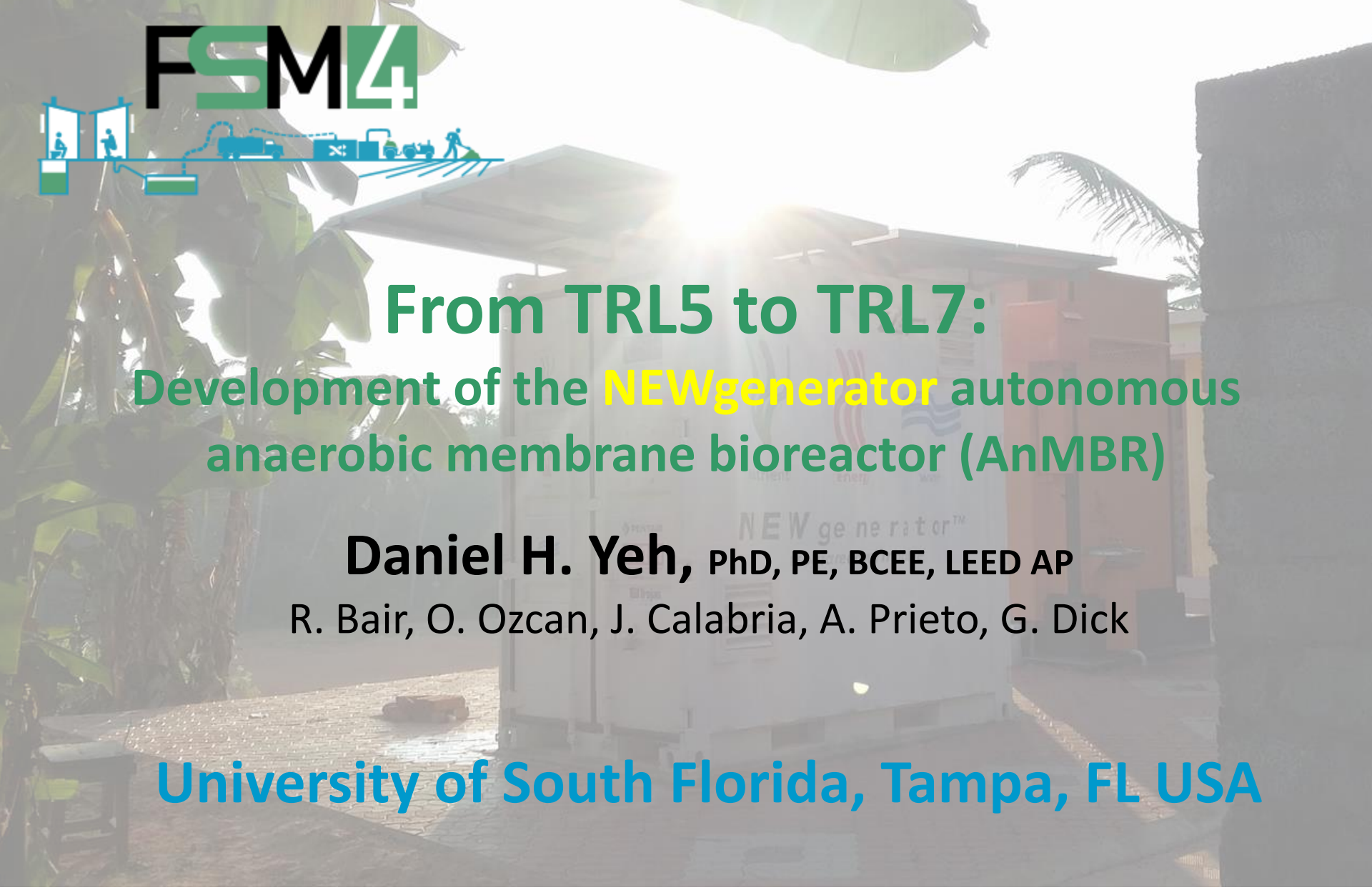


From TRL5 to TRL7:

Development of the NEWgenerator autonomous anaerobic membrane bioreactor (AnMBR)

Daniel H. Yeh, PhD, PE, BCEE, LEED AP

R. Bair, O. Ozcan, J. Calabria, A. Prieto, G. Dick

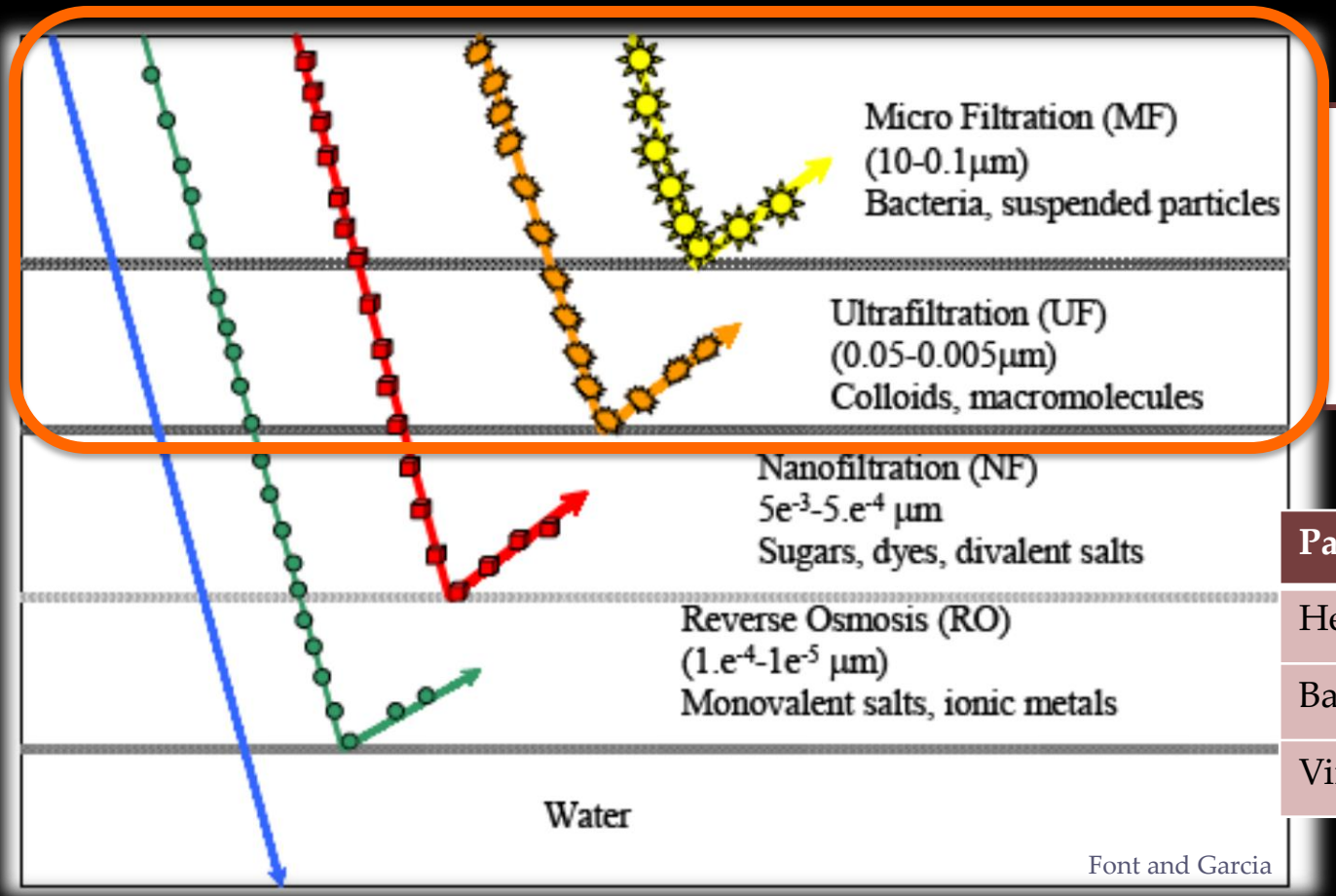
University of South Florida, Tampa, FL USA

