Seneca College King Campus Net-Zero Energy Project

Conceptual Design Specifications

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Executive Summary

Ontario's Climate Change Action Plan (CCAP) requires the province to cut its greenhouse gas emissions and mandates that public institutions like Seneca College's King City Campus implement renewable technologies to meet this target. Jon Dilworth, Seneca's Project Manager of Energy Services, thereby aims to change King Campus into a net-zero facility. A net-zero energy facility is defined by its ability to generate as much renewable energy as it consumes.

Despite preliminary energy conservation measures on King Campus (e.g. converting to LEDs and upgrading boilers), there is no system in place to produce 13 GWh, which is the yearly combined usage of King Campus' electricity and gas usage. In order to address this gap, the design will focus on converting or purchasing renewable energy for electricity generation, and then transmitting this electricity to all of King Campus' buildings.

A design for onsite or off-site energy generation will need consultation from the Seneca Student Federation to discuss potential changes in budget allotments. Such a design will also interest the Ontario Energy Board because it may need to adjust energy prices to offset the reduced usage. Most importantly, this design must operate effectively in the natural and built environments of King Campus. The design will remain operational within the yearly average temperature range for King City (- 7º~22º) and cannot disrupt the college's farm animals or wildlife. It should also integrate into the physical landscape, namely Lake Seneca, roads, fields, and natural flora (largely forests and wetlands).

To best achieve the net-zero goal, an effective design should produce 13 GWh of electricity annually. Factors such as maintainability (maintenance cost and frequency) and GHG reduction should also be optimized. Considering these criteria and obstacles such as, land-use regulations, operating climate, and resource availability, the team generated 50 ideas through modifying and merging existing and emerging renewable technologies. Creativity techniques such as SCAMPER, lateral benchmarking, and biomimicry were employed.

The three alternative designs are: Photovoltaic System, Renewable Energy Credits, and Enhanced Geothermal System . These were chosen because, they best adapt to King Campus' environmental conditions and access to resources in addition to satisfying functions and objectives. The proposed design, consisting of smartflower™ and SunPower® X21-345 units, captures sunlight radiation to meet electricity generation goals. Compared to the two alternatives: Enhanced Geothermal System, which has a higher annual cost, and Purchasing Renewable Energy Credits, which lacks student involvement, the PV system has the most durability and maintainability while satisfying the client's preference for a "living lab" design.

After its electricity generation is numerically modelled using Solagis pvPlanner, the design will be subject to a series of tests to measuring its success in electrical performance, durability and efficiency. Finally, architectural modelling using BIM software will take place.

Following review of this design document, further development of the proposed design will be showcased during the Design Review Gateway and final presentations.

1.0 Introduction
Ontario's 2016 Climate Change Action Plan (CCAP) set a province-wide goal for the reduction of its greenhouse gas (GHG) emissions [1]. Presently, buildings in operation contribute to about 12% of Canada's GHG emissions [2]. Thus, Seneca College needs to minimize its contribution by reducing GHG emissions [3]. Jon Dilworth, the client and the Project Manager of Energy Services for Seneca College, leads this project. The initial step in reaching this goal is converting King campus into a net-zero energy facility. A net-zero facility meets its annual energy load through onsite renewable energy generation or purchasing renewable energy credits [4].

2.0 Problem Statement
Currently, the campus relies on Ontario's electrical grid [5], largely powered by non-renewable systems [6]. King Campus consumes an annual maximum of 6.3 GWh of electricity (Figure 21-Appendix A) [6] and 622 000 m^3 of gas [7], for this project the gas usage is combined with the electricity usage, equivalent to 13 GWh annually (Calculations-Appendix C) [6]. To reach the net-zero goal, the gap is the lack of a renewable system that meets the annual energy demands of the campus.

Seneca has made investments in passive energy reduction such as implementing LED lighting and upgrading boilers [8], but has not yet introduced any system to meet its annual energy consumption. This project focuses on determining which renewable energy systems are feasible for the campus to pursue.

Despite benefits of increased comfort, better air quality, stabilized energy prices, and improved building science [9],[10], various obstacles have obstructed past implementation of renewable energy generators. In addition to high capital and operating costs [11], renewable energy generators can increase fossil fuel market volatility [12] and decrease employment in the energy sector [13]. Situating transmission lines [11] and changing site infrastructure is hindered by land-use constraints [3] and heritage building regulations [14],[15] specific to King Campus. There is also a lack of standard solutions available in the building industry [12], in which older buildings were not retrofitted with renewable technologies because it was not mandated by policy [9].

3.0 Detailed Requirements
This project's aims to utilize available renewable resources to produce electrical energy and distribute it to campus facilities. Renewable energy generation intends to increase Seneca's energy efficiency and environmental sustainability [16]. The following detailed requirements consider system optimization and adherence to regulations, including environmental restrictions and King Township by-laws.

3.1 Functions

The design's purpose is to produce and transmit renewable energy to Seneca College King Campus, achieving net-zero energy usage. Forms of electricity generation that are explored include wind, solar, geothermal, biomass and hydro. The following functional tree (Figure 1) results from analyzing structural decomposition of possible means (Figure 33-Appendix B).

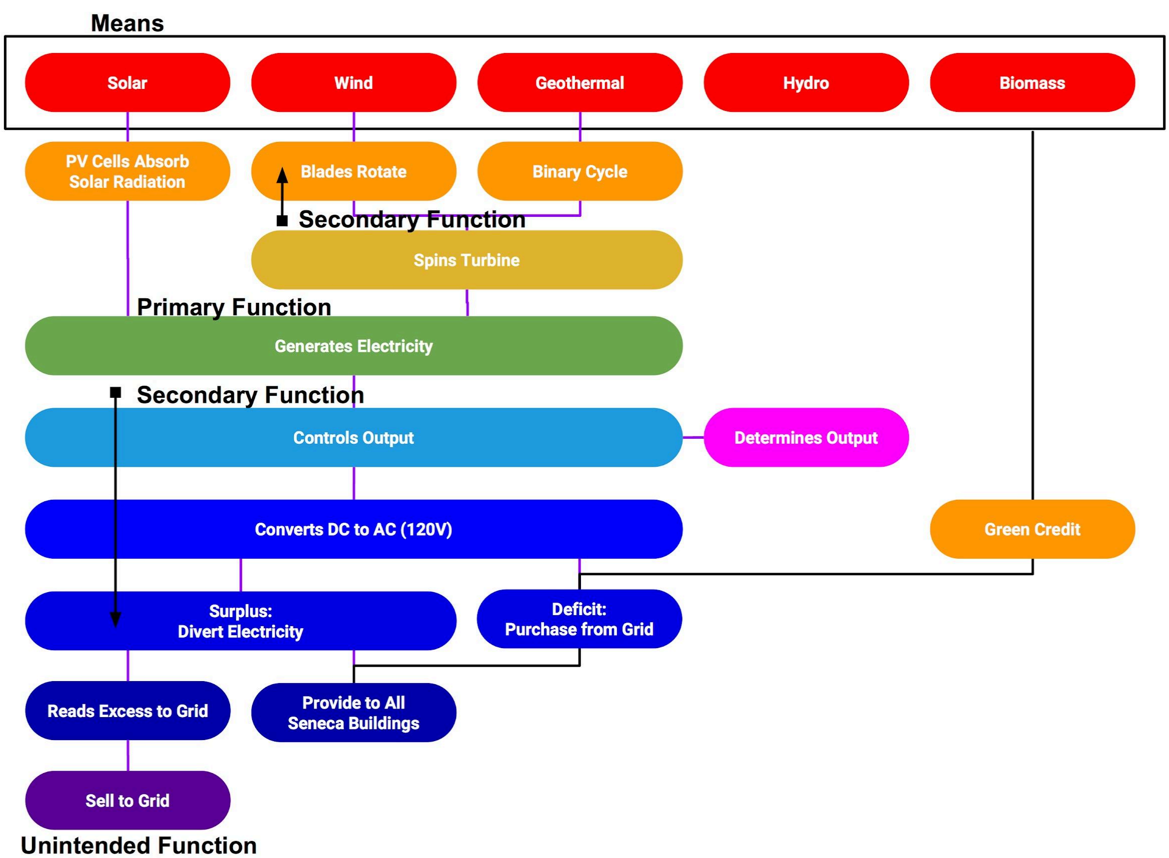

Figure 1 - Shows the primary function and its decomposition

3.2 Objectives

The following objectives were generated and prioritized based on research and client information (Pairwise Comparison-Appendix D). Self-sufficiency is prioritized in order to convert the campus to net-zero. Durability and maintainability ensure increased lifespan with minimal maintenance. To lessen the campus's environmental impact, GHG production is considered. The budget, not explicitly specified, is based on Seneca's yearly earnings.

3.2.1 Self-Sufficient

- Provide 13 GWh/year - King Campus' yearly combined electricity and gas usage (Calculations-Appendix C) [6]

3.2.2 Durable

- Design functions year-round in King City (temperature range -32.5 to 37˚C) [14]
- Outdoor design withstands wet conditions (Grade 4, IEC 60529) [17]
- 25 year life cycle [18]

3.2.3 Maintainable

- Any built design requires maintenance once per year, benchmarked from existing renewable energy sources [19],[20]
- Training and maintenance costs less than $390 000 per year (Calculations-Appendix C) [21]

3.2.4 Environmentally Sustainable

- Design produces maximum 100g CO_2/kWh (80% reduction of natural gas output) [22]

3.2.5 Affordable

- Costs less than $3.23 million per year, Seneca College's net earnings between 2016 and 2017 (Calculations-Appendix C)

3.3 Constraints

As the design operates within multiple jurisdictions and conservation areas, it must adhere to all bylaws and environmental policies. Heritage buildings on King Campus are subject to regulation.

3.3.1 Legal Regulations

- Shall not compromise the ecological function and biodiversity of natural heritage systems as per 2.1.2 of the Provincial Policy Plan, 2014 [15]
- Shall not operate on streams, wetlands, lakes, or seepage areas, adhering to 26(1) of the Oak Ridges Moraine Area (ORMA) Conservation Plan, 2001 [23]
- Shall not operate within 30 metres around vegetation area nor 120 metres around area of influence outlined in the ORMA Zoning By-law 2005-23 [24]
- Shall operate South of the lake outside of areas regulated by the Landform Conservatory Area [23]

3.2.2 Timeline

- Design shall be implementable by 2050 in accordance with CCAP [1]

3.3.3 Temperature

- Design must be fully operable from -7˚C to 22˚C [8]

3.3.4 Renewability

- Renewable energy source replenishes faster than it is extracted [25]

4.0 Service Environment

Seneca's King Campus includes natural elements and pre-existing physical and virtual infrastructure. The information below details the operational environment.

4.1 Physical Environment

This section details the yearly climate, sourced from a station in King city – within 1 km of the campus (Figure 22-Appendix A) [8]. Furthermore, it includes geography, and built environment of the campus.

4.1.1 Climate [8]

- Temperature: High 22ºC/Low -7ºC
- Monthly Precipitation: ≤100 mm
- Average Wind Speed: 3.5 m/s
- Daily Solar Radiation: 1.27~5.86 kWh/m^2 (Mean 3.59)
- Underground temperature: 10.1ºC [26]

4.1.2 Geography

- Topography: 300-330 metres elevation (Figure 2)
- Land: 700 acres of woods, fields and a lake [28]

4.1.3 Built Environment

- Connected to Power Grid (Figure 24-Appendix A) [29]
- Accessible by Road (Figure 25-Appendix A) [30]
- Campus Structures: 35 000 m^2 (Figure 26-Appendix A) [31]
- Campus and Heritage Buildings (Figure 2)

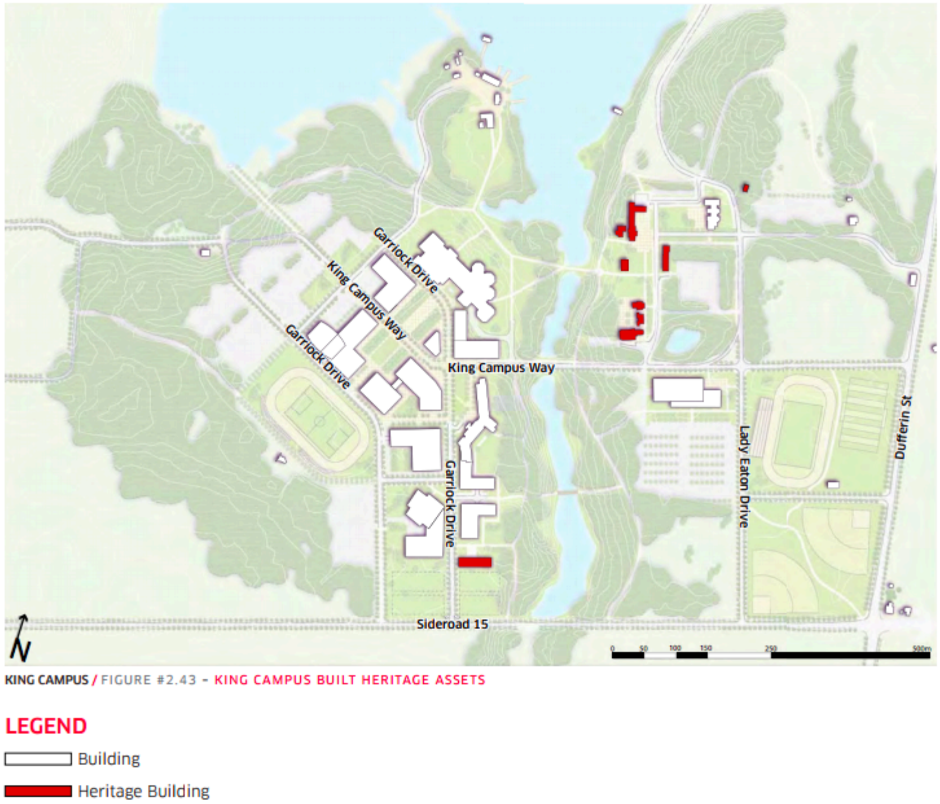

Figure 2 - Campus Map and Heritage Buildings [23]

- Farm land surrounds campus (Figure 27-Appendix A)

4.2 Living Things

King Campus offers study programs that involve work with animals and natural environment. Human activity on campus outside of college activities is also considered.

