Programmable Plants:

Development of an *in planta* System for the Remote Monitoring and Control of Plant Function for Life Support

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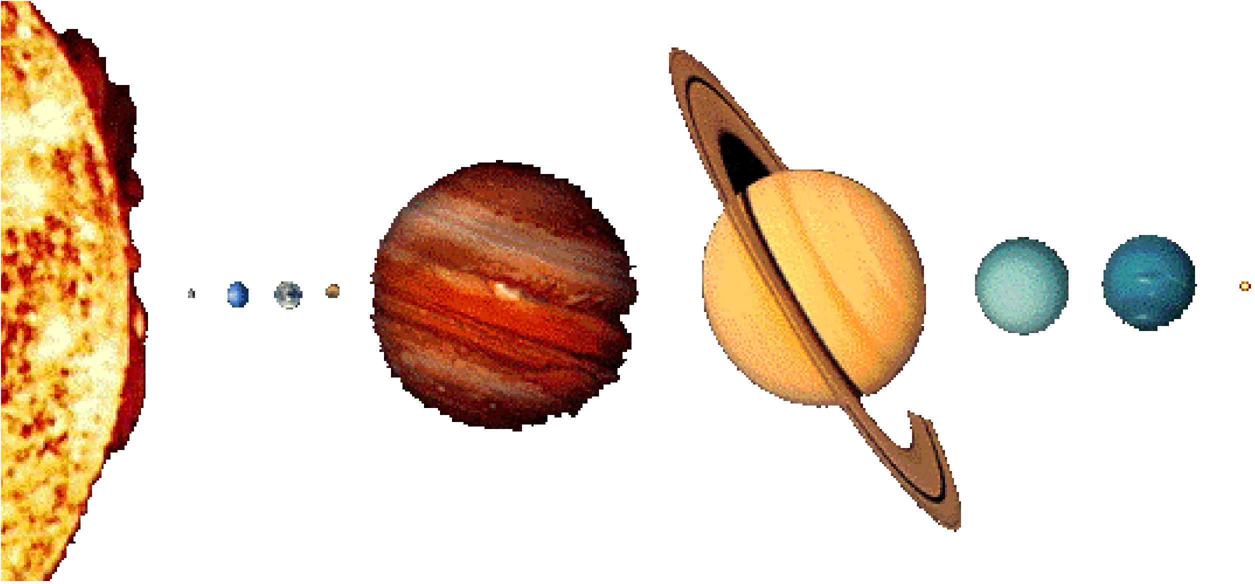
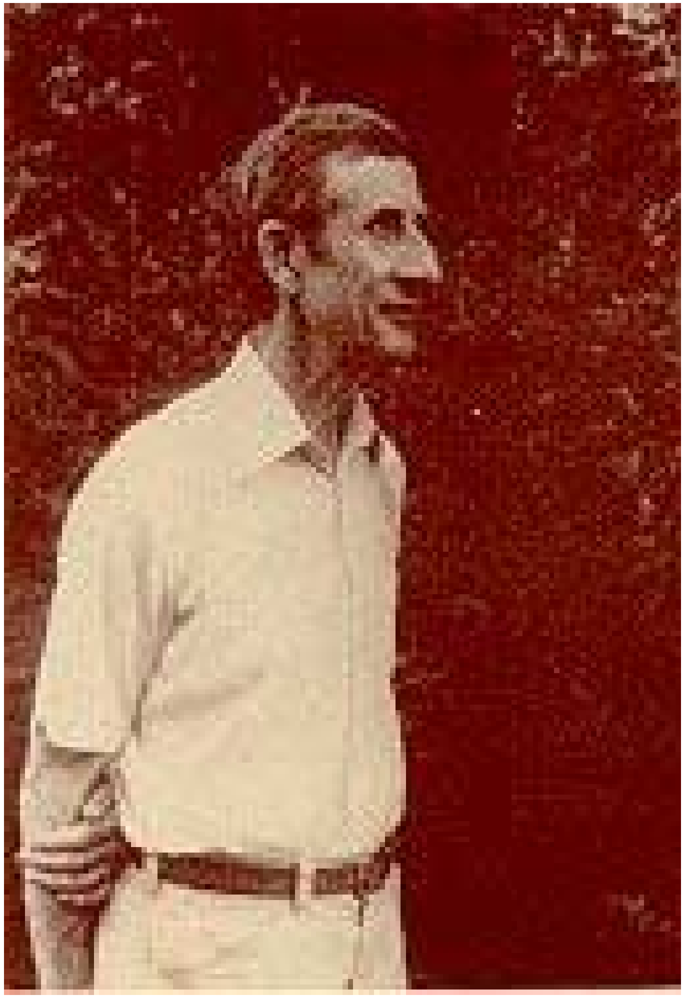
DYNAMAC CORPORATION

