November 25, 2014

Sustainable Approaches to Controlled Environment Agriculture

Marcela Crowe

Report of a Major Portfolio submitted to the Faculty of Environmental Studies in partial fulfillment of the requirements for the degree of Master in Environmental Studies, York University Ontario, Canada

Student's Signature:

Supervisor's Signature:

Table of Contents

ABSTRACT 4

FOREWORD 5

PART 1: ARTICLES 7

URBAN AGRICULTURE AND THE RISE OF PLANT FACTORIES WITH ARTIFICIAL LIGHTS (PFALS) 7

BIBLIOGRAPHY 11

CHALLENGES FACED BY COMMERCIAL AQUAPONICS FARM OPERATIONS 12

BIBLIOGRAPHY 16

ALTERNATIVE SOLAR TECHNOLOGY FOR GREENHOUSE OPERATIONS IN CANADA 17

BIBLIOGRAPHY 20

DIRECT APPLICATION OF GEOTHERMAL ENERGY AND GEOTHERMAL GROUND SOURCE HEATING FOR GREENHOUSE CROP PRODUCTION IN CANADA 21

BIBLIOGRAPHY 26

PRODUCT LIFE CYCLE ASSESSMENTS ARE NEEDED IN THE URBAN AGRICULTURE SECTOR TO PROMOTE GREATER TRANSPARENCY 27

BIBLIOGRAPHY 29

PART 2: REFLECTION PAPER 30

SUSTAINABLE APPROACHES TO CONTROLLED ENVIRONMENT AGRICULTURE 30

INTRODUCTION 30
FOOD SECURITY DEFINITIONS 31
LOCAL FOOD SYSTEMS & SHELTERED AGRICULTURE 33
CONTROLLED ENVIRONMENT AGRICULTURE (CEA) 34
A BRIEF HISTORY 34
CHALLENGES 36
SUSTAINABLE APPROACHES TO CONTROLLED ENVIRONMENT AGRICULTURE 37
PASSIVE SOLAR ENERGY GREENHOUSES 38
WASTE HEAT CAPTURE AND CO-GENERATION GREENHOUSES 41
AQUAPONICS: MULTI-TROPHIC AGRO-ECOSYSTEM FOR FOOD PRODUCTION 43
CONCLUSION 47
BIBLIOGRAPHY 48

PART 3: TECHNICAL PAPER 51

EXCERPTS FROM TWO (2013) RESEARCH REPORTS WRITTEN ON BEHALF OF YORK REGION FOOD NETWORK (YRFN) IN SUPPORT OF THE UPSTREAM AQUAPONICS SOCIAL ENTERPRISE FACILITY IN NEWMARKET, ONTARIO 51

INTRODUCTION **51**
AQUAPONICS SYSTEMS LAYOUT **54**
CROP RECOMMENDATIONS **57**
ENVIRONMENTAL CONTROLS FOR PLANT & FISH PRODUCTION **59**
PRODUCTION CAPACITY ANALYSIS/FINDINGS **65**
POSITION DESCRIPTIONS **70**
APPENDICES **74**
APPENDIX A – PLANT PRODUCTION RECORD 74
APPENDIX B - IPM RECORD 75
APPENDIX C – ONSITE WATER QUALITY RECORD 76
APPENDIX D – INVENTORY RECORD 77
APPENDIX E – ENVIRONMENTAL CONTROLS 78

Abstract

This Major Portfolio explores the role sustainable controlled environment agriculture has in responding to concerns about local food security in a cold weather climate such as Canada. The technologies and processes examined within this Major Portfolio are plant factories with artificial light (PFALs), aquaponics, passive solar energy, photovoltaic, cogeneration and geothermal greenhouses, as well as a household hydroponic vertical growing kit for home and office food production. While some of the technology that is assessed is well established, others represent fairly new developments within the arena of CEA and require further advancement to assess whether they have a place as an adaptation response to climate change or can effectively play a roll in a local food systems approach to community food security in Canada.

An essential question that guided my Major Portfolio research is, in what way, if at all, can growing food in an enclosed environment be a response to a local food systems approach to community food security in a cold weather climate such as Canada?

As part of my Major Portfolio I examine under what conditions sustainable CEA technologies can be a part of a strategy aimed toward greater food security. The following are questions that informed my Major Portfolio research:

- What are the most recent developments in sustainable CEA?
- What are the groups, organizations and businesses that are operating in this space?
- What are potential ways in which sustainable CEA can serve as a mitigation and adaptation strategy to climate crisis?
- How can the concerns levied towards 'sustainable' CEA from the perspective of climate crisis be resolved?
- How can sustainable CEA technologies be adapted to reflect the priorities of food security and food sovereignty movements?

Foreword

This Major Portfolio looks mainly in depth at one significant pillar to my Plan of Study, and that is sustainable approaches to controlled environment agriculture (CEA). However an examination of this pillar cannot be achieved without touching on another pillar in my Plan of Study, green business. The products of my Major Portfolio necessarily look at the economic opportunities that exist for farmers, entrepreneurs, and social entrepreneurs within the arena of sustainable CEA, but also looks critically at the dangers of 'green washing,' while simultaneously advocating for greater levels of transparency of commercial greenhouses, or newly emerging indoor urban agriculture farms to be more accountable to their sustainability claims and positioning for example, within the local food security movement.

This Major Portfolio is an interdisciplinary work comprised of a series of five articles, as well as a reflection paper and a technical paper. Rather than submit a Major Research Paper I opted to submit articles, a technical report and a reflection paper as part of my Major Portfolio. This has allowed me to approach the themes of my research in a manner that is multidisciplinary.

In an effort to make accessible the findings of my research I have written short stand alone articles for the general public, that breakdown some of the large themes I address in the reflection paper, and zero in on particular urban agriculture companies, technological processes to explore them in more detail. The articles explore emerging and often sizeable vertical or indoor farming companies as well as technologies that have been positioned, or position themselves within the food security and urban agriculture movement. I place emphasis on critically examining the claims made by these companies or proponents of these technologies in an effort to provide an overview of the existing terrain as well as some of the challenges these companies and processes face in meeting environmental sustainability claims.

The reflection paper examines emerging or established technologies within the arena of controlled environment agriculture (CEA) and evaluate their merits according to their application and use within a local food systems approach to community food security in a cold weather climate such as Canada. I provide an overview and brief history of CEA, taking note of the inherent environmental sustainability challenges within the sector.

The technical paper consists of excerpts from reports I submitted to York Region Food Network (YRFN) between August and December 2013, in support of their 1000 square food indoor aquaponics farm pilot project and social enterprise, in Newmarket, Ontario.

Part 1: Articles

Urban Agriculture and the rise of Plant Factories with Artificial Lights (PFALs)

Vertical farming seeks to offer a solution to the world's major challenges through the use of highly technical, hydroponic forms of urban agriculture, utilizing the indoor space of office towers, and other indoor environments, as a response to environmental degradation associated with conventional soil based field agriculture.[1] American ecologist Dickson Despommier first used the term vertical farming to describe a world where large-scale food production systems would exist in high-density urban environments, where skyscrapers could theoretically produce vegetables, fish, and poultry, using forms of renewable energy to support production.[2] Rather than increase the area of land that is farmed globally, he sees agriculture in part moved to the city, utilizing the vertical space of high rises.[3]

This highly technically sophisticated form of urban agriculture is still very much in its infancy, and there are a number of technical and engineering challenges such as transporting produce up and down skyscrapers and the high energy requirements of such structures and artificial lighting that have raised concerns about what purports to be a sustainable solution to addressing the problems of hunger and climate change. What has emerged over the last decade, however, is the utilization of warehouse space, in highly dense urban environments, for the purpose of large-scale commercial food production. Known as Plant Factories with Artificial Lights (PFALs), the largest of these

---

[1] The Vertical Farm. The Vertical Essay (http://www.verticalfarm.com/the-vertical-essay/) Accessed 2014
[2] http://www.verticalfarm.com/the-vertical-essay/
[3] Ibid.

facilities is capable of producing up to 25,000 heads of lettuce each day.[4] PFALs are often times outfitted with multi-tiered stacked hydroponic growing units, which can reach up to 20 feet high. They are environmentally controlled, so that heating, lighting, relative humidity, pH, and CO2 levels are adjusted to provide optimal conditions for the production of leafy greens, such as lettuce. There are approximately 150 PFALs in Japan growing leafy greens and herbs sold primarily to the food services industry.[5] These facilities are touted as a form of sustainable urban agriculture as to some degree they are resource efficient. For example, in Japan "[w]ater consumption for irrigation in PFALs is reduced by about 95 percent compared to open-field production by recycling the water transpired by leaves, using the air conditioning system as a condenser… Energy use for transport from production to consumption sites and loss of produce during transport are also reduced considerably."[6] These facilities however require a lot of energy to both regulate indoor temperatures, and to provide sufficient lighting for the plants. Unfortunately there are no known life cycle assessments (LCAs) of PFALs that identify the energy and resources per unit required to produce crops in such facilities. In the US, where PFALs are beginning to gain traction, and in part in Japan, underutilized and abandoned warehouses and manufacturing plants have been repurposed as indoor farms, lessening the environmental impact and energy associated with the materials and construction of these buildings from scratch.

A non-profit social enterprise in Chicago that has transformed a four-story warehouse into a 'food incubator' and indoor farm, called The Plant, plans to offset their environmental impact associated with both heating and lighting the entire building with the use of an anaerobic digester. The anaerobic digester

---

[4] Kozai, Toyoki. "What PFAL Means to Urban Agriculture." Resource. American Society for Agricultural and Biological Engineers (ASABE) (March April 2013):12
[5] Toyoki, p.12
[6] Ibid.

"converts food waste into biogas"[7] and captures "methane from 27 tons of food waste daily."[8] A combined heat and power engine will be used and is set to both generate heat and electricity from the digester and according to Executive Director, John Edel, "The Plant will remain connected to the public electrical grid and natural gas pipeline, providing ...[The Plant] …not only with a backup power source but also the possibility of feeding ... [it's] surplus electricity back to the public grid."[9] The Plant houses a number of food businesses such as a mushroom and aquaponics farm.[10]

While The Plant is in large part in its early stages of development, and the farm itself is intended to be a "proof of concept and serve as a tool for education,"[11] FarmedHere, a company also located in Chicago has shown that there is commercial application to large scale PFAL technology. In operation since 2011, and under the leadership of CEO Jolanta Hardej, FarmedHere currently has three PFALs in operation, the most recent of which is reportedly the largest PFAL in the US at 90,000 square feet. FarmedHere began with two fairly small facilities, one 4,000 and the other 10,000 square feet. Because the indoor production units are stacked utilizing the vertical space of the warehouses, FarmedHere currently has a growing area amounting to 3.5 acres.[12] The 90,000 square foot facility is set to "produce an anticipated 1 million pounds of chemical-, herbicide- and pesticide-free leafy greens -- including basil, arugula, mints and other greens -- to the Chicago area once it hits full production."[13] Unlike PFALs in Japan, the plants in the 90,000 square foot facility are grown using a form of agricultural production known as aquaponics.

---

7 Marks, Josh. "Food Waste Fuels Vertical Farming in Chicago." inHabitat, April 10, 2014 (http://inhabitat.com/food-waste-fuels-vertical-farming-in-chicago/)
8 inHabitat, April 10, 2014
9 The Plant. Frequently Asked Questions. (http://www.plantchicago.com/about/faq/) Accessed 2014
10 inHabitat, April 10, 2014
11 The Plant. Frequently Asked Questions. (http://www.plantchicago.com/about/faq/) Accessed 2014
12 Meinhold, Bridgette. "FarmedHere: The Nation's Largest Indoor Organic Farm Now Growing in Chicago." inHabitat, May 27, 2014 (http://inhabitat.com/farmedhere-the-nations-largest-indoor-organic-farm-now-growing-in-chicago/)
13 Ibid.

"Plants are grown in beds stacked as much as six high by using a mineral-rich water solution which is derived from tanks of hormone-free tilapia offering up nutrients to the plants in a controlled environment that ensures optimal growing."[14] "Whole Foods, which sells the company's greens in its Chicago stores, helped finance the new facility with a $100,000 loan"[15]

While as commercial operations, PFALs are a fairly new phenomenon, there is potential for these systems to create future protection from climate variability due to climate change. There is much room to drastically reduce lighting and energy requirements. However, protection from soil contamination, extreme weather conditions and in Japan, protection from nuclear radiation, put PFALs in the category of a strategic adaptation response to climate change. In Fukushima a microchip plant was just recently converted into a PFAL, where plants are grown in a converted semiconductor plant free from radiation and other "environmental contaminants and pests."[16] In a fully controlled and enclosed environment, plants are able to grow all year round, regardless of the outdoor climate. If existing waste can be used to heat and light the indoor facility year round, there is even potential for this technology to work as part of a mitigation strategy to climate change. As it stands, there is still much more research to be done to explore the economic feasibility of the inclusion of renewable energy, such as solar, to these facilities, as well as to conduct product life cycle assessments. This is an area of research where to date little ground has been broken.

Breakthroughs in lighting technology research and design, such as in the field of light emitting diodes (LEDs), may also significantly reduce energy

[14] Ibid.
[15] "FarmedHere, Nation's Largest Indoor Vertical Farm, Opens In Chicago Area." Huffington Post, March 22, 2013 (http://www.huffingtonpost.com/2013/03/22/farmedhere-nations-largest-vertical-farm_n_2933739.html)
[16] Lisa, Ana. "Fujitsu Converts Fukushima Microchip Factory into a Radiation-Free Lettuce Farm." inHabitat, May 19, 2014 (http://inhabitat.com/fujitsu-converts-fukushima-microchip-factory-into-a-radiation-free-lettuce-farm/)

consumption.[17] Toyoki Kozai, Chief Director of the Japan Plant Factory Association, and Professor Emeritus, Chiba, predicts the cost to construct and operate PFALs will be reduced by 50% over the next 10 years[18], making its adoption much more tenable to smaller scale urban farmers. Even with a 50% reduction in costs, PFALs will still be cost prohibitive to many farmers, however, as PFALs can be built within existing industrial buildings as we have seen with examples such as FarmedHere and The Plant, it can also revitalize neighborhoods and can serve to bring employment to people in urban centres. For example, FarmedHere has seen the potential to positively impact its local community. By the 2014 the company "will be providing about 200 jobs to the community, many of them via a partnership with Windy City Harvest, a Chicago Botanic Garden-led urban agriculture training program targeted to underserved local youths."[19] PFALs in themselves are not inherently sustainable. Benefits PFALs can have on local communities, and the environment depends in large part to the ownership and the social purposes of the enterprise.

