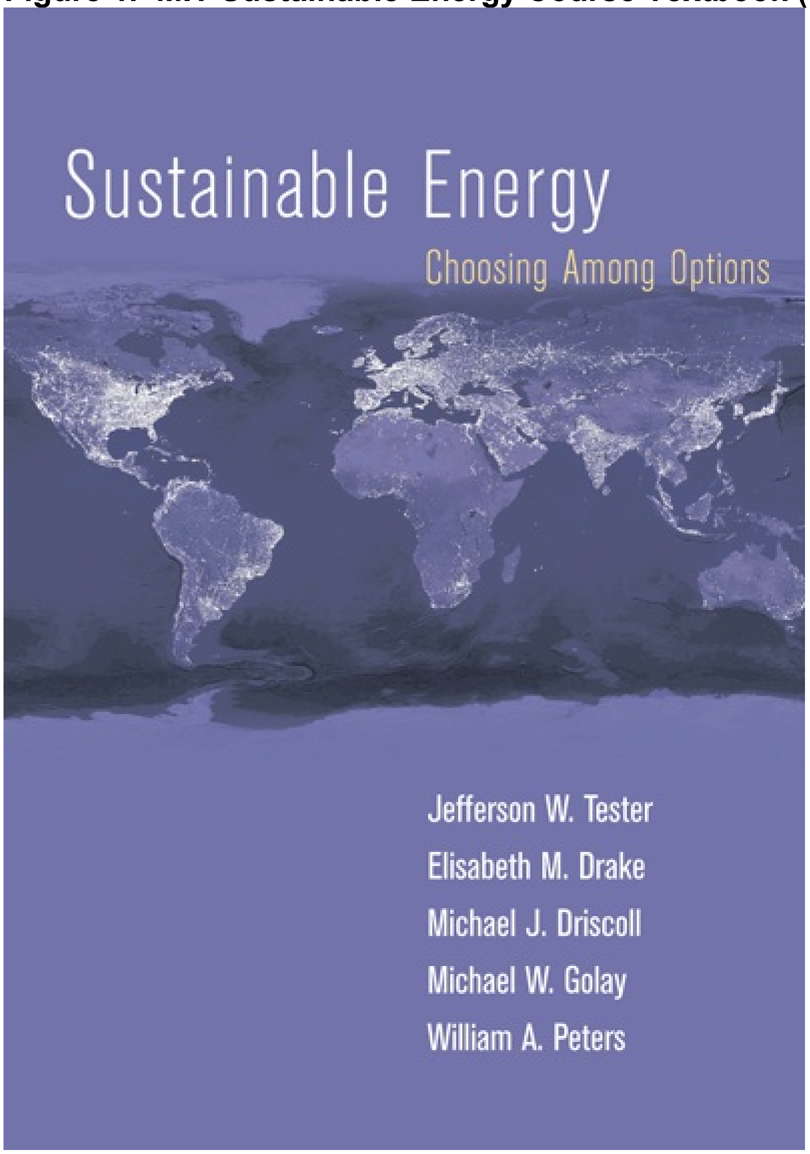
Sustainable Energy: Choosing among options

Elisabeth M. Drake, Jefferson Tester, Michael Golay (Massachusetts Institute of Technology, Cambridge, MA)

A new textbook has just been published to provide an educational framework and knowledge-base for choosing pathways to a more globally-sustainable supply and usage of energy. Available energy sources, production, conversion, and use technologies are presented, along with energy system analysis techniques and discussion of trade-offs and uncertainties inherent in making business, policy, and technological decisions to meet both today's needs and the well-being of future generations. See Figure 1.

Figure 1. MIT Sustainable Energy Course Textbook (June 2005)



Available from MIT Press: http://mitpress.mit.edu/main/home/default.asp
Interested instructors can receive a free "examination copy."

The history. The impetus for the book evolved in the early 1990's out of awareness of MIT students' growing interest in energy-related topics and that many students were ill-informed about energy issues outside of their particular research interests. We concluded that there was a need for an upper level elective course that quantitatively presented energy in a broad framework

Energy technology and economics have been major research interests at MIT over the years, with a continuing stream of major technology innovations to support the growth of the fossil fuel and nuclear industries. Some early research on renewable energy also came from MIT. In the 1960s, Prof. David Rose of the Nuclear Engineering Department developed a popular graduate engineering elective course on "energy in context." Another popular graduate course on "New Energy Technology" was offered around the same time frame by Professors Hottel and Howard of Chemical Engineering – resulting in the publication of a book with the same title in 1973. But these offerings ended with the untimely death of Prof. Rose and Prof. Hottel's retirement from classroom teaching.

