Local Food Production in a Carbon-Constrained World

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9 February 2010

www.fingerlakesfresh.com
Local Food Production in a Carbon-Constrained World

Overview:

Options and Technologies
A Continuum from Simple to Complex, as Follows
Vertical Farms

High Tunnels

Living Wall Greenhouses

Conventional Greenhouses

Rooftop Greenhouses

New Ideas

CEA Greenhouses

+ energy

Supermarket Chains
Large Produce Markets

+ energy

Local Produce Markets

NASA

Moon and Beyond

+ energy

Farmers Markets
Local Produce Markets

Urban Food Belts
Controlled Environment Agriculture (CEA) is a System With Many Legs
CEA is a System with many physical components

Most of which have energy and CO$_2$ implications!
CEA is a Tough Business

If it were easy, and highly profitable, lots of people would be doing it!

However....
CEA can be highly productive

Production is equal to 85 heads/foot²-year
Or 20x CA field production
Goals:

- Grow vegetables locally at a high volume
- Limit environmental discharge
- Substitute electricity for diesel fuel!
- Continually refine to reduce energy inputs
- Limit or eliminate “–cides”
- Reduce water use to the minimum
- Include HACCP capabilities

(Beyond organic)
CEA can be highly productive

Productivity is the key!

Even with high energy & other inputs, if productivity is high per unit area of growing space, production efficiency can favor high-input systems.

Perhaps a better term than “Efficiency” is “Efficacy”, or production per unit of input (e.g., kg edible product/kWh required).
ENERGY INVESTMENTS AND CO₂ EMISSIONS FOR FRESH PRODUCE IMPORTED INTO NEW YORK STATE COMPARED TO THE SAME CROPS GROWN LOCALLY

NYSERDA FINAL REPORT 08-10
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Request link information: email me at albright@cornell.edu
ENERGY INVESTMENTS AND CO₂ EMISSIONS FOR FRESH PRODUCE IMPORTED INTO NEW YORK STATE COMPARED TO THE SAME CROPS GROWN LOCALLY

Considers aspects such as

• Usage – losses before the farm gate
• Embodied energies
• Production energies
• Transportation energies
Average miles traveled to NYS by imported crops in this study were:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Imported</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head lettuce</td>
<td>2980</td>
<td>2953</td>
</tr>
<tr>
<td>Fresh tomato</td>
<td>2224</td>
<td>2026</td>
</tr>
<tr>
<td>Fresh spinach</td>
<td>2956</td>
<td>2897</td>
</tr>
<tr>
<td>Fresh strawberry</td>
<td>2894</td>
<td>2742</td>
</tr>
<tr>
<td>Fresh apple</td>
<td>2995</td>
<td>520</td>
</tr>
</tbody>
</table>

Not included in the above data: On a national basis, shrinkage is important and increases effective miles per unit of consumed product. (and...more transport/handling → more shrinkage)
Energy, MJ/kg, to produce and transport outdoor crops to New York State (of quantity eaten)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Imported</th>
<th>Local</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head lettuce</td>
<td>24</td>
<td>7.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Fresh tomato</td>
<td>35</td>
<td>9.8</td>
<td>3.6</td>
</tr>
<tr>
<td>Fresh spinach</td>
<td>48</td>
<td>12.6</td>
<td>3.8</td>
</tr>
<tr>
<td>Fresh strawberry</td>
<td>23</td>
<td>3.2</td>
<td>7.2</td>
</tr>
<tr>
<td>Fresh apple</td>
<td>23</td>
<td>7.2</td>
<td>3.2</td>
</tr>
</tbody>
</table>
Energy, MJ/kg, to produce and transport **CEA greenhouse** crops to New York State (of quantity eaten)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Imported</th>
<th>CEA</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head lettuce</td>
<td>24</td>
<td>97</td>
<td>0.25</td>
</tr>
<tr>
<td>Fresh tomato</td>
<td>35</td>
<td>95</td>
<td>0.37</td>
</tr>
<tr>
<td>Fresh spinach</td>
<td>48</td>
<td>179</td>
<td>0.27</td>
</tr>
</tbody>
</table>

12 month, supplemental lighting

Herein lies the challenge for local CEA crop production
Energy, MJ/kg, to produce and transport crops to New York State (some considerations and nuances)

1. Better control of supplemental lights and carbon dioxide has been shown to reduce electricity for supplemental lighting in CEA by half in upstate New York

2. Adopting options related to dehumidification of greenhouse air, temperature modulation during the day, and limited air conditioning to keep vents closed are expected to improve energy efficacy further for CEA crop production
Energy, MJ/kg, to produce and transport crops to New York State (some considerations and nuances)

3. Energy for CEA production in New York is largely for electricity. Electricity in New York from liquid fuels is 8% of the total electricity mix. Diesel is 100% liquid fuel.

4. Electricity can be produced from renewable resources, which greatly reduces the ratio of traditional energy used for CEA production, compared to imported.

5. As liquid fuels become less abundant and more expensive, these characteristics should favor local CEA production … if total suitable systems are developed.
Energy, MJ/kg, to produce and transport crops to New York State (some considerations and nuances)

6. Heating energy can be reduced markedly with better thermal screens.

7. CHP, perhaps using biofuels, is attractive because heat needs and electricity needs for lighting are seasonally synchronous.

