Sustainable energy research and education

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- ❑ Context -- to Cornell and back again
- ❑ Many opportunities for multiscale, multidisciplinary energy research
- ❑ The metrics and dimensions of sustainable energy
- ❑ Lessons learned from pursuing energy education at MIT

Energy research is inherently multiscale and multidisciplinary

Multiple Scales

- **Energy level** from 1 atto Joule (10^{-18} J) …………………… 100's of Exa Joules (10^{+18} J)
- **Size scale** from < 1 nano meter (10^{-9} m) ……………………….. 1000 of km
- **Mechanistic scale** from intermolecular encounters ……………… Global climate dynamics

Quantum mechanics Statistical mechanics	Biochemistry Physical Chemistry Geophysics Environmental Science	Process Engineering Mechanical Design Geotechnical Design	Economics Political Science Sociology

Multiple Disciplines

The energy landscape

- Multiple dimensions
  - 5D's from discovery to deployment
- Multiple scales
  - Power for villages versus megacities
  - Fuels for cars versus industrial processes
- Multiple impacts
  - Natural resource consumption (land, water, etc.)
  - Local and regional environmental and health impacts
  - Global environmental impacts
- Economic wellbeing is important
- Social justice and equity are important
- National policies should reflect individual goals and values

It's not just about finding a technology solution

Engineers love to tackle big problems

1. Over 5-Ds from
   - Discovery
   - Definition with basic research
   - Development of technology
   - Demonstration at commercial scale
   - Deployment in the field
2. Many options including fossil, nuclear, renewable [10+]
3. Multiple scales from 1 kW to 1000 MW [5+]
4. Multiple end uses include heat, power, combined heat and power, transport, buildings, industrial processes [5+]
5. Multiple attributes for sustainability [10+]
6. Performance metrics including energy efficiency [5+]

Energy space dimensionality > 5x10x5x5x10x5 > 62,500

Listing sustainability attributes is simple

- Non-depletable
- Low impacts on natural resources -- land, water, etc., across process life cycle
- Accessible and well distributed – available close to demand
- Emissions free – no NO_x, SO_x, CO_2, particulates, etc.
- Scalable and efficient – from 1 kW to 1000 MW (t or e)
- Dispatchable - for base load, peaking, and distributed needs
- Robust - simple, reliable, durable and safe to operate
- Flexible - applications for electricity, heat, and co-gen
- Economically competitive

But, quantifying and weighting them to map out energy research or technology options is complex given uncertainties in performance, cost, and environmental impacts

Multidisciplinary research versus education

Observation 1 -- **Research and education are synergistic – key to success in either.**
Observation 2 – **Research across disciplinary boundaries can occur naturally in many situations but not all**
Observation 3 -- **Good research universities can conduct quality multidisciplinary energy research but only a few are capable of implementing comprehensive, multidisciplinary energy education programs**

In 2006, MIT's Energy Education Subcommittee recommended that

"Education should be a focal point of MIT's Energy Initiative"

Sustainability education – key requirements

1. **"The people we need"** -- In order to have transformational change in our energy system, a new generation of university teachers and graduates is needed that understands the language and syntax of sustainability in making energy choices.

2. **"Multiple domains"** The dialogue must transcend traditional disciplinary boundaries and connect with the domains of energy science and technology, environmental and ecological science, and economic and other areas of social science and humanities

3. **"Application to practice"** Close ties to hands-on real world activities that address sustainability

4. **"Service to Society"** Students need preparation in how to practice science and engineering to meet local and global societal needs

5. **"Institutional buy-in"** Create a university-wide task force for implementation

Teaching Sustainability – issues and challenges

- ❑ Serious collaborations among energy, environment, and economic and social scientists are not common
- ❑ Coherency and depth across disciplines in energy education are not widely practiced
- ❑ Undergraduate curricula within disciplines are often inflexible and constrained
- ❑ Often misperceived as "softer and less rigorous" than focused research and disciplinary core teaching
- ❑ A sustainability major may not be appropriate for specific degrees that require depth in a single discipline
- ❑ Limited numbers of trained faculty to teach sustainability
- ❑ Funding for multidisciplinary energy education is constrained by the disciplinary structure of universities

