Arizona/NASA Space Grant Ralph C. Steckler Phase II Program Review

19 - 20 July 2012
Tucson, Arizona

"Lunar Greenhouse Prototype for Bioregenerative Life Support System"

Heather Ogletree,
JSC Space Grant Intern Coordinator, and
Ralph C. Steckler Grant Coordinator

Tim Swindle,
Arizona NASA Space Grant PI

Susan Brew,
Arizona NASA Space Grant Program Manager

ARIZONA SPACE GRANT CONSORTIUM

CEAC Controlled Environment Agriculture Center

NASA

The University of

Arizona

Controlled Environment Agriculture Center

Systems and Industrial Engineering

Sadler Machine Company

Thales Alenia-Space (TAS-I)

Aero-Sekur

Hungry Planets Systems

University of Naples Federico II

Pima County College

Safford Middle School

University of Southern California

NASA-KSC

NASA-Ames

ARIZONA SPACE GRANT CONSORTIUM

CEAC Controlled Environment Agriculture Center

NASA

Raymond Wheeler, NASA Technical Advisor [unable to attend]
John Hogan, NASA-Ames Technical Support

Gene Giacomelli, UA-CEAC faculty, Technical PI
Phil Sadler, Sadler Machine Co, Primary Small Business Collaborator
Roberto Furfaro, UA-SIE-AME faculty, Co-PI
Murat Kacira, UA-CEAC faculty, Co-PI
Lane Patterson, UA-CEAC, Project Engineer, Lab Manager
Cesare Lobascio, Thales-Alenia Space- Italy, Industry Collaborator
Giorgio Boscheri, Thales-Alenia Space- Italy, Industry Collaborator
Marzia Pirolli, Aero-Sekur, Industry Collaborator
David Story, UA-CEAC, PhD Student
Ehab Tamimi, UA-CEAC, MS Student

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Brandon Parham, former student and Crop Manager
Monica Garcia-Teruel, former student and Crop Manager
Derrick Wibben, UA Student
Michael Downing, UA-CEAC, Student
Thomas Hillebrand, UA-CEAC, Student
Tyler Jensen, UA-CEAC, Student
Marianna Yanes, UA Student
Neal Barto, UA-CEAC Project Engineer

Michael Munday, Hungry Planets Systems
Madhu Thangavelu, University Southern California
Daniel Wright, Pima County College
Maria Catalina, Astronaut Teachers Alliance
Alex Kallas, Ag Pals
Claire Corcoran, videographer

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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

Bio-Regenerative Life Support System Development for Lunar/Mars Habitats

Summary of Current Efforts

Mentor/Student Activities
- Outreach to K-12 and Post Graduate
- USC; Teacher Alliance; AgPals;
- LGH-Operations & Training Module

Small Business Collaborator – USA
International Collaborators – Italy

Operation of Lunar Greenhouse (LGH) Prototype Units
Demonstrating poly-culture production of food crops
with a semi-closed gas and water cycle
Solar Plant Lighting/Power System
System Monitoring/Telepresence

Bio-Regenerative Life Support System Development for Lunar/Mars Habitats

Gene A. Giacomelli, Roberto Furfaro, Murat Kacira, Lane Patterson and David Story
The University of Arizona, Tucson, Arizona

