Workshop on
Challenges in Vertical Farming

26 September 2012
University of Maryland Conference Center, MD, USA

“Technological Opportunities in Indoor Food Growing Systems:
Working examples of South Pole and Moon Applications”

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The opportunities of hydroponic crop production, nutrient delivery, environmental control, and automation and management systems have been demonstrated for operational systems, including the Lunar Prototype Greenhouse (LGH), and the South Pole Food Growth Chamber (SPFGC). The presentation will include design, production and operations experiences for vegetable crop production at the SPFGC and Prototype Lunar Greenhouse applications, as well as for future Earth applications of greenhouse food production. It will highlight specific hardware components which attempt to resolve the challenges of such systems, including the Sadler water-cooled HPS lamps for semi-closed crop production; light-weight hydroponic nutrient delivery systems for crop production; telepresence platforms for operations management and control; and other systems engineered and tested for production, management, control, and outreach.
Objective

Use concept of ACE-SYS [per KC Ting]

to evaluate two operating systems for
	heir Hydroponics and Controlled Environments

to grow a food product, or
create a better quality of life, or
establish an outreach/educational opportunity

South Pole Food Growth Chamber

Prototype Lunar Greenhouse
Take-Home Message

10 – 13 g per kWh

grams of fresh, wet-weight, edible biomass produced per electrical power required

Where energy included: 1. for lighting; 2. for environmental control; 3. for monitoring & services

Within a Polyculture, not optimized for any crop (not maximizing crop productivity) having one environment and crop culture for all
The two examples are:

**SOUTH POLE FOOD GROWTH CHAMBER**

and

**PROTOTYPE LUNAR GREENHOUSE**

South Pole Food Growth Chamber

Prototype Lunar Greenhouse
Most isolated location on Earth....
Accessible only by airplane….
NEW AMUNDSEN-SCOTT SOUTH POLE STATION

For The Day: June 09, 2004
Ambient Conditions: -61 °C / -81 °C (wind-chill)

From: +38 °C in Tucson, AZ
To: -73 °C at South Pole!

The South Pole....
....where all points are North

Frozen arid desert!
Standing inside the Enviro-Room,
Looking directly ahead into the Plant Growth Room,
Looking right to see the Hobby Hydroponics System
THE UNIVERSITY OF

ARIZONA®

Controlled Environment Agriculture Center
Tucson, AZ

Contract with
Raytheon Polar Services Company
Mr. Tim Briggs,
contact for deployment

Operating Contractor
for Office of Polar Services
US National Science Foundation

Mr. Martin Lewis and Mr. Andy Martinez,
Contacts for Operations
RPSC 2004 – 2011
Lockheed–Martin 2012
Sub-Contract with
Sadler Machine Company
Tempe, AZ
Mr. Phil Sadler

Creativity & Vision
Craftsman
Experienced ‘on the ice’

Sadler Manufactured:
nutrient delivery system,
HVAC system
water-cooled lamps,
plant growth trays
The UA Design and Construction (and Research) Team

Lane Patterson - student, liaison to RPSC
Stephen Kania – Staff engineers
Neal Barto    Engineering & systems design, Instrumentation & control
Merle Jensen – Plant Sciences Faculty Hydroponics & nutrition
Chieri Kubota – Plant Sciences Faculty Plant microclimate
(Phil Sadler) - sub-contractor
Gene Giacomelli – PI, put out fires
Expectations of Deliverable

SPole Food Growth Chamber shall include:

- Fresh vegetable production
- Energy efficiency
- Resources conservation
- User-friendly operation & maintenance
- Turnkey operation
- Minimum assembly
- Therapeutic passive use
- Green space visibility
- Integration with Amundsen-Scott Station
South Pole Food Growth Chamber

**PR**

- **Volume:**
  - 57 m³
  - 2000 ft³

- **Area:**
  - 23 m²
  - 250 ft²

**EnviroRoom** 4.3x3.1m; 14x10ft

**Production Room** 4.3x5.5m; 14x18ft

**Starter Trays**
- Seedlings, herbs

**Tall crops**
- Tomato, pepper, cucumber

**Leafy crops**
- Upper troughs; (raise/lower)
- Lower troughs; (translate)
3 Rooms of the South Pole Food Growth Chamber

- **Plant Growth Room**
- **Enviro-Room**
- **Utility Room**

Access Door

Entrance
Tomatoes, cucumbers, peppers

Lettuce, herbs, greens

10 kilograms per week

22 lb/week harvest
Lane Patterson
First operator
2005
Design Solutions
Component & Process Developments

