Cornell Energy Challenge:
100% Renewable kWh

Background: In September 2016 the Cornell University Senior Leaders Climate Action Group, co-chaired by Dean Collins, issued a report on "Options for Achieving a Carbon Neutral Campus by 2035". One important recommendation of that report was this: "Cost effective wind, water, and solar projects should be pursued to strive to meet or offset 100 percent of the expected annual campus electricity demand." Subsequently, Dean Collins created an Energy, Environment and Sustainability Task Force as one of several working groups within the Engineering College Council (ECC). This Task Force held several in person and phone meetings and presented its recommendations at the Fall 2018 ECC meeting. The group's principal recommendation was to pursue the "100% Renewable kWh" objective as quickly as possible.

Following the Fall 2018 ECC Meeting, the Task Force members exchanged emails on how to proceed and that led to preparation of a draft white paper in early January 2019 outlining a suggested work plan aimed at developing the data on the Cornell energy system, and specifically on kWh usage, supply and costs, as a basis for preparing a full business plan to accomplish the "100% Renewable kWh" goal. After a period of comment by the Task Force and Cornell faculty, a Draft 2.0 of that plan was circulated fairly widely and subsequently presented at the ECC Spring Meeting in early March 2019.

Following the ECC meeting, Dean Collins sent the Draft 2.0 plan to Mr. Bert Bland, Associate Vice President for Energy and Sustainability and he graciously agreed to meet by phone with Task Force members to discuss the plan. Following the discussions with Mr. Bland, and a review of data on the university's electric energy consumption at the *energy-fast-facts* website, it became clear that the draft plan that the Task Force had prepared was off the mark.

The Task Force went back to the drawing board and considered various options and issues that needed to be addressed in developing a new plan that would give Cornell an opportunity to achieve the "100% Renewable kWh" goal and perhaps the zero-carbon goal, given the very interesting reality of Cornell's energy situation. (Section 1 below)

As it turns out, Cornell – a community with a fully integrated energy system – is an excellent prototype, not only for other universities but for communities of any size, from small cities to states and even countries, that are seeking to address the climate crisis and reduce their carbon emissions to zero over time. The conundrum that Cornell – a 30,000+/- person community – faces is that it owns *relatively new* energy system hardware that burns natural gas and emits CO2. Although the possibility of shutting down/abandoning this hardware and replacing it has been considered as one scenario of the University's Climate Action Plan, doing so will be economically painful and may not be acceptable to the university's leadership. In that case some way must be found to keep operating the existing system without emitting carbon. This same dilemma is faced by communities and corporations around the world. If Cornell can solve this problem successfully then it will be a beacon of hope for the world that carbon-induced warming can be brought under control in a timely way.

This white paper presents the current thinking of the ECC Energy Task Force on potential ways to achieve the "100% Renewable kWh" goal and a summary of the tasks that need to be completed in order to develop a comprehensive plan for achieving the initiatives required to meet that goal. The Task Force members have reviewed plans for the Earth Source Heat (ESH) project and have had discussions with a few people engaged in this project. It is clear that the early phases of the ESH project are almost certain to produce very interesting research results and are likely to be financeable, at least in part, by government grants and contracts. If the ESH project is eventually successful it will impact the current Central Energy Plant in a number of ways. However, given the risks and potential elapsed time before completion of this project, it may not be prudent to rely on it as the only avenue to carbon removal from the university's heating system.

1. <u>Cornell's Energy System</u>

   Cornell has made major changes in its energy system over the last decade or so and now has an exceptionally efficient and sophisticated energy plant which includes four groups of facilities:

   - The Central Energy Plant (CEP) located on Route 366 south east of campus;
   - The Lake Source Cooling (LSC) facility along the Cayuga Lake shore;
   - The Water Filtration and Hydroelectric plant on Fall Creek; and
   - A group of five Solar Photovoltaic Plants located on University properties near campus, and a new 18 MW plant that is soon to be commissioned.

   The history and current capabilities of these facilities are described in an attachment to this white paper. What follows is a brief description of the energy system.

   The University has an internal 13.2kV electric microgrid that connects to the NYS electric utility system at a single 115kV substation. Cornell has its own generating capacity (see below) which is sufficient to serve the university's entire kW load much of the time. From New York State Electric and Gas (NYSEG) Corporation's perspective it is a single load that looks much like a municipal utility connected to a larger grid for backup.

   1.1. <u>Load</u>: The University has a relatively flat daily and seasonal load curve.

   - Average load is ~24 MW, peak can reach 36 MW, but is typically 30 MW or less.
   - There are two principal reasons that the load curve is relatively flat:
     - The space conditioning of most buildings (heating and cooling) is done with the university-wide steam system in the winter (see below) and the Lake Source Cooling (LSC) system, which uses a separate set of pipes, in the summer. The exceptionally high

efficiency of the LSC means that peak summer load is much lower than it might be if standard cooling system technology were used.