NC STATE UNIVERSITY NSCORT NASA Specialized Center of Research and Training



NASA's Strategic Enterprise Goals

- **Space Science**
  - Enable human exploration beyond low-Earth orbit
- **HEDS**
  - Conduct human missions in the solar system
- **Aero-Space Technology**
  - Reduce the cost of interorbital transfer by an order of magnitude



"The practical feasibility of cheap human voyages and settlement of the solar system depends on fundamental advances in biology…and will have a timescale tied to the timescale of biotechnology …a hundred years."

Freeman Dyson 1999. ***The Sun, the Genome & the Internet*, Oxford University Press.**

Our Goal

To validate the viability and define the major feasibility issues of producing <u>programmable plants</u> which could be used for NASA's mission of solar system exploration

What is a Programmable Plant?

- Able to receive input (instructions)
- Able to process information
- Able to transmit data
- Designed for specific purposes (tunable)

Exploit natural components
e.g. phytochrome, signaling pathways, fluorescence, biodiversity

Utilize implanted nanodevices
e.g. sensors, communication, control

- **Advanced Life Support**
- **Genomics**
- **Nanotechnology**

Advanced Life Support

- **What - Air, water and food**
- **Why - Ensure mission success**
- **How - Physicochemical**
- **How - Bioregenerative**

Goal is to minimize:

Mass (volume)
Energy (power)
Crew time

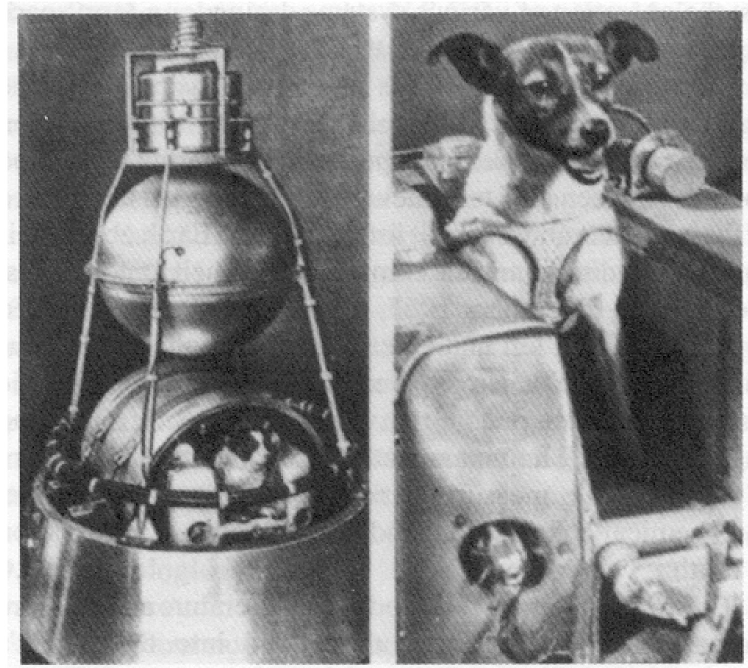


Fig. 15 The first living creature in near-Earth orbit—the dog Layka (November 1957)

