Controlled Environment Agriculture (CEA) LED Lighting Systems. New Metrics

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1. Problem Statement.

The problem that we have addressed is an **initial evaluation of potential metrics to be used in a model to properly evaluate solid state lighting (SSL/LED) in controlled environment agriculture (CEA)**. Our evaluation is in **financial and operational terms**. The detailed plant physiology research has to be done by specialized horticultural institutions, but can easily be incorporated in our model (that will be presented in a poster during the exhibition).

We have studied different lighting fixtures from different lighting manufacturers and the problem that we have found is that it is **difficult to properly compare horticultural fixtures**.

This comparison is crucial from an investment point of view, not only for the growers, but also for financial institutions that would finance this kind of investment. Also, for governmental funding and granting agencies that need to evaluate the feasibility of funds for this technology in the real world.

Solid stated lighting (SSL/LED) is an **innovative technology** that is still in the **early adoption** stage in the market (conservative in nature). There are many different reasons for this, as we will explain later, but the lack of expertise in the market and the **lack of standardization in the industry** are clearly the most important ones.

Supplemental lighting is a must in CEA in order to have continuous production during the whole year. This is particularly important in territories with a great variation of sunlight during the year (either because of location or because of weather –clouds, sky spectra, etc-).

But not every crop will be suitable for this kind of investment. Different agencies have studied what is called "**Specialty Crops**", classified in terms of **profitability and financial performance**. As an example, in a study accomplished by the Minnesota Department of Agriculture[1], they found that strawberries, assorted vegetables and raspberries are the three main performers. This will be a key point of our model, as it will promote the technology adoption in the market.

2. <u>Project Summary/Background</u> (2 pages)

In this project we established a model to evaluate potential metrics to be used in controlled environment agriculture (CEA). This model links the environmental effect with lighting system parameters, and therefore gives guidance in evaluation of solid state lighting (SSL/LED) for horticulture.

Traditional greenhouses use **high pressure sodium light sources**, which consume lots of energy and do **not have control flexibility**. LED sources provide much higher energy efficiency and variable spectral components that meet plant needs. However, existing greenhouse lighting systems haven't integrated the capability of real-time control. The equipped LED sources obtain preset spectral power distribution, which don't consider **different lighting needs of plants in different growth cycles** and the environmental impacts. As comparison, our solution – controlled environment agriculture based on new metrics provides the following new features:

1) New metrics that link the environmental effect with lighting system parameters. This could help to identify suitable lighting products for specific greenhouse lighting applications. Those metrics are beyond energy consumption, but reached to plant/crop biomedical outcomes, as well as environmental footprints. As a result, this helps greenhouse owners make informed

decisions on lighting product purchasing. And helps institutions such as NYSP2I have methods to evaluate existing greenhouse lighting systems.

2) Controlled environment agriculture (CEA) that provides tailored lighting solutions for specific crops at specific growth cycle. Based on the new metrics, we have designed smart lighting systems that enable **real-time control of the spectral power distribution (SPD) of the greenhouse lighting fixtures**. A time sequence of the different SPD serves as a tailored **lighting receipt/regime** for specified plants. As a result, the CEA provide exactly the system needs without waste energies on unnecessary energy consumptions on spectral components, space, and time.

To apply our promoted CEA with new metrics, the new system requires a learning cycle to study the environment, before providing optimal lighting solution. As a tradeoff, during this learning cycle, the system could be operated in states where the environmental impacts are not minimized, such as inefficient lighting brought by frequent switch on/offs or high ambient temperature for testing ranges of parameters and etc.

In recent relative researches, controlled Environment Agriculture (CEA) is defined as a combination of engineering, plant science, and computer managed greenhouse control technologies used to optimize plant growing systems, plant quality, and production efficiency. NYSERDA recognizes that CEA technology offer the potential to increase local food production. Now, NYSERDA's is developing more energy efficient CEA technologies so as to mitigate impacts on electric utility grid[2]. As a result, NYS is likely to be recognized as the leader of the CEA industry in the Northeast of the US, where CEA is an established and growing industry[3]. A report from the urban design lab in Columbia University discussed in detail the market and capacity of urban agriculture for different areas in New York City[4]. Now several on-farm

programs are performing in New York State, searching for high productive and environmental friendly local farming possibilities[5,6].

