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"

Dr. Gene Giacomelli
The University of Arizona, Tucson, Arizona, USA
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COLLEGE OF AGRICULTURE AND LIFE SCIENCES
CEAC
Controlled Environment Agriculture Center

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

Gene A. Giacomelli
The University of Arizona, Tucson, Arizona, USA (**giacomel@ag.arizona.edu**)

The opportunities of hydroponic crop production, nutrient delivery, environmental control, and automation and management systems have been demstrated 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.

Arizona
College of Agriculture and Life Sciences
CEAC
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Objective

Use concept of ACE-SYS [per KC Ting]

to evaluate two operating systems for

their 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

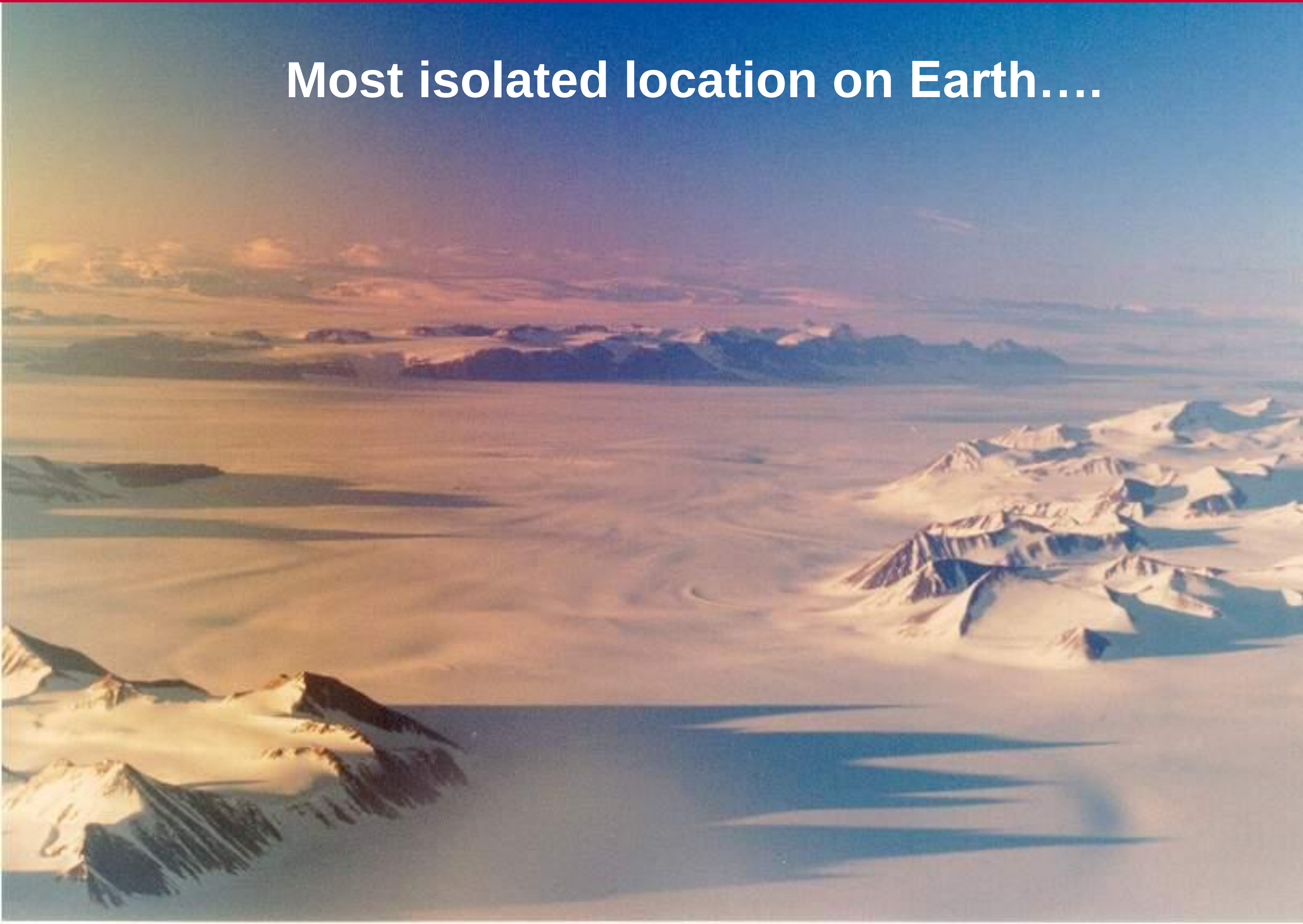
and

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 ^{o}C /-81 ^{o}C (wind-chill)

From: +38 ^{o}C in Tucson, AZ
To: -73 ^{o}C at South Pole!

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

Frozen arid desert!

South Pole Food Growth Chamber

Standing inside the Enviro-Room,
Looking directly ahead into the Plant Growth Room,
Looking right to see the Hobby Hydroponics System

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Tucson, AZ

<u>Contract with</u>

<u>Raytheon Polar Services Company</u>

Mr. Tim Briggs,

contact for deployment

<u>Operating Contractor</u>

<u>for Office of Polar Services</u>

US National Science Foundation

Mr. Martin Lewis and Mr. Andy Martinez,

Contacts for Operations

RPSC 2004 – 2011

Lockheed–Martin 2012

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Tucson, AZ

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

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Controlled Environment Agriculture Center
Tucson, AZ

