CHAPTER 1

Technically Based Programs in Science, Technology, and Public Policy

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1.1 Background

In this chapter, we review and discuss academic programs in technology and public policy, focusing on those that are either located in an engineering college or have a strong engineering focus. We consider what constitutes technically focused research in programs melding engineering and policy, where and how this work is done, the focus of these programs at the undergraduate and graduate levels, and the challenges of building and sustaining such programs.

Many academic programs in the United States and elsewhere focus on the *social studies* aspects of science, technology, and public policy. Indeed, most programs listed in the original American Association for the Advancement of Science guide to graduate education in science, engineering, and public policy were in this category (Levey, 1995). Few programs combine deep technical education and understanding with modern social science and policy-analytical skills and knowledge.

Of course, some policy problems related to technology do not require the policy maker or analyst to get "inside the black box" (Rosenberg, 1982), meaning he or she has no need to understand the detailed workings of technology at play. Indeed, for many such problems, spending too much time considering the technical details can be a distraction or lead the analyst astray. However, a subset of policy problems can lead to poor or nonsensical results: those in which the technical details are integral to the policy issue. Table 1.1 illustrates both kinds of problems. Examples of both types of problems involve direct satellite communication in which the technical details are not critical to a solution of the policy problem and in which it is essential to "get inside the black box," for which a reasonable technical solution requires a deep familiarity with the technical details.

[*] Morgan (2010, 2011) were used with permission from the publisher.

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Table 1.1 *Examples of problems*

A problem related to technology	A problem in which technical details are centrally important
Delivery of continuing adult education through direct-broadcast satellite to rural India. To adequately address this problem, the analyst does not need to know much at all about how direct-broadcast satellites work. So long as the analyst knows what the technology costs, who is needed to run it, and similar details, a nontechnical policy analyst can address this problem very well. Indeed, getting too bogged down in the technical details could easily distract the analyst from the central issues.	*Developing India's negotiating positions for an upcoming international conference on reallocated parking orbits for geostationary satellites.* To adequately address this problem, the analyst must have a deep technical understanding of the relative advantage of gain on the ground versus gain on the spacecraft, the likely future cost and performance of microwave amplifiers, and a variety of similar issues. Without such knowledge, the resulting policy conclusions could be seriously misinformed.

In the United States, most programs in technology and policy date to the early 1970s. One notably earlier high-visibility program was the Harvard Program on Technology and Society, created with a substantial endowment from IBM. This program started in 1964 and ran through 1972 under the direction of philosopher Emmanuel (Manny) Mesthene. The focus was not particularly on policy analysis but rather on technology impacts on society and on technology and social change. The program published a series of high-visibility annual reports but was never successfully integrated into the mainstream of academics at Harvard. Later, a portion of the endowment was used to support the professorship of Louis M. Branscomb, who ran the Science, Technology, and Public Policy Program in the Belfer Center for Science and International Affairs of the Kennedy School at Harvard. In contrast to Mesthene, Branscomb had a much stronger involvement in policy-analytic work, leading to a focus that continues at the Belfer Center today. The Harvard program predated most other programs that started to emerge in its very last years.

In the early 1970s, Arthur Singer at the Sloan Foundation made a series of grants to develop programs in science, technology, and public policy. A few years later, William Blanpied at the National Science Foundation also made a number of grants to build programs in this area. Since the late 1970s, however, no major ongoing foundation or government support has emerged in the United States to build interdisciplinary academic programs

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in science, technology, and public policy, although foundations, such as the Exxon Education Foundation, have made occasional grants.

Despite limited support, many science and engineering educators have come to recognize the importance of preparing students with rigorous technical backgrounds who are also capable of addressing policy problems in which technical details matter. This has not always been true. In the 1950s and 1960s – and even today on some campuses – the strong postwar tradition of engineering science and education created an environment in which many faculty belittled any activity that was not laden with partial differential equations. Fortunately, recent decades have witnessed a rebalancing of engineering education. However, even today, developing and sustaining programs in technology and policy present numerous challenges:

- Processes for academic promotion and tenure apply traditional disciplinary templates in evaluating junior faculty and give no weight to cross-disciplinary accomplishments and impact in that realm, such as technical policy surrounding energy, environment, information and communications technology, and biomedical engineering issues.
- Few faculty candidates can combine deep technical knowledge and skill with solid modern social-scientific, policy-analytic, and policy-application knowledge and skills.
- Many faculty candidates educated in the more qualitative social sciences, or in social studies of technology, have limited interest in or ability to address policy problems with deep technical content.
- There is difficulty engaging the nature and interests of funding sources and the relative ease of funding.
- Stakeholders lack vision in defining interesting research questions and in being watchful for – and building on – insights that can be generalized in this field.

1.2 Building and Sustaining a Program in Technology and Policy

In a conversation I had years ago with physicist Ray Bowers (who, together with chemist Frank Long, started Cornell's program in science, technology, and policy), Bowers spoke about why Mesthene's Harvard Program on Technology and Society had not survived, despite a generous endowment from IBM. Bowers argued that it had not been integrated into the academic fabric at Harvard but rather had been built off to the side. Thus no one was available to defend it "among those with real power in the

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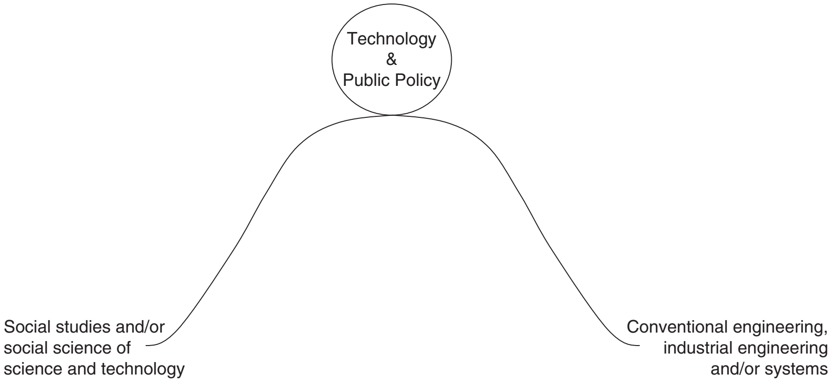

