Cornell Energy Task Force

Engineering College Council

Cornell University

Winter 2017-2018

Outline (Presentation will be brief overview)

- Topics from 10/27/17 ECC Meeting
- Cornell Energy
  - Needs, sources, storage
- Cornell Climate Action Plan
- Cornell Resources
- Possible Energy Plans for Cornell
- Transportation
- Microgrids
- Renewable Energy Center
- Utility Pricing Models
- Energy Task Force Opportunities

Discussion Topics from 10/27/2017

- Climate Change
  - There is no problem more important than the question of Climate Change
    - Increased carbon dioxide in the atmosphere is the major cause
    - Energy production and transportation are the major carbon contributors
  - What can/should Cornell do?
    - Make Cornell campus net-zero carbon by 2035
    - Make Cornell attractive for energy conscious students
      - Add energy based student projects
      - Add energy majors
      - Partner with energy companies for co-op and research opportunities
    - Educate students and public on energy issues
      - Energy Resource/Education Center (solar, wind, electricity, heat, cooling, storage)\
      - Wind and solar farms on Cornell land to support the Center
    - Develop Earth Source Heat as a new green technology
    - Use big data to make the Cornell region a smart region
      - Transportation (including electric vehicles)
      - Electricity grid optimization (smart meters)
    - Make Cornell a microgrid for disaster and emergency response
      - Include renewables and storage
      - Stay synchronized with the grid even when functioning as a microgrid

Discussion Topics (continued)

- Research/Industrial Cooperation
  - Battery recycling studies
  - Other partnerships with industry in the energy space
  - 2000 new beds (North Campus) as a ground up technology opportunity
  - Can Engineering partner with the Ag school
    - Carbon sequestration
    - Biogas generation
  - Partner with utilities on load balance, future pricing, supply-demand matching
- Investment/donation opportunities
  - Help with Earth Source Heat financing
  - Support biodiesel student project
  - Support energy conservation projects
    - LED lighting
    - Smart classrooms

Additional Topics

- Cybersecurity
  - How do we make the grid less vulnerable?
  - Are microgrids a more secure energy option?

Cornell Energy Needs

- Electricity
  - Lights (LED)
  - PEV (Plug in Electric Vehicles)
- Heat
  - Electricity production
  - Hot Water
  - Space Heating
  - Cooling/AC
  - Freezing
- Work
  - Transportation
    - Autos, buses, trucks

Cornell Energy Sources

- Electrical Grid
  - Carbon based
  - Renewable
    - Solar, wind
- Hydrocarbons
  - Natural gas for electricity, heat
  - Transportation fuel (gasoline, diesel)
- Local Renewables
  - Solar, wind, biofuel, wood, biodiesel
- Sun (variable)
  - Solar PV, hot water
- Hydro
  - Limited (seasonal)
- Earth (steady)
  - Deep geothermal heat
  - Lake source cooling

Energy Storage

- Electricity
  - Batteries (short term, automotive)
- Heat
  - Earth storage (shallow, seasonal)
  - Phase change materials (PCM)
  - Hot water tanks
- Lake Source Cooling
  - Could this be used for storage?

Transportation

- Present
  - Gasoline
  - Diesel fuel
  - Electric vehicles
- Future (net zero carbon)
  - Electric vehicles
  - Hydrogen vehicles
  - Biodiesel trucks, buses