The MIT Energy Laboratory was founded in 1971 by a group of interested faculty as an interdisciplinary laboratory to focus on energy technology and economics. An active syn-fuels research program was established following the first oil shock – interest later waned with a return to low oil prices. The focus of the lab then shifted back to improving the environmental and economic performance of the conventional energy technologies.

In 1991, the MIT Joint Program on the Science and Policy of Global Change began to conduct interdisciplinary research, independent policy analysis, and public communication on issues of global environmental change. The Joint Program's vision was to integrate the work of researchers in the natural and social/economic science aspects of the climate issue, to produce analyses useful to ongoing national and international discussions. Students from diverse backgrounds were co-located to work interactively on the development and continuing improvement of the MIT Integrated Global System Model. The IGSM is a comprehensive research tool for analyzing potential anthropogenic global climate change and its social and environmental consequences, including consideration of climate science, technical change, and economic and social sciences, in an interacting set of computer models designed for study of the sensitivities and uncertainties that are crucial to policy evaluation. A key attribute of the Joint Program is the series of periodic symposia where researchers interact with colleagues from other leading institutions, with sponsors from around the world, and with select global policy makers and non-profit organizations.

Researchers at the MIT Energy Lab, aware that there were increasing indications of a connection between emissions from fossil fuel use and climate change, organized a new initiative in 1992 focused on "Energy Technologies for a Greenhouse Gas-Constrained World." Major research activity clusters under this initiative included:

"Green" Buildings
Sustainable Mobility
Integration of Distributed and Renewable Sources into the Electric Supply System
Feasibility of Carbon Sequestration as a Fossil Transitional Technology

These activities expanded internationally with the founding in 1994 of the ***Alliance for Global Sustainability***, initially among MIT, the Swiss ETH, and the University of Tokyo.

With these international partners, the research and educational collaborations expanded in scope to include technology choices for rapidly developing countries, as well as for "cleaner energy technologies" in a European and Japanese context.

In 1996, several of the principals in the MIT Energy Lab decided that there was a demand for a graduate level, multi-departmental, elective course that quantitatively presented the spectrum of energy supply, conversion, and use technologies in a broader context of present and future issues relating to environmental, economic, and societal factors. Further, students needed to be aware of analytical tools that might aid decision-makers in sorting through the uncertain and complex attributes of alternatives to find robust policy and technology choices. This course, ***Sustainable Energy***, was first offered in the Spring of 1997 and has been evolving ever since.

The *Sustainable Energy* course. The course was structured in three modules: An <u>Overview: Energy in Context</u> (with lectures on present trends in energy use and the ties to development and quality of life, on aspects of production and consumption locally and globally, on resources, on economic issues, on the spectrum of environmental impacts, and on assessment frameworks and metrics for making informed energy choices); <u>Specific Energy Technologies</u> (fossil, nuclear, biomass, geothermal, hydropower, solar, ocean, wind – and for energy storage, transportation and distribution); <u>Energy End Use, Option Assessment, and Tradeoff Analysis</u> (Electricity, Transportation, Industrial, Building Sectors and an integrative final section on energy as part of a synergistic complex system). The first offering in the Spring of 1997 ended up with about thirty students from a diversity of backgrounds – engineering, policy, economics, and environmental sciences, including some students from area universities like Harvard, Tufts, and Brandeis. Some of the students were international and others had attended foreign schools. Class discussions were enriched by this diversity of knowledge and cultural backgrounds. The core teaching group consisted of five MIT faculty or staff – two chemical engineers, two nuclear engineers, and a chemist.

The course was designed to balance information transfer and opportunities for discussions and independent study. The core teaching team attended as many lectures (about 40 1-hour lectures and 10 1-hour recitation/problem sessions) as they could, and gave lectures in their particular interest areas. Expert guest lecturers were invited to speak on some of the other topics and invited participants were drawn from MIT researchers, other academic colleagues, local energy technology entrepreneurs, government representatives, etc. Attempts were made to have time for interactive discussion at the end of each lecture – having the core group argue points among themselves was very interesting to the students and encouraged them to jump into discussions.

Since the student population included both technologists and policy specialists, we used homework assignments as a way to assure that the students all had the basic analytical skills to perform energy analyses. Two teaching assistants with regular office hours were essential for providing tutorial help to students who were uncomfortable with quantitative assessments and thermodynamics.

Another element of the course was a term paper – on an energy topic chosen by the student with faculty approval. Topics were chosen early in the term, students had to submit an annotated outline with information sources by the fourth week of the term, and 20 to 30 page technical papers with detailed references were due at the tenth week. The papers were graded and returned promptly to the students with comments – each student then made a half-hour formal presentation on their topic during the week of final exams. Almost all the students did quality work on these papers and presentations and told us that this was the most valuable learning experience they got from the course. The paper and orals typically constituted 40% of the grade. Homework was 25% of the grade; a mid-term exam, 25%; and class discussion was 10%. Student feedback was very positive, though most noted that they put more work into this course than into a typical graduate elective.