Human life support requirements:

Inputs

	Daily Rqmt.	(% total mass)
Oxygen	0.83 kg	2.7%
Food	0.62 kg	2.0%
Water (drink and food prep.)	3.56 kg	11.4%
Water (hygiene, flush laundry, dishes)	26.0 kg	83.9%

TOTAL 31.0 kg

Outputs

	Daily Rqmt.	(% total mass)
CO_2	1.00 kg	3.2%
Met. Solids	0.11 kg	0.35%
Water	29.95 kg	96.5%
(metabolic / urine		12.3%)
(hygiene / flush		24.7%)
(laundry / dish		55.7%)
(latent		3.6%)

TOTAL 31.0 kg

Source: NASA SPP 30262 Space Station ECLSS Architectural Control Document. Food assumed to be dry except for chemically-bound water.

Slide courtesy of Dr. Ray Wheeler

Physicochemical Technologies

Air

O_2 generation – Static water feed electrolysis

CO_2 removal – Four bed molecular sieve

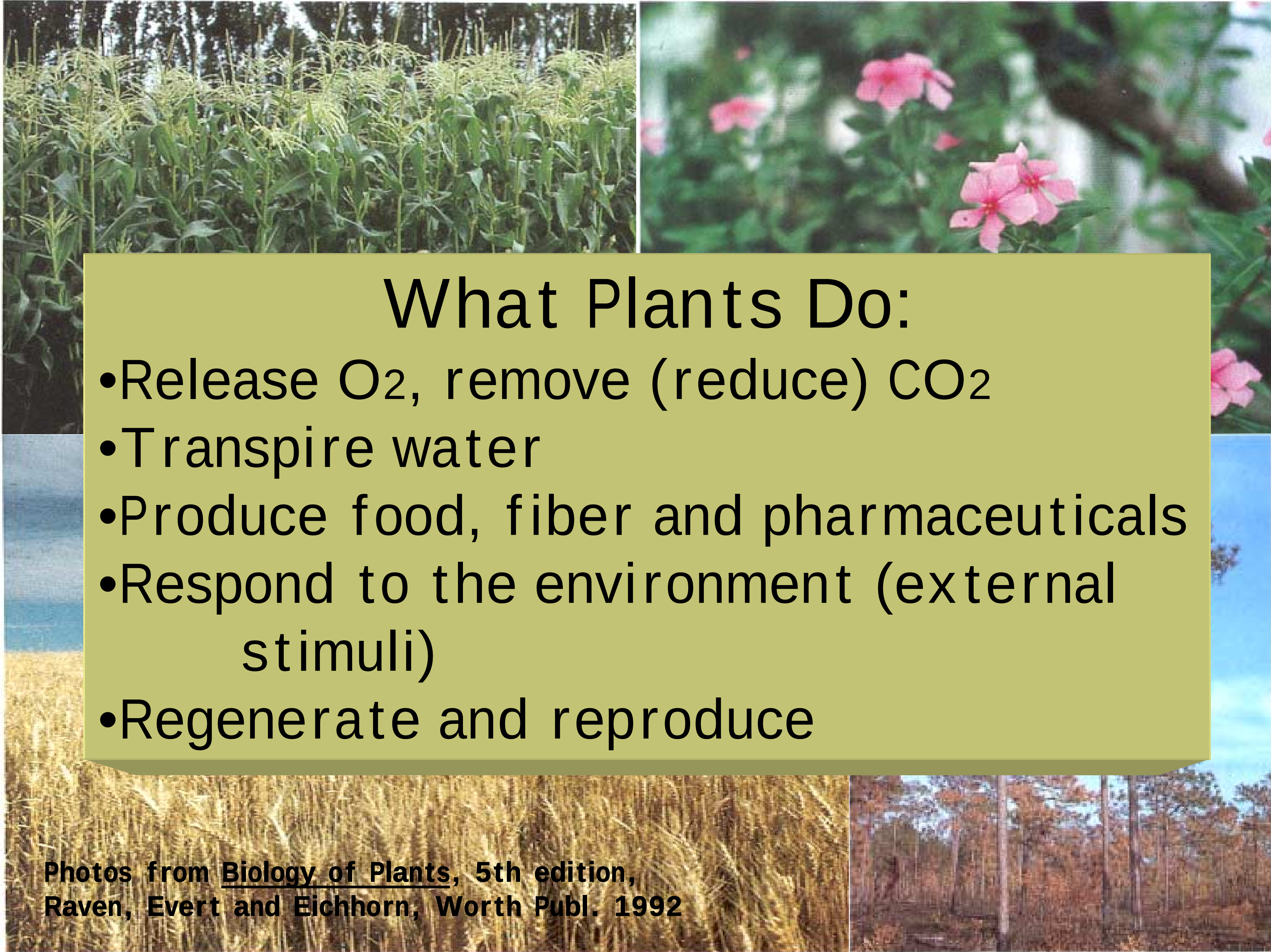
CO_2 reduction – Bosch reactor

Water Recycling

Potable – Multifiltration and Bosch

Hygiene – Ultrafiltration and reverse osmosis

Urine – Thermoelectric integrated membrane evaporation

