A light micrograph showing numerous green, oval-shaped microalgae cells. The cells are scattered across the field of view, with some appearing in small clusters. The background is a light, slightly textured grey.

Resource recovery from organic waste by microalgae for global sustainability and space exploration

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20.0 μm

Earth – spaceship-space station

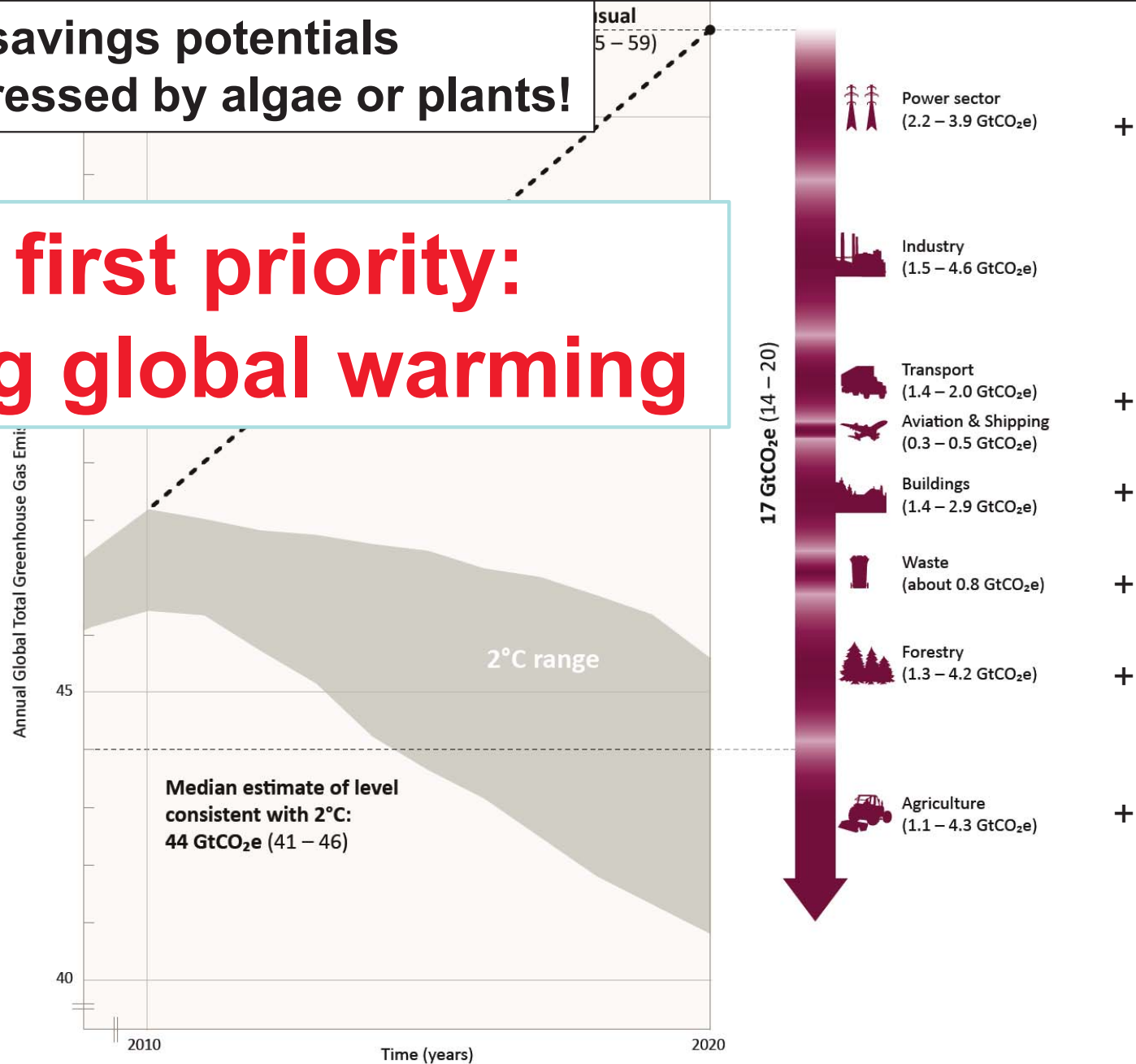
1. Same questions, same problems – different dimensions;
2. Biology is much simpler and much more efficient than engineered technologies;
3. No long term live support without photosynthesis!
4. Key challenge: convincing the stakeholders of that simple fact!



GHG negative technologies can balance the global GHG budget

Major savings potentials can all be addressed by algae or plants!