4.2.1 Animals

- Pack of coyotes in Northern part of campus [33],[34]
- Farm animals housed inside the barn and trained on campus grounds [28]: dogs, cats, goats, sheep, cows, horses [34]

4.2.2 Vegetation [36]

- Total campus land coverage is 700 acres, with 470 acres natural cover (Figure 3)

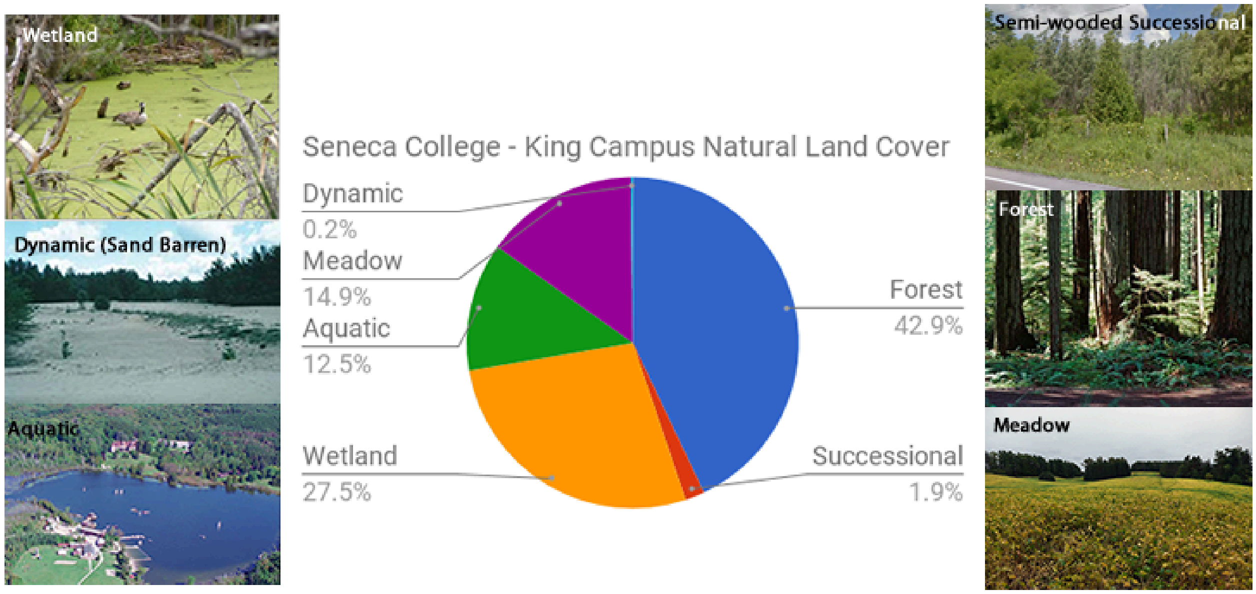

Figure 3 - Natural Cover breakdown [37],[38]

4.3 Virtual Environment

The following communications infrastructure is available for campus staff and students.

4.3.1 Internet Access [28],[40]

- Wireless internet access across entire campus.

4.3.2 Cellular Coverage [41]

- Cellular tower on campus. Providers: Bell, Rogers, Telus, Freedom

5.0 Stakeholders [42]-[44]

The following table shows agencies that are influenced by and influence the design (Ranked Decision Making-Appendix D).

Table 1: Stakeholders in Descending Level of Influence

Stakeholder	Impact
Government	
General Impact: Design is situated within jurisdictions and subject to regional law.	
Government of Ontario - Ministry of the Environment and Climate Change	• Greenbelt / Oak Ridges Moraine Protection Plan [45],[46] • Zoning Bylaw [47],[23]

Regional Municipality of York Township of King	○ Design must follow legal requirements and seek approval for construction in Greenbelt (Details-Appendix B)
Regulatory Groups	
Ontario Energy Board	● May decrease demand leading to higher unit cost for provincial customers [48],[49]
Nonprofit Organizations	
Ontario Power Union	● Support and create new job opportunities for energy sector workers [50]
Toronto and Region Conservation Authority	● Possibly reduce biodiversity in natural landscape [40]
Public Institutions	
Ontario Trails Council	● Disrupt natural landscape and recreational use of Oak Ridges Moraine Trail and King Trail [51]
Seneca Student Federation Inc.	● May encourage integration of sustainability in curriculum [52],[53]

6.0 Alternative Designs

The following designs represent a range of methodologies and costs. Due to lack of standardized solutions in net-zero energy design [38], case studies and existing technologies were benchmarked during ideation. A challenge was developing solutions that could sustain all of Seneca College's energy needs—small-scale, independent, renewable energy generation is generally less efficient and accessible than nonrenewable sources. Creativity techniques produced over 50 ideas which were reduced based on energy generation capabilities and resource accessibility. Ideation emphasized merging and re-engineering of existing technologies to improve feasibility. Biomimicry research that may be on the market within the timeline of this project was explored (Techniques-Appendix E).

The final alternative designs were chosen because they efficiently adapt to service conditions and resource accessibility while generating the required electricity through practical means.

6.1. Photovoltaic System (Rooftop Panels and smartflower™)

3.9 GWh of electricity will be produced using 6000 SunPower X21-345 solar panels (Calculations-Appendix C) mounted on the roofs of Garriock Hall and the residence building. This model uses 1.63 m^2 per panel (Figure 4) and provides 38% more power than conventional panels [54],[55].

The remaining annual 9.1 GWh of electricity will be generated by 2275 smartflower POP units, each producing 4000 kWh/year [56],[57] (Calculations-Appendix C) (Figure 5). Smartflower employs a rotating, dual-axis solar fan that ensures the optimal 90º sun alignment (Figure 5) [58]. The device tracks the sun, generating electricity for all daylight hours, which generates 51% more energy than traditional means (Figure 5) [56],[59]. Rear-ventilation also prevents inefficiency [57] due to overheating. Each device consists of 12 petals, with 25 m^2 required set-up space (Figure 5) [59]. Each plugged-in unit will feed excess electricity to the grid. The smartflower has a security setting in case of power outages and wind speeds rise above 15 m/s [60].

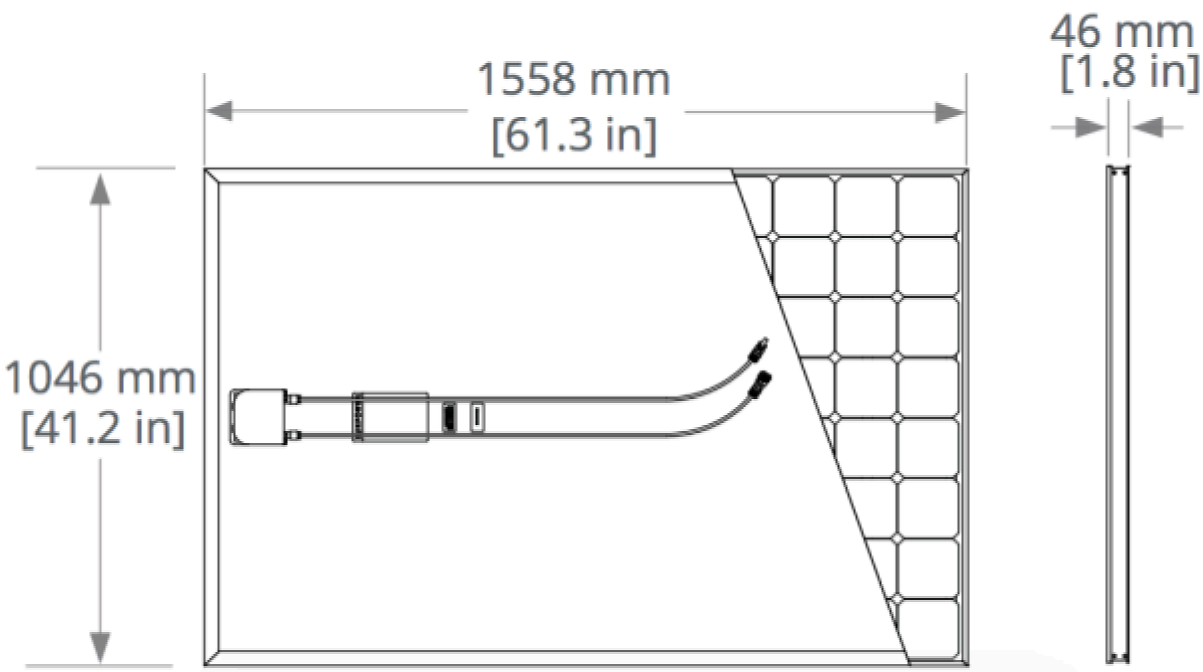

Figure 4: Dimensions of SunPower X21-345 [61]

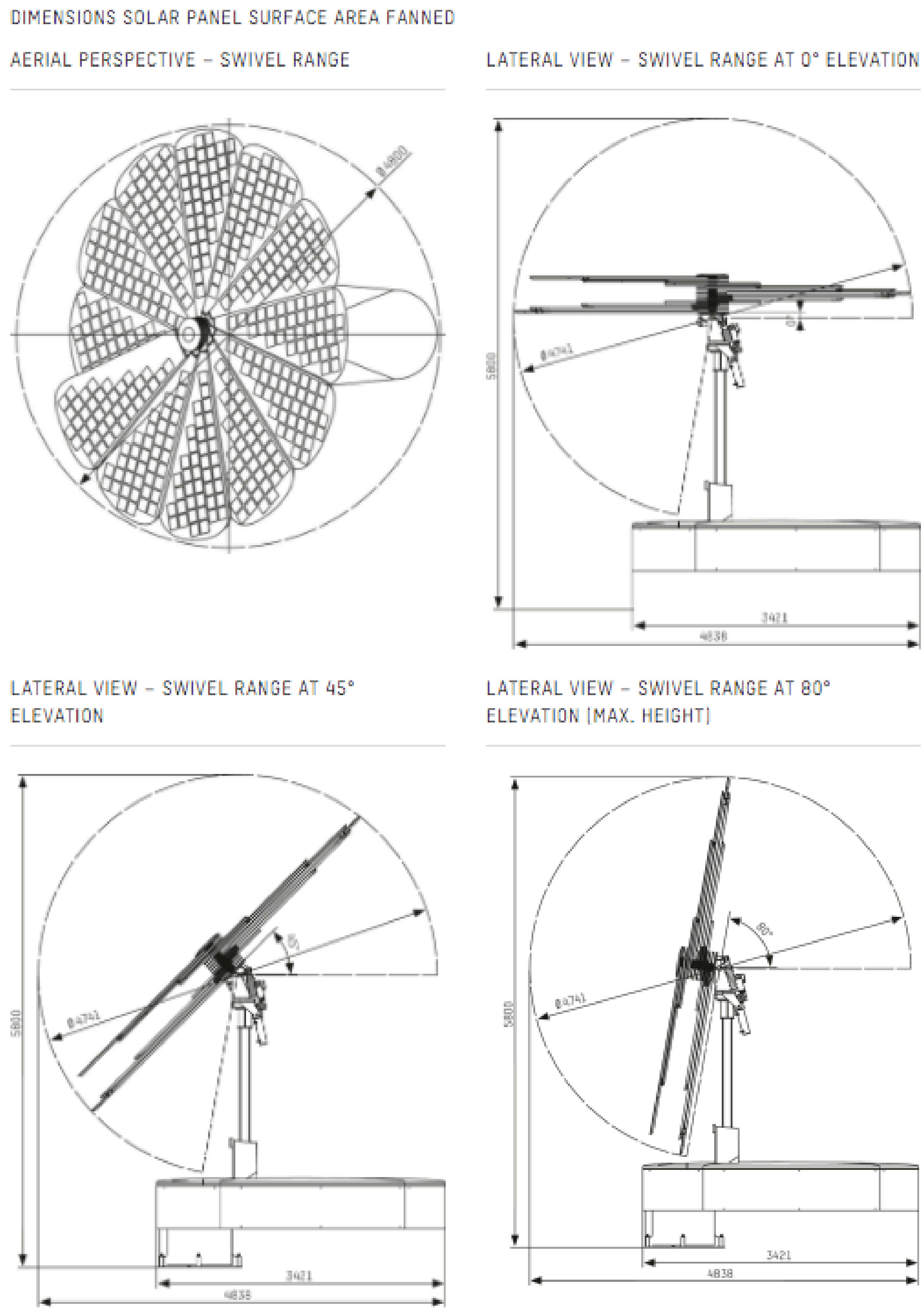

Figure 5: Dimensions of smartflower (max 5m x 5m)

Figure 6 - smartflower expansion and retraction (sun-tracking) [59]

Table 2: Photovoltaic System

Objective	Specifications
Self-Sufficient	Total production: 13 GWh/year (Net-zero energy use, connected to grid) **smartflower: 9.1 GWh/year** **SunPower X21-345: 3.9 GWh/year**
Durable	Lifetime: 25 years for both [54],[57] smartflower: ● Operational from -20~60ºC ● Endure heavy rain [62] SunPower X21-345 ● Operational from -40~80ºC ● IEC 61215 (all geographical weather)
Maintainable	Maintenance Costs: $230 000/year [63] (Calculations-Appendix C)
Environmentally Sustainable	20-55g of CO_2/kWh [64],[65]
Affordable	Implementation cost amortized over lifetime: $2.33 Million [54],[57] ● smartflower: $1 890 000 ● SunPower: $440 000

6.2. Purchasing Renewable Energy Credits

Renewable energy credits (RECs) are certificates purchased from energy providers each representing one MWh of renewable energy supplied to the grid [71]. The purchase of RECs in addition to the current utility bill of $1.6 million [35],[71] ensures that Seneca's energy consumption is net-zero. The premium paid to renewable energy providers support wind, solar, biomass, geothermal and hydro energy generation methods [71].

Purchasing RECs from the below companies provides an infrastructure-free solution to the net-zero goal [66]. Publicly available information and quotes from private communications from these companies are detailed below.

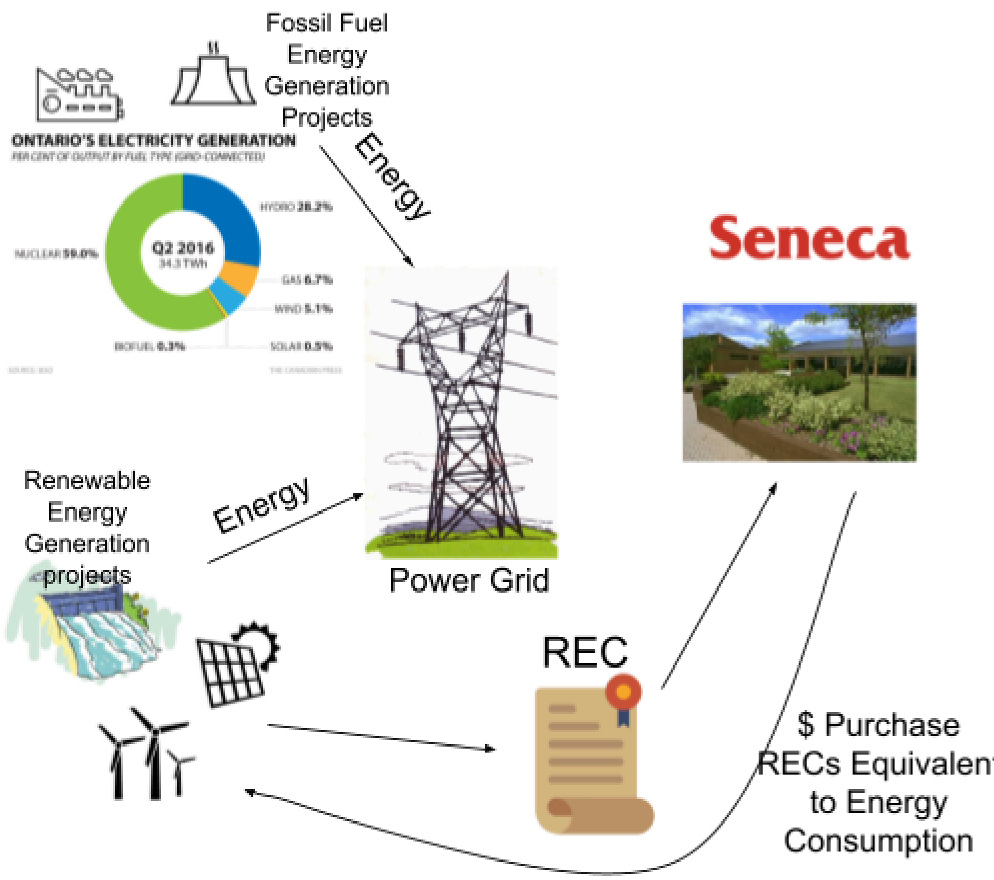

Figure 7: Process Overview for Renewable Energy Credits Purchase. Modified using Piktochart.

