Overview of Energy Research and Education in Cornell Energy Institute

Engineering College Council Meeting

Jeff Tester – Croll Professor of Sustainable Energy Systems and Director, Cornell Energy Institute
Todd Cowen – Professor of Civil and Environmental Engineering, Director of Energy Programs, Atkinson Center for a Sustainable Future

- Energy Institute's current portfolio of research
- Energy Institute role in the context of sustainability at Cornell
- Energy education
- Energy research examples
  - Earth Energy program (geothermal, unconventional fossil energy, and carbon management)
  - Wind and water power Aerodynamic and Hydrodynamic energy
  - Solar energy and energy materials
- Energy at scale in a living laboratory context

Overview of Energy Research and Education in Cornell Energy Institute

For an introduction to Energy Institute's education and research activities please explore our web site at
http://energyinstitute.engineering.cornell.edu/energyinstitute
(especially under the Energy Institute and "About Us" tabs)

To learn more about our flagship program in Earth Energy focused on the sustainable utilization of geothermal and unconventional fossil energy resources, and the sequestration of carbon consult our web site at

http://www.earthenergyigert.cornell.edu/

Cornell Energy Institute in Engineering

Lead organization for technology-based energy research and education

Focus

1) Education through the development and delivery of energy related curricula,
2) Technology- based energy research leading to scalable, sustainable energy solutions,
3) Connecting energy education and research in a "living laboratory"
4) Outreach to promote energy literacy and responsible deployment of sustainable energy options.

Tackling sustainability challenges with innovative research and education

The Energy Institute's three principal activities

1. Education -- Energy education using a modular approach

2. Research -- Multi-disciplinary, Multi-investigator energy research

3. Learning in a living laboratory -- Scalable demonstrations of energy technology on campus, in NY State, and other regions

For details see
http://energyinstitute.engineering.cornell.edu/energyinstitute
(especially under the Energy Institute and "About Us" tabs)

Evolving Roles of the Energy Institute

- **Enhancement** -- Grow Cornell's presence in the energy sector by working within the disciplinary departments of the COE and other units
- **Education** - Promoting the development of course curricula and instructors that delivers "sustainable energy literacy" to educate the next generation of energy leaders, including energy undergrad and grad minors, MEng in Energy Economics
- **Strategic faculty hiring and Realignment** - Assist in hiring of new faculty and support faculty realignment to sustain and enhance Cornell's capacity for energy research and teaching to address high impact energy problems
- . **Engagement in Campus Sustainablility -** Impact at scale in addressing climate change with deployment of renewables and energy efficiency
- **Research program development -** Engaging industry, government, NGOs and foundations to create partnerships and new avenues for supporting multi-investigator research

Sustainability provides a unifying theme for Cornell with strong connections to energy research, education, and on-campus deployment

The grand challenge of sustainability is dealing with the global human footprint at scale

Characterizing, understanding, managing, and mitigating the impacts of humans in order to provide a safe and secure future for coming generations.

Energy accessibility and affordability and its interactions with the environment are at the heart of this struggle

Cornell's approach to sustainability research addresses three key elements

ECONOMIC DEVELOPMENT

- Food & Water Systems
- Human Health, Nutrition & Education
- Institutions, Policy & Governance
- Population and Migration
- Poverty Reduction

ENERGY

- Renewable Sources – solar, wind, biomass, geothermal
- Infrastructure – electric power, smart grids, T&D
- Carbon capture and sequestration
- Efficiency and storage
- Transportation
- Systems Analysis

ENVIRONMENT

- Biodiversity
- Biogeochemistry
- Climate Change
- Buildings to Cities
- Environmental Sociology
- Mitigation/Adaptation
- Sustainable Agriculture
- Water Resource Mgmt.

Cornell Energy Institute in Engineering

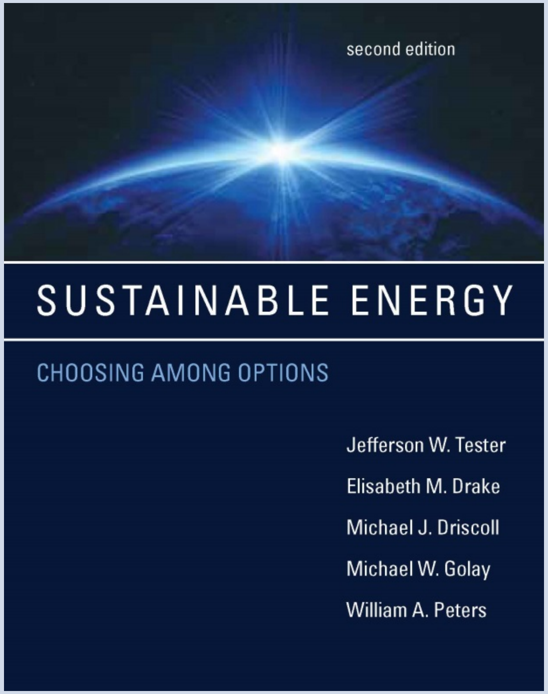
Leadership of the Energy Institute involves CBE, EAS and CEE faculty -- Director Tester (CBE) and Assistant Directors Terry Jordan (EAS), Jery Stedinger (CEE), and Paulette Clancy (CBE), ex officio Todd Cowen (CEE/ACSF)

Along with over 50 COE faculty and staff, for example:

• Zellman Warhaft	Norm Scott	Susan Riha
• Al George	Phil Liu	Chris Clark
• Alan Zehnder	Larry Brown	Geoff Abers
• Katie Keranan	Matt Pritchard	Chuck Greene
• Rick Allmendinger	Lynden Archer	Rod Howe
• Tobias Hanrath	Larry Walker	Don Koch
• Beth Ahner	Lou Derry	Abe Stroock
• Emmanuel Giannelis	Chris Shoemaker	Yong Joo
• Sid Leibovich	Lars Angenent	Larry Cathles
• Derek Warner	Chris Earls	Perrine Pepiot
• Paul Steen	Patrick Reed	Ruth Richardson

Core Textbook - *Sustainable Energy - Choosing Among Options*

Designed for Analysis of Sustainable Energy Systems course (CHEME 6660) and to provide context and background material for 12 energy technology modules.



Sustainable Energy - Choosing Among Options
Tester, J.W., E.M. Drake, M.J. Driscoll, M. W. Golay and W.A. Peters, 2nd edition, 1019 pp, 2012. MIT Press, Cambridge, Mass

Energy Institute Leadership in Energy Education

1. **Sustainable Energy Systems minor for undergrads and grad students**

2. **8 Core courses in Earth Energy and Energy Economics**
   - Analysis of Sustainable Energy Systems (CBE)
   - Earth System Behavior and Resources (EAS)
   - Earth Energy Science and Engineering (EAS, CBE)
   - Energy Economics and Energy Engineering (CBE)
   - Energy Seminar and Hydrocarbon Resources (CBE, ECE)
   - Air Pollution (CBE)

3. **14 Energy Modules 66xx**
   - Typically 1 to 2 months long , with 12 to 24 lecture hrs.
   - 36+ COE faculty serves as instructors in their areas of expertise

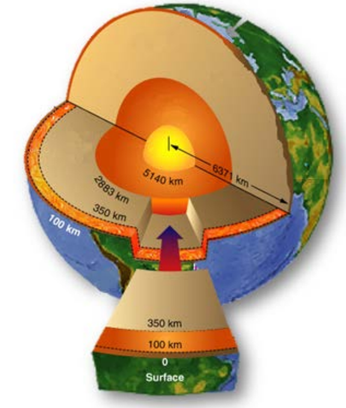
IGERT: Training Program in Sustainable Energy Recovery from the Earth – Educational Innovation at the Intersection of Geosciences and Engineering

“Earth Energy IGERT”

http://www.earthenergyigert.cornell.edu/

EAS/CHEME 6668: Earth System Behavior and Resources

1 credit, completed in last month of semester
Homework, reading assignments, and 1 exam
November 3-December 5, 2014
MWF 9:05-9:55 AM, Snee 2146



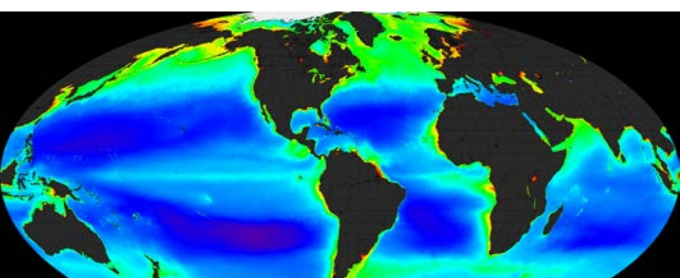
seismo.berkeley.edu

Core course 1 of the Earth Energy program

Overviews the natural processes that are sources of energy and are impacted by energy technologies. Focal topics include climate, water, fossil fuels, and geothermal heat. Components include solid earth cycles in relation to resource distribution, climate and oceans; climate controls and response times; natural and anthropogenic earth system change; Earth's hydrologic system; the energy-water nexus; formation of fossil fuels.

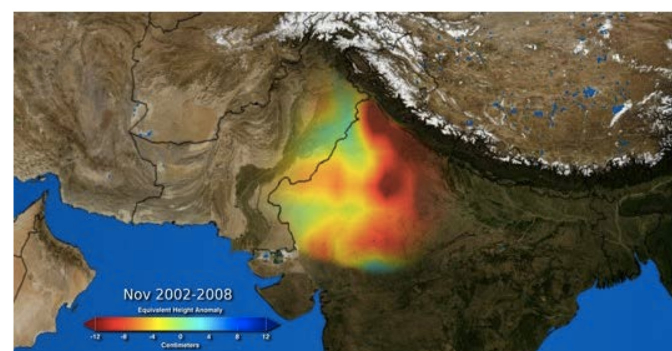
Instructors: Earth & Atmospheric Sciences Professors Jordan, Derry, White; Civil & Environmental Engineering Professor Reed

earthobservatory.nasa.gov



Production of organic matter: biogeochemical cycles and fossil fuels

Questions?
Contact Prof. T. Jordan
tej1@cornell.edu



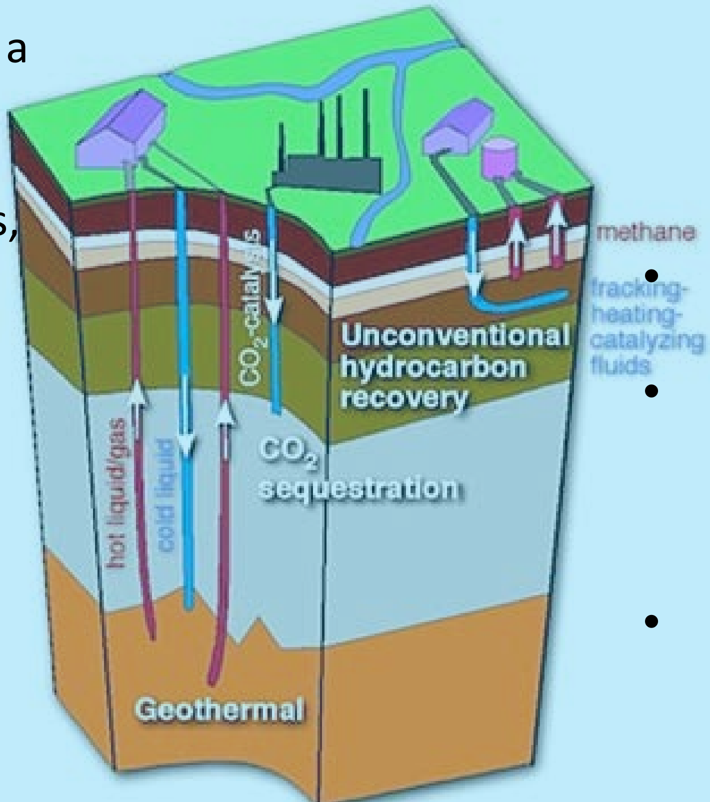
Depletion of groundwater in India's breadbasket (Image: GRACE/NASA)

2. Analysis of Sustainable Energy Systems

(CHEME 6660 – Fall Term)

Summary

Quantitative methods of engineering and life cycle analysis for energy choices in a contemporary sustainability context. Fundamental principles of thermodynamics, transport, and reaction kinetics applied to representative energy supply and end use technologies. Topics include resource assessment, energy extraction/capture, conversion, distribution, storage, and consumption; environmental and economic consequences; local to global scales.



