology sufficiently advanced is indistinguishable from magic.
Arthur C. Clarke

Few phenomena play a more important role in our economies, societies, and daily lives as technology. Much, if not most, of the world's populations live in technologically rich – if not technologically saturated – environments. Human beings have, of course, used technologies of one sort or another for as long as there have been human beings: fire, stone axes, digging sticks, boomerangs, fishing hooks, bows and arrows, adzes, and countless other devices to hunt, farm, and make goods. Indeed, technological prowess was one of the keystones to the emergence of the planet's first superspecies (Ambrose 2001). Technologies are integral to making our products, cleaning up our messes, fighting our wars, moving us around, and building our cities, landscapes, and social structures. Technologies shape how we think about and act in the world: they do not simply reflect societies, they also constitute them. From the individual body to the global economy, technologies are ubiquitous, inescapable, and surrounded by clouds of hope, fear, dreams and, often, unrealistic expectations.

Not surprisingly, there exist considerable popular confusion and misunderstanding about technologies. Technologies are not simply 'things' – machines, robots, airplanes – but *systems* that enmesh people, objects, knowledge, techniques, procedures, and places into a seamlessly integrated whole. Some equate 'technology' with advanced machinery – computers, nuclear weapons, and space flight. Yet a technology, in the simplest and broadest definition, is but a means of converting inputs into outputs; technological change involves the growth of output per unit input (e.g. labor hour or hectare of land) or, conversely, reduced inputs per unit of output. Technologies can be primitive or amazingly complex, used to enhance human and environmental wellbeing or to surveil, harm or kill people.

Since the dawn of capitalism, and particularly the Industrial Revolution, technological change, grounded in theoretical science and applied engineering, has accelerated at exponential rates, raising productivity levels, moving people, goods, and information ever more quickly across the Earth's surface, allowing us to communicate more easily, entertaining us, and making daily life immeasurably safer, cleaner, and more convenient. Not surprisingly, technological change has captured the popular imagination: think, for example, of the first flight of the airplane in 1903, or Neil Armstrong landing on the moon in 1969. Typically, important new technologies are greeted with breathless enthusiasm, and their long-term effects are greatly over-estimated (recall that nuclear power in the 1950s was going to lead to free electricity). Technological change is widely heralded as being synonymous with progress, national or regional competitiveness, and a solution to pressing social dilemmas.

Arguably the most common and pernicious myth about technology is that of

technological determinism (Staudenmaier and John 1985; Smith and Marx 1994), a term widely attributed to Thorsten Veblen. In this reductionist view, technological change acquires the aura of some omnipotent, external, asocial actor whose power drives all other changes. Technology acts, society reacts. All other domains – the social, political, and cultural – are reduced to secondary analytical importance. There is, simply put, a one-way line of causality, one that denies the historical and geographical contingency with which technologies are produced, adopted, and have effects. Technological determinists range from famed historian Lynn White (1966), who focused on the impacts of the stirrup on medieval European warfare, to noted columnist and author Thomas Friedman (2005), who proudly accepted the label in his best-selling book *The World is Flat*. Marxism too exhibits aspects of this line of thought (Bimber 1990).

Given the speed and depth with which technological change has progressed, it is admittedly difficult to avoid falling into this trap. The advent of sophisticated microelectronics instruments has unleashed so many changes that contemporary life is inconceivable without their fruits, including the Internet and cellular or mobile phones. Yet technological determinism is a fatally flawed, and thus widely rejected, ideology. Technological determinism frequently offers an unwarranted optimism, the notion that new technologies will inevitably offset diminishing returns or resolve environmental crises, when the evidence indicates otherwise (Huesemann and Huesemann 2011). More importantly, technologies are always and inevitably social products (Bijker et al. 1987). Their design and purpose emanate from concrete historical circumstances; they are, in short, created to address particular problems. Embedding technologies in their social contexts allows us to appreciate the complexity and unevenness of innovation and technological adoption, the power relations and politics that accompany it, and the differential effects as costs and benefits are borne by different classes, genders, ethnicities, and regions. Far from being inevitable, new technologies can be resisted (e.g. the Luddites). To approach technologies in any other way is to reify technological change, to assign it an autonomous status it does not deserve, to make it into a teleological force in which politics and culture play no role. Viewed in this way, technological relations and social relations are deeply intertwined. Rather than a one-way causality, it is more productive to view this relationship as simultaneously determinant.