  - The R&D laboratories, the computing systems, and much lighting run throughout the night, and pretty much so in all seasons. Student and research activity is not confined to an 8 hour day.

1.2. Electric Generation and Steam Boilers: Cornell has sufficient on-campus / nearby generation to serve virtually its entire load. Indeed, Cornell is often an exporter of power to the NYSEG grid when its internal generating output exceeds the load, and is paid at bulk power rates for those kWh exported.

- Gas Turbine Generators: Around a decade ago, Cornell replaced the old coal fired heating plant with two 15MW gas turbine driven generators. These turbine generators were financed with an $82M development bond issued by the Tompkins County Municipal Bond Authority. That bond is only partially paid down at present.

- Solar Generation: The university has 10MW of solar PV capacity under contract at five 2 MW facilities near to campus, and will soon have 28 MW of solar when the 18 MW facility on university land near campus is completed and commissioned. This solar capacity is in principal enough to cover the entire electric load when the PV plants are running at or near peak output. However, the five small plants actually generate only 15,000 MWh of the ~200,000 MWh the University actually uses, and the new 18 MWh facility will offset about 27,000 MWh via REC's. Cornell is also is an active member of the recently formed NYS Regional Energy Purchasing Consortium to procure additional renewably generated electricity; the process of setting up this consortium is complete but its exact impact on the university energy situation is not yet defined.
- Hydropower: There is also a modest hydroelectric facility in the Fall Creek Gorge using run of the stream flow from the impoundment that creates Beebe Lake. At peak this two unit facility generates almost 1.5 MW, and delivers around 7,000 MWh/year of energy to the internal grid. This is a very old facility that has been substantially upgraded over time.

- Steam Boilers: The in-ground steam system is served by five natural gas fired boilers, which are in the same facility as the two turbines on the southeast edge of campus. Additional heat to produce steam is provided by utilizing the high temperature exhaust stream from the gas turbines.

- Steam Turbine Generators: The CEP also includes two heat recovery steam turbine generators which serve both as thermal input to the district heating system and generate 7.5MW of electric power. These units also burn natural gas and have oil backup.

- Natural Gas: The University buys natural gas to operate the turbines and the steam boilers under an agreement with Dominion at approximately $2.25/MM BTU, a very competitive price. Most of the gas is purchased on the day ahead market.

Given this existing energy system, what are the potential challenges to convert the entire system to one that relies entirely on renewable resources?

2. The Dilemma Cornell Faces

Despite the excellent progress Cornell has made in sourcing much of its electricity supply from renewable sources, there remains a serious dilemma: A large portion of the kWhs used, and actually all of its space heating requirements, are provided with hardware that uses natural gas. This is true not only for Cornell but for many municipalities, large corporations, indeed most of the United States and other nations.

It is unlikely that directors and officers of many of these entities are going to be willing to abandon this hardware before it is fully depreciated, no matter how concerned they are about the ever increasing carbon in the atmosphere. Nor is it likely that governments will require that they do so. Consequently it is problematic to imagine that carbon emissions reduction can occur in a short enough time period to avoid the likely severe impacts of global warming unless a way can be found to insure that existing power generating and thermal generation hardware at Cornell, and everywhere on the planet for that matter, can remain in service without adding carbon to the atmosphere.

There are really only two pathways for accomplishing that:

2.1. Carbon Capture and Storage (CCS): Capture the carbon (CO_2) produced by burning natural gas before it enters the atmosphere and either sequester or store it in a place where it cannot escape into the atmosphere, or chemically bind the CO_2 in a compound which is stable and benign. This option has received a lot of attention at the U.S. DOE and research institutions around the world, and is being pursued actively in R&D efforts by a number of Cornell faculty. The Energy Task Force is preparing another white paper focused specifically on this option. It is certainly an option that should be considered, but it is quite economically and technically challenging, especially in the transport and storage aspects.

2.2. Substituting Renewable Fuels for Natural Gas: Two possibilities are potentially worth considering:

- Biofuels: Synthesis gas ($CO+H_2$), methane, ethanol, and other hydrocarbon fuels can potentially be produced by chemical processing of biological feedstocks (i.e. corn stover, bagasse, soy, soft wood chips, etc.). Numerous processes have been studied, a few are commercial (e.g. ethanol from corn), but the challenge is the tradeoff of arable land between food and fuel production. In the end food wins.

- Hydrogen: H2 gas is widely produced in enormous quantities around the world today using steam methane reforming (SMR), but this method is clearly not carbon free. Electrolysis of water to separate the H2 from O2 using several different techniques is also widely used commercially and is cost effective in many applications. It has the advantage of being able to be done by distributed hardware using from a few kW to several MW of renewable (PV or wind) power. The most common approach today is using PEM [Proton Exchange Membrane] electrolysis hardware produced by a number of companies worldwide.

