**Chapter 3. Energy Generation, Purchasing, and Distribution**

The single largest source of campus carbon dioxide emissions is energy generation and purchasing, which provides heating, cooling, and electricity. The majority of energy generation on campus is from the burning of coal and natural gas at the Abbott Power Plant, which cogenerates steam and electricity. In FY14, the overall efficiency of electricity production was about 21% and the overall efficiency of steam production was about 45%. The electricity generated on campus is supplemented by the purchase of grid electricity, which enters campus at a substation just south of Abbott.

Replacing our reliable, cost-effective, fossil-fueled combined heat and power system with a large-scale zero-carbon-emission system is a daunting task. The 2010 iCAP called for a detailed study that examines campus energy generation and distribution, to be completed by 2012. The firm Affiliated Engineers Inc. (AEI) was hired in 2012 to perform this study, but we do not yet have the benefit of their report (as of October 2014).

To get a feeling for the scale of the problem, we show in Table X the amount of power consumed on campus in FY14. On average, the total campus demand for electric power was about 55 MW. Of that 55 MW, about 23 MW was purchased. The National Petascale Facility alone used about 10 MW of electric power. The primary energy in the coal and natural gas used in FY14 corresponds to a average power of about 150 MW. This produced about 32 MW of electricity and about 67 MW of steam sent to campus. Thus our campus currently consumes about 55 MW of electric power and 67 MW of thermal power.

|  |  |  |
| --- | --- | --- |
| **Fiscal Year 2014** | | |
|  | **Million BTU (MMBTU)** | **Megawatt (MW) Average** |
| **Coal usage** | 900,208 | 30 |
| **Natural gas usage** | 3,574,095 | 120 |
|  |  |  |
| **Total primary energy consumption** | 4,474,303 | 150 |
|  |  |  |
|  | **Megawatt Hours (MWh)** | **Megawatt (MW) Average** |
| **Generated electricity** | 275,894 | 32 |
| **Purchased electricity** | 205,590 | 23 |
|  |  |  |
| **Total electricity usage** | 481,484 | 55 |
|  |  |  |
|  | **Kilopounds (klbs)** | **Megawatt (MW) Average** |
| **Steam sent to campus** | 1,708,885 | 67 |

**Energy Generation**

The UIUC campus has an area of 4552 acres (18.4 km2),[[1]](#footnote-1) including the South Farms. Based on this area, we can estimate the potential average energy generation of on-campus solar photovoltaics, wind, biomass, and a nuclear reactor. This section is only intended to give a sense of the scale of these energy sources. We do not address any of the details, including the issues of energy fluctuations and storage.

**Solar:** Solar photovoltaic modules (15% efficient) can deliver a peak power density of about 150 W/m2. The capacity factor of flat modules in central Illinois, including nighttime, clouds, and DC to AC conversion, is about 12.5%,[[2]](#footnote-2) so the average power density is about 19 W/m2 (the Solar Farm will have an average power density of 9 W/m2 due to spacing between the rows of modules).[[3]](#footnote-3) Thus if the entire campus were covered with flat solar photovoltaic modules (not possible in practice), the average power would be 345 MW, which is greater than our energy usage. Thus **solar photovoltaics could potentially play a major role in our energy future.**

**Wind:** The average wind speed at 80 m above ground level in this region is about 7 m/s (16 mph).[[4]](#footnote-4) A utility scale wind farm could potentially produce an average power density[[5]](#footnote-5) of about 2 W/m2 (the nearby California Ridge wind farm has an average power density of 0.6 W/m2, presumably due to suboptimal turbine spacing).[[6]](#footnote-6) Filling the entire campus area with such a wind farm (again, not possible in practice) would produce an average power of about 37 MW. However, only a fraction of that power is possible in practice, due to siting issues. The 2010 iCAP called for up to three turbines, which would deliver an average power of under 2 MW. We conclude that **in order for wind to make a significant contribution to campus energy generation, we would need a wind farm that is off campus.**

**Biomass:** Another option for alternative campus energy generation is to replace the burning of coal and natural gas with the burning of biomass. An energy crop such as Miscanthus grass can potentially produce a primary energy per year of about 1.3 W/m2.[[7]](#footnote-7) Planting the entire campus area with such a grass (yet again, not possible in practice), and ignoring the energy cost of growing, harvesting, processing, and transporting the grass yields a power of 24 MW of thermal energy when burned. Since only a fraction of this power is possible in practice, we conclude that **burning biomass for energy requires sourcing material from off campus.**

**Nuclear:** Another non-fossil-fueled energy source is a nuclear reactor. A small modular reactor could produce 225 MW of electric power, larger than our energy use, using an area of only 15 acres.[[8]](#footnote-8) If sited on campus, such a reactor could potentially be used for combined heat and power. Alternatively, a nuclear reactor (small or large) could potentially be sited at the existing Clinton Power Station, which has a vacant site. Thus **nuclear energy could potentially play a large role in our energy future.**

**Energy Purchasing**

At this time, all of the above energy sources are available for purchase.