Table 3: Objective Fulfilment with Different Energy Service Providers

<table>
<tr><th rowspan="2">Objective</th><th colspan="3">Potential Companies</th></tr>
<tr><th>Bullfrog Power</th><th>Just Energy</th><th>Terrapass</th></tr>
<tr><td rowspan="2">Self-Sufficient</td><td rowspan="2">- Returns 13 GWh of electricity to grid [66]
- Audited by Deloitte annually to ensure accuracy [66]
- Non-GHG emitting power generators as certified by EcoLogo [67]</td><td colspan="2">- Can purchase enough renewable energy credits to entirely offset 13 GWh/year [68],[70]
- Standards:
    - Verified Carbon Standard Organization of Standardization Climate Action Reserve</td></tr>
<tr><td></td><td>- Standards:
- Gold Standard
- American Carbon Registry [68]</td></tr>
<tr><td>Durable</td><td colspan="3">N/A</td></tr>
<tr><td>Maintainable</td><td colspan="3">- No onsite part installation. [66]
- $364.44 annual operational cost for accounts payable.
- clerk expected salary is $63 169.60 [69]</td></tr>
<tr><td>Environmentally Sustainable</td><td colspan="3">GHG emissions for renewable energy technologies range from 74.9-650g CO_2/kWh [72]</td></tr>
<tr><td>Affordable Total = Utility Bill + REC Cost (Includes Tax)</td><td>- $25.00/MWh [66]
- RECs (Quote): $355,498 [67]
- Total: $1 955 498</td><td>- $28.50/MWh [71]
- RECs: $418 665 [73]
- Total: $2 018 665</td><td>- $6.44/MWh [68]
- RECs: $83 871.60 [68]
- Total: $1 683 972</td></tr>
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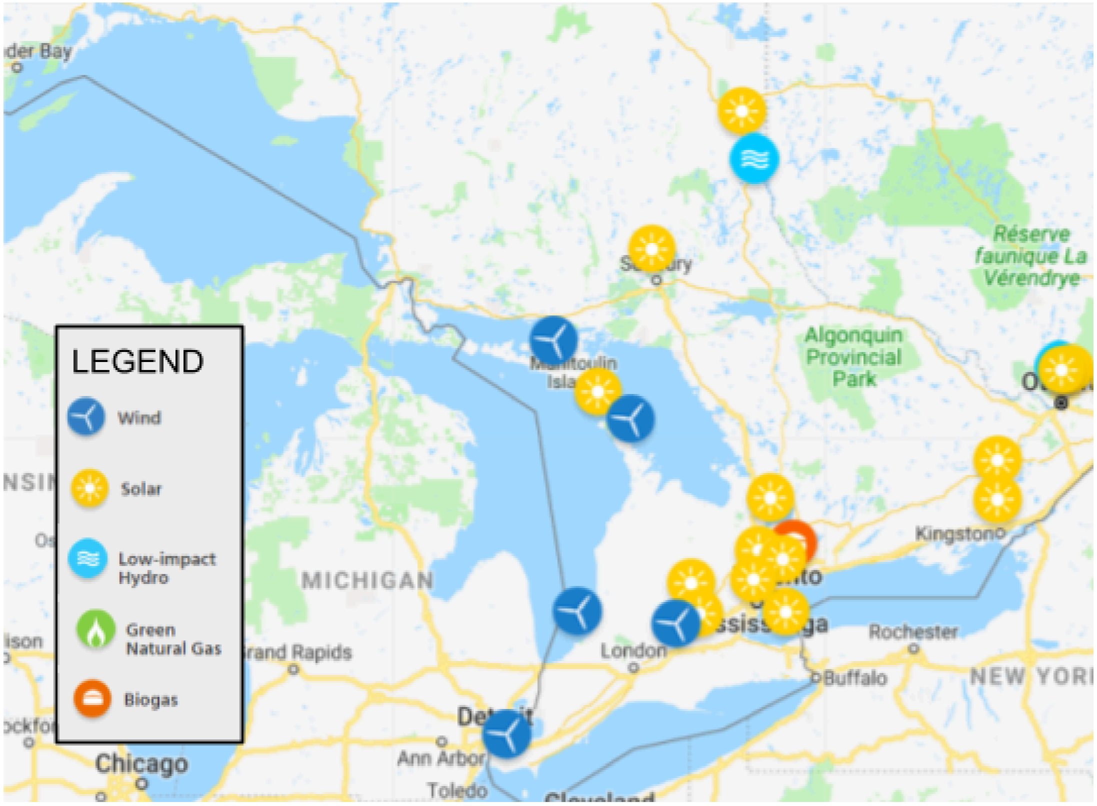

Figure 8: Map of Bullfrog Projects and Sources Supported In Ontario

6.3. Enhanced Geothermal System (EGS) - Binary Cycle

This design uses an enhanced geothermal system (EGS) for geothermal electricity generation. Fluid is injected at high pressure into hot subterranean rock, opening fractures which act as an engineered heat reservoir. A vertical 10 km hole is to be drilled into the ground to access rock temperatures ranging from 80~150˚C, the optimum range [74]. A closed loop high-pressure water system located near earth's surface transfers heat to another closed loop filled with isopentane [75]. This fluid, heated beyond its 28˚C boiling point [76], flows to a turbine to generate electricity. It is then cooled into a liquid and returned to the heat exchanger. Fuji Geothermal Binary System is chosen as it can produce 19 GWh/year with 1276 m^2 of operating space [75], but any binary system that generates 13 GWh/year will work. Further study of underground features must commence before a location can be determined.

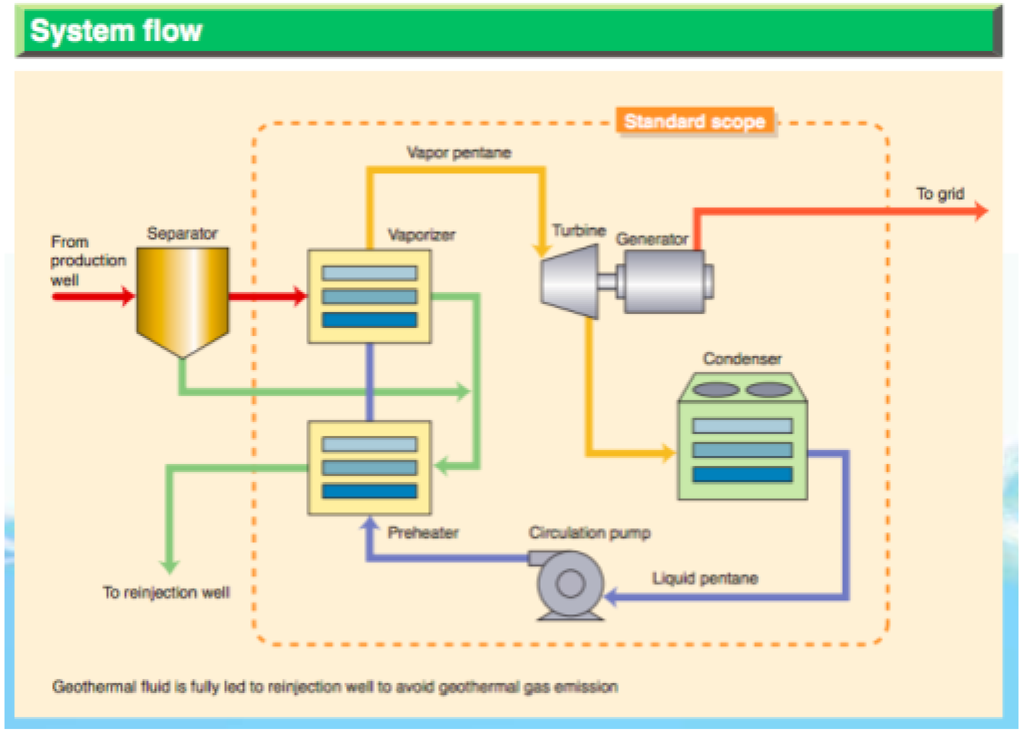

Figure 9: Binary Cycle System Diagram [75]

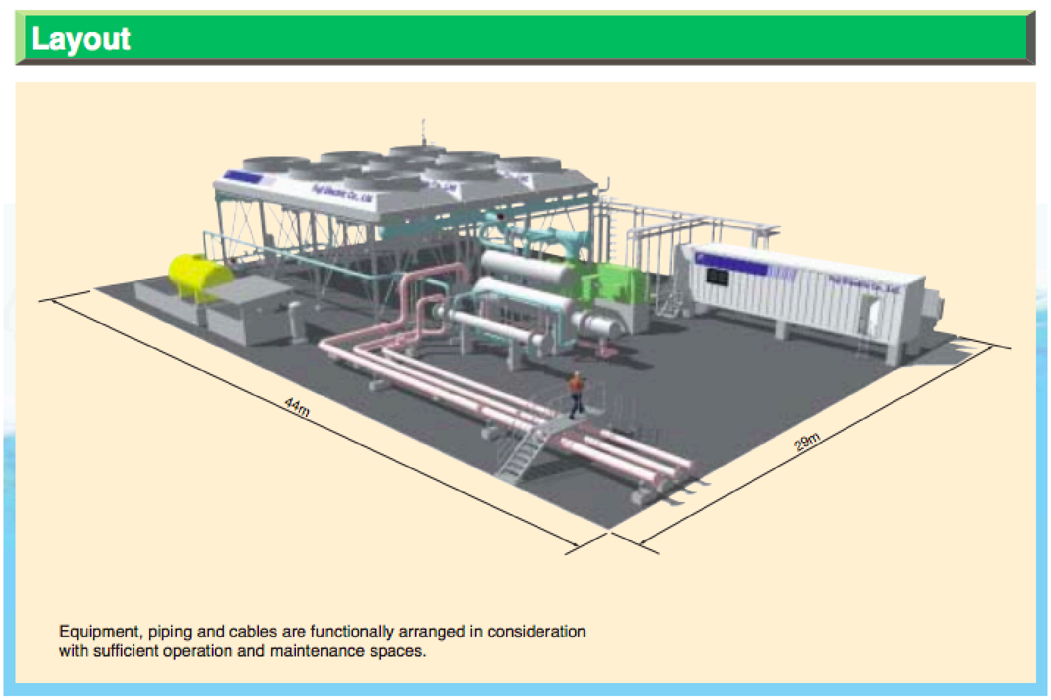

Figure 10: Exterior Layout [75]

Table 4: Binary Cycle EGS Specifications

Objective	Specifications
	Binary Cycle EGS
Self-Sufficient	- Fuji Geothermal Binary System produces up to 19 GWh/year [75] (Calculations-Appendix C)
Durable	- Satisfies waterproof objective (Grade 4, IEC 60529) [77] - Operates from -12˚C [78],[79] to 40˚C [80],[81] - Lifespan of 30 years [82]
Maintainable	- Routine maintenance once per year [83] - For 140˚C, 2.5 MW plant, operating & maintenance costs = $750 571/year [83]
Environmentally Sustainable	- 78g CO_2/kWh [72]
Affordable	- $5.87 million CAD/year for plant lifespan [83] (Calculations-Appendix C)

Figure 11: Geothermal Plant Size [84]

7.0 Proposed Conceptual Design (Photovoltaic System)

The combined smartflower/rooftop solar panel is the design that best fulfills the campus's net-zero energy goal. The system harvests light radiation to produce 13 GWh of electricity per year.

This decision was reached through considering the key objectives in addition to client input, stakeholder interests, and the service environment. Despite green credits excelling in objective evaluation, the client expressed that the proposed design should produce data for academic purposes and allow student involvement [9]. Thus, the team opted for an onsite design. The PV system is the only design using commercially available technologies.

Table 5: Objective Evaluation

Objectives	Photovoltaic System	RECs	EGS
Self-Sufficient	Yes		
Durable	-20 - 60˚C [54],[57]	**N/A**	-12 - 40˚C [79],[81]
Maintainable	IEC 61215 [62] $230 000/year [63] 25 year lifespan [54],[57]	**N/A**	Grade 4, IEC 60529 [77] $750 571/year [83] 30 year lifespan [82]
Environmentally Sustainable	20-55g CO_2 /kWh [64],[65]	74.9-650g CO_2/kWh [72]	78g CO_2/kWh [72]
Affordable	$2 330 000/year [54],[57]	$1 955 498/year [71]	$5 870 000/year [83]

The rooftop solar panels occupy otherwise unused space, neither altering internal building structure nor affecting heritage buildings. This reduces the necessary number of smartflower units, which are energy-efficient but require land and greater costs [57]. The total land usage is 56 875 m^2 of field and 9800 m^2 rooftop space (Figure 12). The installation uses electronically configured earth screws (Figure 13) and mounts on rails (Figure 14), not requiring added infrastructure construction. Smartflowers will generate most electricity by remaining optimally functional under northern climates and winters. These units track the low-lying winter sun, and the silicon components increase in conductivity at low temperatures [57].

