MycoGourmet at Artemis

Whole Food Production from ISRU Carbon and Nitrogen

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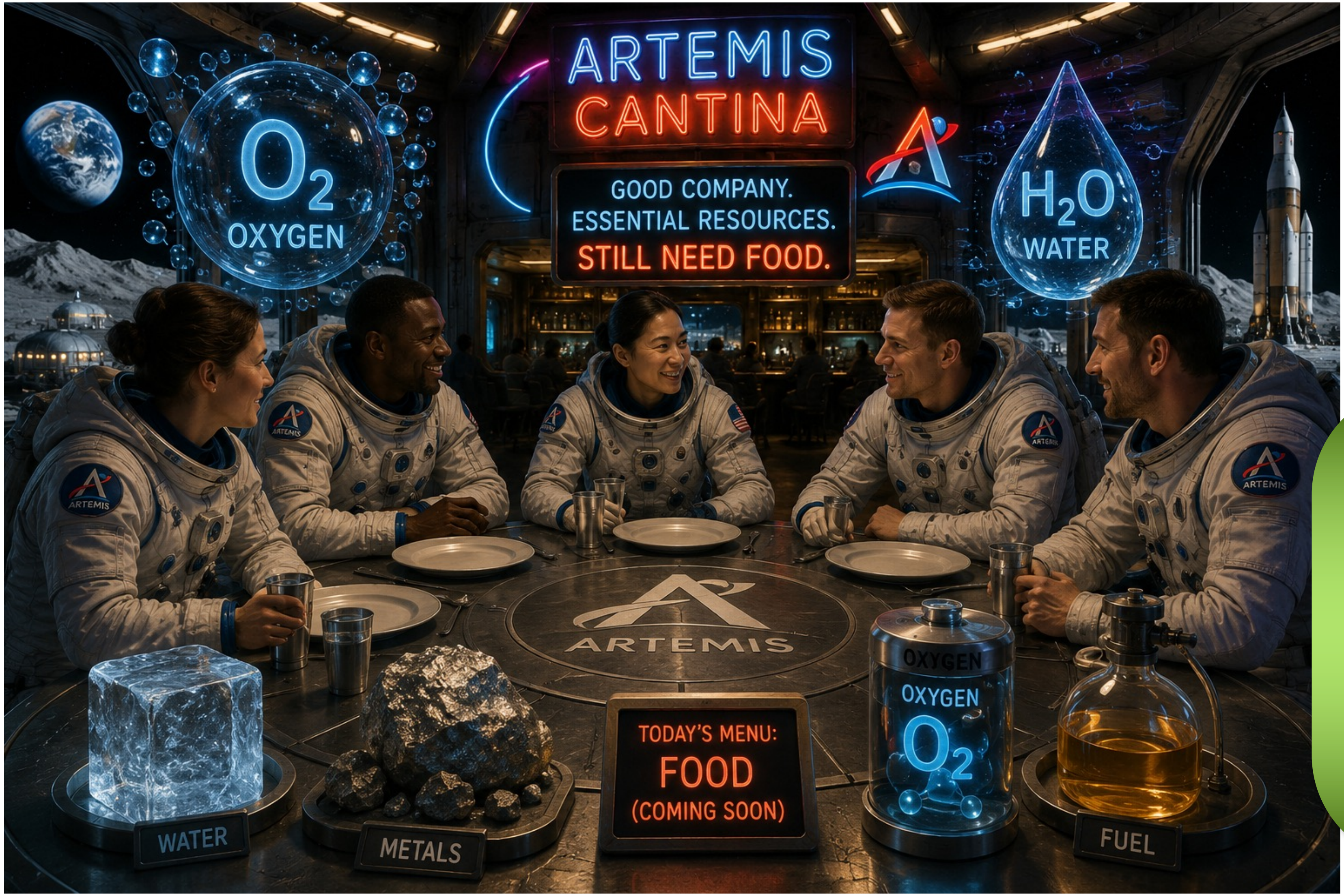
Even Superhero Astronauts Need Food

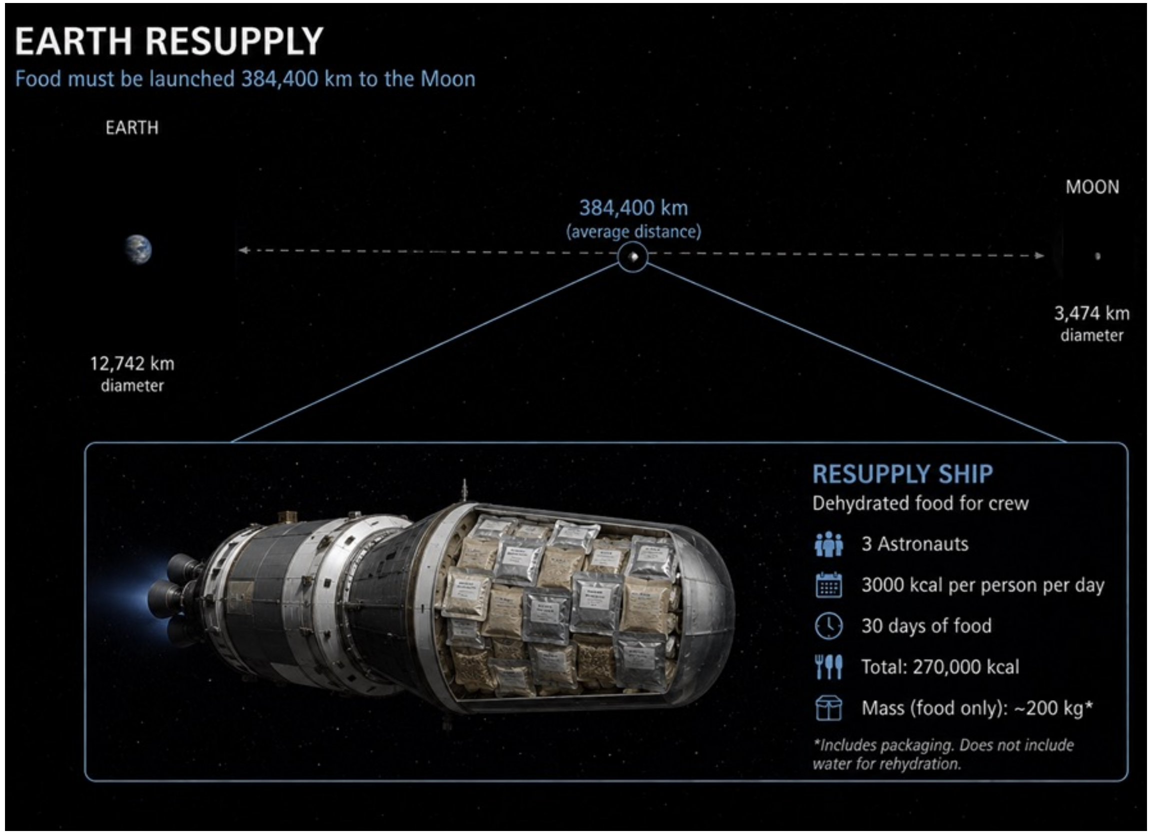
We will make oxygen, water, metals, fuel, and infrastructure on the Moon. We still need food.