Wresting our gaze away from the traditional economic focus on technology, cultural critics have pointed to its countless social, cultural and ideological effects (e.g. Green 2001). The printing press, for example, facilitated widespread literacy, the rise of nationalism, the Protestant Reformation, and the Enlightenment (Eisenstein 1979). Neil Postman (1985, 1992) similarly laments the role of television on consciousness and, more broadly, how discourses of scientific progress marginalize other ways of knowing the world. In the same vein, critics of the Internet argue that it is having profound effects on attention spans and the ability to concentrate (Carr 2010). In short, technologies are every bit as much cultural and political as they are economic in nature.

Another serious but widespread myth about technology is that it is only a force for good. Given that Western capitalism has benefited enormously from rapid and continuous technological change, this view is not altogether unexpected. For many, technological change is intimately wrapped with broader notions of social progress. Yet even a casual glance at the evidence reveals that technologies can be used against people as well as for them. Military technologies come to mind, such as the potential of nuclear weapons to

annihilate whole societies, whereas drones raise serious questions about the legality of targeted assassinations (see Chapter 16 this volume). Likewise, the Internet can be used for surveillance. There is, in short, nothing inherently good or evil about technologies: their effects are contingent, dependent on the intentions of those who use them and the power relations that enable or constrain their deployment. Moreover, new technologies frequently have unintended consequences (Tenner 1997).

There are numerous superb histories of technology that portray in depth the multiple ways in which technologies arose, their movements across and within cultures, and their innumerable social, economic, and scientific consequences. World histories abound (Pacey 1991; Cardwell 1995; McClellan and Dunn 2006; Headrick 2009; Friedel 2010), while others focus only on the United States (Pursell 1995). Influential historian William McNeill (1982) focused on the role of military technology during and since the medieval era, while Headrick (1981, 1988) detailed how technologies enabled European imperialism. David Landes's (1993) magisterial *The Unbound Prometheus* still stands as the definitive history of technological change during the Industrial Revolution. At a very different spatial scale, authors such as Cowan (1983) reveal how technologies have reshaped the meaning of housework, and not entirely in ways that liberate women. Many other histories can be found easily. This vast corpus of work serves to show how technologies are deeply, inevitably *social* in nature, that they are wrapped up in relations of power and culture, and that their effects vary enormously over time and space: historicizing technology is the antidote to technological determinism.

Technologies have clear implications for gender relations (see Chapter 3), both reflecting and shaping the power differences between men and women. Traditionally, machinery was a man's world, and men enjoyed disproportionate advantages from things such as automobiles (Oldenziel 1999). The Internet is used by more men than women in many countries. Yet, as an insightful stream of feminist research has illustrated, it is not enough to point out the differential uses and effects of technologies. Rather, jettisoning dichotomies such as male/female or human/non-human has led feminists to theorize technologies in new and creative ways (Haraway 1991; Wajcman 2010).

Economists have long celebrated technological change as a major driver – if not the driver – of productivity growth and rising standards of living (Helpman 1998; Archibugi and Filippetti 2015). In this view, the dynamism of market-based economies unleashes round upon round of Schumpeterian 'creative destruction' as firms innovate and adopt new technologies. This process is widely held to have given the West a decisive advantage over other parts of the world, as argued by Jared Diamond in his hugely popular but controversial book *Guns, Germs, and Steel* (1997), a discrepancy that accelerated in the 19th century (Allen 2012) and still accounts for global differences in growth rates today (Fagerberg 1994).