Cornell Climate Action Plan

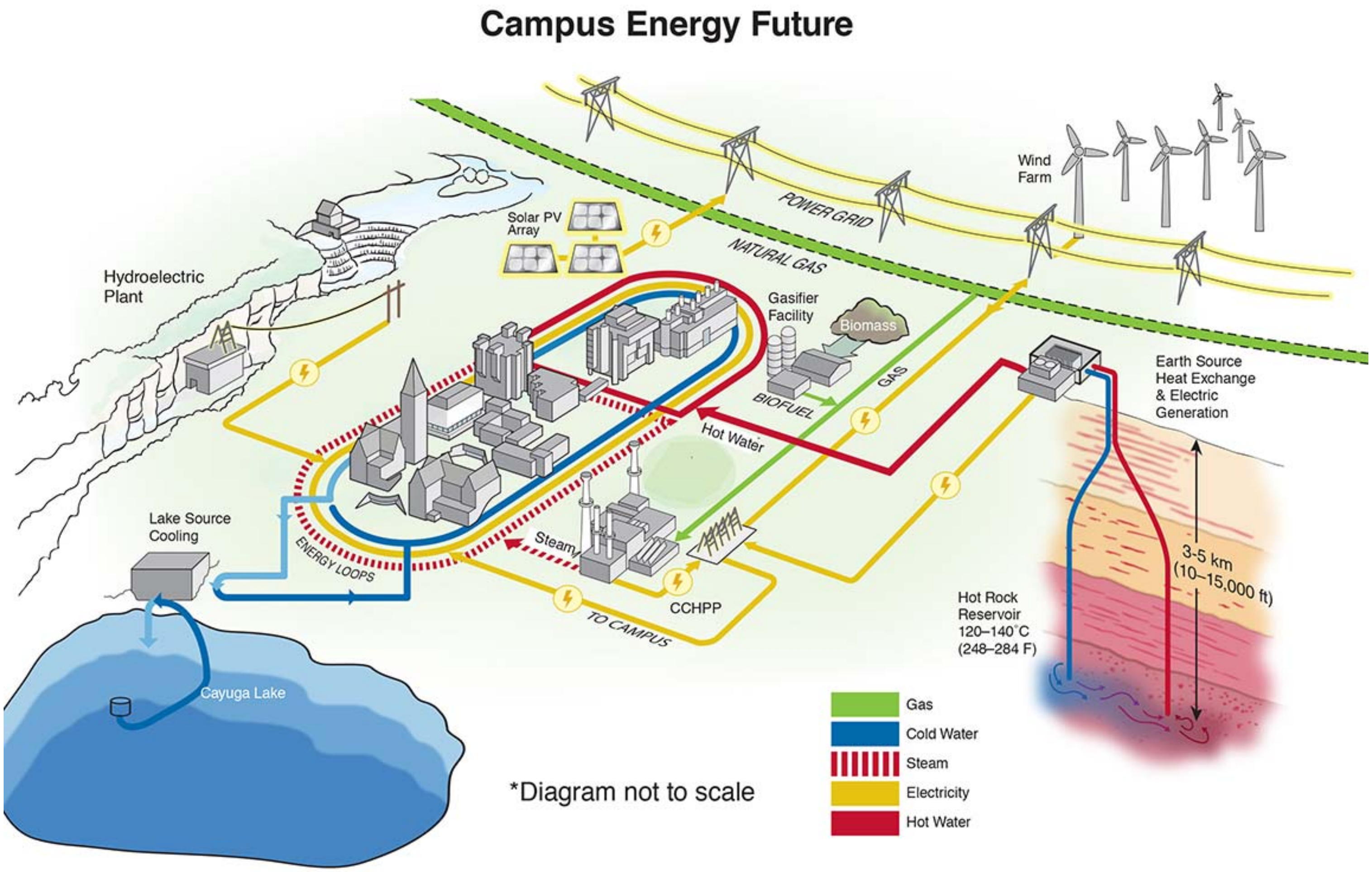
- The Big Goal
  - Carbon neutral campus by 2035 (not the same as zero carbon?)
    - Electricity
    - Heat/cooling
    - Transportation
- Is this all there is to the Action Plan?
  - Knowledge
    - Carbon capture
      - From atmosphere
    - Global cooling
    - Utility modeling, pricing
    - Demand control
    - National Grid
      - Existing rights-of-way (Interstates, pipelines, railroads) (Solve NIMBY)