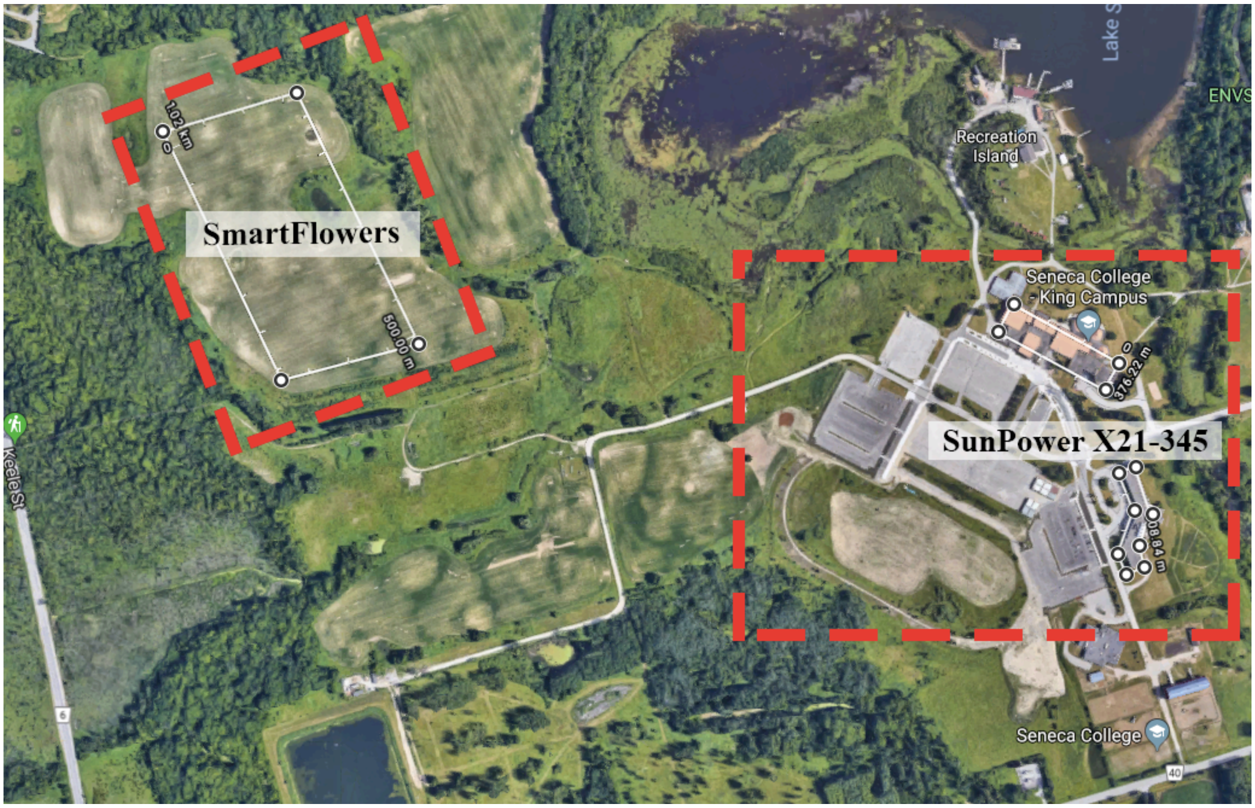

Figure 12 - Smartflower field usage and SunPower X21-345 rooftop placement (white perimeters)

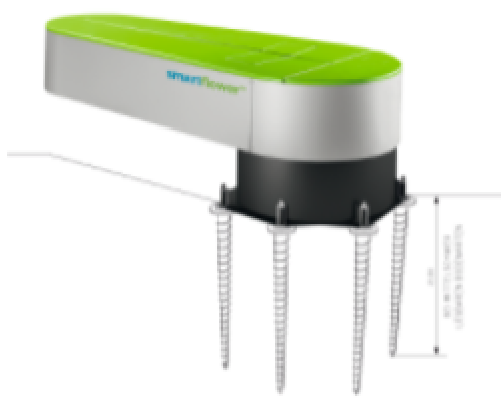

Figure 13 - 6 Earth screw fixtures per smartflower (attach to base)

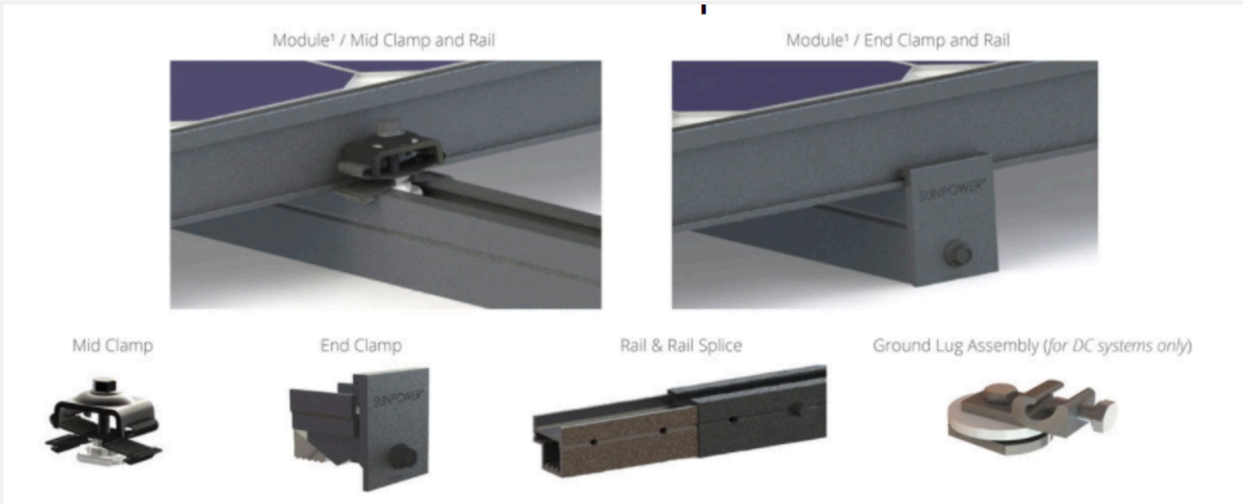

Figure 14 - All required components for rooftop mount [85]

Onsite system installation introduces positive social externalities to King Campus. Smartflower implementation at Mary Baldwin University [86] and Kufstein University of Applied Sciences [87] incorporated energy data management into research and training, and exemplified tangible commitment to sustainable energy. This aligns with the client's intentions of implementing a "living lab" by allowing students to study the data and manage the systems.

8.0 Measure of Success

Before implementation, a series of tests will evaluate the proposed design's functional performance in the King Campus service environment.

8.1 Numerical Modelling

Preceding physical tests, the Solargis pvPlanner software will be used to verify the number of panels and smartflower devices needed to produce 13 GWh/year of electricity [88] and model electricity production (Figure 15).

- Input geographical coordinates and product's technical data into Solargis database
- System calculates yearly and monthly electricity production, simulating radiation and temperature in 15-minute increments [89]
  - Accuracy of data and modelling follows guidelines used in Mesor [90] and IEA SHC Task 36 [91]

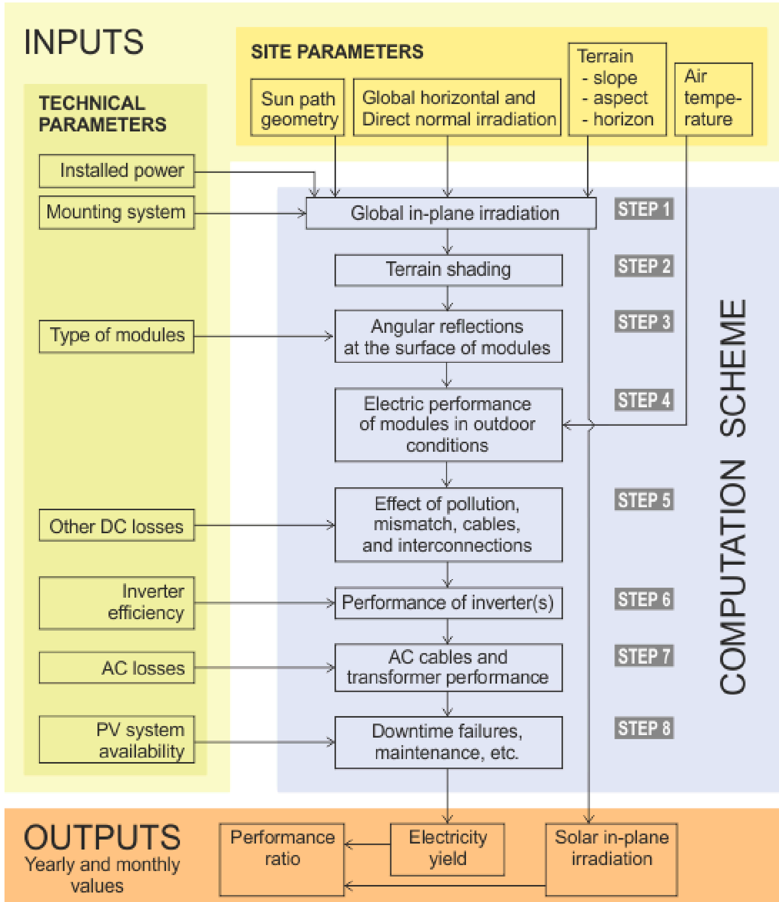

Figure 15 - algorithm used for electricity yield calculations

8.2 Electrical Performance

To evaluate electrical performance of the mono-crystalline smartflower [57] and SunPower PV modules against advertised numbers, tests will be conducted in accordance to ASTM E1036 and ASTM E948 [39]. Reference modules with equivalent specifications as the respective data in Figure 15 and Figure 17 will be exposed to a programmed solar simulator for data collection (Figure 18).

Electrical Data		
	SPR-X21-335-BLK	SPR-X21-345
Nominal Power (Pnom)[11]	335 W	345 W
Power Tolerance	+5/−0%	+5/−0%
Avg. Panel Efficiency[12]	21.0%	21.5%
Rated Voltage (Vmpp)	57.3 V	57.3 V
Rated Current (Impp)	5.85 A	6.02 A
Open-Circuit Voltage (Voc)	67.9 V	68.2 V
Short-Circuit Current (Isc)	6.23 A	6.39 A
Max. System Voltage	600 V UL & 1000 V IEC	
Maximum Series Fuse	15 A	
Power Temp Coef.	−0.29% / ° C	
Voltage Temp Coef.	−167.4 mV / ° C	
Current Temp Coef.	2.9 mA / ° C	

Figure 16: Electrical data of SunPower X21-345 [92]

SMARTFLOWER™	MODUL 1
Nominal Power Pmpp	239 Wp
Open Circuit Voltage Uoc	32,90 V
Nominal Voltage Umpp	27,90 V
Nominal Current Impp	8,60 A
Short Circuit Current Isc	9,10 A
Maximum Power Tolerance	+/-3%
Current Temperature Coefficient (I_{SC})	0,04 %/° C
Voltage Temperature Coefficient (U_{DC})	-0,32 %/° C
Power Temperature Coefficient (P_{MPP})	-0,40%/°C
NOCT	46° C
Cells	51 monocrystalline solar cells
Cell-Dimensions	6" – 156 x 156 mm

Figure 17: Electrical data of smartflower [92]

Figure 18. Simulator, Pyranometer, radiometer, power supply set-up [88]

8.2.1 Maximum Continuous Output Power

This test establishes the max output power level maintainable for 180 minutes at the max ambient operating temperature. Conduct experiment according to test conditions listed in Figure 19 and report AC output power over 5 minute intervals - the max continuous output will be the minimum of the five reported values [93].

Test	V_{dc}	V_{ac}	Maximum Power
A	V_{nom}	V_{nom}	
B	V_{max}	V_{nom}	
C	V_{min}	V_{nom}	
D	V_{min}	102% V_{min}	
E	V_{max}	98% V_{max}	

Figure 19 - Maximum Continuous Output Power Test Conditions [93]

8.2.2 Conversion Efficiency [93]

Determines inverter efficiency between DC source and AC output.

- Environment air temperature = 25°C±3°C
- Adjust operating voltages to nominal values and power output to 100%, run for 150 minutes
- Conduct test under conditions in Figure 20
    - Efficiency=AC Output Power/Average DC Input Power
    - Use average of measured values

Test	V_{dc}	V_{ac}	Inverter DC Input Power Level						
			100%	75%	50%	30%	20%	10%	5%
A	V_{nom}	V_{nom}							
B	V_{max}	V_{nom}							
C	V_{min}	V_{nom}							
D	V_{min}	102% V_{min}							
E	V_{max}	98% V_{max}							

Figure 20 - Efficiency Test Conditions [93]

8.3 Durability

The ability of the design to operate safely under conditions of King Campus should be tested with the following standards:

ASTM E1171 - 15 [94]

- Exposed to thermal cycling, extended duration damp heat, and humidity-freeze cycling processes

ASTM E1830 - 15 [95]

- Mounted according to manufacturer specifications and mechanical stresses applied
- Static load tests: 2400 Pa for wind loads and 5400 Pa for snow

ASTM E2047 - 10 (2015) [96]

- Tests integrity of wet insulation and determine PV system's ability protection against electrical hazards

8.4 Installation/Spatial Implementation

The mounting of solar panels and ground fixation of smartflower will be evaluated as follows to ensure safety:

- Rooftop mounting procedures follow ASTM E2766-13 [97]
- Earth screws evaluated against tests and standard procedures outlined in STP835 [98]

To determine whether intended number of solar panels/smartflowers can be feasibly installed, an architectural design is to be created using BIM, an intelligent 3D model-based process that allows construction planning [99].

9.0 Conclusion

Considering the project requirements, three alternative designs were generated to meet Seneca King Campus' need for net-zero energy use. Although each design fulfills the gap in renewable electricity generation, the combined PV system of rooftops panels and smartflowers best achieves self-sufficiency, durability, and maintainability. This evaluation will be subject to standardized testing. Following client CDS review and signoff, further development of the design will be introduced in the Design Review Gateway Presentation.

10.0 References

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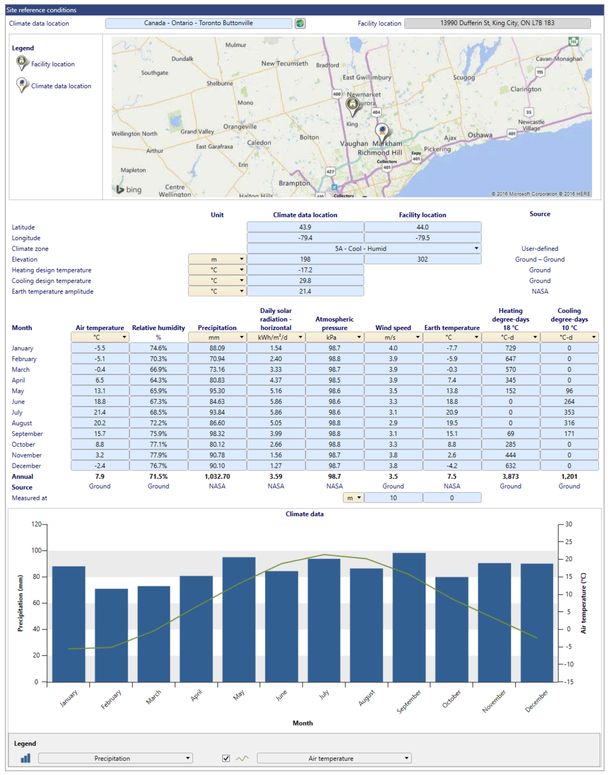
11.0 Appendices

APPENDIX A: Additional Figures

This appendix outlines any figures that supplement the information in the primary document, but do not fit into the content's flow.