Limitations of gravity settling (sedimentation):

- Footprint
- Colloids
- Hydraulic loading

Membrane Filtration Spectrum

nutrients energy water



Membranes provide an absolute physical barrier for pathogen removal for safe dewatering

Pathogen	Log removal
Helminths	8 (99.999999%)
Bacteria	6 (99.9999%)
Viruses	4 (99.99%)

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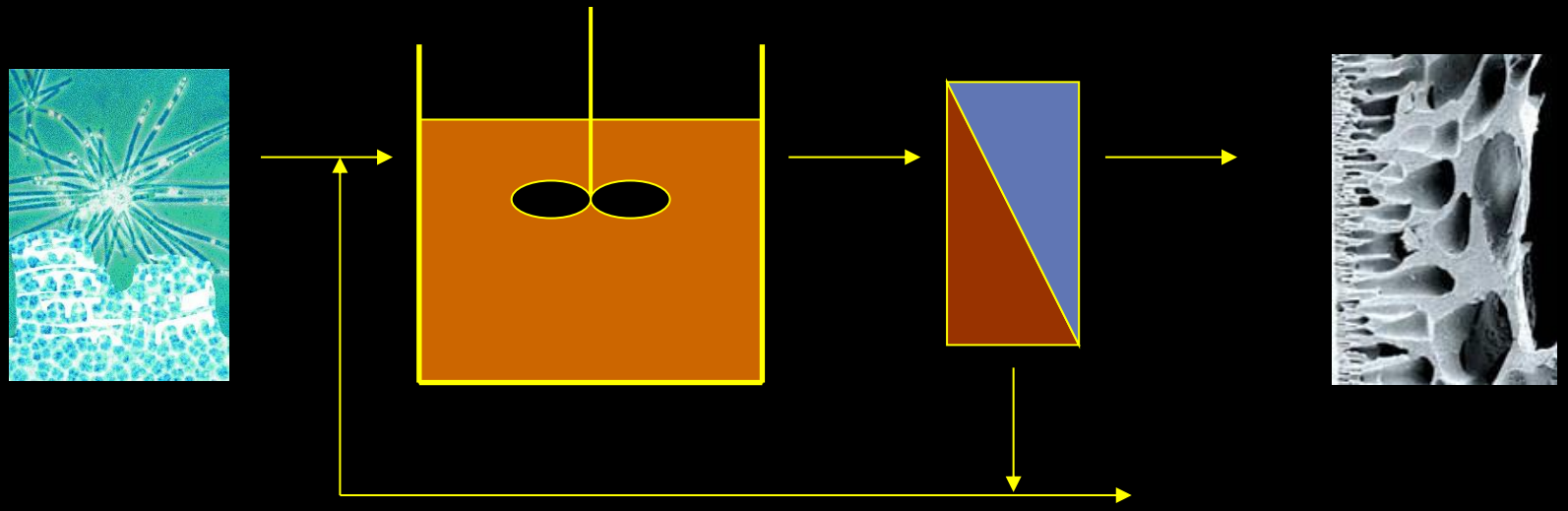
Membrane bioreactor (MBR)



- State of the art WWT technology
- Hybrid integration of membrane and biological processes,
- Decoupling of HRT and SRT → high hydraulic throughput
- Resilient, transient loading, safety barrier, high rate, greater performance, compact design
- Process intensification!

SAFE WATER FOR EVERYONE

Experts suggest that membrane bioreactors may be a key to global water sustainability

Francis A. DiGiano, Gianni Andreottola, Samer Adham, Chris Buckley, Peter Cornel, Glen T. Daigger, A G (Tony) Fane, Noah Galil, Joseph G. Jacangelo, Alfieri Pollice, Bruce E. Rittmann, Alberto Rozzi, Tom Stephenson, and Zaini Ujang

Figure 2. Wastewater Reuse in Decentralized MBR Systems

Bellagio Framework 2004

Gathering of world's top WW experts

Sustainability Criteria for MBR Technology

(Balkema *et al.*, 2002 and indicates the Team's ratings for MBRs)

Criteria	Indicators	Improvement needed	Good now
Economic	Cost and affordability	X	
Environmental	Effluent water quality		
	Microbes		X
	Suspended solids		X
	Biodegradable organics		X
	Nutrient removal		X
	Chemicals usage	X	
	Energy	X	
	Land usage		X
Technical	Reliability		X
	Ease of use	X	
	Flexible and adaptable		X
	Small-scale systems		X
Socio-Cultural	Institutional requirements	X	
	Acceptance	X	
	Expertise	X	
OVERALL SUSTAINABILTY GOOD			

The red boxes indicate state-of-technology barriers to overcome, and provided a roadmap for MBR R&D in our lab for the past 12+ yrs

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Go Anaerobic !