1. Water-Cooled HID Lamps
   2001 cooperation with NASA-JSC
   Space Act Agreement at Univ. Arizona

2. Double-Pass Growing Tray
   modular crop production unit
   integrated with Station facilities
   three independent NDS

3. Automated Monitoring & Control System
   appropriate for volunteer staff
   robust for automated operations
HPS Lamps

2 rows of
6 water-jacketed
1000 W lamps

12 kiloWatts

400 µmol m\(^{-2}\) s\(^{-1}\)
PPF
Bi-Axial Lighting Symmetry for plant surfaces within South Pole Food Growth Chamber
Development and Evaluation of an Advanced Water-Jacketed High Intensity Discharge Lamp

Gene A. Giacomelli
Randy Lane Patterson
University of Arizona

Phil Sadler
Sadler Machine Company

Daniel J. Barta
NASA Johnson Space Center

Paper Number 2003-01-2455
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Vancouver, B.C. Canada
July 8, 2003
Support Frame

1000 Watt HPS Lamp

Double-walled annular water-jacket

SMC, 2001
Water-Jacketed Lamp with Reflector

SMC, 2001
Phil Sadler, Sadler Machine Co, 2003
3-Part NFT Tray
Top lid w/plants; False bottom; Bottom return
Inflow & outflow at same end
3-Part NFT Tray
False bottom;
Bottom return
Inflow & outflow at same end
Bio-Regenerative Life Support System Development for Lunar/Mars Habitats

Overall Technical Objective

Establish the technical merit and feasibility of a high fidelity membrane structure (Prototype LGH) and its food production system (Cable Culture) by demonstrating and evaluating performance.
Lunar Greenhouse Prototype

Provides all oxygen & water and 50% food calories for one person per day.
Performance Based on Input and Output to the LGH

Input:
- energy
- water
- nutrients
- $CO_2$
- labor

Output:
- oxygen
- water
- biomass
The Steckler Collaboration

+16 total; 7 students, 3 USA and 1 Italian faculty
6 International collaborators from 2 companies
Thales Alenia Space-Italia, Torino and Aero-Sekur, Aprilia
1 USA small business (Sadler Machine Co, Arizona)

TAS-I Recyclab Team

UA-CEAC Team

AeroSekur

University of Naples

Collaborative Exchange
Measured Production/Consumption Metrics

Average daily values

Biomass increase → 0.06 ± 0.01 kg m\(^{-2}\) day\(^{-1}\) (ww)
Water production → 21.4 ± 1.9 L day\(^{-1}\).

Water consumption → 25.7 L day\(^{-1}\)
CO\(_2\) consumption → 0.22 kg day\(^{-1}\)
Elec. power consumption → 100.3 kWh day\(^{-1}\) (361 MJ)
Calculated Biomass Production Output per Energy Input

24 ± 4 g biomass (ww) per kWh
(83 g biomass (ww) per MJ)
edible + non-edible biomass

Measured Labor Demand
35.9 min day\(^{-1}\) labor use for operations
SPFGC vs Lunar Greenhouse Prototype Comparisons

• Lighting system
• Nutrient delivery system
• Telepresence system and procedures
• Multi-cropping system

Edible biomass from SPFGC 10 g/kWh vs. 13 g/kWh LGH
Polyculture Inter-Planting Crop Production

Lettuce, tomato/cucumber, sweet potato, and strawberry or cowpea.

Volume space utilization. Radiation intercepted. Biomass production per area (or volume) per unit time (kg/m²/24hr, or kg/m³/24hr).

8 cable culture rows.

Plant within row spacing is 15 cm for lettuce, 20 cm for strawberry and cowpea, 20 cm for sweet potato, and 30 cm for tomato or cucumber.

Row-to-row spacing is 20 cm, for all rows, and a 45 cm walkway.

Tomato/cucumber crop on perimeter up to the overhead lamps. Sweet potato vines grow at the cable level and downward beneath rows of cable culture. Strawberry or cowpea, and lettuce at cable level (1 m above floor).
End view of LGH when in current full production indicating growing areas 

Polyculture inter-planting crop production

Environmental Conditions
Photoperiod/darkperiod air temperature and relative humidity average 20.5 °C / 65% and 18.5 °C / 70%, respectively.