Figure 1.1 Schematic of the unstable equilibrium faced by academic programs in technology and policy. Faculty and administrators must devote continuous attention and energy to keeping the program balanced, that is, with substantial technical content, modern applied social science, and substantive/rigorous policy-analytic methods.

university." Bowers and Long worked to weave science and technology policy into the academic fabric of Cornell University. The Cornell department that grew out of their early efforts, Science and Technology Studies, is now an established department in the College of Arts and Sciences. However, it no longer performs the deep, technically focused policy work that Bowers and Long pioneered.

For a number of reasons, sustaining a program in technology and policy in which technical rigor is integral to the program's education and research involves an unstable equilibrium, illustrated in Figure 1.1. Without continuous effort to maintain the unstable balance, a program will evolve either into more conventional forms of engineering or into social studies of science and technology.

Cornell faculty and administrators applied that continuous effort. When Bowers and Long left the program, a number of excellent non-scientists took their place, including sociologist Dorothy Nelkin and linguist and lawyer Sheila Jasanoff. Walter Lynn continued to contribute a technical perspective while he was still active, but as the program grew and was merged with a program in the history of science, it evolved into a very different kind of effort. Today, the undergraduate major in science and technology studies "aims to further students' understanding of the social and cultural meanings of science and technology" (Cornell University Department of Science and Technology Studies, 2018c, para. 2). Using perspectives and tools "that cross the traditional boundaries of sociology, philosophy, politics, and history," doctoral-level studies in the department treat "science and technology as historical and cultural productions" (Cornell, 2018a, para. 3). The "approach throughout is both descriptive (aimed at understanding how science and technology are accomplished) and normative (e.g., showing where actual practices and professed norms are in conflict)" (Cornell, 2018b, para. 2). Although such work is interesting and important, it is quite different in focus from the pioneering technology-assessment activities of Bowers, Long, and their colleagues on topics such as video telephony and solid-state microwave devices, where deep technical knowledge was applied to substantive policy analysis.

A second way activities that begin in technology and public policy may migrate toward the social studies side of Figure 1.1 is to shift toward conventional public policy. We make no normative argument. Important problems in public policy are either unrelated to technology or concern it but do not require a deep understanding of technical issues.

A third example of a movement away from the unstable equilibrium toward the social studies side of Figure 1.1 is the evolution of the Association of Public Policy and Management (APPAM) and its *Journal of Policy Analysis and Management* (*JPAM*). Individuals at the Sloan Foundation and academics like Charlie Wolf, Pat Crecine, Toby Davis, and Ray Vernon worked intently to include scientists and engineers in the workshops that led to APPAM's creation. Participants made a serious effort to include technical people in the early mix of those involved in the organization. However, over time, most members of the association and most readers of *JPAM* had no deep interest in technical issues. As a result, the technical people shifted their efforts away from APPAM/JPAM to more technically focused societies and journals.

On the right-hand side of the unstable equilibrium in Figure 1.1 is the example of the Department of Technology and Human Affairs at the School of Engineering and Applied Sciences at Washington University. Under the leadership of chemical engineer Robert Morgan,[1] Washington University established the Interdepartmental Program in Technology and Human Affairs in 1971; it grew into a full-fledged department in the engineering school in 1976. Its name was subsequently changed to the Department of Engineering and Policy. The department offered a full range of degrees, from BS to PhD. However, when Morgan stepped down,

[1] No relation to the coauthor of this chapter.

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the new department head and several deans became interested in issues like midcareer continuing technical education, and the department's new leadership did not devote the necessary attention and energy to sustaining the program, which ultimately collapsed.

In addition to requiring continual balancing of energies from faculty and administrators, programs in technology and policy that have survived and grown have evolved in ways that allowed them to adapt to the strengths and limitations of their host institutions. However, all have faced some common problems, of which the greatest may be finding appropriate faculty who combine strong technical knowledge with well-honed policy analysis skills. The careers of most First-Wave faculty active in this area evolved from traditional roots. Some had already developed strong technical careers, were safely tenured, and had the luxury to move into more interdisciplinary undertakings. In other cases, young faculty took considerable career risks to pursue an intellectual venture they viewed as critically important.

In the Department of Engineering and Public Policy (EPP) at Carnegie Mellon University, where we teach, the strategy has been never to compromise on the technical credentials of new faculty. In some cases, we found faculty candidates who had already built strong backgrounds in technology and policy. A few junior hires had strong technical backgrounds and clear policy interests but little formal or practical policy background. Because Carnegie Mellon actively encourages interdisciplinary work, it has been practical to hire such individuals and develop their policy expertise over time, cultivated by those in leadership positions and by faculty who already have such expertise. Many institutions find it difficult or impossible to do this. However, the situation is changing. Although the pool remains small, in the last fifteen years, EPP has increasingly been able to recruit junior faculty who combine excellent technical skills with strong policy interests and demonstrated accomplishments.

1.3 Undergraduate Technology and Policy Programs Offered by Engineering-Based Departments

In the United States and a number of other countries, many engineering undergraduate programs flourish in areas, such as industrial engineering, environmental engineering, and systems engineering, that sometimes touch on issues of public policy. However, we are aware of only a few technically based programs that offer undergraduate degrees in science, technology, and public policy. One of the oldest is the set of double-major programs offered with each of the five traditional engineering departments of Carnegie Mellon's Department of Engineering and Public Policy. We describe these in detail in the section on Carnegie Mellon undergraduate programs in engineering and public policy.