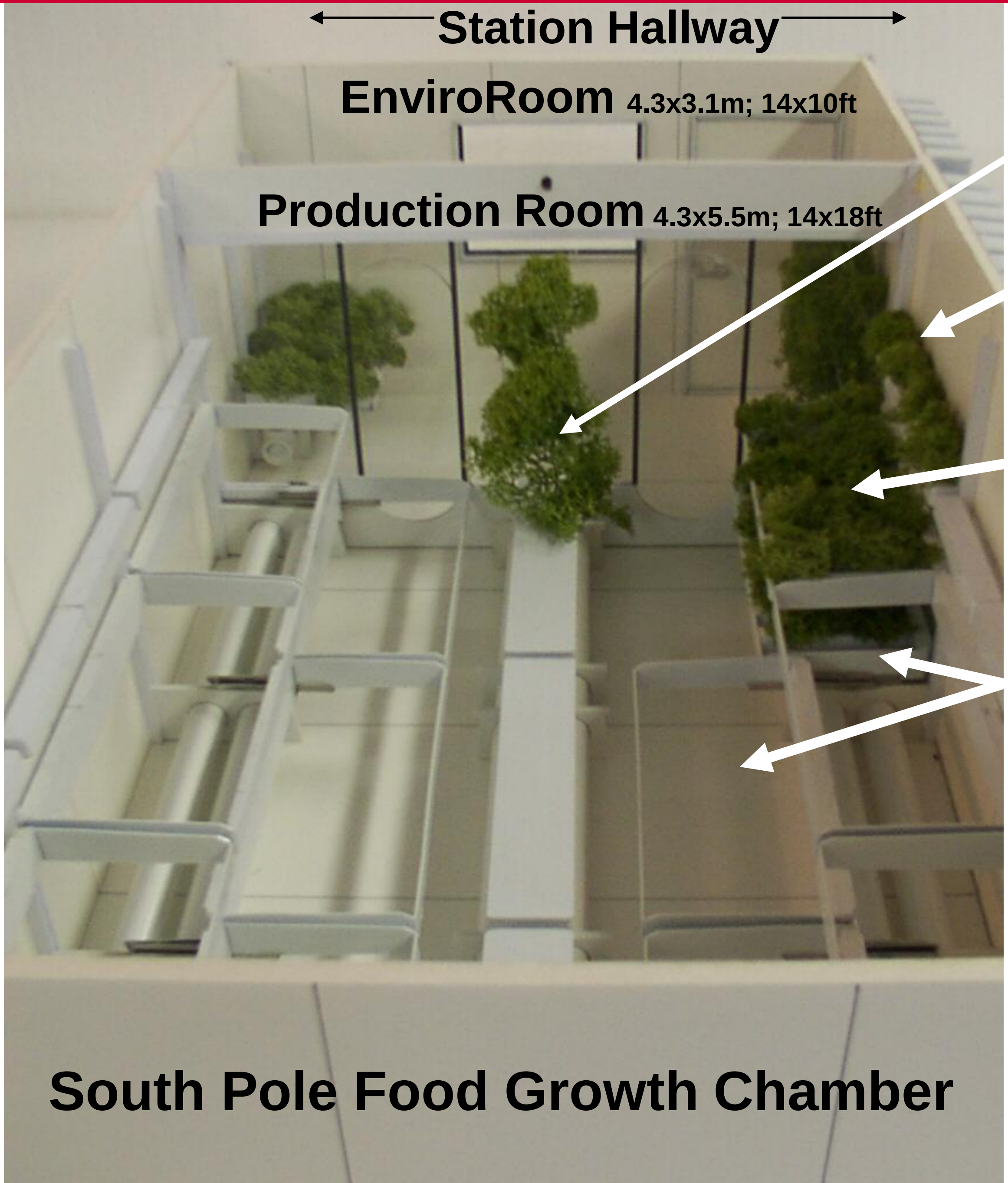
The UA Design and Construction (and Research) Team

Lane Patterson - student, liasion 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



PR Volume:

57 m^3
2000 ft^3

PR Area:

23 m^2
250 ft^2

Tall crops
Tomato, pepper, cucumber

Starter Trays
Seedlings, herbs

Leafy crops
Upper troughs; (raise/lower)

Leafy crops
Lower troughs; (translate)