KWH @ PLAC	Garriock	Chalets	Sewage	Gatehouse	Eaton	Villa Fiori		Total	Incomplete T	Monthly Average of Year	COST @ PLAC
01-Nov	325,658								325,658		
01-Oct	338,537								338,537		
01-Sep	314,041								314,041		
01-Aug	285,600				10,200				295,800		
01-Jul	302,400								302,400		
01-Jun	341,600	5,000	12,660	1,179	23,400	2,240		386,079			
01-May	336,000	4,160	11,840	1,258	22,600	640		376,498			
01-Apr	380,800	14,960	15,690	1,776	30,400	320		443,946			
01-Mar	375,200	17,560	14,050	1,904	32,800	480		441,994			
01-Feb	344,400	16,200	14,640	2,113	29,800	351		407,504			
01-Jan	364,000	19,200	16,000	2,134	32,200	3,360		436,894			
01-Dec	355,600	13,880	15,930	2,116	27,600	2,240		417,366		373,893.08	
01-Nov	319,200	12,000	1,530	1,147	17,600	2,080		353,557		376,218.00	
01-Oct	330,400	1,320	15,370	1,024	21,800	2,240		372,154		379,019.42	
01-Sep	324,800	5,040	16,150	1,208	13,200	2,400		362,798		383,082.50	
01-Aug	305,200	4,600	1,720	1,470	27,600	2,080		342,670		386,988.33	
01-Jul	358,400	14,160	13,230	1,504	17,400	3,840		408,534		395,832.83	
01-Jun	487,200		13,720	1,456	21,600	640			524,616	407,377.58	
01-May	179,200		9,400	1,246	27,600	320			217,766	394,149.92	
01-Apr	358,400	8,440	15,460	2,137	29,600	480		414,517		391,697.50	
01-Mar	355,600	46,640	12,860	2,999	32,800	320		451,219		392,466.25	
01-Feb	369,600	3,320	8,640	2,788	23,400	2,880		410,628		392,726.58	
01-Jan	380,800	23,320	12,310	2,975	16,600	2,720		438,725		392,879.13	
01-Dec	313,600	23,320	19,380	3,190	19,400	2,240		381,130		389,859.44	
01-Nov	324,800	3,320	13,980	1,600	18,000	2,080		363,780		390,711.36	
01-Oct	347,200	2,040	17,640	1,587	14,600	2,400		385,467		391,820.76	
01-Sep	313,600	2,640	1,830	1,558	10,000	2,080		331,708		389,229.94	
01-Aug	375,200	1,960	1,740	1,502	13,400	2,080		395,882		393,664.24	
01-Jul	280,000		1,610	1,944	18,400	2,240			304,194	384,969.24	
01-Jun	291,200		15,900	1,765	22,800	800			332,465	368,956.63	
01-May	319,200	18,480	14,500	1,787	28,400	320		382,687		382,700.09	
01-Apr	347,200	18,880	5,900	1,802	32,800	480		407,062		382,078.79	
01-Mar	414,400	19,000	12,900	1,936	40,000	320		488,556		385,190.24	
01-Feb	403,220	34,040	12,500	2,044	42,000	2,880		496,684		392,361.60	
01-Jan	420,000	10,640	9,500	2,180	34,400	2,880		479,600		395,767.86	
01-Dec	246,400	8,320	30,700	2,353	26,800	2,240		316,813		390,408.14	
01-Nov	352,800	5,000	24,000	2,061	20,400	2,080		406,341		393,954.89	
01-Oct	313,600	7,920	24,600	1,950	14,600	2,400		365,070		392,255.13	
01-Sep	274,400		3,800	2,191	9,600	2,080			292,071	388,952.01	
01-Aug	257,600	2,240	3,400	2,105	9,800	2,240		277,385		379,077.27	
01-Jul	324,800	1,880	4,100	2,392	9,400	2,080		344,652		382,448.79	
01-Jun	285,600	6,520	15,700	2,132	15,200	800		325,952		381,906.07	
01-May	324,800	15,440	14,500	2,453	25,000	320		382,513		381,891.50	
01-Apr	397,600	36,680	17,000	2918.5380		480			451,760	385,616.37	
01-Mar	347,200		11,600	2,600	30,600	320			392,320	377,596.67	
01-Feb	425,600	28,160	12,100	2,437	31,800	2,880		502,977		378,121.08	
01-Jan	336,000		14,400	2,417	31,600	2,240			386,657	370,375.86	
										386,562.36	4,638,748.37

Figure 21 - King Campus Electrical Data [3]



	Unit	Climate data location	Facility location	Source
Latitude		43.9	44.0	
Longitude		-79.4	-79.5	
Climate zone		5A - Cool - Humid		User-defined
Elevation	m	198	302	Ground – Ground
Heating design temperature	°C	-17.2		Ground
Cooling design temperature	°C	29.8		Ground
Earth temperature amplitude	°C	21.4		NASA

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	-5.5	74.6%	88.09	1.54	98.7	4.0	-7.7	729	0
February	-5.1	70.3%	70.94	2.40	98.8	3.9	-5.9	647	0
March	-0.4	66.9%	73.16	3.33	98.7	3.9	-0.3	570	0
April	6.5	64.3%	80.83	4.37	98.5	3.9	7.4	345	0
May	13.1	65.9%	95.30	5.16	98.6	3.5	13.8	152	96
June	18.8	67.3%	84.63	5.86	98.6	3.3	18.8	0	264
July	21.4	68.5%	93.84	5.86	98.6	3.1	20.9	0	353
August	20.2	72.2%	86.60	5.05	98.8	2.9	19.5	0	316
September	15.7	75.9%	98.32	3.99	98.8	3.1	15.1	69	171
October	8.8	77.1%	80.12	2.66	98.8	3.3	8.8	285	0
November	3.2	77.9%	90.78	1.56	98.7	3.8	2.6	444	0
December	-2.4	76.7%	90.10	1.27	98.7	3.8	-4.2	632	0
Annual	**7.9**	**71.5%**	**1,032.70**	**3.59**	**98.7**	**3.5**	**7.5**	**3,873**	**1,201**
Source	Ground	Ground	NASA	NASA	NASA	Ground	NASA	Ground	Ground
Measured at					m	10	0		

Figure 22 - Climate data in King City [8]

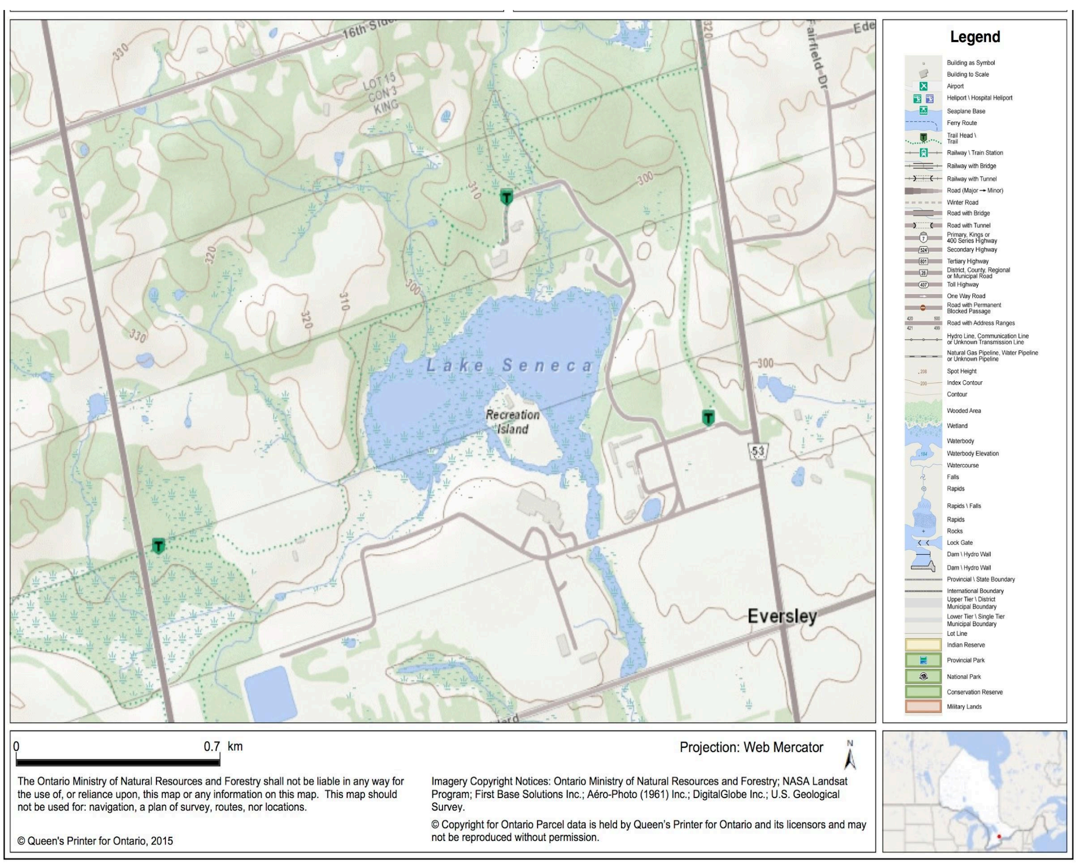


Figure 23 - Produced from Ministry of Natural Resources and Forestry [27]

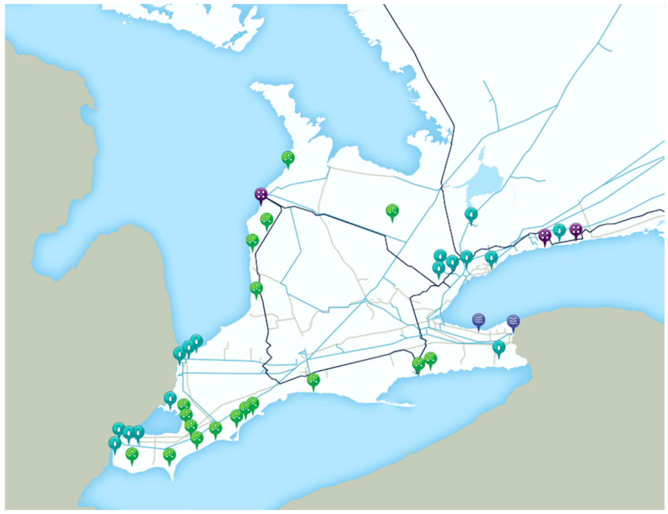


Figure 24 - Power Grid Map [29]

Figure 25 - Road Map: the black circle shows the location of King City, which is connected to the road [31]

KING	BOAT HOUSE	3,300
KING	CHILD CARE CENTRE(KOLTS)	8,643
KING	CRIME SCENE LAB	1,658
KING	EATON HALL	50,172
KING	ENVIRO LANDSCAPE MNGMT	7,071
KING	GREENHOUSE BUILDING	10,237
KING	GARRIOCK HALL	143,837
KING	KING RESIDENCE	82,894
KING	KW BUILDING	6,825
KING	LAW LODGE	4,567
KING	PAVILION	3,339
KING	PORTABLE CLASSROOM	8,530
KING	QUARTERMASTER OFFICE	1,077
KING	RED HORSE BARN	15,821
KING	RECREATION ISLAND	2,671
KING	RIGGING SHOP	1,031
KING	SHEEP & COW BARN	1,576
KING	UNDERWATER SKILL STORE	864
KING	VET TECH	21,816
KING (KG) Total	KING	375,929

Figure 26 - King Campus Buildings in Square Feet [31]

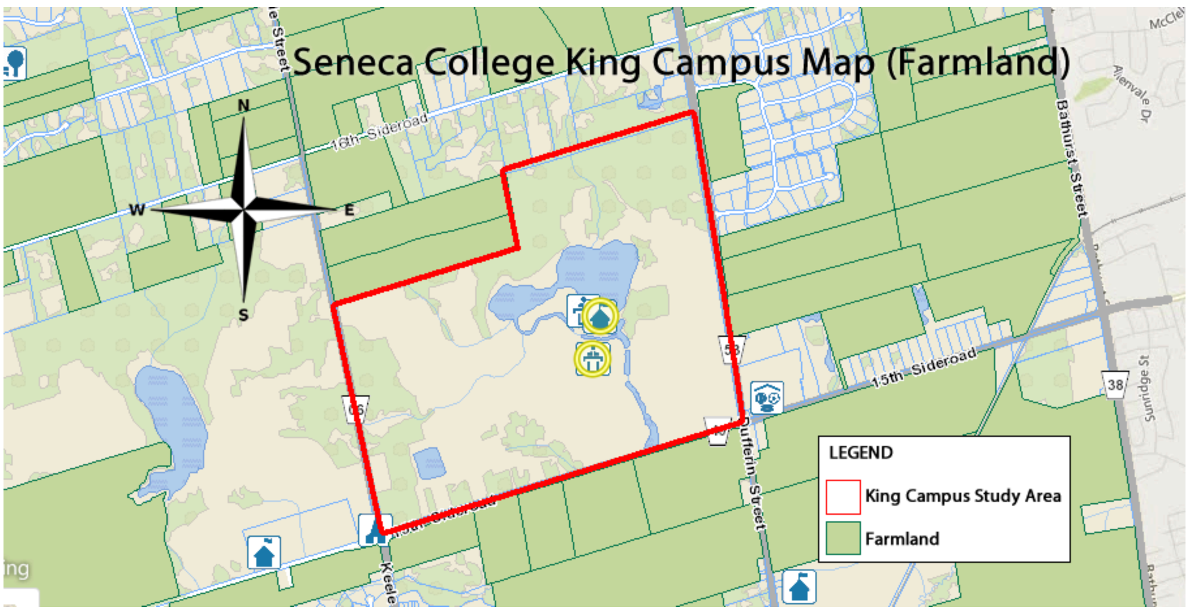


Figure 27 - Seneca College King Campus Including Surrounding Farmland. Image Based on Modified Map [32]. Modified with Adobe FireWorks.

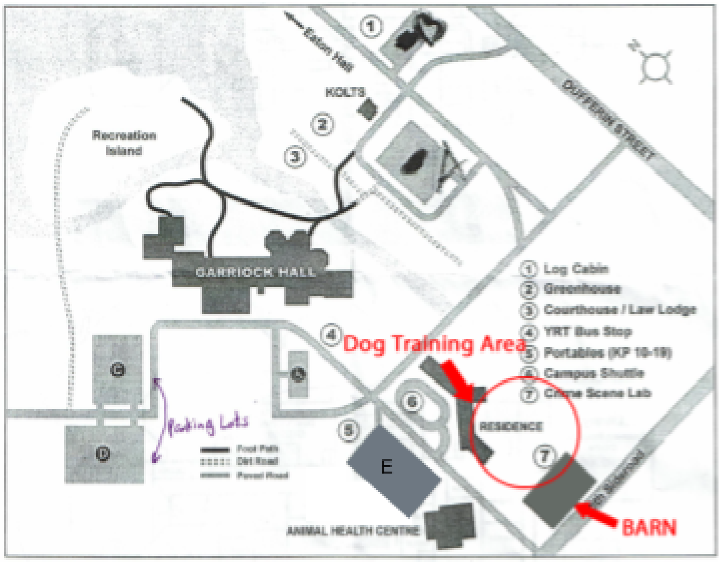


Figure 28 - Seneca College King Campus Map.
Image Based on Modified Map [35]. Modified with Adobe Fireworks.

Figure 29 - Signs along roads indicating nearby children (left) and providing direction to the day camp (right) [39].

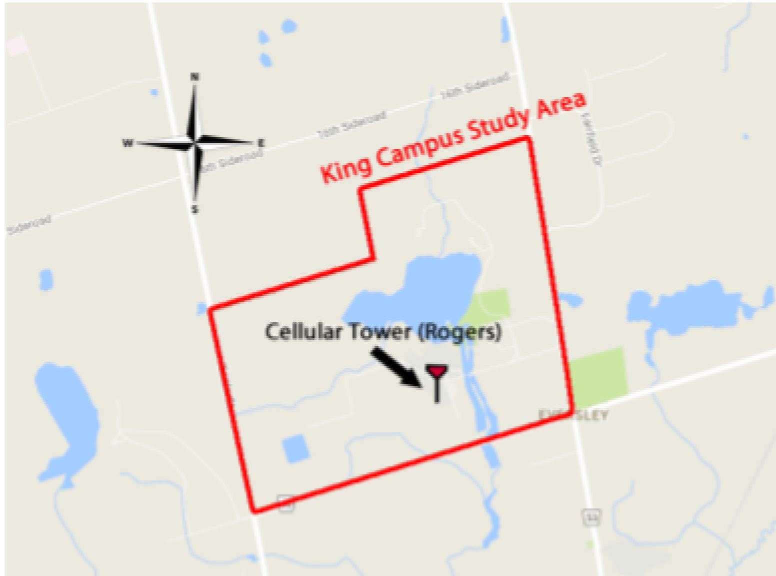


Figure 30 - Map of Rogers Cellular Tower on King Campus.
Image Based on modified map [43]. Modified with Adobe Fireworks.