Bibliography

"FarmedHere, Nation's Largest Indoor Vertical Farm, Opens In Chicago Area." Huffington Post, March 22, 2013 (http://www.huffingtonpost.com/2013/03/22/farmedhere-nations-largest-vertical-farm_n_2933739.html)

Kozai, Toyoki. "What PFAL Means to Urban Agriculture." Resource. American Society for Agricultural and Biological Engineers (ASABE) (March April 2013):12

Lisa, Ana. "Fujitsu Converts Fukushima Microchip Factory into a Radiation-Free Lettuce Farm." inHabitat, May 19, 2014 (http://inhabitat.com/fujitsu-converts-fukushima-microchip-factory-into-a-radiation-free-lettuce-farm/)

Marks, Josh. "Food Waste Fuels Vertical Farming in Chicago." inHabitat, April 10, 2014 (http://inhabitat.com/food-waste-fuels-vertical-farming-in-chicago/)

Meinhold, Bridgette. "FarmedHere: The Nation's Largest Indoor Organic Farm Now Growing in Chicago." inHabitat, May 27, 2014

[17] "FarmedHere, Nation's Largest Indoor Vertical Farm, Opens In Chicago Area." Huffington Post, March 22, 2013 (http://www.huffingtonpost.com/2013/03/22/farmedhere-nations-largest-vertical-farm_n_2933739.html)

[18] Huffington Post, March 22, 2013

[19] Huffington Post, March 22, 2013

(http://inhabitat.com/farmedhere-the-nations-largest-indoor-organic-farm-now-growing-in-chicago/)
The Plant. Frequently Asked Questions. (http://www.plantchicago.com/about/faq/) Accessed 2014

The Vertical Farm. The Vertical Essay (http://www.verticalfarm.com/the-vertical-essay/) Accessed 2014

Challenges Faced by Commercial Aquaponics Farm Operations

Over the last ten years, aquaponics has been gaining in popularity, evidenced by vocal and enthusiastic backyard hobby gardeners around the world uploading and sharing their resources online.[20] A growing number of social entrepreneurs and non-profit organizations have embraced aquaponics as one of the most ecologically sound agricultural practices around – one with multifarious benefits such as promoting environmental stewardship, as well as producing nutrient rich fruits, vegetables and fish. [21] Professor Nick Savidov, at the University of Alberta, explains that "aquaponics is an example of an artificial ecosystem or agro-ecosystem designed for the purpose of food production"[22] Quite simply, it is a symbiotic farming practice involving the successful combination of aquaculture and hydroponics using no pesticides. In this 'closed looped' system, fish waste is converted into nutrients that feed the plants, which in turn purify the water for the fish. [23]

Permutations of this farming method can be found in ancient civilizations. For example, "[t]he ancient Aztecs built 'chinampas' (networks of canals and stationary artificial islands) in which they cultivated crops on the islands using

[20] 1) Urban Aquaponics. (www.urbanaquaponics.com/) Accessed 2014. 2) Aquaponics Forum. (aquaponicpeople.com/) Accessed 2014 3) Aquaponics Nation Forum and Community. (aquaponicsnation.com) Accessed 2014.
[21] 1) The Growhaus. (http://www.thegrowhaus.com/careers/) Accessed 2014. 2) Sweet Water Foundation. (http://sweetwaterfoundation.com/aquapons/) Accessed 2014. 3) AquaponicsUK. (http://www.aquaponics.org) Accessed 2014 4)
[22] Nick Savidov. "Agro-Ecology in Aquaponics." Nick. Aquaponics Course, November 2013. University of Alberta. p.31
[23] Manna Farms Aquaponics. (http://www.mannafarmva.com/aquaponics-2/) Accessed 2014.

nutrient-rich mud and water from the canals."[24] In ancient China, duck and fish waste was used to irrigate crops such as rice. [25]

Although aquaponics in its most modern expression has been around for several decades, it is still fairly new as a commercial endeavour. In what is a fairly new field, much can be learnt from the mistakes made by some early adopters. Following news trends over the last few years in the US, it is not uncommon to see an enthusiastic and positive article touting the innovation, and sustainability efforts of a newly founded aquaponics company seeking to build a commercial aquaponics facility, creating employment for local communities, and fresh produce for local markets, only to find a few years later that, sadly, the company is struggling to stay afloat, or has folded.

Three notable examples of U.S commercial aquaponics facilities that have closed their doors in the last few years are Sweetwater organics, Santa Cruz Aquaponics and Aqua Vita.[26] Overly optimistic business plans, projecting early profits; fundamental problems with the design and operation of the facilities; and poorly identified markets, are some of the reasons cited by these companies for their decision to close shop.[27]

For both Santa Cruz and Sweetwater Organics, design challenges led to extreme complications with their operations. Essentially they "attempted to scale up a system not intended to be commercially viable" and then spent time and effort trying to modify and change the system, to no avail.[28] The owners at Sweetwater Organics interned with Will Allen, a well-known farmer and educator, at Growing Power in Milwaukee. Growing Power is known for their highly productive permaculture 40-acre farm, which includes aquaponics, and

---

[24] Eden Aquaponics. *A Brief History of Aquaponics.* (http://edenaquaponics.com/2010/04/a-brief-history-of-aquaponics/) Accessed 2014.
[25] Ibid.
[26] Bach, Craig. "Blog: Failures in Aquaponics." Nelson & Pade, (http://aquaponics.com/blog/post.php?i=250) August 21, 2013
[27] Ibid.
[28] Ibid.

community and youth training programs that has served as a model for other communities and non-profit organizations in the US. The owners at Santa Cruz also admit to making countless mistakes from the outset even though they studied aquaponics for over 5 years, including the system at Growing Power. While it would be tempting to conclude that somehow the owners were uniquely misguided and overly ambitious, there is a danger in treating this case study as an isolated incident. Rather, what is important to see is that there exists a need for systematic and qualified training applied specifically to commercial aquaponics operations.

Interestingly, Will Allen himself does not say that his system can be scaled up and commercialized.[29] Small scale and backyard aquaponics can be extremely efficient and well-balanced systems, however, as soon as the system is scaled for commercial use, a number of challenges emerge, such as waste management.

Aqua Vita, a two-tiered vertical aquaponics operation in New York State build inside a warehouse, relying exclusively on artificial lighting, garnered international media attention several years ago for its "'zero-waste' approach to farming."[30] The company invested $500,000 but could not make the system profitable within the first two years.[31] The owners claim that they needed those two years to make some significant changes to the system itself, but by then they were compelled to sell off their equipment as they had to pay back their bank loan.[32] It is questionable whether such a system relying exclusively on artificial lighting could be economically feasible, says Charlie Schultz, an

---

[29] Bach, Craig. "Blog: Failures in Aquaponics." Nelson & Pade, (http://aquaponics.com/blog/post.php?i=250) August 21, 2013
[30] Cazentre, Don. Aquaponics pioneer Aqua Vita Farms of Sherrill closes; to sell off equipment and assets. Syracuse.com. July 22, 2013, (www.syracuse.com/news/index.ssf/2013/07/aquaponics_pioneer_aqua_vita_farms_of_sherrill_closes_to_sell_off_equipment_and.html) Accessed 2014-11-12
[31] Ibid.
[32] Ibid.

aquaponics researcher and consultant at Lethbridge College.[33] "Unlike the greenhouse model, which only requires supplementary electricity, in order to run [a warehouse aquaponics operation] … 'you've got to throw a lot of energy into lighting an indoor facility,' says Schultz… 'I've seen facilities that are funded by companies that have supplied all the fish tanks and all the blowers and all the infrastructure at no cost, and that model might work,' he syas. 'But if you're just buying property, a warehouse, and you have no energy angle, I think it's gonna be tricky to make it in this industry…"[34]

In any aquaponics facility, within a greenhouse or inside a warehouse, air ventilation and environmental controls that can adequately monitor/regulate air and water temperature, relative humidity, dissolved oxygen levels in the water, as well as good filtration, and waste management etc. are necessary to keep the system running effectively. Without them, a facility can neither accurately determine nor optimize its production capacity. Working with well-researched designs from the outset can help to mitigate some of the initial challenges faced by new aquaponics farm companies. In their absence, plant diseases and pests, unsafe working and living conditions, and damage to the building may also emerge.[35]

In Canada there are only a handful of commercially successful aquaponics farms in operation for at least three years. Many of them are located in Alberta where there has been support from the government to fund aquaponics research. Specialists from the University of Alberta and Lethbridge College support entrepreneurs and farmers in the early stages of the design of an aquaponics facility, right through the production, harvesting and post-harvest

---

[33] Sherman, Josh. *Aquaponics: urban growers gaining ground.* Spacing. October 29, 2014 (www.spacing.ca/national/2014/10/29/aquaponics-urban-growers-gaining-ground/) Accessed 2014
[34] Ibid.
[35] Sherman, Josh. *Aquaponics: urban growers gaining ground.* Spacing. October 29, 2014 (www.spacing.ca/national/2014/10/29/aquaponics-urban-growers-gaining-ground/) Accessed 2014

handling of crops and fish. This support is extremely critical considering design challenges can be a major issue in commercial aquaponics.

Some universities, including the University of Alberta, the University of Arizona, and the University of the Virgin Islands, all offer extension services and courses that help start-ups and farmers design and operate commercial aquaponics facilities. Programs and specialists in this field is paramount to the continued growth of this emerging sector as training programs, site specific-cost-benefit analysis, and further research are all support to the development of best practices in response to challenges in the burgeaoning commercial aquaponics industry.

Bibliography

Aquaponics Forum. (aquaponicpeople.com/) Accessed 2014

Aquaponics Nation Forum and Community. (aquaponicsnation.com) Accessed 2014.

AquaponicsUK. "Like Cycle Assessment." (http://www.aquaponics.org.uk/projects/life-cycle-assesment/) Accessed 2014.
AquaponicsUK. (http://www.aquaponics.org) Accessed 2014

Bach, Craig. "Blog: Failures in Aquaponics." Nelson & Pade, (http://aquaponics.com/blog/post.php?i=250) August 21, 2013
Cazentre, Don. Aquaponics pioneer Aqua Vita Farms of Sherrill closes; to sell off equipment and assets. Syracuse.com. July 22, 2013, (www.syracuse.com/news/index.ssf/2013/07/aquaponics_pioneer_aqua_vita_farms_of_sherrill_closes_to_sell_off_equipment_and.html) Accessed 2014-11-12

Eden Aquaponics. A Brief History of Aquaponics. (http://edenaquaponics.com/2010/04/a-brief-history-of-aquaponics/) Accessed 2014.

Falkowitz, Max. "Behind the Scenes at Aqua Vita Farms, Growing Aquaponic Fish and Produce in Sherrill, NY." Serious Eats. December 4, 2012 (http://www.seriouseats.com/2012/12/aqua-vita-farms-seneca-ny-aquaponic-lettuce-fish.html) Accessed 2014

Jones, Donna. "Future agriculture venture aims to be worlds largest aquaponics farm." *Santa Cruz Sentinel.* September 10, 2013 (http://www.santacruzsentinel.com/ci_23836792/future-agriculture-venture-aims-be-worlds-largest-aquaponics) Accessed 2014

Manna Farms Aquaponics. (http://www.mannafarmva.com/aquaponics-2/) Accessed 2014.

Nick Savidov. “Agro-Ecology in Aquaponics.” Nick. Aquaponics Course, November 2013. University of Alberta. p.31

Seager, Charlotte. “Aquaponics: a sustainable solution to food insecurity?” The Guardian (UK), (http://www.theguardian.com/global-development-professionals-network/2014/oct/02/aquaponics-a-sustainable-solution-to-food-security) Thursday 2 October 2014

Sweet Water Foundation. (http://sweetwaterfoundation.com/aquapons/) Accessed 2014

Sherman, Josh. *Aquaponics: urban growers gaining ground.* Spacing. October 29, 2014 (www.spacing.ca/national/2014/10/29/aquaponics-urban-growers-gaining-ground/) Accessed 2014

The Growhaus. (http://www.thegrowhaus.com/careers/) Accessed 2014

Urban Aquaponics. (www.urbanaquaponics.com/) Accessed 2014.

Alternative Solar Technology for Greenhouse Operations in Canada

As climate variability due to climate change becomes more apparent, the importance of well-designed controlled environmental systems in greenhouses will increase in importance. While traditionally, conventional greenhouse operators rely on natural gas and fossil fuels to generate sufficient electricity to run commercially competitive greenhouses, there is a need within the greenhouse sector to rely more emphatically on renewable sources of energy. This is due in large part to concerns mounting over climate change, food security and peak oil. For example, in order to adopt the construction and operation of greenhouses as part of a local food security strategy in cold weather climates, special attention needs to be placed on the sources of energy such facilities draw from. Greenhouse gas emissions (GHG) associated with running commercial facilities must be drastically reduced so as to sustainably accommodate the four-season production of leafy greens and vegetables in Canada.

In the Netherlands the energy used to artificially light and heat greenhouses has been reduced by 50% since 1990.[36] Professor and researcher, Leo F. M. Marcelis, from Wageningen UR Greenhouse Horticulture lists the following measures taken by the greenhouse industry in the Netherlands to effect this change**.** "These energy-saving measures include:

- Better insulation using energy screens and high-tech covering materials.
- New growing strategies that take advantage of natural energy sources and off-peak energy costs.
- Development of semi-closed green-houses, in which solar heat is captured and stored."[37]

Marcelis also predicts, "[i]n the future, greenhouse production without fossil fuels can be achieved by using heat pumps, geothermal heat, waste heat from other industries, and green electricity."[38]

Many processes, technologies and strategies are envisioned and no one is a panacea for greenhouse energy consumption challenges. With regards to green electricity, researchers have been conducting trials using an off-the-grid photovoltaic (PV) integrated greenhouse at the University of Arizona's, Controlled Environment Agriculture Center (CEAC).[39]

Solar photovoltaic integrated greenhouse system (Image)[40]

[36] Marcelis, Leo F.M, Hemming Silke. "Greenhouse Production in The Netherlands." Resource: Energy and technology for a sustainable world. American Society for Agricultural and Biological Engineers (ASABE), Special Issue March/April 2013, p.14

[37] Marcelis, p.14

[38] Ibid., p.14

[39] "Solar Powered Off-the-Grid Research Update." Controlled Environment Agriculture Center. University of Arizona. 2013

[40] Controlled Environment Agriculture Center. University of Arizona. Solar Powered Off-the-Grid Research Update. 2013

So far, they have found that a greenhouse running solely on power generated from photovoltaics, or solar panels, has application in remote arid climates where there is little to no access to the grid.[41] However, the technology has not proven to be commercially competitive as a stand alone, in parts of the world where there is pre-existing access to electricity or for extreme cold weather climates. In places where there is ready access to natural gas, hydro, and fossil fuels, its widespread adoption among commercial greenhouse growers is doubtful.

Thus the benefits of PV-integrated greenhouses exist conditionally. In parts of this country where there is no access to the electrical grid, PV-integrated greenhouses could offer a certain degree of protection from climate variability. However, PV-integrated greenhouses would no doubt require additional energy conservation methods and processes to enable the effective operation of greenhouses in the extreme cold. One energy conservation method researched by a team at the University of Manitoba's Biosystems Engineering Department is passive solar energy greenhouses.