3 Rooms of the South Pole Food Growth Chamber


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

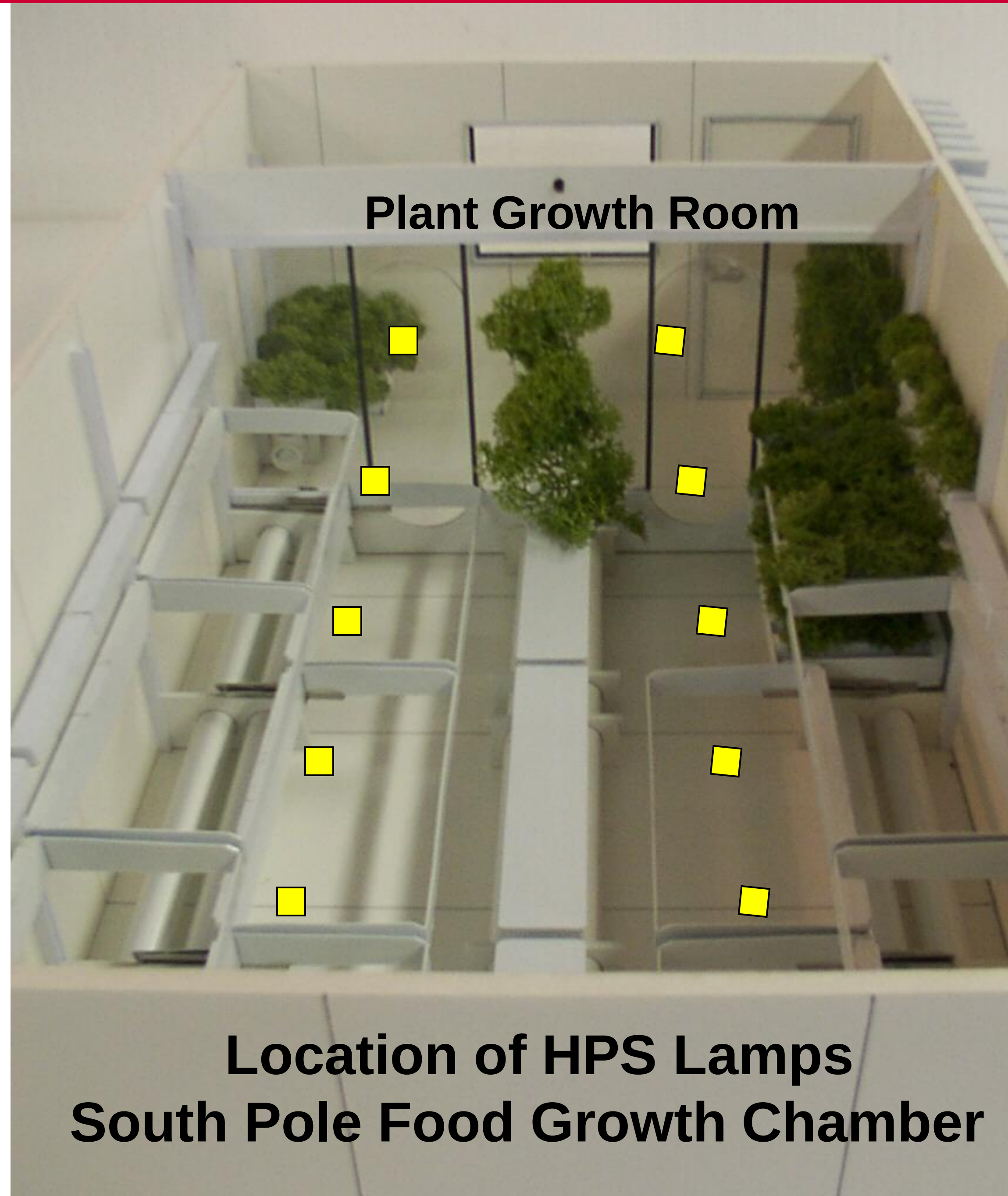
3. Automated Monitoring & Control System
   appropriate for volunteer staff
   robust for automated operations