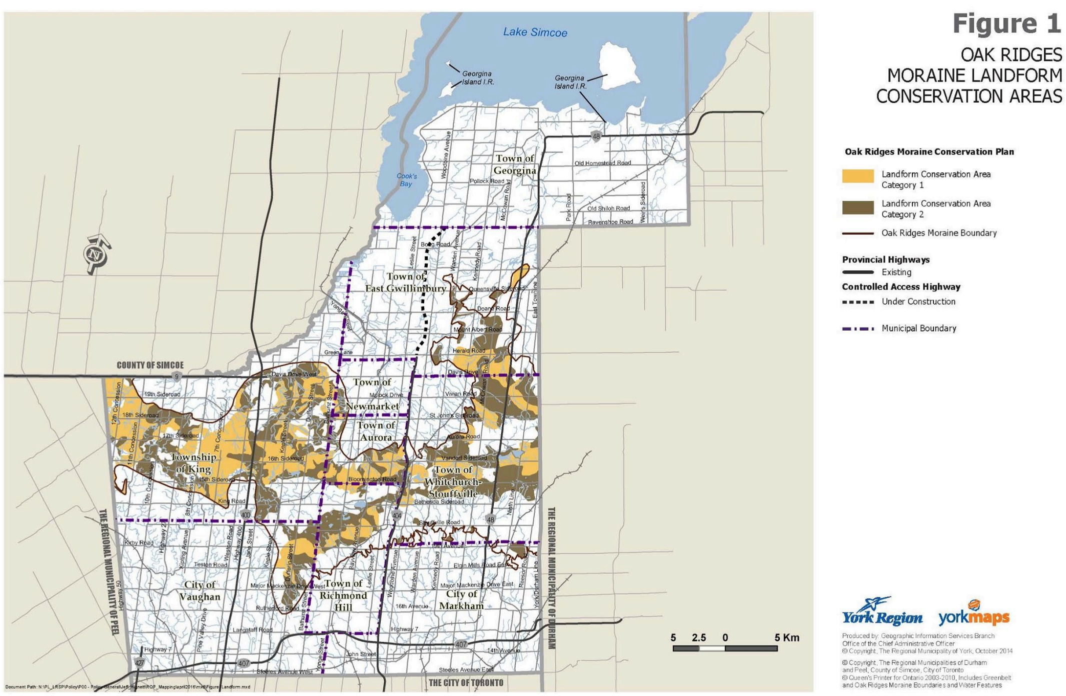


Figure 31 - York Region Oak Ridges Moraine Landform Conservation Area, Taken from []

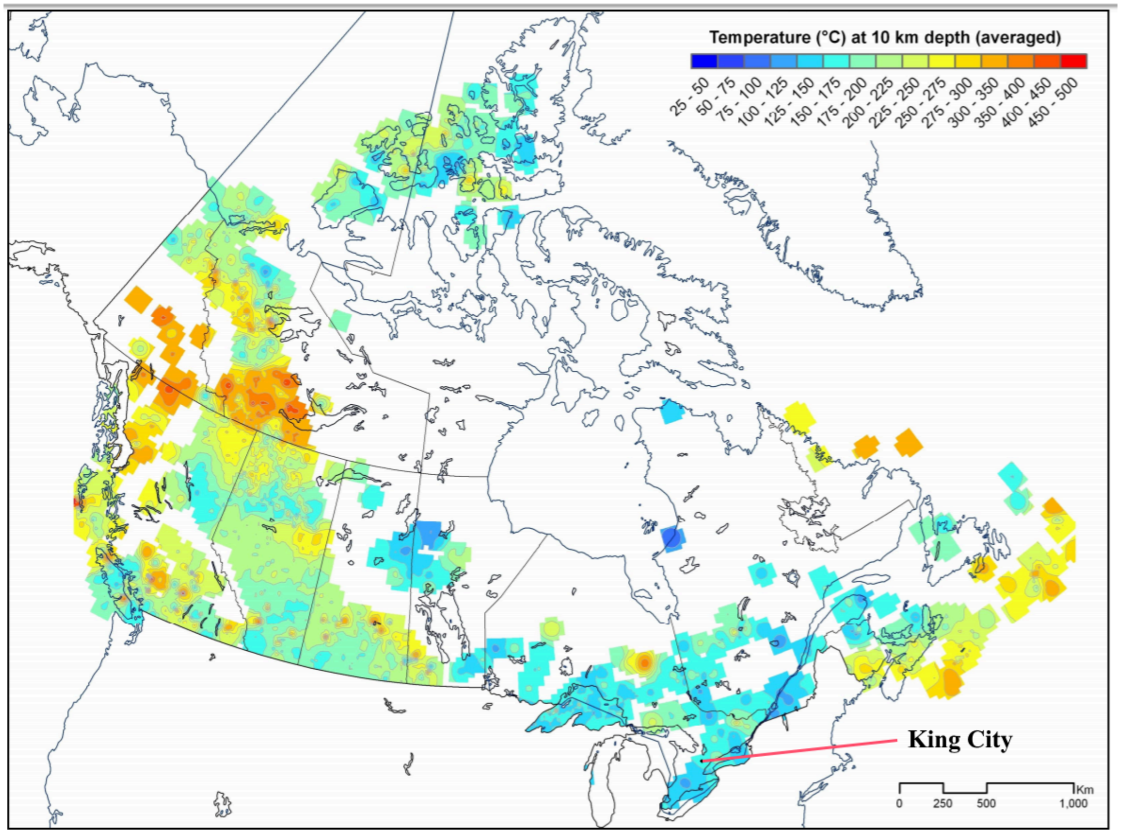


Figure 32 - Temperature at 10 km depth map (p.76), Taken from Geological Survey of Canada report [74]. Modified.

APPENDIX B: Others

This appendix contains miscellaneous supplemental information that provides additional depth to the document.

Structural Decomposition

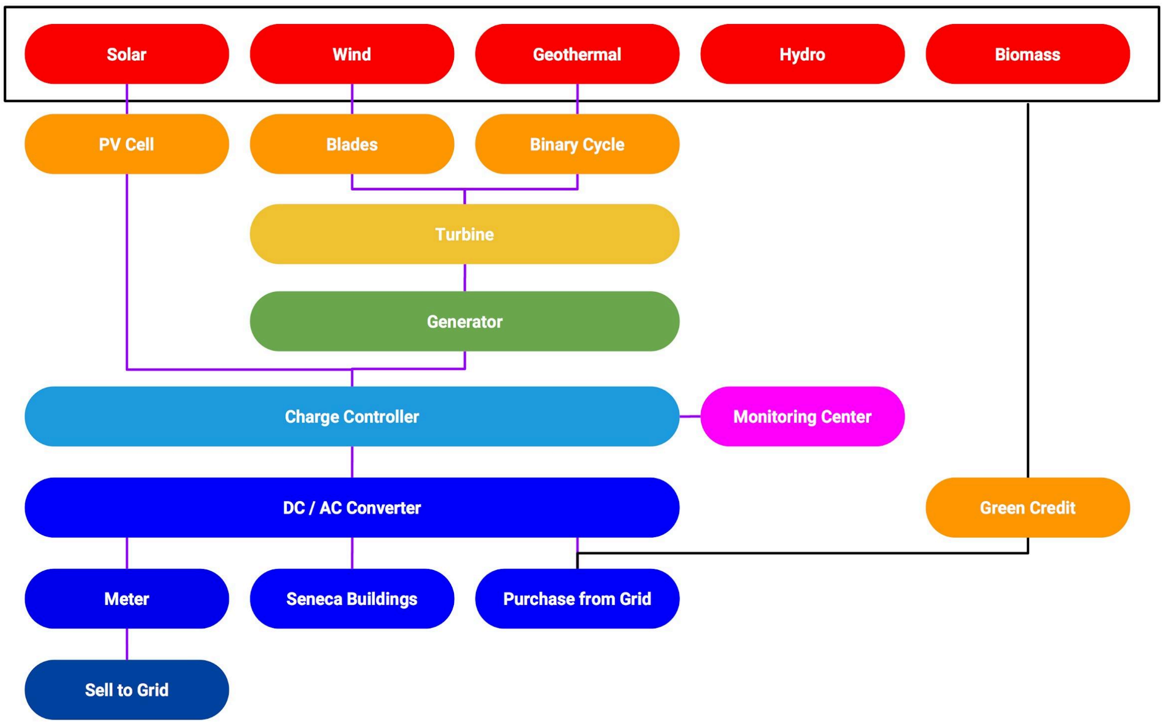


Figure 33 - From the structural decomposition, we can determine the related functions for the functional tree

Further Context on Government Stakeholders

Table 6 - Specific Impact for Stakeholders

Stakeholders	Specific Impacts
Government of Ontario - Ministry of the Environment and Climate Change Regional Municipality of York	• Greenbelt / Oak Ridges Moraine Protection Plan [44],[46] (Figure 14, 15 Appendix A) ○ Natural Core Areas ■ Very limited usage ○ Natural Linkage Areas

<table>
<tr><td>Township of King</td><td>
Mineral aggregate and wayside pits allowed in addition to natural core areas
Countryside Areas
Agriculture, institutional, recreational usage allowed
Zoning Bylaw [47],[40]
30 m vegetation protection zone around Moraine
120 m around buffer requiring approval before construction
</td></tr>
</table>

APPENDIX C: Calculations

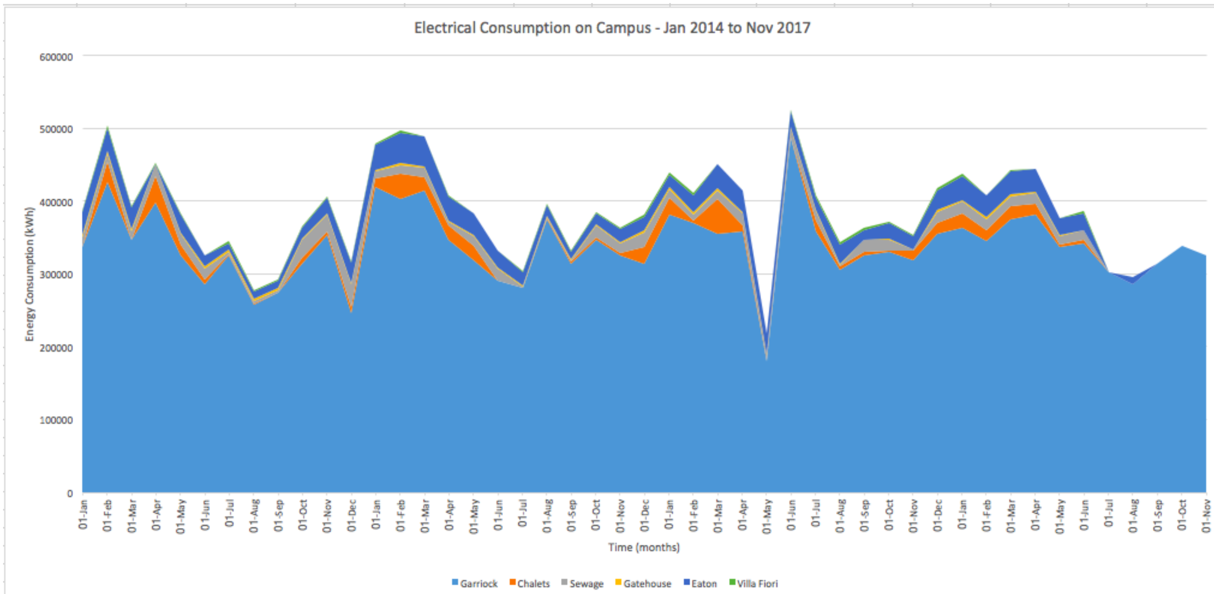
Average Monthly Energy Usage (kWh) [7]

Use average function in Microsoft Excel for each building and added them:	
Garriock:	332 485
Chalets:	14 117
Sewage:	16 690
Gatehouse:	2 022
Eaton Hall:	22 974
Villa Flori:	1 775
Total:	390 063

Average Monthly Gas Usage (m^3) [8]

Animal:	3 758
Portable:	871
Cabin:	432
Eaton:	5 979
Rec Island:	110
Garriock:	17 792
Farm Office:	624
Shop:	2 167
Turf:	26
Greenhouse:	3 040
Daycare:	1 609
Residence	15 385
Total:	51 793

Max Yearly Usage [7]:



July 2016: 524 616 kWh

Figure 34 - Electrical Consumption on Campus - Jan 2014 to Nov. 2017

Yearly Energy Consumption:

Generates at most 524 616 kWh a month.

Max electricity yearly usage = max monthly usage x 12 months
= 524 616 kWh x 12 months
= 6 295 392 kWh per year
≈ 6.3 GWh per year

Natural Gas conversion from m^3 to GWh equivalent.