Listed among the strategies employed in the Netherlands, solar energy greenhouses drastically reduce greenhouse energy consumption[42]. They are often built with one solid wall that absorbs heat from the sun during the day and

---

41 "Ibid.

42 E. Beshada, Q. Zhang, and R. Boris. "Winter performance of a solar energy greenhouse in southern Manitoba." Canadian Biosystems Engineering. Volume 48. 2006. p.5.1 http://www.engr.usask.ca/societies/csae/protectedpapers/c0611.pdf

which releases this heat in the evening – thereby reducing heating costs and reliance on peak oil and natural gas. "According to the Commission of the European Communities (1986), more than 75% of thermal energy consumption in agriculture is devoted to greenhouse heating in northern countries."[43] In a study evaluating the "Winter performance of a solar energy greenhouse in Manitoba"[44], the authors concluded that "[s]olar energy may provide the most cost effective means for greenhouse heating."[45] Once reduced, the remaining energy requirements of a greenhouse may be met by PV panels[46], however further research is required to determine if another energy source would be more feasible in remote and cold regions of Canada such as geothermal, or waste heat capture.[47]

Bibliography

"Solar Powered Off-the-Grid Research Update." Controlled Environment Agriculture Center. University of Arizona. 2013
E. Beshada, Q. Zhang, and R. Boris. "Winter performance of a solar energy greenhouse in southern Manitoba." Canadian Biosystems Engineering. Volume 48. 2006. p.5.1
http://www.engr.usask.ca/societies/csae/protectedpapers/c0611.pdf

Faisal Mohammed Seif Al-Shamiry et al. "Design and Development of a Photovoltaic Power System for Tropical Greenhouse Cooling." American Journal of Applied Sciences, (http://thescipub.com/PDF/ajassp.2007.386.389.pdf) 4 (6): 386-389, 2007 ISSN 1546-9239

Francoeur, Renée. "Northern greenhouse project receives boost." Northern Journal. January 22, 2013 (http://norj.ca/2013/01/northern-greenhouse-project-receives-boost/), Accessed 2014
Love, Myron. "The Solar Solution." Greenhouse Canada. (http://www.greenhousecanada.com/content/view/1562/) Accessed 2014

---

43 Ibid., p.5.1

44 Ibid., p.5.1

45 Ibid., p.5.1

46 Love, Myron. "The Solar Solution." *Greenhouse Canada.* (http://www.greenhousecanada.com/content/view/1562/) Accessed 2014

47 Francoeur, Renée. "Northern greenhouse project receives boost." *Northern Journal.* January 22, 2013 (http://norj.ca/2013/01/northern-greenhouse-project-receives-boost/), Accessed 2014

Marcelis, Leo F.M, Hemming Silke. "Greenhouse Production in The Netherlands." Resource: Energy and technology for a sustainable world. American Society for Agricultural and Biological Engineers (ASABE), Special Issue March/April 2013, p.14

Direct application of geothermal energy and geothermal ground source heating for greenhouse crop production in Canada

There is a need to identify cost competitive alternatives to non-renewable forms of energy to reduce both the greenhouse footprint incurred by operators in the greenhouse industry, as well as the expense associated with the industry's energy consumption. According to Statistics Canada, in 2005 the greenhouse industry "…consumed more than 40 PJ of fossil fuels ($260M) and released about 2 million tonnes of CO2 and other air pollutants into the atmosphere."[48] At approximately 20-40% of the total, energy is the number one cost for greenhouse operators in Canada.[49]

Researchers at the Organic Agriculture Centre of Canada at Dalhousie University have found that the "… the use of geothermal energy for greenhouse production, as well as recent developments of closed or semi-closed greenhouses, may contribute to significant reductions of the environmental footprint associated with this industry, and increase Canadian competitiveness by energy saving."[50]

Geothermal energy is "heat from the Earth…. Resources of geothermal energy range from "shallow ground to hot water and hot rock found a few miles

---

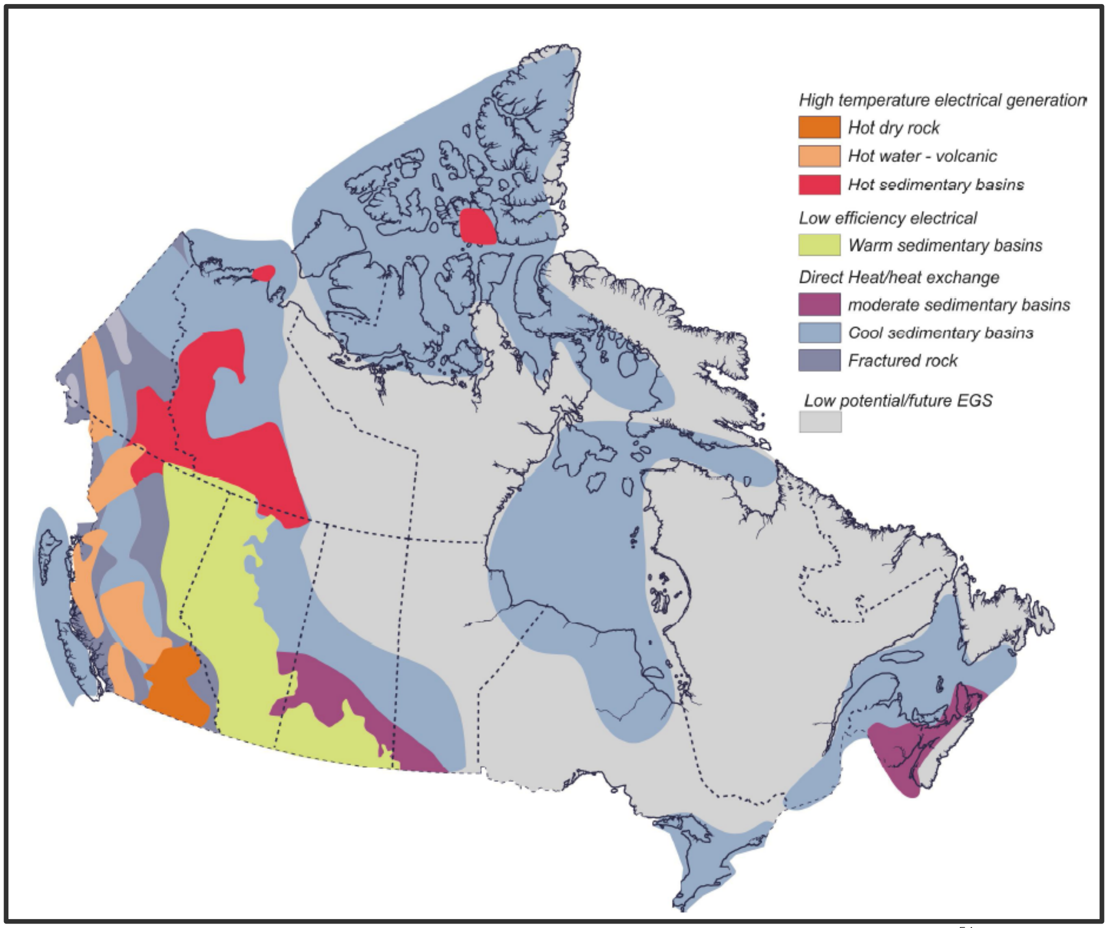
[48] Activity C.7: Feasibility of using geothermal energy as heat and humidity control for an organic greenhouse tomato crop. Organic Agriculture Centre of Canada, Dalhousie University. (http://www.organicagcentre.ca/OSC/Subproject_C/osc_activity_c7_summary.asp) Accessed 2014

[49] Ibid.

[50] Ibid.

beneath the Earth's surface, and down even deeper to the extremely high temperatures of molten rock…"[51] In 2010 the worldwide capacity for greenhouse heating was 1544 MWt and utilization was 23, 264 TJ/y.[52]

In Canada where there is "abundant geothermal resources,"[53] there is potential for geothermal energy to offset the use of non-renewable sources of energy.



Map showing distribution of geothermal potential in Canada based on end use[54]

---

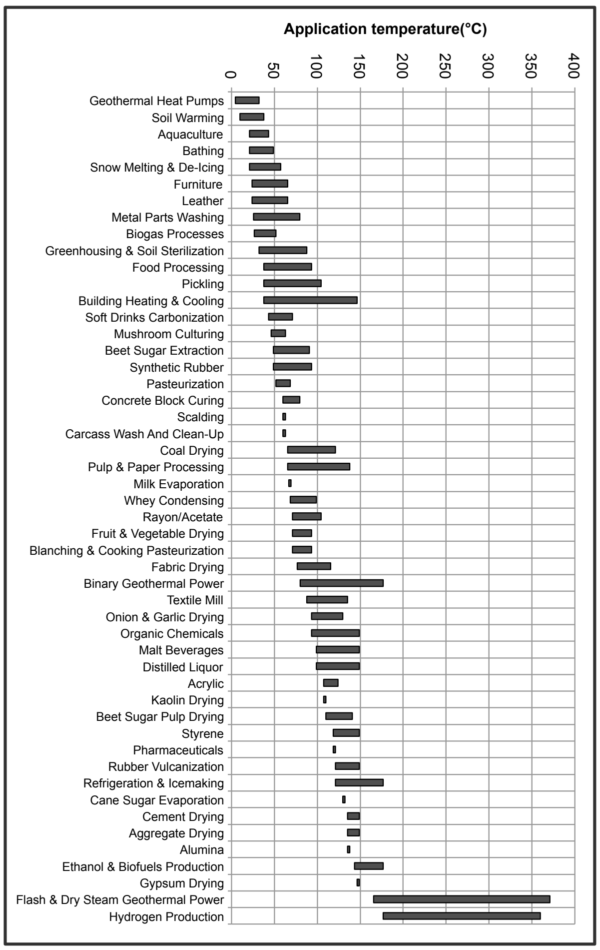
[51] RenewableEnergyWorld.com. *Geothermal Energy*. (http://www.renewableenergyworld.com/rea/tech/geothermal-energy) Accessed 2014

[52] ("Worldwide (Lund, et al., 2011), the installed capacity of direct geothermal utilization is 48,493 MWt (thermal) and the annual energy use is 423,830 TJ (117,740 GWh) distributed among 78 countries; the leading countries are presented in Table 1. This amounts to saving an equivalent 250 million barrels (38 million tonnes - TOE) of oil annually, preventing 107 million tonnes of CO_2 being released to the atmosphere.")
"Direct Utilization of Geothermal Energy: Suitable Applications and Opportunities for Canada." Canadian Geothermal Energy Association. August 2014 (http://www.cangea.ca/uploads/3/0/9/7/30973335/direct_use_final_report.pdf) Accessed 2014 p.3,6

[53] Ibid. p.125

[54] Ibid., p. 123

The Canadian Geothermal Energy Association (CanGEA) identifies commercial greenhouse operations located primarily in British Columbia, the Yukon, the Northwest Territories, Alberta and Saskatchewan, as suitable for direct utilization of geothermal energy. "Most direct use applications[55] [including greenhouse heating] require geothermal fluids in the low-to-moderate temperature range between 50° and 150°C, which are typically much more abundant and located at shallower depths than the high temperature resources needed for power generation."[56]



CanGEA – Temperature ranges for direct geothermal energy applications

55 Direct utilization means that the heat from geothermal energy is not converted into electricity, but rather used directly to heat for example a building such as a greenhouse. Direct Utilization of Geothermal Energy: Suitable Applications and Opportunities for Canada." Canadian Geothermal Energy Association. August 2014 (http://www.cangea.ca/uploads/3/0/9/7/30973335/direct_use_final_report.pdf) Accessed 2014 p.3

56 Ibid., p. ix

Rather than drill 2 km below the Earth's surface, geothermal fluids with temperatures ranging from 50° and 150°C can be reached by drilling down roughly 1000 m depending on the site.[57]

Geothermal energy systems[58] can be extremely capital intensive and involve a lengthy project lifecycle, which includes resource identification, resource rights, permitting and studies, resource exploration, project design and construction.[59][60] Securing a return of investment within the first five years requires an economy of scale that makes adoption of this technology for many farmers cost prohibitive. Economically, according to a feasibility study conducted in the Netherlands, geothermal energy makes sense for greenhouses with a surface area of 6 hectares (15 acres) or more, assuming the greenhouse is growing "heat-intensive crops such as tomatoes and cucumbers."[61]

In a recent study however, reviewing both the environmental and economic costs of greenhouse heating such as natural gas, propane, solar thermal, and geothermal, geothermal "ground source heat pumps," were found to be the "most economical and environmentally sensitive choice for a 4320 square foot commercial greenhouse in Minnesota."[62]

"Geothermal ground source heat pumps can be installed anywhere using normal ground and groundwater temperatures between 5° and 30° C. They are

---

57 "Direct Utilization of Geothermal Energy: Suitable Applications and Opportunities for Canada." Canadian Geothermal Energy Association. August 2014 (http://www.cangea.ca/uploads/3/0/9/7/30973335/direct_use_final_report.pdf) Accessed 2014 p.31

58 "The primary components of most low-to-moderate temperature direct-use systems are well and circulation pumps, transmission and distribution pipelines, peaking or back-up plants, and various forms of heat extraction equipment. Fluid disposal is either surface or subsurface (injection)." Ibid., p.31

59 Ibid., p.31

60 Ibid., p.35

61 Appleyard, David. Commercial Geothermal Growing in Netherlands. RenewableEnergyWorld.com. July 31, 2013 (http://www.renewableenergyworld.com/rea/news/article/2013/07/commercial-geothermal-use-grows-in-netherlands) Accessed 2014.