The Department of Management Science and Engineering at Stanford offers a BS degree program that "trains students in the fundamentals of engineering systems analysis to prepare them to plan, design and implement complex economic and technological management systems where a scientific or engineering background is necessary or desirable" (Stanford University, 2018, para. 1). In addition to a set of standard science, mathematics, and engineering core courses, students take accounting, computer science, deterministic optimization, economics, and organizational theory and complete a capstone senior project.

The Department of Technology and Society in the College of Engineering and Applied Sciences at the State University of New York, Stony Brook, offers an undergraduate degree in technology-systems management and a minor. The department describes its program as focusing "on technological advances that shape every facet of modern life. Students develop an understanding of the characteristics, capabilities, and limitations of current and emerging technologies. Successful practices in government, industry, education, and personal life depend on such understanding" (Stony Brook University, 2018a, para. 3). Students take several courses in mathematics and natural sciences and select a cluster of "seven related courses ... in one area of natural science, engineering, applied science or environmental studies" from a traditional department (Stony Brook University, 2018b, para. 6). The department offers a significant number of its own courses in technology-systems management, from which students are expected to select eleven. The department also offers minors in technology-systems management and nanotechnology studies.

The Engineering School at McMasters University in Ontario, Canada, offers a BS program in engineering and society that combines historic analysis, social science, and engineering to "investigate how technology affects society and how in turn society influences the development of technology" (McMaster University, 2018, para. 2).

University College London (UCL) has recently developed an undergraduate minor in engineering and public policy for students in any of the core engineering disciplines. Jason Blackstock, who has been leading efforts to establish an EPP program at UCL, told us that a recent trend in the United Kingdom incorporates *policy exposure* into mainstream undergraduate engineering programs. For example, Blackstock is working with the Royal Academy of Engineering to run some Engineering a Better World programs aimed at UK undergraduate engineers. This program will expose students to sustainable-development goals and help them identify how their capabilities might contribute. Several universities have asked for support to model offerings on UCL's curriculum. Blackstock noted,

> This is definitely not the same as training in technically rigorous engineering-policy analysis, but the trend is starting to generate considerably more interest (most importantly, a pipeline of interested engineering graduates) in graduate degrees that blend technical engineering and policy analyses.

At Delft University of Technology in The Netherlands, the faculty in Technology, Policy, and Management offers a BS program in Technische Bestuurskunde (loosely translated as "systems engineering and policy analysis"). Although the faculty's graduate programs operate in English, the BS program operates in Dutch. In a recent self-assessment prepared for one of the national reviews that all Dutch academic programs receive, faculty at Delft explained:

> The BSc programme *Technische Bestuurskunde* teaches students to analyze systems that are technically, socio-economically and politically complex. Examples include large-scale infrastructures for telecom, transport and energy, or medium-scale systems like business information systems or wind farms. Many disciplines are involved, and therefore the TB curriculum includes subjects ranging from calculus, computational modelling and technology to economics, law and governance.

Some universities, including Ohio State University (John Glenn College of Public Affairs, 2018) and Pennsylvania State University, offer minors in public policy or additional policy coursework for engineering students. Although more abbreviated than a major, these often involve only three to five courses. Dartmouth offers a "major modified with Public Policy" in a "program for the aspiring public servant who realizes it will be useful to understand technology – and for the engineer who realizes that public policy affects which technologies are funded and chosen for development and adoption" (Thayer School of Engineering at Dartmouth, 2018, para. 4). Programs such as the civil engineering program at the University of Michigan (Michigan Engineering, 2018) consider policy issues related to a specific discipline, such as civil or environmental engineering, but narrowly tailor these and do not provide the scope of methods or breadth of a full major.

1.4 The Undergraduate Program in Engineering and Public Policy at Carnegie Mellon

In contrast with other programs that began with a focus on graduate education, the activity that led to the Department of Engineering and Public Policy at Carnegie Mellon began with an undergraduate program designed to add additional dimensions and skills for engineering students, most of whom go on to conventional engineering careers. EPP now offers undergraduate programs designed to suit the needs of engineering and nonengineering students.

The main undergraduate degree is the EPP double-major program, which earns students a joint degree between EPP and any of the five primary engineering departments: chemical, civil, electrical and computer, mechanical, and materials science. EPP also offers double majors and minors in Science, Technology, and Public Policy for students outside the engineering college who are earning a BS, including students in the Mellon College of Science, the School of Computer Science, and in select majors in Dietrich College. Similar to the double major in engineering and public policy, this new double major is meant to broaden perspectives on a student's primary major and provide additional career skills. Last, for Carnegie Mellon University students outside the College of Engineering, EPP administers the technology and policy minor, designed to allow students to explore the interactions of technology and policy without adding too much to the course requirements in their major curriculum.

Students earn double-major degrees by EPP taking over all the technical and nontechnical elective-course space in the single-major undergraduate curriculum to comprise the second half of the degree. In that elective-course space, all students must take introductory courses in microeconomics and engineering statistics. Then, they select one of several social-analysis electives in the area of decision science; a course in writing and communication (beyond their freshman writing course); at least three "technology-policy" electives, most of which are offered by the department; and a course entitled Applied Methods for Technology-Policy Analysis. They also complete two EPP project courses.

EPP has evolved undergraduate courses and course sequences in areas such as energy systems; air pollution; telecommunication policy; computer security and privacy; management of technical innovation; and risk perception, assessment, and analysis. These are regular technical electives in the College of Engineering (often double-listed in traditional departments as well), open to all students in the college who meet the prerequisites. It is not unusual for a large portion of students in EPP technical elective courses in telecommunication policy to be single majors in electrical and computer engineering. Similarly, many students in EPP courses in air pollution are pursuing single majors such as civil engineering, chemical engineering, or mechanical engineering. This cross-pollination is supported across the college and is very common.