Our first priority: stopping global warming



Emission free circular bio-economy development in the Negev: Recovery and reuse of waste and water resources by microalgae

CAN SAVE 40000 HECTARES OF
RAINFOREST
WALSH ET AL
40 million tons CO₂

Municipal and
gardening waste
from 500000
inhabitants

Forestry waste >10000
tons from Negev alone
(GHG negative)

**1500 hectare
Microalgae**

Gasification or combustion
with co-generation:
~ 1500 GWhrs electricity

CO₂ and
nutrients

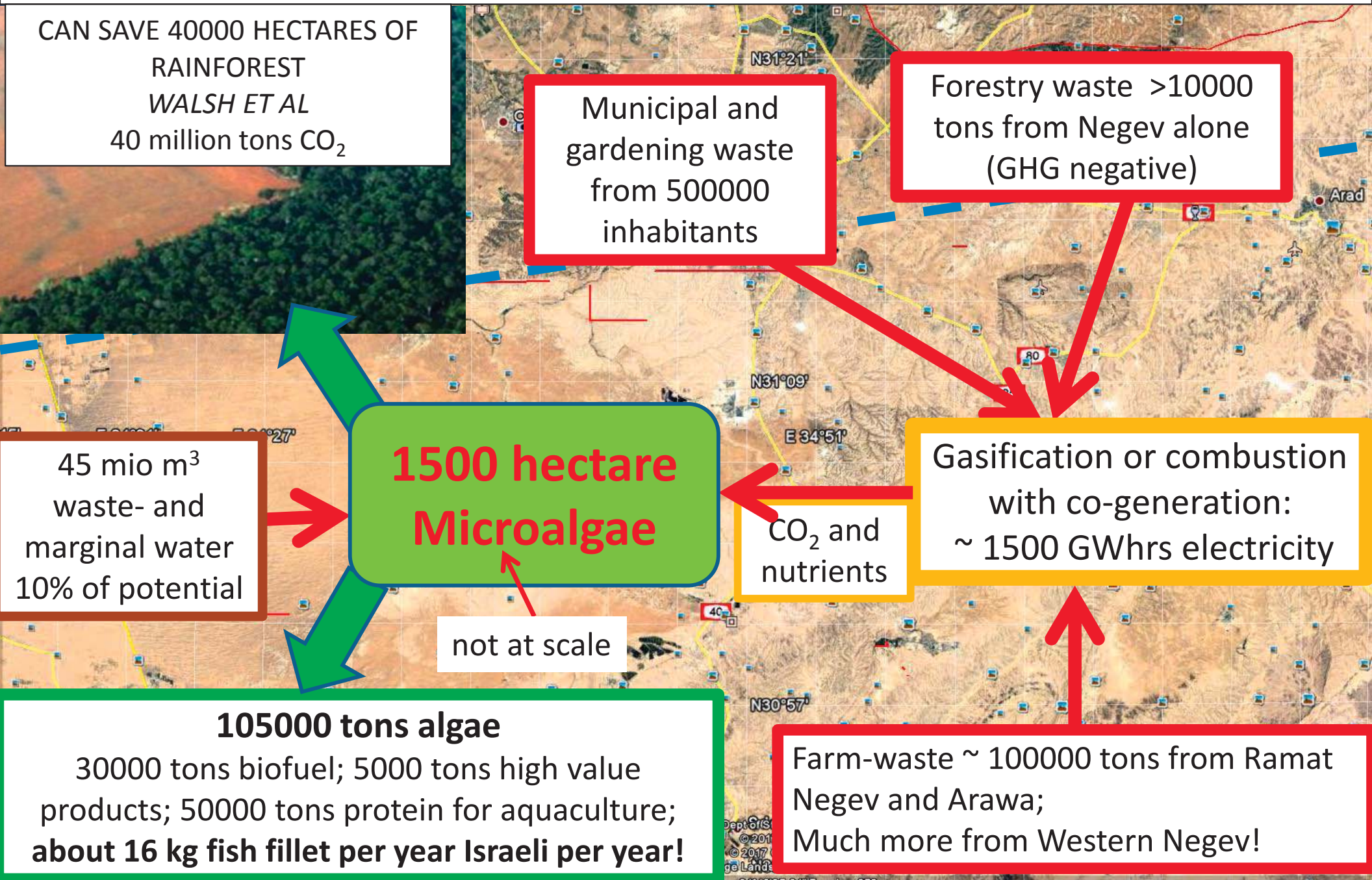
not at scale

45 mio m³
waste- and
marginal water
10% of potential

105000 tons algae

30000 tons biofuel; 5000 tons high value
products; 50000 tons protein for aquaculture;
about 16 kg fish fillet per year Israeli per year!