Giorgio Boscheri and Cesare Lobascio
Thales Alenia Space - Italia, Torino, Italy

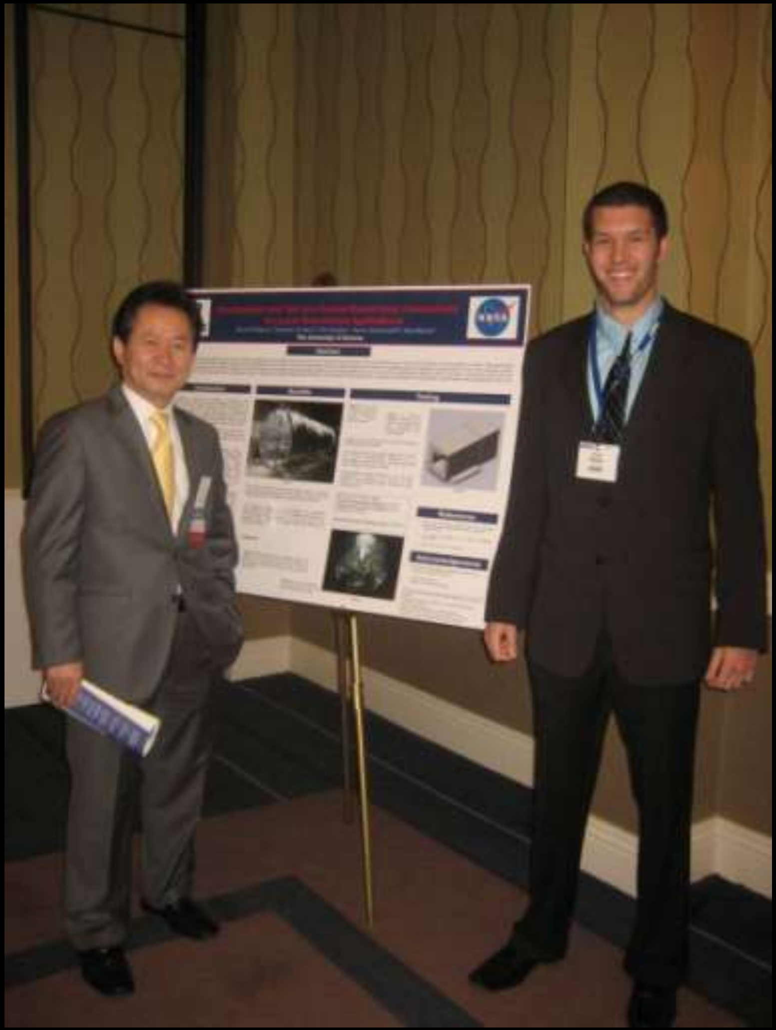
Phil Sadler
Sadler Machine Company, Tempe, Arizona

Marzia Pirolli and Roberta Remiddi
Aero-Sekur SpA, Aprilia, Italy

Madhu Thangavelu
University of Southern California, Los Angeles, California

Maria Catalina
Astronaut Teacher Alliance, Bonita, California

International Conference On Environmental Systems (ICES)



Derrick Wibben

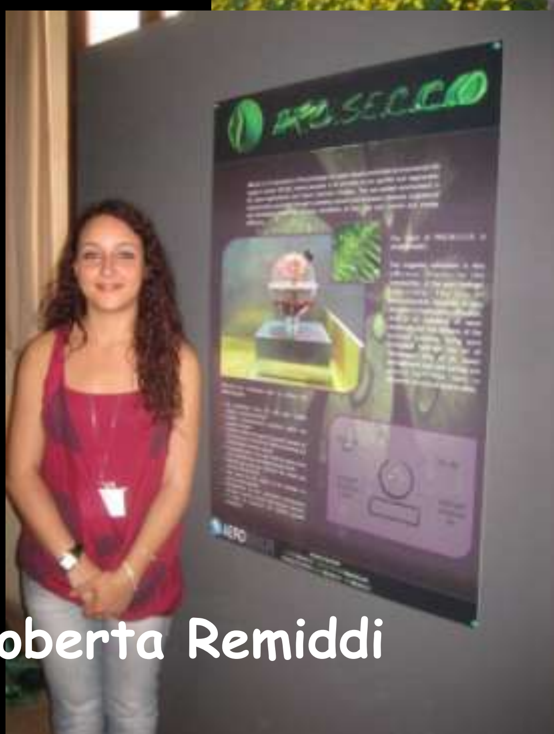
Poster Contest 3RD Place!