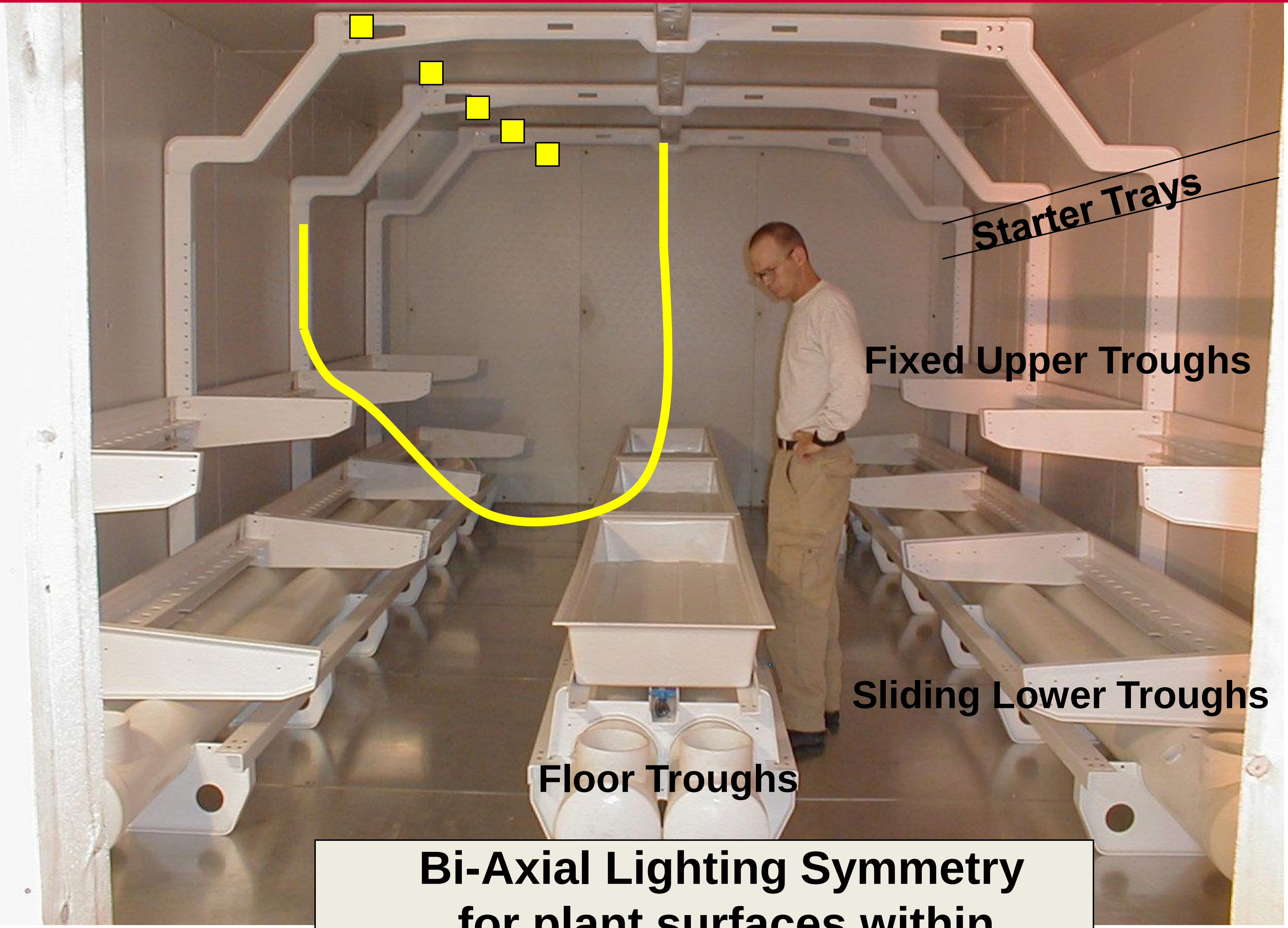
<u>HPS Lamps</u>

2 rows of 6 water-jacketed 1000 W lamps

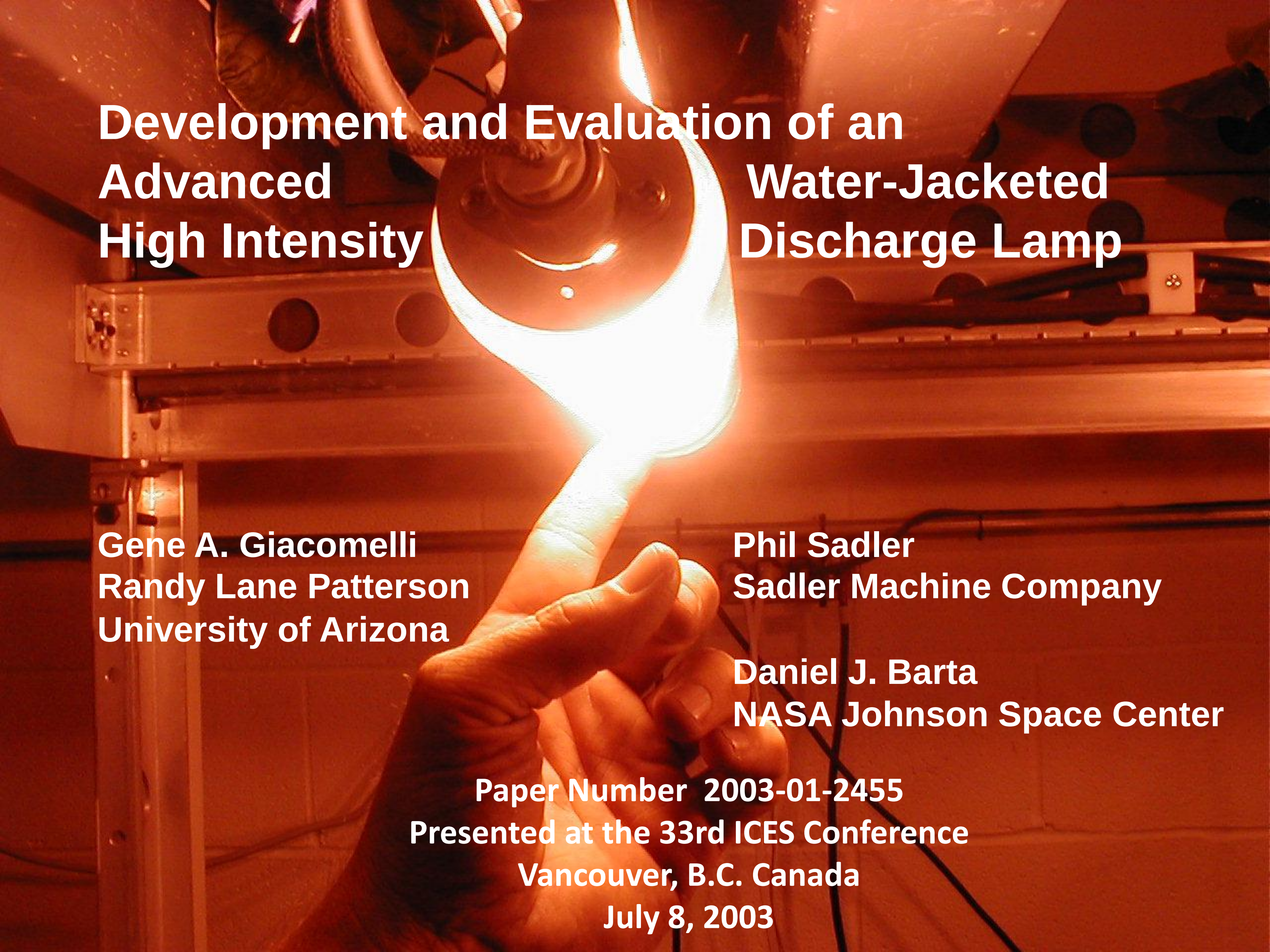
12 kiloWatts

400 µmol m^{-2} s^{-1} PPF





Bi-Axial Lighting Symmetry for plant surfaces within South Pole Food Growth Chamber



