Project Appendix

This document will contain sample calculations and sources to the PV study carried out on the university:

I. Sample Calculation

A. **Solar roof analysis:** The calculations for size, cost, AC output and 25yr output (with degradation) of solar system.

Roof space location: Memorial Art Gallery

$$\textbf{Total roof space} = 35286\ \mathrm{ft}^2$$

$$\text{Convert to } \mathrm{m}^2 = 35286\mathrm{ft}^2 * \frac{0.0929\mathrm{m}^2}{\mathrm{ft}^2} = 3278\mathrm{m}^2$$

$$\textbf{Solar DC system size} = \text{Solar roof area } (\mathrm{m}^2) * \frac{1\mathrm{KW}}{\mathrm{m}^2} * \text{ Module efficiency } (15\%)$$

$$= 3278\mathrm{m}^2 * \frac{1\mathrm{KW}}{\mathrm{m}^2} * 0.15$$

$$= 492\mathrm{KW}$$

Cost of the system: Solar system sizes and their respective prices were collected from the Solar Liberty (the largest solar energy installer in NY state) project proposal as shown in table 1. It was plotted as shown in figure 1 and the prices of the solar units in this study were extrapolated from the data mentioned.

Table 1: Set of proposed solar system sizes with their respective sizes

System Size/KW	Cost (Post-incentive)
15.84	$44,510
56	$135,360
104.4	$224,460

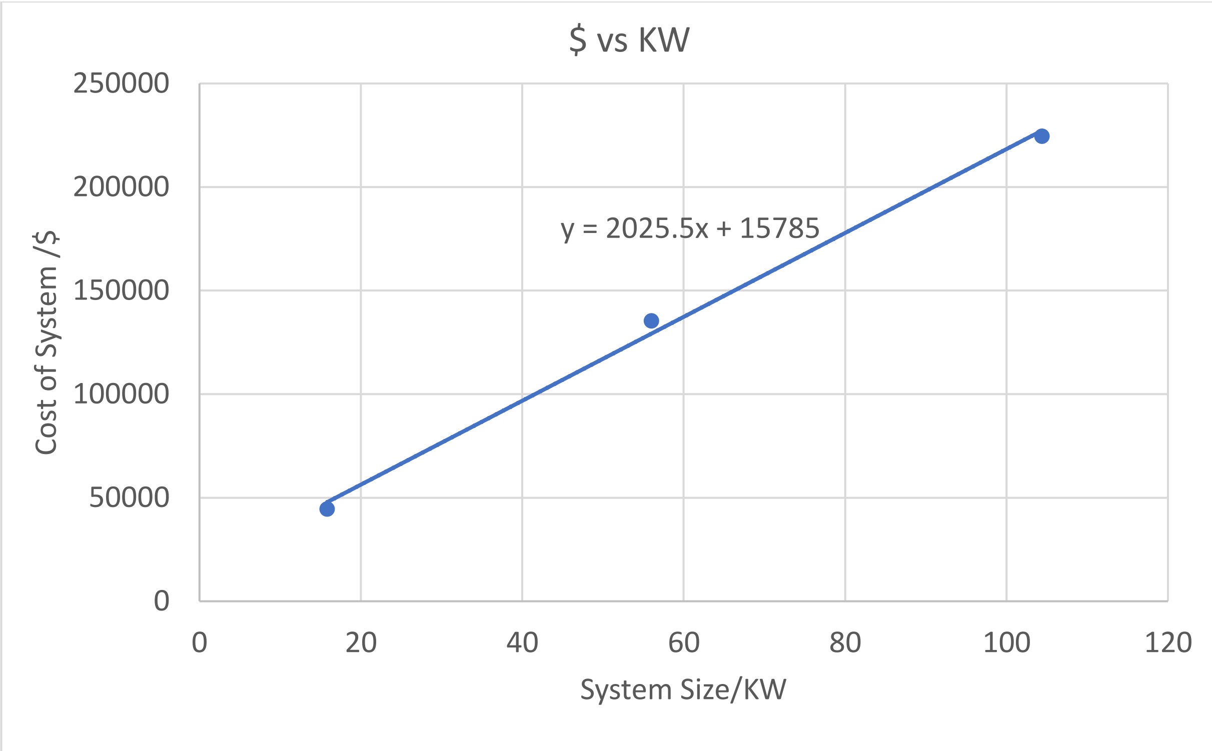

Figure 1: Cost of system versus size of system.