Testing the LED Lamp

Michael Downing

AgroSpace Workshop 2012

Phil Sadler, Ursella Slusher
Marzia Pirolli, Ray Wheeler



Roberta Remiddi

Cesare Lobascio

Student education and Outreach to world

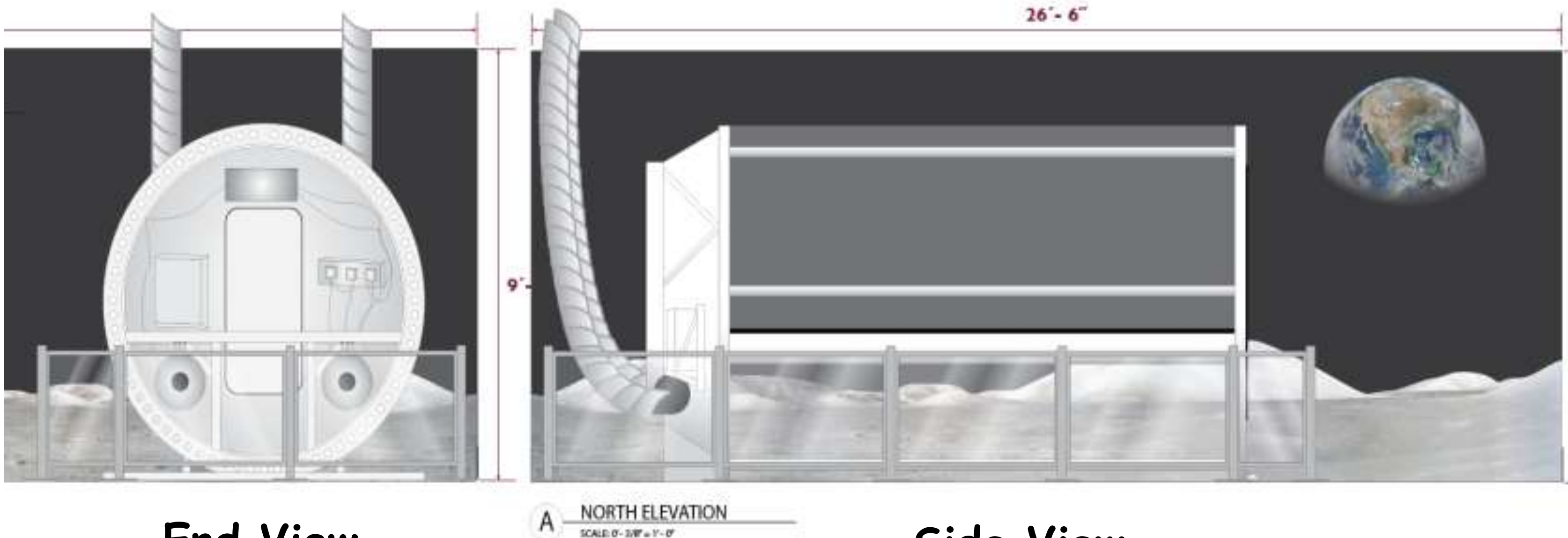
Lunar Greenhouse – Outreach & Teaching Module (LGH-OTM)

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)

Lunar Greenhouse Prototype

THE UNIVERSITY OF ARIZONA®

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

Design Targets

Bioregenerative Life Support

- Per Person Basis
  - 0.84 kg/day O_2
  - 3.9 kg/day H_2O
  - 50% of 11.8 MJ/day [BVAD Values, 2006]

- 2000 Cal/day diet
- Buried habitat
- Six month crew change duration
- Solar for energy supply
- Autonomous deployment
- South Pole Antarctic analog

Measured Production/Consumption Metrics

Average daily biomass increase → 0.06 ± 0.01 kg m^{-2} day^{-1} (ww)
Average daily water production → 21.4 ± 1.9 L day^{-1}.

Average daily water consumption → 25.7 L day^{-1}
Average daily CO_2 consumption → 0.22 kg day^{-1}
Average daily elec. power consumption → 100.3 kWh day^{-1} (361 MJ)

Measured Biomass Production Output per Energy Input

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

Measured Labor Demand

35.9 min day^{-1} labor use for operations

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.