Anaerobic Digestion

Anaerobic Microbes

Energy
(Biogas)

Nutrients
(N, P, K)

Organic Waste

Water

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Challenges with conventional AD for WWT

- Pathogen removal, disinfection
- Effluent management – particulates, colloids, high MW DOC, ammonium, phosphate
- Transient operations (spikes, intermittent use)
- Relatively slower kinetics necessitating longer residence time (or larger reactor) to enable degradation and avoid biomass washout.
- Difficulty treating dilute wastewater (low COD)
- Fats, oil & grease (difficult for UASBs)

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AnMBR addresses conventional AD limitations:

Membrane Filtration

Safely removes bacteria and viruses

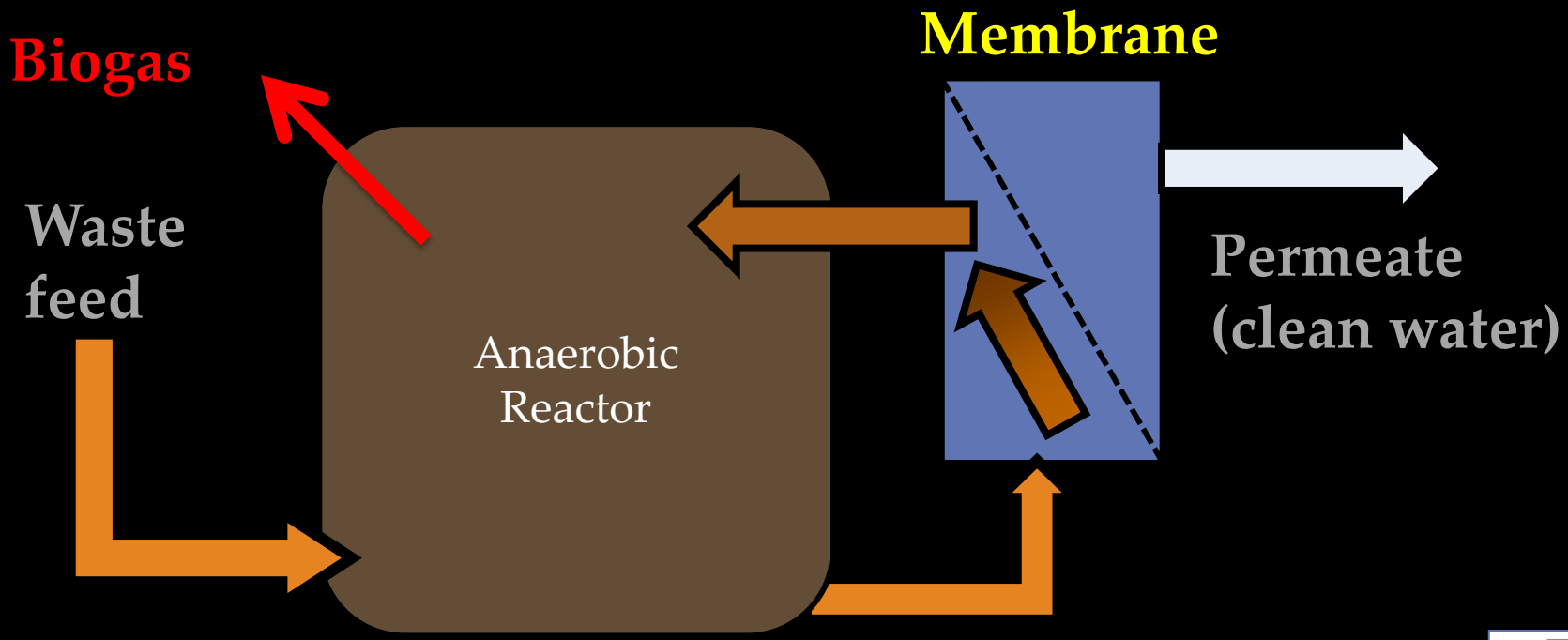
- regardless of temperature
- regardless of loading
- Enhances safety and reliability

Ultrafiltration (0.03 micron)

Anaerobic Membrane Bioreactor (AnMBR)

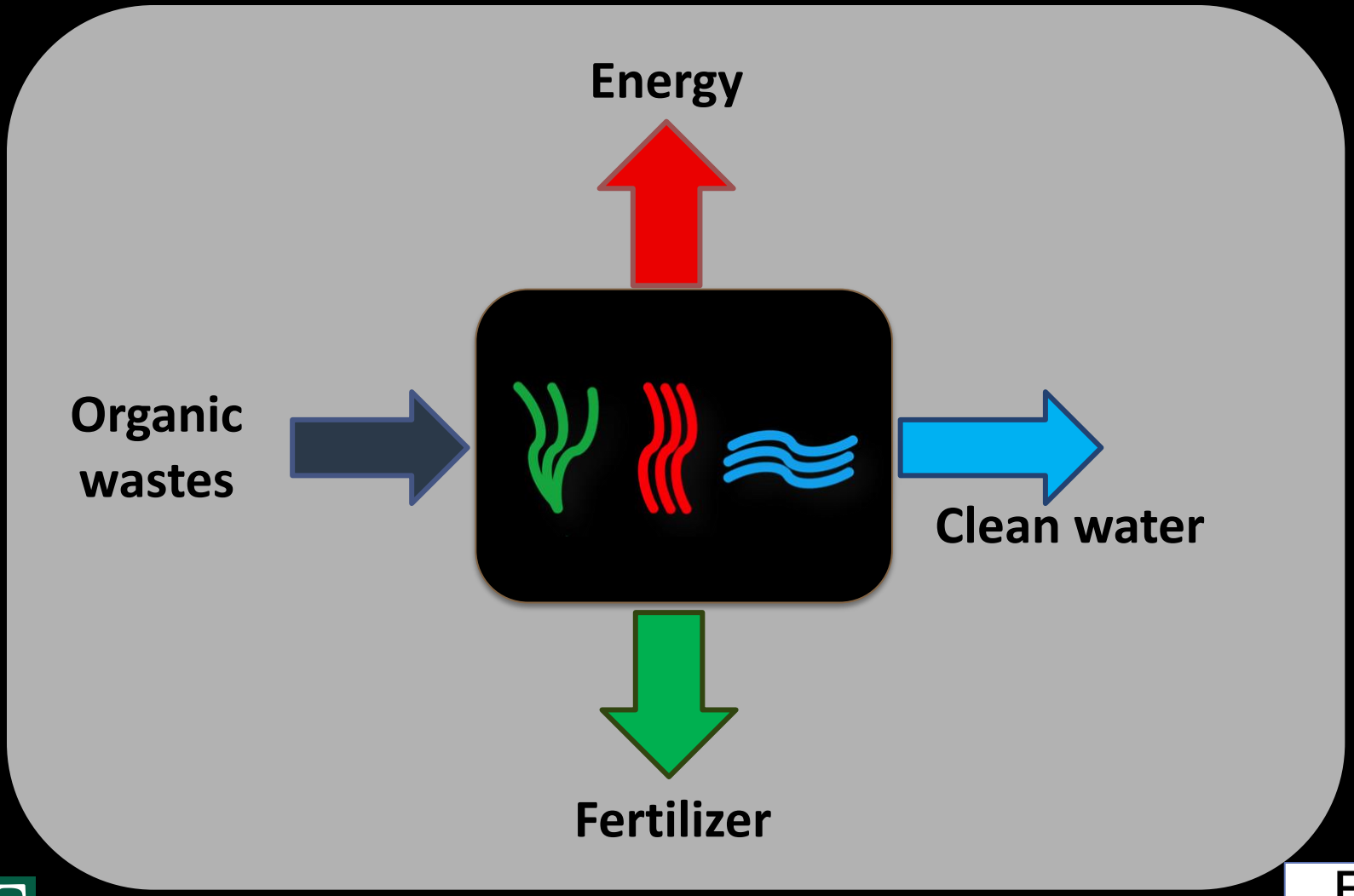
Advantages over aerobic MBR:

- Lower biomass (sludge) production than aerobic (8-10X less)
- No aeration requirement
- Carbon redirection - reroutes COD to biogas (or other products) for energy recovery
- Process can potentially be energy neural or positive.



Anaerobic Membrane Bioreactor Platform

NEWGENERATOR™



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Fills the critical gap between

Low-tech onsite sanitation

Centralized wastewater treatment

NEWGENERATOR™

Treatment

+

Recovery

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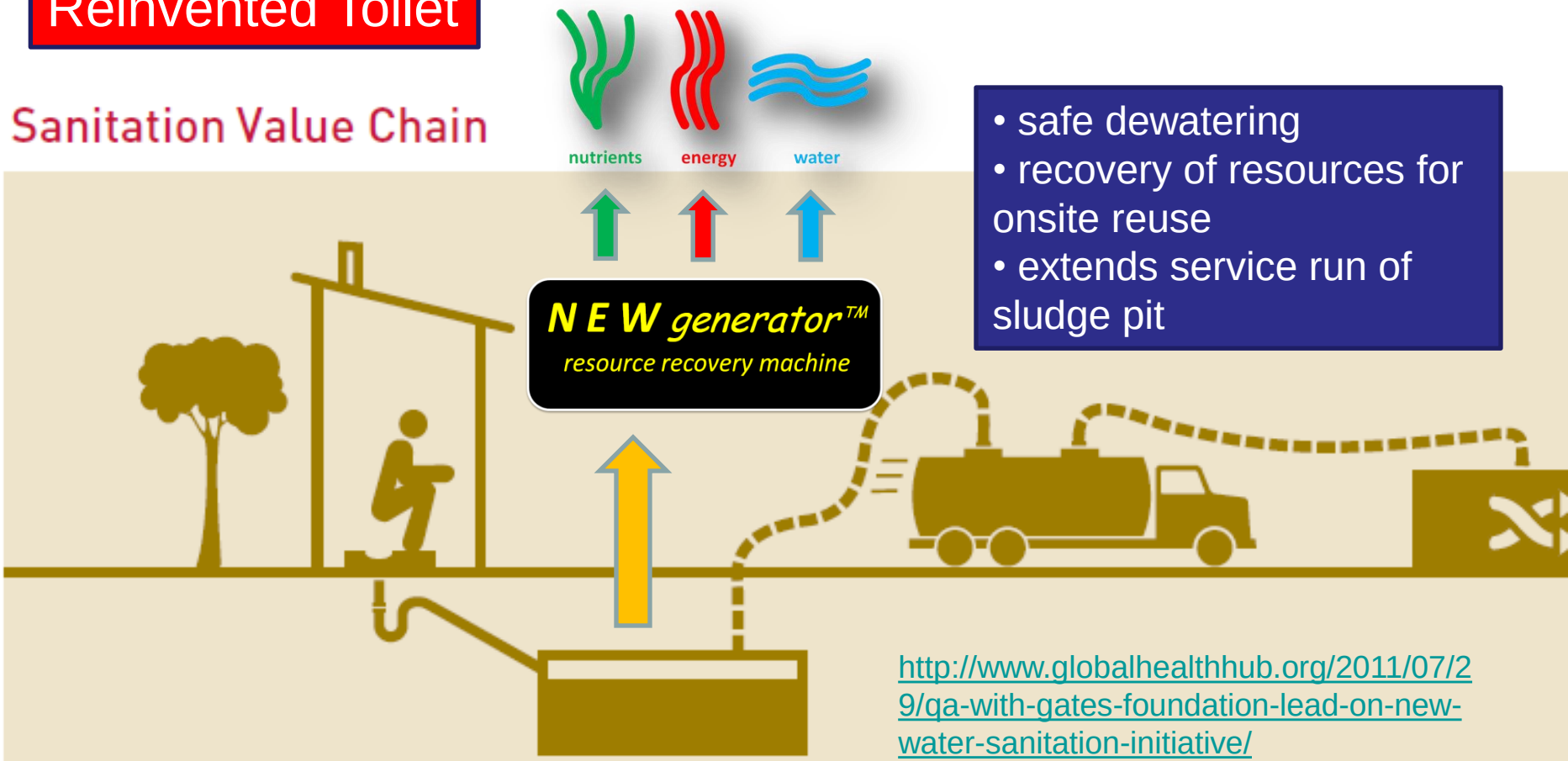
Small-scale *NEWgenerator*™
for **onsite** resource recovery and reuse

Reinvented Toilet



- safe dewatering
- recovery of resources for onsite reuse
- extends service run of sludge pit

http://www.globalhealthhub.org/2011/07/29/qa-with-gates-foundation-lead-on-new-water-sanitation-initiative/