Use equation of the line of fig.1 to get cost of system

$$= 2025.5 * 492 \text{ KW} + 15785$$
$$= \$\, 1{,}011{,}777$$

AC System Output

Regarding the AC System Output, it was derived from the PVWatts Calculator with all the parameters being default except for array type which is fixed (roof mount).

$$\text{AC system output} = 592{,}821 \frac{\text{KWh}}{\text{yr}}$$

Adobe Acrobat Document

NREL

Caution: Photovoltaic system performance predictions calculated by PVWatts® include many inherent assumptions and uncertainties and do not reflect variations between PV technologies nor site-specific characteristics except as represented by PVWatts® inputs. For example, PV modules with better performance are not differentiated within PVWatts® from lesser performing modules. Both NREL and private companies provide more sophisticated PV modeling tools (such as the System Advisor Model at https://sam.nrel.gov) that allow for more precise and complex modeling of PV systems.

The expected range is based on 30 years of actual weather data at the given location and is intended to provide an indication of the variation you might see. For more information, please refer to this NREL report: The Error Report.

The energy output range is based on analysis of 30 years of historical weather data for nearby , and is intended to provide an indication of the possible interannual variability in generation for a Fixed (open rack) PV system at this location.

RESULTS

584,433 kWh/Year*

System output may range from 567,076 to 602,901 kWh per year near this location.

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Value ($)
January	1.97	25,493	1,642
February	3.19	36,317	2,339
March	4.44	52,191	3,361
April	5.14	57,311	3,691
May	6.24	69,311	4,464
June	6.23	65,851	4,241
July	6.32	68,264	4,396
August	6.03	64,147	4,131
September	5.22	54,636	3,519
October	3.33	38,404	2,473
November	2.42	28,506	1,836
December	1.88	24,003	1,546
Annual	**4.37**	**584,434**	**$ 37,639**

Location and Station Identification

Requested Location	university of rochester
Weather Data Source	Lat, Lon: 43.13, -77.62 0.7 mi
Latitude	43.13° N
Longitude	77.62° W

PV System Specifications *(Commercial)*

DC System Size	492 kW
Module Type	Standard
Array Type	Fixed (roof mount)
Array Tilt	20°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2

Economics

Average Retail Electricity Rate	0.064 $/kWh

Performance Metrics

Capacity Factor	13.6%

25yr System Output

This study then assumes the solar systems have a lifespan of 25yrs at degrades at the rate of 2% Year 1 and 0.2% Years 2-25.

Table 2: Derivation of 25yr average production factor for solar systems

Year	Degradation (%)	Cumulative Degradation (%)	Degraded Production (%)	Undegraded Production (%)
1	2		100	100
2	0.2	2	98	100
3	0.2	2.2	97.8	100
4	0.2	2.4	97.6	100
5	0.2	2.6	97.4	100
6	0.2	2.8	97.2	100
7	0.2	3	97	100
8	0.2	3.2	96.8	100
9	0.2	3.4	96.6	100
10	0.2	3.6	96.4	100
11	0.2	3.8	96.2	100
12	0.2	4	96	100
13	0.2	4.2	95.8	100
14	0.2	4.4	95.6	100
15	0.2	4.6	95.4	100
16	0.2	4.8	95.2	100
17	0.2	5	95	100
18	0.2	5.2	94.8	100
19	0.2	5.4	94.6	100
20	0.2	5.6	94.4	100
21	0.2	5.8	94.2	100
22	0.2	6	94	100
23	0.2	6.2	93.8	100
24	0.2	6.4	93.6	100
25	0.2	6.6	93.4	100
		Total	**2,396.8**	**2,500**