Learning Objectives

- Quantify current energy supplies and demands. Learn and appreciate the importance of geopolitical/social context in sustainability analysis
- Develop advanced engineering analysis skills
- Minimize energy consumption or maximize energy production in processes
- Assess and compare options for sustainable energy recovery from our natural environment, including geothermal, bio, and solar energy

3. Earth Energy Science and Engineering

(Fall. 2013)

Summary

- Characterization of subsurface properties and modeling
- Earth science fundamentals including earth materials and natural fluids in the earth
- Detection of subsurface conditions and changes
- Transport processes, such as the interplay of pore and reservoir-scale reactive transport processes in CO_2 sequestration
- Computational modeling tools for earth engineering and subsurface reservoir modeling

Learning Objectives

- Understand minerals and phase equilibria, brittle and ductile deformations, fractures, and thermodynamics and kinetics of extraction processes
- Apply computer modeling methods in reservoir engineering for reactive and non-reactive transport in fractured porous rock
- Relate large-scale models of transport processes, dissolution and precipitation in the CO2 – brine rock system to small-scale models of pore-space flow fields based on lattice-Boltzman methods

Image source: GE Energy

14 Energy Modules 66xx

- Geothermal (CBE and EAS)
- Shale gas and oil (CBE and EAS)
- Solar (CBE)
- Energy T&D and storage (CBE, ECE)
- Bioenergy and Biofuels (CBE and BEE)
- Fossil Fuels (CBE)
- Energy metals (EAS and CBE)
- Energy and Society (CRP and CBE)
- Carbon sequestration (EAS, CEE and CBE)
- Transportation Energy Systems (CEE)
- Nuclear Energy (ECE with MAE)
- Wind and water energy (MAE, CEE)
- Electric Power Systems (ECE, BEE, CBE)

A set of slides follows describing the content of the modules

CREDIT: Stockxpert

CHEME 6663: Geothermal Energy

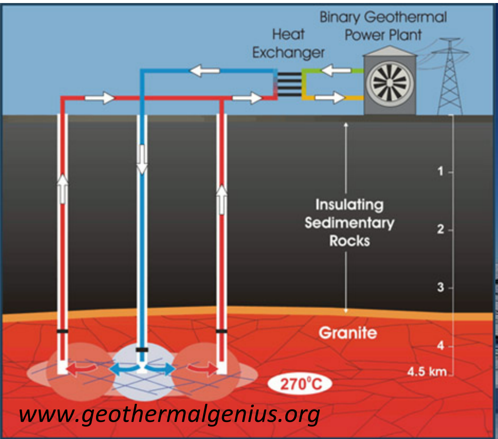
Homework, reading assignments and 1 exam
January 22-February 14
TTh 11:40-12:55 AM, Olin 165 or 245

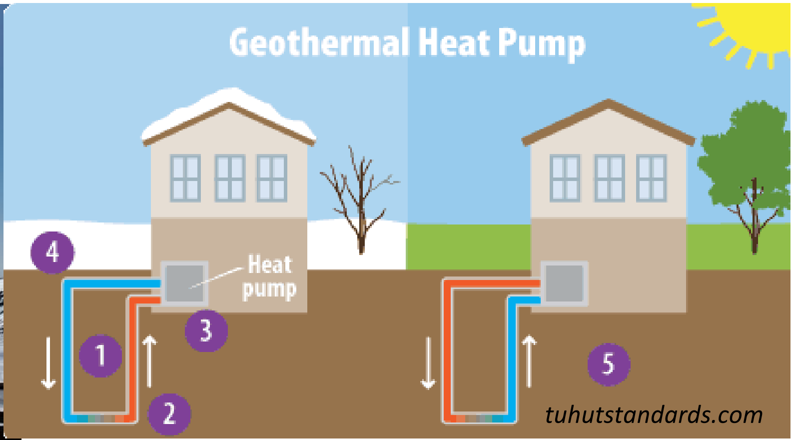
geography.learnontheinternet.co.uk

This 1-credit energy module with 8 lectures focuses on the utilization of low-temperature geothermal energy: geothermal heat pumps, district heating systems for heating and cooling, hybrid geothermal systems and cogeneration applications. It also discusses shallow and deep geothermal reservoir thermal modeling.

Lead Instructors: Prof. Tester & Prof. Horowitz with assistance of K. Beckers, D. Fox and M. Lukawski

Questions?
Contact Prof. J. Tester
jwt54@cornell.edu





CHEME 6675 - Life Cycle Assessment and Techno-Economic Analysis Methods for Energy Systems -- MWF 800 to 850 am Jan 22th- Feb 19th

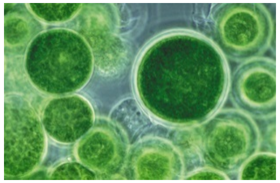
Olin 245 Instructors - Jeff Tester, Leda Gerber, and C Lyndsay Anderson

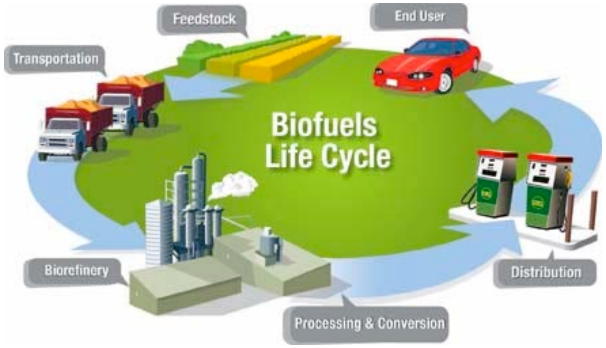
TA – Arna Pallsdottir

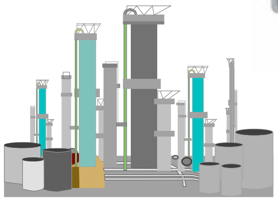
Life cycle environmental impacts, net energy requirements, costs and economic competitiveness are key aspects to be accounted for by the engineers when designing a system or choosing among options for energy services supply. This module provides an introduction to life cycle assessment (LCA) and techno-economic analysis (TEA) for evaluating environmental and economic performances of energy systems with applications to other energy processes - bioenergy, geothermal, fossil, solar, and wind.

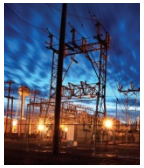
Learning objectives

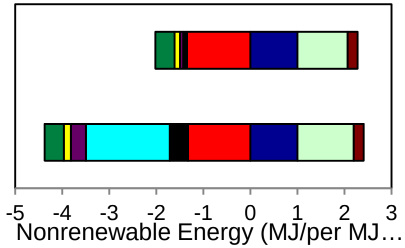
- ❑ Master the methodological frameworks of LCA and TEA.
- ❑ Understand the diverse metrics used in LCA and TEA
- ❑ Understand when LCA and TEA methods can be applied
- ❑ Analyze critically conducted LCA studies in industry or research.
- ❑ Demonstrate capability to apply LCA and/or TEA to case studies.











<u>Contact</u> Prof. Jeff Tester (jwt54@cornell.edu)

Fossil Energy (CHEME 6670) MWF 8-850 am and TTH 840 – 955 am

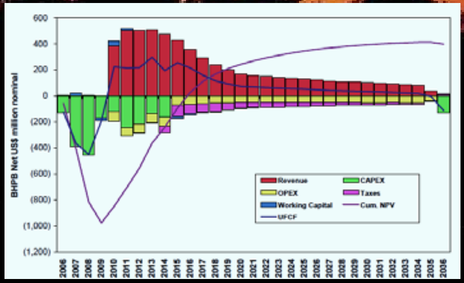
March 17 – March 28 Snee 2146 Instructor – Mike Weill TA -- Chris Siron

Summary:

This module presents an overview of resource assessment, exploration, energy extraction and recovery from. Major themes include the geology of marine reservoirs, exploration and reservoir characterization methods, drilling techniques, energy recovery and processing, along with a range of economic, environmental and social considerations.

Learning Objectives:

- Discuss how Fossil Fuels fit into Energy Mix – now and in the future
- Appreciating the geopolitics of oil
- An understanding of the Life Cycle of E&P
- An appreciation of the scale
- Technology development – today and in the future
- Dealing with a complex blend of Risk/Uncertainty/ Technology/Economics

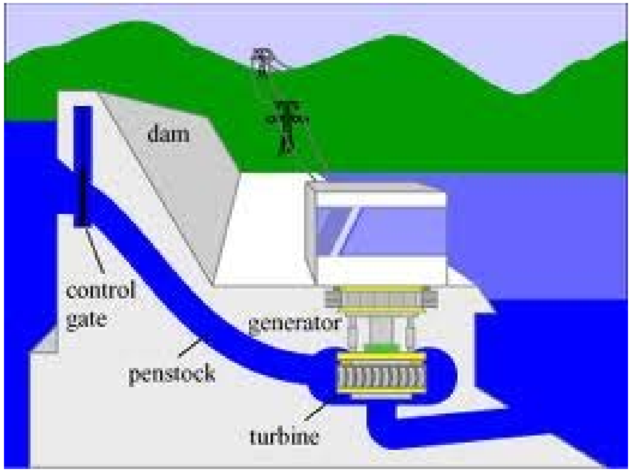


Hydrokinetic and Aerodynamic (Water and Wind) Energy Module

CHEME 6664 -- Spring 2014 Meets TTh 1:25 -2:40 pm April 8- May 1, 2014

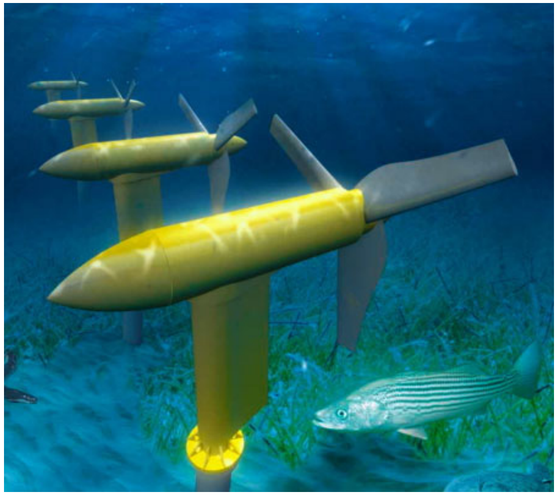
Hollister 320 Instructors – E. Todd Cowen and Jeff Tester TA – Arna Palsdottir