Max gas yearly usage = 622 000 m^3 [7]* ~10.563 = 6 570 000 kWh per year
≈ 6.6 GWh per year

Electricity Production Equivalent = Max electricity yearly usage + Max gas yearly usage
≈ 6.3 GWh + 6.6 GWh
≈ 13 GWh per year

Maintenance Costs (Objective):

Yearly consumption: 13 GWh
Standard Maintenance costs: $0.03 per kWh [21]

Yearly maintenance costs = yearly consumption*standard maintenance costs*10^6 kWh/GWh
= 13 * 0.03 * 10^6
= $390 000 per year

Net yearly affordability (Objective 3.2.5):

Net earnings between 2016 to 2017: $50 million
Student population for all of Seneca: 98 000 [100]
Student population for King Campus: 3200 [101]

Ratio net earnings for King Campus: $1.63 million / year
+ Electricity & Gas bill ($1.60 million / year)
Net yearly affordability = $3.23 million / year

Cost Calculations for Photovoltaic System:

Cost per SunPower system: $55 380 (30 panels per system) [102]
6000 SunPower X21-345 panels: $11 076 000

Cost per smartflower POP: $20 800 [103]
2275 smartflower POP units: $47 320 000

Total capital cost: $59 080 000
Capital amortized over 25 years (lifespan): $2 363 200 / year
+ Maintenance cost per year: $230 000 / year

Total cost per year: $2.6M / year

Average maintenance cost of a solar power plant:

Lifetime NPV by Service Type			
Service	Avg. Cost/Yr	NPV (Life)	% of Total
Administrator	$8,139	$88,635	5%
Cleaner	$25,239	$274,892	15%
Inverter specialist	$71,551	$550,944	31%
Inspector	$26,850	$286,646	16%
Journeyman electrician	$29,261	$216,399	12%
PV module/array Specialist	$14,563	$114,939	6%
Network/IT	$186	$1,825	0%
Master electrician	$7,223	$53,383	3%
Mechanic	$2,132	$14,926	1%
Designer	$0	$0	0%
Pest control	$1,702	$18,536	1%
Roofing	$0	$0	0%
Structural engineer	$10	$69	0%
Mower/Trimmer	$16,424	$178,884	10%
Utilities locator	$6	$44	0%
Total	**$203,285**	**$1,800,124**	**100%**

Cost excluding administrator, pest control, mower: $177 011 US (convert)

Total maintenance cost: $230 000 / year

Area and Number of Products for Photovoltaic System:

<u>SunPower X21-345:</u>

Available rooftop space: 9800 m^2
SunPower X21-345 Size: 1.046 m (height) x 1.558 m (width) = 1.63 m^2
Number of panels available to fit: 9800 m^2 / 1.63 m^2 = 6035 ≥ 6000 panels

A 10 kW system = 30 SunPower X21-345 panels
6000 panels / (30 panels / system) = 200 systems

Energy Production: 200 systems * 10 kW * 1959 bright hours per year [104] = 3.9 GWh

<u>smartflower POP:</u>

Necessary energy production: 9.1 GWh

Yearly energy production of a smartflower POP: 4000kWh
Number of smartflower POP: 9.1 GWh / 4000kWh = 2275 [59]

Area of Required Set-Up: 25 m^2
Total Area of smartflower POP: 25 m^2 x 2275 = 56 875 m^2

Operation Cost for purchasing Renewable Energy Credits:

Accounts Payable Clerk hourly salary for Seneca College: $30.37 [69]
2080 hours a year
Total salary = $30.37/hr x 2080 hrs = $63169.60 / year
Assumed time spent per month paying REC Bills = 12 hr
Operation Cost for REC Financial Management = $30.37/hr * 12 hr = $364.44

Cost of Purchasing Renewable Energy Credits

All prices from global retailers are in CAD.
King Campus's Maximum Annual Energy Bill = $1.6 million
Yearly Energy Consumption = 13 GWh = 13 000 MWh

Bullfrog Power
Unit Cost of Renewable Energy Credits (RECs) = $25.00/MWh [67]
Custom Quote for King Campus (Annual) = $314 600 [66]
Custom Quote for King Campus (Monthly) = $26 216.67
Total Annual REC Cost (13% HST) = 1.12 * $314 600 = $355 498
Total Cost = $1 600 000 + $355 498 = $1 955 4998

Just Energy
Unit Cost of RECs = $28.50/MWh [71]
Annual REC Subtotal = $28.50/MWh * 13 000 MWh = $370 500
Total Annual REC Cost (13% HST) = 1.13 * $370 500 = $418 665
Total Cost = $1 600 000 + $418 665 = $2 018 665

Terrapass (Individual costs include tax)
*As of US-Canada March 7 Exchange Rates
Unit Cost of RECs = $6.44/MWh [68]
Total Annual REC Cost = $6.44/MWh * 13 000 MWh = $83 720
Total Cost = $1 600 000 + $83 720 = Total: $1 683 972

Fuji Geothermal Binary System Electrical Output:

Power: 2200 kW [76]

Yearly electrical output = power output per 1 hour * (hours in a year) * (GWh per kWh)
= 2200 kW/1 hour * (8760 hours / year) * (1 GWh / 10^6 kWh)
≈ 19 GWh / year

Cost for Geothermal Binary System Geothermal:

Cost of Wells (2 required): 2 x $20 000 000 USD = $40 000 000 USD [105]
Cost of Power Plant Generator: $6 600 000 USD [82]

Total capital cost: $46 600 000 USD
Capital amortized over 30 years (lifespace): $1 533 333 USD / year

For 140˚C, 2.5 MW Power Plant
- Part Replacement: $118 417 USD/year
- Operations & Maintenance: $581 838 USD/year = $750 571 CAD/year
- Annual Well Replacement: $168 921 USD/year
- Production: $2 129 831 USD/year
- Total: $4.55 million USD

= $5.87 million CAD/year for plant life

Appendix D: Preliminary Work

This section provides some context on the process the team underwent to organize information in some order of importance using specific engineering design tools.

Pairwise Comparison

The pairwise comparison method was used to order objectives listed in section 3.2. in descending importance. Note that "sustainable" refers to "Environmentally Sustainable."

Table 7 - Pairwise Comparison for Evaluating Top Objectives

	Sustainable	Affordable	Maintainable	Efficient	Durable	Total	Rank
Sustainable	-----	1	0	0	0	1	4
Affordable	0	-----	0	0	0	0	5
Maintainable	1	1	-----	0	0	2	3
Efficient	1	1	1	-----	1	4	1

Durable	1	1	1	0	-----	3	2

Stakeholder Analysis
This subsection details how the stakeholder interests were characterized from most important to least according to their potential influence and interest in the project.

Table 8 - Brainstorming Stakeholders and Characterizing their Categories of Interest

Environmental ● Toronto and Region Conservation Authority ● Ontario Trails Council ● Ontario Nature	Economic ● Ontario Energy Board ● Hydro One ● Ontario Power Generation
Legal ● Government of Ontario - Ministry of Environment and Climate Change ● Regional Municipality of King ● Township of King	Social ● Ontario Power Union ● Rural Ontario Institute
Human Factors ● Recreational trail users ● Seneca College Students ● King Township Historical Society	

Stakeholder Prioritization
The client, design team and users/operators are primary stakeholder which is why they have not been included in this chart. Note that the final stakeholders section omits multiple stakeholders that have been analyzed as they would not affect the way the final solution is designed.

Table 9 - Stakeholders Organized by Influence and Interest in Project

Low Interest High Influence - Government of Ontario - Ministry of Environment and Climate Change - Regional Municipality of King - Township of King - Ontario Energy Board	High Interest High Influence - Seneca Student Federation - Ontario Power Union - Toronto and Region Conservation Authority
Low Interest	High Interest

Low Influence - Rural Ontario Institute - Hydro One - Ontario Power Generation	Low Influence - Ontario Nature - Ontario Trails - Recreational Trail Users - King Township Historical Society

Appendix E: Idea Generation and Evaluation Process

There were two stages in the selection of three conceptual designs; idea generation and evaluation. Idea generation involved the use of multiple creativity methods (ex. SCAMPER, brainstorming) to employ divergent, analogical and lateral thinking to produce ideas that occupy the solution space broadly. In idea evaluation, systematic decision making tools (ex. graphical decision matrix) were key in objectively identifying the most feasible renewable energy opportunities for Seneca College to pursue. Below, each stage is broken down by creativity and decision making techniques.

STEP 1: Idea Generation

1.A: Free Brainstorming

Free brainstorming is a collaborative brainstorming technique in which ideas are produced by the whole group. At this point, the group had mostly conducted research on case studies of Canadian institutions and individuals employing onsite renewable energy generation and the current state of net zero energy design to develop the initial design criteria. The purpose of this session was to gauge which topics to explore further and identify key areas of interest. The means brainstormed (Figure 35 and Table 10)largely focused on energy generation as opposed to distribution or storage as this is the most important feature of the solution which must be considered for feasibility.

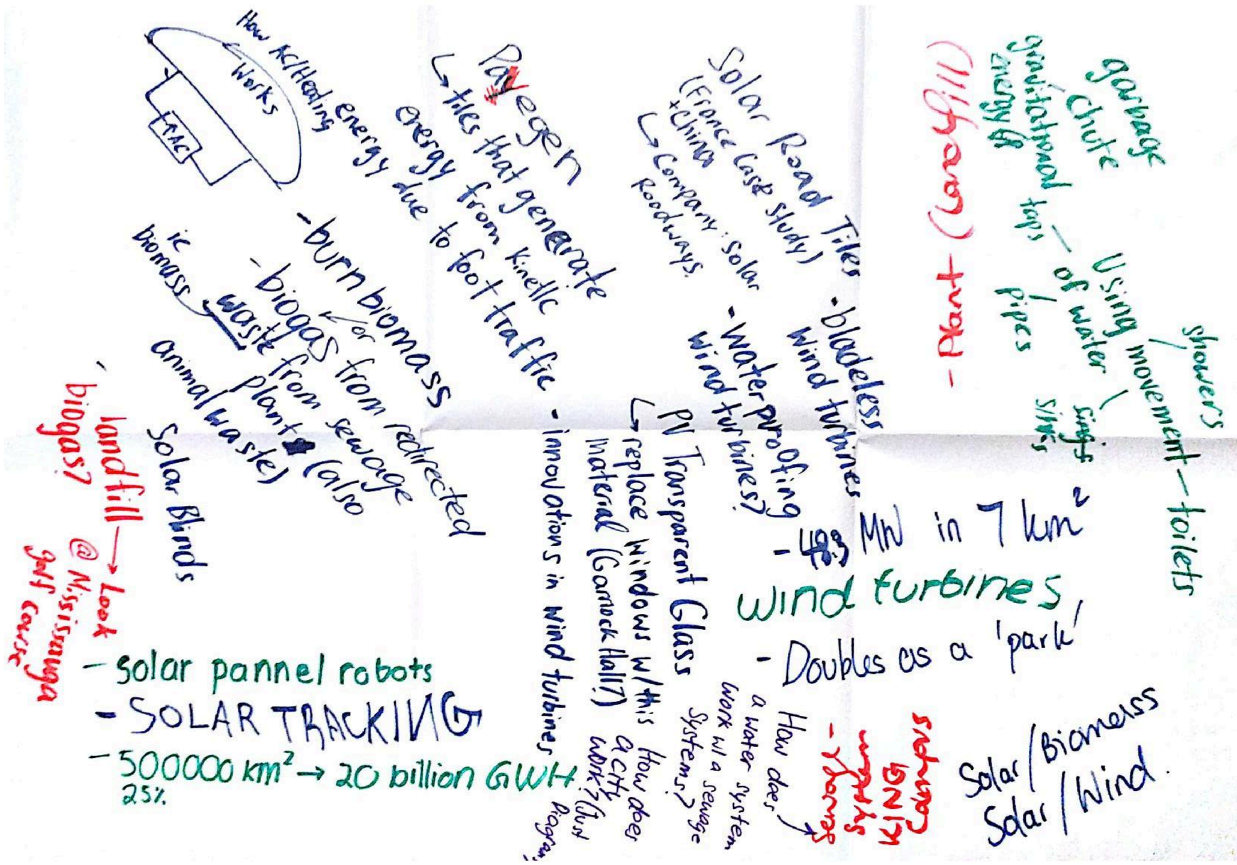


Figure 35: Free Brainstorming Result on Chart Paper

Table 10: Organized Free Brainstorming Result

- Solar Panel Robots
    - Autonomously follows the sun throughout the day by rotating and moving its position on the ground.
- Biomass Use + Sources
    - Wood, Animal Waste, solid waste,
    - Crop Residues from neighbouring farms (King Campus is surrounded on three sides by farmland (Figure 4)
- Wind Energy (Turbines)
- Use landfill gas generation (ie biogas)
- Divert waste for Seneca College's Sewage System
    - Case Study 1: Mississauga Golf Course
    - Case Study 2: Nanaimo District (BC, Canada)
    - Burn biogas (complete combustion) from redirected waste from sewage plant as well as animal waste (from barn, veterinary tech buildings)
- Wind Turbine Farm which doubles as a Park
    - Based on a Case Study: Alberta schools
- Using Movement of Water

    - showers
    - toilets
    - sink (water flowing down drain)
    - pipes
    - sink taps
- Solar Window Blinds
- Floor Tiles
    - Tiles that generate energy from kinetic energy from foot traffic
    - Company: Pavegen
- Bladeless Wind Turbine
- Converting energy due to gravity to electrical energy.
    - garbage chute with a pressure plate the bottom which converts the impact of the trash into electrical energy.
- Solar Road Tiles
    - Case Studies: France + China
    - Company: Solar Roadways
- Photovoltaic Transparent Panels
    - Replaced Windows at Seneca with This Material

After applying this method, the team observed that fundamentally, most renewable energy products (as well as non-renewable) involve converting mechanical energy to electrical via a rotating turbine. Also, based on case studies across Canada and the world, successful energy generation methods used by cities were often integrated into the functionality of the city. Thus, unification of Seneca College's daily operations (eg. sewage and water treatment plant, food waste) with their energy generation could help the proposed design function more efficiently and also reduce the number of parts required to be installed.

1.B: SCAMPER (Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, Reverse)
SCAMPER is a creativity tool and mnemonic which aids the design process by prompting the improvement of existing products or services to yield more inventive solutions. The intention of this project is not to invent new energy generation solutions however, so SCAMPER was heavily supported by research of products currently available in the market or emerging technologies being tested by institutional research.
SCAMPER specifically allowed the team to expand their knowledge of the continued development of solar, wind and biomass opportunities which are often considered the traditional methods in the renewable energy field. Some of the resulting ideas were also biomimetic.

Table 11: Specific SCAMPER Terms Applied to Each Renewable Energy Cluster

Renewable Energy Cluster	SCAMPER Term	Resulting Idea

Solar	C: What if solar energy cannot sustain the entire campus independently?	Hybrid Solar and Wind Farm Case Study: Australian Gullen Range Hybrid Solar & Wind Farm
	P: How can the sun be used in another way in addition to radiant light? C: Is there a way to use the concept of peltier tiles, which generate a current from a temperature difference between two conductors or semiconductors?	Panels with dual solar photovoltaic and thermal energy conversion functionality to increase efficiency [106].
	E: The solar energy collecting instrument cannot be connected to Seneca structures?	Solar Panels placed on street lights storing and providing their energy.
	P & A: Can solar panels serve a function beyond electrical energy generation?	1. Transparent solar tiles, which will replace windows - possibly triple or quadruple paned (with only 1 solar layer) for improved insulation [107]. 2.Photovoltaic thermal hybrid solar collectors which collect radiant energy and capture waste heat to be used to heat a building and also water. This would be exclusively installed on buildings. Company: SolarWall by Conserval Engineering Inc. (Global) [108] 3. Floor tiles which generate energy from foot traffic (kinetic energy) and also have solar energy collecting abilities.
	E: What if solar panels could not be installed on the ground?	1. Offshore Floating Solar Farm [109] Case Studies: China built a floating solar farm on a deserted coal mine [109] and Netherlands is currently implementing

		similarly structured solar farms [110]. 2. Solar Balloons (Company: Cool Earth) [111]
	E: What if solar panels could not absorb energy from radiant light?	Solar thermal energy plant: Collect and concentrate sunlight to heat a fluid, which will produce steam and power a turbine [111]. Case Study: Kuthu Solar Park CSP Plant, South Africa
	M: How could solar panels become more efficient without altering their material but instead changing their physical or mechanical properties?	1. Solar Panels which mechanically track the movement of the sun to maximize absorption of light. Product: Smartflower Pop + Company: Smartflower (Austrian) [112] 2. Concentrated Photovoltaic Cells which are curved and mirrored to maximize exposure to the sun's rays [113].
	A: What other products could be used for inspiration in the creation of a solar panel? S: What other existing processes (natural or engineered) could a solar panel emulate?	Biohybrid solar panels which mimic the natural photosynthetic process by converting photonic energy into electricity. These panels are made of organic matter [114]. Institution Conducting Research: Vanderbilt University
	S: What other materials could be used to reduce environmental impact of construction of the solar panels themselves?	Biobased solar panel which uses plant based materials for its backsheet, and have high thermal conductivity so they do not overheat like many traditional petroleum based solar panels. Product: BioBacksheet

Wind	E: What if wind turbines did not have blades?	1. Bladeless Wind Turbines Product: Saphonian Company: Saphon Energy 2. Corkscrew Wind Turbine: Turbine specifically designed for low wind areas. Multiple off-the-shelf wind turbines are fit into grooves of a large plastic corkscrew which directly funnels more wind into each turbine.
	M: What if wind turbines did not have vertically spinning blades?	Vertical axis wind turbines Company: State of the Art Wind Technologies (SAWT) (USA)
	R: Is there a process with the purpose of minimizing energy while circulating/processing/draining a fluid that a wind turbine could emulate?	1. Replicating the spiral fluid flow found in nature (ex. in whirlpools, tornadoes) which minimizes energy while circulating large volumes of fluid. Product: Lily Impeller 2. Using biophysics to analyze how hummingbirds are able to expend so little energy 150-200x per minutes. The final product is a wind converter which does not spin but flaps its wings [115]. Company: Tyer Wind
Biomass	C: How can biomass exist cohesively with closeby sites of other renewable energy technologies?	Multifunction Environmental Energy Tower, based on a conceptual design. This is a vertically developed building that integrates several renewable energy technologies with the premise of isolating the energy generation to a single, limited location. For instance, the roof would be covered with photovoltaic panels, the building would have a dedicated geothermal system, and a

		biodigester in the main stem of the tower. The dimensions of this buildings would be 10mx10m with 35m height [116]. Institution Developing Conceptual Design: University of Perugia
	M: Could biomass alternatively be used as natural gases are traditionally used?	Algae as biofuel
		Food Waste 1. Biodigestors to enable anaerobic digestion -> Biogas 2. Ethanol Fermentation -> Bio-ethanol/CO_2 3. Incineration to produce Heat + electricity 4. Pyrolysis & Gasification to produce sungas/bio-oil/Char 5. Hydrothermal carbonization o produce Hydrochar/Gas

After learning about the products of biomass electricity generation, the team realized that this resource may not be a top option for Seneca College. This is because their overarching goal is to become a net-zero carbon campus and the combustion process involved in biomass releases carbon dioxide (CO_2), albeit less harmful than methane (CH_4).