Farm-waste ~ 100000 tons from Ramat
Negev and Arawa;
Much more from Western Negev!



Algae for space exploration



Even more than on earth, microalgae are the only sustainable option for long term life support in space!

BGU is developing an appliance highly suitable for space life support

Integrated microalgae biotechnology can significantly add to safe, comfortable and pleasant roundtrips to Mars, or Mars colonization :

- Life support (air and water regeneration, integrated food production, waste recovery and reuse);
- Health: antioxidants, essential FA and AA, vitamins etc;
- Safety (PBRs can act as radiation shields, emergency heating or cooling, etc);
- Comfort, pastime and distraction;

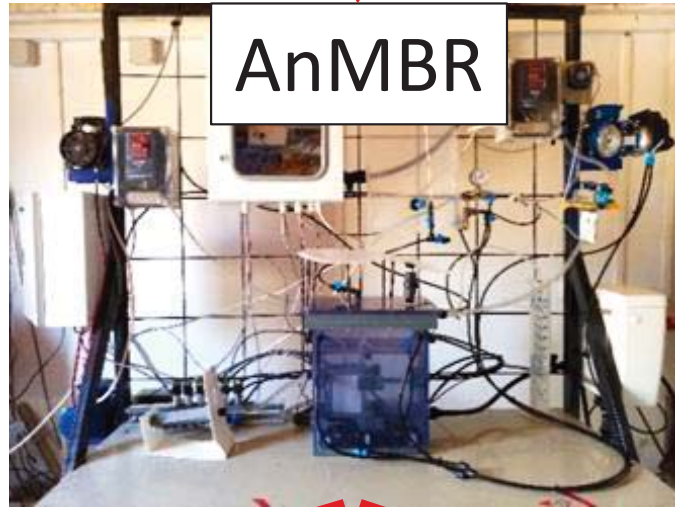
AnM-PBR is an appliance for waste water treatment under recovery of all resources!

First results at TRL level 4:

- The system works fantastically well when challenged to fluctuating weather and substrate composition;
- High value edible biomass with high nutritional value can be produced at $0.4 \text{ g l}^{-1} \text{ day}^{-1}$;
- high essential AA and FA, vitamins, antioxidants and caloric value can be varied at will;
- Ammonia and phosphate are completely removed, near drinking water quality is released!

AnM-PBR: an adaptation to space live support

Spaceship waste water



AnMBR

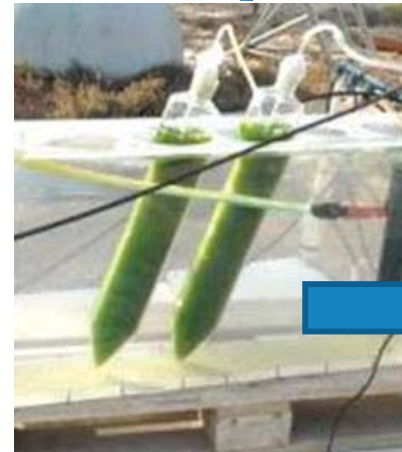
Sterile effluent
= nutrients

CO₂

Sludge
Biochar and nutrients

Methane
and CO₂

Regenerated air



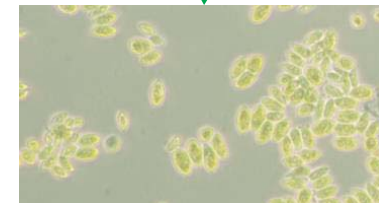
High efficiency PBR
(250 l per person)

Spent air

Oxygen

Drinking water

High value food
grade biomass



- A mix of microalgae is nutritionally complete (AA, EPA, essential AA, FA profile, carotenoids);
- Microalgae grow in drinking water quality;
- Microalgae have superior stress survival strategies;
- Nutritional composition can be optimized to human (or fish) food requirements by growth conditions (e.g. 30% of calories fat, 40% carbohydrates, 30% protein for maintenance);