This module gives an overview of water and wind energy resources and technology both on and off shore. Emphasis is on water power from conventional and pumped hydro, wave energy, and tidal basin systems., hydro turbine technology, design and performance Interactions with the environment are discussed



Topics Covered Include:

- Resource assessment
- Hydrodynamic and aerodynamics fundamentals
- Energy capture and conversion
- Hydro turbine design
- Hydroturbine performance Curves
- Siting issues and environmental impacts

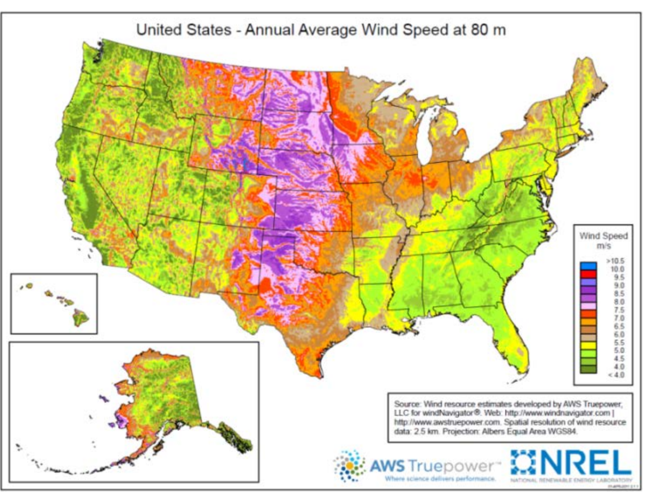


Learning Objectives

- Understand the prospects for hydrokinetic generated energy and issues in siting and Construction conventional hydro, tidal and run of river systems
- Understand how to estimate the efficiency of energy production by a hydroturbine

Wind Energy Module
(CHEME 6664)

This module gives an overview of wind as an energy resource both on and off shore. Emphasis is on atmospheric dynamics, standard wind turbine and farm design and conversion efficiency. Interactions with the environment are discussed (birds and bats).



Topics Covered Include:

- Energy Demand and Supply, Wind Prospects
- Wind Energy Conversion
- Turbine Performance Curves, Grid Frequency Constraints
- Atmospheric Structure and Dynamics
- Variability of Wind: Atmospheric Stability and Turbulence
- Assessing the Wind Energy Potential on a Site, Topographical Effects
- Wind Turbine Siting and Design
- Birds, Bats and Wind Turbines

Learning Objectives:

- Understand the prospects for wind generated energy and issues in siting a wind farm
- Understand how to estimate the efficiency of energy production by a turbine

Biomass Energy Module
(CHEME 6661)

This module provides a comprehensive overview of the technologies used for conversion of biomass feedstock into liquid and gaseous fuels, electricity and heat. Diverse sets of feedstocks including algal and cellulosic biomass, manure and food waste are analyzed together using LCA methods to find the most sustainable options.

Topics Covered Include:

- Bioenergy issues and challenges - dealing with multiple feedstocks, conversion routes and products
- Ethanol production from lignin cellulosic feedstocks
- Feedstock logistics issues
- LCA methods for coupling of feedstock logistics to the production of bioenergy and biofuels
- Anaerobic digestion and gasification
- Thermochemical pathways for biomass; chemical reformation, pyrolysis and combustion, and hydrothermal treatment; liquefaction and gasification of cellulosic feedstock, manure and food wastes
- Algal biomass as a source of high energy densitybiofuels

Solar Energy Module:

Learning Objectives:

This module provides a comprehensive overview of solar energy conversion technologies. Major themes range from fundamental (nuts and bolts) solid-state concepts and operating principles of photovoltaics to manufacturing of cells and modules, balance of system aspects, and perspectives on second- and third- generation photovoltaic technologies. The module also summarizes solar thermal power technologies including passive and active solar heating, concentrated solar power plants.

Major Topics:

- solar energy resource assessment
- basic principles of photovoltaic energy conversion
- current PV systems (silicon and thin film)
- applied PV modules: system level aspects
- 2nd and 3rd generation PV technologies (organic, thin film, and quantum dot solar cells)
- solar thermal systems and concentrated solar power for electric and process heat.

Contact Info:

Tobias Hanrath (th358)
Jefferson Tester (jwt54)

Course Time:

Oct 26-Nov 23 Tu & Th
11:40-12:55 OLH 255

Unconventional Natural Gas

(CHEME 6666)

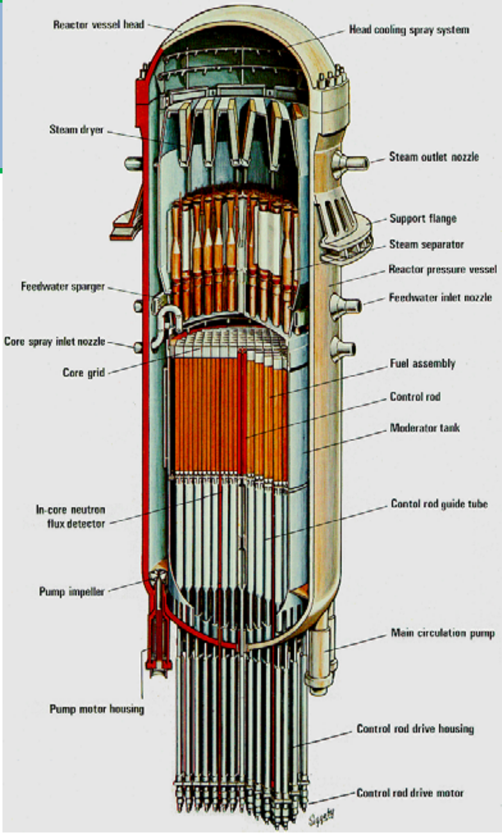
Summary:

This module presents an overview of energy recovery and generation from unconventional natural gas resources, using the Marcellus Shale as a case study. Students will examine the shale-gas life-cycle from exploration to extraction to end-use. Major themes include the geology of gas reservoirs, exploration and reservoir characterization methods, drilling techniques, energy conversion and power plants, and the economic, environmental and social considerations of natural gas use.

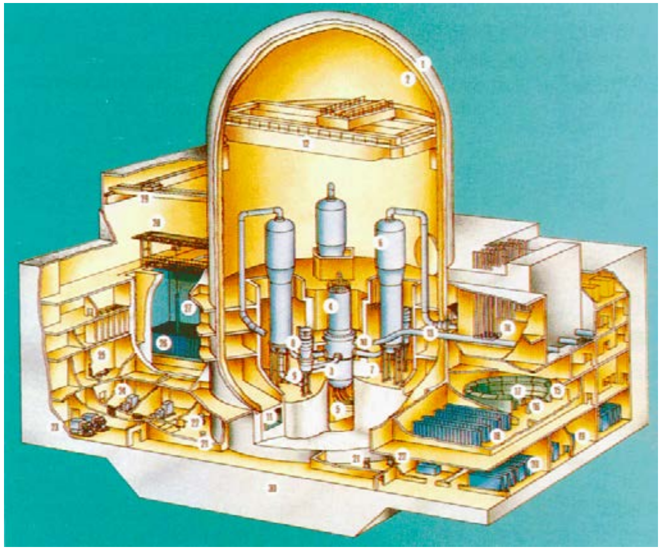
Learning Objectives:

- Unconventional natural gas reservoir geology
- Exploration and reservoir characterization
- Drilling, logging, stimulation, and completions
- Energy conversion systems and power plants
- Risk and risk management

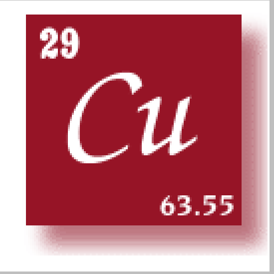
Nuclear Energy Module: Nuclear Energy Systems
Sustainable Baseload Electric Power for the Future



Course Description & Objectives: This module will provide a description of the operation of nuclear fission power plants in their several manifestations and the fuel cycle associated with them. Their benefits will be described along with the reasons why they are cause for concern. Topics will include the principles of reactor operation and control, reactor safety features (natural and engineered), normal and abnormal operation, spent fuel safety and nuclear waste disposal, etc. Advanced reactors now under construction and to be constructed in the near and more distant future will also be discussed.

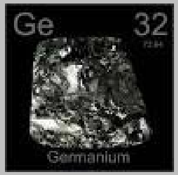


The module coordinator is Professor David Hammer
dah5@cornell.edu; 255-3916
The lectures will be given by two visiting lecturers who are experts on nuclear power systems.
Dates: October 1 – October 29
Tu-Th 10:10 – 11:25



Energy Metals – EAS/CHEME 6674

This module focuses on metals that are important in energy generation, distribution, and storage in the context of supply and demand, and the supply chain from their source in the earth to their use and recycling.

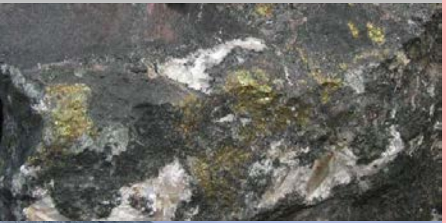


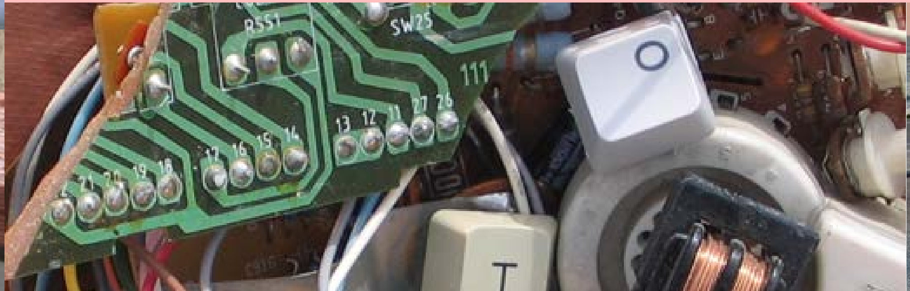
Contact Prof. J. Thompson
jft66@cornell.edu

Topics covered include

- The role that metals play in the generation, distribution and use of electrical power
- The relationship among natural endowment, supply, demand, and cost in determining availability
- Potential for new sources, extraction technologies, and improved practices – potential impact on supply
- The relationship between metal production and energy and opportunities for change
- New energy-related technologies and metal demand
- Recycling opportunities and challenges for energy metals