To live on the Moon
we must
(eventually)
grow food on the Moon

Artemis Food Options

Current Artemis systems rely on Earth resupply or photosynthetic agriculture.

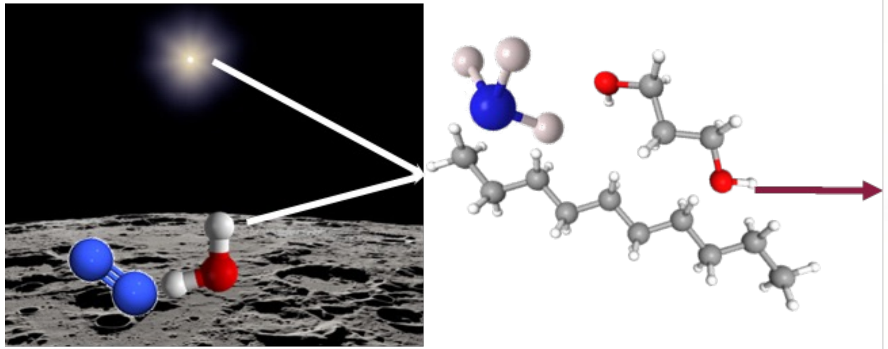


~1000 kg for 3 astronauts every 6 months

~600 m^3 of garden for 3 astronauts

Food can Come From Earth—or From a Very Large Garden. *Or?...*

MycoGourmet: A Third Food Option



Lunar resources
+ recycling

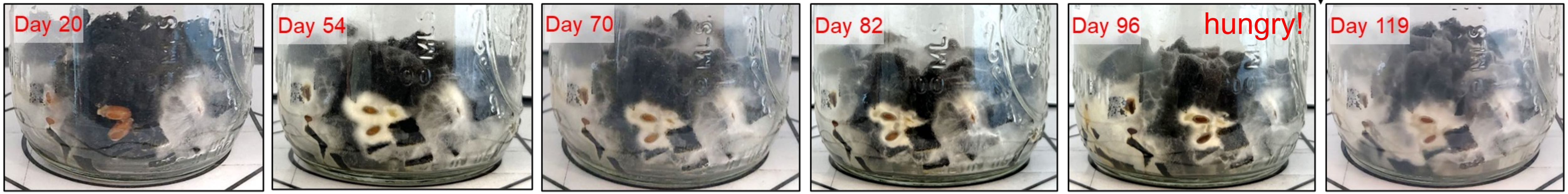
fixed carbon
+ nitrogen

Food From ISRU Carbon and Nitrogen—Without Photosynthesis

Mycelium on HC Growth: Early Experiments

Nutrient substrate: Foam + Water + **1,3–butanediol + urea + phosphate + K** + micronutrients

growing… growing… growing… hungry! Day 98: +10 mL; Day 105: +10 mL growing…



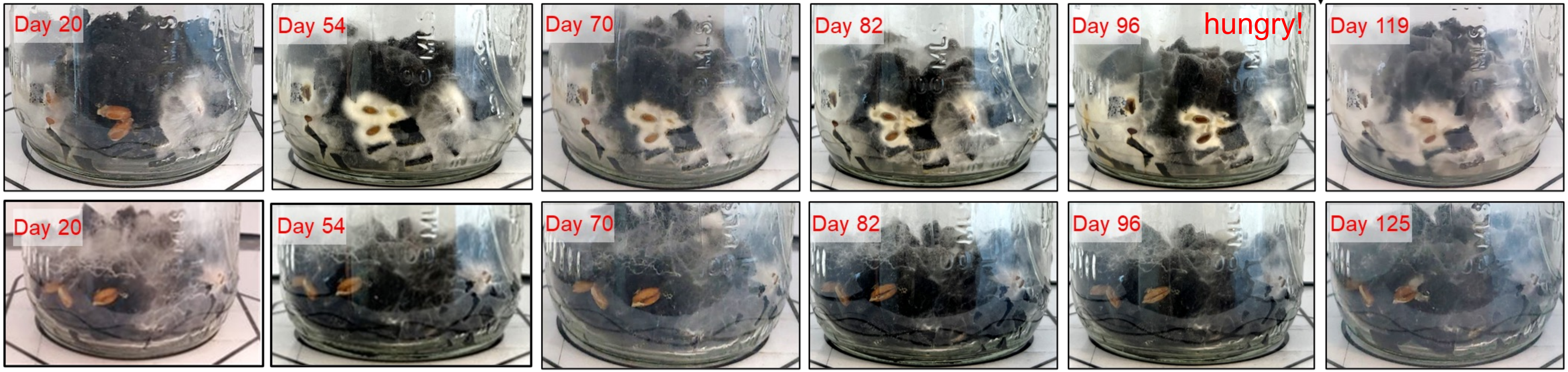
Pearl oyster (*P. ostreatus*) mycelium, 1.6%C 1,3–butanediol water solution