62 Hansen. Madeline. "Exploring the heating options of winter productive greenhouses." Environmental studies CSB SJU Advisors : Dr. Jean Lavigne and Dr. Derek Larson. (www.csbsju.edu/Documents/Environmental%20Studies/curriculum/395/Hansen(0).pdf) Accessed 2014

normally installed in shallow holes up to 100 meters deep (closed-loop design), or using shallow groundwater wells (open-loop design). The closed loop design can also be installed in horizontal trenches approximately two meters deep."[63]

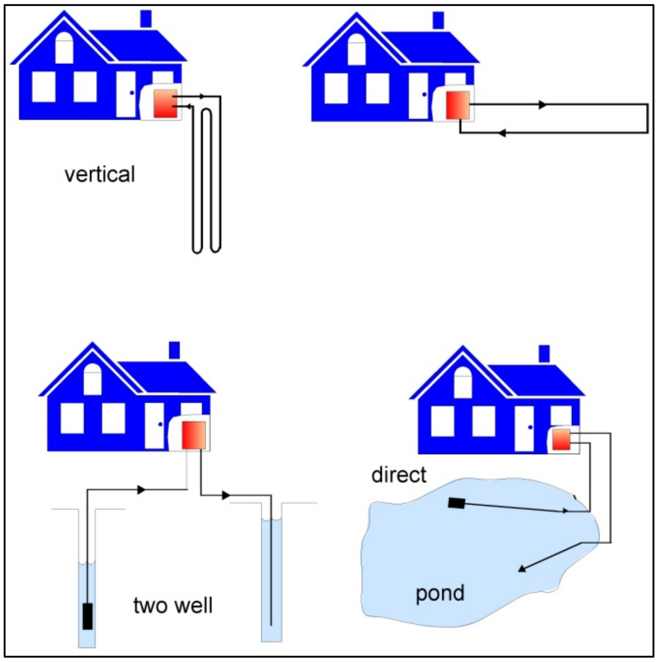


Image: Ground source and ground water geothermal installations[64]

This source of geothermal energy however would not meet the energy demands of multi-hectare commercial greenhouses. Ground source geothermal heat pumps according to this study would also not be economical for greenhouses even smaller than 4320 square feet. Rather, the study identified passive solar energy as the most economical energy source.[65]

More research however is required to determine the economic feasibility of geothermal energy to heat greenhouses that are not as large as multi-hectare

---

63 "Direct Utilization of Geothermal Energy: Suitable Applications and Opportunities for Canada." Canadian Geothermal Energy Association. August 2014 (http://www.cangea.ca/uploads/3/0/9/7/30973335/direct_use_final_report.pdf) Accessed 2014 p.25

64 Ibid.

65 Rather, passive solar energy would be economically suitable. Hansen. Madeline. "Exploring the heating options of winter productive greenhouses." Environmental studies CSB SJU Advisors : Dr. Jean Lavigne and Dr. Derek Larson. (www.csbsju.edu/Documents/Environmental%20Studies/curriculum/395/Hansen(0).pdf) Accessed 2014

operations, but are nevertheless larger than 4320 square feet. Otherwise there appears to be to narrow a size range for greenhouse structure in which all the variables align. This could potentially make geothermal energy more inclusive and readily accessible to small to medium greenhouse farmers thus increasing its potential to contribute to significant reduction in greenhouse gas emissions.

Bibliography

Activity C.7: Feasibility of using geothermal energy as heat and humidity control for an organic greenhouse tomato crop. Organic Agriculture Centre of Canada, Dalhousie University. (http://www.organicagcentre.ca/OSC/Subproject_C/osc_activity_c7_summary.asp) Accessed 2014

Appleyard, David. Commercial Geothermal Growing in Netherlands. RenewableEnergyWorld.com. July 31, 2013 (http://www.renewableenergyworld.com/rea/news/article/2013/07/commercial-geothermal-use-grows-in-netherlands) Accessed 2014.

"Direct Utilization of Geothermal Energy: Suitable Applications and Opportunities for Canada." Canadian Geothermal Energy Association. August 2014 (http://www.cangea.ca/uploads/3/0/9/7/30973335/direct_use_final_report.pdf) Accessed 2014

"Geothermal Favourability Map Northwest Territories." Northwest Territories Environment and Natural Resources. April 2010. (http://www.enr.gov.nt.ca/sites/default/files/reports/geothermal_favorability_report.pdf) Accessed 2014

"Grower going geothermal." Chilliwack Times. July 22, 2008 (http://www.canada.com/story.html?id=b591a570-fa7a-45db-bd44-8882929cea1c#__federated=1) Accessed 2014.

Hansen. Madeline. "Exploring the heating options of winter productive greenhouses." Environmental studies CSB SJU Advisors : Dr. Jean Lavigne and Dr. Derek Larson. (www.csbsju.edu/Documents/Environmental%20Studies/curriculum/395/Hansen(0).pdf) Accessed 2014

RenewableEnergyWorld.com. *Geothermal Energy*. (http://www.renewableenergyworld.com/rea/tech/geothermal-energy) Accessed 2014

Product Life Cycle Assessments are needed in the Urban Agriculture sector to promote greater transparency

Urban agriculture covers a broad range of processes and technologies, including rooftop greenhouses, farms built on under-utilized lots and public spaces, plant factories, on-the-ground greenhouse facilities, and vertical farming. Often agricultural processes and technologies purport to be environmentally sustainable, trading on an overly simplified notion that local means sustainable. However, for many new agriculture products or growing processes, there is not sufficient information to determine whether they are truly environmentally sustainable.

WindowFarms, founded by Britta Riley, is a social enterprise that uses the science of hydroponics and the collaborative nature of the Do-it-Yourself movement to offer blueprints and online support for people wishing to build their own vertical hydroponic system near a windowsill. Windowfarms first began as an "art project and an experimental design project to harness the power of internet-based mass collaboration..."[66] The company's core product offering includes "vertical indoor food gardens that optimize the conditions of windows for year-round indoor growing of greens, herbs, and small vegetables."[67] The company also offers for sale in New York locally grown starter packs of young plants to transplant into the vertical hydroponic system . The company was born out of the collaborative efforts of an "online community of growers," now 40,0000 members.[68]

At a time when 'barriers to imitation' is considered an effective hallmark of a

[66] WindowFarms. *Main Page*. (www.Windowfarms.com) Accessed 2014
[67] Ibid.
[68] WindowFarms. *Main Page*. (www.Windowfarms.com) Accessed 2014

company's business strategy, WindowFarms provides an alternative case – one which harnesses the power of online communities to help improve their product and inspire wide-scale behavioral change.[69] While the company has garnered a lot of media attention over the last few years[70], the next step towards even greater transparency is to make public a product Life Cycle Assessment (LCA), ensuring that the energy to produce and ship the product, made primarily out of plastic, does not outweigh the benefits of growing food hyper locally. "Life Cycle Assessment charts the course of all inputs and outputs, and their resulting environmental impacts, for a given product system thoughout its lifecycle."[71] "LCA provides a detailed breakdown of the magnitude of various environmental impacts along each step in the product lifecycle…[W]ith this knowledge, companies can target supply chain improvements that drive the greatest environmental impact."[72] For example, LCA can help to determine the best type of product packaging based on its environmental impact.[73]

In an effort to embrace local food production, it is important to know whether new products, technologies and growing processes positioned within the local food security movement, truly meet their sustainability claims on all accounts.

Similarly, although aquaponics is considered to be one of the most water resource efficient and sustainable forms of agriculture[74], in the absence of renewable energy sources, it too can have negative environmental impacts. A life cycle assessment conducted in the UK, found that mitigating the effects of

---

69 Pratt, Emmanuel. "Urban Agriculture: A New Paradigm of Planning and Policy." *Resource: Energy and technology for a sustainable world.* American Society for Agricultural and Biological Engineers (ASABE), Special Issue March/April 2013, p. 21

70 WindowFarms. *Media Coverage.* (http://www.windowfarms.com/media-coverage/) Accessed 2014

71 "Lifecycle Assessment: Where is it on your sustainability agenda?" *Deloitte Development LLC.* 2009. (http://www.deloitte.com/assets/Dcom-UnitedStates/Local%20Assets/Documents/us_es_LifecycleAssessment.pdf) Accessed 2014

72 Ibid., p.3

73 Ibid., p.4

74 Slaughter, Graham. *Aquaponics Brings Fish Fuelled Vegetables to Toronto.* The Toronto Star. Jan 3, 2014. (www.thestar.com/news/gta/2014/01/03/aquaponics_brings_fishfuelled_vegetables_to_toronto.html) Accessed 2014

climate change using aquaponics as an agricultural approach, is contingent upon the energy source used to operate the system.[75]

In colder climates like the UK and Canada, aquaponics must be conducted indoors, where electricity is used to pump the water throughout the system, as well as provide heating and lighting. Even in a warmer climate electricity is always required if only to run the necessary pumps and air blowers for the system. Oxygenated water is essential for both the health and survival of the fish and plants in an aquaponics system. If there is a power outage, and the air blowers and the pump stop working, the fish will not survive and considerable strain will be put on the plants. By stocking the system with fewer fish there is less chance that a power outage will result in killing off the fish, however a backup generator is still advisable and raises concerns about the application of aquaponics in remote locations or urban centres where there is no renewable energy source, or energy backup such as a generator.[76]

Life Cycle Assessments are not common among new and established urban agriculture companies, in what is still quite a burgeoning sector. However, a true assessment of the energy requirements to produce agricultural products such as tomatoes, leafy greens and fish would move urban agriculture forward, ensuring companies and production methods that purport to be environmentally sustainable are held up to a greater degree of accountability.

Bibliography

AquaponicsUK. "Like Cycle Assessment." (http://www.aquaponics.org.uk/projects/life-cycle-assesment/) Accessed 2014.

Seager, Charlotte. "Aquaponics: a sustainable solution to food insecurity?" The Guardian (UK), (http://www.theguardian.com/global-development-professionals-network/2014/oct/02/aquaponics-a-sustainable-solution-to-food-security)

---

[75] AquaponicsUK. "Like Cycle Assessment." (http://www.aquaponics.org.uk/projects/life-cycle-assesment/) Accessed 2014.

[76] Seager, Charlotte. "Aquaponics: a sustainable solution to food insecurity?" The Guardian (UK), (http://www.theguardian.com/global-development-professionals-network/2014/oct/02/aquaponics-a-sustainable-solution-to-food-security) Thursday 2 October 2014.

Thursday 2 October 2014.

Slaughter, Graham. *Aquaponics Brings Fish Fuelled Vegetables to Toronto*. The Toronto Star. Jan 3, 2014. (www.thestar.com/news/gta/2014/01/03/aquaponics_brings_fishfuelled_vegetables_to_toronto.html) Accessed 2014

Woo, Andrea. "Critics slam Canada's northern food program." *Globe and Mail*. November 4, 2014. (http://www.theglobeandmail.com/news/critics-slam-canadas-nothern-food-program/article21451386/) Accessed 2014.

"Lifecycle Assessment: Where is it on your sustainability agenda?" *Deloitte Development LLC.* 2009. (http://www.deloitte.com/assets/Dcom-UnitedStates/Local%20Assets/Documents/us_es_LifecycleAssessment.pdf) Accessed 2014

Part 2: Reflection Paper

Sustainable Approaches to Controlled Environment Agriculture

Introduction

There exists a need for sustainable technologies and growing methods adapted to the year round cultivation of affordable, healthy and nutritious fruits and vegetables in cold weather climates. Joseph Nasr, Rod MacRae and James Kuhns, authors of *Scaling up Urban Agriculture in Toronto: Building the infrastructure*, state ""[i]n colder climates such as Toronto's, season extension has emerged as the next frontier for ensuring the viability of many urban farming operations."[77] These authors observe that there are a number of season extension approaches to promote urban food in a cold climate, that range from the "use of simple, inexpensive covers such

[77] Joseph Nasr, Rod MacRae & James Kuhns with Martin Danyluk, Penny Kaill-Vanish, Marc Michalak & Abra Snider. *Scaling up Urban Agriculture in Toronto: Building the Infrastructure*. Metcalf Foundations, June 2010. p.34

as low tunnels to shelter… crops from cold and wind," to "controlled environmental agricultural operations that require high capital investment but can yield high returns."[78] Nasr, MacRae, and Kuhns predict that much of the development over the years will depend on the "ingenuity of making best use of the urban environment," such as the integration of greenhouses into buildings in a manner that captures waste heat.[79]

While physical infrastructure such as sheltered growing environments represent but one component to an over arching strategy to promote local food production – also involving knowledge, governance, financial support, and food chain infrastructure – [80] this paper provides an overview of some emerging technologies and growing methods within the arena of controlled environment agriculture, that make greenhouse and plant factory operations more environmentally friendly, as well as examines under what conditions these technologies and methods might be adopted for use as part of a local community food security strategy in a cold weather climate such as Canada.

Food Security Definitions

Over the last few decades, approximately 200 definitions of the term food security have emerged.[81] For example, the World Food Summit defines food

---

[78] Ibid., p.34

[79] Ibid., p.34

[80] Joseph Nasr, Rod MacRae & James Kuhns with Martin Danyluk, Penny Kaill-Vanish, Marc Michalak & Abra Snider. *Scaling up Urban Agriculture in Toronto: Building the Infrastructure*. Metcalf Foundations, June 2010. p.13
For example a challenge faced by urban farmers is their need for "long-term and stable access to land… Ensuring long-term access will involve changes to official plans, zoning bylaws, and land taxation on the aprt of government, and ownership or lease arrangements on the part of landowners." (*Scaling Up Urban Agriculture*. p.15)

[81] MacKeown, David. *Food Security: Implications for the Early Years*. Toronto Public Health, February 2006. (www.toronto.ca/health/children/pdf/fsbp_final.pdf) Accessed 2014. p.20.

security as "existing when 'all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life.'"[82] Authors "Ganapathy et al. (2005) and Power (1998)," on the other hand, "see the core of food security as a bivariate concept composed of anti-hunger or poverty elimination goals on the one hand and goals related to food system issues on the other."[83] In Canada, 1.7 Million households experienced food insecurity in 2012.[84] This equals approximately one in eight households.[85] Food insecurity effects one in six children in Canada and "[o]ne in three people experience food insecurity every month in Nunavut."[86] Dr. David MacKeown author of, *Food Security: Implications for the Early Years*, a background report written on behalf of Toronto Public Health, observes that the meaning of the term food security has "…evolved and expanded over time to integrate a wide range of food related issues and to more completely reflect the complexity of the role of food in human society."[87] He expounds, "[t]he food system approach expresses a concern with the quality of food that is available, how food is produced and the impact of its production, distribution and consumption on individuals and communities."[88] A development that has taken place over the last decade or so has been the appearance of the term community food security.[89] In "its 2002 position paper, *A Systemic Approach to Community Food Security: A Role for Public Health*," the Ontario Public Health Association, defined community food security as encompassing issues relating to "the economic, environmental and

---

[82] Woo, Andrea. *Critics slam Canada's northern food program.* The Globe and Mail. November 4, 2014. (www.theglobeandmail.com/news/critics-slam-canadas-northern-food-program/article21451386) Accessed 2014.

[83] MacKeown, David. *Food Security: Implications for the Early Years*. Toronto Public Health, February 2006. (www.toronto.ca/health/children/pdf/fsbp_final.pdf) Accessed 2014. p.20.

[84] Tarasuk, Valerie. *Report on Household Food Insecurity in Canada, 2011.* PROOF Annual Report 2011. (http://nutritionalsciences.lamp.utoronto.ca/resources/proof-annual-reports/annual-report/)

[85] Ibid.

[86] "Food Secure Canada." Northern Remote Food. 2014 http://foodsecurecanada.org/community-networks/northern-remote-food

[87] MacKeown, David. *Food Security: Implications for the Early Years.* Toronto Public Health, February 2006. (www.toronto.ca/health/children/pdf/fsbp_final.pdf) Accessed 2014. Page 20.

[88] Ibid., p.20.