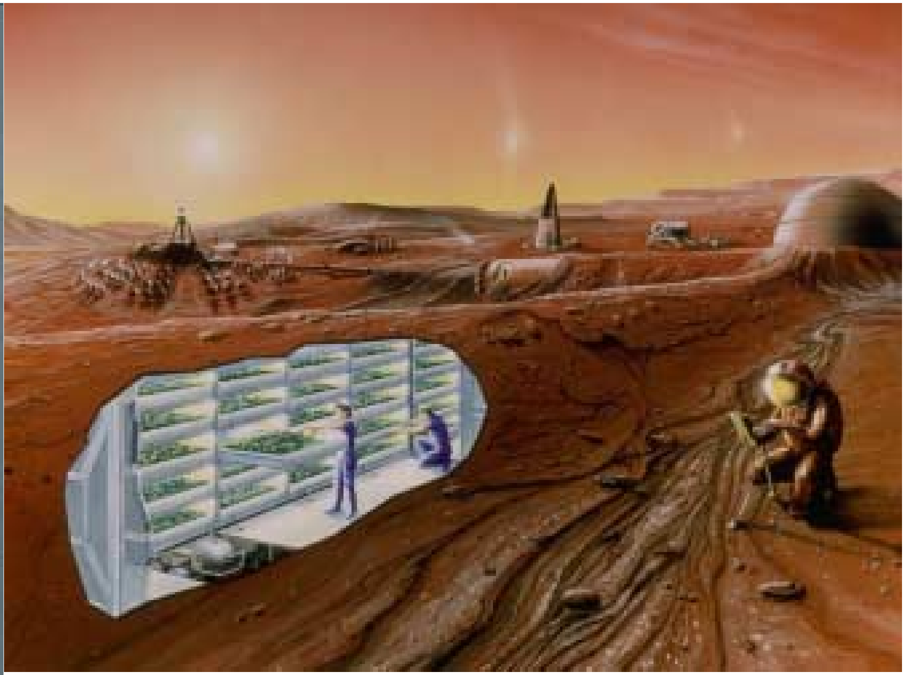


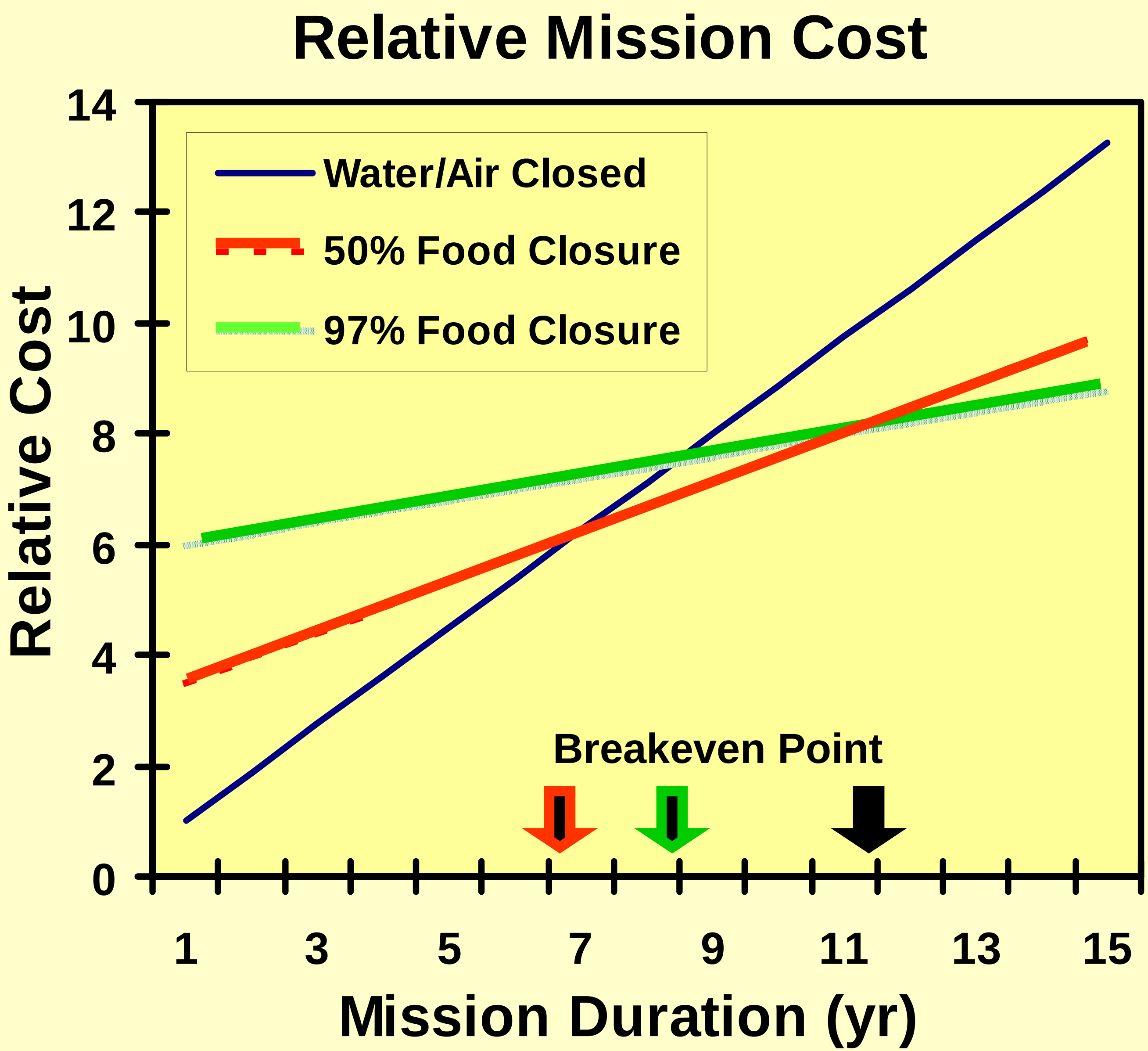
What Plants Do:

- Release O_2, remove (reduce) CO_2
- Transpire water
- Produce food, fiber and pharmaceuticals
- Respond to the environment (external stimuli)
- Regenerate and reproduce

Photos from <u>Biology of Plants</u>, 5th edition, Raven, Evert and Eichhorn, Worth Publ. 1992

As mission duration and distance increase, the economics of a bioregenerative life support system improve.