There are, of course, also multiple, complex and contingent geographies of technology, just as there is a geography of everything else. Vast literatures have been dedicated to the subject. Entire regions are named after specific technologies (Silicon Valley, Steel Belt). The global expansion of capitalism and the forging of a world-system were integrally intertwined with the acceleration of technological change (Hugill 1993). Historically and at the present moment, technologies are bound up in geopolitics, including the Cold War (Hecht 2011). The invention and adoption of new technologies are intermingled with the uneven geographies of science, as Livingstone's (2003) careful analysis of Enlightenment

science illustrates. Geographers study technology from several conceptual perspectives, although Science and Technology Studies (STS) has become perhaps the dominant mode (Jasanoff et al. 1995; Truffer 2008; see Chapter 4 this volume). STS attempts to overcome traditional empiricist interpretations of technology by embedding it within shifting networks of people, practices, and power, emphasizing the contingent nature of scientific discovery, innovation, and adoption. Much geographical work has focused on which places are innovative, and which are not, and the reasons that underpin these differentials (Fagerberg 2006). Technological innovation is highly uneven, typically concentrated in large cities; density, it appears, is key to the social production of creativity (Boschma 2005; Gordon and McCain 2005). Knowledge spillovers represent a kind of technological diffusion in this regard. Indeed, because technologies diffuse unevenly over time and space, diffusion has been a core geographic concern (Rogers 2003; Robertson and Patel 2007; Robertson and Jacobson 2011; see Chapter 2 this volume). The impacts of technologies are unevenly felt: for example, labor-saving agricultural technologies may enhance productivity in temperate grasslands environments in the developed world but increase unemployment in tropical environments in the developing world. Others focus on how transportation and communications technologies lead to massive time–space compression and the creation of new geographies of centrality and peripherality (Kirsch 1995; Warf 2008).

The discipline of geography is also, of course, shaped by and in turn a producer of technologies. One collection of essays, *Geography and Technology* (Brunn et al. 2004), is more focused on technology's impacts on the discipline of geography rather than the geographies of technological change in society at large. Earlier generations relied on maps, globes, and compasses, which enabled the exploration and conquest of the globe (McDonald and Withers 2016). Geographical information systems (GIS), or more broadly, geospatial technologies that include remote sensing and global positioning systems, have been an extremely important example of the discipline's contributions to technological change, revolutionizing not only academic geography but also applied fields such as marketing and urban planning.

The *Handbook on Geographies of Technology* is an attempt to provide meaningful insights into a series of technologies, both old and new, that generate important social and spatial repercussions. The focus of this volume is not so much geography as a discipline but on how key technologies have been deployed to shape the world at large. Its goal is to elucidate the multiple and complex means by which technologies come into being, their social uses and misuses, how they shape landscapes and social formations, and the ideologies and politics that swirl in their wake. Obviously, given the plethora of changes that have occurred over the last few decades, it cannot hope to cover all relevant technologies. For example, missing from this volume (among others) are discussions of wind energy, nuclear energy, fusion energy, lasers, and submarines; alas, too few geographers study these topics. Geographic Information Systems have received so much attention elsewhere that they are not addressed here.

SKETCH OF THIS VOLUME

The volume is divided into seven sections, one of which is conceptual in nature while the others are concerned with a cluster of related technologies. In Part I, three approaches to understanding geography and technology are proffered. Chapter 2, by Paul L. Robertson, focuses on technological diffusion and transfer, a long-standing concern for geographers. Robertson analyzes this issue at several scales, ranging from individual organizations to the global economy. Far from a simple linear path from science to development to diffusion, he shows that the process is much more complex and path-dependent, involving the uneven movement of different types of knowledge, external returns and spillovers, outsourcing, and differential ability to incorporate new techniques. At the social level, rates and patterns of diffusion reflect different national propensities to innovate, the size and level of integration of networks of firms and individuals, and the presence or absence of industrial clusters. International movements of knowledge are even more complex, with complicated distributions for its export and import that function with varying degrees of effectiveness, including foreign direct investment.