Cornell Climate Action Plan

- Big Unknowns (18 years in the future)
  - Will Deep Geothermal work and supply sufficient energy
    - How well does Deep Geothermal generate electricity (120 C to 140 C)?
  - How much will the price of storage (electricity, heat) decline?
  - Will sufficient carbon free electricity be available from the grid?
  - Will the grid be stable with high percentage of renewable energy?
    - Adequate storage for stability
    - Dispatchable loads
  - Can we sell renewable energy to the grid for carbon credits?
  - Can we buy from the grid and store as heat (or hydrogen) when grid prices become very low?
    - Times of excess solar and/or wind energy
  - What will the utility pricing model become?
    - Fixed pricing (unlikely)
    - Time of day (TOD) pricing
      - Month, day, or hour in advance (grid stability as prices step change?)
      - Instantaneous (would grid be stable)?
  - Can we access Canadian hydro for storage/grid stability?
  - How much excess energy will be available from offshore wind farms?

Cornell Campus Energy Resources

- Gas fired co-generation power plant (2009)
  - Generates electricity
  - Waste heat used for campus heating (steam)
  - 60% efficiency
  - 80% of campus energy requirement (kW,kWH?)
- Lake Source Cooling (2000)
  - Chilled water loop around campus
  - Technology specific to Cornell campus (not adopted elsewhere)
  - Carbon neutral (except for electrical pumping)
  - Closed campus loop, open lake water loop
- Four solar farms (connected to power grid) (kW?)
  - Snyder Road (2014)
  - Geneva (2015)
  - Ledyard, Hartford (2017)
- Hydroelectric Plant (1880s) (kW?)
- Modest wind resources (not developed) (NIMBY)
- Biofuel (to create and store gas) (RESEARCH)
- Steam and/or hot water loops for campus buildings
- Hot rock layers at 3 to 5 km deep (120-140 C) (RESEARCH)


Campus Energy Future
Wind Farm
POWER GRID
NATURAL GAS
Solar PV Array
Hydroelectric Plant
Gasifier Facility
Biomass
BIOFUEL
GAS
Hot Water
Earth Source Heat Exchange & Electric Generation
Lake Source Cooling
ENERGY LOOPS
Steam
CCHPP
TO CAMPUS
Hot Rock Reservoir 120–140˚C (248–284 F)
3-5 km (10–15,000 ft)
Cayuga Lake
*Diagram not to scale
Gas
Cold Water
Steam
Electricity
Hot Water

Cornell Resources

- Knowledge
- Research
- Lots of Land
- Agriculture
- Good relations with energy parties
  - Local utility
  - State government

The Business of Cornell is Knowledge

- Research – Create knowledge
- Education – Pass on knowledge
- Student Projects – Learn to apply knowledge
- Outreach – Provide a worldwide reach for knowledge
- Business – Make the results of knowledge available to the public

Cornell Energy Liabilities

- High latitude (42 degrees, 26 minutes)
- Cold weather in winter
  - Heat is a major energy requirement
  - Currently mixture of steam and hot water
- Contrast with Pitcairn Island (South Pacific)

New Opportunities (Development and Construction)

- 2,000 bed North Campus
- Roosevelt Island Campus

Energy Sources for Cornell

- Power Grid
  - Can we buy sufficient renewable energy? At what price?
  - Can we enter into sufficient Power Purchase Agreements (PPA) to supply campus with renewable energy?
  - This may be Plan C if Earth Source is not sufficient
  - With sufficient heat storage (Plan B) we can be a sink for excess grid energy
- Conservation
  - Smart classrooms
    - Preheat/precool based on usage schedule
    - Set reasonable temperature goals (70 F heating, 78 F cooling)
    - LED lighting
- Geothermal (Two forms)
  - Deep Geothermal (RESEARCH) (more to follow)
  - Shallow Geothermal (Seasonal storage) (more to follow)