An important feature of the EPP undergraduate curriculum is project courses, run jointly by faculty in the Department of Engineering and Public Policy and the Department of Social and Decision Sciences in the College of Humanities and Social Sciences. The typical course hosts 20 to 25 students. Projects address some real-world problems in technology and public policy, typically with an outside client for whom the work is being done. (See Table 1.2 for examples of recent topics.) The Department has run project courses since 1970. Today, it runs two such projects every semester. Students start the semester with a vaguely defined problem area and various background materials, which they use to define and shape a workable problem. Then, they undertake the necessary analysis to frame and address the problem. Typically, two faculty advisors and two PhD students serve as managers. Over the first few weeks, students work to develop a thorough understanding of the subject and define the focus of the work they propose to do. Approximately halfway through the semester, they make a first formal presentation to an outside review panel who bring various types of expertise and represent differing points of view in the problem area. The review panel assists students by providing critical comments on their structuring of the problem and by suggesting various resources and information sources. At the end of the semester, the students prepare a final written project report of about 100 pages and make a final verbal presentation of their findings and conclusions to the review panel. It is impossible for 20 to 25 people to work on a single problem collaboratively, so much of the work occurs in smaller working groups of four to six students.

Project courses serve several important educational functions. First, they are the venue in which students have an opportunity to assemble various technical and social-analysis components of their education and gain practical experience applying them to a real-world problem. Second, they provide a valuable opportunity for students to develop and refine their verbal, oral, and presentation skills. In the real world of daily engineering practice, these skills are as important for success as core mathematical and quantitative analytical skills. Project courses are rigorous and complex, requiring a great deal of work. However, over the past 20 years, EPP has undertaken three surveys of all of its double-major undergraduate alumni

Table 1.2 *Examples of topics addressed by a number of recent undergraduate technology-policy group project courses in the Department of Engineering and Public Policy at Carnegie Mellon University*

Spring 2017: Air Quality Benefits from Vehicle Emissions Testing
Spring 2017: The Future of Emergency Alerts and Warnings
Fall 2016: Pittsburgh Bicycling: An Analysis of City Impacts, Stakeholders, Project Prioritization, and Infrastructure Options
Spring 2016: The Kariba Dam
Fall 2015: Police Body Cameras
Fall 2015: Personal Environmental Monitoring
Spring 2015: California's Water Problem: A Survey of New Technical and Social Solutions
Spring 2015: Big Data in the 'Burgh: Evaluating the Impacts of an Open Data Portal in Pittsburgh
Fall 2014: Optimal Scheduling for Medical Clinics
Fall 2014: Providing Information to Non-English Speakers during Disasters
Spring 2014: Adaptation in Pittsburgh
Spring 2014: A Plastic Bag Tax for Pennsylvania?
Fall 2013: Local News in Pittsburgh in the Internet Age
Fall 2013: How Clean Is Clean Enough? Public Response to Radioactive Contamination
Spring 2013: What Are the Prospects for Natural Gas Vehicles in the Pittsburgh Region?
Spring 2013: Advancing Wind Energy
Fall 2012: The Locks and Dams Crisis
Fall 2012: Bridging the Digital Divide
Spring 2012: Emergency Messaging with Social Media
Spring 2012: Vehicle Use, Transportation, and Energy Policy

Note. A full list of past EPP project courses can be found at www.cmu.edu/epp/prospective/undergraduate/epp-project-courses/index.html

and, in all three cases, the strong response has been that "project courses were the single most valuable experience in my four years at Carnegie Mellon," because they teach students how to work in interdisciplinary teams, how to quickly master an entirely new problem domain, how to manage to a schedule, and how to produce a set of professional-quality products.

The college has carefully designed the EPP double-major program to correspond with all traditional engineering undergraduate majors to produce curricula that meet Accreditation Board for Engineering and Technology (ABET) accreditation.[2] Traditionally, when ABET reviews an engineering college, it sends a separate accreditor to visit EPP to

[2] ABET is the US program that accredits engineering programs. They explain, "The letters A.B.E.T. stood for Accreditation Board for Engineering and Technology. But over the last 80 years our scope has broadened, and now we [also] accredit Computer Science, Applied Science, and Engineering Technology programs" (ABET, 2018, para. 5).

confirm that compatibility with all traditional majors is in compliance. However, in 2014, EPP became separately accredited through ABET to allow a student to obtain an engineering degree with only a major in EPP (and not including a traditional dual major such as electrical and computer engineering or civil engineering). However, EPP has no intention of allowing students to complete only an EPP degree, because faculty see great value in students having depth in a core discipline in science or engineering.

For a few years, the Engineering Department also offered a single-major accredited degree in engineering and public policy. Students were still required to focus their technical studies in one of the traditional fields of engineering, but did not have to take enough courses to meet the requirements of an accredited degree in that field. The idea was that this broader degree, involving more engineering courses in other fields and more social-analysis content, would offer an effective background for a student who wished to enter a career in a field such as patent law or science and technology journalism. The department graduated a small number of single majors, but each time a student proposed to do a single major, the faculty immediately set out to convince them otherwise, arguing that with "just three more courses you can get a conventional engineering degree . . . life is uncertain . . . you never know when that might be valuable." After a few years, the faculty decided they did not believe in the single major and stopped offering it.

1.5 Graduate Education and Research in Technology and Policy

The Technology and Policy Program (TPP) at the Massachusetts Institute of Technology (MIT) was one of the first master of science (MS) programs in technology and policy and is still one of the largest and most successful. Although students are not required to have an undergraduate background in science or engineering, most do. They take a series of core courses and then take additional technical and social science courses from across the institute. Many students enter the program without support, but because MIT is such a large, diverse institution, they subsequently fan out across the institute to discover and secure a position in a research program of interest, through which they also obtain support.