Wind and solar power may be purchased via two different mechanisms. A Power Purchase Agreement (PPA) enables the construction of new energy generation facilities, and therefore directly expands renewable energy. The purchased power is bundled with Renewable Energy Certificates (RECs) that represent the environmental attributes of the purchased power. A second option is to purchase unbundled RECs from existing facilities. It is not clear at this time if the voluntary purchase of unbundled RECs facilitates the construction of new energy generation.

At present the only potential opportunity to use biomass directly on campus is to cofire a small percentage with coal at Abbott. This would require close monitoring of the pollution control systems as the less dense biomass tends to carry over into these systems and create problems. It would also require the campus to obtain a modification to the existing campus air permit. Alternatively, one may purchase biomass RECs, as well as RECs for landfill gas, anaerobic digestion, biodiesel, small-scale hydroelectric, and solar thermal electric, all of which are considered renewable sources of energy under the Illinois Renewables Portfolio Standard.

Nuclear energy is not considered a renewable energy source, so there is no REC market for nuclear energy. However, a PPA with an existing nuclear power plant could be investigated, and if deemed a viable option would reduce the carbon emissions from purchased electricity.

**Energy Distribution**

Energy distribution is intertwined with energy generation. The current combined heat and power system distributes steam to campus via underground pipes. Cooling needs are met via regional chiller plants serving a large central piping loop that distributes chilled water to campus.

Heat recovery chillers can be found in some of the newer campus buildings. These are more efficient than ordinary chillers since they use the heat that would otherwise be rejected to the atmosphere via cooling towers. A district heating and cooling system based on large heat recovery chillers is possible, with the thermal energy stored in the ground (often called a geothermal system). This is a very efficient way to generate, store, and distribute thermal energy (via chilled and hot water), but would require a very large geothermal field. Geothermal systems may also be designed to serve individual buildings.

An alternative way to heat and cool buildings is via air-source heat pumps. These may be deployed in individual offices (ductless mini-splits) or to serve several offices (variable refrigerant flow systems). In the latter case, the systems can potentially provide heating and cooling simultaneously.

**Energy Generation, Purchasing, and Distribution emission goals**

Campus has made good progress in reducing carbon dioxide emissions, largely due to improvements in energy efficiency in buildings. Looking ahead, we expect to see continued reductions due to improvements in energy efficiency. However, it is also necessary to change the way we generate, distribute, and purchase electricity if we are to get to zero carbon emissions.

Below we list goals for total carbon emissions from energy generation, purchasing, and distribution.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **ACUPCC Emissions** | | | | | | | | | | | |
| **Fiscal Year** |  | **Power from Coal and Natural Gas** | | |  | **Purchased Electricity** | | |  | **Energy Emissions** | |
|  | **MMBTU** | **MT eCO2** | **% change from FY08** |  | **kWh** | **MT eCO2** | **% change from FY08** |  | **MT eCO2** | **% change from FY08** |
| 2008 |  | 5,615,377 | 378,803 | n/a |  | 144,418,473 | 85,303 | n/a |  | 464,106 | n/a |
| 2009 |  | 5,075,067 | 370,923 | -2% |  | 145,808,263 | 80,937 | -5% |  | 451,860 | -3% |
| 2010 |  | 4,832,524 | 313,584 | -17% |  | 139,717,455 | 78,421 | -8% |  | 392,005 | -16% |
| 2011 |  | 4,611,791 | 306,996 | -19% |  | 139,918,719 | 78,550 | -8% |  | 385,547 | -17% |
| 2012 |  | 3,946,109 | 250,211 | -34% |  | 184,615,708 | 103,893 | 22% |  | 354,103 | -24% |
| 2013 |  | 4,266,108 | 279,379 | -26% |  | 192,669,793 | 108,459 | 27% |  | 387,839 | -16% |
| 2014 |  | 4,447,303 | 275,858 | -27% |  | 200,250,071 | 115,950 | 36% |  | 391,808 | -16% |
| 2020 |  |  |  |  |  |  |  |  |  | 324,874 | -30% |
| 2025 |  |  |  |  |  |  |  |  |  | 278,463 | -40% |
| 2030 |  |  |  |  |  |  |  |  |  | 232,053 | -50% |
| 2040 |  |  |  |  |  |  |  |  |  | 116,026 | -75% |
| 2050 |  |  |  |  |  |  |  |  |  | 0 | -100% |