Possible Energy Plans

- Plan A – Earth Source Heat (Deep Geothermal)
- Plan B – Seasonal Heat Storage
- Plan C – Purchase and Generate Renewable Energy
- Plan D – Hydrogen Based Energy Plan
- Plan E - Grid based energy plan

Plan A – Earth Source Heat

- Plan A – Earth Source Heat (Deep Geothermal)
  - Five year decision
  - How is electricity generated?
  - How are electricity and heat requirements balanced?
  - How deep for heat needs only (60C)?
  - 5,500 meters is around 90C to 95C (Norway Rock Energy)
  - What is the temperature vs. depth for gas and oil wells
  - Typically 20C to 25C per kilometer of depth
  - What is life of wells (30 year life, 30 year recovery)

Deep Geothermal

- Uses earth heat
  - Nearly infinite amount (therefore considered renewable)
  - Requires at least 2 deep wells (3 to 5 km deep) some distance apart
    - Expected temperature 120C to 130C
    - Can we access much more rock volume with horizontal drilling?
    - Parallel pipes from two widely spaced wells (RESEARCH)
    - What is the depth for 60C (heating only)?
  - Rate of renewal (heat conduction into the active space) may be slow
    - Additional well pairs may be needed after a few years
  - Energy available at the same rate the full year
    - Flow rates can be varied to draw less than the maximum rate
  - Need to know what is down there (RESEARCH)
    - Rock structure (type, porosity, conductivity, specific heat)
    - Is fracking required to open flow passages?
    - Can we assess potential without drilling? (RESEARCH)
  - How about an investment partnership with PPA to Cornell?

Comments on Deep Geothermal

- Our former company drilled exploratory wells near Ithaca in the early 2000's. I'll see what geologic/geophysical data we have.
- In my opinion to have real success with geothermal you need some natural porosity/permeability. From our work in the area, the Oriskany sand is a possibility, but it's around 3000', so not ideal from a geo perspective. There is also a potential sand much deeper (10,500' approximately) called the Potsdam, but it has not been explored widely. Without natural porosity/perm I think deep geothermal wells would be very expensive and I question the effectiveness, but I'm not an expert in geothermal. I do have a lot of experience in conventional/unconventional oil and gas drilling/completions/production and would be happy to leverage my background and our company where it can be helpful.
- Kyle Mork, President and CEO, Greylock Energy 304-925-6100

Plan B – Seasonal Heat Storage

- Plan B – Seasonal Heat Storage
  - Large PCM heat storage facility (earth or water tank)
  - Plan B1
    - Summer heat is pumped into storage (heat pumps) using renewable energy
    - PV Solar can be used to directly add heat to storage
    - Excess (or low price) electricity bought when available to run heat pumps
    - Waste heat from buildings, waste processing, etc.. pumped into storage
    - Electricity purchased from grid renewables via Power Purchase Agreements
  - Plan B2
    - Current gas cogeneration units are retained (high efficiency, low carbon)
      - Excess summer heat is dumped into storage (smaller PCM storage required)
      - Carbon sequestration used to balance carbon use
      - Extra renewable (PV) energy is created to be sold for its carbon offsets
      - Biogas used when available

Heat Sources for Cornell

- Electric Heat Pumps
  - Heat sources
    - Air (can be cold in winter)
    - Water (Lake source heat?)
      - Warmer than winter air (what is the deep lake temperature?)
    - Earth
    - Ice production? (32 F, 0 C) (for very cold days)
      - Where do we get liquid water to freeze? Wells? Lake?
    - Stored heat
      - Hot water (Phase change storage?)
      - Earth (Geothermal)
- Natural gas
  - Co-gen reject heat (steam)
  - Has to be phased out to become carbon neutral
    - Could still operate with sufficient biogas (how much gas storage/production available?)
- Deep Earth Source (Geothermal) (RESEARCH)
  - What is the energy potential? Depth? Cost? Life Cycle?
- Solar
  - Solar modules can directly drive resistance heaters in hot water tanks
  - Maximum power point tracking DC devices are available for hot water
  - AC could be used if panels are at a distance from hot water tanks
  - Solar modules are most efficient in cold weather (but require sunlight)