For many years, one tenure-track faculty member, Richard de Neufville, solely operated TPP, working with a number of instructors supported with soft money. When MIT established its Engineering Systems Division (ESD), TPP became part of the Division and eventually became well-

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staffed by a number of tenure-track faculty. ESD also offered a PhD program. For a variety of reasons, many traditional engineering faculty at MIT decided ESD needed to change direction. After some extended internal discourse, in 2015 the Institute for Data, Systems, and Society replaced the ESD. The Institute for Data Systems, and Society developed a doctoral program that it describes as (a) driven by problems of societal interest, (b) application-domain driven, (c) involving quantitative methods, (d) relying on real-world data, and (e) engaging the societal aspects of the problem. This program is in early development. TPP remains a strong separate MS program.

At Stanford, the Department of Engineering Economic Systems was one of the first to offer technology and policy MS and PhD degrees, focusing heavily on methodological development in decision analysis. Over the years, it merged with the Department of Operations Research. Later, a second merger occurred with the Department of Industrial Engineering. The resulting department is now called the Department of Management Science and Engineering and has a broader research focus than Engineering Economic Systems originally had.

The Energy and Resources Group at the University of California, Berkeley, offers Master of Arts (MA), MS, and PhD degrees focused primarily on issues of energy and sustainability. Much of the research focuses on very dynamic energy issues that have been unfolding in the State of California. John Holdren founded the program and, while he was still at Berkeley, the Energy and Resources Group addressed issues related to national security.

At Carnegie Mellon, the Department of Engineering and Public Policy has chosen to focus its attention at the graduate level on developing a PhD program designed for students with science and engineering backgrounds. EPP combines technical analysis with social science, economics, and policy analysis to address problems in which knowledge of technical details is critical to decision-making. Current areas of research include the environment and energy; risk analysis and risk communications; information and communications technology; engineering education; and design, organization, and technology change.

EPP also offers an MS in Engineering and Technology Innovation Management (E&TIM) for students with science or engineering backgrounds who wish to develop skills in managing technical projects. The timing is unusual in that courses begin in January and end in December, with a summer internship in the middle. Students can combine this degree with a traditional engineering MS that they begin in the fall semester before starting E&TIM and finish in the spring semester after completing the E&TIM degree.

Other programs have come and gone. Today, several new program show significant promise. For example, at the University of Maryland, the Clark School of Engineering and the School of Public Policy jointly offer an MS in engineering and public policy. Also the Department of Technology and Society in the College of Engineering and Applied Sciences at the State University of New York, Stony Brook, offers BS and MS degrees and recently initiated a PhD program in Technology, Policy, and Innovation.

In addition to US programs defined broadly as working on a range of areas in technology and policy, a much larger number of programs address smaller domains. The University of Colorado has long had an MS program in telecommunications and policy. The many environmental programs include strong ones at the Yale School of Forestry, the Department of Environmental Studies at the University of California, Santa Cruz, and the program in Environmental Science and Engineering at the University of North Carolina. New programs continue to develop; for example, at the Nicholas School at Duke.

In Canada, the University of Calgary set out to build a major program in science, technology, and policy. For various reasons, that effort stalled and is no longer taking new students, although it may be restarted. Also, in Canada, McMaster University has established an MS program in engineering and public policy, and the University of British Columbia at Simon Fraser has technically based policy activities.

Europe has several technically based MS and PhD programs. In the Netherlands, Delft University of Technology's Faculty in Technology, Policy and Management has long offered several MS programs and a PhD. Other Dutch universities have offered similar programs, though less developed and stable, including Eindhoven, Utrecht, and Twente. In Portugal, PhD programs are emerging in engineering and public policy at the Instituto Superior Técnico in Lisbon and the University of Porto. Both collaborate with EPP at Carnegie Mellon.

Several UK universities have long had some technically based policy work, including Cambridge and Oxford. Cambridge offers a master in philosophy in technology policy that was originally developed in collaboration with TPP at MIT. For a while, Oxford hosted a program in engineering, economics, and management, but it closed in the late 2000s. For a while, the MS program in Oxford's Blavatnik School of Government included a mandatory unit on science and public policy. Whether that will continue as a required unit or become optional is unclear.

The Science Policy Research Unit at Sussex initially had quite a strong technical focus, but today is significantly less technical. At the School of Civil Engineering and Geosciences at Newcastle University, the Earth systems science, engineering, and management program does a significant amount of policy work with deep technical content. A number of more specialized programs align with traditional departments and include some attention to policy; these include the Energy Institute at University College London and the Center for Environmental Policy at Imperial College London. The University of Manchester offers a PhD in science, technology and innovation policy. University of College London has recently created a Department of Science, Technology, Engineering, and Public Policy offering MS and PhD degrees. Other parts of the world provide a few programs. For example, the Division of Engineering and Technology Management in the Faculty of Engineering in the National University of Singapore offers a variety of MS programs and is creating a PhD program.

Table 1.3 lists the Web pages of the programs noted in the preceding discussion. (Apologies to any program we missed.)

In these programs, the number of problems falling in the notion that policy problems in which the technical details are of critical importance is enormous. Successful programs have therefore focused on a subset. Rather than adding faculty in unrelated areas, colleges recruit faculty with overlapping interests, thereby building several discreet focal areas.

The relative ease of securing research support is a factor that often shapes how a program evolves. Although funding does not tend to be a significant problem in an area such as energy or the environment, other areas, such as telecommunications policy, have very little government or private-foundation support. Firms in telecommunications tend to be reluctant to support policy-related work (e.g., on spectrum policy) unless they can be assured that the conclusions and policy recommendations will support their positions. When only a few sources of interested funding exist, it is difficult to amass a balanced portfolio of support. Programs able to attract support from private firms more easily than from the National Science Foundation may focus away from public policy and toward private-sector issues and problems.