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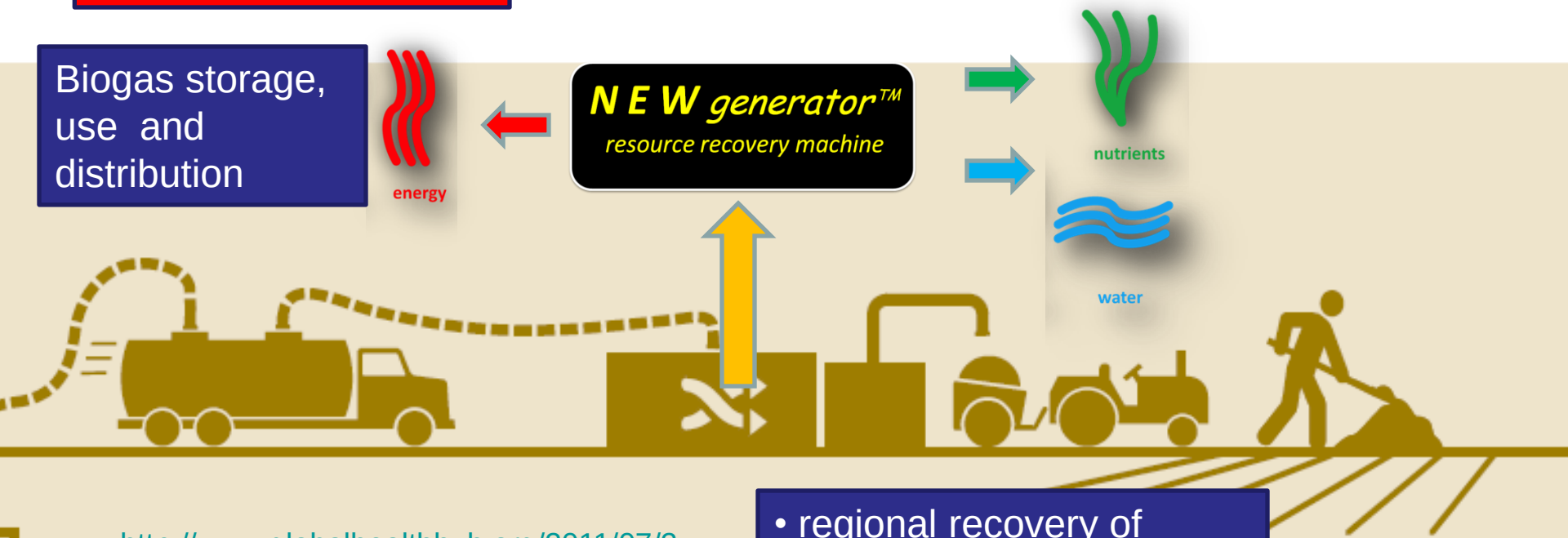
Larger-scale *NEWgenerator*™
for **regional** resource recovery and reuse

Omni Processor



http://www.globalhealthhub.org/2011/07/29/qa-with-gates-foundation-lead-on-new-water-sanitation-initiative/

- regional recovery of resources for reuse
- steady operation
- economy of scale

RAGE › TRANSPORT › TREATMENT › REUSE

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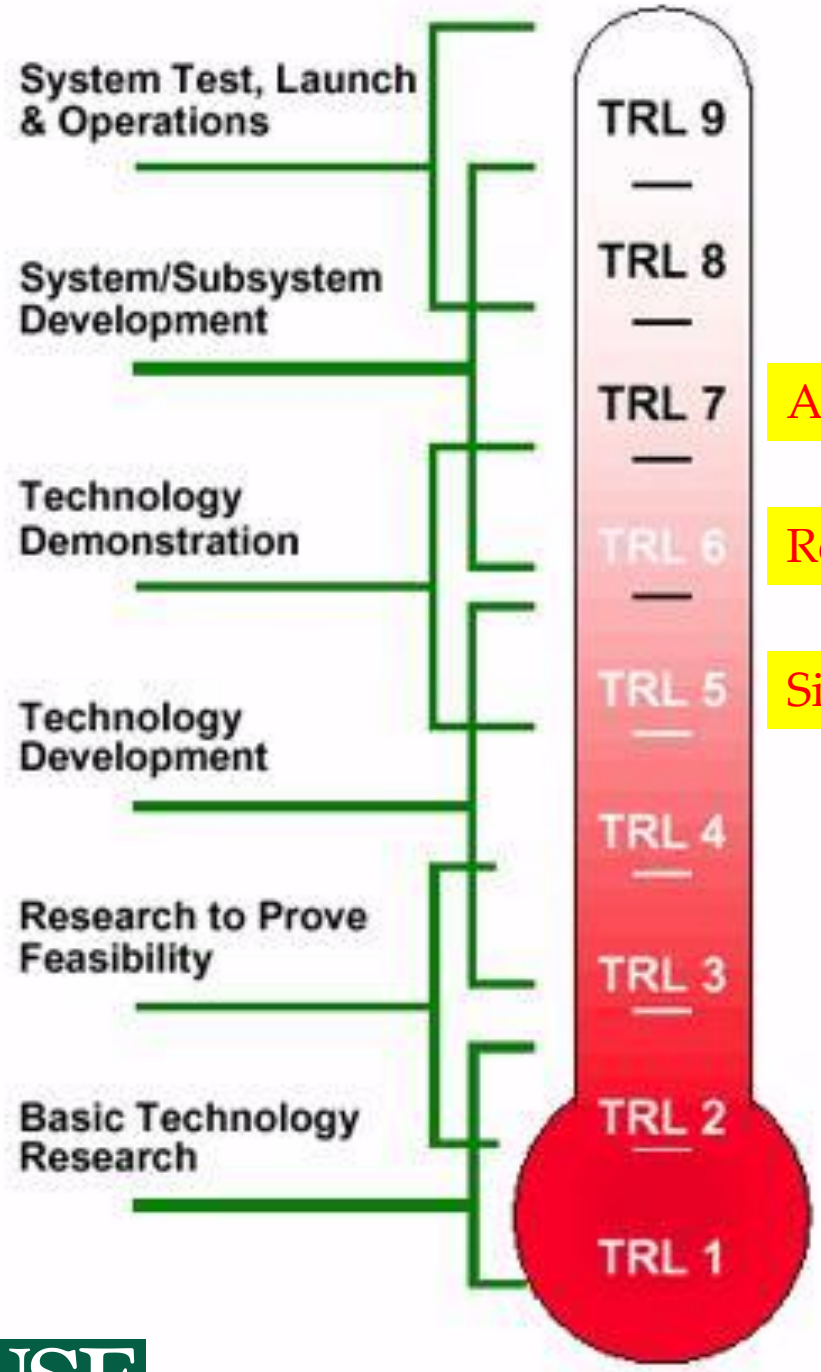