  Although electrolytic H2 produced using PV solar plants generating electricity at 3¢/kWh or less is competitive with gasoline when used in fuel cell vehicles, unfortunately H2 cannot compete with natural gas using currently available technology. One kg of H2 has about the same energy content as a gallon of gasoline (~114,000 BTU), but at $5-$8/kg H2 is roughly 20 times more expensive than natural gas at $2-$4/million BTU. Closing this cost gap, at least partially, with continued refinements of electrolysis technology (e.g. replacing PEM membranes with AEM's) is likely to occur over time but it will almost certainly take regulatory initiatives (including attaching a price to carbon) to make H2 competitive with natural gas. There are numerous opportunities for launching R&D programs and for designing creative policy initiatives, but it is hard to project the likely timescale for success, so at present H2 substitution for natural gas is not an economically attractive option.

3. The Challenges Ahead

Given the excellent initiatives already taken and currently planned by the Energy and Sustainability Group, Cornell has a reasonably certain ability to achieve by 2025 the interim "100% Renewable kWh" objective of the "Carbon Neutral by 2035" initiative. This goal can be accomplished by committing to obtain on the order of 200,000 MWh/year of renewably generated electricity, likely in the form of REC's from as yet to be developed solar PV, or wind facilities. Some, or perhaps all, of those facilities could be developed by the newly formed Renewable Energy Purchasing Consortium, but it may be essential for Cornell to independently develop, own, and perhaps operate, renewable generation in resource- favorable parts of the country, and contract to wheel the power generated to Ithaca on existing transmission lines. No electrons actually move, only dollars/MWh .

However, this solution does not eliminate the emission of CO2 because the gas turbines and steam cogen units will still need to be run. The only way to achieve zero carbon emissions on the electric generation component of Cornell's energy system is to develop options that enable the University to shut down the combustion turbine and steam turbine generators.

The Earth Source Heat project, if successful, will largely reduce, or even eliminate, the need for the steam boilers, the two steam turbines, and the recovery of heat from the two 15MW gas fired generators. However,

- It will take several years at least to establish the feasibility of the project with test bores and then several years more to complete the entire facility, which could require multiple bores, the precise number depending on currently unknown variables such as the rock's temperature and its thermal recovery time. In the meantime the boilers and the steam and combustion turbines will still need to be utilized and will be emitting carbon.

- The initial effort to drill and study the first "test" well is budgeted to cost $12M. Assuming the first well indicates a promising geological target (depth) for geothermal transfer, a second well will be drilled and connected, a heat transfer and pumping building will be constructed, and the system will be connected to the proposed future hot water system. This second phase of work will cost another ~$18M for a total demonstration project budget of about $30M.

- The cost of the entire ESH project, if testing is successful and the proposed plant is built, is difficult to estimate at this point in time, and will depend on the number of bores required to achieve the desired thermal output on a continuous basis. Once the comprehensive engineering studies for the ESH facility are completed and accurate total ESH expenditure projections can be made, it would be useful to compare them to the cost of alternatives.
- For example, solar PV plus storage plants are now being built in the US and around the world with delivered energy costs of 4-5¢/kWh or less. Capital costs of such plants are in the range of $1-3/W so a 100 MW solar plus batteries facility could likely be less than $300M and would provide as much as 300,000 MWh/year or more, enough to allow the gas fired generators to be used only on standby, and enough additional electric energy to serve various options (e.g. distributed or central heat pumps) for meeting some or all of the building heating requirements.

4. Next Steps

The Energy and Sustainability Group (ESG) has done a lot of creative thinking about the issues outlined above. The ECC Energy Task Force could support the ESG efforts in a number of ways if the group's leadership felt that would be valuable. For example:

- The Task Force has not reviewed in detail all the plans for achieving a Carbon Neutral Campus by 2035 that have been developed by ESG so far, but would be happy to do so, and provide suggestions for refinements if appropriate.

- Clearly the technical and economic analysis of options for replacing the heat produced and kWh generated by the steam and combustion facilities burning natural gas, along the lines noted above, needs to be completed, if it has not already been done. This analysis will need to include establishing an effective cost of emitted carbon using various approaches.

- It would also be valuable to consider developing a plan for demonstrating on-site renewable electrolytic production of H_2 initially for use in on-campus fuel cell vehicles, where the economic benefit, at scale, is favorable for hydrogen, and potentially for use in the turbines if the costs of electrolyzer systems and H_2 storage are reduced, and if the cost of carbon emissions is included in the analysis. This plan could offer opportunities for student project participation and a living laboratory for educational purposes.

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The ECC Energy Task Force would welcome the opportunity to work with the ESG, and potentially the new Sustainable Cornell Council and its Carbon Neutral Campus Committee, on these and other activities.

Prepared by ECC Energy Task Force Members
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