1.6 Technically Focused Policy Analysis (Science for Policy)

Brooks of Harvard (1964) was careful to always draw a distinction between policy for science and science for policy. This section of the chapter explores what Brooks called science for policy: the analysis of

Table 1.3 *Web addresses of a number of the academic programs in technology and policy*

Program	Web address
Carnegie Mellon University, Department of Engineering and Public Policy	www.cmu.edu/epp
Energy and Environmental Systems Group (ISEEE), University of Calgary, Alberta, Canada	www.ucalgary.ca/pubs/calendar/grad/current/energy-environmental-systems-eess.html
MPhil in Technology Policy, Judge Business School, Cambridge, UK	www.jbs.cam.ac.uk/programmes/mphil_techpol/index.html
Faculty of Technology, Policy, and Management, Delft University of Technology, Netherlands	www.tudelft.nl/en/tpm/
Industrial Engineering and Innovation Sciences, Eindhoven University of Technology, Netherlands	www.tue.nl/en/university/departments/industrial-engineering-innovation-sciences/
IN+ at Instituto Superior Técnico, Lisbon, Portugal	http://in3.dem.ist.utl.pt/
Institute for Data, Systems, and Society and the Program in Technology and Policy, MIT	http://idss.mit.edu/ http://tppserver.mit.edu/
SUNY Stony Brook, Department of Technology and Society in the College of Engineering and Applied Sciences	www.stonybrook.edu/est/
Civil Engineering and Geosciences at Newcastle, UK	www.ncl.ac.uk/postgraduate/courses/degrees/civ-eng-geotechnical-engineering-geology-mphil-phd/#profile
University of Manchester, Science, Technology, and Innovation Policy	www.manchester.ac.uk/study/postgraduate-research/programmes/list/10323/phd-science-technology-and-innovation-policy/
Division of Engineering and Technology Management, University of Singapore, Singapore	www.isem.nus.edu.sg/
Department of Management Science and Engineering, Stanford University	www.stanford.edu/dept/MSandE/
Faculty of Geosciences, Utrecht University, Netherlands	www.uu.nl/en/organisation/faculty-of-geosciences
University College London (UCL), Department of Science, Technology, Engineering, and Public Policy (STEaPP)	www.ucl.ac.uk/steapp
UC Berkeley Energy and Resources Group	https://erg.berkeley.edu
UC Berkeley Energy, Civil Infrastructure, and Climate Program	www.ce.berkeley.edu/programs/ecic

Table 1.3 (cont.)

Program	Web address
FEUP Porto, Doctoral Program in Engineering and Public Policy (EPP)	https://sigarra.up.pt/feup/en/cur_geral.cur_view?pv_curso_id=767
University of Sussex, Science and Technology Policy Research program (SPRU)	www.sussex.ac.uk/spru/
University of Colorado, Boulder, Interdisciplinary Telecommunications	www.colorado.edu/itp/
Yale, School of Forestry and Environmental Studies	https://environment.yale.edu
UC Santa Cruz, Department of Environmental Studies	http://envs.ucsc.edu
University of North Carolina, Environmental Sciences and Engineering	http://sph.unc.edu/envr/environmental-sciences-and-engineering-home/
Duke, Nicholas School of the Environment	https://nicholas.duke.edu
McMaster University, Engineering & Society Program	www.eng.mcmaster.ca/engandsoc/
Penn State University, Engineering Design, Technology, and Professional Programs	www.sedtapp.psu.edu
Ohio State University, Science, Engineering, and Public Policy Minor	http://glenn.osu.edu/undergraduate/sepp/
Dartmouth, Engineering Science Major Modified with Public Policy	http://engineering.dartmouth.edu/academics/undergraduate/ab/modified/policy/
University of Michigan, Civil and Environmental Engineering	http://cee.engin.umich.edu/academics/undergrad-studies

policy issues in which the technical details are integral to the issue and drive, or at least should drive, the analysis. As we noted, many problems are *about* technology. These are problems for which a competent policy analyst can do a competent study without deep technical understanding. As in Table 4.1, an analyst need not know anything about the details of how satellites, data, or TV sets function. In contrast, to prepare for a meeting on world radio communication, analysis must rest on a deep understanding of the technologies involved. This latter class of technically focused policy analysis highlights the need for technical policy programs.

1.6.1 Typical Analytical Strategies

Although many of the tools necessary to perform technically focused policy analysis are similar to those of all policy analysis, an important difference is that this form of analysis involves problems in which, if one is to avoid reaching oversimplified or ineffective answers, it is necessary to get "inside the black box" (Rosenberg, 1982) and consider the details of the technical systems involved. A first step in any such analysis is to determine whether the technical details actually matter and, if so, how much detail is pertinent. As Quade (1975) noted, "Good policy analysis should seek to establish the boundaries of the issue under investigation where thought and analysis show them to be and not where off-the-cuff decisions or convention . . . would have them" (p. 4).

Tools for technically focused policy analysis have evolved gradually over many decades. Skilled analysts choose from a large repertoire of analytical tools and methods. Often, they start by building or adopting a static or dynamic model that describes the operation of the physical and social system they are analyzing. Such models may take many forms, ranging from simple formulations based on conservation of mass and energy to closed-form dynamic models of physical processes, ranging from air pollution transformation and dispersion to accounting tools such as input–output models that link to environmental loadings or agent-based models in which system performance is an emergent property of many interacting simple rules or influences. Analysts should keep the analysis simple but adequate to the needs of the problem (Morgan & Henrion, 1999). Because technical people and organizations easily become enamored of model-building, this is often a real-world challenge.

Having developed an appropriate characterization of the relevant physical and social system, most analyses then develop a formal characterization of the preferences of decision makers and apply those in some form of normative assessment, such as cost effectiveness, benefit cost, or probabilistic decision analysis, using either single or multiple attributes to evaluate and compare various policy options. This stage of analysis is typically similar to any form of quantitative policy analysis.