Pearl oyster fruit

Mycelium on HC Growth: An Encouraging Start

Nutrient substrate: Foam + Water + **1,3–butanediol + urea + phosphate +** micronutrients

growing… growing… growing… hungry! Day 98: +10 mL; Day 105: +10 mL growing…



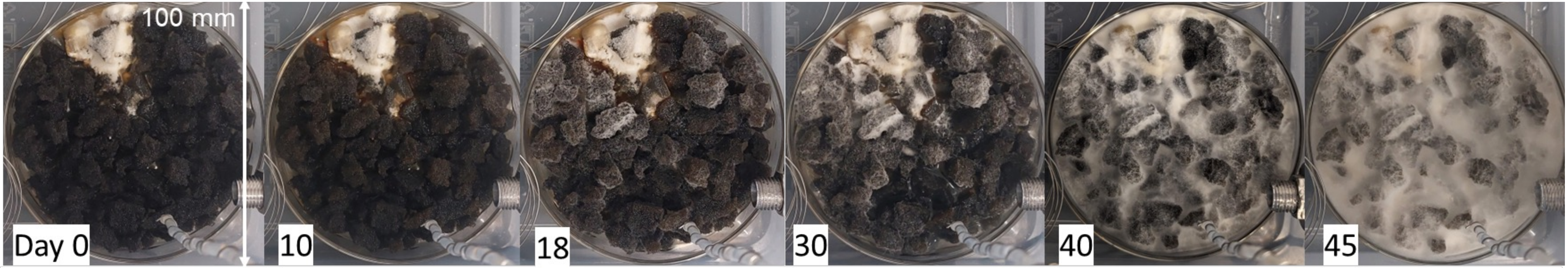
nothing… nothing… nothing… nothing… nothing… nothing…

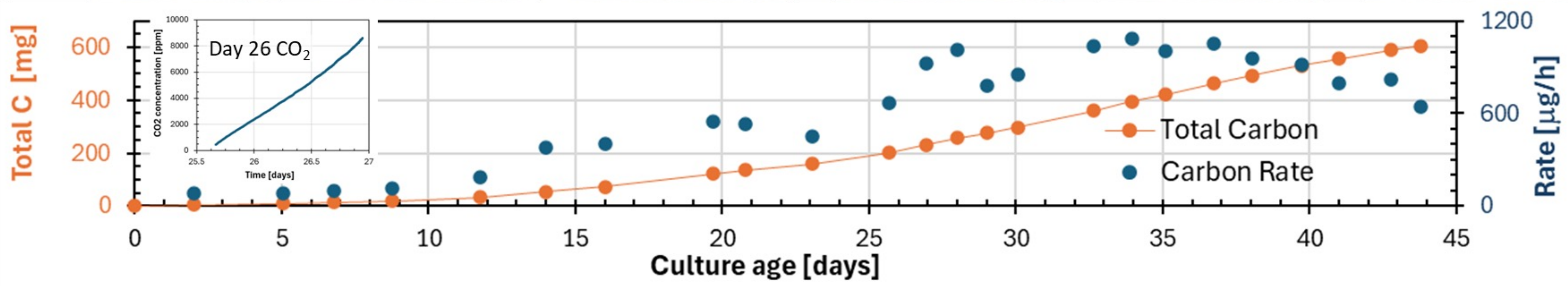
Control: Foam + Water + **urea + phosphate +** micronutrients

No Photosynthetic Biomass Needed to Grow Pearl Oyster Mycelium

Efficiency: Early Data

Phoenix oyster (*P. pulmonarius*) on 3%C **1,3-propanediol**





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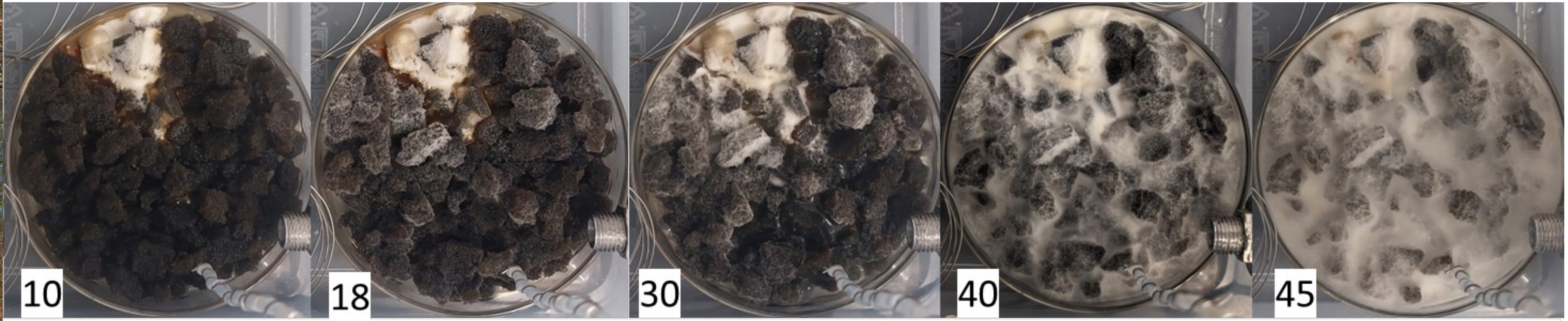

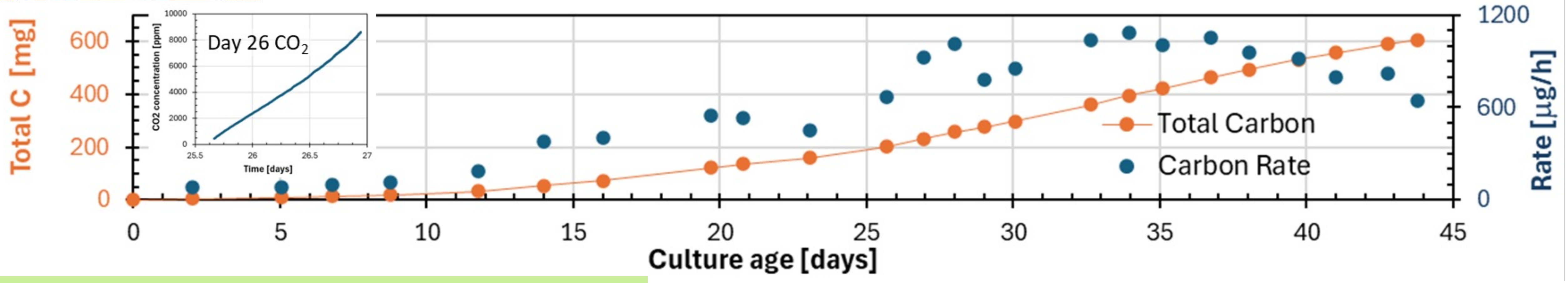

HC mass conversion(“FCR”): **0.43 g/g**
HC energy conversion: **0.22 J/J**

First Efficient Growth!