Table xx: Energy Generation and Purchasing Emissions, Existing and Goals

**Energy Generation, Purchasing, and Distribution objectives**

Stating the long-term objective is simple: zero emission of carbon dioxide from energy generation and purchasing as soon as possible. Achieving the objective is challenging, even on a time scale of 2050.

Abbott Power Plant has two natural gas turbines with heat recovery steam generators, and is in the process of installing one new natural gas boiler, with a second planned. These, together with three coal boilers, will generate all the steam used on campus, and cogenerate electricity. Chillers generate chilled water for cooling.

The first objective is to develop a plan to replace the existing fossil-fueled system with a zero-carbon system. No such plan exists at this time. The AEI report mentioned above will provide useful input to this plan.

Regardless of which plan emerges, there will certainly be a need for electricity. A second objective is to expand the use of solar photovoltaics on campus.

In the short term and possibly even the long term, it will be necessary to purchase renewable or other zero-carbon energy from off campus. A third objective is therefore to increase the amount of purchased energy that comes from such sources.

A summary of the energy generation, purchasing, and distribution objectives is

1. Create a plan for energy generation, purchasing, and distribution that achieves zero carbon dioxide emissions
2. Expand on-campus solar photovoltaics
3. Expand the purchase of off-campus renewable and other zero-carbon energy

## Energy Generation, Purchasing, and Distribution strategies

**Create a Plan for Energy Generation, Purchasing, and Distribution that Achieves Zero Carbon Dioxide Emission**

The campus community has considerable intellectual resources that can be brought to bear on the future of energy generation, purchasing, and distribution. We recommend forming consultation groups consisting of faculty, staff, students, and other interested individuals, centered around each of the most promising technologies. We will then be in a position to recommend a master plan for the future of campus energy generation, purchasing, and distribution. Below we list the most promising technologies.

#### Geothermal heating and cooling

A large-scale district geothermal heating and cooling system was commissioned at Ball State University in 2012. It uses large heat-recovery chillers to simultaneously produce chilled and hot water, which is pumped through 3,600 vertical wells of depth up to 500 feet. The Earth serves as a large-scale thermal energy storage system. The system has a design coefficient of performance of 3.8 for heating and 2.9 for cooling, meaning that for each unit of electric energy consumed 6.7 units of heat are moved. Ball State University is at almost the same latitude as our university, so the same performance can be expected here.

Our average heating demand could be met with an average electricity use of about 67 MW/3.8 = 18 MW. The coefficient of performance of 2.9 for cooling is about half that of the existing chillers, so there would be a net increase in campus electricity use, but our reliance on the burning of fossil fuels on campus for heating would be dramatically reduced.

The amount of carbon dioxide emissions associated with heating and cooling would depend on the source of the electricity to run the heat-recovery chillers. As the amount of non-fossil-fueled electricity increases both on and off campus, the amount of carbon dioxide emissions would decrease.

#### Air-source heat pumps

Many campus buildings are heated by steam but cooled by window air conditioners. If these were replaced by air-source heat pumps, each room could be both heated and cooled by the same unit. The required capacity of the heat pumps could be reduced by a deep retrofit of the building, including replacing the windows with high quality double pane windows, reducing the size of oversized windows, and adding insulation to the interior or exterior of poorly insulated walls. The room would be conditioned only when occupied, producing further energy savings. There is no need for ductwork to distribute the cooled air, and the transmission of airborne disease throughout the building is eliminated.

As above, the amount of carbon dioxide emissions associated with heating and cooling these buildings would depend on the source of the electricity used to run the air-source heat pumps.

#### Biomass

Biomass can replace coal for direct combustion, or replace natural gas if it is first gasified. In 2013, The University of Missouri commissioned a 100% biomass-fueled boiler in their combined cooling, heat, and power plant, initially utilizing waste wood as the primary feedstock. Eastern Illinois University installed a gasifier in 2011, but it is not yet working reliably. These projects highlight two necessary conditions for the success of biomass: establishing a sustainable supply chain, and utilizing a reliable technology.