Performing adept policy analysis is as much art as science (Morgan & Henrion, 1999) requiring a deep understanding of the limitations and strengths of the available tools and methods and a willingness and ability to choose strategies and methods that fit the problem. Too often, analysts master only a few specialized tools and use them on whatever problem they encounter. As Maslow (1966) noted, "When the only tool you have is a hammer, every problem begins to resemble a nail" (p. 15). Furthermore, people have become increasingly specialized and their tools are not always applicable beyond a limited scope.

1.6.2 Historical Development of Technically Based Policy Analysis Tools

Some of the earliest tools and methods in quantitative policy analysis are those of operations research. These grew from British and US efforts during the Second World War to improve targeting of antiaircraft fire and aerial bombing and to locate and destroy enemy submarines (Little, 2002). These methods were further refined in the postwar period by groups such as the RAND Corporation, first for defense and subsequently for a range of civil applications, such as dispatching fire and police services (Ignall et al., 1975). At Harvard (Raiffa & Schlaifer, 1968) and Stanford (Howard & Matheson, 1977), faculty refined and applied the closely related ideas of optimal statistical decision theory, or decision analysis, to a range of policy problems, largely for private firms, but occasionally for public policy (Howard, Matheson, & North, 1972).

At about the same time, scholars developed methods of technology assessment to anticipate how specific technologies might evolve and with what consequences. Early examples include the work of Cornell's Bowers (Bowers & Frey, 1972), National Academy of Sciences participants (Brooks & Bowers, 1977), and practitioners such as Roy Amara at the Institute for the Future and Joe Coates at the US Congress Office of Technology Assessment.

Conventional tools of engineering analysis, including such simple but powerful ideas as mass and energy balance (Morgan & McMichael, 1981) and more complex strategies such as simulation modeling also became common. However, with the exception of the work of analysts in the decision-analytic tradition, most work in quantitative policy analysis through the 1980s involved deterministic analyses using best estimates (or sometimes upper bounds). When two analyses reached conflicting conclusions, researchers were often unable to determine if those conclusions contradicted each other or both lay within an unstated range of uncertainties.

The language and ideas of microeconomics have become the *lingua franca* of much work in policy analysis, with ideas such as marginal cost and consumer surplus now widely used. Several tools originally developed in economics are now part of the standard repertoire of those who practice quantitative policy analysis. *Cost–benefit analysis* is perhaps the most obvious example (Lave, 1996; Mishan, 1972). Recent years have also seen the application of ideas, such as the use of *options* (de Neufville & Scholtes, 2011; Patiño-Echeverri, Morel, Apt, & Chen, 2007), originally developed in corporate finance.

For more than a century, the characterization and treatment of uncertainty has been an integral part of experimental science. As Sagan (1995) noted, "Every time a scientific paper presents a bit of data, it's accompanied by an error bar – a quiet but instant reminder that no knowledge is complete or perfect." As more professionals whose original training was in experimental science entered the field of policy analysis, that culture gradually transferred (Morgan & Henrion, 1999). For example, as late as the1970s, most analyses performed for the US Environmental Protection Agency contained little or no formal treatment of uncertainty. Today, virtually all such analyses contain at least some quantitative discussion and formal treatment of uncertainty.

Bottom-up *life-cycle analysis* (LCA) has become an increasingly popular tool (Miller & Blair, 1985). To overcome the limits that such analysis can encounter when the boundaries of analysis are drawn too narrowly, researchers have developed an economy-wide approach known as economic input–output (EIO)/LCA (Hendrickson, Lave, & Matthews, 2006). This approach uses an input–output table of the entire economy (the EIO part), such as links to databases on energy use and environmental emissions. EIO/LCA inherently yields only approximate answers, but because it looks across the full economy; it can sometimes identify large impacts that have been overlooked by conventional LCA.

Technically based policy analysts have been slow to incorporate ideas from modern behavioral decision science (Kahneman, Slovic, & Tversky, 1982; Morgan, Fischhoff, Bostrom, & Atman, 2002), although examples are becoming more common (Paté-Cornell & Fischbeck, 1993; Paté-Cornell, Lakats, Murphy, & Gaba, 1997). Application methods from Bayesian inferences are also relatively rare, but growing more common (Small, 2008; Stiber, Small, & Pantazidou, 2004; Wasserman, 2000). Most technically focused policy analysis does a poor job of considering interest-group politics and the political environment in which policy recommendations must be implemented (Pressman & Wildavsky, 1973). Presumably this is because most such analysts have little or no experience in these areas. Improving this situation presents a clear challenge for those engaged in educating future generations of technically focused policy analysts.

1.6.3 Who Performs Technically Based Policy Analysis?

Institutions that perform high-quality technically based policy analysis can be classified into five groups:

1 Private-sector firms
2 Consulting firms and think tanks
3 Government mission-oriented agencies
4 Analysis groups whose specific mission is to support government
5 University academic and research programs

Private-sector firms. A few large corporations have a tradition of in-house development and use of technically based policy analysis, such as large telecommunications and oil companies. More often, companies commission such analysis from consulting firms, especially in areas such as the application of decision analysis to strategic planning (Howard & Matheson, 1977; Lumina Decision Systems, 2009).

Consulting firms and think tanks. Think tanks, including Federally Funded Research and Development Centers such as RAND (Research ANd Development), MITRE, and IDA (Institute for Defense Analyses), have been a primary source of analysis for federal agencies, especially the Department of Defense. Analysis conducted in most nonprofit think tanks, such as Resources for the Future or the Brookings Institution, tend to be heavily economics-based and to involve only modest technical content. However, in some areas, such as environmental regulation or space or telecommunications policy, some of these organizations have developed considerable technical expertise.