In Chapter 3, Jessica McLean, Sophia Maalsen, and Alana Grech turn to the question of gender and technology. Various feminist perspectives highlight how technologies are embedded in the power relations that form the core of gender relations, an important means of noting that technologies are much more than simply objects. Opportunities for women in technologically advanced fields have traditionally been limited. Moreover, feminism helps to overcome simple dichotomies such as human/machine that have long underpinned masculinist understandings, and open the door to relational and post-human understandings. They conclude with a case study of Destroy the Joint, a feminist online group, to assess feminist geographical research in cyberspace.

The fourth chapter, by Jordan P. Howell, summarizes the literature on STS, perhaps the most popular mode for theorizing science and technology today within the social sciences. Born of the post-structural turn that celebrates positionality, embodiment, and relational interpretations – particularly the work of Bruno Latour – STS emphasizes networks of actors (both human and non-human) in the production of scientific knowledge. Howell critically summarizes the origins and evolution of STS, its leading journals, and major conceptual debates, including Actor-Network Theory. This approach profoundly socializes science, leading Howell to examine related issues such as the influence of industry and the state on the construction of scientific knowledge, as well as the public's understanding and science education. He concludes by pointing to the geographic implications of this line of thought.

Part II addresses a series of computational technologies. As capitalism has become ever more information-intensive in nature, a process manifested in the steady, inexorable rise of services the world over, technologies to collect, process, and transmit information have grown accordingly. Martin Dodge, in Chapter 5, delves into the reciprocal relations between software and space: so pervasive has code become that contemporary geographies are inconceivable without it. Code turns the world into algorithms and databases, foregrounding some issues and backgrounding others. Dodge penetrates the taken-for-granted nature of software to explore the discourses that surround it, how it animates ever-larger legions of objects to give them almost lifelike qualities. His geographic exploration notes how code is embedded in a hierarchy of phenomena ranging from

individual objects to coded infrastructures and processes. The final sections delineate code in spaces such as the home to the surveilled self.

Chapter 6, by Daniel Sui, offers a comprehensive look at location-based services (LBS), those that deploy users' spatial locations to provide individually tailored outcomes. As networked devices become increasingly common, the LBS industry has grown in size and influence. Sui summarizes the technical aspects of LBS, including RFID tags, and then turns to key applications. For individuals, LBS not only offers convenient information, but can also be used to track children or people with dementia. For businesses, LBS has become central to the so-called 'sharing economy' (e.g. Uber) as well as marketing and geofencing to delineate specified areas digitally. Governments also use LBS, such as for emergency management or to deploy citizens as sensors. Sui also looks at concerns about LBS such as privacy, inequality, and environmental sustainability.

In Chapter 7, Michael Batty, Hui Lin and Min Chen describe the geographic dimensions of virtual reality. As the real and the virtual worlds become more intertwined, virtual reality has become ever more sophisticated and lifelike, engaging users interactively. The chapter traces the history of virtual reality systems, and notes the various types such as standalone and networked systems. The primary focus is on virtual reality representations of cities, although they also discuss virtual geographic environments. Virtual reality systems have become commonplace, and are widely used in planning and other applications. Finally, the chapter turns to how the virtual and real worlds can be blended as virtual data are projected back into the world, such as with augmented reality.

Part III concerns communications technologies, arguably the most dynamic sector of contemporary capitalism. The ongoing aftermath of the microelectronics revolution, computers, and the digitization of information has been so unprecedented that it is almost impossible to document these changes in their entirety. In Chapter 8, Barney Warf describes fiber optics – by far the most important telecommunications medium in the world, forming the core technology that underpins the Internet as well as electronic funds transfer systems. Warf summarizes the history of fiber optics and situates it within the contemporary information-intensive global economy. He points to the urban implications of fiber, and maps the world's major systems that emerged over the last three decades. Finally, the chapter turns to some of the impacts of the massive global boom in fiber capacity, including the dot-com crash, excess capacity, and the steady erosion of the satellite industry.