The Ice House Experience

- When I was a child, as soon as the ice on White's Pond became 8 inches thick we would drive the truck onto the ice and load it with blocks of ice cut from the frozen pond surface. This ice was taken to the Ice House (a building dedicated to storage of ice), buried in saw-dust (a good insulator), and then taken from the ice house during the summer to power the ice boxes (pre-refrigerators). We successfully stored the cold from the winter season and used it during the summer season.
- Key items which made this possible:
  - Ice has a high latent heat. A lot of cold is stored at 32F, 0C.
  - The sawdust was a good insulator, available in quantity at a low price (come and get it).
  - The winters were reliably cold, and White's Pond had a large surface area.

Seasonal Storage of Heat

- The ice house successfully stored the winter cold to be available during the hot summer. How do we reverse this process to store heat for use in the cold winter?
  - We need a very efficient insulation (better than saw-dust) to reduce heat loss from the heat store. (RESEARCH)
    - How about multiple temperature storage in concentric tanks?
    - Thermos bottle technology
  - What are possible heat stores?
    - Hot water tank (Closed system, not potable water)
      - Needs to be very large, unless we can utilize a phase change material (PCM) (RESEARCH)
        - PCM needs melting point of above 50 C
        - PCM needs a high latent heat so it can store much more heat than hot water
        - If the PCM melts at a single temperature measurement of energy storage becomes difficult (RESEARCH)
        - A eutectic with a small range of melting (45C to 55C) would facilitate energy measurement (RESEARCH)
        - Paraffin wax is a likely candidate (phase change at 60C)
          - I calculate a metric ton of paraffin wax can store 55 kWH of heat (200 kJ/kg)
          - Raw material price as little as $200 per metric ton (or $3.60 per kWH storage
          - Compare with batteries at $200 per kWH storage
          - Paraffin expands upon melting, so flexible encapsulation is required (RESEARCH)
            - Pour hot, shrink on cooling
            - Only one cycle per year (low heat transfer rates are not a problem)
        - Solid to solid phase change materials are also available
    - Earth (soil or rock)
      - Cornell has lots of land, and this does not restrict surface usage
      - How is the block of storage insulated? (RESEARCH)
      - Need heat pumps to store energy (summer) or extract energy (winter) (Require electricity)
  - We need to move the heat to where it is needed with little loss
  - We need to capture all waste heat and heat pump it back into the heat store

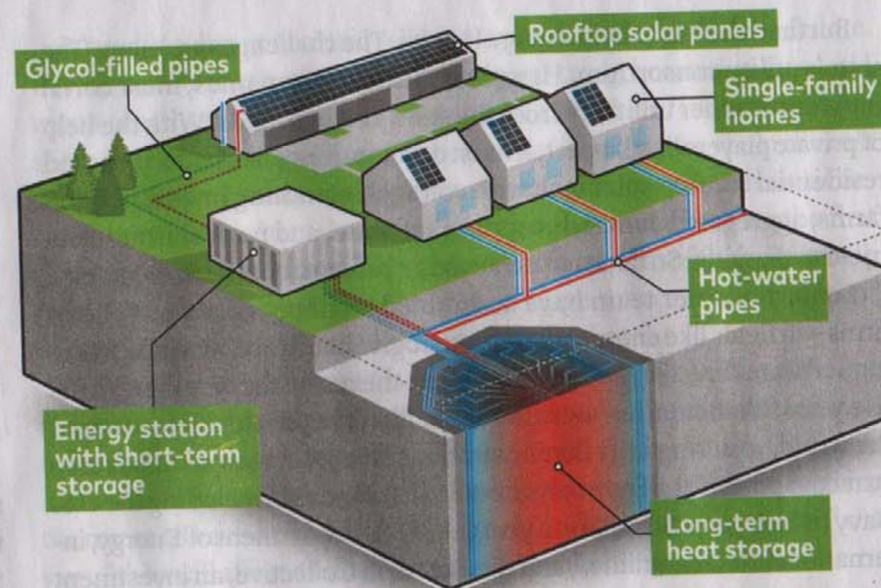
Recent Earth Storage Article

THE EARTH IS A BATTERY

Forget warehouses packed with lithium-ion cells: We'll soon store renewable energy in the dirt and grab it when we need it.