Government mission-oriented agencies. Government agencies often turn to consulting firms for specific analyses they need. They often use think tanks or the National Research Council (NRC) when the analysis they need is more general in nature. Many think tanks are capable of performing sophisticated modeling and other forms of quantitative policy analysis. The NRC, however, rarely does complex analysis, but is much more likely to synthesize and evaluate work that is already available.

Some mission-oriented federal agencies, such as the Department of Energy, the Environmental Protection Agency, and the Department of Defense, have developed considerable in-house expertise in technically based policy analysis for their own use and to inform broader policy discourse. Such capability is much less common at the state-government level.

Analysis groups whose specific mission is to support government. Three organizations created specifically to provide analysis for government entities deserve mention here: the Office of Technology Assessment of the US Congress (OTA), the Congressional Research Service, and the General Accountability Office (GAO).

OTA was established in 1972 to provide independent, technically focused policy analysis for Congress. After struggling for a few years to find a working model, it became a very successful bipartisan analysis group under the leadership of Jack Gibbons (Morgan & Peha, 2003). However, Congress chose to defund it in 1995 after the Republican sweep of both houses. Over time, the Congressional Research Service has begun to build more comprehensive technical analytical capability and to perform assessments that are quite substantive.

As an experiment, beginning in 2002, Senator Bingaman's office explored using the GAO for technology assessment. A small number of such studies have since been produced (US Government Accountability Office, 2002, 2005). Several other efforts re-funded the OTA or created other institutional arrangements to fill what many see as a gap in analytical capability for Congress (Knezo, 2005; Morgan & Peha, 2003).

1.6.4 Does Analysis Matter?

Kingdon (1995) articulated a model of the policy process that involves the three parallel streams of processes of problems, policies, and politics. The first and, to a slightly lesser degree, the second, are in the realm of technically based policy analysis. Analysts identify issues that they believe are important problems and perform analysis that clarifies the nature of the problem and suggests possible solutions. Policy entrepreneurs then work to promote related policy strategies and solutions. Occasionally, the broader political agenda shifts so the three streams align and a policy window opens. If, at that moment, good solutions – buttressed by good analysis – are available, analysis can have a significant impact on policy. This was the case, for example, in the decision to adopt an emissions-trading approach to the control of sulfur dioxide. Air pollution experts analyzed the sources, transport, and deposition of sulfur air pollution for many years. In collaboration, economists at CalTech, Resources for the Future, and elsewhere developed ideas about tradable emissions permits. When the Clean Air Act rewrite occurred in a political environment that was not friendly to conventional command-and-control regulation, policy entrepreneurs in Washington, in the Council of Economic Advisers, and elsewhere used

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technically based policy analysis to promote a market-based solution and were successful (Hahn, 1989; Hahn & Noll, 1982).

Occasionally, analysis performed at just the right moment can have a major impact on an ongoing policy debate. This was the case, for example, when Lave, Hendrickson, and McMichael (1995) demonstrated, at the same time that California was debating requiring the adoption of electric vehicles, that recycling the lead-acid batteries of electric cars would result in more lead released to the environment than if those same cars were fueled with leaded gasoline. However, analysis more commonly has an impact on policy through a slow process of diffusion. Someone performs a small part of the analysis that yields a result. Other analysts see the analysis, get interested, and do related work. Over time, a consensus builds so that ultimately, when decision makers address the issue, they get much the same advice from most experts. At times, this process can be *very* slow. For example, it was over half a century from the time that Ronald Coase and Leo Herzel first showed the advantages of allocating radio-frequency spectrum through auctions to the FCC's eventual adoption of the idea in the 1990s (Coase, 1998; Hazlett, 1998).

This process can be disrupted by political manipulation designed to overemphasize uncertainty in the minds of nonexperts or even to distort and misrepresent the science (Mooney, 2006). The current widespread public confusion over whether climate change is "real" – in the face of many NRC and Intergovernmental Panel on Climate Change assessments – is a clear example of the power of money spent by groups like the Global Climate Coalition to confuse stakeholders and delay action on an important issue. Laws that say, "make it so," or that otherwise ignore physical reality, will not make real problems in technology and public policy disappear any more than the Indiana State House of Representatives could change physical reality when, in 1897, it passed House Bill #246 – by a vote of 67 to 0 – to simplify the value of π to 3.2. The Indiana Senate tabled the "Pi bill" after speaking with a mathematician (Agricultural Economics, Purdue University, 2003).

Clearly, ideology, short-term political interests, or simple ignorance or misunderstanding of the natural world or of engineered systems will, from time to time, lead to senseless and ultimately unrealistic policy outcomes. Although certainly an extreme example, the former Soviet Union is not the only society that has fallen – or will fall – prey to misguided pseudoscientific policies of the sort promoted by the notorious Soviet agrobiologist Trofim Denisovich Lysenko (Joravsky, 1986). The objective of practitioners of careful and balanced technically focused policy analysis is to ensure, whenever possible, that such illogical outcomes are avoided and, when they are not avoided, to work to ensure that realistic policy prescriptions ultimately prevail.

1.7 Impacts

No systematic national or international assessment of the educational, research, and public policy impacts of academic programs in technology and policy has emerged, although several programs have conducted limited assessments. Anecdotal evidence suggests that the impacts are large and growing. Virtually all programs have faculty and graduates who have made major contributions in government or private-sector decision-making.

Although it was not our intention to explore this issue in depth here, it is worth pointing out a few high-level impacts. Thanks in large part to work conducted in several programs in technology and policy, current policy-analytical work is much improved in how problems are framed and in the analytical tools used, than was the case just 30 years ago. For example, techniques pioneered in several of these programs – such as decision analysis, the systematic characterization and analysis of uncertainty, and methods in quantitative risk analysis – are now nearly ubiquitous. Perhaps most importantly, the thousands of graduates of programs in technology and policy approach their work in a more encompassing way than their more conventionally educated engineering colleagues.

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