8. Innovative luminaire design may save another 40%

9. Finally, year-round consumption of fresh vegetables is desired by most customers.
Moving On….What can we do?

Some ideas to grow food locally with greater energy efficiency, consistent productivity, and sustainability

1. Choose a location other than Ithaca!
2. Control environmental parameters optimally, particularly the daily light integral
3. Add carbon dioxide optimally, to make light more effective
4. Control air temperature through a daily cycle
5. Plan for arrival of smart grid technologies
6. Design lighting systems with greater efficacy
7. Consider limited air conditioning & humidity control
8. Design to limit exposure to air pollutants
9. Design for efficient infrastructure, transport and distribution

Some have been done, some are being done, some remain to do
Moving On….Some details on options?

First, we need to understand about light and plants.
What caused this?

Too little light!

Plants are Photovores
Photosynthetic Sunlight Averaged Over the Earth

Photosynthetic sunlight is measured by mols of photons within a certain range of wavelengths of light (400-700 nm).

Earth average: 26 mol/m$^2$ per day
Ithaca average: 24.5 mol/m$^2$ per day
Here are Ithaca daily light integrals: 1983–1996

(Our goal for lettuce is ~16-17 mol/m²)
But ... Need Computerized Control; Here are simulation results:
Which Works in Practice…
here in the demonstration greenhouse
Next: Substitute Carbon Dioxide for Light

![Graph showing CO2 concentration vs. PAR integral for Lettuce](chart.png)
## CO₂ Benefits, Simulation Results

<table>
<thead>
<tr>
<th></th>
<th>With CO₂</th>
<th>Without CO₂</th>
<th>% Saved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual cost, lighting</td>
<td>$8,638</td>
<td>$17,151</td>
<td>50%</td>
</tr>
<tr>
<td>Annual cost, CO₂</td>
<td>$1,426</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Annual cost, total</td>
<td>$10,064</td>
<td>$17,151</td>
<td>41%</td>
</tr>
<tr>
<td>Hours using lights</td>
<td>1361</td>
<td>2665</td>
<td>49%</td>
</tr>
<tr>
<td>Off-peak %</td>
<td>75</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>kWh electricity for light</td>
<td>135,120</td>
<td>264,581</td>
<td>49%</td>
</tr>
</tbody>
</table>

United States Patent 7,184,846, February 27, 2007
United States Patent 7,502,655, March 10, 2009
Luminaire and Lamp Improvements?

<table>
<thead>
<tr>
<th>Average Watts 400 W HPS</th>
<th>Mol PAR/kWh (efficacy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>426</td>
<td>2.92</td>
</tr>
<tr>
<td>435</td>
<td>3.51</td>
</tr>
<tr>
<td>461</td>
<td>2.85</td>
</tr>
<tr>
<td>414</td>
<td>2.84</td>
</tr>
<tr>
<td>424</td>
<td>3.06</td>
</tr>
<tr>
<td>476</td>
<td>2.81</td>
</tr>
<tr>
<td>398</td>
<td>3.22</td>
</tr>
<tr>
<td>396</td>
<td>2.89</td>
</tr>
</tbody>
</table>

Collaborative research to improve reflector efficiency and lamp efficacy is in progress in an effort between Cornell CEA and a small company in Ohio.
Solid State Commercial Plant Lighting

Some Proposed advantages:

• LEDs will be able to produce more light per watt-hour input

• LEDs can emit light of an intended color; for example, wavelengths that influence plant morphology and perhaps pests & diseases

• LEDs can be dimmed

• LEDs can have an extremely long life span (up to 50,000 hours) if they are not overheated

• LEDs produce little heat on the light source
However, the implementation of LEDs in greenhouses is still at an early stage so it is expected that it will take several years before the technology is ready for use in commercial horticulture.

Remaining problems include ...
The output of LED luminaires is less than the output of HPS lamps.

LEDs are still expensive; companies are working to improve this aspect.

While LEDs produce little heat on the front side of the lamp where the light is emitted, much heat is produced at the back of the device. Cooling devices now available are large for greenhouse applications.

It must be seen how beneficial insects in the greenhouse react to LED lighting.
Some Smart Grid Considerations:

• Plants can be Energy Buffers (averaging temp and light…)

• Demand Modulation (dimming lights/variable speed pumps/demand controlled HVAC…)

• Load Adjustments (e.g. three day averaging…)

• Day-Ahead-Market lighting control (to be developed…)

• Real-Time Market?

• Decentralization (CHP) (heat/light seasonal synchronicity…)
Air Pollution Considerations

JFK, Long Island

Syracuse, Upstate NY
Air Pollution Considerations

NO$_x$, SO$_2$, and ozone from vehicle exhaust

Damage levels of ozone (?30 to 40 ppb)

Urban levels of ozone (?>100 ppb)

NO$_x$ in city centers; ozone in suburbs

One of several reasons to consider urban green belts for food production rather than central city locations
Some CEA direct issues yet to resolve

- Vertical integration – benefit?
- Labor at all levels – Education/Training
- Food safety and local production
- Differing standards imposed by customers
- Separate seeding from growing
- Separate harvesting and packaging
- Continue to reduce energy inputs
- Source water quality
- Marketing!!!!!!!!!!
Thank You!!!

35 days
Seed to harvest
Every day of the year