$$\textbf{25 Year Average Production Factor} = \frac{2396.8}{2500} * 100 = 95.9\%$$

$$\text{25yr system output for Memorial Art Gallery} = 14{,}212{,}883 \frac{\text{KWh}}{\text{yr}}$$

$$\textbf{Cost of electricity per KWh} = \text{Cost of} \frac{\text{system}}{\text{25yr}} \text{Output}$$

$$= \frac{\$1{,}011{,}777}{14{,}212{,}883 \text{ KWh}} = \frac{\$0.07}{\text{KWh}}$$

Table 3: Solar roof analysis of University's buildings

	Total roof space (10^3*ft^2)	Available Solar Roof space (10^3*m^2)	Solar DC System Size (KW)	Cost of System ($)	AC System Output (KWh/Year)	25 yr Output including PV degradation (KWh)
Memoral Art Gallery	35	3	492	1,011,777	592,821	14,212,883
South Campus	180	17	2,515	5,109,071	2,987,497	71,625,241
Middle Campus	11	1	149	317,383	176,993	4,243,407
Eastman	62	6	864	1,766,772	1,026,321	24,606,046
River Campus	442	41	6,162	12,497,632	7,319,665	175,488,968
Medical Center	496	46	6,911	14,013,834	8,209,381	196,819,909
Total	**1,226,580**	113,953	17,093	34,716,469	20,312,678	486,996,455

B. GHG Emissions Reduction: PURCHASED ELECTRICITY

In this analysis, the energy data for FY18 was used to determine how solar PV could offset GHG emissions by 1,2,5,10,15 and 20% respectively. The following calculations are performed: GHG emitted, saved, the cost and size of the solar system to offset the GHG emitted. Thereafter an offset comparison is done between solar and tree planting. A sample calculation would be shown for 10% GHG emission (GHGE) reduction.

$$\text{Reduction in purchased electricity}$$
$$= (1.0 - 0.1) * \text{ yearly purchased electricity by the university}$$
$$= 0.9 * 147989128 \frac{\text{KWh}}{yr} = 133{,}190{,}215 \frac{\text{KWh}}{yr}$$

$$\text{CO}_2 \text{ emitted in} \frac{\text{tons}}{\text{yr}} = \text{CO}_2 \text{ emission factor}^1 \left(\frac{\text{lb}}{\text{MWh}}\right) * \text{ purchased electricity reduction}$$
$$= \frac{253.1\text{lb}}{\text{MWh}} * 133190.215 \frac{\text{MWh}}{yr} * 0.0005 \frac{\text{tons}}{lb} = \frac{16{,}855 \text{ tons}}{yr}$$

[1] NYUP power profile from the EPA provided the CO_2 emission factor. https://www.epa.gov/egrid/power-profiler#/

$$\mathrm{CO_2\ Savings_{R=10}\ in\ \frac{tons}{yr}} = \mathrm{GHGE_{R=0}} - \mathrm{GHGE_{R=10}}$$

$GHGE_{(R=0)}$ is the CO_2 emitted throughout the FY18

$$\mathrm{CO_2\ Savings_{R=10}\ in\ \frac{tons}{yr}} = \mathrm{GHGE_{R=0}} - \mathrm{GHGE_{R=10}}$$

$$= 18728 - 16855 = 1873$$

Following the same method to size and cost of solar system in section I.A.