Experimental Results

Sample	Name	NO ₃ ⁻ [ppm]	NH ₄ ⁺ [ppm]	Biomass productivity [g l ⁻¹ day ⁻¹]
1	<i>Scenedesmus</i> 1	1.23	0.42	0.2
2	<i>Scenedesmus</i> 2	-0.06	0.34	
3	<i>Chromochloris</i> 1	0.05	0.63	0.155
4	<i>Chromochloris</i> 2	1.23	0.52	
5	BZ-1/1	1.13	0.33	0.195
6	BZ1/2	1.51	0.49	
7	BZ2-1	1.52	0.42	0.22
8	BZ2/2	1.05	0.40	
9	Effluent1	2.55	73.66	-
10	Effluent2	3.90	72.70	-

Water treatment and nutrient removal are near perfect with 99.5% ammonia removed

Species	kg biomass per m ³ treated WW**	Projected value (\$) per m ³ treated WW	kg protein per m ³ treated WW**	MJ biomass per per m ³ treated WW
<i>Scenedesmus</i> sp	1.2	3.6	0.55 – 1*	21.6 – 65*
<i>C. zofingiesis</i>	.93	~9*	0.44 - .8*	18.6 – 55*
BZ-1 (EPA)	1.17	15**	0.50 – 1*	21.1 – 65*
BZ-2 (<i>Scenedesmaceae</i>)	1.32	4.3	0.60 – 1.2*	23.7 – 70*

1 m³ of waste water can generate over 65 MJ (15000 kcal) of high value algae biomass!

* partly starved, oil rich

**balanced growth

Issues (true for any algae operation):

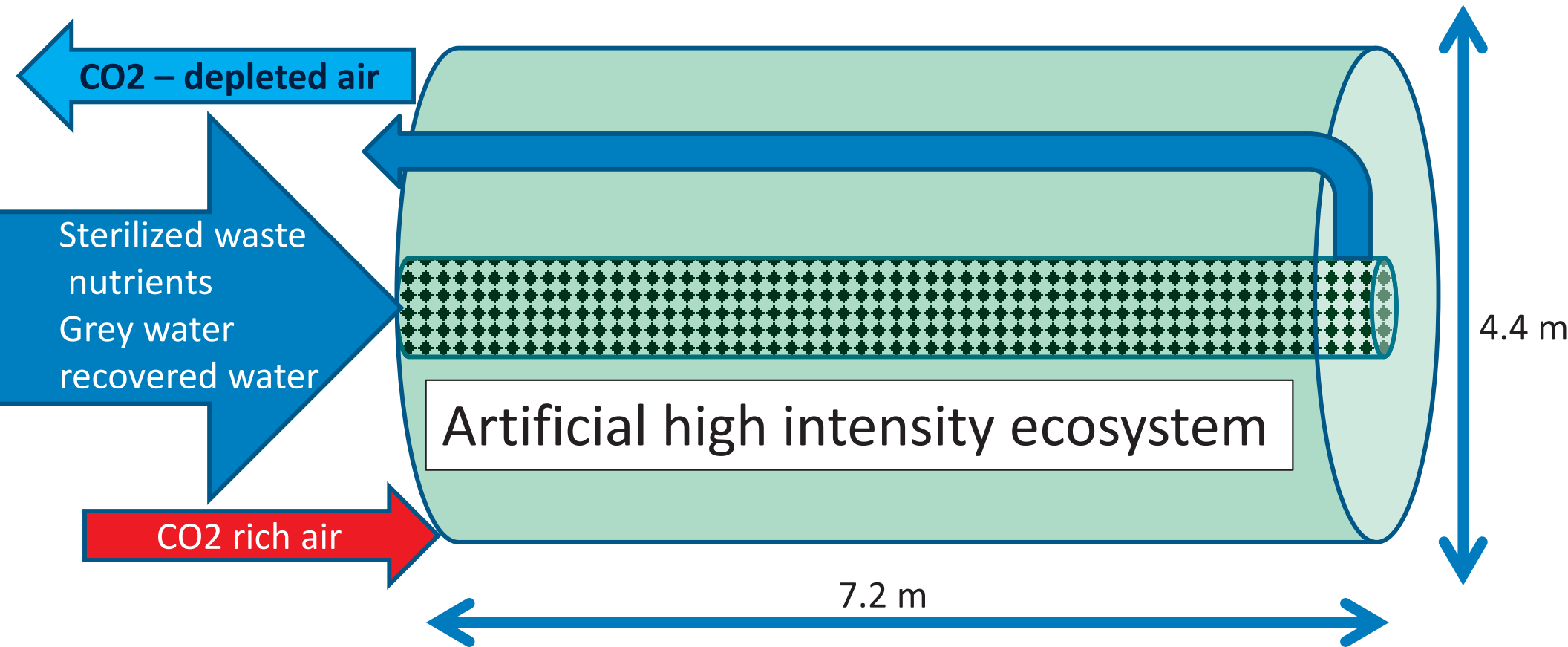
- **Many moving parts, sensors, filters, pumps, electronics;**
- **Maintenance intensive, biofilms and biofouling;**
- **Need for algae harvesting and processing;**
- **Risk of failure;**
- **Much better than a heavy engineering approach**