General Approach taken at MIT

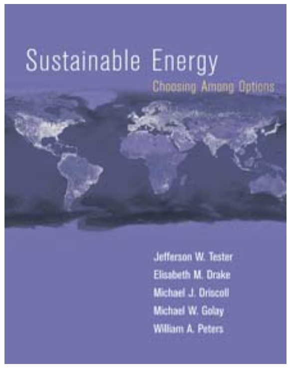
- ❑ Increase number of core energy subjects as electives in Schools of Science, Architecture, Engineering, and Humanities – we now have 14 core subjects
- ❑ Integrate energy-related education into existing departmental programs and the GIRs (General Institute Requirements)
- ❑ Increase energy technology content and focus of undergraduate and graduate subject offerings
- ❑ Develop project-related electives and capstone courses in energy
- ❑ Develop Institute-wide energy minor for undergraduates and for graduate students

Sustainable Energy

10.391J/1.818J/2.65J/11.371J/22.811J/ESD.166J

- •12 units (3-1-8) – grad credit
- •Tues/Thurs 3-5 pm
- •Room 56-114
- •Pre-requisite: permission of instructor
- •URL: http://web.mit.edu/10.391J/www/

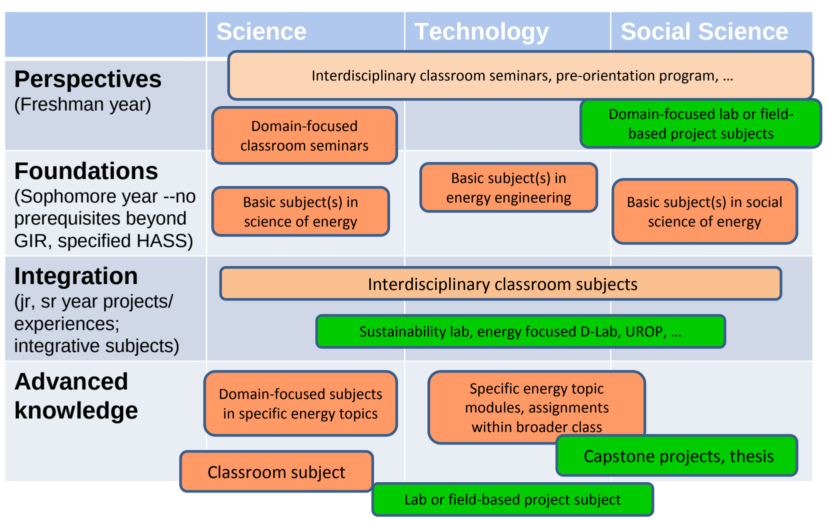
Sustainable Energy – choosing among options



J. Tester, E Drake, M. Driscoll.
M. Golay, and W. Peters
22 chapters --- 850 pages
Available from MIT Press ,
Cambridge, MA
http://mitpress.mit.edu

- ❑ 10 years of course development
- ❑ group/team teaching of system analysis with many performance attributes and large uncertainties and risks
- ❑ appreciate multiple scales of supply and demand -- from watts to TW
- ❑ toolkit of core fundamentals – resource assessment, energy capture and conversion, environmental and sustainability metrics, full lifecycle analysis, economic methods, system modeling
- ❑ assessments of energy supply technologies
- ❑ energy utilization in transport, industry, buildings, and electric power generation
- ❑ case study approach with in-depth project work

MIT EETF's Roadmap for Undergraduates



MIT EETF – D. Lessard, et al.

MITei
MIT Energy Initiative

Framework for an Institute-wide Undergraduate Energy Minor

Integrates foundational work students complete via GIRs

Science domain	Technology domain	Policy/business domain
2 subjects	2 subjects	2 subjects
• Six subjects total • Five subjects outside of major • One project-based or experiential subject • Supervised by a faculty committee (with appointments by Dean of each School)		

We are currently

Identifying subjects within each domain
Gathering input from students and faculty

Thank you!
If you are interested in learning more about geothermal energy come to my talk on Friday

The Blue Lagoon in Iceland