Adapted from R.L. Olson, NASA Contract NAS2-11148 Final Report, 1982

Candidate crops for bioregenerative life support systems

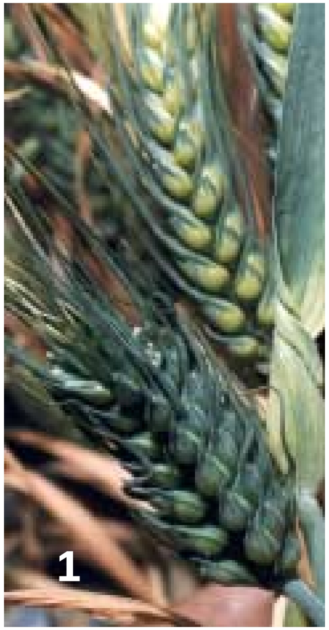
Staple

Wheat
Soybean
White potato
Sweet potato
Peanut
Rice
Quinoa
Dry bean/Pea
Sugar beet

Supplemental

Lettuce
Tomato
Spinach
Radish
Strawberry
Chard/Beet
Chufa
Kale
Onion
Carrot
Broccoli
Cabbage
Melon

Image – USDA-ARS



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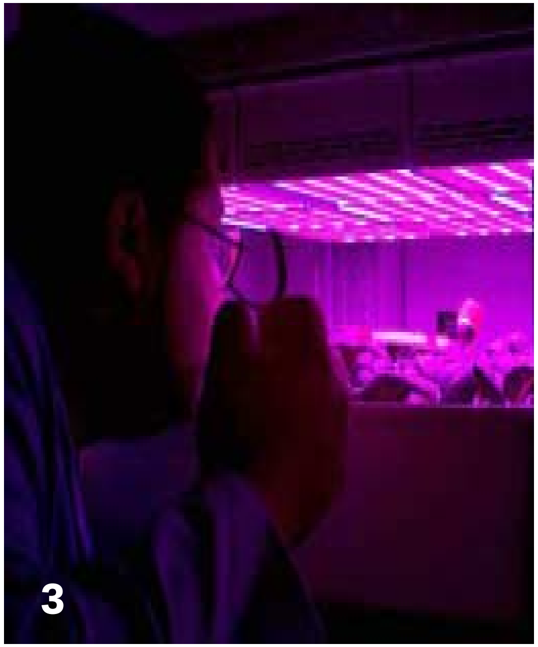

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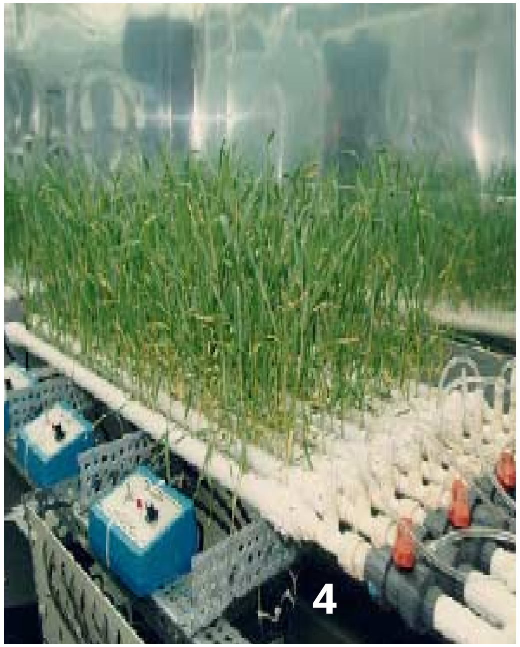

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Yarinks and Drucker,1999

In developing a bioregenerative life support system, we have been striving to use terrestrial plants in space by engineering a suitable environment.