Efficiency Survey: Fungi and Hydrocarbon Species

Hydrocarbon Substrate											Mycelium			
Species	C/H_2O	HC/H_2O	Input		Remaining		Used HC		Used urea		Species	Dry mass	Conversion	
	g/g	g/g	HC [g]	Urea [mg]	HC [mg]	Urea [mg]	mg	%	mg	%		mg	m %	E %
Propylene glycol	1.5%	3.17%	1.587	51.4	368.5	8.29	1219	**76.8**	43.1	83.9	A. auricula-judae	251.8	**20.0**	**10.9**
Propylene glycol	1.5%	3.17%	1.957	53.7	494.9	7.54	1462	**74.7**	46.2	86.0	A. auricula-judae	229.4	**15.2**	**8.3**
Propylene glycol	1.5%	3.17%	1.957	54.2	798.9	14.27	1158	**59.2**	40.0	73.7	A. auricula-judae	158.8	**13.3**	**7.2**
2,3-butanediol	2%	3.75%	1.286	85.8	128.2	5.45	1158	**90.0**	80.4	93.7	A. auricula-judae	785.9	**63.5**	**30.8**
1,3-butanediol	1.5%	2.81%	1.417	54.0	159.6	17.84	1257	**88.7**	36.2	67.0	T. versicolor	231.2	**17.9**	**8.3**
Propylene glycol	1.5%	3.17%	1.593	51.7	438.6	19.16	1154	**72.5**	32.6	63.0	T. versicolor	208.4	**17.6**	**9.5**
Propylene glycol	1.5%	3.17%	1.952	61.3	72.1	13.78	1880	**96.3**	47.6	77.5	A. auricula-judae	521.1	**27.0**	**14.6**
2,3-butanediol	1.5%	2.81%	1.561	61.0	238.8	12.08	1322	**84.7**	48.9	80.2	A. auricula-judae	165.5	**12.1**	**5.7**

incorporated "FCR"

Wood ear (*A. auricula-judae*)

Turkey tail (*T. versicolor*)

Excellent Survey Outcomes!

Hydrocarbon Utilization Implications

Hydrocarbon Substrate											Mycelium			
Species	C/H_2O	HC/H_2O	Input		Remaining		Used HC		Used urea		Species	Dry mass	Conversion	
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- All these diols are chiral
- No concern about chirality

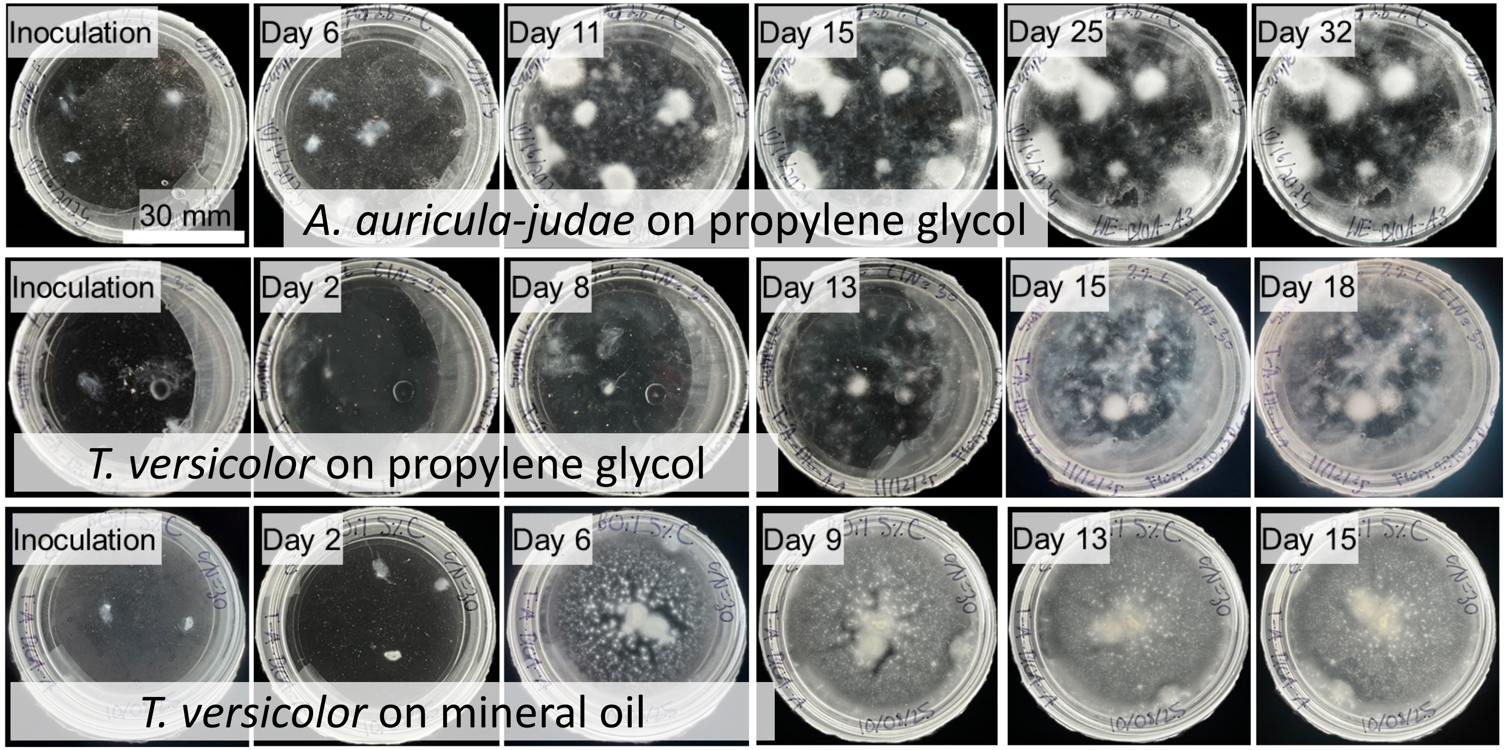
used

incorporated
"FCR"