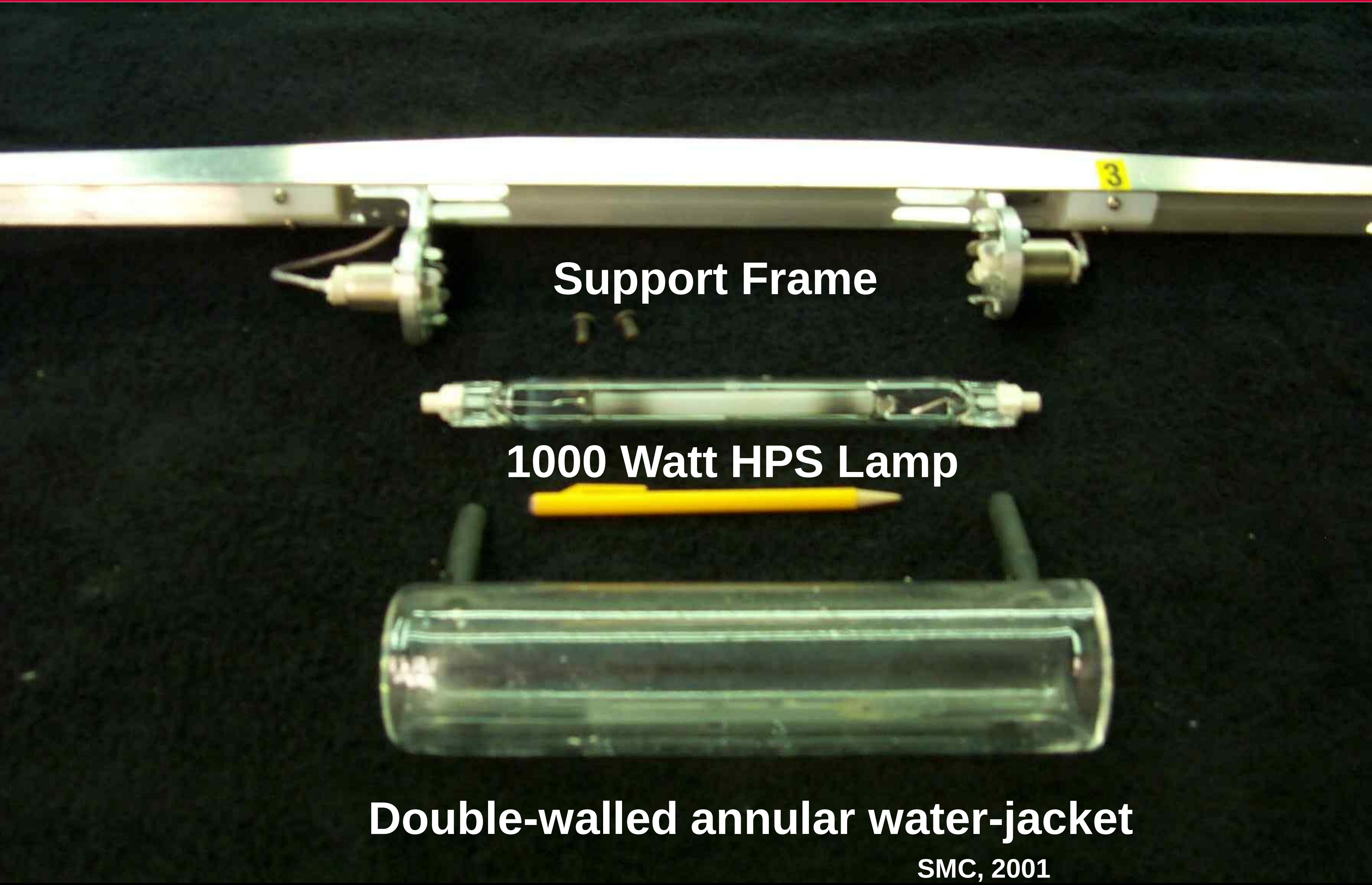
Development and Evaluation of an Advanced Water-Jacketed High Intensity Discharge Lamp

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
Presented at the 33rd ICES Conference
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