[89] Ibid., p.20.

social aspects of the food system, issues of adequate incomes for consumers and producers, local and diverse food production, environmental sustainability, protection of local agricultural lands and fish habitat, widespread access to healthy food and food based community economic development and social cohesion (OPHA, 2002)."[90]

Local Food Systems & Sheltered Agriculture

A local food system that produces fresh produce year round in urban centres or in remote areas of the Canadian North, can act in favor of community food security. To affect this response, however, production methods and growing environments must adapt to the cold and extreme weather climate in a manner that is environmentally friendly and socially responsible. This is especially pertinent given the fact that conventional commercial greenhouse operations consume an inordinate amount of energy, often lack a socially and environmentally responsible supply chain policy, incur high expenses associated with artificial lighting and heating, and involve high start-up costs, further compounding the issues related to wide scale adoption. That is to say that the technologies & growing methods to support the local production of food in cold weather climates, must be measured against the alternatives, such as importing food from other countries with more flexible growing environments. The growing methods and their sheltered environments should: rely on minimal fossil fuels or be entirely reliant on renewable energy; bring culturally appropriate, nutritious and affordable food to local communities; be accessible to both new and small farmers; be accessible to community groups and individuals; and offer protection from the increasing effects of climate change.

[90] Ibid., p.24

In this paper I examine three sustainable technologies and growing methods that show promise in the field of controlled environment agriculture:

- Solar energy greenhouses
- Cogeneration integrated greenhouses
- Aquaponics

Controlled Environment Agriculture (CEA)

A Brief History

At the Controlled Environment Agriculture Center (CEAC) at the University of Arizona, "Controlled Environment Agriculture (CEA) is defined as an integrated science and engineering based approach to provide specific environments for plant productivity while optimizing resources including water, energy, space, capital and labor."[91] Most commonly identified with greenhouses, CEA includes plants produced in any sheltered environments including warehouse facilities (plant factories), or growing chambers.

The first proto-greenhouses on record were built in the 1st century on behalf of Roman Emperor Tiberius who insisted on growing off-season cucumbers, which involved providing shelter using "transparent stone (mica)."[92] There are not many accounts of greenhouses for centuries afterwards until the 1500s. By the 17th century large greenhouses were built in France and England and were found among large estates, and universities.[93] Charcoal and coal were

[91] Controlled Environment Agriculture Center. *Main Page.* University of Arizona. 2014 http://ag.arizona.edu/ceac/

[92] Controlled Environment Agriculture Center. *Hydroponic Historical Review*. University of Arizona. 2014 (http://ag.arizona.edu/ceac/hydroponic-historical-review)

[93] Campus Extension. *History of Greenhouses.* (www.campus.extension.org/pluginfile.php/45642/mod_resource/content/0/Unit-01/ghhistory.html) Accessed 2014

used as fuel to heat greenhouses during this time.[94] “The aristocracy of Paris, St. Petersburg and Vienna competed with each other in creating ever more magnificent glass structures… as they had become fond of newly-discovered tropical fruits,” such as oranges and pineapples. By the 19th century glass become more readily available and “manufactured in large quantity,” coinciding with an upsurge of greenhouse production.[95]

By the early 20th century large greenhouses had very much become a reflection of the industrial era, evidenced for example by increasing automation. “During World War I, heating costs, and a shortage of skilled gardeners in Britain, curbed the popularity in greenhouse construction.”[96] However “[g]reenhouse areas began to expand significantly in Europe and Asia during the 1950s and 1960s,” in large part due to the low cost of plastic materials.[97] “Plastics were used not only in the glazing of greenhouses, but also in place of concrete in lining. ...[Plastics] were also important in the introduction of drip irrigation.” During this time, “[n]umerous promotional schemes involving hydroponics became common with huge investments made in growing systems.”[98]

The development of commercial greenhouses is very much a product of modern industrialization with a strong dependence of nonrenewable forms of energy, such as fossil fuels. In the 1970s and 1980s “there was a major research emphasis on the use of solar energy and (waste) heat from large industrial units.” “Although …technically feasible,” it received minimal uptake by large commercial operators who did not see it as “economical because of

---

94 Ibid.

95 Dave’s Garden. *A Short History of the Greenhouse.* (www.davesgarden.com/guides/articles/view/3607/#b) Accessed 2014

96 Baird, Craig. *The Complete Guide to Building Your Own Greenhouse.* Atlantic Publishing Group Inc.; Ocala, Florida, 2010. p.18

97 Controlled Environment Agriculture Center. *Hydroponic Historical Review.* University of Arizona. 2014 (http://ag.arizona.edu/ceac/hydroponic-historical-review)

98 Ibid.

collection and storage costs." [99] This period also saw an increase in interest in availability of home and hobby greenhouses, as well as research into low cost thin plastic, high and low tunnels, used primarily for season extension among soil-based farmers as part of their season extension efforts.

Challenges

Given the arena in which greenhouses have 'evolved,' it is not surprising that concerns should be levied against these facilities due to their reliance traditionally on nonrenewable forms of energy. Historically the dominant trajectory of the commercial greenhouse industry has not been seen as environmentally or socially responsible. For example a greenhouse growing produce year round requires copious amounts of energy for artificial lights, heating and cooling, fertigation units, and environmental control systems. High capital costs place an inordinate amount of pressure to generate high returns for investors, and make growers and owners of such facilities reticent to radically change their distribution model.

Commercial greenhouses are extremely capital intensive, producing massive volumes of produce year round. On the surface this seems great, however, the irony is that much of the produce grown in large greenhouse facilities for example, in Canada, is then shipped to the United States, encouraged by trade agreements and the dominant food distribution channels.[100] It is precisely high capital and operating costs that leave commercial greenhouse facilities beholden to the existing food distribution model. These facilities are over designed with costly climate

[99] Ibid.
[100] MacRae, Rod. Class 9 Go Local and Direct. Fall 2012.

controllers and environmental control software focused more on uniformity of the produce and high volume. While it might not seem obvious at first, large commercial facilities can threaten community food security because in order for these facilities to turn a profit, they must seek large markets, and put profit at the centre of the decision-making.

In a recent article, *The Food System and Climate Change: An Exploration of Emerging Strategies to Reduce GHG Emissions in Canada*, researches found that "… despite significantly lower shipping emissions from Leamington (about 92% less than shipping from the San Juan Valley, California), total emissions in the greenhouse scenario (including production, embodied energy in structures, transport and waste) were still four times higher per unit of product weight than California imports."[101]

Sustainable Approaches to Controlled Environment Agriculture

In the Netherlands the energy used to artificially light and heat greenhouses has been reduced by 50% since 1990.[102] Professor and researcher, Leo F. M. Marcelis, from Wageningen UR Greenhouse Horticulture lists the following measures taken by the greenhouse industry in the Netherlands to effect this change. "These energy-saving measures include:

- Better insulation using energy screens and high-tech covering materials.
- New growing strategies that take advantage of natural energy

[101] Rod MacRae , Vijay Cuddeford , Steven B. Young & Moira Matsubuchi-Shaw (2013): The Food System and Climate Change: An Exploration of Emerging Strategies to Reduce GHG Emissions in Canada, Agroecology and Sustainable Food Systems. p.13

[102] Marcelis, Leo F.M, Hemming Silke. "Greenhouse Production in The Netherlands." Resource: Energy and technology for a sustainable world. American Society for Agricultural and Biological Engineers (ASABE), Special Issue March/April 2013, p.14

sources and off-peak energy costs.

- Development of semi-closed green-houses, in which solar heat is captured and stored."[103]

Marcelis also predicts, "[i]n the future, greenhouse production without fossil fuels can be achieved by using heat pumps, geothermal heat, waste heat from other industries, and green electricity."[104]

In the 2007 *International Symposium on High Technology for Greenhouse System Management: Greens, presenters*, J. Nelkins and T. Caplow presented on the topic of "Sustainable Controlled Environment Agriculture for Urban Areas." They maintained: "Environmental impacts of CEA can be aggressively reduced through carbon neutral energy supply, water recapture and recycling, and sitting on pre-existing or underutilized structures."

Passive Solar Energy Greenhouses

It is clear that one major obstacle to adopting greenhouses as part of a food security strategy in a Northern climate such as Canada is the energy consumption often associated with such facilities. "In cold climates, a substantial amount of supplemental heating is required to run greenhouses in the winter season. According to the Commission of the European Communities (1986), more than 75% of thermal energy consumption in agriculture is devoted to greenhouse heating in northern countries. This shows that reducing consumption of fuels for greenhouse heating is of paramount importance to the existence of horticulture in the future (FAO 1987)." [105] To this end, researchers from the department of Biosystems Engineering at the University of Manitoba have found that the energy consumption associated with heating greenhouses

---

[103] Marcelis, p.14

[104] Ibid., p.14

[105] E. Beshada, Q. Zhang, and R. Boris. "Winter performance of a solar energy greenhouse in southern Manitoba." Canadian Biosystems Engineering. Volume 48. 2006. p.5.1
http://www.engr.usask.ca/societies/csae/protectedpapers/c0611.pdf

year round in cold weather climates is drastically reduced through the use of solar energy greenhouse design[106]. Solar energy greenhouses are often built with one solid wall that absorbs heat from the sun during the day and releases this heat in the evening – thereby reducing heating costs and reliance on oil and natural gas. The solid wall is built on the northface, and steel framing and thin polyethylene covering is used on the other walls. Additional components to solar energy greenhouses include the use of thermal blankets, which also provide insulation and heating.[107] Scientists have also found that the use of argon gas pillows, placed between the air inflated double poly plastic film and the steel frame in a 2000 sq. foot greenhouse, adds enough insulation to keep temperatures up to 10 ˚C during the cold winter nights.[108] The studies at the University of Manitoba were conducted in a greenhouse small enough to be of interest to small farmers. The study includes low cost materials, such as double poly plastic film, argon gas pillows and the basic solar energy storage wall design (see diagram below).[109]

In a study evaluating the *Winter performance of a solar energy greenhouse in Manitoba*[110] the authors concluded that "[s]olar energy may provide the most cost effective means for greenhouse heating. In the middle and northern China, simple, inexpensive, and energy conserving solar energy greenhouses have been used to produce vegetables in winter, late fall, and early spring since the1980s (FAO 1994)."[111] While there is no clear data on the costs or potential returns, the National Sustainable Agriculture Information Service

---

106 Ibid., p.5.1

107 Ibid., p.5.2

108 "Manitoba Hydro." Solar Greenhouse Research – 06/07 Results. Accessed 2014 https://www.hydro.mb.ca/your_business/farm/solar_energy_greenhouses_results.pdf

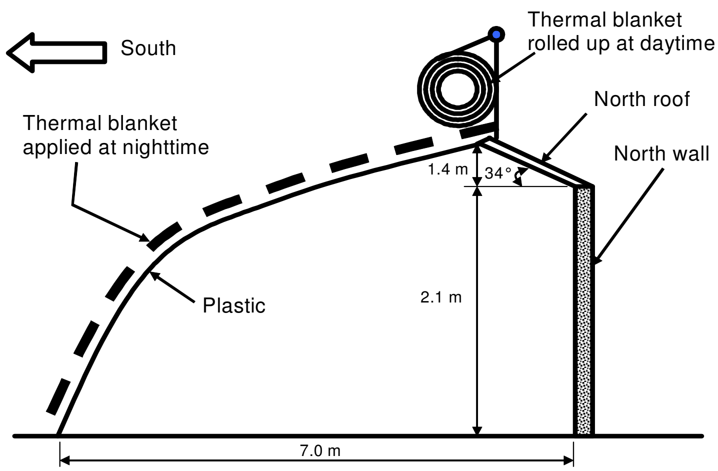
109 Ibid.

110 E. Beshada, Q. Zhang, and R. Boris. "Winter performance of a solar energy greenhouse in southern Manitoba." Canadian Biosystems Engineering. Volume 48. 2006. p.5.1 http://www.engr.usask.ca/societies/csae/protectedpapers/c0611.pdf

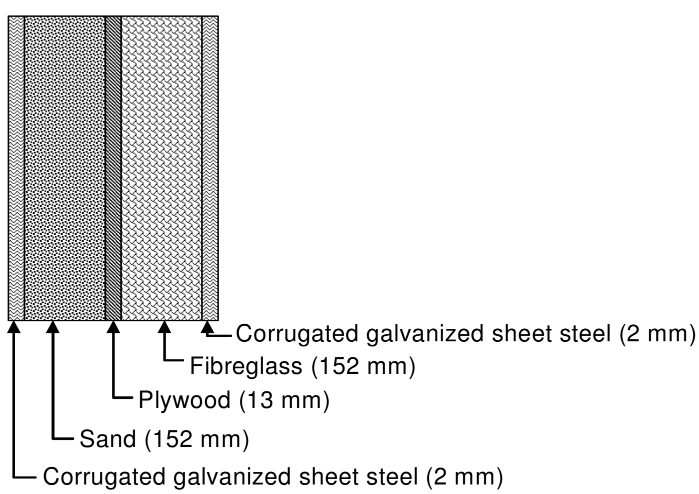
111 Ibid.

in the US state on their website that “[p]assive solar greenhouses are often good choices for small growers, because they are a cost-efficient way for framers to extend the growing season.”

Side view of the solar energy greenhouse, University of Manitoba[112]



Structure of the solar energy storage north wall, University of Manitoba[113]



112 E. Beshada, Q. Zhang, and R. Boris. “Winter performance of a solar energy greenhouse in southern Manitoba.” Canadian Biosystems Engineering. Volume 48. 2006. (http://www.engr.usask.ca/societies/csae/protectedpapers/c0611.pdf) p.5.2

113 Ibid., p.5.2

Waste Heat Capture and Co-generation Greenhouses

Cogeneration (co-gen) facilities utilize combined heat and power (CHP) engines that produce "both electricity and thermal energy for heating or cooling from a single fuel input," thus enabling the "transfer of heat and electricity from the engine to the greenhouse or interconnection site."[114] Truly Green, a greenhouse enterprise in Chatham Ontario owned by the Devries family has constructed a tomato greenhouse – a project costing $65 million – next to an ethanol plant to capture waste heat and carbon dioxide from the plant using cogeneration technology. Co-gen utilization is estimated to result in a 50% reduction in heating costs for the Truly Green greenhouse, and the capture of the ethanol plant's carbon dioxide pumped into the greenhouse is expected to result in a 3 to 5% increase in production.[115] Plans to "…supply hot water to the greenhouse… [which will then be]… returned to the ethanol plant through an expanded cooling water loop… will mean there's no longer a visible plume from the ethanol plant."[116]

While it is very encouraging to see waste heat and carbon dioxide are both captured and utilized by the greenhouse, even with a 50% reduction in heating costs, it would be interesting to know what the remaining energy requirements are to both heat as well as artificially light the facility – information not currently available. It is also questionable as to whether ethanol itself, especially using a food based crop such as corn, is a truly "green fuel."[117] Other

---

[114] Sustainable Agriculture Management Branch, *Regulating combined heat and power generation at greenhouses in the ALR: Discussion Paper and Standards Draft*, MC Ministry of Agriculture (http://www.al.gov.bc.ca/resmgmt/sf/co_generation_in_ALR/CHP_Discussion_Paper_December_2011.pdf) December 15, 2011.

[115] "A tomato greenhouse hooks up with an ethanol plant to save energy." *The Grower.* (http://www.thegrower.org/readnews.php?id=2w4b4n6x8j3s) Accessed 2014.

[116] Ibid.