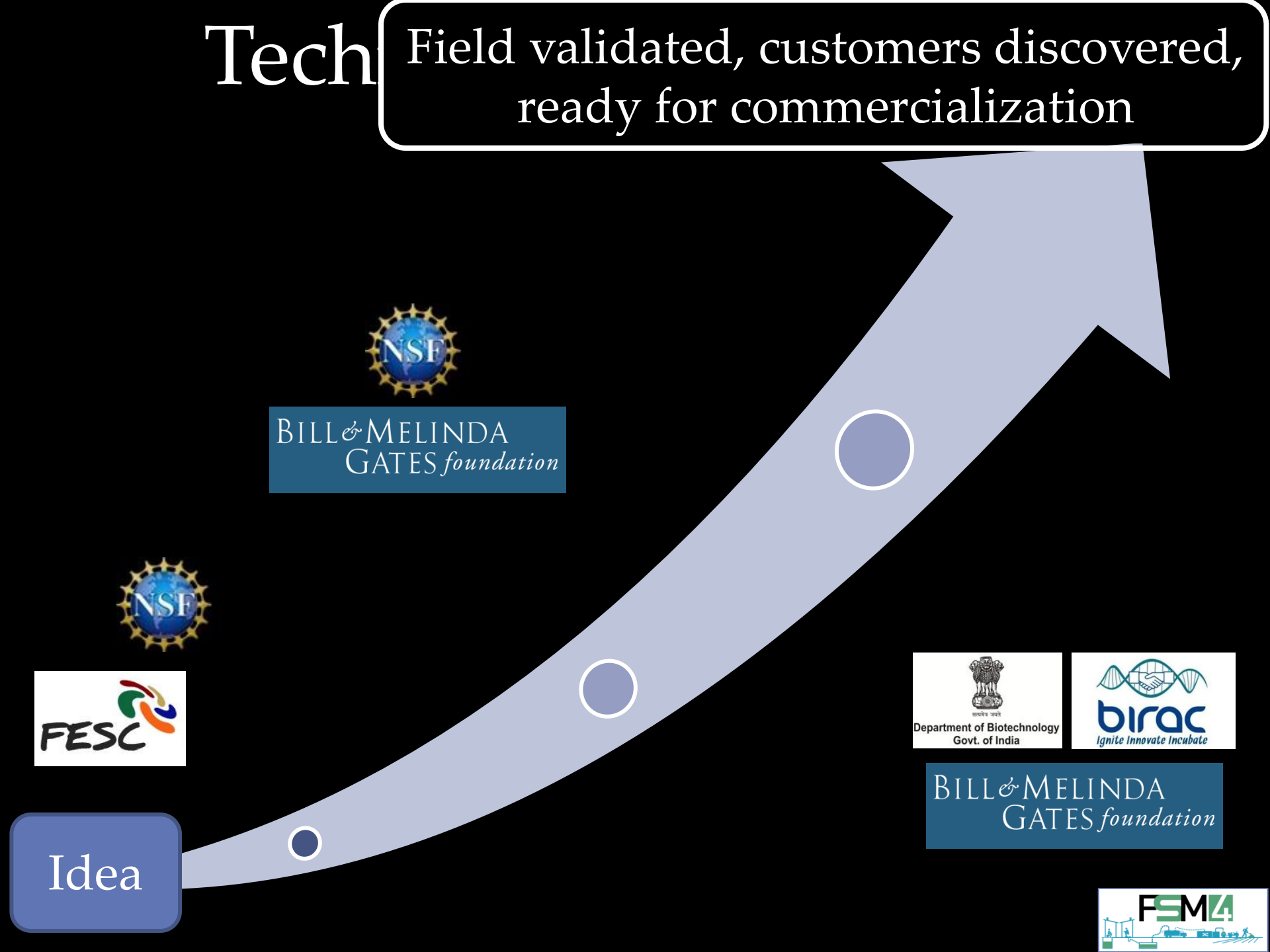
NASA's TRL

Technology Readiness Levels

Describes steps to mission readiness and commercialization

Tech

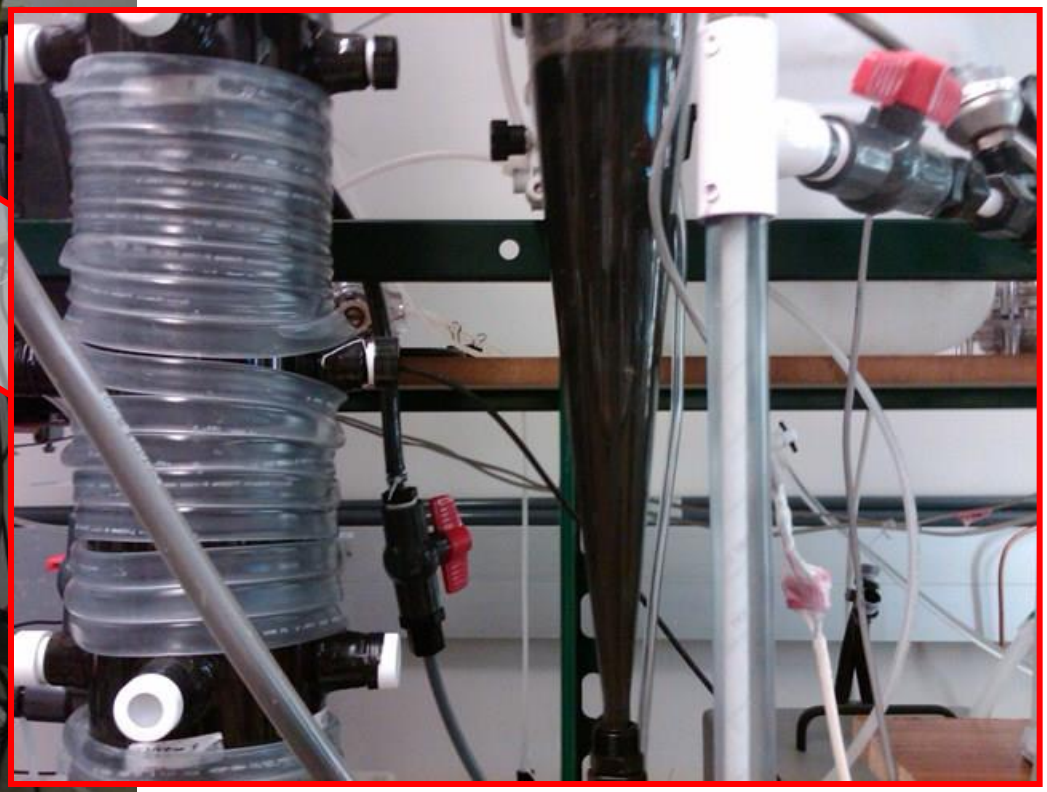
Field validated, customers discovered, ready for commercialization