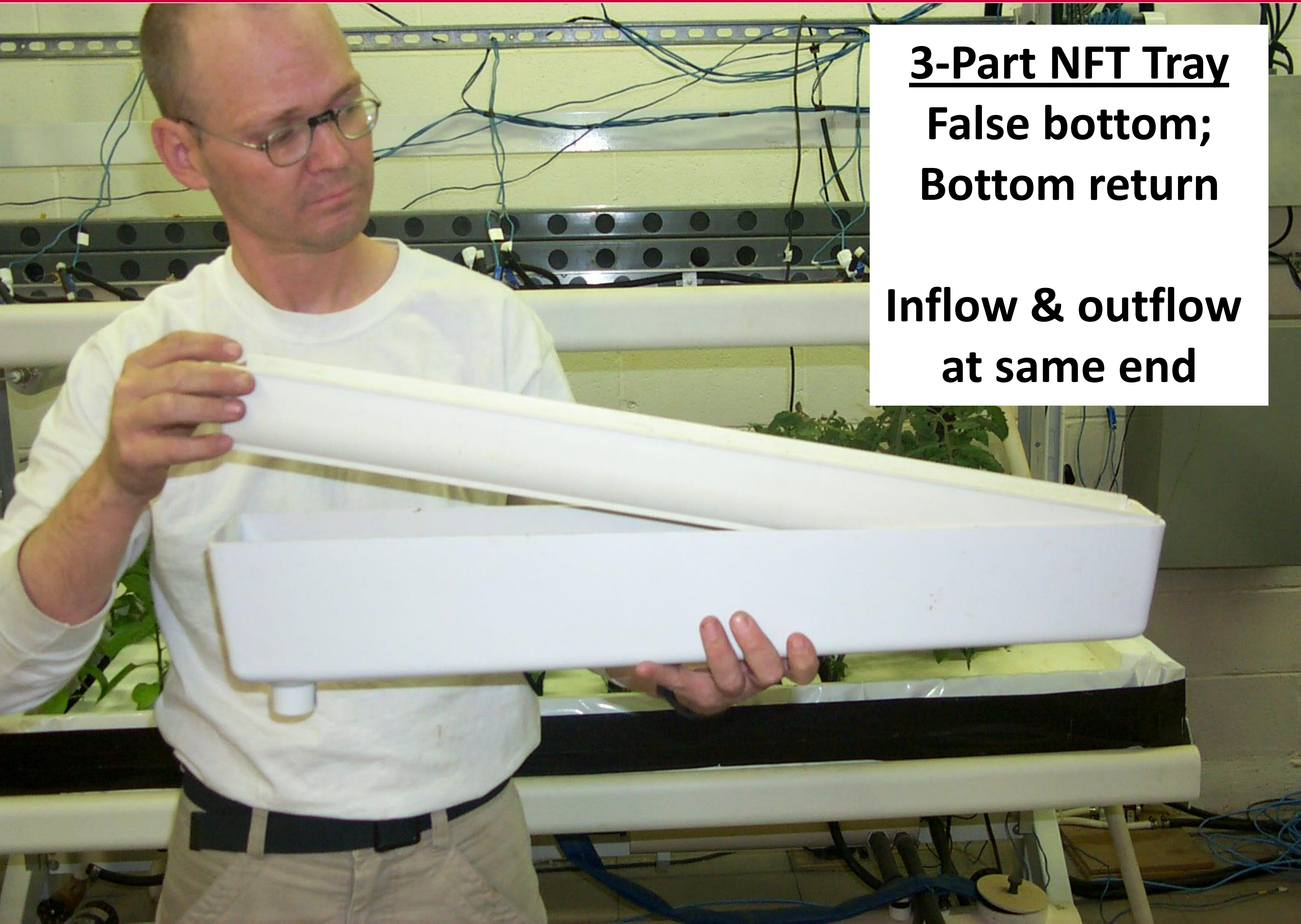
SMC, 2001

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

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NASA


Lunar Greenhouse Prototype
2.1 m
5.5 m
CEAC
AGC
Provides all oxygen & water
and 50% food calories
for one person per day


CEAC
AGC
the ultimate
greenhouse
cover

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

Collaborative Exchange

UA-CEAC Team

AeroSekur

University of Naples

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 ($kg/m^2/24hr$, or $kg/m^3/24hr$).

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).

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.

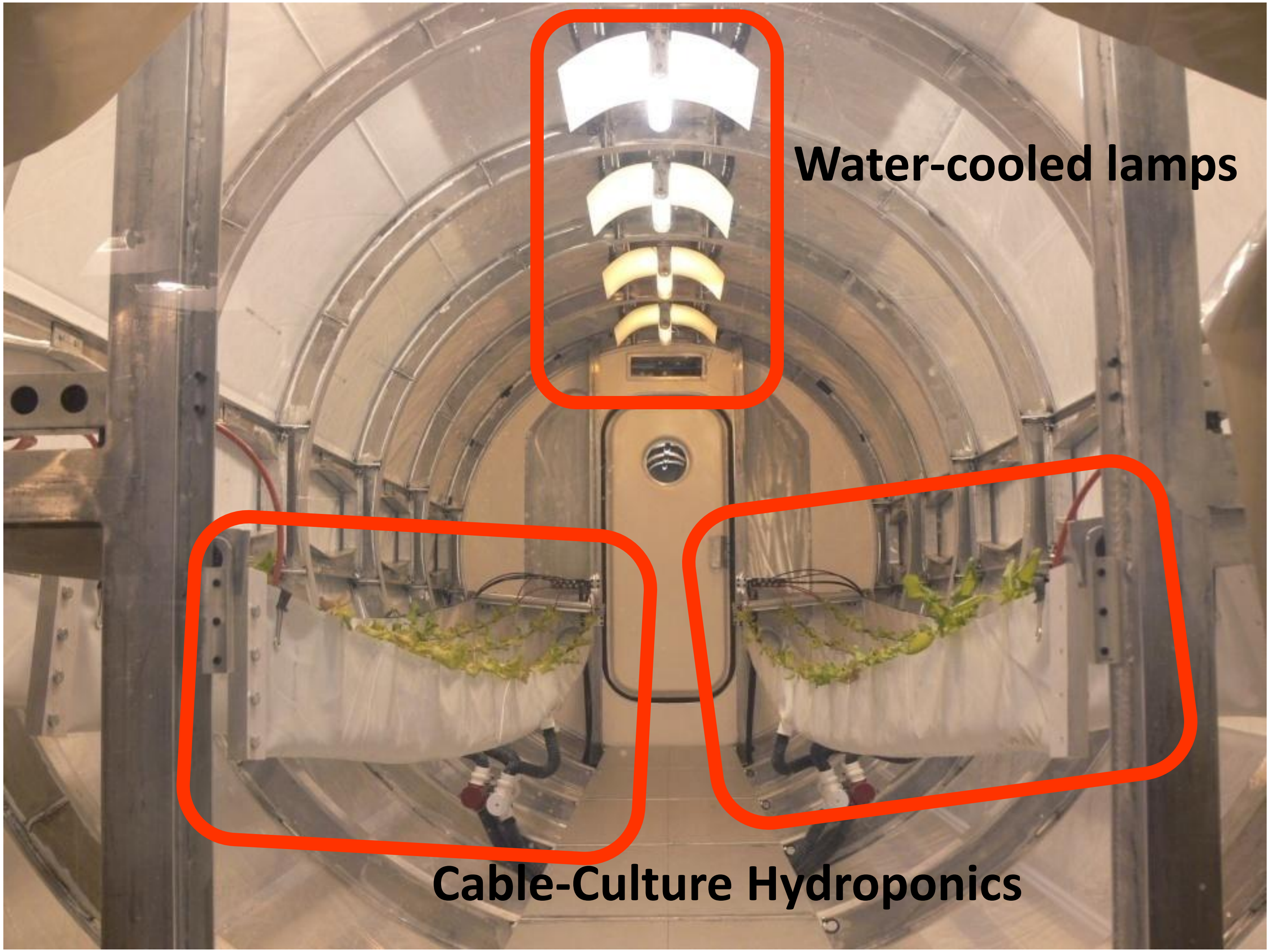
Atmospheric CO_2 is elevated to 1000 ppm during 17 h photoperiod at 300 μMol m^{-2} s^{-1} at the cable level.