[117] Saskatchewan Eco Network. *Ethanol Index.* (http://econet.ca/issues/ethanol/energy.html) Accessed 2014

"If energy consumed in the production of ethanol is generated through the use of "dirty" fuels such as coal, the overall environmental impact is less positive. The net energy gain and environmental benefits of ethanol co-gen integrated greenhouse facilities have generated electricity using waste energy crops, such as manure, or waste from landfills.

In Ladner B.C, Village Farms, a 100 acre commercial greenhouse operation has recently purchased a cogeneration facility ($5.2 million) that uses "methane gas from the Vancouver Landfill to generate electricity for B.C. Hydro and thermal heat for the greenhouse."[118] The cogeneration facility has been in operation since 2004 however as part of a $7.5 million project, quad-generation at the facility was made possible this year using "fuel cells that utilize a highly efficient electro-chemical process to generate power that avoids the emission of virtually any pollutants, due to the absence of combustion."[119] Now, the facility produces not only electricity and thermal heat but also carbon dioxide used in the greenhouse and hydrogen for sale.

Co-gen integrated greenhouses, may make commercial greenhouses in Canada a more environmentally friendly option. However, much depends on the energy source[120] as the "environmental impacts are quite dependent on the biomass resource used as a starting point and the conversion efficiency in the process."[121] For example, it is doubtful as to whether ethanol is truly a 'green' crop. The production of ethanol requires a fair amount of farmland – land that could otherwise be used to grow food.[122] "In a 2005 study, Cornell University researcher David Pimental factored in the energy needed to grow crops and

---

blended fuel are compromised when "dirty" fuels are used to power any of the various stages of the production process." Maybe this needs to go in the body

[118] "A tomato greenhouse hooks up with an ethanol plant to save energy." *The Grower.* (http://www.thegrower.org/readnews.php?id=2w4b4n6x8j3s) Accessed 2014.

[119] Ibid.

[120] "Electricity produced from biogas made from non-waste energy crops has significantly higher total environmental impacts than the average electricity form grid in Switzerland. Therefore, such electricity cannot be considered as green, in contrast to electricity made from biogas produced from waste substrates, which has significantly lower environmental impacts." Stucki, Matthias, Niels Jungbluth, and Marianne Leuenberger. *Life Cycle Assessment of Biogas Production from Different Substrates.* October 1, 2012 (http://www.esu-services.ch/fileadmin/download/publicLCI/stucki-2011-biogas-substrates.pdf) Accessed 2014. p. 42

[121] Ibid., p. 42

[122] "Replacing only five percent of the nation's diesel consumption with biodiesel would require diverting approximately 60 percent of today's soy crops to biodiesel production," says Matthew Brown, an energy consultant and former energy program director at the National Conference of State Legislatures. "That's bad news for tofu lovers." West, Larry. "What are the drawbacks of using Ethanol?" *Aboutnews.* (http://environment.about.com/od/ethanolfaq/f/ethanol_problem.htm) Accessed 2014

convert them to biofuels and concluded that producing ethanol from corn required 29 percent more energy than ethanol is capable of generating."[123]

Co-gen or quad-gen integrated greenhouses have led to cost saving measures for large greenhouse operations, however it is not clear whether it will become economically feasible for smaller greenhouse operations. There are significant barriers to adoption of these multi-million dollar co-gen projects namely investment costs, and technical knowledge and skill. This raises concerns as to the technology's contribution to a robust food security strategy in Canada. Smaller scale co-gen systems that are relatively low tech[124] that support farms focused on delivering fresh produce to nearby markets, rather than large facilities bound to transnational agreements, or collaborative initiatives where many small farmers benefit from a cogeneration facility – but where no one farmer bears the entire capital and operating cost – would go much further to simultaneously address both climate change and food security in Canada.

Aquaponics: Multi-Trophic Agro-Ecosystem for Food Production

In addition to seeking ways to more sustainably address heating and energy requirements in greenhouses in cold weather climates, alternative food production methods may also contribute to local and ecologically sound farming practices. Over the last ten years, aquaponics has been studied rather extensively in various research facilities throughout the world.[125] Its popularity as a farming practice comes in large part from vocal and enthusiastic backyard

[123] West, Larry. "What are the drawbacks of using Ethanol?" *Aboutnews.* (http://environment.about.com/od/ethanolfaq/f/ethanol_problem.htm) Accessed 2014

[124] Washington State University. Center For Sustaining Agriculture and Natural Resources. Small-scale Biogas Technology. (http://csanr.wsu.edu/anaerobic-digestion/small-scale-biogas-technology/) Accessed 2014

[125] Kevin Fitzsimmons. "Aquaponics Overview." Greenhouse Engineering Short Course, 2011. Controlled Environment Agriculture Center, University of Arizona.

hobby gardeners around the world, which has led to many DIY resources and community forums online.[126]

Professor Nick Savidov, at the University of Alberta, defines aquaponics as a "multi-trophic agricultural production system"[127] More simply, aquaponics is a recirculating system that combines aquaculture and hydroponics, where fish waste is converted into nutrients that feed the plants, which in turn purify the water for the fish. "Biologically," writes Savidov, "aquaponics is an example of an artificial ecosystem or agro-ecosystem designed for the purpose of food production"[128] Through his research, Savidov has demonstrated that "Agro-ecosystems are superior to conventional agricultural practices based on monoculture as they recycle nutrients, use resources like water more efficiently and do not have a harmful environmental impact."[129]

The results from studies conducted through the University of Alberta suggest that "biologically active aquaponic solutions" stimulate "nutrient uptake and assimilation by plants."[130] In addition, in trials comparing aquaponics and hydroponic plant production, plants grown aquaponically outperformed plants grown hydroponically.[131]

Comparison of plant growth between hydroponic and aquaponic nutrient solutions [Table][132]

126 "Backyard Aquaponics". Forum. 2014 http://www.backyardaquaponics.com/forum/

127 Nick Savidov. "Agro-Ecology in Aquaponics." Aquaponics Course, November 2013. University of Alberta. p.25

128 Nick Savidov. "Agro-Ecology in Aquaponics." Nick. Aquaponics Course, November 2013. University of Alberta. p.31

129 Ibid., p.32

130 Ibid., p.59

131 Ibid., p.52

132 Ibid., p.52

	Hydroponic			Aquaponic		
Crop Plant	**Height (cm)**	**Shoot (g)**	**Root (g)**	**Height (cm)**	**Shoot (g)**	**Root (g)**
Basil	**30**	**226**	**68**	**35**	**301**	**111**
Rosemary	**31**	**141**	**119**	**35**	**226**	**290**
Cucumber	**138**	**1180**	**219**	**156**	**1580**	**274**
Tomato	**110**	**1616**	**198**	**114**	**1841**	**279**

Tissue analysis comparing cucumber plants grown in an aquaponics system versus a hydroponics system found that although the there were higher concentrations of nutrients found in the water of the hydroponics system than the aquaponics system, the cucumbers grown in the aquaponics system were able to absorb nutrients more efficiently and were in fact more nutrient dense.[133] The disparity between plant growth rates, and nutrient density, in a hydroponics system versus an aquaponics system highlights one of the fundamental differences between hydroponics and aquaponics. "In conventional hydroponics and aquaculture systems microorganisms are not desirable. In integrated systems microflora is an inherent part of the system."

Nick Savidov identifies, "[a]t least five distinct microbiotas, or microbial communities," found in aquaponic systems.[134] They are: "[t]he populations within the water column; the aerobic bioreactor populations that covert organics into plant nutrients; fish gut microbiota; the root's rhizosphere communities; and biofilms."[135] "Beneficial bacteria living in the rhizosphere of plants" (referred to as "plant-growth promoting rhizobacteria or PGPR) "…promote plant growth through: nitrogen

133 Nick Savidov. "Agro-Ecology in Aquaponics." Nick. Aquaponics Course, November 2013. University of Alberta. p.31

134 Ibid.

135 Ibid.

fixation; plant hormones production; improving plant mineral nutrition; suppression of plant pathogens."[136]

Table highlighting the differences between hydroponics and aquaponics[137]:

	Hydroponics	Aquaponics
Principals	Conventional	Biological
Recirculation	Possible	Closed loop
Source of nutrients	Synthetic fertilizers	Fish waste, nutrients released due to biological activity
Beneficial microorganisms	Practically excluded	Essential part of the system
Building multitrophic relationships in the system	In some extent	Yes
Balance	One-component system	Balanced
Self-regulation	No	Yes
Creating an ecosystem	No	Yes
Stability of a mature system	Not stable	Very stable

Aquaponic farms are fairly new in Canada, with less than a dozen that are "up and running and generating revenue for three years or more."[138] Most of these "large-scale aquaponics systems … are located in Alberta, where the ministry of agriculture has invested in researching and developing systems."[139] All of the successful operations are greenhouse farms.[140] In combination with, for example, passive solar energy greenhouses, aquaponic production in cold weather climates can be a strategic response to food insecurity. Further research and programs to

---

136 Nick Savidov. "Agro-Ecology in Aquaponics." Nick. Aquaponics Course, November 2013. University of Alberta. p.90

137 Ibid., p.90

138 Sherman, Josh. *Aquaponics: urban growers gaining ground.* Spacing. October 29, 2014 (www.spacing.ca/national/2014/10/29/aquaponics-urban-growers-gaining-ground/) Accessed 2014

139 Slaughter, Graham. *Aquaponics Brings Fish Fuelled Vegetables to Toronto.* The Toronto Star. Jan 3, 2014. (www.thestar.com/news/gta/2014/01/03/aquaponics_brings_fishfuelled_vegetables_to_toronto.html) Accessed 2014

140 Sherman, Josh. *Aquaponics: urban growers gaining ground.* Spacing. October 29, 2014 (www.spacing.ca/national/2014/10/29/aquaponics-urban-growers-gaining-ground/) Accessed 2014

develop systems throughout the rest of Canada would do much to encourage its uptake.

Conclusion

While the examples of technologies and production methods in this paper are hopeful, more data is required to measure their impact, how they fit into accessible and affordable food systems, and to understand how best to encourage their adoption. Largely lacking within the greenhouse sector are product life cycle assessments as a benchmark to determine the environmental sustainability of any given greenhouse structure, material and production method. As the authors of *Scaling up Urban Agriculture in Toronto* observe, "… the potential environmental benefits of local production will be realized only with careful attention to minimizing transport with small vehicles, which emit more kilograms of carbon dioxide per tonne-km than large trucks, trains, or ships (Edwards-Jones et al. 2008)."[141]From the data that is available, solar energy greenhouses can do much to advance sustainability in the field of controlled environment agriculture, lowering the cost to heat a greenhouse, and drastically reducing the greenhouse gas emissions typically produced by conventional operations.

The technology and production methods presented in this paper were selected for their broad application across the spectrum of small-scale farm operations, to large commercial operations. However, their adoption must work in tandem with further field-based research, public education, and market assessments. These solutions may be attractive to farmers seeking to transition out of their existing agricultural production practices.

141 Joseph Nasr, Rod MacRae & James Kuhns with Martin Danyluk, Penny Kaill-Vanish, Marc Michalak & Abra Snider. *Scaling up Urban Agriculture in Toronto: Building the Infrastructure*. Metcalf Foundations, June 2010. p.34

Although there may be some short-term impact, the solutions presented above really gain significance as the impact of climate change is more acutely felt in Canada. Research conducted now, has wide scale application in the present and well into the future. Though more research is needed on the economic feasibility of passive solar greenhouses, what research into aquaponics at the University of Alberta suggests is that aquaponic plant production rivals that of conventional hydroponic production.

Solar energy greenhouses show promise in cold weather climates as evidenced by the research conducted at the University of Manitoba, and when drastically scaled, down, cogeneration, when used in conjunction with an energy source such as waste crops, can provide a two fold solution, as it also diverts waste that would otherwise be headed to, for example, a landfill. In an era where we must look to sustainable agricultural practices if we are to grow food locally and develop a comprehensive food security strategy in cold weather climates, continued research into sustainable approaches to greenhouse operations is required. This research is worthwhile as the authors of Scaling up Urban Agriculture in Toronto, note, "[i]f even 1.5% of Toronto's surface area were made available to market gardeners and greenhouse operators, [a] … $16 million a year industry" would be created, "growing 10% of [Toronto's] fresh vegetables."[142]

Bibliography

"A tomato greenhouse hooks up with an ethanol plant to save energy." *The Grower.* (http://www.thegrower.org/readnews.php?id=2w4b4n6x8j3s) Accessed 2014.

"Agriculture Energies." Solar Greenhouse Farming. 2014 http://www.agriculturesolar.com/3b_solar_greenhouses_farming.html#.VCbMalaprwI

Alice-Marie Archer. "MAKING AQUAPONICS ACCESSIBLE." A Schumacher

[142] Toronto's Food Charter. (www.foodsecuritynews.com/presentations/Toroto_Food_Charter.pdf) p.3

Institute Challenge Paper.

"Backyard Aquaponics". *Forum*. 2014
http://www.backyardaquaponics.com/forum/

Baird, Craig. *The Complete Guide to Building Your Own Greenhouse*. Atlantic Publishing Group Inc.; Ocala, Florida, 2010

Campus Extension. *History of Greenhouses.*
(www.campus.extension.org/pluginfile.php/45642/mod_resource/content/0/Unit-01/ghhistory.html) Accessed 2014

"Controlled Environment Agriculture Center." University of Arizona. 2014
http://ag.arizona.edu/ceac/

Controlled Environment Agriculture Center. University of Arizona. Greenhouse Engineering Short Course, 2011.

Controlled Environment Agriculture Center. *Hydroponic Historical Review*. University of Arizona. 2014 (http://ag.arizona.edu/ceac/hydroponic-historical-review)

Dave's Garden. *A Short History of the Greenhouse.*
(www.davesgarden.com/guides/articles/view/3607/#b) Accessed 2014

E. Beshada, Q. Zhang, and R. Boris. "Winter performance of a solar energy greenhouse in southern Manitoba." Canadian Biosystems Engineering. Volume 48. 2006. http://www.engr.usask.ca/societies/csae/protectedpapers/c0611.pdf

Fitzsimmons, Kevin. "Aquaponics Overview." Greenhouse Engineering Short Course, 2011. Controlled Environment Agriculture Center, University of Arizona.

"Food Secure Canada." Northern Remote Food. 2014
http://foodsecurecanada.org/community-networks/northern-remote-food

"Gotham Greens." 2014 http://gothamgreens.com/our-approach-to-sustainable-agriculture

Joseph Nasr, Rod MacRae & James Kuhns with Martin Danyluk, Penny Kaill-Vanish, Marc Michalak & Abra Snider. *Scaling up Urban Agriculture in Toronto: Building the Infrastructure*. Metcalf Foundations, June 2010.

MacKeown, David. *Food Security: Implications for the Early Years*. Toronto Public Health, February 2006.
(www.toronto.ca/health/children/pdf/fsbp_final.pdf) Accessed 2014.