Conversion Efficiency for Both Chiral Enantiomers of Each Diol

Growth Rates

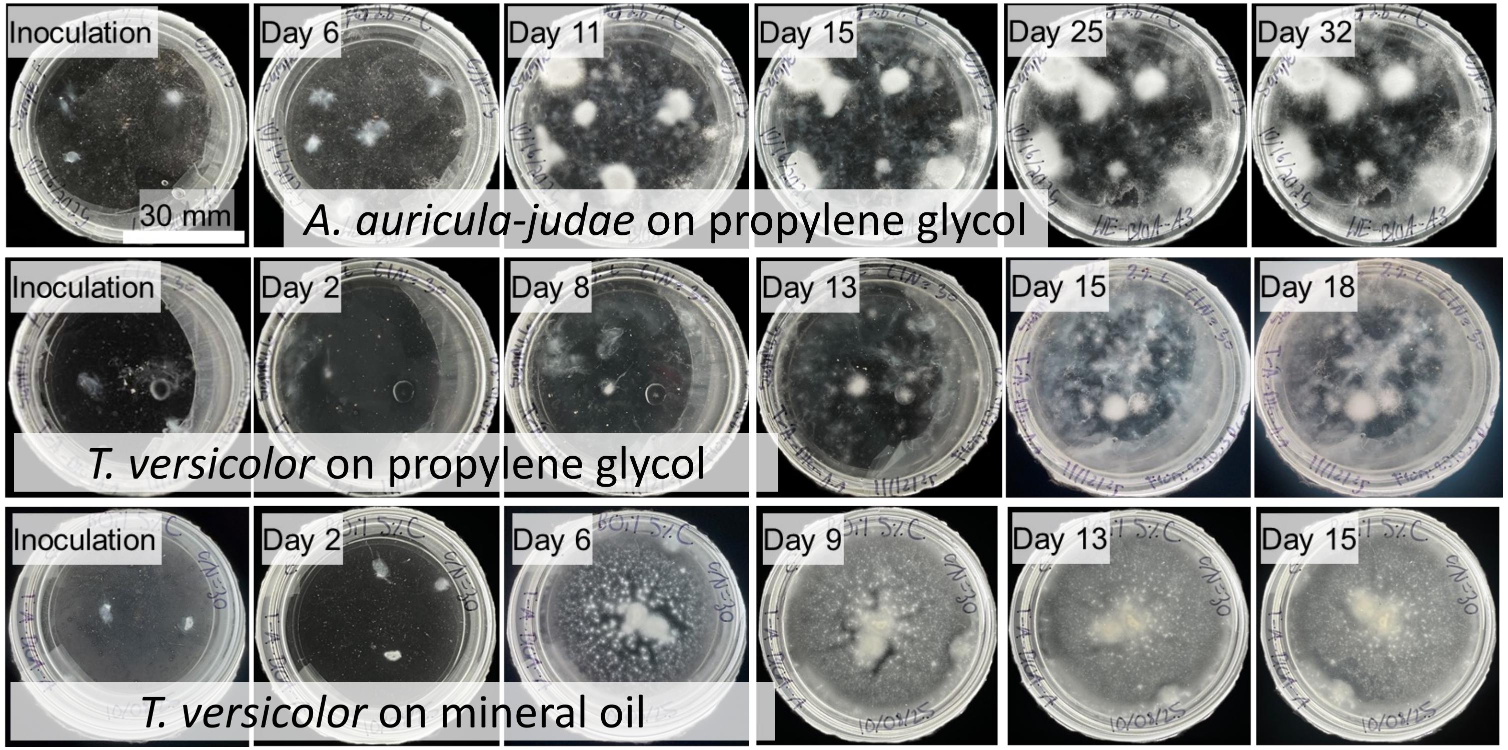
Growth rates determine equipment size



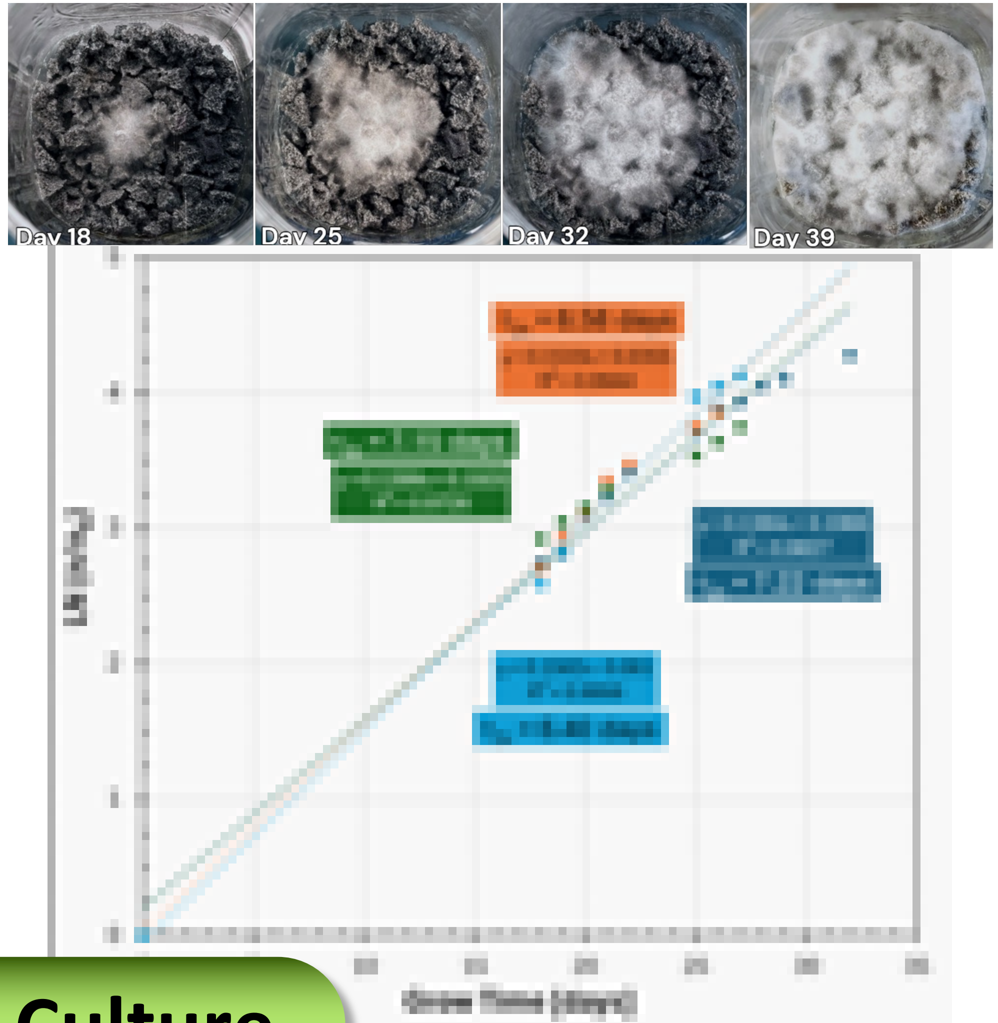
Liquid culture on food-safe hydrocarbons