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

<u>Decision Support System</u>

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

Welcome Giacomelli [Logout]

LGH System Overview | Graphical Data | **Resource Input/Output** Live Imagery |Alarms| Blog

Starting Date

11/09/2010

Number of Days

1

Report Output

- To Screen
- Excel
- PDF

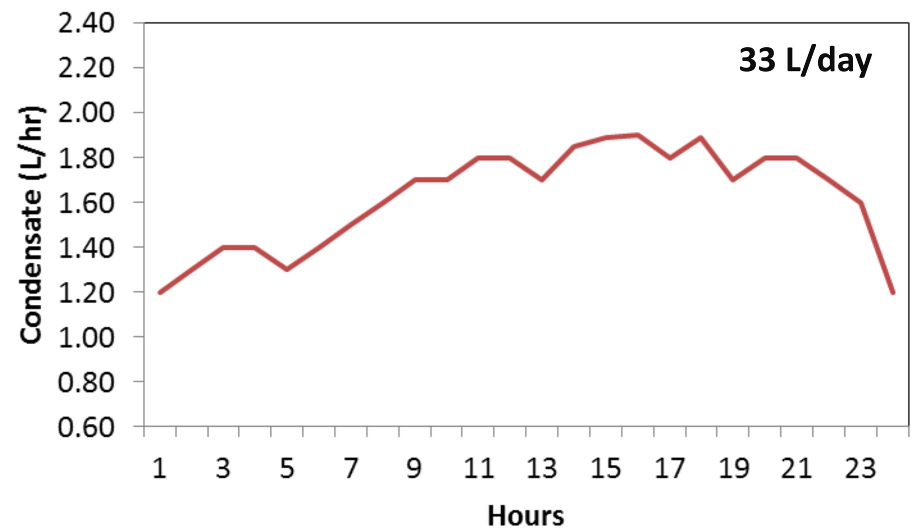
Resource Inputs

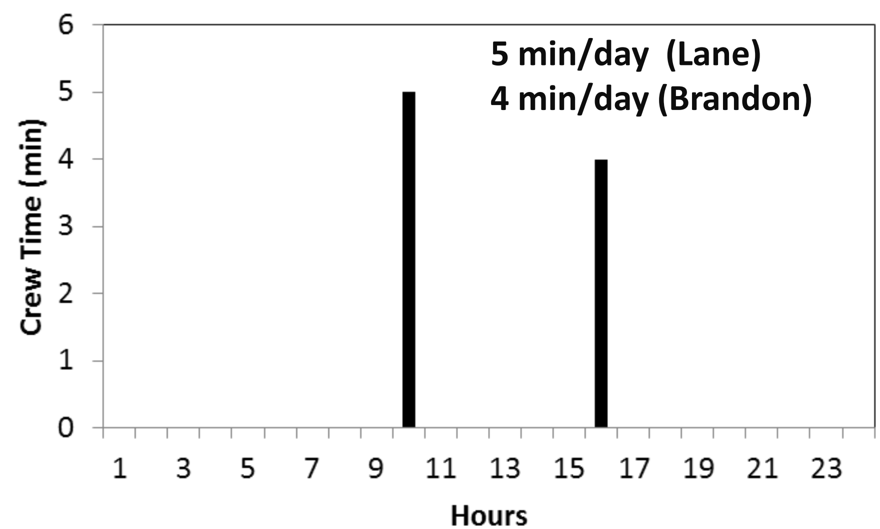
- Water (g/hr)
- Nutrients (g/hr)
- Carbon Dioxide (g/hr)
- Energy Use (kWh)
- Crew time (min/day)

Resource Outputs

- Water Condensate (L/hr)
- Oxygen generated (g/hr)
- Biomass (g/day)

View Data





LUNAR GREENHOUSE RENDSys

ARIZONA

Welcome Lane [Logout]

LGH System Overview | Graphical Data | Resource Input / Output | **Live Imagery** | Alarms | Blog

Date

11/09/2010

Crop Monitor Database

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

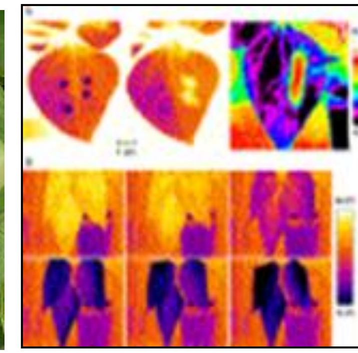
Model Databases

- Neural Network
- Mechanistic

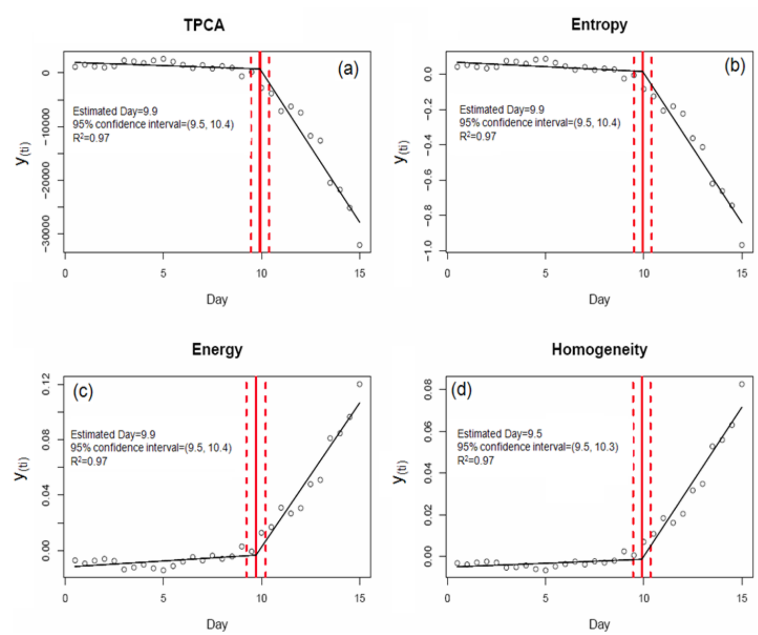
View Data

[Still] [Live]

[Still] [Live]



[Crop Health]



Acknowledgements

Thank you!