Solar panels generate plenty of energy on summer days. Not so much in winter, especially in northern climes. If we intend to go all in on renewable power, storing the stuff for use when we need it later is key. Underground thermal energy storage allows engineers to take excess energy, shunt it below ground, and save it there indefinitely. Existing caverns, subterranean rocks, or even man-made holes are ideal spots to stash juice. The process is fairly simple:

Solar panels on rooftops—say, garages—heat **pipes filled with glycol**, a conductive organic compound used in antifreeze. The hot glycol travels to an **energy station** where it transfers its heat to water. Some of the warmed H_2O flows into **pipes** to nearby homes, providing hot showers. Excess heat directs into **long-term storage**, hundreds of pipes in bored holes up to 120 feet deep. Hot water moves through these tubes, warms the earth to about 175 degrees, cools off, then travels back to the energy station where the process repeats. Because the earth holds the heat, it can return it to the water pipes in winter.



LEFT TO RIGHT: ILLUSTRATION BY PETE SUCHESKI; DOUGLAS PEEBLES/C

Shallow Geothermal (Seasonal storage)

- Shallow earth/rock is used as a heat storage reservoir
- Heat is pumped into the reservoir during hot months
- Heat is extracted from the reservoir during cold months
  - The reservoir is used at the heat source for heat pumps.
- Significant land area is required, but it can also be used for other purposes
  - Parking, agriculture, etc..
  - How is reservoir insulated from surroundings?
    - Low conductivity of earth/rock?
    - Additional bottom, side, top insulation?
    - Needs to be isolated from groundwater
- Heat Pumps
  - Heat pump CoP (Coefficient of Performance)
    - CoP = Thot/(Thot – Tcold) (Carnot Limit) (0C to 60C CoP is 5.5, 0 to 30C CoP is 10)
    - Actually efficiency typically 50% of Carnot Limit

Paraffin Wax Phase Change Shrinkage

Plan C – Purchase and Generate Renewable Energy

- Plan C – Purchase and Generate Renewable Energy (Might include Plan B2)
  - Generate as much renewable energy as possible (mostly PV, some wind)
  - Purchase the required additional amounts of green electricity from the grid via PPA
  - Use air source or ground source heat pumps for heating
  - Work with grid to obtain clean energy
    - Hydro based energy from Canada
      - Use Canadian hydro for excess renewable energy (ref: Denmark and Norway)
    - Offshore wind energy is not that far away

Plan D – Hydrogen Based Energy Plan

- Plan D – Hydrogen Based Energy Plan (Thanks to Bob Shaw)
- Generation
  - Generate as much renewable electrical energy as possible (mostly PV, some wind)
  - Use excess energy for generation of hydrogen (electrolysis)
  - Purchase the required additional amounts of green electricity from the grid via PPA
  - Generate and store hydrogen when grid has low price excess energy
- Hydrogen Storage
  - Salt Caverns (1,000 psi)?
  - Pressure Vessels (10,000 psi)
- Usage
  - Fuel Cells for Electricity generation
  - Direct combustion for heating
  - Hydrogen fueled buses and trucks, cars will be electrical
  - Fueling terminals can support truck and bus fleets

Hydrogen plan comments

- I have a little experience with the hydrogen cycle from a project in Costa Rica. We are making hydrogen from electrolysis (using electricity from a wind turbine) and using the hydrogen to power a fuel cell bus. I can gather some date if you're interested.
- Tony Satterthwaite, Vp Cummins Inc, President Cummins Distribution Cell: 612-618-1367
- Current cycle efficiencies are low (30% to 40%)
- May be difficult with student, faculty transportation