As mentioned earlier, the biomass must mostly come from off campus. This could be in the form of dedicated energy crops or agricultural waste. One must take into consideration the energy cost of growing, harvesting, and transporting the biomass. While the biomass itself is carbon neutral if it is regrown, the growing, harvesting, and transporting steps release greenhouse gasses if they involve fossil fuels or certain fertilizers. On the other hand, the land that supports the biomass can potentially be a carbon sink.

**Expand On-Campus Solar Photovoltaics**

Regardless of which plan for energy generation, purchasing, and distribution emerges as the best for our campus, there will be a need for renewable electricity. We recommend that a consultation group be formed to expedite the installation of photovoltaics on campus. Solar thermal should also be considered where appropriate.

#### Solar Photovoltaics

The campus has a 33 kW photovoltaic array on the roof of the Business Instructional Facility, and is installing a 300 kW array on the roof of the new Electrical and Computer Engineering Building. The 5.88 MW Solar Farm on the south campus is nearly ready to be installed. There are many other buildings, parcels of land, and parking lots that are well positioned to host significant photovoltaic arrays. Although each array in itself would make a small contribution to campus electricity generation, taken together the contribution could be large.

We recommend that a consultation group undertake a study to identify the best places to install the next round of photovoltaic projects, and begin to move forward on several projects simultaneously.

The best time to plan for the installation of photovoltaics on a building is during the design phase. We recommend that all new construction and additions include solar photovoltaics on the roof. In some cases it may be effective to install photovoltaics on the exterior walls of the buildings as well.

There is a solar thermal array on the roof of the Activities and Recreation Center. Solar thermal may make sense in some situations, and should be considered as well.

**Expand Purchase of Off-Campus Renewable and Other Zero-Carbon Energy**

In the near term and possibly even in the long term, it will not be possible to meet our emissions goals entirely with on-campus energy generation. We must therefore purchase some off-campus renewable and other zero-carbon energy.

#### Power Purchase Agreements

A Power Purchase Agreement (PPA) is a contract with an energy generation facility. A long-term PPA with a renewable energy generation facility could enable the construction of new renewable energy generation.

Renewable Energy Certificates (RECs) represent the environmental attributes of the produced energy. To be considered renewable, the purchased energy would need to be bundled with RECs. Only the owner of the RECs can claim that they are using renewable energy.

Although nuclear power is not considered renewable, an existing nuclear power plant produces no carbon dioxide emissions, and can help us meet our emissions goals. A PPA with a nuclear power plant would enable us to claim that we are using energy from a zero-carbon source.

We recommend that the campus pursue PPAs as a way to help meet our emissions goals.

**Conclusion of Energy Generation, Purchasing, and Distribution section**

We have outlined three different paths to reducing and potentially eliminating our carbon dioxide emissions from energy generation and purchasing. Two of the paths (geothermal and air-source heat pumps) rely on the electrification of heating. As the source of the electricity becomes less carbon intensive, our carbon emissions decrease. We can help that transition by installing solar photovoltaics on campus and by purchasing renewable or nuclear energy. The third path replaces coal and natural gas combustion with the combustion of biomass. Since we will still need electricity in this scenario, installing photovoltaics on campus and purchasing renewable or nuclear energy would still be objectives we would pursue. We recommend forming consultation groups to study these three different paths more closely, and a fourth consultation group to accelerate the installation of solar photovoltaics on campus.

1. http://illinois.edu/about/overview/facts/facts.html [↑](#footnote-ref-1)
2. http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/version1\_index.html [↑](#footnote-ref-2)
3. 5.88 MW on 20.8 acres with a capacity factor of 14% for modules angled at 20 degrees [↑](#footnote-ref-3)
4. http://www.nrel.gov/gis/images/80m\_wind/USwind300dpe4-11.jpg [↑](#footnote-ref-4)
5. David MacKay, Sustainable Energy, p. 33 [↑](#footnote-ref-5)
6. 217 MW on 54 square miles with a capacity factor of 0.4 [↑](#footnote-ref-6)
7. 24 t/ha/yr x 17 MJ/kg [↑](#footnote-ref-7)
8. http://westinghousenuclear.com/New-Plants/Small-Modular-Reactor [↑](#footnote-ref-8)