TRL5

The gas-lift anaerobic MBR

at Univ. South Florida



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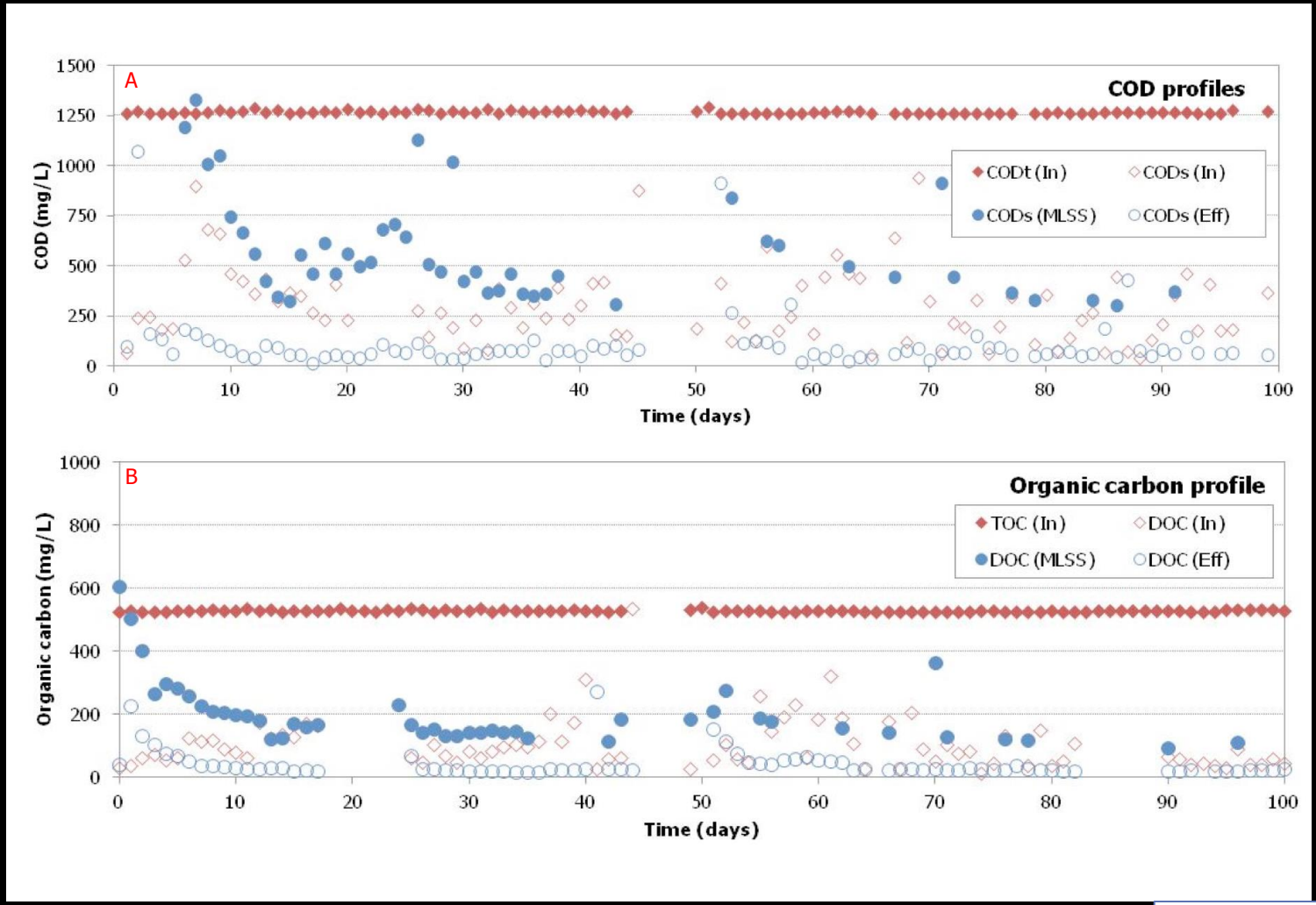
Prieto et al., 2013, JMS

TRL5

Carbon conversion

98% COD conversion

95% TOC conversion



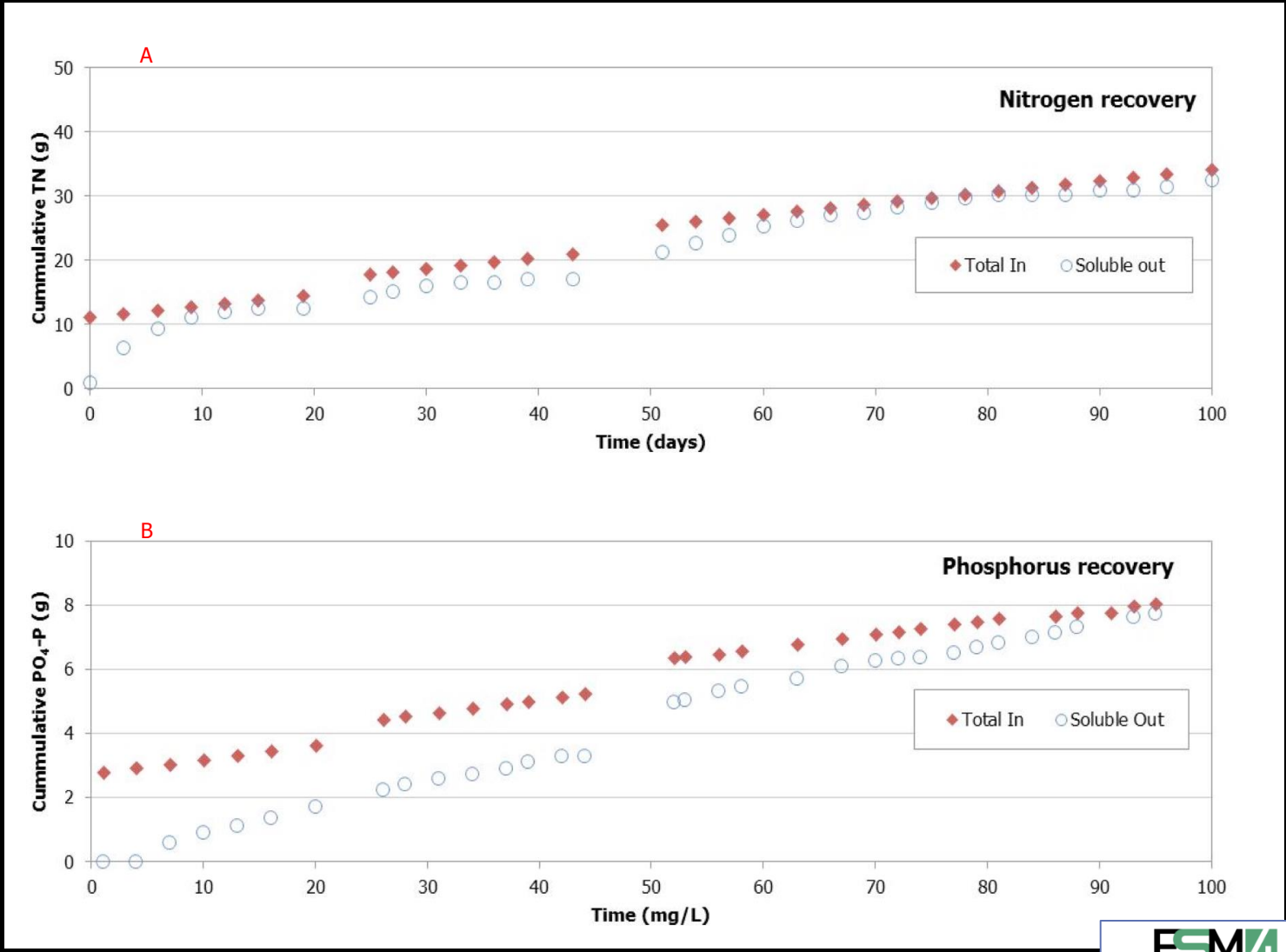
Prieto et al, 2013

TRL5

N, P recovery for reuse (fertigation)