Therefore, Size of solar system required for offset $=$ 11,372 KW

Price of system $=$ \$23,050,518

What if trees were used to offset the emissions

$$\text{Tree quantity} = \frac{\dfrac{\mathrm{CO_2\ Savings_{R=10}}}{\mathit{tons\ to\ lb\ conversion\ rate}}}{\text{Mature tree } \mathrm{CO_2} \text{ uptake rate } \dfrac{\frac{lb}{tree}}{yr}}$$

$$= \frac{\dfrac{1873\,\frac{\mathrm{tons}}{\mathrm{yr}}}{\frac{0.0005\mathrm{tons}}{\mathrm{lb}}}}{\dfrac{\frac{50\ lb}{tree}}{yr}} = 74{,}912 \text{ trees}$$

Assuming it costs \$1500 to plant a mature tree.

$$\text{Cost of planting trees} = 74912 \text{ trees} * \frac{\$1500}{\text{tree}} = \$112{,}368{,}145$$

In the study the cost per tons of CO_2 avoided was calculated.

$$\frac{Cost}{tons\ of\ CO_2\ avoided} = \frac{Cost\ of\ system - Cost\ of\ Electricity\ Not\ Spent}{CO_2\ savings\ over\ lifetime}$$

$$= \frac{\left[\$133{,}190{,}215 - \left[\frac{(147{,}989128 - 133{,}190{,}215)\ KWh}{yr} * \frac{\$0.06}{\mathrm{KWh}} * 25yr\right]\right]}{1873\,\frac{\mathrm{tons}}{\mathrm{yr}} * 25\mathrm{yr}} = \frac{\$21}{tons}$$

Note:

- The rate of \$0.06/KWh is the electricity rate which is a combination of the variable and fixed charge to the university.
- \$21 per tons of CO_2 avoided means it costs \$21 to avoid a ton of CO_2

Table 4: GHG Emission analysis for the university at different rates

% GHG Reduction	Purchased Electricity (KWh/yr)	GHG emission (tons/yr)	GHG Savings (tons/yr)	Solar PV - GHG Offset		Trees for GHG Offset	
		CO_2 - Purchased	CO_2 - Purchased Electricity	Solar DC Size (KW)	Cost of System ($)	Trees Qty	Cost of planting trees
0	147,989,128	18,728	-	0	0	-	-
1	146,509,237	18,541	187	1,137	2,319,258	7,491	11,236,814
2	145,029,345	18,353	375	2,274	4,622,732	14,982	22,473,629
5	140,589,672	17,792	936	5,686	11,533,151	37,456	56,184,072
10	133,190,215	16,855	1,873	11,372	23,050,518	74,912	112,368,145
15	125,790,759	15,919	2,809	17,059	34,567,884	112,368	168,552,217
20	118,391,302	14,982	3,746	22,745	46,085,250	149,824	224,736,290

C. Maximum Solar Rooftop Solar PV investment

From Table 3 above,
Fully Utilized PV Rooftop System Size is 17 MW at a cost of $35M.
25-year cumulative output = $4.87*10^8$ kWh over 25 years

$$Value\ of\ 25-year\ cumulative\ output\ =\ 4.87*10^8\ kWh\ x\frac{\$0.06}{KWh}\ =\ \$29.2M$$

$$25-year\ return\ on\ investment\ =\ \frac{value}{cost}\ =\frac{29.2}{35}=\ 0.834$$