"Manitoba Hydro." Solar Greenhouse Research – 06/07 Results. Accessed 2014
https://www.hydro.mb.ca/your_business/farm/solar_energy_greenhouses_results.pdf

Marcelis, Leo F.M, Hemming Silke. "Greenhouse Production in The Netherlands." Resource: Energy and technology for a sustainable world. American Society for Agricultural and Biological Engineers (ASABE), Special Issue March/April 2013

Nick Savidov. “Agro-Ecology in Aquaponics.” Nick. Aquaponics Course, November 2013. University of Alberta.

Rod MacRae. Class 9 Go Local and Direct. Fall 2012.

Rod Macrae , Vijay Cuddeford , Steven B. Young & Moira Matsubuchi-Shaw (2013): The Food System and Climate Change: An Exploration of Emerging Strategies to Reduce GHG Emissions in Canada, Agroecology and Sustainable Food Systems, DOI:10.1080/21683565.2013.774302

Saskatchewan Eco Network. *Ethanol Index.* (http://econet.ca/issues/ethanol/energy.html) Accessed 2014

Sherman, Josh. *Aquaponics: urban growers gaining ground.* Spacing. October 29, 2014 (www.spacing.ca/national/2014/10/29/aquaponics-urban-growers-gaining-ground/) Accessed 2014

Slaughter, Graham. *Aquaponics Brings Fish Fuelled Vegetables to Toronto*. The Toronto Star. Jan 3, 2014. (www.thestar.com/news/gta/2014/01/03/aquaponics_brings_fishfuelled_vegetables_to_toronto.html) Accessed 2014

Stucki, Matthias, Niels Jungbluth, and Marianne Leuenberger. *Life Cycle Assessment of Biogas Production from Different Substrates.* October 1, 2012 (http://www.esu-services.ch/fileadmin/download/publicLCI/stucki-2011-biogas-substrates.pdf) Accessed 2014.

Sustainable Agriculture Management Branch, *Regulating combined heat and power generation at greenhouses in the ALR: Discussion Paper and Standards Draft*, MC Ministry of Agriculture (http://www.al.gov.bc.ca/resmgmt/sf/co_generation_in_ALR/CHP_Discussion_Paper_December_2011.pdf) December 15, 2011.

Toronto’s Food Charter. (www.foodsecuritynews.com/presentations/Toroto_Food_Charter.pdf)

Valerie Tarasuk. “Report on Household Food Insecurity in Canada, 2011” PROOF Annual Report 2011. http://nutritionalsciences.lamp.utoronto.ca/resources/proof-annual-reports/annual-report/

Washington State University. Center For Sustaining Agriculture and Natural Resources. Small-scale Biogas Technology. (http://csanr.wsu.edu/anaerobic-digestion/small-scale-biogas-technology/) Accessed 2014

West, Larry. “What are the drawbacks of using Ethanol?” *Aboutnews.* (http://environment.about.com/od/ethanolfaq/f/ethanol_problem.htm) Accessed 2014

Woo, Andrea. Critics slam Canada’s northern food program. The Globe and Mail. November 4, 2014. (www.theglobeandmail.com/news/critics-slam-canadas-northern-food-program/article21451386) Accessed 2014.

Part 3: Technical Paper

Excerpts from two (2013) Research Reports written on behalf of York Region Food Network (YRFN) in support of the upStream Aquaponics Social Enterprise Facility in Newmarket, Ontario

Introduction

In 2013, York Region Food Network (YRFN), a non-profit and charity signed a two-year lease for the use of warehouse and office space in downtown Newmarket to run a pilot indoor aquaponics operation. Construction began in the spring 2013, and the first plants went into the system by September 2013.The contents of this report have been adapted from two research reports I completed on behalf of York Region Food Newtwork(YRFN) in support of their social enterprise, upStream Aquaponics, in the capacity as a consultant. These reports were produced on behalf of YRFN, between July 2013 and December 2013, as the facility transitioned from pre-operational to operational in September 2013. I worked independently on the reports mainly onsite at the upStream facilities, under the supervision of the YRFN executive director, Joan Stokehocker. The proposals for each report were developed in consultation with the YRFN team, and upStream Aquaponics co-founder Steven Looi,

The first one was produced in August, 2013 and included the following:

- Crop recommendations for both the water culture raft and gravel units
- A description of the cultural requirements for the plants
- An initial description of an Integrated Pest Management Plan relevant to the aquaponics system

Recommendations for the water culture raft units were based on the following performance considerations:

- High yields and
- Low maintenance

Crop recommendations specific to the facility's gravel unit were based on the following performance considerations:

- High profitability
- High market demand

The second report produced in December 2013, included the descriptions and recommendations of the following:

- Plant and fish production operating procedures
- Water quality requirements for optimal plant and fish production
- Environmental controls for optimal plant and fish production
- upStream facility production capacity analysis and findings
- Job/volunteer position descriptions for upStream Aquaponics

YRFN/UpStream Report Research Questions

The following are questions that guided research for the report completed in August 2013:

- *What crops require minimal maintenance? Which crops are likely to generate considerably high yields, in a 1000 square foot indoor aquaponics facility?*
- *What crops have been grown successfully in indoor aquaponics facilities?*
- *What are the crops that have the potential to be highly profitable and of great market value?*
- *What are the cultural requirements, such as temperature, lighting and relative humidity (RH) of the recommended crops?*

- *What are some of the common plant based pests and diseases that may emerge within an indoor aquaponics facility?*
- *What are some of the steps that can be taken to mitigate and prevent the presence of pests and diseases in a small indoor aquaponics facility?*

The following are questions that guided the research and activities of the second report completed in December, 2013:

- *How can the production of greens and fruiting plants be optimized at upStream?*
- *What documentation and materials will aid in the day-to-day tasks at upStream?*
- *What is the actual production capacity of the facility to-date?*
- *What are best practices and procedures associated with operating an aquaponics facility?*
- *What roles and positions are found in an indoor aquaponics facility?*

List of Excerpts

The following are excerpts I have taken and adapted from the two YRFN reports:

- Crop Recommendations
- Environmental Controls for Plant and Fish Production
- Production capacity analysis/findings
- Position descriptions
- Appendices

The photos included in this document were not included in the original reports, but have been included here to help the reader get a clearer picture of the facility layout and design as well as some of the developments that took place during the autumn, 2013. In addition a description of the aquaponics system is included below.

Aquaponics Systems Layout

The surface area of the warehouse, not included storage or office space is 1000 square feet. There are two main growing units, and one, germination 'chamber' in the facility. The growing chamber consists of wooden shelving and a door to allow seeds to germinate in the dark. The growing units are a combination of long two multi-tiered deep water culture beds, and one long water culture gravel unit. The system design is based on plans that were provided to participants of an aquaponics workshop conducted by the Aquaponics Training Institute. Co-founder of upStream Aquaponics, Steven Looi, attended this workshop in February 2013, and adapted these designs for the warehouse space.

In this system, two intermediate bulk containers (IBC) tanks have been filled with water containing tilapia. As the tilapia increase in size, they are fed organic fish feed pellets and worms from a small vermicompast bin. The water from the IBC fish tanks are led by gravity to a long blue swirl tank, where sediment and non-soluble waste are separated from the fish effluent and eventually removed from the system to be composted. From the swirl tank the fish effluent is then, by way of gravity, deposited into a large black food grade plastic sump tank. The sump tank is positioned at the lowest point of the entire aquaponic system. All the water in the system flows back to the sump tank, and it is from here, that the fish effluent is pumped up into a holding tank, positioned a few meters directly above the sump tank. A back up generator rests on top of the sump tank. In the event of a power outage this back up generator will continue to pump water up to the header tank. From the header tank water is carried to the rest of the system. The water transported throughout the system is carried by 2" food grade PVC pipes.

Picture of the aquaponics system at upStream Aquaponics in Newmarket, Ontario. Credit: Marcela Crowe

The water culture gravel units, in addition to supporting the production of vine crops, also serves as a secondary biofilter, capturing non-soluable organic waste. It is there where much of ammonia produced by the fish is converted into nitrates absorbed by the plants, through a process call nitrification. The water culture gravel unit, or biofilter bed, is filled with clay pebbles, called hydroton balls. Water is ‘flooded’ into the bed, and when it reaches a certain level, siphons, placed in the bio-filter bed, are activated and the water is drained out, and taken back to the sump tank. Floating styrofoam rafts are placed on top of the deep-water culture beds which are permanently filled with water. A biodegradable coco-coir and polymer blend plug, or growing substrate, is placed in the rafts' prefabricated holes, allowing the roots of plants grown in the plug to be immersed in the water, and the rest of the plant on the other side of the Styrofoam rafts, is exposed to air and light. Throughout the system the water is oxygenated using air blowers to ensure plants are able to absorb the nutrients from the water. Oxygenation also occurs through friction generated as water flows through the plumbing and rest of the system. As the entire system cycles, a biologically active aquaponic solution containing fish effluent and other nutrients is produced, and pumped throughout the system. Establishing microbial communities within the system is essential. Nitrosomonas bacteria and nitrobacter bacteria, common bacterias found in soil, are key to establishing healthy microbial communities within the system. These bacteria were introduced to the system using water extracted from a nearby aquaponics system. Once introduced the nitrosomonas bacteria will continue to be present so long as levels of ammonia are present in the system. Ammonia, both produced by and toxic to the fish, is converted into nitrites by nitrosomonos bacteria, and nitrites are converted into nitrates, by nitrobacter bacteria. Once established however, there are many more microbes in the system. For example, plant growth promoting rhizobacteria (PGPR) are found on the plant roots, and the biofilm that aids in the nitrification process is also found at the bottom of the Styrofoam rafts.

T5 florescent lights hang about three feet above the raft beds. They emit a bluish light encouraging vegetative growth. High Pressure Sodium (HPS) lights are suspended above the water culture gravel unit. The HPS light bulbs emit a red and orange light, used to encourage plants to produce fruit. The facility also houses a stainless steel washing station and a small fish tank not connected to the rest of the system, where tilapia fingerlings are grown until they are large enough to be placed in the IBC tanks.

T5 Florescent lights used at the upStream Aquaponics facility in Newmarket, Ontario.

Crop Recommendations

Many different plants can be grown within an aquaponic system, using appropriate techniques. Strictly speaking, plants that do not work well in aquaponics, are those requiring extreme alkaline conditions. The correct pH is crucial to a successful aquaponics operation. Finding a balance between the pH of the plants and that of the microbes, or beneficial bacteria, that populate the system, is critical in an aquaponic operation. For example, nitrifying microbes prefer a pH around 7.5, whereas plants prefer a lower pH. Typically, plants grown in aquaponics are leafy green vegetative plants like lettuce and basil, as these crops offer greater market value in volume and yield. Most vegetative growth in an aquaponic unit requires little to no nutrient supplementation because the waste by products of the fish provide enough for suitable plant growth. Fruiting plants, such as tomatoes, peppers, cucumbers and strawberries, require a lower ratio of nitrogen (N) compared to phosphorus (P) & potassium (K), so nutrient supplementation such as iron (Fe) or calcium (Ca) may be necessary for these types of crops.

Nitrifying microbes are an essential component to an aquaponic system, as it is what convert toxic levels of ammonia released from the gills of the fish into nitrates, which at >500 mg/L the fish can tolerate, and which are required by the plants for growth. Most aquaponic systems function best with a pH between 6.8 and 7.2. Selecting plant varieties that can grow within these conditions is a determining factor in crop recommendations detailed below. [143]

Vegetative Crops

Specific varieties of recommended vegetative crops are detailed below. These varieties were selected for the following reasons:

- Suitability of production within an indoor facility
- Disease resistance
- Production Rates and High Yields
- Tolerance to either increases (summer months) or decreases (winter months) in temperature

The seed varieties recommended, can be sourced from a number of companies in both the US and Canada, such as Vesey's and Johnny's Selected Seeds. High performing organic varieties were informed the recommendations listed below. These selections optimize the criteria listed above.

[143] Note that spinach is not recommended here as an initial crop to grow at the upStream facility as in a water culture system, they are prone to a water born pathogen called Pythium aphanadermatum that attacks the roots and causes poor crop quality and crop death. There are methods to treat and mitigate the presence of this pathogen, however, it is recommended that spinach may be grown in the upStream facility only after the environmental conditions have been stabilized and an IPM strategy has been successfully implemented for a considerable time.

LETTUCE

ButterheadVarieties:

- Tom Thumb (Organic) Lettuce

(Lactuca sativa)

Romaine Varieties:

- Ridgeline (Organic) Romaine Lettuce
- Jericho (Organic) Romaine Lettuce (Lactuca sativa)

Salad Mix Varieties

- Encore Lettuce Mix (Organic)
  (Lactuca sativa)

HERBS

Basil Varieties:

- Aroma 2 basil (Ocimum basilicum)

Parsley Varieties:

- Titan Italian Parsley (Petroselinium crispum)

PAC CHOI

Pac Choi Varieties:

- Mei Qing Choi (Brassica rapa (Chinensis group)

Environmental Controls for Plant & Fish Production

Crops are affected – both yield and quality – by their surrounding microclimate:

- Photosynthesis
- Respiration
- Transpiration
- Leaf & Fruit Temperature
- Water temperature

Environmental factors affecting plant growth are:

- Air flow
- Light
- Air temperature
- Relative humidity
- Carbon dioxide
- Pollutants
- Root environment

It is important to control the plant environment, so as to ensure that crops grow optimally and are not left susceptible to pests and diseases. The following are steps to take when seeking to control the plant environment:

- Monitor indoor conditions
- Know conditions
- React promptly and appropriately

The following are environmental controls that can manipulate the environment for optimal plant and fish production

- Heating (ie. hot air heater)
- Cooling (ie. passive and active)
- Humidity control
- Carbon Dioxide (CO_2) enrichment
- Supplemental Lighting

Environmental control systems are a requirement to control and manage operations. In the context of the aerial environment, environmental control systems consist of the following:

- Heating systems
- Ventilation and cooling systems

- Supplemental light systems
- CO_2 enrichment

Environmental Control systems for the root microenvironment consist of the following:

- Heaters
- pH, E.C., and D.O. control systems, such as meters and test kits.
- General plant production management systems

All of these systems and operations are bound together in an intricate way. Accurate control of an indoor growing environment can be challenging. For example if the relative humidity is too high around the plants, then the plants are not able to transpire, which is a necessary function for optimal growth. Low levels of dissolved oxygen in the system can inhibit a plants ability to absorb nutrients even if nutrients are present in the system.

Air Ventilation

It is recommended that upStream install an air ventilation unit to ensure adequate air ventilation and purification:

- Air ventilation and air speed affects transpiration, evaporation, leaf temperature, CO_2 availability
- It is important that there is good exchange of air between the inside and outside of the facility

For further detail, see recommendations outlined in Appendix E.

Power Back-up

- Have smaller mobile generator that can run key aeration systems

- Manually exercise second generator from time to time and keep it fully fuelled

Remove Solids

- Remove solid waste through filtering or settling (swirl tank) before it enters the plant based part of the system.