1.C: Benchmarking

While 1.B. unintentionally integrated SCAMPER with a benchmarking process, this time the group exclusively focused on benchmarking in terms of types of energy available for electricity conversion, innovations in energy storage and very new technology that could become more widespread in the future.

Mechanical Energy

- SOCCKET (Soccer Ball) and Pulse Jump Rope: Converts kinetic energy from play (kicking/hitting other surfaces) in electricity and stores it for later use.
- Footstep energy generation (tiles)
- Hydro/tide from Seneca Lake or Seneca's Wastewater Treatment Plant Excretion
- conversion of piezoelectric energy (seismic activity) into electricity [117]
- Waterotor, a wind turbine for aquatic locations where the speed of moving water is very low (down to 2 mph)

- Create a Decentralized hydro plant beside any source of travelling water like a river.
  - Company is called Turbulent (Belgian)

Energy storage

- Air breathing battery
  - Using the rusting process of iron to store energy.
- More efficient energy storage in plastic PV cells based on pasta dishes [119]

Miscellaneous Emerging Technology

- Using static (triboelectricity) to power nanogenerators [118]
- Electromagnetic harvester that converts ambient radio frequency energy electricity - just enough power for very small devices, especially Internet of Things devices [118].
- Optical Rectenna converting electromagnetic energy into DC current [118]
  - Solar panels convert light particles into electricity whereas optical rectenna converts light WAVES into electricity.
  - (since light is considered to be both a wave and a particle)

1.D: Biomimicry (Divide by emerging technology and existing technology)

The field of biomimicry draws inspiration from animals or natural processes, Although the observations made during this creative method session are not immediately actionable, they are currently being used to improve the existing technology in the renewable energy technology space which may be in the market by 2050.

- Photosynthesis Mimicry
  - Artificial Leaf which splits solar and water [119]
  - Solar Botanic [120]
    - artificial trees which collect both electromagnetic energy and wind energy
    - No products yet, are current conducting R&D with Brunel University in London)
  - understanding how fern leaves are able to store so much energy in their leaves artificial photosynthesis
  - Emulating the wrinkles and deep folds of organic structures in photosynthesis for photovoltaic cell potential
- Based on the design of a whale's fin, wind turbine design based on them as they are able to move so fluidly in the water
- Minimizing Turbulence caused by wind turbine blades
  - Arranging vertical wind turbine in a "school of fish" pattern to maximize energy efficiency of wind turbines and minimize negative impact of wind turbines on eachother and actually aid in movement of other fish.

    - more efficient arrangement of wind turbines can emulate the optimal fish school arrangement
- Schools of Fish are organized in a way such that their individual movements do not deter the movement of other fish. This pattern could be replication with wind turbines. They can be organized in a such a way to ensure turbulence does not affect turbine performance.
    - Most of the time, conventional horizontal axis wind turbines placed close to each other experience reduced power coefficient.
- Concrete which emulates the Growth of Coral
    - Concrete mimics coral reef skeleton formation in its own formation.
    - Concrete draws in carbon from the atmosphere in its production, which is useful for both 1) Carbon Sequestration and 2) Buildings
    - Product: Concrete Company: BluePlanet
- Seaweed-inspired hydropower
- Butterfly wings have tiny scales that make up their wings and act like tiny solar collectors
    - In research labs, butterfly wings used as templates for producing thin solar panels for which angle of exposure to the sun does not affect how much radiant energy is absorbed by the solar panel.

1.E: Lateral Benchmarking

After having a of the field of sustainable energy production, other fields were explored through lateral benchmarking through the functional basis of “converting energy.”

- At this point, we knew enough about the field of sustainable energy and wanted to explore other fields
- Gasoline in Cars:
    - Gasoline (chemical) -> kinetic -> Thermal energy

1.F: Structured Brainstorming

During the second client meeting, the client broadened the scope slightly more by recommending that the team research Renewable Energy Credits for the purpose of net zeroing the campus. Thus, each team member did a final review of research on existing technology and possible companies with this increased scope. Each team member produced 5 lateral benchmarks and 10 biomimicry examples which are included in the multi-voting list of ideas.

STEP 2: Idea Evaluation

2.A: Multivoting

The group started with over 50 ideas, and exclusively means for energy conversion as this is the most important aspect of the project. Each group member voted for 7-8 ideas resulting in 12 ideas.

Ideas + Categories	Votes
1. Wind power a. Standard wind turbines b. Bladeless wind turbines c. SAWT product (spins horizontally) d. Butterfly/Hummingbird Wings e. Whale fins f. Arranging vertical wind turbines in a "school of fish" pattern	I IIIxx III
2. Solar Power (Types) (Top Products) a. PV/Wind hybrid Farm i. Potentially additional planning for maximized usage b. Artificial photosynthesis i. Electrolyzers ii. Artificial leaves 1. (slide 3/11) Artificial Leaf Device c. Dual solar PV/thermal panels to increase efficiency d. Solar on lights e. Transparent Solar Tiles f. Floating PV Farm g. Solar Thermal Energy, heating fluids, steam runs through and runs turbines h. Plant based solar panels: BioBacksheet i. Solar energy -> chemical process to produce hydrogen fuel cells. (photoelectrochemistry). Now, the focus is on powering cars. j. biosolar cells Project that mimic process of photosynthesis k. Smartflower l. Solar panel windows	IIIII I II I II IIIII II
3. Biomass a. Cooking Oils b. Wood c. Biogas d. Animal Waste e. Garbage/Sewage f. Food-waste to energy	III

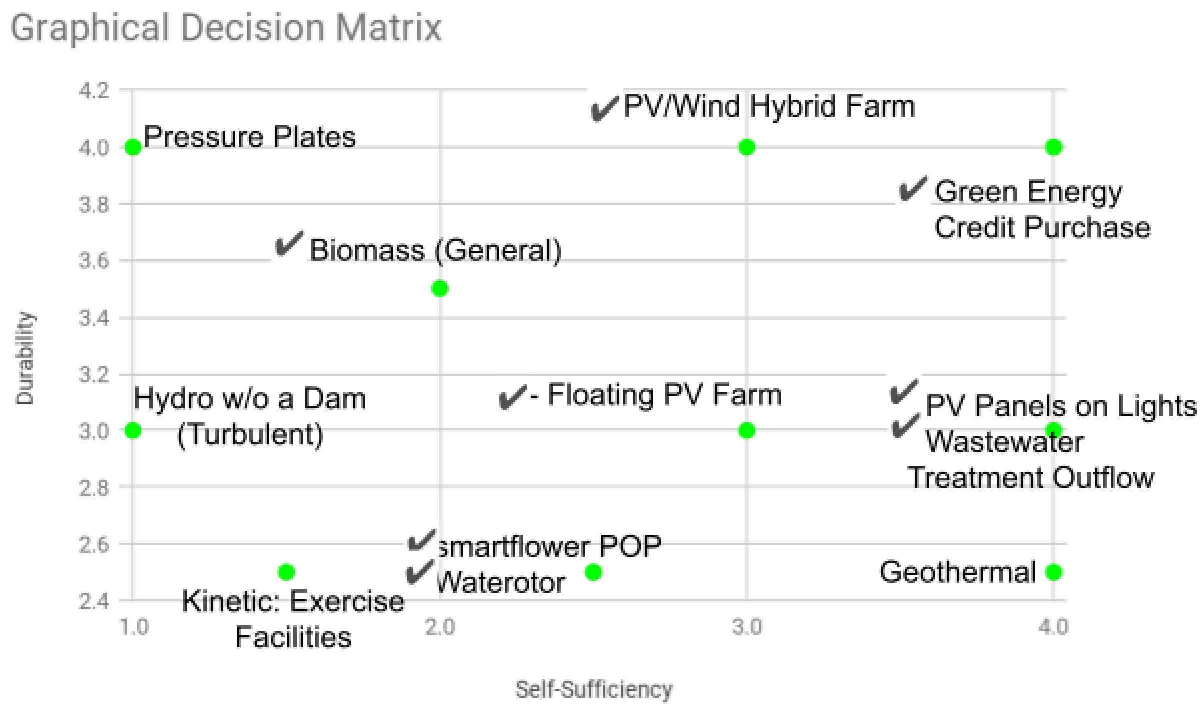
4. Water a. hydro/tide (from the lake) (Wastewater Treatment Plant Outflow) b. Seaweed inspired hydropower i. bioWAVE c. Rainfall into lake d. Generator in slow moving water i. Waterotor e. Hydro power without a dam i. Turbulent	II IIII I
5. Kinetic Energy a. Pressure Plates on Roads and Sidewalks i. Footstep energy generation Foot traffic energy b. Pulse Jump rope c. SOCCKET (Kinetic Soccer Ball) d. Use the idea of converting kinetic energy to electrical e. Fan Powered Jump Rope i. Internal fans in HVAC potential candidates ii. Building on the idea of Pulse Jump Rope idea f. Gasoline in cars: i. Gasoline (chemical) -> kinetic + thermal energy g. Flashlight (mechanical) - pump flashlights i. Convert mechanical energy into light energy & heat byproduct h. Speed Bumps (absorb kinetic energy) i. Hook it up to the freeway… i. Lots of energy released in earthquakes. There are technologies that can potentially harvest this energy. i. Fracking provides energy but usually causes more earthquakes (even in regions never prone to earthquakes) j. Kinetic Energy from waves from Swimming Pools (People Swimming)	IIIII I I II
6. Misc. a. Harvesting ground wave energy b. Isothermal expansion c. Convert static to usable electricity d. Electromagnetism to electricity e. Buying Green Credits	IIII

7. Geothermal ● (Fuji Electric) prepackaged geothermal binary units	III

2.B: Graphical Decision Matrix

The top objectives were self sufficiency and durability. The former was most important because some technology in this relatively new field does not produce high efficiency ready-to-install products . Thus, this was one of the biggest challenges faced in the decision making process. Durability was also essential because the life cycle of a renewable technology has to be long enough to justify a high initial cost. This decision making method helped narrow the range of ideas from 12 to 9. The table below gives objective fulfilment ratings for each idea, and the following graph visualizes these ratings.

Idea	**Self-Sufficient (x axis)**	**Durable (y axis)**
PV Wind Hybrid Farm	3.0	4.0
Pressure Plates (Walkway, roads, speed bumps)	1.0	4.0
Smartflower POP Product	2.5	2.5
Biomass (general for now)	2.0	3.5
Hydropower w/o a dam (Turbulent)	1.0	3.0
Waterotor	2.5	2.5
Buying Green Credits	4.0	4.0
Wastewater Treatment Plant Outflow	4.0	3.0
Floating PV Farm	3.0	3.0
PV panels on lights	4.0	4.0
Kinetic: Exercise facilities	1.5	2.5
Geothermal	4.0	2.5



2.C: Weighted Decision Matrix

To determine which ideas to pursue, the team chose the top 9 ideas from the graphical decision matrix and created a weighted decision matrix. This matrix takes each objective and multiplies it by its relative weight and a score generated on a 0 to 5 scale on the design's ability to meet the goal. When creating the relative weights of each objective, the team prioritized self-sufficiency and durability since they ultimately achieved Seneca's main goals of net-zero energy consumption. The other three objectives were low priorities according to the client whose purpose was to understand the feasibility of all renewable energy opportunities at the campus.

Also, at this stage, the group decided to explore the potential of Renewable Energy Credits (REC) since it would achieve the goal of net-zero but outsourced the electricity generation. Participating in the REC system would relinquish some power and transparency about where the renewable energy sources are located, and what they are. Therefore, the design criteria and identified scope were altered to encompass both onsite and offsite options and affected this stage of the decision-making process.

Table 13: Ranking Objectives by Weight Carried in Weighted Decision Matrix Process.

Objective	Rank	Weight
Self-Sufficient	1	45%

Durable	2	20%
Maintainable	3	15%
Environmentally Sustainable	4	10%
Affordable	5	10%
Total		**100%**

Table 14: Ranking Objectives

Objective rank	Description of rank
0	Does not meet objective at all
2	Meets objective weakly
4	Meets objective to a small degree
6	Meets objective to some degree
8	Meets objective to a large degree
10	Completely meets objective

Table 15: Final Weighted Decision Making Matrix
*WW = Wastewater, PV = Photovoltaic

Objectives	**PV on Lights**	**Waterotor**	**Floating PV**	**PV**	**WW Treatment Outflow**	**Green Credits**	**Biomass**	**Geothermal**
Self-Sufficient	0.45	2.70	3.15	4.50	2.70	4.50	1.35	4.50
Durable	1.60	1.20	1.40	1.60	1.40	2.00	1.80	1.60
Maintainable	1.35	1.05	0.90	1.05	1.05	1.50	1.35	1.20
Environmentally Sustainable	0.60	0.70	0.60	0.60	0.70	1.00	1.00	0.80
Affordable	0.90	0.50	0.70	0.70	0.80	0.70	0.90	0.30
Total	4.90	6.15	6.75	8.45	6.65	9.70	6.40	8.40

Final Ideas to be Pursued:

1. Green Credits
2. Geothermal for power generation, NOT heat.
3. Photovoltaic Cells, possibly using the Smartflower Product of campus and the smartflower