Today, roughly 50% of the world's population uses the Internet, perhaps the defining technology of our historical moment. Chapter 9, by Aharon Kellerman, notes how the Internet came to be, and the primary types of applications, including mobile Internet usage. He emphasizes that the Internet is deeply geographical, including the location of users and the screens that allow them access. The spatiality of the Internet is also evident in the movement of information through that medium, including the widespread use of open code. The impacts of the Internet on physical space – making life safer, faster, and more convenient for many – also speak to its geographic nature. Kellerman also writes of the Internet as action space, in which it substitutes for physical movements. Finally, he notes that the Internet is inevitably shaped by local cultures; abstract as cyberspace may appear, it is not independent of the physical and social realities that it reflects and in turn affects.

Radio is such a long-standing technology that it may appear unworthy of attention;

geographers have written remarkably little about it, preferring to study visual media. Yet as Catherine Wilkinson shows in Chapter 10, the soundscapes of radio are important in several ways. She offers a brief history of radio, from its infancy in the 1920s to the explosion in usage in the 1960s, when transistors made it portable. Today radio is an intimate part of everyday life, a major source of news and entertainment. Traditionally, the geographies of radio were bound by the transmission capacities of stations: it has long been primarily a community medium, and she stresses that it helped to forge ‘imagined communities’ at that scale. In the digital age, the spatiality of radio has undergone a sustained transformation, including podcasts, which greatly expanded the medium’s spatial reach, creating complex new sonic geographies.

Chapter 11 concerns satellites, which have had a series of economic, military, and discursive implications. Here, Barney Warf defines the oft-confused terms concerning satellites and Earth stations, then turns to the history of the technology. Much of the chapter is concerned with the international regulation of geostationary satellites, a story that traces the rise and demise of the International Satellite Organization (Intelsat) and several regional competitors. As neoliberalism has reshaped telecommunications, like everything else, Intelsat’s power has eroded, and private satellite operations have risen in importance. Finally, Warf notes the powerful impacts of fiber optics on the satellite industry and the hopes presented by low-orbiting satellites that service the world’s mobile phones.

Cellular or mobile phones have become increasingly ubiquitous worldwide: 70% of the planet now owns one. Jonathan C. Comer and Thomas A. Wikle summarize this technology in Chapter 12. Far from being simply devices for talking, smart mobile phones allow Internet access, photography, video, and other applications. The impacts of mobile phone adoption are monumental. They note that it has diminished the importance of physical distance, a common consequence of telecommunications. More people than ever before can now communicate over long distances and search for information, a process that has blurred the boundaries between public and private spaces. The chapter traces the evolution of the cellular concept and the global diffusion of mobile telephony, mapping its growth over time and space. They also explore the factors that lead to cell phone adoption, paying particular attention to the developing world.

In Chapter 13, Ramon Lobato addresses the changing nature of television, not a new technology to be sure but surely one of the most influential. The digital revolution thoroughly altered the landscapes of television, as witnessed by the rise of Netflix, which he uses to explore contemporary geographies of the medium. Noting that television involves a bundle of technologies, he also cautions that the medium is embedded in multiple geographies simultaneously: the individual viewer, the infrastructure, flows of culture across borders, and so forth. The streaming infrastructure that makes Netflix possible has changed how people watch TV. The chapter also explores the changing distribution of content distribution, which has altered the relationship between programming and place. Finally, he turns to television platform spaces, the interface between users and their screens, in which complex algorithmic structures become intertwined with viewers’ consciousness.