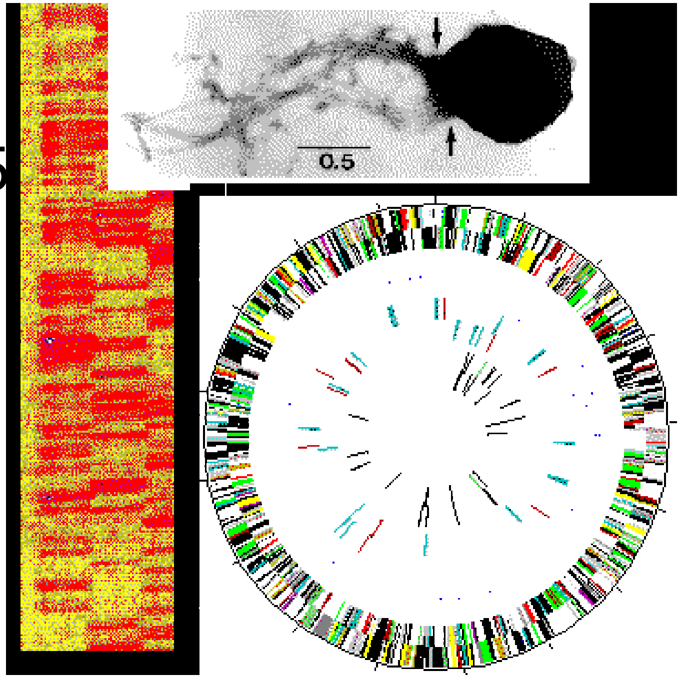
To succeed in the long run, we must return to the original paradigm of agriculture, which is selecting plants to fit the environment.

Genomics

- Derivation of (complete) genetic sequences for living organisms
- The study of the genome (the genetic makeup) of an organism
- Analyzing the structure and function of genes (functional genomics)

Doug Armand/Tony Stone Images

- *Haemophilus influenzae*
  - First, Fleischmann et al. 1995
  - Bacteria, 1.8 mbp
  - Menengitis, ear infections
- *Methanococcus jannaschii*
  - Bult et al. 1996
  - Archaea
  - Deep sea thermal vents, 85C
- *Deinococcus radiodurans*
  - Radiation damage, reassembly
- *Drosophila melanogaster*
- *Homo sapiens*
  - Completion by 2003



www.ornl.gov/hgmis

Plant Genomics

- ***Arabidopsis thaliana***
- ***Oryza sativa* (rice)***
- ***Zea mays* (maize)**
- **Barley, canola, cotton, lettuce*, loblolly pine, peach, poplar, potato*, sorghum, soybean*, sunflower, tomato*, wheat***

*candidate crops for BLSS

Genomics – Promise for the Future

Access to genomic information, the availability of tools to exploit it and public acceptance will result in the application of genetic methods for species improvement

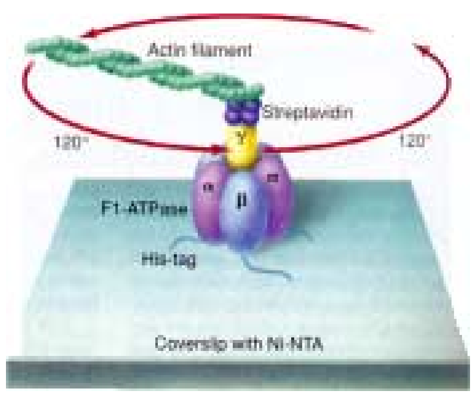
Genetically engineered barley that resists attack by barley yellow dwarf virus (image – USDA-ARS).