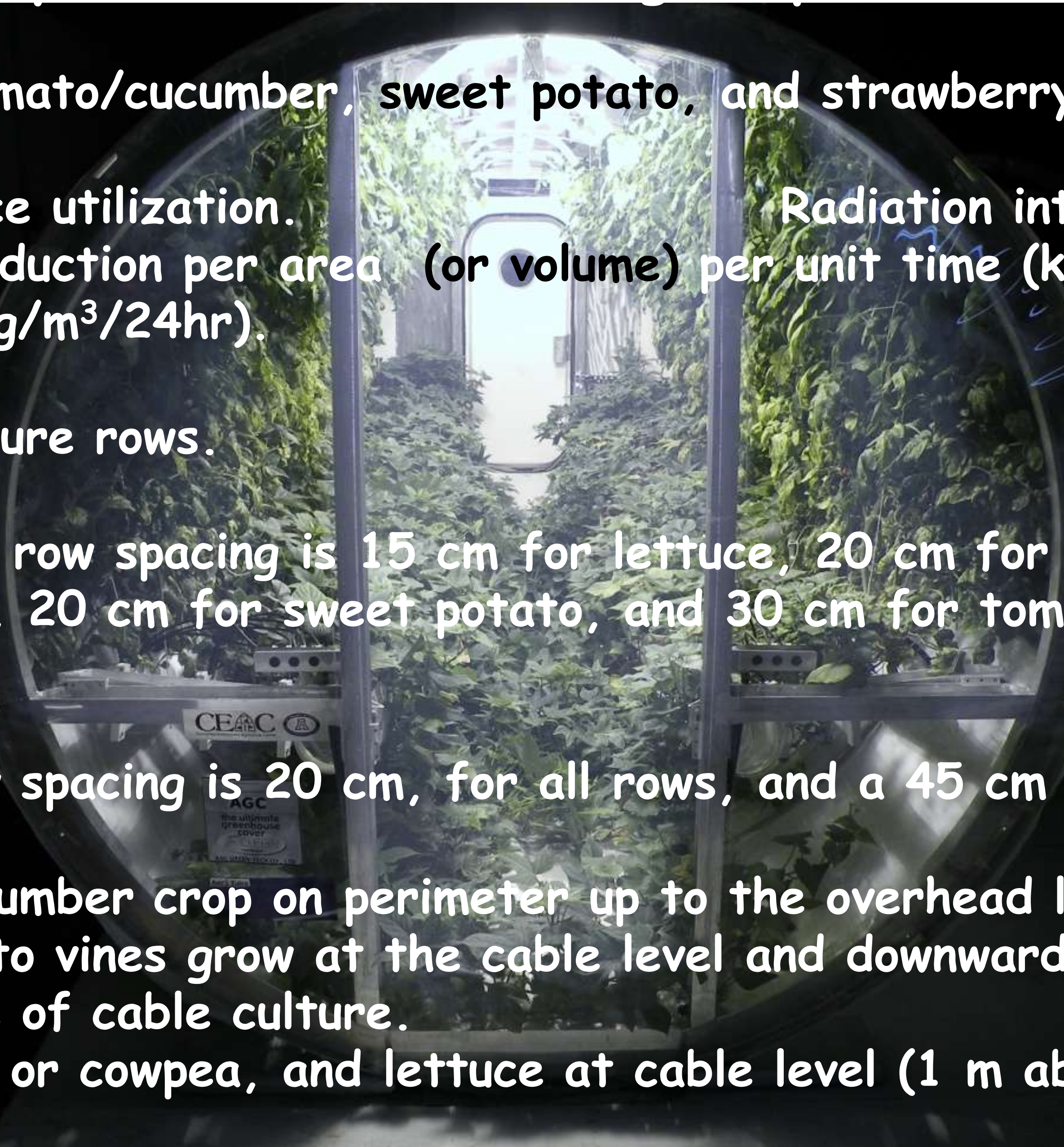
Plant within row spacing is 15 cm for lettuce, 20 cm for strawberry and cowpea, 20 cm for sweet potato, and 30 cm for tomato or cucumber.