As you might imagine, this course also took a lot of faculty and teaching assistant time – especially after the class size doubled in a few years. It succeeded because the core group was sufficiently interested to put in the extra hours without "official credit" from departments. The guest lecturers also donated their time and usually were happy to make repeat appearances the next year.

The new *Sustainable Energy* textbook. When we started the course, we searched for an appropriate textbook, but instead found several that covered only some of the relevant material or were quite out-of-date. Therefore, we collected our lecture materials, improved each time we presented them, into a draft textbook format. Each of the five authors wrote particular chapters, but then each was read and edited by all the other authors. In addition, our students would provide helpful criticism or suggestions on the draft lecture notes that we would then incorporate. The first full rough draft was assembled in 2000; the book was published by MIT Press last July (2005). The format of the book follows the format of the course. It also has an extensive index and many good homework problems. The book has given us the freedom to make the course somewhat less comprehensive, because students can read from the text to learn more about specialized topics than can be presented in lectures.

Obviously, we all welcome any feedback and comments on the book and on your experiences in teaching sustainable energy topics at your institution.

Nucleation of companion subjects at MIT. Since the *Sustainable Energy* course provides broad coverage of so many different aspects of energy supply, conversion, and use, there are many students who are interested in more in depth coverage of some aspects of this topic. There are four new courses in various stages of development at MIT: *Applications of Technology in Energy and the Environment* (case studies on fuel cells, etc.)*; Fundamentals of Advanced Energy Conversion Systems* (applications in fossil, nuclear, and renewable technologies)*; Electrochemical Energy Conversion;* and *Multiscale Analysis of Energy Processes* (focus on biomass, geothermal, gas hydrates, and carbon sequestration). In addition, there are many courses in energy-intensive use areas (e.g., mobility, buildings, electrical systems and components) and others that focus on specific subjects that are part of the broad energy topics – from science, to technology, to policy and economics. These traditional courses are being adjusted to include the new challenges facing global energy use.

Dissemination to other universities. In 2001, as part of a larger collaboration between MIT and the University of Cambridge (we refer to each other as "Cambridge East" and "Cambridge West" – referring to sides of the Atlantic!), we worked with a group of Cambridge East faculty who were interested in teaching a course of this sort. The first year, we agreed to present the course via video link in real time. This meant that MIT students in a class from 2-4 pm were participating with Cambridge students who were meeting from 7-9 pm UK time. As a further complication, the Cambridge University “Lent Term” was about half the length of the MIT Spring Term – and started a couple of weeks earlier. To solve this dilemma, it was decided to have MIT lecturers travel to Cambridge East to present lectures for the first couple of weeks. Then the classes linked up by video. The classes enjoyed the interaction, but the arrangement was a bit difficult on both sides. The hit of the course was a joint session on US and British energy policy – with experts from both universities participating as lecturers and then as leaders of a trans-Atlantic hour-long discussion.

During the first year of our collaboration, all the lectures at MIT were videotaped. The second year, we moved into a combination of joint and separate class sessions, still requiring the UK students to meet in the 7-9 pm time slot. Since then, the classes have met separately, except for the joint class on British - US energy policies. The UK class now meets in the afternoon and is linked to one or more MIT faculty (without trying to match the MIT class time) by video. The lectures at Cambridge East are given by a mix of Cambridge University faculty (who have become interested in the course), videos of past MIT lectures, and some live faculty lectures from MIT. The MIT faculty interact with the UK class via video in the class discussions there. The course is growing in popularity at Cambridge University and is developing its own flavor (flavour?) and focus. With an exchange of students between MIT and Cambridge University, we find our students in their class and their students in ours.

After developing the videos of the course for our program with Cambridge University, we found interest in the course coming from Malaysia, where some MIT faculty were working with the Malaysian University of Science and Technology (MUST) to develop a new graduate program with a focus on energy. The following year we made another set of videos of the course that were sent to MUST to be used as background for Malaysian engineering faculty in developing a similar course that would be adapted more to the needs of Malaysia. One of our early Sustainable Energy course graduates from MIT is now in residence in Malaysia doing some of the teaching and assisting with course development. Interested MIT faculty (who get some research funding from MUST collaborations) are available to respond to queries coming from MUST faculty as the program evolves there.

We are hoping, with the publication of the textbook, that more universities will consider offering similar courses on this increasingly timely topic. Our web site posts our syllabus and most of the lecture materials. It is generally accessible at:

http://web.mit.edu/10.391j/www/index.html

What are the key messages?