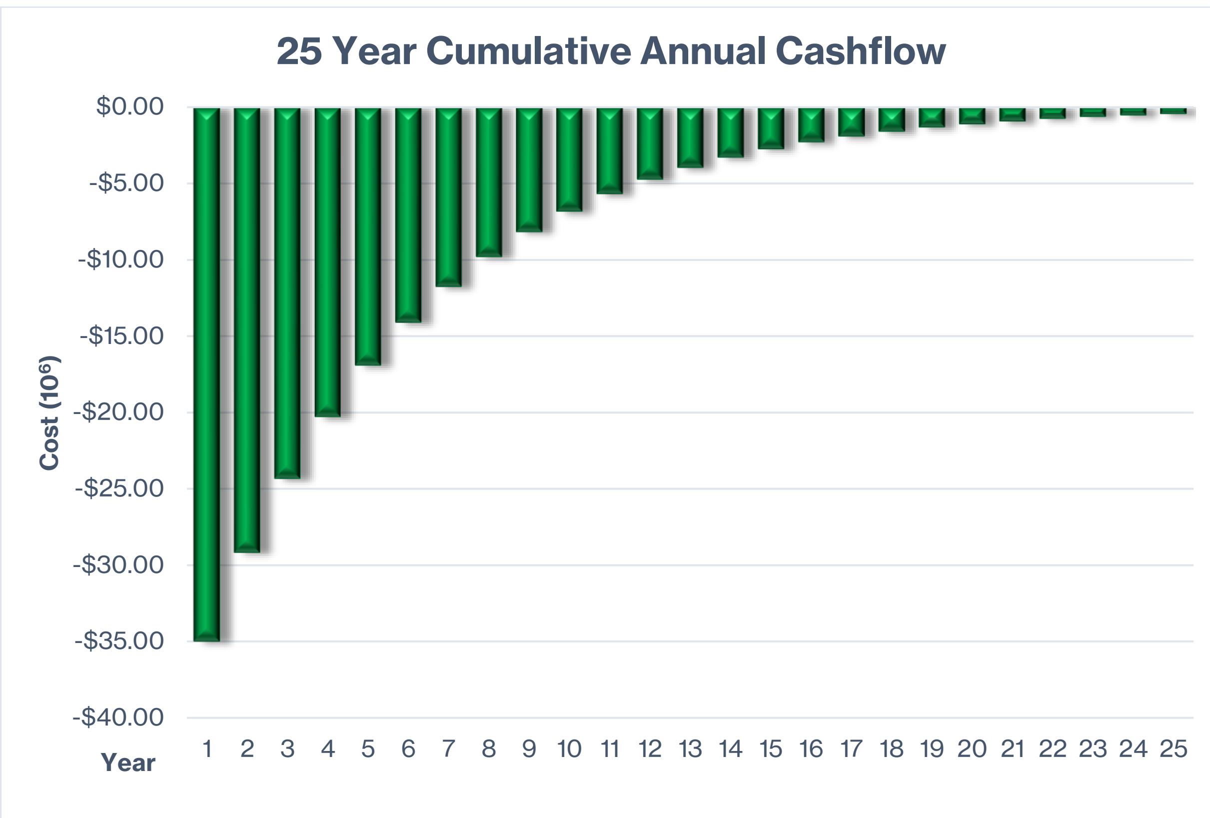

Figure 2. ***25 Year Cumulative Annual Cashflow***

D. Energy Comparison of 'River Campus' Peers

Boston University
Utilities Management : http://www.bu.edu/cpo/what-we-do/energy/energy-sources/
- It purchases its electricity from third parties and local distribution company, Eversource Energy.
- It purchases its natural gas and is transported by the local gas company, National Grid.
- Low temperature and hot water are handled by Boston Water and Sewer Commission

Purchase RECs : http://www.bu.edu/sustainability/what-were-doing/bu-wind/

Bucknell University
Co-generation: https://forthemedia.blogs.bucknell.edu/bucknell-earns-performance-excellence-in-electricity-renewal-certification/
On-site solar and wind: https://www.bucknell.edu/life-bucknell/sustainability/energy-water-transportation
Planned Solar expansion:https://forthemedia.blogs.bucknell.edu/bucknell-exploring-solar-project-with-encore-renewable-energy/
- Bucknell University is exploring the installation of a 2.1 peak megawatt (MWp) solar project in partnership with Encore Renewable Energy of Burlington, Vt.