In Part IV, five transportation technologies are examined. Some, such as railroads, are relatively old, while others, such as drones, are products of the 21st century. Capitalism has long sought to conquer space by means of more rapid movements of people and

goods, a process Harvey (1982) famously attributed to the constant need to minimize the turnover rate of capital and produce successive new ‘spatial fixes’. Initiating this section is Chapter 14, by Aaron Golub and Aaron Johnson, who write about automobility, or the geographies created by the world’s one billion cars. The world today would be unthinkable without the automobile, which shapes cities, production, consumption, trade, and everyday life in countless ways that vary greatly by class, gender, ethnicity, and place. It is a major consumer of energy and producer of CO₂. Few innovations can rival it in importance. Drivers are enmeshed in complex systems of automobility that greatly transcend driver and car, but form, as Golub and Johnson note, assemblages of people, things, ideas, and power. They trace the history of automobility, how it varied over time, and then proceed systematically to uncover the various systems that enter into its making, such as government policies, household behavior, and planners and developers. They also explore the infrastructures, including global flows of petroleum, which are essential to the mobility enjoyed by so many. Finally, they offer a useful summary of the externalities imposed by driving, including fatalities, air pollution, health impacts, and social inequality. They conclude by speculating on the nature of an auto-free future.

Aviation is the aerial equivalent to automobility. In Chapter 15, Andrew R. Goetz notes the historical development of this technology, which saw the Wright brothers’ first flight eventually evolve into the Concorde. The changing regulatory framework that governs air travel also receives scrutiny, as does air freight. Goetz also examines conceptual issues pertaining to this industry, such as its role in time–space convergence (or compression) and globalization. Next he turns to the impacts of deregulation and the rise of low-cost carriers, which increased competition and gave rise to the familiar hub-and-spoke pattern we see today. Finally, Goetz examines recent trends in aviation and the associated geographies that accompany them, as assessed by airlines and airports.

Drones have recently surfaced as one of the most ominous – yet simultaneously promising – technologies. In Chapter 16, Thomas Birtchnell studies the role these machines play in military and civilian life, their definition, history, and much-debated role in conflicts, where they have revolutionized warfare. Yet drones have wide non-military uses as well, such as delivering cargo, nature conservation (e.g. keeping an eye on poachers), and emergency management. Concerns about privacy and safety loom large in this context. Many researchers also use drones, which have, among other things, facilitated the growth of volunteered geographic information.

Since the Industrial Revolution, railroads have been an important form of transportation within and among cities, albeit one often overlooked by geographers. Chapter 17, by Linna Li and Becky P.Y. Loo, explicates the dynamics of this technology at several spatial scales. Recent years have witnessed a railroad renaissance, including high-speed trains. Li and Loo’s chapter examines the global distribution of railroads, then delves into their geographical implications, such as increased regional integration. The governance and financing of rail systems vary considerably among nations, as does their integration with other forms of transportation.

Shipping moves most of the world’s goods. In Chapter 18, Jean-Paul Rodrigue notes that this ancient technology has been utterly modernized since the advent of containerization in the mid-20th century, which dramatically reduced shipping costs. The geographies of shipping networks reflect both the shifting landscapes of global capitalism and physical constraints (e.g. the Malacca Straits). Enormous undertakings such as the Suez

and Panama Canals are also testimony to capitalism's incessant need to remake landscapes to accelerate the movement of capital, goods, and people. Rodrigue notes that the push for economies of scale has led to stunningly large 'post-Panamax ships' capable of carrying vast quantities of cargo, further driving down costs. Finally, he turns to ports and the multiple ways they have been woven into their hinterlands, adopted automation, and cultivated supply chains.