Plan E - Grid based energy plan

- Plan E - Grid based energy plan
- By 2035 there may be plenty of carbon free electricity on the grid
  - May be small additional charge for green energy
  - Use electricity for heat pumps for building heat

Comparison of Energy Systems

- Heat System
  - Generation
    - Solar
    - Heat Pumps
    - Deep Geothermal
  - Storage
    - Hot water tanks
    - Shallow earth geothermal
  - Transmission Grid
    - Insulated pipes
    - Heat may be added at several points

Electrical System

Generation

Solar
Wind
Grid

Storage

Batteries

Transmission Grid

Insulated wires

Power may be added at several points

Hydrogen System

Generation

Solar
Wind
Grid

Storage

Pressure vessels
Salt Caverns
Fuel Cells for electricity & heat

Transmission Grid

Stainless steel pipes
Hydrogen may be added at several points

Transportation (a large user of energy)

- Public Transportation
  - Buses (currently diesel powered)
  - Lyft, Uber ride sharing (electric vehicles?)
  - What is the carbon content of the electricity used for charging?
- Private Transportation
  - Private Automobiles
    - Mainly educators and staff (electric vehicles?)
    - Some students
  - Car pools (electric vehicles?)
  - Parking structures need to have charging facilities
- Cornell Vehicles
  - Convert to electrical automobiles (replacement schedule)
  - Trucks and buses

Transportation

- The future is electric (Plug in Electric Vehicles) (PEV)
  - On campus charging must be available (either free or at modest charge)
  - Cars will be stationary during the day
    - Research typical duty cycle of vehicles coming to campus (large data?)
      - Distance traveled, stay time (RESEARCH)
  - Hardware cost per charging station must be acceptable.
    - Level II charging (240 volts, 40 amps) typical
      - 3 to 4 miles per kWH of charge is typical for PEV (3 to 6 hours of charging)
    - Time slice multiple vehicles attached to a single charging station
      - Reduces investment in charging station
      - Cars do not have to be moved during the day
      - John Swanson has studied this, can advise
- May be able to use biodiesel (B100, green) conversion for short term
  - Conversion kits cost about $10,000 per vehicle
  - They utilize biodiesel 85 to 90 percent of time, even in cold climate
  - (Disclosure) Swanson has investment in biodiesel conversion company
    - I plan to fund a five vehicle student project test.

Transportation (Hydrogen)

- How about hydrogen powered cars?
  - Advantages:
    - Fast fueling (5 minutes)
  - Disadvantages:
    - Hydrogen infrastructure is not built, and is unlikely
- How about buses, trucks?
  - Fleets can have a common refueling point
  - Still need a electrolysis source of hydrogen

Water Cycle(s)

- Consider water and heat content of water
- Water in Heating Loop
  - Closed system
  - Steam or hot water
- Pure (potable) water
  - Drinking, cooking, showers, laundry
    - Where is hot water produced?
    - What energy source (Natural gas, hydrogen, electric heat pump, electric resistance, solar collection)?
  - Pure water in, grey water out
- Waste disposal (toilets, etc.)
  - Grey water in, black water out
  - What is the energy (heat) content of waste water?
  - It should be disposed at ambient temperature
  - Capture excess heat with heat pump to thermal storage