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.

Lunar Greenhouse Prototype

Collapsible for transport

Deployable

Expands to 4.5 times
its stowed volume

See video at Youtube.com search "lunar greenhouse"

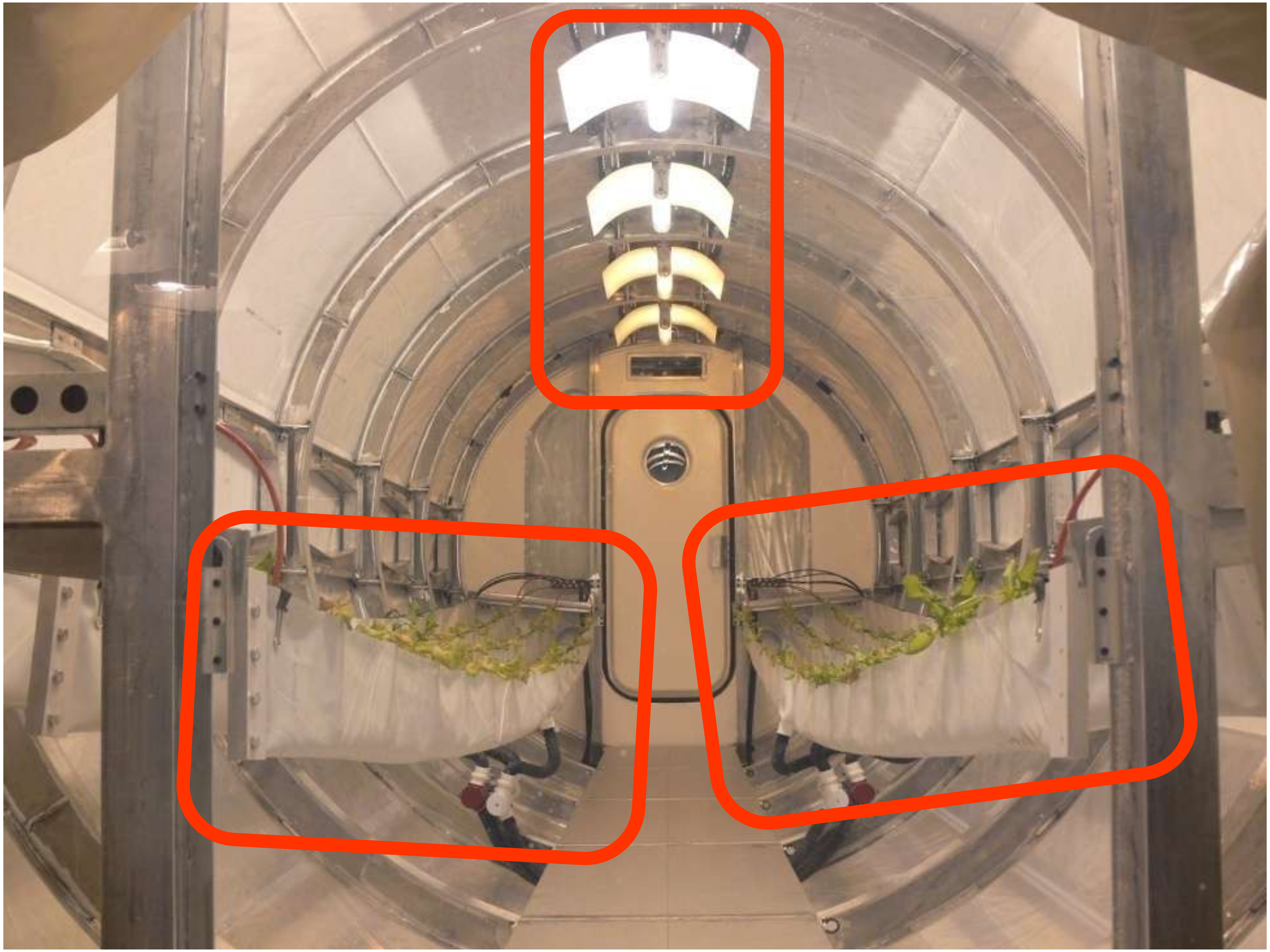
Initial Demonstration Deployment of an Inflatable Prototype Lunar Greenhouse