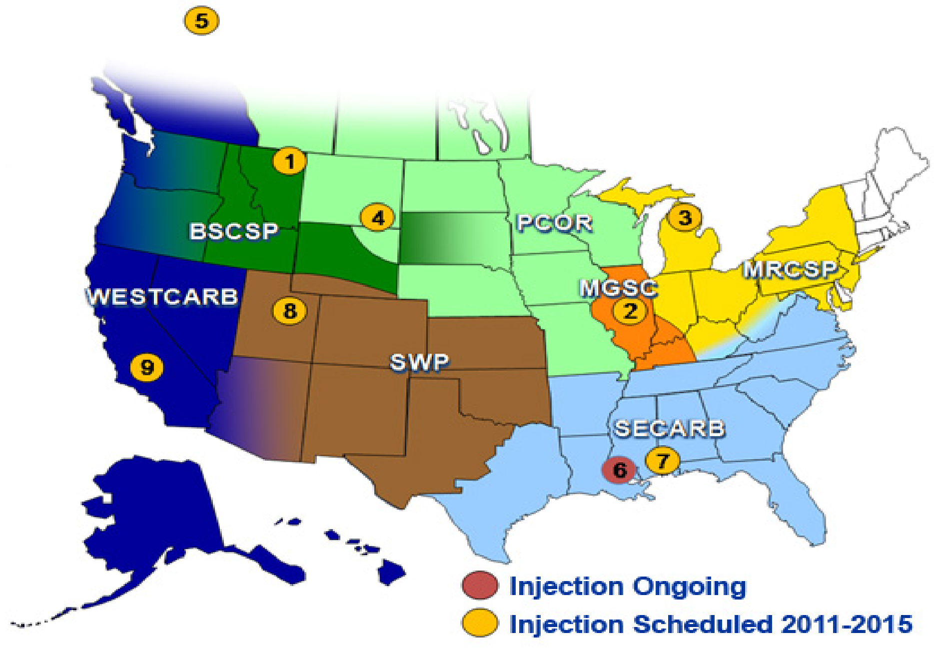
MWF 8:00-8:50
April 7-May 2
Snee 2146
TA –Chris Siron





Geological Carbon Sequestration (CHEME6665)

This module focuses on the principles of sequestration as a science, with the application to carbon management as the motivation.

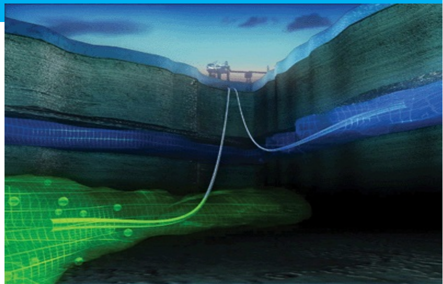


Topics Covered Include:

-The physics of fluid flow in porous media, and the understanding of Darcy’s Law.
-The role that porosity and permeability play in determining CO2 injection capacity.
-The uncertainty of local pressure conditions in geologic formations.
-How local geology affects CO2 mobility and migration after injection and how monitoring wells can be used to determine plume location.

Learning Objectives:

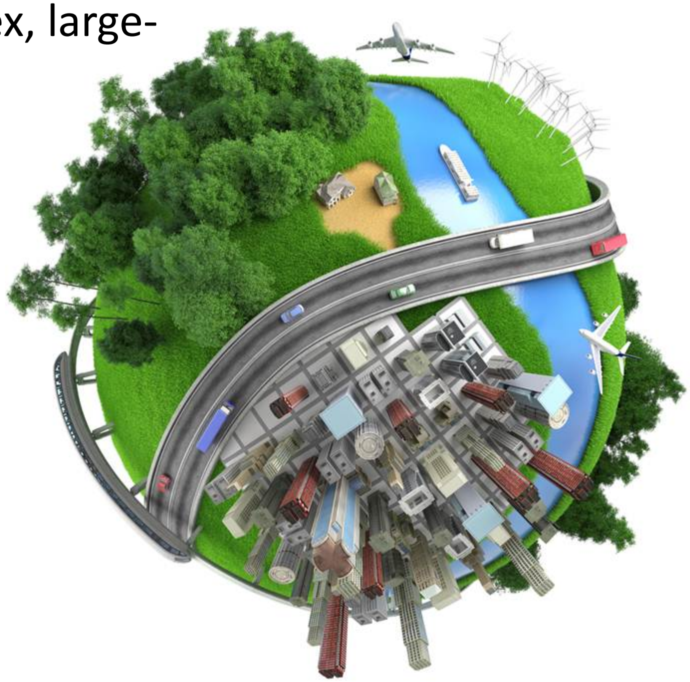
-How does sequestration capacity compare to CO2 production?
-How well does storage location correlate to CO2 emission?
-What are the long term consequences of CO2 sequestration?



Transportation Energy Systems (CHEME 6667 / CEE 6055)

Course Description & Objectives: The course focuses on understanding the link between transportation demand and energy consumption and on how to build a path for a conversion to sustainable energy sources. The objective of the course is to provide students the engineering systems tools for analyzing the interactions among the transportation, economic, energy, and environmental systems. Analytical tools from transportation economics and engineering will be covered to assess the energy consumption and environmental effects of long-term projects over complex, large-scale transportation systems.

Oct 30-Nov 25
MWF
09:05am-9:55pm
HLS 401



Topics Covered Will Include:

- Introduction to energy and environmental economics
- Transportation energy demand
- Environmental impacts of travel behavior
- Energy sources for sustainable transportation
- Ultra-low emission vehicles
- Willingness to pay for energy efficiency

Contact:
Ricardo A Daziano
Email: daziano@cornell.edu
Phone: 255-2018
Office: 305 Hollister Hall, School of Civil and Environmental Engineering

CHEME 6672, Electric Power Systems

When?
Tuesdays and Thursdays from October 2 to October 30, 2014 from 8:40 to 10:00 AM
Who?
Michal Moore, Eilyan Batar, and C. Lindsay Anderson
Where?
Olin 245
Topics to be covered:
Electricity Markets and the implications of risk and uncertainty in finance and engineering
The Structure of Electric Systems including power flow models, system operations and economics
Changes in technology, from green to community scale distribution, with a focus on wind integration
Changes in planning and operations evolving to manage uncertainty in both load and generation
Regulation and Policy Initiatives
Waste and Carbon Markets

Limits and Qualifications:
a. successful completion of CHEME6660, permission of the instructor
b. interest and enthusiasm

Learn the SHOCKING facts about electric power markets and discover recent evidence of ABUSE.

Discover what all those wires criss-crossing the countryside are all about. Delve into the nature of electricity generation, fuel sources, transmission and distribution systems, as well as markets and pricing of electric power. Discuss decisions are made for all the elements of an electricity system, both in terms of operations and management as well as planning and investing to meet demand. A significant portion of the course will address the differences between so-called fossil fuel generation and renewable power and use this knowledge to frame the trade-offs between demand for electricity and environmental quality.

CHEME 6672 Energy Transmission, Distribution and Storage

1 credit, completed in 2nd month of semester

Homework, reading assignments, and 1 exam

February 18 - March 15

Tu & Th 11:40 – 12:55, Olin 165 or 245

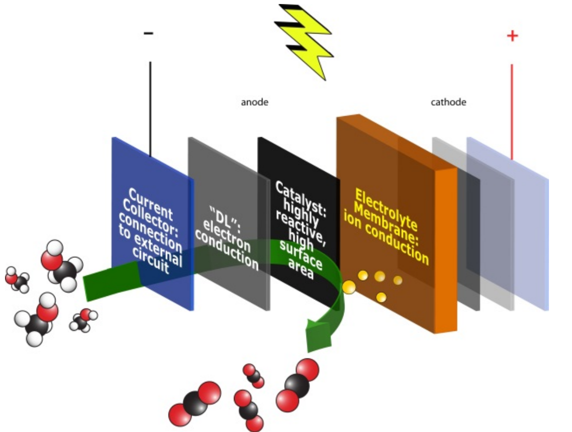
Part 2 of Energy Technology Modules

The infrastructure used to transmit, distribute and store chemical, electrical , and thermal energy is extensive, multiscale, and capital intensive. Coverage in this module includes oil, gas, coal, and electric power transmission and distribution, thermal energy storage, and electrical energy storage and conversion. Technologies evaluated include fuel cells, batteries, compressed air energy storage (CAES), pumped hydro, supercapacitors and flywheels.

Instructors – Jeff Tester and Frank DiSalvo (leads)

with Tito Abruna, Tobias Hanrath, Lynden Archer, Emmanuel Giannelis, and Eilyan Bitar

Questions?
Contact: Prof. Tester (jwt54)



Summary of Energy Institute's Involvement in Energy Education

- Leadership in creating accessible energy courses for seniors and graduate students
- Created MEng specialization in Energy Economics and Engineering
- Assistance in organizing COE's weekly energy seminar
- Management of the Graduate and Undergraduate Minor in Sustainable Energy Systems
- Leadership of Earth Energy IGERT educational program
- Created and deployed 3 core energy analysis courses and 14 modular energy courses with accompanying text

Areas of COE's Multidisciplinary, Multi-investigator Energy Research

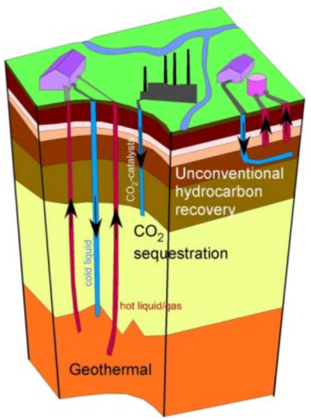
1. Earth energy - geothermal, unconventional fossil, and carbon capture and sequestration
2. Solar energy
3. Energy conversion and storage (with MSE) batteries, SCF thermal storage, CHP, hybrid cycles
4. Bioenergy and Biofuels (with BEE)
5. Computational modeling of energy systems (with AEP and MAE)
6. Electric power systems (ECE)
7. Energy systems for the built environment (MAE)
8. Wave and wind power (MAE and CEE)

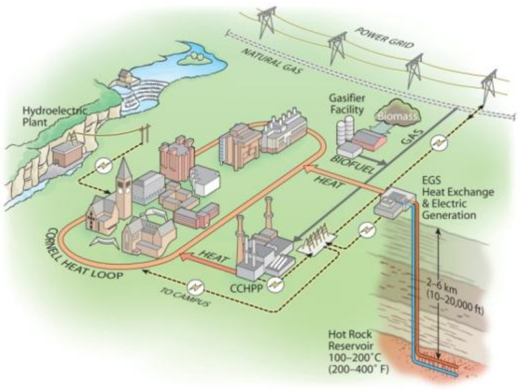
A few examples are given on the slides that follow

Earth Energy

Multidisciplinary research and education program for more sustainable, cleaner energy recovery and use of subsurface resources