1. The availability of plentiful and affordable fossil fuels has led to the quality of life enjoyed today in most affluent countries. Not only do we use these energy sources directly, but energy is embedded in the manufacture and use of essentially all the products and services we enjoy.
2. Greenhouse gas levels in the atmosphere are rising as a result of human activities and are likely to produce future adverse climate effects if not limited.

3. Our economy is based on present low energy prices; significant energy cost increases will require adjustments in our use of energy and will open opportunities for new technologies. There will be winners and losers during the transition, but this will come at some major cost to the poor and to countries dependent on plentiful supply and low energy prices.
4. The world is experiencing rapidly increasing growth in energy demand and use – both because of growing global population and the desire for increased individual consumption at all levels of wealth or lack thereof. Global population has more than tripled in my own lifetime. When the Pilgrims came to America, global population was only half a billion! The US uses about twice as much energy per capita as the average citizen in Japan or most of Europe – and about ten times as much as the average Chinese citizen. And we all seem to desire "more."
5. The world's wealth and energy use are very unevenly distributed. The US with 4.5% of the world's population, produced about one-third of world GDP and caused one-quarter of world energy consumption. China with 20% of the world's population, in 2002 consumed 11% of the world's energy and only had 4% of world GDP. Today, the gap is closing with China as their economy is growing twice as fast as the US economy. But there still are over a billion people on this planet living on less than $1/day PPP – and about 2.5 billion, on less than $2/day. Poverty contributes to major societal problems as well -- and even co-exists with wealth in the US. Access to electricity and clean fuels is key to alleviating this situation.
6. Energy supply and demand patterns are also very unevenly distributed. Growing urbanization and new "megacities" require large localized energy availability; rural areas required less concentrated energy services. Energy storage and flexible transmission/distribution systems are important parts of dealing with energy transients on both the supply and demand side.
7. Technology innovation is going to be very important in helping the world address the adverse impacts of energy use – but there is no "silver bullet." The change will involve portfolios of solutions that will need to be tailored to local resources and needs. R, D, & D investment by the public and private sectors will be important. We will need to value energy at levels that allow us to also address the adverse impacts responsibly – valuing the future as well as today and the well-being of others as well as our own self interests.
8. As engineers, we need to help society to sort through the good ideas and false hype for miracle technologies. Each energy technology involves some impacts and some benefits. These must be understood quantitatively if wise energy choices are to be made. Using the tools we have learned from thermodynamics and engineering analysis, comparing alternatives on a life cycle basis, using risk assessment techniques, we can identify opportunities for making positive change.
9. At some point in the future, we will need to move away from our dominant obsession with universal economic growth, which today means increasing fossil fuel use. Reducing fossil fuel dependency will include not only alternative technologies, but higher energy prices that will have some impact of GDP, but also will encourage more responsible use of energy. Society needs to step up and start paying for the costs that will be involved in transitions to a better future world.

10. Education of young people will be important to creating an informed and responsible citizenry. The book describes several frameworks that have been suggested as pathways to a better future through societal decisions involving the economy, the environment, and local and global society. We hope that many of today's students will be the creative and responsible practitioners of more sustainable energy options for the future.

The Road Forward. MIT's new president, Dr. Susan Hockfield, in her inaugural address, announced a major new energy initiative, saying that the Institute had a responsibility to address the world's energy problems. "Over the last 30 years, these two words – energy and the environment – have gotten a little tired, not from overuse, but from lack of progress… I believe that the country and the world may finally be ready to focus on these matters seriously…and it is our responsibility to lead in this mission," she said. She and the Provost then announced the establishment of a 16-person faculty "Energy Research Council." This group is charged with developing the Institute's energy-related research strategy, in consultation across the MIT community, with other academic partners, with industry, with policy and security specialists, with governmental agencies, and with representatives of local and environmental interests. The Energy Research Council has three main charges: to develop a picture of the current state of MIT energy-related research and expertise, to develop a list of promising research areas that match global needs and MIT's capabilities, and to recommend an administrative structure that would facilitate interdisciplinary research on energy problems among faculty at the Institute. This strategy will also guide recruitment of five or six new faculty members whose research will address energy production and use.

The problems the world faces in the future are very complex and inter-related. Education is probably the most important way to move forward to intelligent and responsible progress. All of us, wealthy and poor, in many different nations and cultures, engineers and policy makers, business leaders and politicians, can work together if we know what we need to do and if we want to do it. I hope that students who have taken our course and others, who will read our new textbook, will gain insights about the magnitude of the problems we are facing and the ways that we can put together portfolios of solutions that will fit local conditions, while protecting the global environment. Inertia is our enemy if we are heading in the wrong direction – as Pogo said: "We have met the enemy and he is us!"