University of Arizona
Controlled Environment Agriculture Center
Sadler Machine Co Tempe, Az

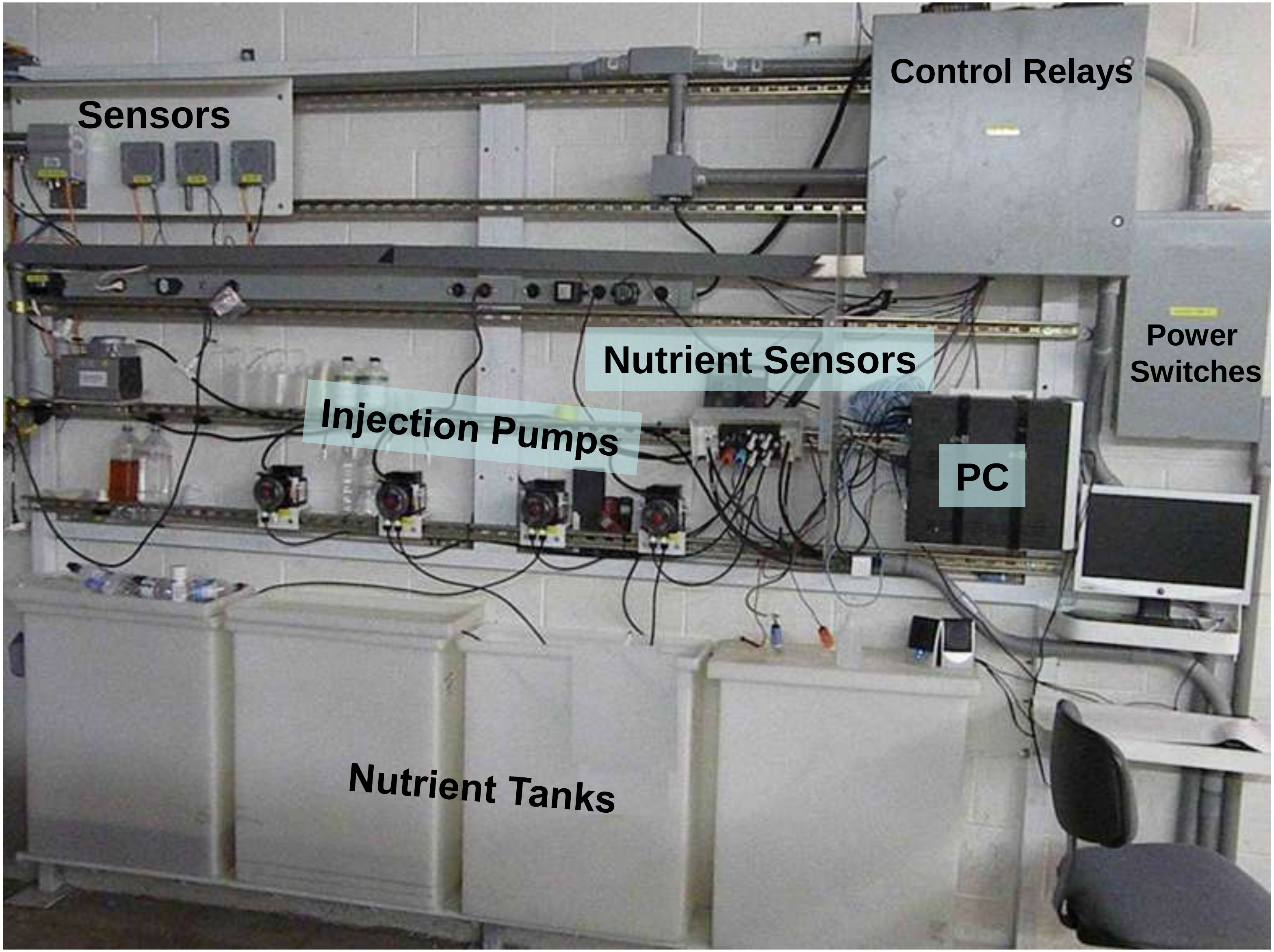
Dr. Gene A. Giacomelli UA/CEAC Director
Phil Sadler Small Business Collaborator
Lane Patterson grad student