Part V concerns itself with a series of technologies related to the production and use of energy in different forms. Absolutely essential to the functioning of advanced divisions of labor, energy technologies have grown in diversity and complexity over time. In Chapter 19, by Kirby E. Calvert, Jamie D. Stephen, M.J. Blair, Laura Cabral, Ryan E. Baxter, and Warren E. Mabee, biofuels are given due consideration. An important alternative to fossil fuels, biofuels utilize portions of animal feed, food, and pulp production that otherwise would go to waste. Liquid biofuels include bioethanol and biodiesel. Using evolutionary economic geography, their chapter draws attention to the changing supply chains of biorefining as a means of revealing how economies and environments presuppose one another. They proceed in three steps: first, by examining the pathways of biofuels and products in the production process; second, by examining the implications of biorefining in light of regional development and land use; and three, undertaking an empirical survey of existing patterns of biorefining.

Dams are the focus of Chapter 20, in which Marcus Nüsser and Ravi Baghel shine light on the 45,000 projects that have fragmented half of the world's major rivers, with profound ecological and economic effects. They classify these hydroscares and unearth how they were produced historically, which typically involved constellations of power and often bitter disputes. Beyond the dam-building industry, with legions of contractors and engineers, national governments were often involved, viewing dams as signs of modernization, as well as international entities such as the World Bank. Dams are often geopolitically important, as when they restrict flows of water between countries. Rich in examples, Nüsser and Baghel's chapter also touches on related issues such as neoliberalism and climate change.

Fracking, or the exploitation of shale gas reserves, has become one of the most contentious energy-related issues in the world. New technologies have made once-unprofitable fields open to exploitation. In Chapter 21, by Peter Jones, Daphne Comfort, and David Hillier, fracking in the United Kingdom is explored in depth, a case study that illuminates the technology and politics of the procedure in many places. They situate British fracking within changing manifolds of global energy supply and demand as well as wider debates about energy security. They also explain the technical dimensions en route to understanding why many regions have adopted fracking. In the British context, they focus on potential shale gas reserves. The environmental risks are explored at length, from local footprints to climate change. They also discuss fracking's poor reputation and why so many people are fearful of it, which has resulted in heated opposition. Such controversial processes invite government regulation and planning, which they also summarize.

Geothermal energy, the topic of Chapter 22 by Edward Louie and Barry Solomon, has become an attractive alternative to fossil fuels. The authors summarize the literature on this topic, including a variety of environmental, land use, and regulatory issues, then move on to pressing conceptual debates. Is geothermal energy renewable? Is it clean? Is it sustainable? Next they address geographic issues pertaining to this energy source,

including its role in a variety of uses such as electricity generation, noting that there remain underutilized sources.

Julie Cidell's chapter (23) on Leadership in Energy and Environmental Design (LEED) buildings is apropos of geographic work on energy conservation. She provides a history of these 'green' buildings, then examines four dimensions: their spatial distribution, the economics of implementing and maintaining them in light of the extra costs incurred, the social aspects (their valuation and uses) and their environmental facets (just how green are they?).

Pipelines are another essential, and efficient, feature of the energy landscape, particularly for natural gas. In Chapter 24, Jeff D. Makholm notes that, while the technology does not vary much among regions, the institutional environment that surrounds them certainly does. First, Makholm addresses pipeline costs and their ties to the energy markets they serve. Next he delves into the technologies of these natural monopolies with significant barriers to entry, in which pressure and distance figure prominently. Third, he turns to market problems of pipelines, whose capital is immobile despite shifting resource patterns and are the topic of government regulation. Frequently pipelines are protected from competition, leading to odd pricing systems. In short, while pipelines may appear simple, or as he notes, not romantic, they lie at the core of complex systems of markets, governments, and geopolitics.

Another alternative to fossil fuels is solar energy, which recently has grown rapidly in popularity. Govinda Timilsina and Lado Kurdgelashvili, in Chapter 25, examine the dynamics of solar energy in depth. Government subsidies are the norm. They begin by charting the evolution of solar energy technologies from their modest beginnings as a way to cook food and heat water to the gradual adoption of solar heaters in a variety of countries. They note its use in electricity generation and explosive growth of photovoltaics. The popularity of solar has, not surprisingly, often fluctuated in inverse proportion to the price of fossil fuels. Next they turn to the evolution of markets for this technology, notably China, the world's largest producer of solar equipment. The largest single use is for heating in residential homes. They also look at various national policies to encourage the growth of solar energy, some adopted with an eye toward climate change, which have led to a precipitous decline in the cost of this technology.