- Develop of multidisciplinary team of faculty researchers resources engineering and earth sciences to tackle multiscale approaches to subsurface resource utilization in geothermal energy, unconventional shale gas, cleaner fossil energy with carbon sequestration, and metals extraction
- Faculty involved include 12 from EAS (Jordan, Allmendinger, Brown, Cathles, Derry, Lohman, Pritchard, Keranen, Abers, Riha, Thompson, Horowitz), 4 from ChemE (Tester, Koch, Stroock, Steen), and 4 from CEE (Warner, Earls, Stedinger, Reed), 2 from Systems (George, Moore)
- Regional connections to direct use of geothermal energy, Marcellus shale gas recovery, carbon sequestration in geologic formations
- Earth Energy IGERT -- Sustainable Energy Recovery from the Earth educational innovation at the intersection of geosciences and engineering
- Seeking DOE, EPA, NYSERDA and industry funds for a geothermal demonstration at Cornell and supporting work on shale gas





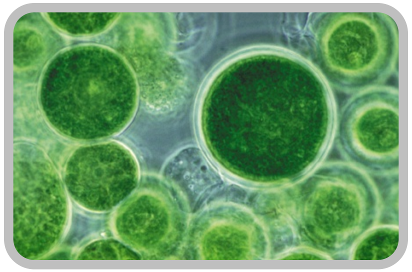
Earth Energy Research Examples

Resource assessment, reservoir performance modeling , and systems analysis with applications to geothermal energy, unconventional fossil fuels, carbon capture and sequestration, metals extraction and recovery

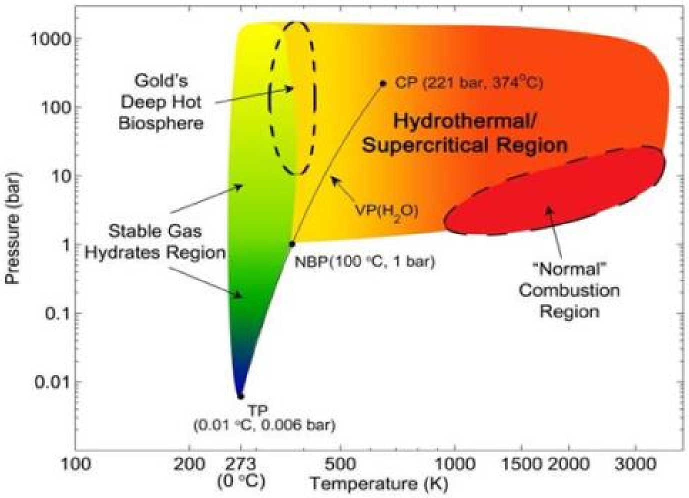
- Quantification of the regional geothermal resource quality NY, PA, New England (Jordan, Tester) with SMU Blackwell et al
- Thermal-hydraulic modeling of heat extraction and recovery in discretely fractured geothermal reservoirs (Koch and Tester)
- Characterization of thermal drawdown in geothermal reservoirs using reactive tracers (Tester, Koch, and Cathles)
- Thermal spallation drilling of hard rock using supercritical jets and hydrothermal flames Performance and subsurface modeling of heat pump systems for cell tower and data center cooling applications (Tester)
- Hybrid biomass – geothermal systems for combined heat and power applications (Tester, Horowitz, Moore, et al)
- Carbon dioxide migration and dissolution in aquifers and geologic formations (Stroock and Koch)
- Hydrothermal desulfurization and upgrading of heavy oils and crudes (Tester, Joo, with Green and Ghoniem (MIT)
- Characterization, impacts and seismic risks associated with fluid injection in subsurface systems (Keranen, Brown, Abers, Lohman, and Horowitz)
- Mitigating the environmental impacts of metals extraction and processing (Thompson and Tester)

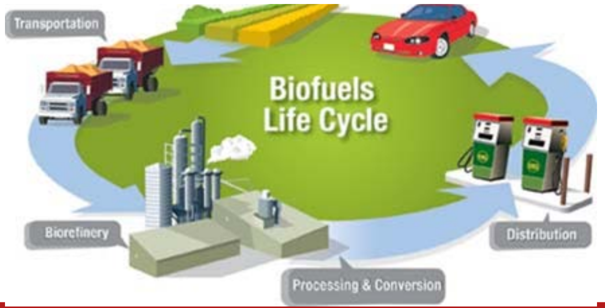
Bioenergy and Biofuels

Expand Cornell's biomass portfolio beyond ethanol from lignin cellulosic feedstocks using different feedstocks and thermochemical processing



- Tester, Ahner, Angenent, Walker, Pepiot, Fisher, Li, Greene, et al. – measurements and modeling of biomass conversion to biofuels, bioenergy and co-products including algal feedstocks, food and animal wastes, and lignin cellulosic energy crops
- Zia and Daniel – modeling lipid separation and sedimentation of dilute algae feedstocks – ASCF venture fund project
- Established external partnerships – Cellana, DOE, USDA for algal and animal waste feeds
- Opportunity exists to expand bio research into metabolic processing for biofuels and bioproducts

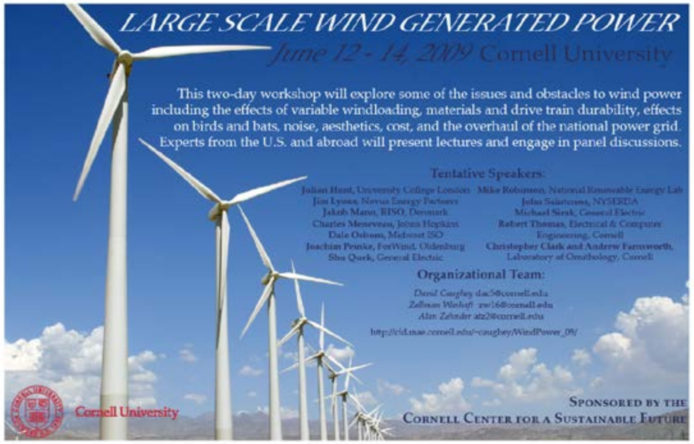




Wind and Water – Aerodynamic /Hydro Kinetic Energy

<u>Overall Goal</u>: Develop a program for research focused on large scale wind power

- Cornell faculty (Barthelmie, Zehnder, Cowen, Warhaft, Liu, Bitar, Clark, and Anderson) with expertise in 5 relevant engineering science areas: *• turbulent fluid mechanics • mechanics of large structures • electric power integration • tidal and wave interactions with land • and bioacoustic research in* Cornell's Lab of Ornithology
- Building a coalition of university researchers to define a national program for collaboration with NREL's National Wind Test Center, industrial partners, and Cantabria, Dublin, Danish partnerships on wind and wave power
- Established working partnership with Verdant Power in NY city on Roosevelt Island



Solar Energy and Energy Storage research examples

Expanding Cornell's solar PV and electric energy storage research portfolio by leveraging strengths in materials characterization (CHESS, etc.), nanofabrication (CNF), imaging, electronics, and multiscale computational modeling capabilities

- Cohesive organized team already exists in (and led by) CBE. Collaborations with MSE, AEP (1), Chemistry (2) and Physics (1) and within KAUST-CU and EFRC-EMC2 (storage only)
- Leverages current strength in PV: electronic materials, polymers, and modeling (Hanrath, Clancy, Escobedo, and Engstrom)
- Leverages current strength in energy storage: synthesis and characterization of energy conversion and storage technologies (Archer, Giannelis and Hanrath)
- New initiative on hybrid [solar PV-thermal energy] storage using engineered supercritical mixtures with nanoparticles (Hanrath, Tester, Archer, with Giannelis)

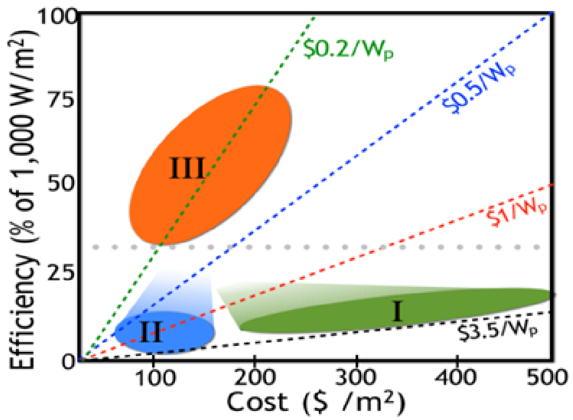
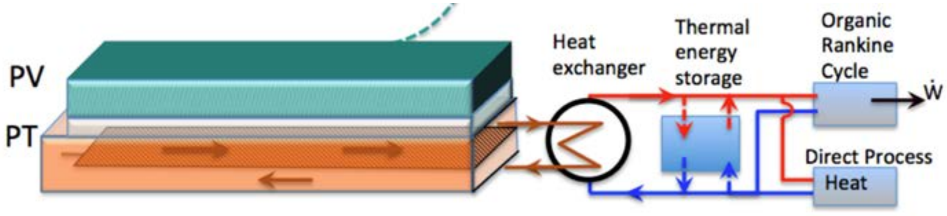
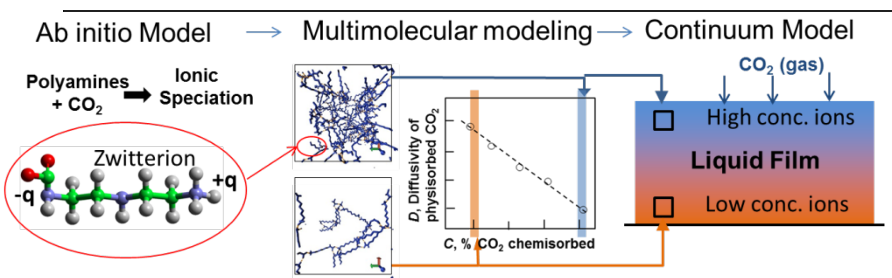
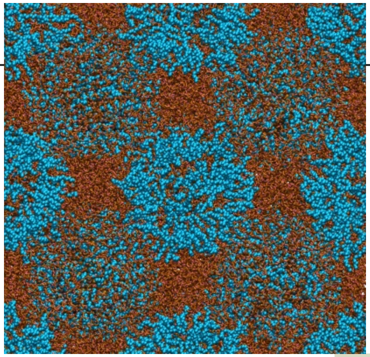


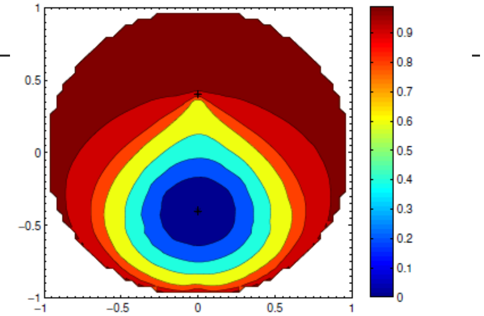
Figure 1- PV electric power cost as a function of module efficiency and area cost