However:

an artificial ecosystem approach based on Permaculture principles may be far superior in all relevant aspects:

- weight
- investment and maintenance cost;
- reliability;
- durability etc

A higher plant based alternative may be profoundly simpler



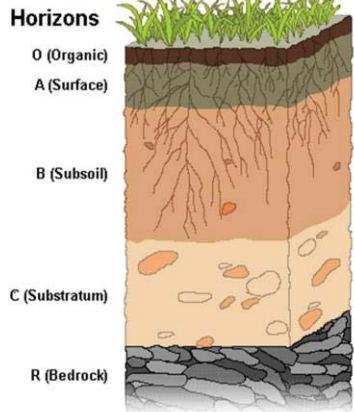
- Such a module has 120 m² illuminated surface, estimated 1.5 tons CO₂ sequestration per year (about 5 astronauts);
- no moving parts!
- no supervision, electronics etc required;
- lighter, cheaper, simpler;
- radiation protection feasible;

Ecosystem approach to creating Mars or Moon based agroecosystems (we also work on rehabilitation of degraded dryland ecosystems)

degraded wasteland soil



**Restore by Vegetation
This we have done!**



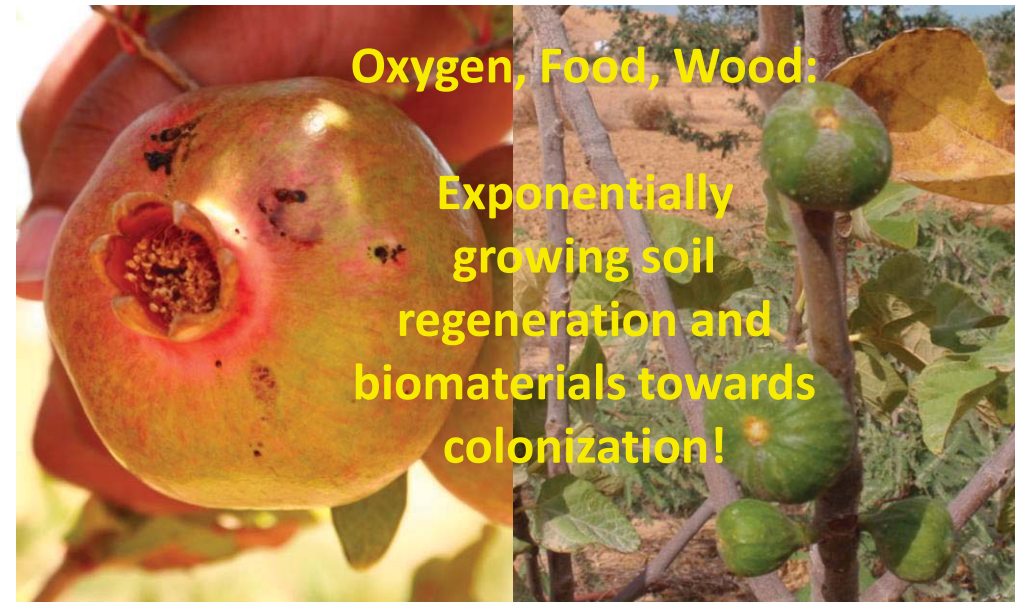
incubator earth soil
profile microbiome

Mars soil:
highly oxidized

+ lyophilized
AnMBR sludge:
highly reduced
complex organics

Oxygen, Food, Wood:

**Exponentially
growing soil
regeneration and
biomaterials towards
colonization!**



Conclusions

- Highly sustainable circular dryland agroecosystems can be created using microalgae;
- Similar principles can be applied for life support in spaceships, or for creating exoplanetary agroecosystems;
- Only microalgae's unique unmatched properties can fully close all relevant cycles and mass balances;
- Higher plant based greenhouse modules can provide food, CO₂ and nutrient recovery cheaper with less weight and far lower cost!
- One of each would provide sufficient redundancy for safe space travel!

- We will be happy to demonstrate all possibilities at any of your research or demonstration facilities;
- Relevant upcoming H2020 opportunities can address various options;

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