Microgrids for Cornell and NYC Campuses

- Why microgrids?
  - Ability to operate if the grid is not available (disasters, emergencies, etc..)
  - Allow renewables (PV/Wind) to operate without the utility grid
  - Are there any other advantages?
- Microgrid characteristics
  - Single point connection to utility grid
  - Local generation
    - Sufficient for essential services
    - How are essential services defined and controlled?
    - Ithaca – Use gas fired co-gen facility for local generation
      - Start with stored biogas
      - Switch to utility gas and take the carbon hit in emergency
    - NYC – Hydrogen fuel cell
      - But hydrogen needs to be created by electrolysis for carbon neutral
  - Local storage
    - Sufficient for essential services until local generation comes on-line
  - Who sets the microgrid frequency and phase? (RESEARCH)
    - Is there a master utility clock? Regional or National?
    - A national master clock would allow energy exchange between regions without AC-DC-AC
    - Can a microgrid clock keep accurate enough time to stay in phase when disconnected and reconnecting?
    - Solar inverters require a frequency signal, or they cannot/will not operate

Renewable Energy Research/Education Center

- Located on Cornell property
- Contains wind turbines, solar farm, battery storage, hot water storage
- Generates electricity, hot water
- Located inside the Cornell microgrid
- Might be configured as a smaller microgrid within the Cornell microgrid
- Provides information on Cornell energy systems
  - Grid energy (amount, carbon content, etc..)
  - Lake source cooling
  - Cornell hydroelectric plant
  - Electricity purchases, generation, storage and usage
  - Hot water generation, storage and usage
  - PV generation from PPA sources
  - Co-gen plant performance
  - Bioenergy production and usage
  - Information (including history) available on-line for student study, research
- Education center open to students, classes, faculty and the public

Utility Pricing Issues

- Current pricing models
  - Fixed monthly charge (typically $10.00 to $60.00)
  - Fixed price per kWH (typically $0.06 to $0.15)
  - Demand charge based on maximum usage (in kW) in any 15 minute interval in the month (typically $5.00 to $10.00 per kW)
    - Independent of what is happening on the system
  - Buy of renewable energy from customers
    - Net metering (buy at current sell price) (not popular with utilities)
    - Buy at discounted price (about 20 percent reduction) (SECO sell $0.124, buy $0.095)
    - Buy at wholesale price (not popular with customers) ($0.03 to $0.05
      - Creates incentive to invest in batteries to store energy instead of selling it
  - Time of Day pricing (TOD)
    - Price set for future use
      - Year in advance (California rate schedule)
      - Next day (allows customer planning of daily activities) PEV, HVAC, water heating, refrigeration, etc..)

        Can cause grid spikes as prices change and loads jump on (e.g. all cars start charging at midnight)

Two monthly utility bills (without TOD pricing)

- Residence with Solar Modules (10/23-11/21) (Residential rate schedule)
  - Customer charge $20.00
  - Electricity used 64.35 (678 kWH at $0.0949)
  - PV Electricity sold -79.22 (999 kWH at $0.0793)
  - Surge protector lease 5.95
  - Taxes 0.55
  - **Total $11.63**
- Temple with Solar Modules (10/11-11/9) (Commercial rate schedule)
  - Customer charge $ 55.00
  - Electricity used 263.52 (3,600 kWH at $0.0732)
  - PV Electricity sold -164.94 (2,080 kWH at $0.0793)
  - Demand charge 273.70 (47.6 kW at $5.75)
  - Taxes 10.95
  - **Total $438.23**

Suggestions for Utility Billing

- Customer charge
  - Make this charge depend on the system installed capacity
    - Reflects wire sizes, cost of installation, etc..
    - Lower price for small residences
- Usage charges
  - Use Time-of-day pricing so customers can help match supply and demand
- PV electricity sales price
  - Adopt a fixed percentage discount on current price (15% looks reasonable)
- Demand charge
  - This is the least rational charge. If I have a high demand in the middle of the night the charge is the same as if the high demand was at the peak of utility usage. Demand charge could be eliminated with TOD pricing. If not eliminated, it should be proportional to the TOD price at the time of the peak demand.

Energy Task Force Opportunities

- Research Advice
- Industrial Contacts in Energy Field
  - Utilities
  - Manufacturers
  - Drillers
- Investments/Donations
  - Conservation
    - LED lighting
    - Smart classrooms
  - Research
    - Research projects
    - Student projects