Examples of computational multiscale energy modeling



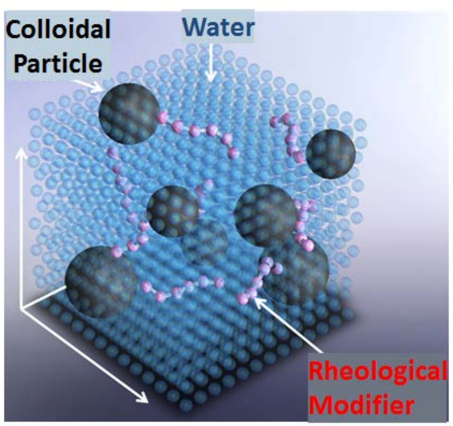


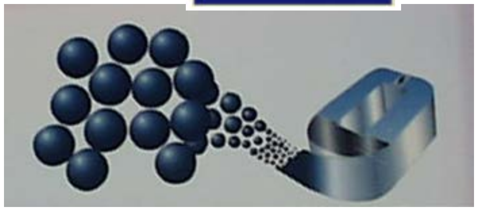


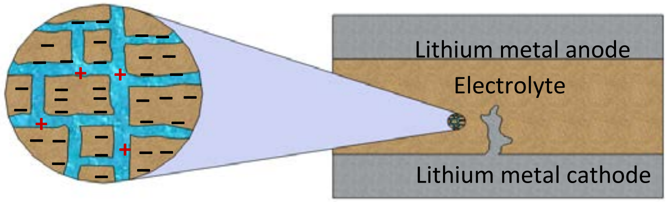
Escobedo-
- CO_2 capture in polyamine thin films
- self-assembly of pure and mixed nanocrystals for photovoltaics

Clancy- Materials design for solar cells
- Quantum dots (w/Hanrath)
- Roll-to-roll processing (w/Bao, Stanford)
- All-organic solar cells (w/Loo, Princeton; & w/Dichtel, Cornell)

Tester- CFD, thermal hydraulic & reaction modeling for geothermal (w/Koch), thermal energy storage, algal bioenergy







Joo- Slurry transport (nuclear waste, hydrofracking)

- Energy storage devices (Li ion, Li air batteries)

Steen- Energy efficient processing of metals

Koch- Modeling transport in porous media:
- Inhibiting dendrite growth in Lithium metal batteries (w/Archer)
- Enhancing CO_2 dissolution in brine for geological sequestration (w/Stroock).

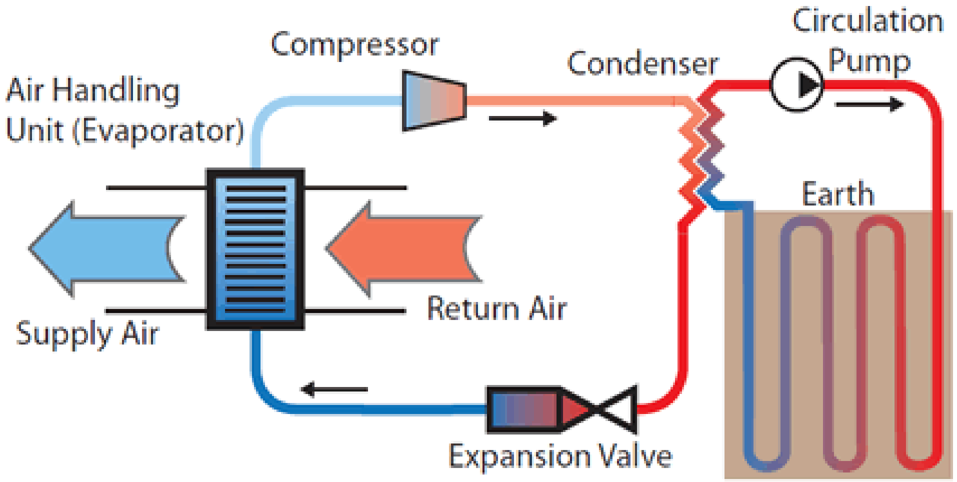
Zia – Algal biofuels

Learning in a living laboratory -- Scalable demonstrations of energy technology on campus, in NY State, and other regions

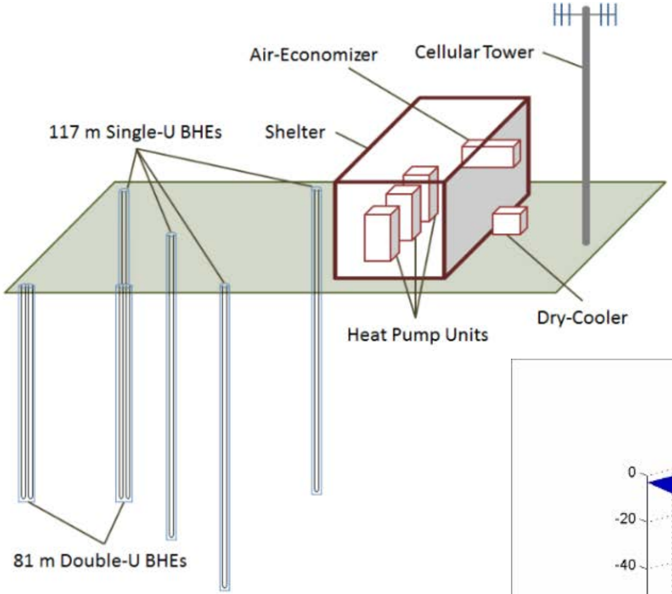
1. Energy efficiency improvements in cell towers and data centers
2. Sustainable agriculture with energy and nutrient recovery
3. Renewable energy options for accelerating Cornell's Climate Action Plan -- geothermal, biomass, wind and solar PV

Geothermal Heat Pumps for Verizon Cellular Towers

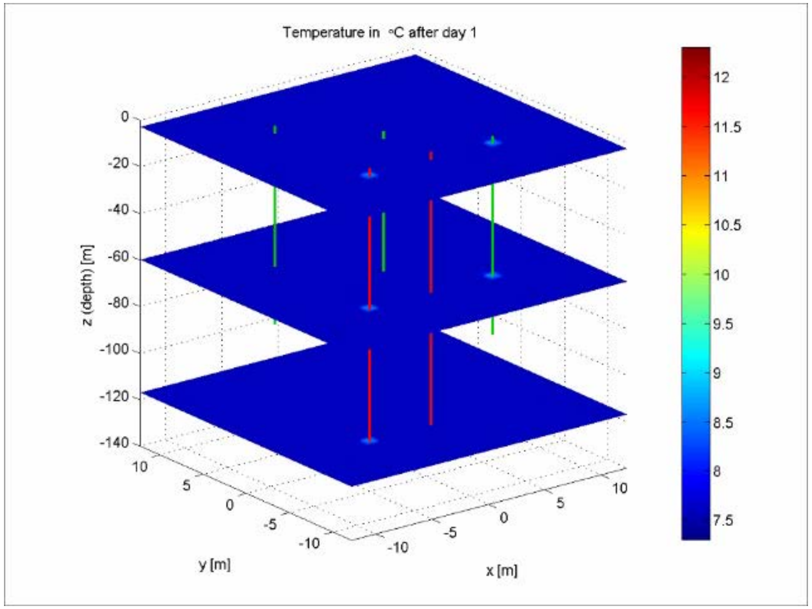
- Feasibility of Using Geothermal Heat Pumps for Cellular Tower Shelter Climate Control
- CO_2, Cost, Energy savings?
- Nationwide impact?



Source: energydesignresources.com

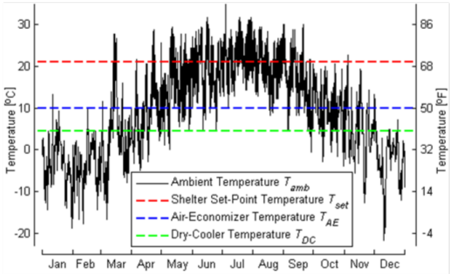


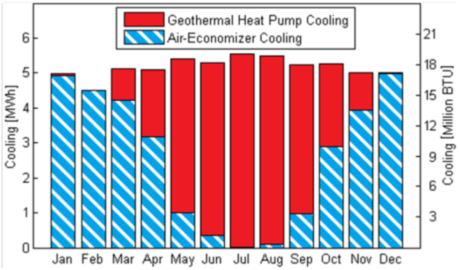
Heat pump performance and economic modeling



Techno-Economic Model

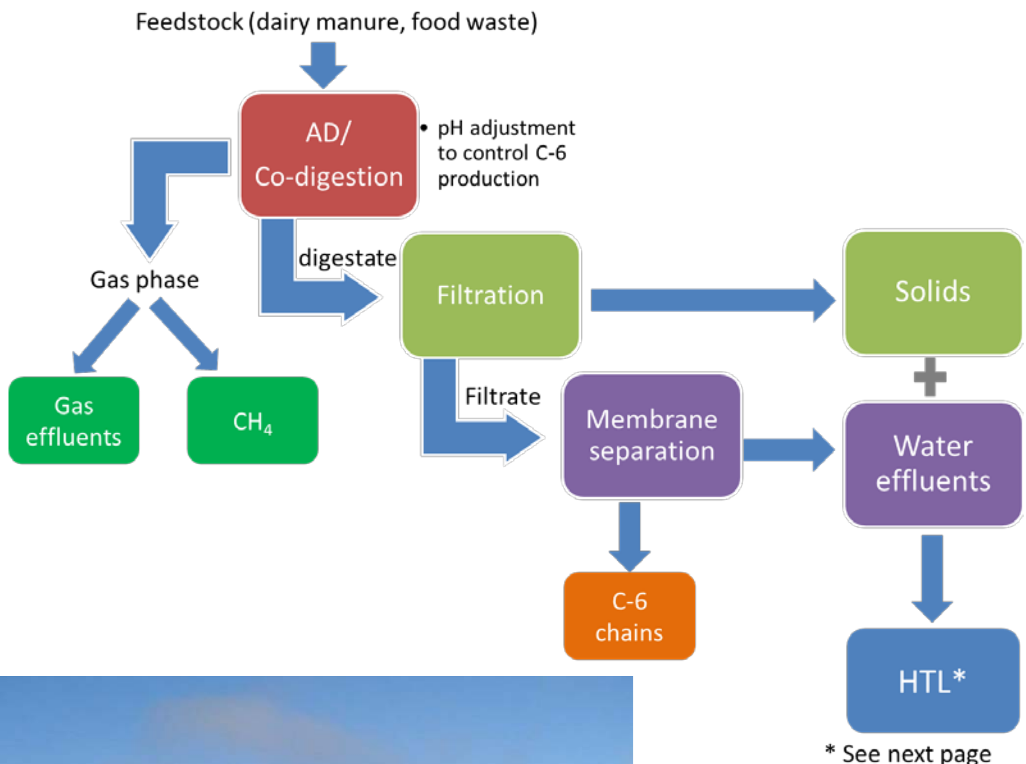
Hourly Climate Data from TMY3 Dataset
↓
Predict GHP and AE Cooling Demand
↓
Simulate Hourly T_{out}, W_{HP}, W_{AE}, W_{DC}
↓
Calculate Life Cycle Cost (LCC)