10/31/08

Cable Culture Recirculating Hydroponics and HPS water-cooled lamps (Dan Barta and NASA Space Grant)



The Lunar Greenhouse Monitoring and Control



LGH Energy balances and production efficiency

	(d)	Electricity (kWh)	Total Biomass (kg)	Total Biomass Electricity (kg kWh^{-1})	Electricity (g kWh^{-1} m^{-2})
C1	14	1404	31.7	0.023	0.6
C2	14	1404	29.3	0.021	0.6
C3	7	702	20.1	0.029	0.8
C4	59	5918	125.7	0.021	0.6

Activities Completed by TAS-I in Steckler Phase 1

- G. Boscheri at UA-CEAC enhanced LGH, and improved Modified Energy Cascade (MEC) predictive model
- ICES 2010 & 2012 paper on collaboration results
- AgroSpace Workshop with poster on collaboration
- C. Lobascio received G. Giacomelli at Recyclab enhanced EDEN; promote collaboration


G. Boscheri at UA-CEAC


EDEN growth chamber at TAS-I Recyclab


TAS-I Recyclab Team

ThalesAlenia Space
A Thales / Finmeccanica Company

Modified Energy Cascade Model adapted for a Multicrop Lunar Greenhouse Prototype

G. Boscheri[c], M. Kacira[a], L. Patterson[a], G. Giacomelli[a], P. Sadler[d], R. Furfaro[b], C. Lobascio[c], M. Lamantea[c], L. Grizzaffi[c]
TAS-I personnel

Objective

Develop an energy cascade model for a multi-crop lunar greenhouse system, validate its performance, and identify the sensitivity of the model outputs to the input parameters.

Model Predicted Values

- Biomass produced
- Net O_2 produced
- Water condensate produced
- Water consumed
- Net CO_2 consumed
- Fertilizer consumed

Aero Sekur (Phase I & II Collaborator)

<u>Activities Completed by Aero-Sekur in Steckler Phase I</u>

- **M. Pirolli - inflatable greenhouse structure with hydroponic plant growth system**
- **S. Rossignoli received & supported G. Giacomelli at Aero-Sekur; promote collaboration; Sept 2009 – June 2010**
- **AgroSpace Workshops May 2010 and 2012**
- **Space Greenhouse – lettuce, arabidopsis, Paolo Nespoli,**