Ralph Steckler NASA Space Grant

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Tim Swindle (Lunar and Planetary Lab Director)

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Dr. Raymond Wheeler (NASA KSC Technical Monitor)

Dr. John Hogan (NASA-AMES)

Dr. Daniel Barta (NASA JSC)

Phil Sadler (Sadler Machine Co.)

Marzia Pirolli, Roberta Remiddi, Silvio Rossignoli (Aero-Sekur, SpA)

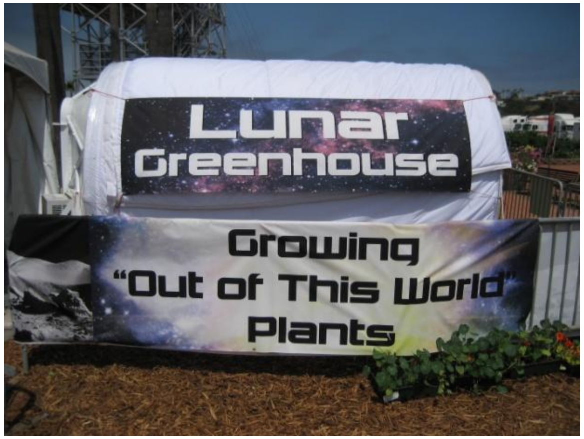
Cesare Lobascio, Giorgio Boscheri (Thales-Alenia Spacio – Italia, SpA)

University of Arizona – faculty, staff, students, facilities support

Student education and Outreach to world

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

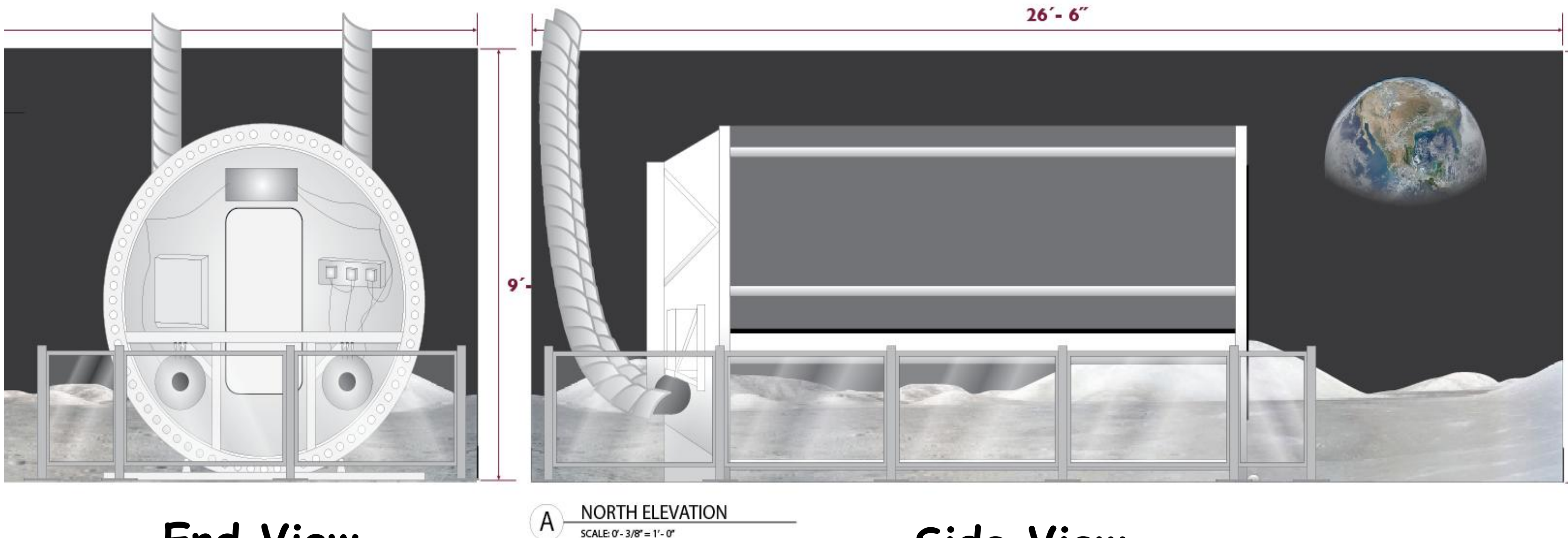
Lane Patterson, hosting student tour from inside Lunar Greenhouse



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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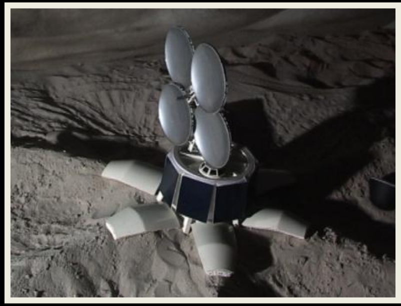

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For Further Information

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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."

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For Further Information

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See the video about CEAC 2011:
"Beyond the Ordinary"
at
http://www.youtube.com/watch?v=87ZPOyeU1dU

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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].

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