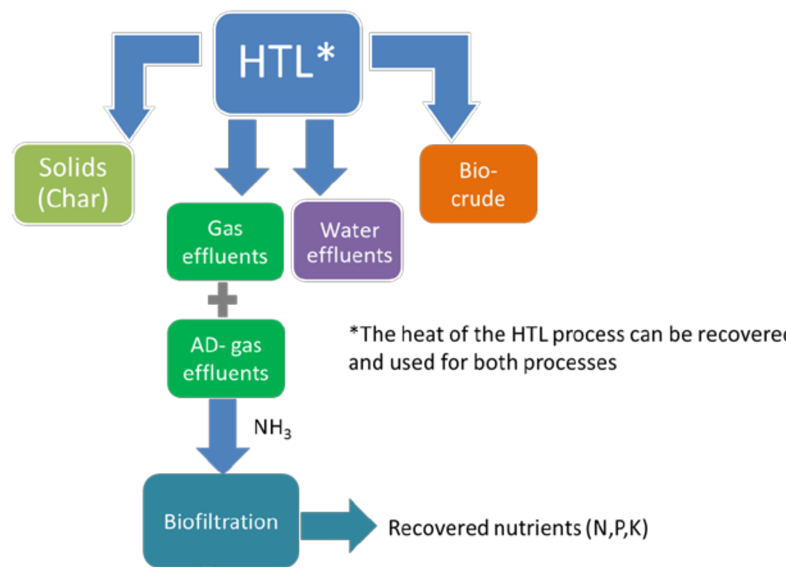




http://www.youtube.com/watch?v=yzfwBZPmJH4

2. Combining anaerobic digestion and hydrothermal liquefaction to maximize biofuel production from dairy manure and food waste





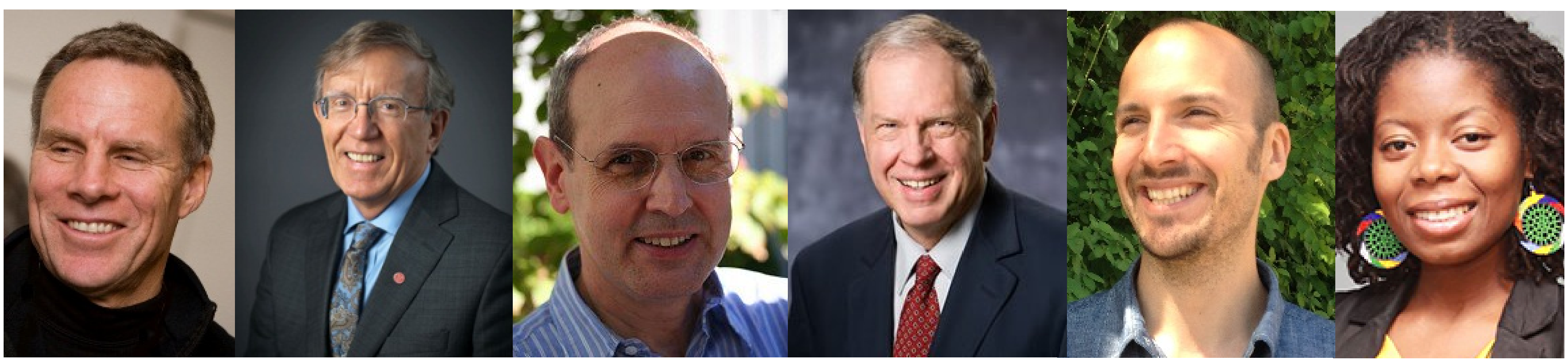
Cornell University

Leadership in Climate Change

- "Of course, among the first places we should seek to create a more sustainable future are our own campuses. Last February, in response to a resolution from the Faculty Senate, I committed the university to creating a plan to accelerate our efforts to achieve carbon neutrality on the Ithaca campus by 2035—a full 15 years sooner than originally planned.

  -- from 2014 State of the University Address on October 17, 2014 by President David J. Skorton

Can Cornell achieve climate neutrality in 20 years and enhance our mission?



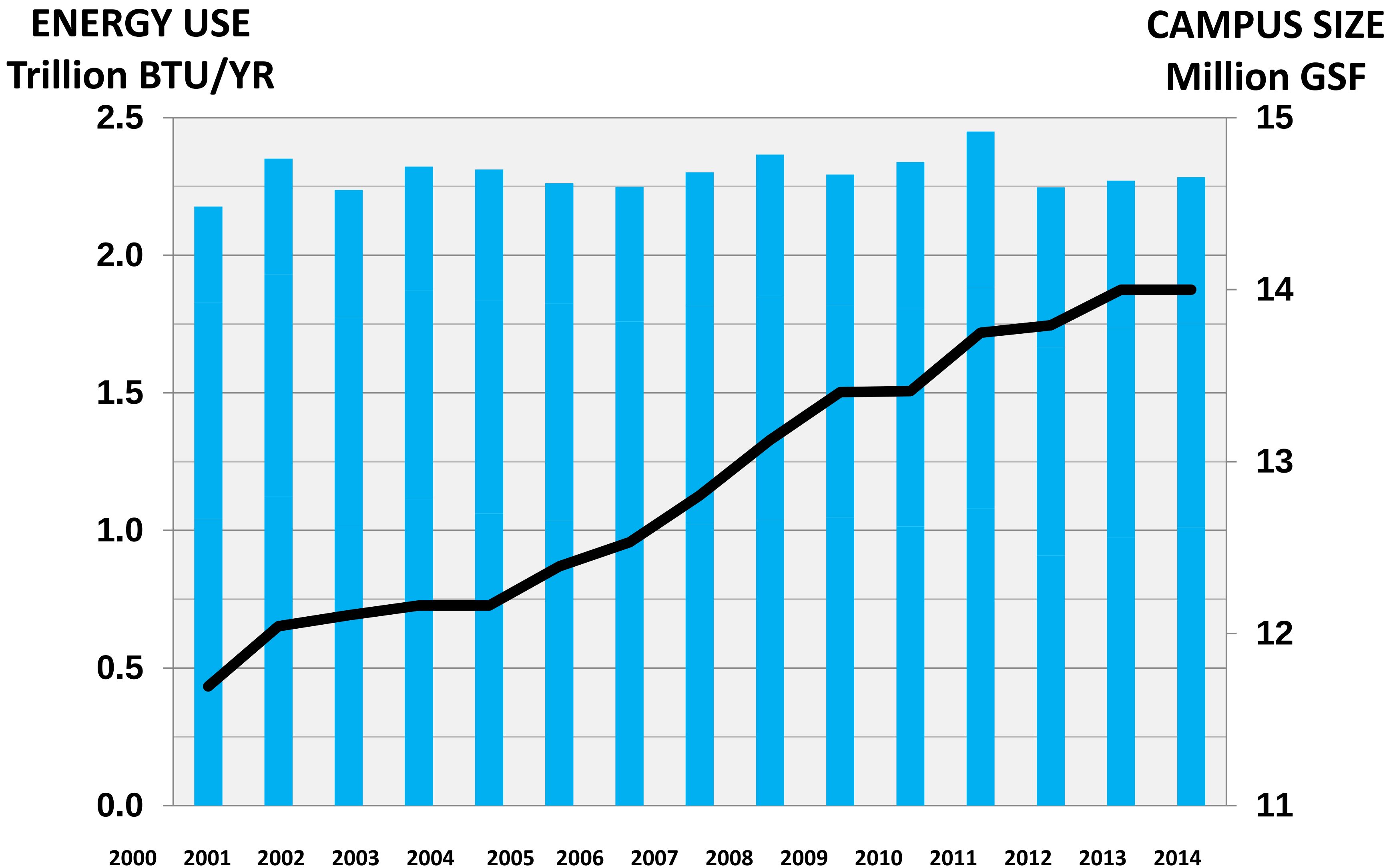
Transition to Todd Cowen

Backup slides

Cornell University

Saving money, reducing carbon

Energy Conservation Initiative



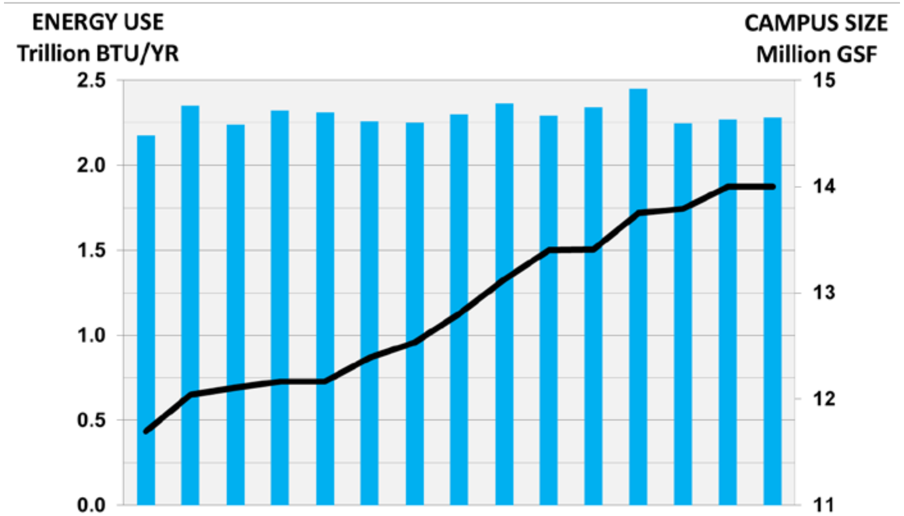
Saving money, reducing carbon

Lake Source Cooling

90% reduction in electricity for cooling = 15 MW peak avoided

Energy Supply Options

Cornell's energy demand is substantial and there are not many renewable options to supply it…