Atmospheric $CO_2$ is elevated to 1000 ppm during 17 h photoperiod at 300 $\mu$Mol m$^{-2}$ s$^{-1}$ at the cable level.

6, SMC water-jacketed, 1000W high pressure sodium (HPS) lamps.

Nutrient solution (modified one-half strength Hoaglands solution)
6.0 pH and 1.8 mS cm$^{-1}$ EC for the lettuce and strawberry,
6.5 pH and 1.8 EC for the sweet potato and tomato.

In situ plant biomass continually monitored and evaluated for intervals of 7 or 14 days of growth, by weighing entire LGH, with load cell measurement system.
Cable Culture Recirculating Hydroponics and HPS water-cooled lamps
Remote Experts Network Decision Support System (RENDSys)

Dr Murat Kacia and David Story
for
NASA Steckler Lunar Greenhouse Project

Decision Support System for LGH Climate and Crop Monitoring and Control

* Information acquisition, monitoring, and continuous control for operations

* Plant health and growth, non-invasive and autonomous
LUNAR GREENHOUSE RENDSys

Date
11/09/2010

Crop Monitor Database
- Biomass production
- RGB
- Texture [Energy, Entropy, Homogeneity]
- Thermal Image [Stresses]
- Temporal

Model Databases
- Neural Network
- Mechanistic

View Data

Crop Health

TPCA

Energy

Homogeneity

Entropy
Acknowledgements

Thank you!
Ralph Steckler NASA Space Grant

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Dr. Daniel Barta (NASA JSC)

Phil Sadler (Sadler Machine Co.)

Marzia Pironi, Roberta Remidi, Silvio Rossignoli (Aero-Sekur, SpA)

Cesare Lobascio, Giorgio Boscheri (Thales-Alenia Spazio – Italia, SpA)

University of Arizona – faculty, staff, students, facilities support
Student education and Outreach to world

Lunar Greenhouse – Outreach & Teaching Module (LGH-OTM)

Lane Patterson, hosting student tour from inside Lunar Greenhouse

San Diego County Fair (June 5 - July 4, 2012)
Student education and Outreach to world

Lunar Greenhouse – Outreach & Teaching Module
(LGH-OTM)

End View  Side View

Chicago Museum of Science & Industry
(July 24, 2012 – January 15, 2013)
Acknowledgements for LGH-OTM

Thank you!

Desert Rain Research, LLC

Hungry Planets, LLC

Mr. Michael Munday

Lane Patterson, Phil Sadler, Neal Barto

Museum of Science & Industry - Chicago

San Diego County Fair

Alex Kallas, AgPals

Maria Catalina, Astronaut Teachers Alliance
5 Great Challenges

1. Know your Market & Market Value (know your competition)

2. Education & Experience (climb learning curves ASAP)

3. Compliance within Situation (know your local code officer)

4. Estimate “gram per kilowatt-hour” metrics (output/input ratios)

5. Allow biology & physics to work for you (not against)
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For Further Information

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Prof. Gene Giacomelli is a faculty member within the Department of Agricultural and Biosystems Engineering at The University of Arizona, and Director of the Controlled Environment Agriculture Center. Giacomelli has gained international reputation through his pioneering work and expertise in the area of protected crops. Growing food on other planets is one of the collaborative international projects that he is leading, which is supported by the NASA Space Grant Consortium at the University of Arizona. The focus is efficient use of water, energy and other resources for implementation of a food and life support system for Moon/Mars. The results from this project will be applied to Earth protected agriculture food production systems.
For Further Information

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See the video about CEAC 2011:
“Beyond the Ordinary”
at
http://www.youtube.com/watch?v=87ZPOyeU1dU
For Further Information

The CEAC (Controlled Environment Agriculture Center) and The University of Arizona are dedicated to development of CE (Controlled Environment) technologies and worldwide applications, and for educating young people about the science and engineering of CE and hydroponic food support systems, and the other CE applications.

We will implement an interactive outreach and educational program to promote the benefits of CE for food production for modern agriculture, as well as, the new technologies of CE for enhancing, restoring, and maintaining critical earth life systems and human quality of life scenarios.

CE systems will be developed to help feed the world, while utilizing energy, labor and water resources effectively, and CE will become the platform for applications of new technologies using plant physiological processes [biomass fuels]; for space colonization life support [recycling all resources]; for remediation of air [carbon sequestration] and water [salts, heavy metals]; and for phytochemicals and plant-made pharmaceuticals [lycopene, vaccines].