Growth Rates

Growth rates determine equipment size



Liquid culture on food-safe hydrocarbons



Encouraging Growth Rates Even in Static Culture

T. versicolor on paraffin

Can the MycoGourmet be a Food System?

Key system elements are falling into place

Feasibility ✓

Efficiency ✓

Growth rates ✓

Nutrition?

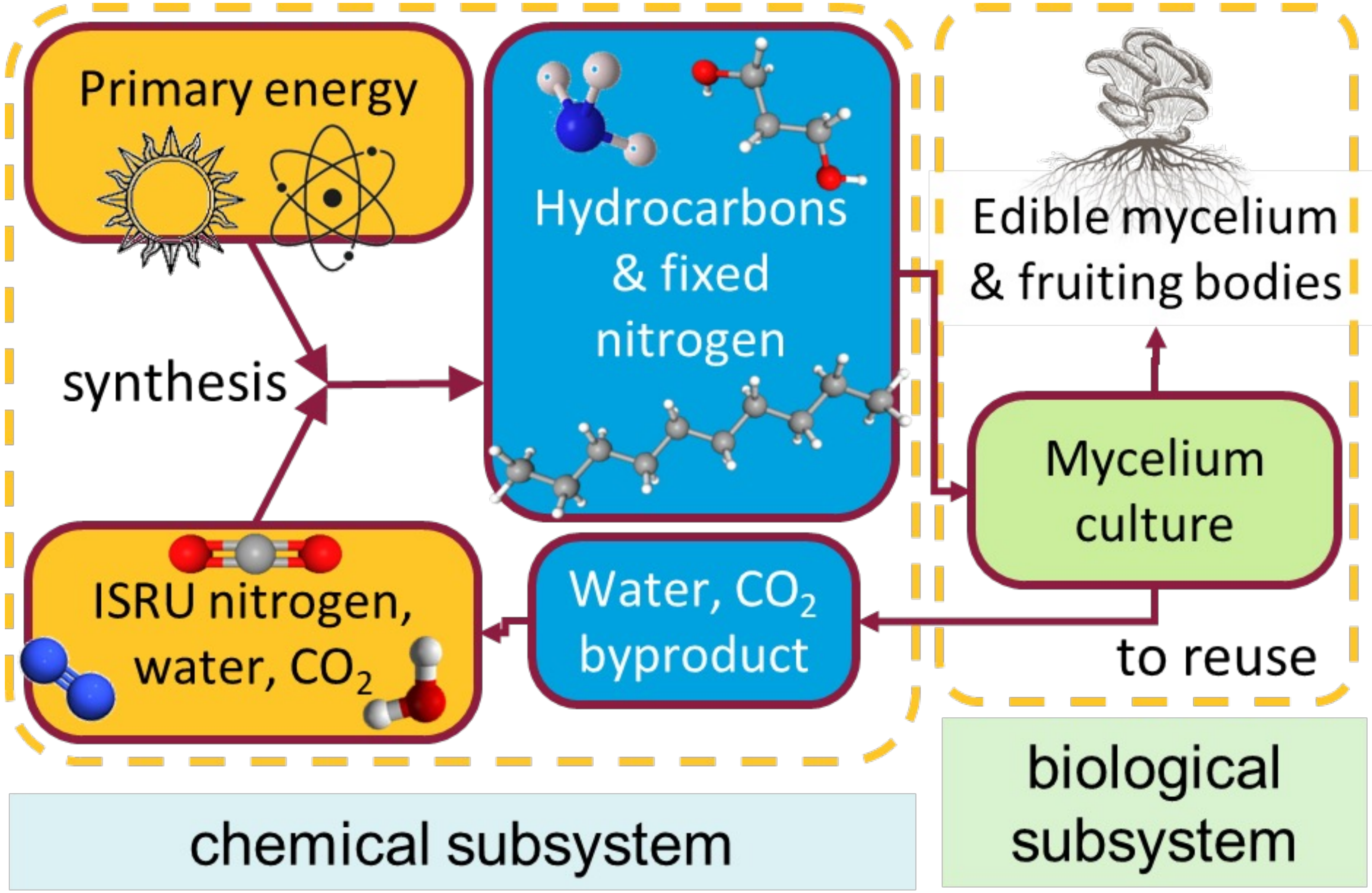
Preliminary:

- ~30% protein
- ~3% lipids
- ~67 carbohydrates

Mass?

Volume

Safety?



What Could This Mean for Artemis?

From Garden to Appliance?

Estimates:

Garden of Artemis

- 600 m^3

MycoGourmet I

- 0.25 m^3
- 60 kg

From the Garden of Artemis to the Fridge of Artemis

Acknowledgements

We are grateful to Arizona State University LightWorks®
for fully funding this research.

Arizona State University LightWorks® is a campus-wide initiative focused on light-inspired research at ASU under one strategic framework. It is a multidisciplinary effort to leverage ASU's unique strengths, particularly in solar-electric energy, sustainable fuels and products, and energy and society.