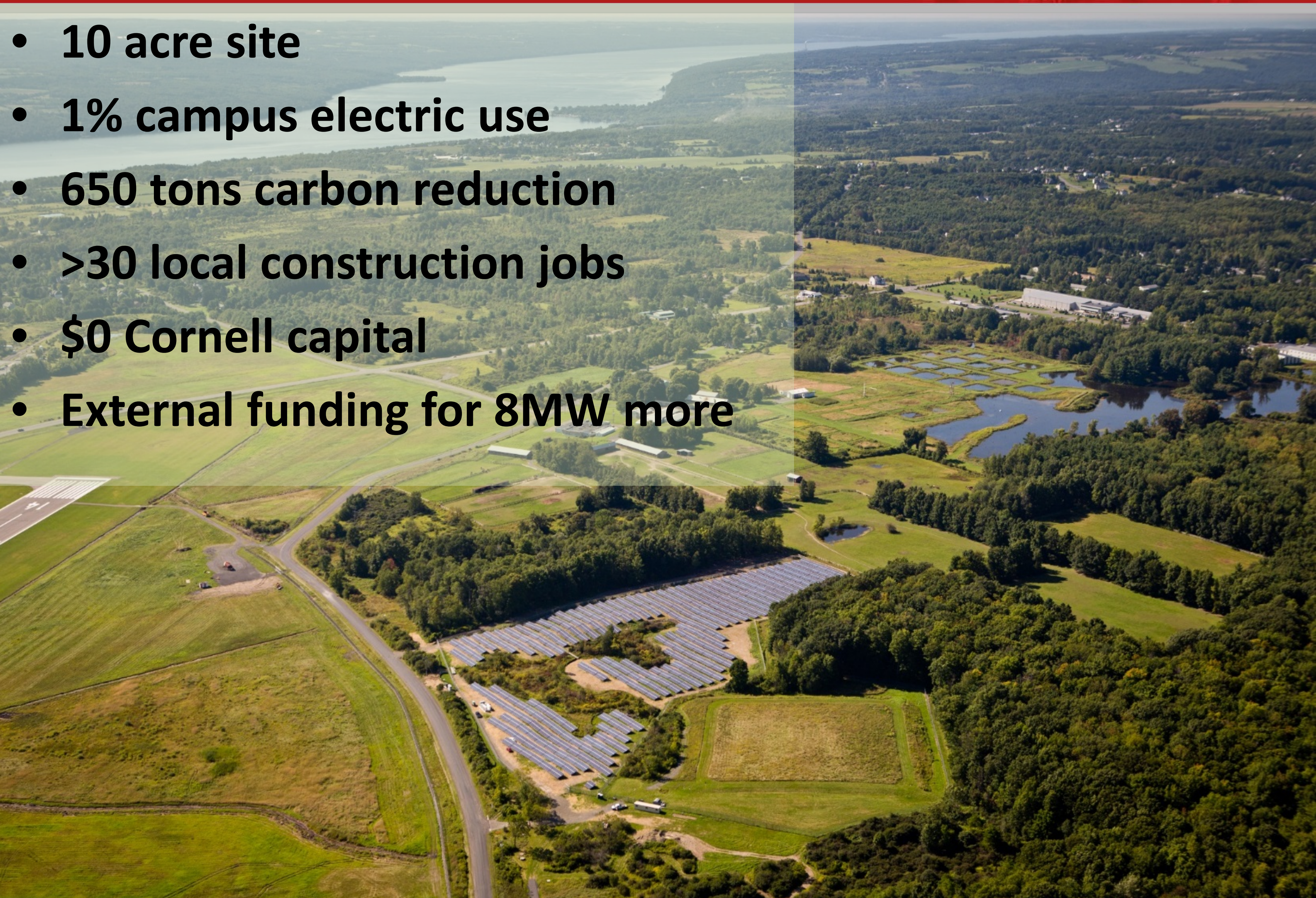
Heat Options

Electricity Options

Cornell University

2MW Snyder Road Solar Farm

- 10 acre site
- 1% campus electric use
- 650 tons carbon reduction
- >30 local construction jobs
- $0 Cornell capital
- External funding for 8MW more



12MW Local Wind Farm

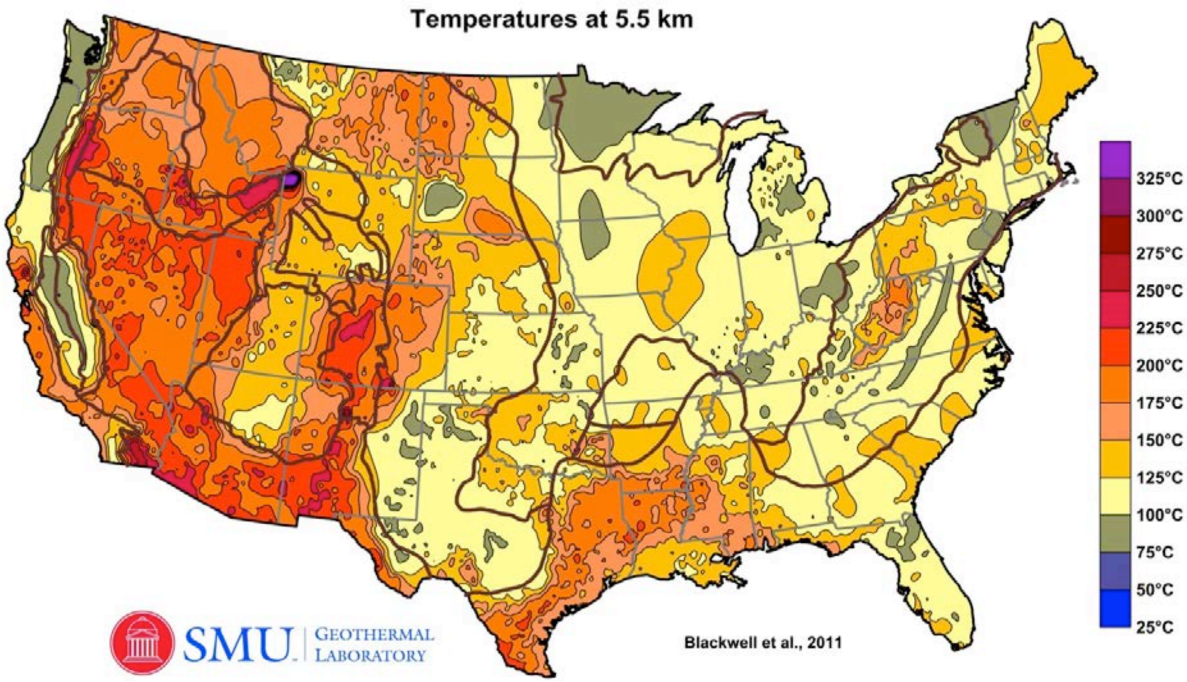
- Power Purchase Agreement
- First wind farm in Tompkins County
- Currently under development
- Investment opportunity for NYS residents

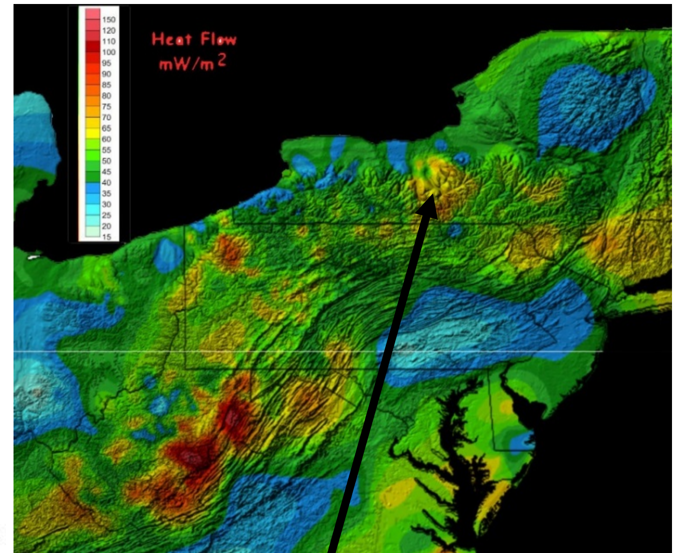
Black Oak Wind Farm

Cornell University

Geothermal Resource

New York contains a large region of higher geothermal heat flow



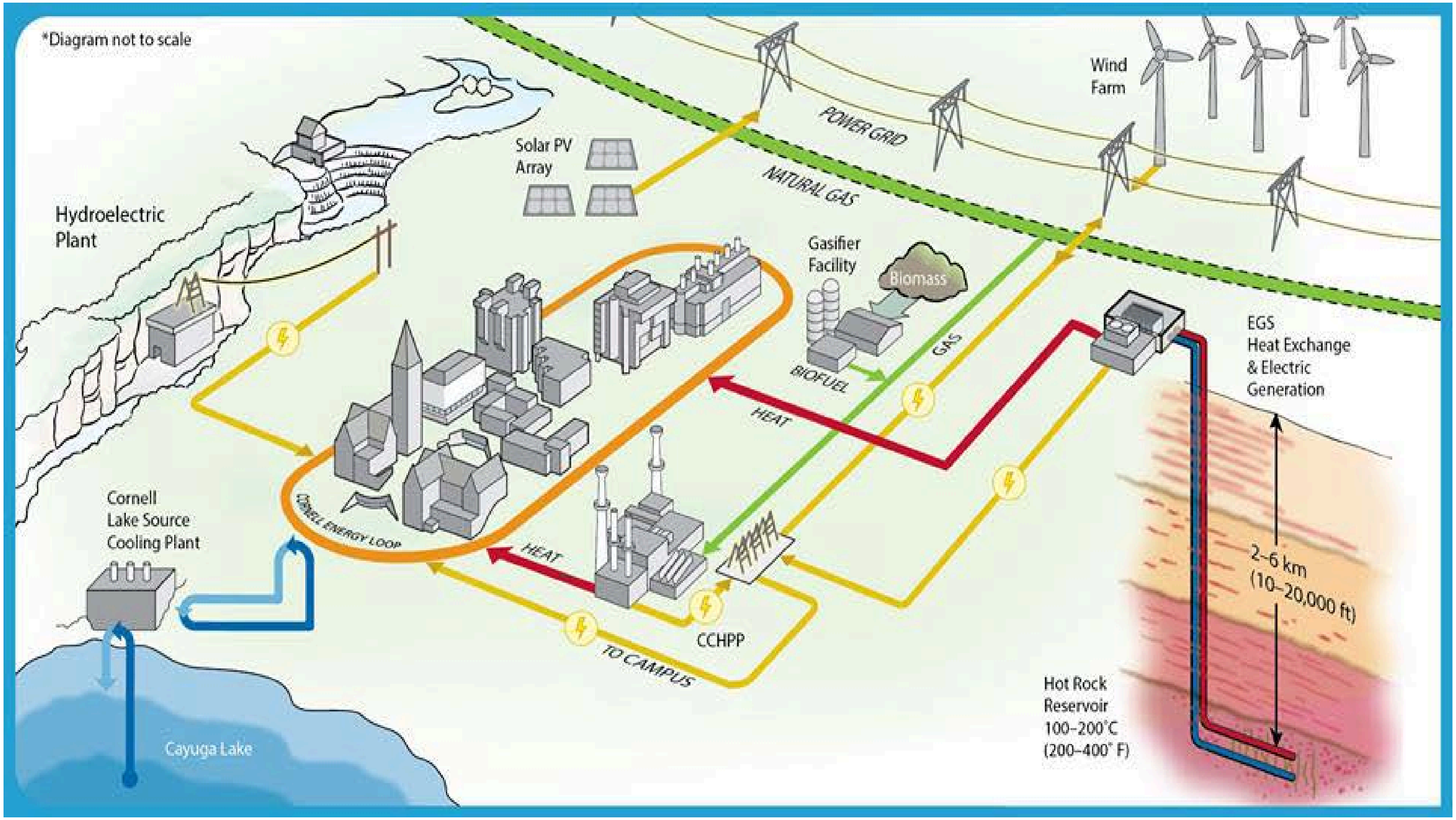


Cornell

To reach rock at 120-140°C well depths of 10,000 to 15,000 ft. are needed

Transformation

To meet its heating demand deep geothermal and biomass are feasible and land exists for siting a demonstration



To achieve this goal a supportive team is needed – faculty, students, staff, NY state NYSERDA, US DOE, and Trustees

A climate neutral campus enhances our mission

Intellectual depth - Requires us to wrestle with tough questions across disciplines

Engagement - Humanities, social science, and community engaged learning and research are all necessary

Impact - Translation of fundamental knowledge to real world problem solving

Scalable model - For New York state and the country

Stewardship - Land grant mission and cooperative extension

Cornell Leadership at a Crossroads

What will Cornell's legacy be 150 years from today?