Nano – one billionth or 10^{-9}

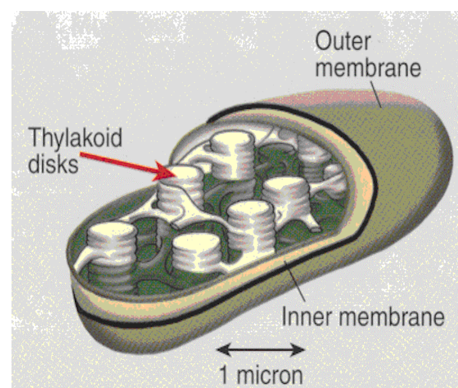
- Nanoscience – how things work on the nanoscale (0.1–100 nm)

- Nanotechnology – molecular (atomic) manufacturing, exploiting improved properties

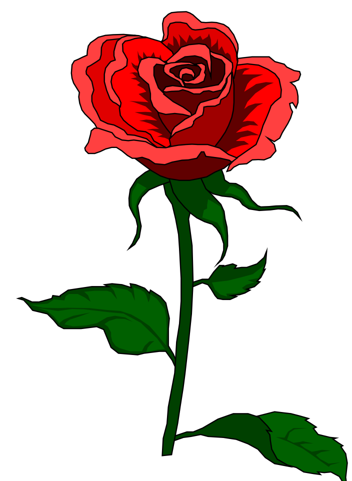
1-10 nm



10 nm



10^3 nm



10^7 nm

Images – Amato, 1999 NSTC

- **Scanning Tunneling Microscopy (STM)**-ability to image nanoscale surfaces
- **Carbon nanotubes**–high strength, low weight, electrical properties
- **Molecular Beam Epitaxy (MBE)**-construction of layers atom by atom, leads to:
- **Nanoscale optical barriers**–film, filters
- **Giant Magnetoresistance (GMR)**-electrical properties change in magnetic field, used for computer hard disk heads

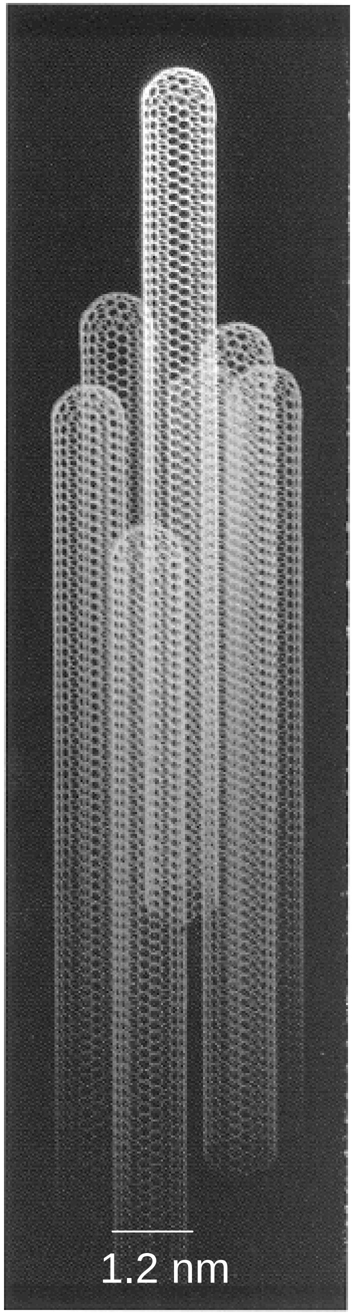


Image – Amato, 1999 NSTC

Nanoscience – Promises for the Future

- Nanostructures with exact shapes and surface properties (cellular automata)
- Small mass, multi-terabit data storage and communication devices
- Nanobiosensors for medicine, agriculture, environment and space

What cutting-edge technologies must we develop to explore, use and enable the development of space for human enterprise?

-- adapted from the NASA Strategic Plan

Biology enters this century in possession, for the first time, of the mysterious instruction book first postulated by Hippocrates and Aristotle. How far will this take us…?

-- Eric Lander and Robert Weinberg

Nanotechnology has given us the tools. The possibilities to create new things appear limitless.

-- Horst Stormer

Collaborators

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NASA

Chris McKay
Ray Wheeler

Dynamac

Andy Schuerger

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Giacomo Marchesi, 1997 The Atlantic Monthly