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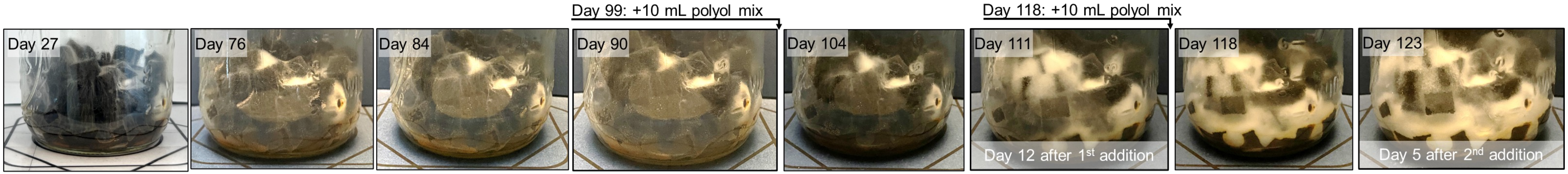
Barrett Honors Research Fellowship Program
and the Sustainability Undergraduate research Experience Program.

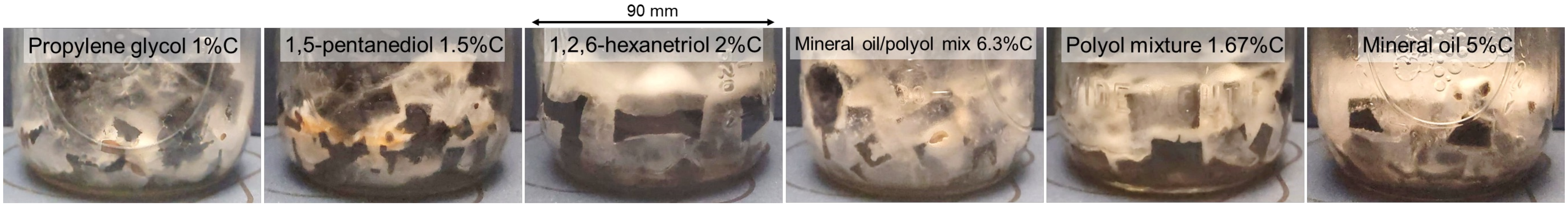
Mycelium on HC Growth: Hypothesis Testing

No hydrocarbon—99 days

Added hydrocarbon—20 days



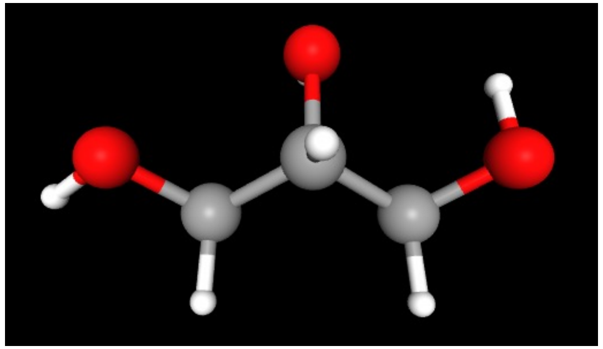
Minimal growth until polyol added



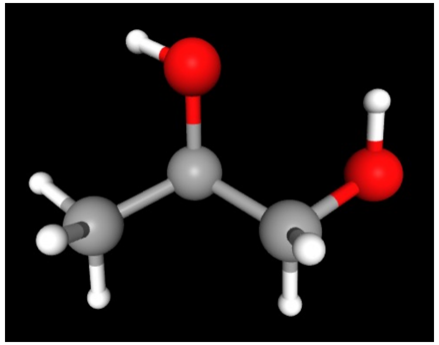
Multiple fungi and HC species successful

Why Polyols?

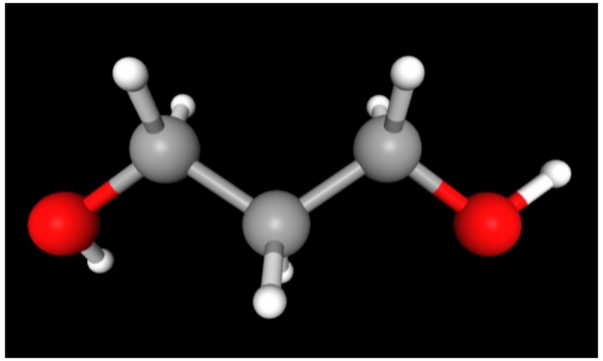
glycerol ($C_3H_8O_3$)