In Part VI, three manufacturing technologies are explored. Just-in-time (JIT) delivery systems have been a hallmark of post-Fordist production, and are explored by Ruth Rama and Adelheid Holl in Chapter 26. They note that, in contrast to most technologies explored in this volume, JIT is a 'soft' technology that consists of procedures and processes. Japanese in origin, it has become widely deployed. They examine its applicability in other contexts, unpacking the issue of whether its adoption is spatially homogeneous or not. Next they turn to the question of whether JIT promotes the clustering of firms, in part because vertically disintegrated production complexes deploy it extensively. Finally, they compare the adoption of JIT with that of other technologies, such as CAD/CAM systems.

Few technologies capture the popular imagination as much as robots, a term that dates back to 1917. In Chapter 27, Antonio López Peláez covers every feature of robots, from Isaac Asimov's three laws to their contemporary use in eldercare. Since the 1950s, industrial robots have grown widely in the number and importance of their applications, particularly with the advent of the microprocessor. In manufacturing, they have contributed

greatly to the decline in the demand for labor. Service robots assist people (e.g. cleaning) but do not manufacture goods. Military robots are revolutionizing warfare. He also explores conceptual issues swirling around robots: few phenomena so poignantly illustrate the possibility of post-human life. Political debates also revolve around robots; while some envision emancipatory possibilities, others see them as a threat to the labor force.

Geographies of the extremely small – nanotechnology – are the subject of Chapter 28, by Scott W. Cunningham. The ability to manipulate matter at the molecular level holds great promise for material science and industrial chemistry, with broad applications in production, health care, biotechnology, and environmental management. Research in this area is funded by both private and public organizations, and universities play a key role. Globally, advanced economies invest the most and are likely to reap the greatest benefits of nanotechnology, and within some countries, such as the United States, emerging nanodistricts are unfolding. Because the industry is in its infancy, the long-term impacts are unclear.

In Part VII, three technologies in the life sciences are addressed. Barney Warf, in Chapter 29, focuses on the biotechnology industry, the molecular and genetic modification of living organisms. He traces its history, from beer making to cloning. Next he turns to its impacts, including the contentious issue of genetically modified organisms (GMOs), perhaps biotech's most famous product, as well as biofuels and uses in manufacturing and health care (e.g. gene therapy). Third, he examines the regulatory impacts at the global, national, and local scales. The fourth part unearths the economic geography of biotech districts, the life sciences' equivalent of new industrial spaces.

New technologies in health care – as described by Mark W. Rosenberg and Natalie Waldbrook in Chapter 30 – are viewed through two perspectives: how geographers have taken them up in their research, and how these technologies are creating new health care landscapes. In the first view, GIS has become instrumental in mapping diseases, understanding various populations and their contexts, and in health care planning (including emergency responses), all of which are facilitated by the rise of national health databases. In the second view, innovations such as telemedicine and virtual care are redefining how health care is provided and to whom; they also focus on the implications for understanding the health geographies of the elderly.

Finally, in Chapter 31 Gabriel Popescu examines biometrics, the digital measurement of individual's unique characteristics to ascertain their identity (e.g. with facial and fingerprint recognition technology). From iPhones to airports to daycare centers, biometrics have been evermore widespread. Understandably, the technology has aroused fear, suspicion and opposition, often over concerns regarding privacy. Popescu summarizes the technicalities of biometrics and critically discusses the ramifications. There are clear geographical implications from this manner of digitally scripting the body, including the changing meaning of borders (i.e. airports) and the ability of the state to restrict mobility.

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