Carnegie Mellon University
Purchase of RECs: https://www.cmu.edu/environment/energy-water/energy-mix/index.html#:~:text=Renewable%20Energy%20Progress,of%20the%20university's%20electricity%20requirements.
- Carnegie Mellon University purchases Renewable Electricity Credits (RECs) of wind power from the Prairie Breeze wind energy farm in Nebraska.

On-site solar:
https://www.sunnyportal.com/Templates/PublicPageOverview.aspx?page=c2d8c09a-37f3-4891-83ae-b790b938274f&plant=a3842dd0-2d36-4b89-bff6-4a19f0c3d37b&splang=en-US

Case Western Reserve University (CWRU)
Cogeneration, On-site, On-site Wind: https://case.edu/sustainability/campus/energy
It buys its electricity from **The Medical Center Company (MCCo)**, a district energy system not-for-profit corporation.

Duquesne University
Co-generation: https://understandingchp.com/files/2016/06/SolarTurbines_dscp-DuquesneUbniv.pdf
Duquesne operates a natural gas-fired power plant that produces approximately 75 percent of the power used for electricity and nearly 100 percent of the heating and cooling of the University's facilities.
Purchase RECs: https://www.duq.edu/news/releases/epa-again-designates-duquesne-as-green-power-champion

It purchases the remainder of its energy needs from renewable sources- a combination of energy generation and renewable energy purchasing led to the University's 100-percent reliance on clean energy. It is procuring renewable energy certificates from Direct Energy.

Massachusetts Institute of Technology
Cogeneration: https://sustainability.mit.edu/mit-central-utilities-plant
On-site solar and wind: https://sustainability.mit.edu/site-renewable-energy
It has five rooftops solar photovoltaic (PV) systems designed to produce an estimated 80,000-kilowatt hours (kWh) of clean energy annually.
Off-site solar: https://sustainability.mit.edu/site-solar-farm,

Northwestern University
Purchase RECs: https://isen.northwestern.edu/northwestern-honored-for-renewable-energy-use
Off-site solar and Solar expansion:
https://news.northwestern.edu/stories/2020/05/northwestern-and-clearway-announce-historic-partnership-to-bring-clean-renewable-energy-to-illinois/

Northeastern University
Energy generation: At Northeastern, 527,258 MMBTUs of energy for heating and cooling are generated from on-site combustion. Of this total, the two main sources are Natural Gas (96.8%), and Oil -distillate fuels (3.2%). Northeastern purchases non-electric energy from renewable sources.
https://facilities.northeastern.edu/wp-content/uploads/2018/03/NEU-Sustainable-Action-Plan.pdf

Syracuse University
On-site Solar: https://sustainability.syr.edu/campus/energy/
Purchase RECs:
https://sustainability.syr.edu/campus/energy/#:~:text=Starting%20in%202005%2C%20SU%20has,to%20lower%20SU's%20carbon%20footprint

- SU has voluntarily purchased electricity each year from renewable sources. Currently 35%, or 41,000,000 kWh, of Green-E Certified American Wind is purchased.
- It buys the rest of its electricity of retail electric suppliers.

https://sustainability.syr.edu/wp-content/uploads/2017/06/Syracuse-University-commits-to-purchasing-at-least-20-percent-of-its-electricity-from-renewable-energy-sources.pdf

The University of Chicago- https://sustainability.uchicago.edu/sp/
Energy Profile:
https://d3qi0qp55mx5f5.cloudfront.net/sustainability/uploads/images/UChicago_OS_GHG_Emissions_Inventory_Overview_FY12-FY17.pdf

- Natural gas and electricity usage in campus buildings contributes to approximately 70 percent of the University’s greenhouse gas emissions.