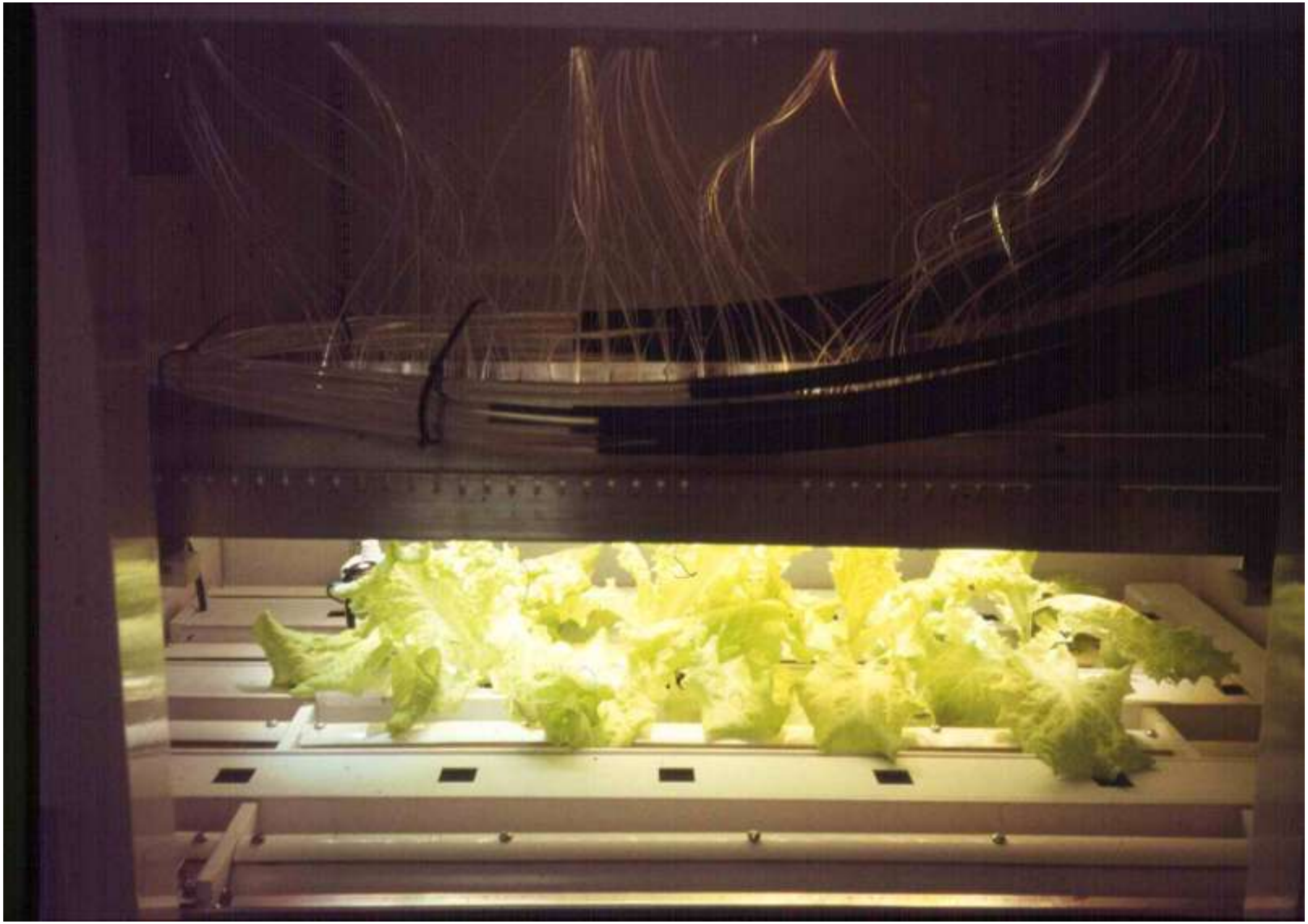
  January – June 2011 on ISS

AERO SEKUR

Himawari Focusing and Tracking Solar Collector
(adjacent to UA-CEAC Extreme Climate Lab)

Fresnel Lens, Fiber Optic Bundle, Capture PAR for plant growth, Infrared for heat, and UV for PV electric power, separately.

Direct Solar Radiation Utilization for Crop Growth with Fiber Optics



Rotary Drum Composter

Bioremediation

Primary water treatment of crew waste stream

Remove air-borne volatiles

Carbon oxidized

Solids reduction and degradation

No progress to date

Remote Experts Network Decision Support System (RENDSys)

Dr Murat Kacia and David Story

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

Machine Vision Guided Monitoring and Evaluation System

Computer vision-guided crop monitoring system of a multi-camera and sensor platform crop signatures in the:

visible bandwidth;

infrared (IR Thermal camera) bandwidth;

near-infrared (Color Camera with NIR filter and Monochrome Camera with filter waveband

Evaluate the canopy temperature; vegetation indices (NDVI, NIR/Green and NIR/red), and **crop morphology**

Acknowledgements

Thank you!

Ralph Steckler NASA Space Grant

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- **Tim Swindle (Lunar and Planetary Lab Director)**
- **Susan Brew (Program Manager)**

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)

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