Lighting standards are usually measured by a variety of metrics. Our group promoted a series of color quality metrics for LED lighting since 2009. The Statistical Color Quality Metrics[7] along with a color rendition engine[8] were developed under the cooperation between Smart Lighting ERC (our group) and Vilnius University in Lithuania. This worked has been applied to various areas including food storage[9] (Now funded by NYSERDA). Also, the LED lighting impact on the production of food was evaluated in 2004[10]. Our project provides plant lighting systems based on new metrics, which enables new understanding of the relationship between plant lighting and environment. Local farming can be improved in terms of less cost and higher production.

3. Relationship to Sustainability (1 page)

Environmentally, tailored LED lighting with **high horticultural efficiency** will reduce energy consumption for CEA and urban agriculture. These savings will benefit the environment through **carbon reductions**. Meanwhile, with a measuring of relationship between plant lighting and water usage, we should also be able to provide **water saving** strategies for local CEA. For example, it is known that traditional HPS lamp will expedite water evaporation in greenhouses, while the optimized LED lighting will not have this disadvantage. Also, by trading off between plant yields and water usage, we could gain better understanding of water saving. And this can be implemented by proper lighting. Moreover, if the production of local farming can be boosted, meeting the demand of local vegetables and fruits will **reduce food transportation costs** and therefore saving more energy. Lastly, LED plant lighting provides the opportunity to

integrate small environmental system such as mini – garden into buildings and offices. Real plants refresh the air and offer a more relaxing working environment in urban area.

Furthermore, local produced vegetables and fruits with higher accessibility and lower price will **reduce social disparities in health access**. Research demonstrated that the demand for vegetables and fruits is linked to people's income level[11]. Lower price of local food means more purchasing capability for consumers and therefore more opportunity for healthy living. Also, local vegetables and fruits are more secure for consumers as time saving in transportation and storage. Finally, if this strategy can be integrated into New York State CEA plan[12], it will help local employment and regional development as demonstrated in the literature review section.

4. <u>Materials and Methods</u> (1 page)

4.1 <u>Performance of the work. Key milestones and project tasks</u>

The work has approximately been done as programmed on our proposal.

Project Task / Milestone	2013	2014			
	December	January	February	March	April
Literature & Internet Review					
Research with Horticultural Lighting Manufacturers					
Research with Greenhouses					
Research with relevant Authorities (NYSERDA)					
Report completion					
Final Presentation (Poster & Powerpoint)					

4.2 <u>Team members' roles. 3rd party contributions</u>

The roles have been totally complementary and we have had a great contribution from our Institution and especially from a research scientific that has collaborated with us from the horticultural side, where we do not have expertise, and that was doing the research with the greenhouses and the relevant authorities.

5. Results, Evaluation and Demonstration (3 pages)

5.1 Results of the project and how the results address the problem

In this project we have identified the metrics needed to properly evaluate a solid state (SSL/LED) lighting system. These metrics are highlighted in the next paragraph.

5.2 Qualitative and/or quantitative evaluations/metrics

Our metrics are qualitative and quantitative and are related to the two systems that are the essential part of the technology (lighting and plants) together with the financial metrics that are required on any kind of investment.

We have identified the following metrics

Lighting:

1. Detailed Spectrum (SPD). Fixed or variable.

2. Spectral Ratios (like B/R, blue to red). Fixed or variable.

3. Timing. Static vs. Dynamic

4. Light sources energy (total maximum and per channel).

5. Angle of light sources (with or without secondary optics)

6. Fixture separation and height placement thresholds (min/max). This will give the area.

7. Uniformity (spatial and spectral)

Greenhouse:

1. Location

2. Horizontal (bench) vs. vertical (multiple-tier)

3. Growing conditions (Temperature, Humidity, CO_2, shading, etc)

Crops metrics (Horticulture): Quantitative and Qualitative

1. Health. Pigment concentration and photosynthetic efficiency (mol CO_2 fixed/quanta absorbed).

2. Morphology (Taylor made). Height, branching, leaf size and thickness.

3. Aroma and taste. Biochemical compounds (gas chromatography)

4. Rate of Growth (Relative Growth Rate, RGR)

    a. Crop classification (families, genera, species, cultivars)

    b. Growth stages (seedling, juvenile, adult). Time, area, energy, nutrients and water

        i. Total time (T) and time per stage (Ti)

        ii. Area, energy, nutrients and water requirement per stage

5. Specific Leaf Weight (Leaf thickness, mass per unit area)

6. Costs and Prices. From production to shelf. Profitability (Specialty Crops)

7. Transportation

8. Shelf life

Financial metrics

1. Financial leverage requirements. Investment vs. Leasing opportunities

2. ROI. Return of investment

3. Waste: Mercury and light pollution. Disposals

4. CO_2 trading and Biomass

Parameters of the model:

Light Fixtures & Controls:

- Detailed Spectrum (SPD). Fixed or variable.
- Spectral Ratios (like B/R, blue to red). Fixed or variable.
- Timing. Static vs. Dynamic
- Light sources energy (total maximum and per channel).
- Angle of light sources (with or without secondary optics)
- Fixture separation and height placement thresholds (min/max). This will give the area.
- Uniformity (spatial and spectral)

Greenhouse:

- Location
- Horizontal (bench) vs vertical (multiple-tier)
- Growing conditions (Temperature, Humidity, CO2, shading, etc)

Crops metrics (Horticulture):

- Health. Pigment concentration and photosynthetic efficiency
- Morphology (taylor made).
- Aroma and taste. Biochemical compounds (gas chromatography)
- Rate of Growth
- Total time (T) and time per stage (ti)
- Area, energy, nutrients and water requirement per stage
- Specific Leaf Weight
- Costs and Prices
- Transportation
- Shelf life

Financial metrics

- Financial leverage requirements. Investment vs. Leasing opportunities
- ROI. Return of investment
- Waste: Mercury and light pollution. Disposals
- CO2 trading and Biomass

5.3 Interpretation of the results. Implications of our findings

All the identified parameters have to be properly weighted to find the "formula" that will give us an approximate idea about the feasibility of the investment depending on the crop and the location of the greenhouse.

This will require further research, out of the scope of a study like this.

Nevertheless, we will have estimation on the poster during the exhibition.

5.4 Benefits of the project: societal, economic, and environmental

The main benefit of the project (together with a further and more detailed study) will be the capacity of enabling the wide adoption of the technology. The social, economic and environmental benefits have been properly addressed in "Relationship to Sustainability (3)".

5.5 Transferability and/or scalability of the approach

The transferability of the approach is immediate. For scalability, outreach education is needed, not only for the greenhouse, but for all the new technicians that are going to work around.

5.6 Concept representation for the exhibition event (e.g. poster, video, model, etc.).

The concept of our project will be presented at the exhibition with a poster and a model that will show the potential of the new technology (light recipes and regimes).

6. Conclusions

The main lesson learned from our project is the **need of standardization** for CEA horticultural fixtures specifications. **Manufacturers do not provide information like exact spectral information**, which is 100% **required for proper systems evaluation**. Without this information is very difficult to properly evaluate an **investment** in solid state lighting in horticulture, or even provide a real feasibility validation for pilot studies prior to general market adoption.

Most of the fixtures are static in terms of spectrum and intensity. Research is beginning to demonstrate that **dynamic lighting** (pulsing, PWM) has a clear advantage. Therefore, future fixtures/systems should incorporate this new methodology as it will happen in the general lighting market.

Also, the **lack of a standard protocol for horticultural lighting** (like Adobe PS for printers in the PC environment), makes it very difficult for **integration of different manufacturers fixtures with the greenhouse main control** (that also accounts for other factors like temperature, humidity, shadowing, etc). This is part of our research.

To asses this conclusions, we only have to check the "status-quo" of the market. A broader study is needed, but we suspect that will only give more validity to our assessment.

About future actions, despite the previous points, the market is in real need of **education**. This technology is an **innovation**, not an incremental development of the previous one. We are in a **paradigm shift** like the PC was for the typewriter machine. We can compare both worlds and see how the traditional "word-processing" tech has evolved into a whole new concept. Same abrupt change will happen with what we know today as "Supplemental lighting for plants". It will be in a few years what a candle is compared today to a high-end smart lighting system with dynamic capabilities. Light is there in both situations, but with different **quality and efficiency**.

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