If solids are not removed, they will adhere to plant roots, decrease oxygen levels as they decay and affect the uptake of water and nutrients. Excess solids will also have an adverse effect on nitrifying bacteria. As solids decompose, oxygen is consumed and ammonia is produced.

Temperature, RH, CO2, Lighting, etc.

Air temperature

- Each crop has specific day/night temperature set-points
- Crop responds well to minimal temperature fluctuations
- Maintain indoor day temperatures between 24-27°C and night temperatures between 14-18°C.

Relative Humidity (RH, %)

- RH is the measure of how much water is in the air
- An RH that is too low negatively effects crops
- An RH that is too high contributes to disease development and prevents plant transpiration
- Maintain indoor day relative humidity between 55-65% and night time relative humidity between 45-55%

Carbon Dioxide

- Plants respond to increase in CO2 levels

- CO2 enrichment is important typically during the winter months in the morning hours
- CO2 levels should be tested and should be 330 ppm
- Lower CO2 reduces growth and overall yields
- CO2 supplementation is not necessary at as there is adequate CO2 levels due to the presence of people that volunteer or pass through the facility.

Light

- Recommend conduct lighting trials to experiment with reducing current artificial lighting usage
- As a baseline run T5 lights 8 hours per day
- Conduct trials in the winter to determine lighting requirements and their effect of crop quality, as they differ from lighting requirements in the summer months

Root environment

Good aeration around the root environment is important in order to provide place support and is a source of nutrients:

- Provides plant support
- Source of nutrients
-

Facility Maintenance

The following are recommendations regarding the facility at upStream as a whole:

- Work with a qualified inspector to test for mold
- Train employees and volunteers about the health risks associated with inhaling toxic molds, or working inside a damp facility

- Regularly clean facility, walls, ceiling, and floors, and use gentle cleaning products such as baking soda, when cleaning surfaces that come into direct contact with the water from the aquaponics unit
- Remove all pest-attracting trash from the site
- Ensure that those working in the upStream facility have access to a sink with potable water, single-use towels, pump hand soap, that the facility has a covered trash can, and a first aid kit
- Covering all packing and production materials so that they avoided getting contaminated by insect or rodent droppings.

-

Two multi-tiered deep water culture beds growing leafy greens and herbs at the upStream Aquaponics facility, in Newmarket, Ontario

Production Capacity Analysis/Findings

Overview

Like any indoor facility, the production of greens and fruiting plants at upStream cannot be optimized without ensuring that both the water quality and aerial environmental conditions for optimal plant production are met. Sections 1 through 6 of this Report detail the conditions required to optimize plant production at upStream.

Currently, in its first year and due to costs, in the absence of adequately designed and installed environmental controls and systems, the environment at upStream has not yet been stabilized. Even with the proper equipment, stabilizing the environment for 4 season production may take up to 1 – 2 years, and therefore plant production data collected in the fall 2013 cannot be projected into the future to offer realistic figures.

Based on data collected in the fall 2013, abstract figures and crop schedules can be presented to offer YRFN known “benchmarks” that can be either matched or exceeded through better environmental control and water quality (ie. solids removal) design. But these “benchmarks” would only reflect the known production capacity at upStream between September and mid-November, 2013. Due likely to high outdoor temperatures, low levels of anaerobic pockets in the raft beds and therefore greater levels of dissolved oxygen (D.O.) in the water surrounding plant roots, indoor daytime temperatures at upStream rose to 27°C, RH reached 70%, the weight of sellable product per raft averaged 3 lbs., and the average growth cycle for leafy greens, was 5 weeks (seed to harvest).

With 36 rafts in the system, if leafy greens are kept in the rafts for 4.25 weeks, and germinate outside of the rafts for .75 weeks (12 annual crop turns), 4 oz. bags are sold for $2/bag (5184 bags sold per year), then annual gross sales would equal $10,368.00. If the bags of mixed greens are sold for $4/bag, then annual gross sales would equal $20,736.00. This assumes no production downtime. If improvements on water quality, the aerial environment and the germination room are made, then it may be possible to harvest more than 3 lbs. per raft of sellable product every 5 weeks from seed to harvest cycle. With improvements to the germination room alone, where leafy greens are kept in the rafts for 3 weeks, left in the germination room for the first 2 weeks (17 annual crop turns), and 4 oz. bags are sold for $2/bag (7344 bags sold per year), then the annual gross sales would equal $14,688.00. If the bags were sold for $4/bag then the annual gross sales would be $29,376.00. A crop loss of 5-10% should also be factored into projections. When making financial and market projections for the first operating year, it will be important to note that based on a 5 week seed to harvest production plan, the first harvest will occur in week 6.

As seed to harvest trials for vine crops were not feasible during such a short period of research conducted in the fall 2013, and the 1000 Watt HPS lights with red spectrum lighting suitable for fruiting plants, installed above the hydroton media beds were not conducive to basil production, there are no known figures associated with the production capacity of the hydroton media bed unit at upStream.

When developing crop schedules to fill specific sales orders it is important to note that major imbalances in the system's water chemistry will emerge if all 36 rafts are harvested at once. It is recommended to stagger harvests.

For example, based on a 5 week seed to harvest schedule, where plants are left in rafts for 3 weeks, where there is market demand, and a distribution plan in place, one way to organize a crop schedule is to plan to transplant 12 rafts, and harvest 12 rafts per week.

Week 1: Arugula seedling transplanted to deep water culture beds on September 18, 2013

Week 3: Romaine lettuce and Salad Mix (Oak leaf, at upStream Aquaponics, Newmarket Ontario.

Week 7: Healthy roots, show signs of adequate levels of dissolved oxygen (D.O.) in the system and a good plant growth promoting rhizobacteria (PGPR) surrounding the plant roots at upStream Aquaponics, Newmarket, Ontario

Position Descriptions

Many of the positions detailed below can be folded into one or two positions, especially considering the relatively small size of the upStream Aquaponics operation.

Farm Technician

A Farm Technician is responsible for the sowing of seeds, plant propagation, crop maintenance, post-harvest processing, packaging, and working under the supervision of the head grower.

<u>In an aquaponics facility, a farm technician's main duties include:</u>

- Monitor water temperature and conditions in fish tanks
- Test for disease among fish
- Track numbers and size of fish
- Feed fish by hand or with automated feeders
- Harvest fish using nets
- Follow the seeding and propagation schedules for different crops
- Careful handling and care for crops.
- Responsible for crop harvest and packaging.
- Ensure proper sanitation of equipment and surfaces.

<u>Main Qualifications for this Role</u>

- Experience in agriculture, aquaculture, horticulture
- Ability to work in hot and humid environments.
- Good computer skills (i.e. Excel and Word)

Supply Chain Technician

A supply chain technician/or manager is responsible for developing relationships with suppliers, forecasting the organization's supply demand, ensuring sufficient supply for continued operations, and for resolving any supply chain challenges

Examples of their duties include:

- Accurately forecast monthly inventory levels based on sales, and ensure supply orders are maintained to sustain operations.
- Build direct relationships with different suppliers giving preference to local suppliers utilizing sustainable practices.
- Maintain regularly updated inventory, supplier product, and supplier database.
- Maintain and improve purchasing, receiving, shipping, and inventory management process.
- Keep records to ensure product traceability

Main Qualifications for this Role

- University degree or college diploma in a business field or related experience.
- Knowledge of greens and fish supply chains in Canada

Pest & Research Technician

A Pest & Research Technician is responsible for overlooking the pest management program, developing new and improved pest management protocols, and collaborating with researchers to improve current growing systems

Examples of the duties of a pest and research technician include:

- Apply the principles of integrated pest and disease management in scouting for insect, disease, and weed infestations; identification of insect pests, and monitoring of pest populations.
- Work with the head grower to establish zones for research and development of new growing protocols
- Apply or release biological materials to manage insects, disease, and weed pests (ie. algae)
- Use pest management data to establish new control thresholds.

Main Qualifications for this Role

- University or College degree in Agriculture, Entomology, Botany, Plant Pathology, or related field
- Experience with horticulture/agriculture.
- Experience in design, implementation, analysis of field trials

Operations Manager

Depending on the size of the operation, the operations manager may perform tasks attributed to for example, a Farm or Pest & Research Technician. In addition they may also directly fill sales orders, and work directly with buyers, and customers. They also may serve as educators, training operations personnel and volunteers.

Examples of the duties of an operations manager include:

- Setting crop propagation schedules to meet sales demands.
- Allocating appropriate indoor space for growth of crops.

- Manage and train facility staff to ensure production of high quality products.
- Develop and provide monthly propagation, growth, and harvest records.
- Develop trials and implement new and improved growing methods.
- Regularly monitor, record, and adjust production plan for both fish and plants as required.
- Read and interpret environmental control sensors and ensure optimal growing conditions.
- Regularly monitor, record, and make pest management decisions based on prescribed thresholds
- Manage facilities, assets, and records.
- Ensure compliance with work hazards and safety for employees
- Research and propose energy efficient solutions for operations that minimize capital costs, reduce operating costs, and reduce the reliance on non-renewable resources.
- Calculate energy requirements associated with the environmental control (i.e. temperature, humidity) of the facility.
- Calculate projected operating costs associated with electricity, natural gas, and other sources of energy at the facility

Main Qualifications for the Role

- University or College experience in Horticulture, Aquaculture, Greenhouse Management, Agriculture or related experience
- Excellent mechanical aptitude
- Need to be a good manager of people and processes

Appendices

Appendix A – Plant Production Record

Sample Spreadsheet

Deep Water Culture Crop Layout Summary Week 8	**Raft #1**	**Raft #2**	**Raft #3**	**Raft# 4**	**Raft #5**	**Raft# 6**	**Raft #7**	**Raft# 8**	**Raft # 9**	**Raft # 10**	**Raft #11**	**Raft # 12**	**Raft#13**
Seed Code	P2												
Variety	Romaine												
Tray #	24												
Date Seeded	03/11/2013												
Date Transplanted	06/11/2013												
Raft location	LSB												
Date of 1st harvest	03/12/2013												
#plugs harvested	26												
Weight of harvest	800 g												
Date of Final Harvest	16/12/2013												
Weight of harvest	2100 g												
#plugs harvested	28												
Total weight from seed to harvest	2900												
Total # days seed to harvest	44												
Notes:	Plants were overcrowded by week 5												

Appendix B - IPM Record

Weekly Scouting Sheet

Location: Scout:	Week Number:
General Comments:	
Disease:	
Nutrient Deficiency:	
Whitefly:	
Aphids:	
Spidermite:	
Root Quality:	

Appendix C – Onsite Water Quality Record

Sample Spreadsheet

Daily Measures	**Date**	**Time**	**Temp.**	**pH**	**NH3**	**NO2**	**NO3**	**DO**	**EC**	**N**	**P**	**Fe**	**NH4**	**(AD)**	**Na**	**Cl**
* Temp = Temperature																
* pH = Power of hydrogen																
* NH3 = Ammonia																
* NO2 = Nitrites																
* NO3 = Nitrates																
* DO = Dissolved Oxygen																
* EC= Electrical Conductivity																
* N = Nitrogen																
* P = Potassium																
* Fe = Iron																
* NH4 = Ammonium																
* (AD) = Algal Densities																
* Na = Sodium																
* Cl = Chloride																

Appendix D – Inventory Record

SAMPLE SEED INVENTORY LIST

Lettuce

Code	Company	Seed Type	Variety	Qty.
P1	PIKE	Lettuce	Grand Rapids	
P2	PIKE	Lettuce	Romaine	
P3	PIKE	Lettuce	Bon Vivant	
P4	PIKE	Lettuce	Simpson	
	Urban	Lettuce,	Lettuce Red	
U1	Harvest	Organic	Flame	
	Urban	Lettuce,	5 Mustard	
U2	Harvest	Organic	Greens Mix	
	Urban	Lettuce,	Luscious	
U3	Harvest	Organic	Lettuce Mix	
	Urban	Lettuce,	Buttercrunch	
U4	Harvest	Organic	Lettuce	
	Martha	Lettuce,		
M1	Living	Organic	Mesclun Mix	
	Martha	Lettuce,		
M2	Living	Organic	Buttercrunch	
	Urban	Lettuce,	Spicy Salad	
U9	Harvest	Organic	Mix	
	Urban	Lettuce,		
U10	Harvest	Organic	Asian Mix	

Herbs/ other

Code	Company	Seed Type	Variety	Qty.
P5	PIKE	Basil	Genevese	
			Sacred	
U5	Urban Harvest	Basil	Basil Tulsi	
U6	Urban Harvest	Basil	Dark Opal	
U9	Urban Harvest	Basil	Genevese	
			Sweet	
F1	Mr. Fothergill's	Basil	Genovese	
			Fordhook	
P5	PIKE	Swiss Chard	Giant	
			Red	
U7	Urban Harvest	Kale	Russion	
			Rainbow	
U8	Urban Harvest	Kale	Dinosaur	

Appendix E – Environmental Controls

Designs to Regulate Temperature, Relative Humidity & CO2

Exhaust Fans and Filter: At 10,000 cubic feet, to exhaust air every five minutes, install two 2000CFM 12” fans to the North facing walls. Apply long ductwork to one fan (ie. closest to garage door) and aim toward the storage room door, suspended over and along the media bed. Attach a 12” Can-Filter at the end of the ductwork, also suspended, and attached to the ceiling (rope, or metal chain). This exhaust fan and air purifying and odour controlling Can-Filter can then be run continuously, pulling air out of the system every five minutes. Install an additional exhaust fan on North facing wall, with shorter length of duct work. Suspend the ductwork along the corridor, in between the deep water culture rafts. Attach a digital controller to the fan to automate fan according to set temperature and relative humidity parameters for the facility (60%). Mount the digital controller’s sensor to one of the deep water culture structures or in an area in the facility where the relative humidity (RH) and temperatures are most high. As temperatures or RH rises above the prescribed range, the exhaust fan will begin to draw air out of the system. This process works well in combination with one or two dehumidifiers.

Environmental Controls

Recommendation

Designs	**Notes**	**Quantity**		**Calculations/ Assumptions**	**10,000 cubic square feet**
Exhaust Fan	Inline, 2000 CFM, $299.99	2	$ 599.98	exchange air every 5 minutes	
Plywood	For windows	2	$	2000	CFM

			20.00	
Flange	12 ", $15 each	2	$ 30.00	
Duct work	$15 for elbows, $35 per 10 foot length - flexible. If want something with more structure, visit Noble Store (spec. in HVAC)	2	$ 100.00	
Can-Filter	12" 10000 cubic feet plus	1	$ 399.99	
Digital Controller	Humidity and Temp, Include sensor, automate exhaust fans	1	$ 229.00	
			$ 1,398.97	before tax

*Note: Intake fans not necessary as air will be pulled passively into the facility through doors, etc.

Currently there is negative pressure that is spilling air out into the storage room, and heading in the office.

With an exhaust fan on the north facing wall, air can be pulled out of the facility, and new air can be drawn in passively from the storage room, and office

Install two exhaust fans, one on each North facing wall. One fan can run continuously 24/7 to purify air and control odour