propylene glycol



$C_3H_8O_2$



1,3-propanediol

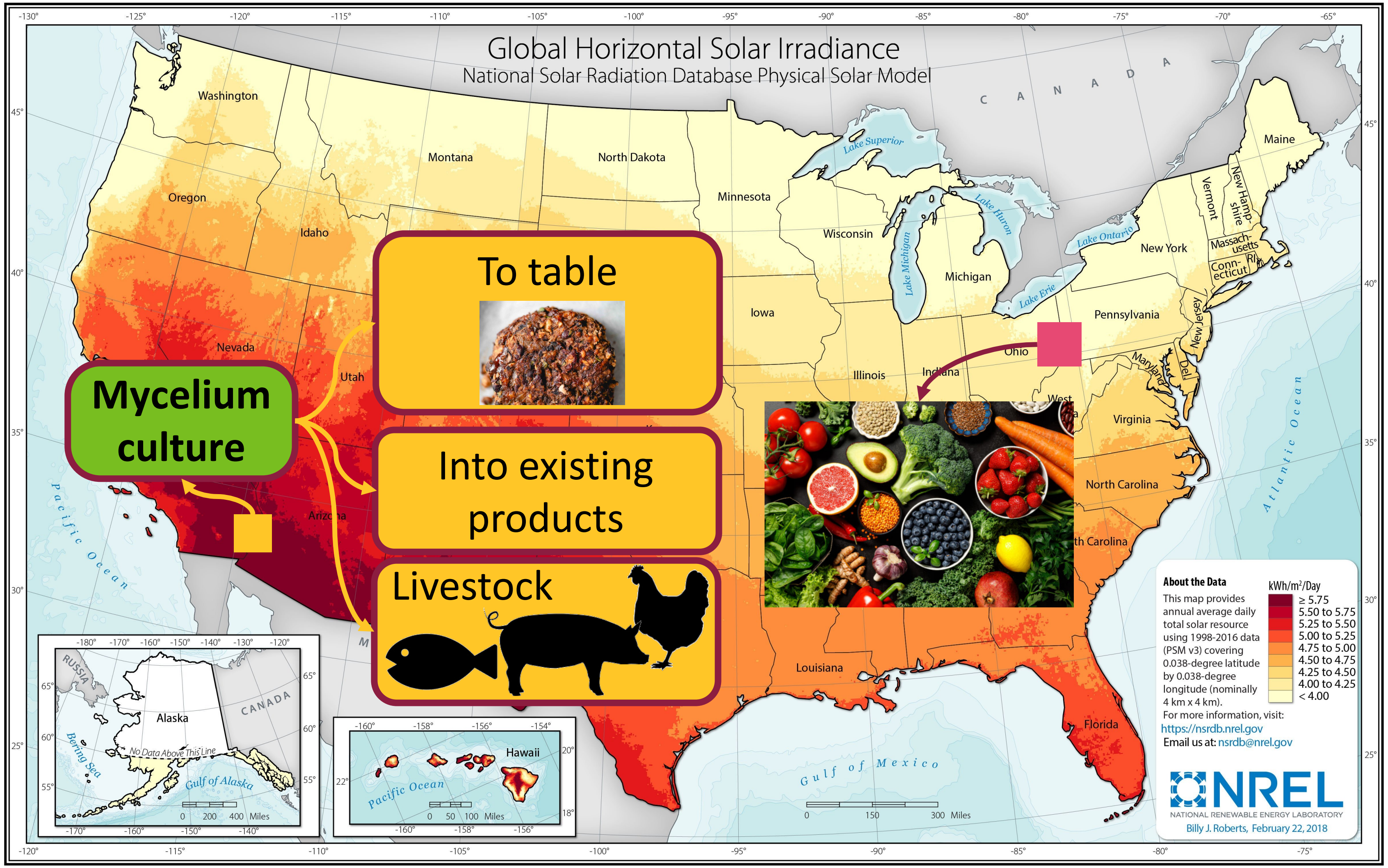
A two-part hypothesis:

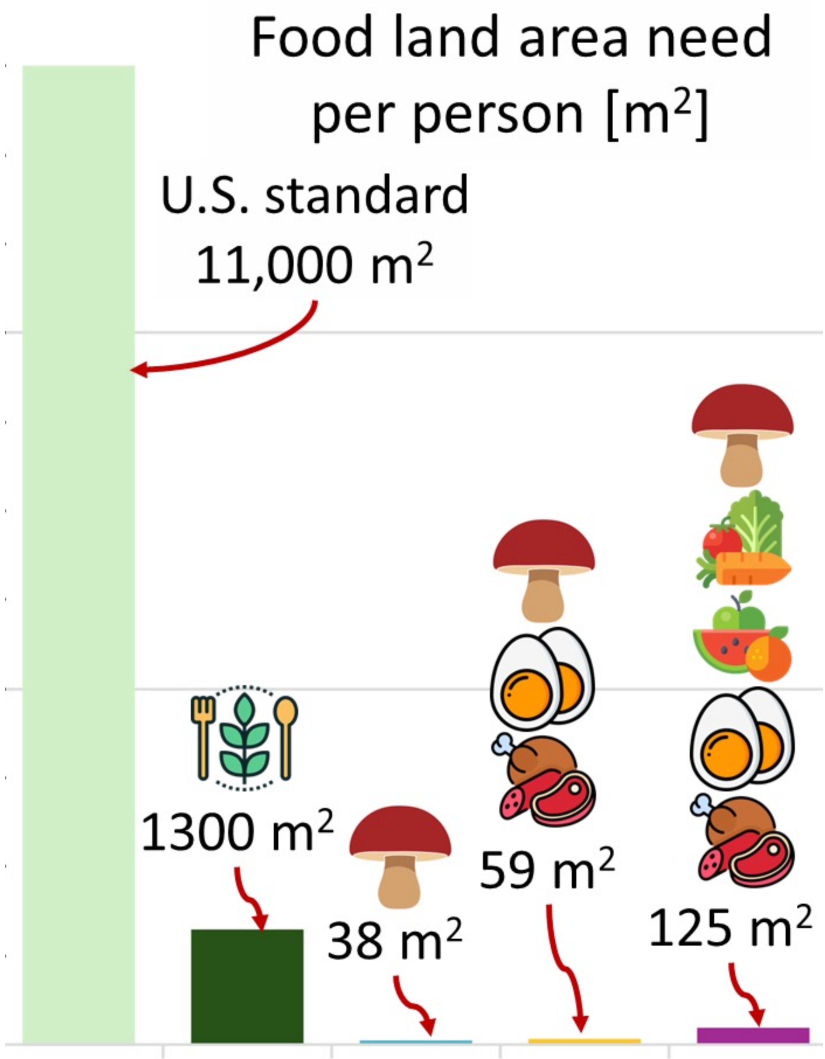
1. Can fungi grow on sugar alcohols? Derived from biomass, “similar” to sugars
2. If so, can they grow on “similar” molecules that are abiotically produced

All our sugar alcohol experiments, from C3 to C6, were successful!

Oxygen Activity and “Similarity” With Sugar Alcohols

Earth Land Use: What Might be Possible?





Bringing the Biosphere Back to a Safe Operating Space

Beyond Food?

Abiotic Substrates Bring

- Electrified biomanufacturing
- Non-agricultural supply chains
- High purity, abundant, consistent substrates

Potential Applications of Mycelium as a Versatile Biological Platform

- Materials (packaging, insulation panels, structural boards, acoustic panels, fire-resistant materials…)
- Textiles (mycelium leather, dense mycelial mats, controllable hyphal morphology, elasticity and strength…)
- Biomanufacturing (enzymes, chemicals, pigments, biopolymers…)
- Construction (bricks, panels)
- Biomedical (wound dressings, tissue scaffolds, drug delivery matrices, antimicrobial materials…)

Circumventing Photosynthesis in Many Applications?