Campus-scale heating system: https://www.gienergyus.com/project-university-of-chicago
https://www.burnsmcd.com/projects/chiller-plant--combined-utility-plant
University of Notre Dame
Co-generation and Campus-scale heating system:
https://www.contractormag.com/plumbing/article/20884260/notre-dame-expands-with-green-energy-in-mind
https://m.nd.edu/notredame/sustainability/_/power_plant

On-site solar and Purchase RECs: https://news.nd.edu/news/notre-dame-backed-solar-project-breaks-ground-in-st-joseph-county/

- Notre Dame currently maintains three solar arrays separate from I&M: a 10-kilowatt array atop Fitzpatrick Hall, a 50-kilowatt array atop Stinson-Remick Hall and a 140-kilowatt array on Kenmore Street in South Bend.
- Indiana Michigan Power (I&M) solar project will provide clean energy credits equal to 10 percent of the University of Notre Dame’s total demand for electricity.

On-site Wind: https://m.nd.edu/notredame/sustainability/_/wind_turbines
Existing Hydro capacity:
https://facilities.nd.edu/projects/current-major-projects/hydroelectric-plant/
https://news.nd.edu/news/hydroelectric-plant-groundbreaking-moves-notre-dame-closer-to-sustainability-goals-and-seitz-park-renovation/

Extra Sources for University of Notre Dame’s utilities

- https://www.nd.edu/stories/notre-dame-ceases-to-burn-coal/
- https://green.nd.edu/mission/strategy/
- https://green.nd.edu/get-involved/energy-emissions/energy-conservation-at-notre-dame/

Monroe Community College
Cogeneration:
https://www.monroecc.edu/fileadmin/SiteFiles/GeneralContent/depts/sustainability/documents/Cogeneration_Narrative_9-30-2015_.pdf

- MCC is in an agreement with Monroe Newpower, to purchase all of the electricity and heat produced by the new plant.

Cornell University
Cogeneration: https://fcs.cornell.edu/departments/energy-sustainability/utilities/district-energy-combined-heat-power
On-site and off-site solar and existing hydroelectric:
https://sustainablecampus.cornell.edu/campus-initiatives/buildings-energy/campus-energy/renewable-energy
Planned solar expansion: https://cornellsun.com/2020/04/15/new-cascadilla-solar-farm-sustainability-powers-10-of-cornell-universitys-annual-electricity-usage/

RIT:
Purchase REC: https://www.rit.edu/news/us-environmental-protection-agency-recognizes-rit-green-power-leadership
On-site/Off-site solar and on-site wind: https://www.rit.edu/sustainablecampus/energy

Green energy rating
STARS Ratings: https://reports.aashe.org/institutions/participants-and-reports/
% RE in grid:
https://www.collegeconsensus.com/rankings/best-green-universities/
https://www.epa.gov/greenpower/green-power-partnership-top-30-college-university
(Carnegie Mellon University, RIT, Northwestern University, Boston University)
Bucknell U: https://reports.aashe.org/institutions/bucknell-university-pa/report/2019-09-23/OP/energy/OP-6/

Case Western U: https://reports.aashe.org/institutions/case-western-reserve-university-oh/report/2018-03-02/OP/energy/OP-6/

Duquesne U: https://duq.edu/news/releases/epa-again-designates-duquesne-as-green-power-champion

MIT : https://news.mit.edu/2017/solar-plant-delivering-promises-carbon-emissions-0323

Syracuse University: https://www.epa.gov/greenpower/green-power-partner-list

U Notre Dame:
https://news.nd.edu/news/notre-dame-backed-solar-project-breaks-ground-in-st-joseph-county/
"Indiana Michigan Power (I&M) broke ground recently on a $37 million solar project that will provide clean energy credits equal to 10 percent of the University of Notre Dame's total demand for electricity…"
https://news.nd.edu/news/hydroelectric-plant-groundbreaking-moves-notre-dame-closer-to-sustainability-goals-and-seitz-park-renovation/
The facility, which will be primarily underground, is expected to generate about 7 percent of the University's electrical needs

Cornell University: https://sustainablecampus.cornell.edu/news/renewable-energy-covers-100-cornells-power-use-first-time-over-100-years