95% N recovered (cumulative)

93% P recovered (cumulative)

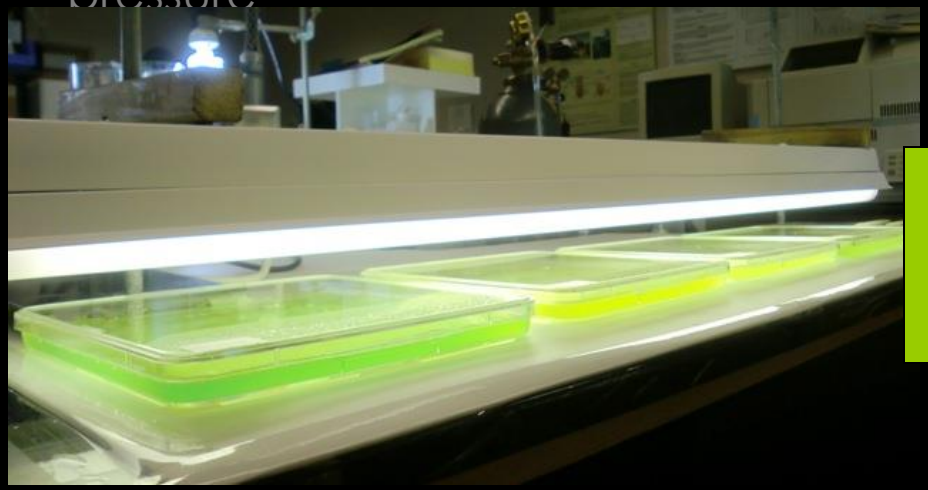


Prieto et al, 2013

TRL5

Algal MBR

- Membrane gas-lift allows efficient mixing, while scrubbing the membrane
- Successful growth on high strength effluents
- HRT 24 hours, operational flux of 4.5 LMH, air-lift flow rate (Q_a) of 0.1 L/min and 0.1 Bars of membrane inlet pressure



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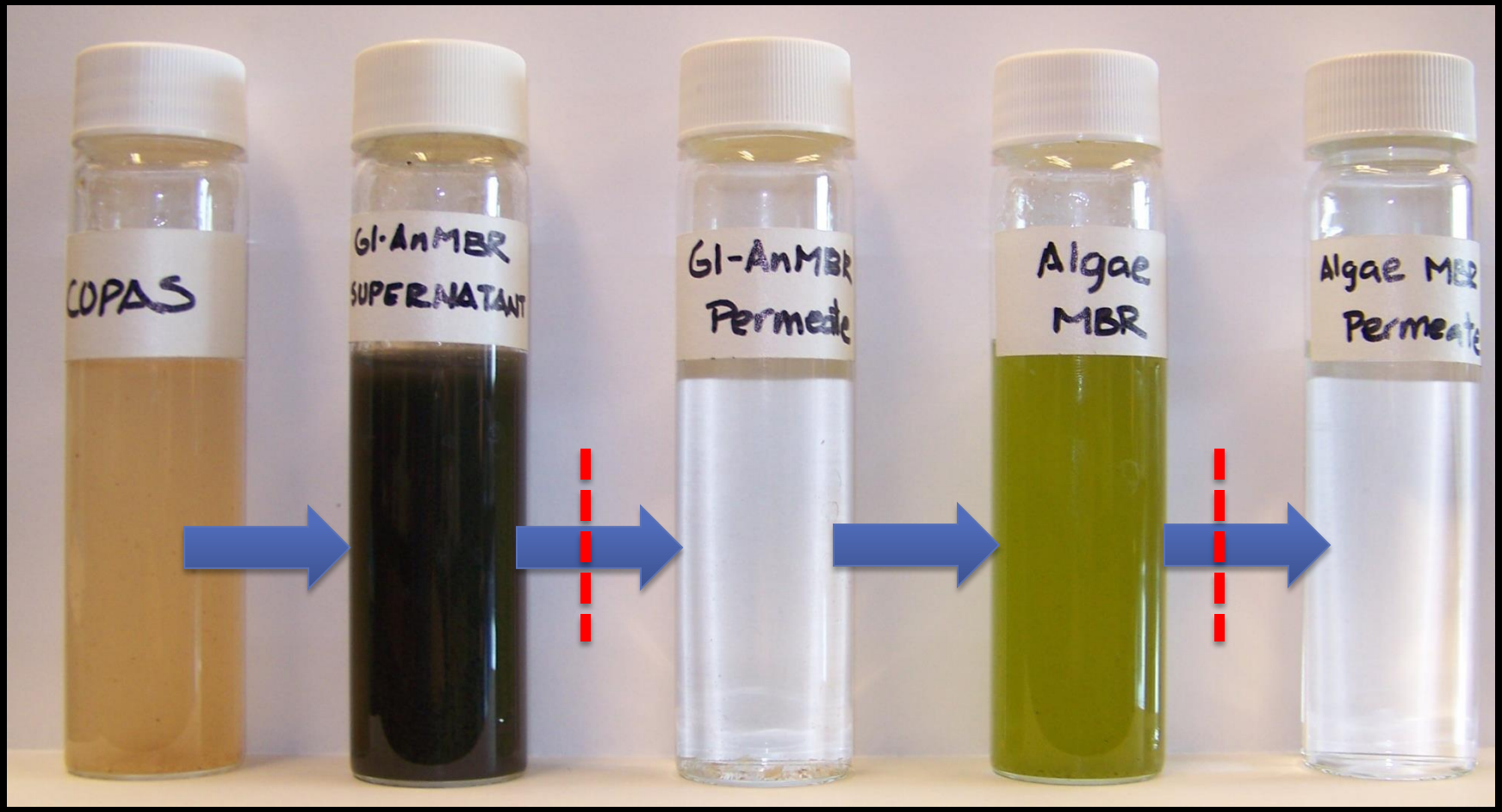
TRL5

Sequential Anaerobic/Algal MBR (A2MBR)

Turbidity
447±8.4 NTU

Turbidity
6.9±2.3 NTU



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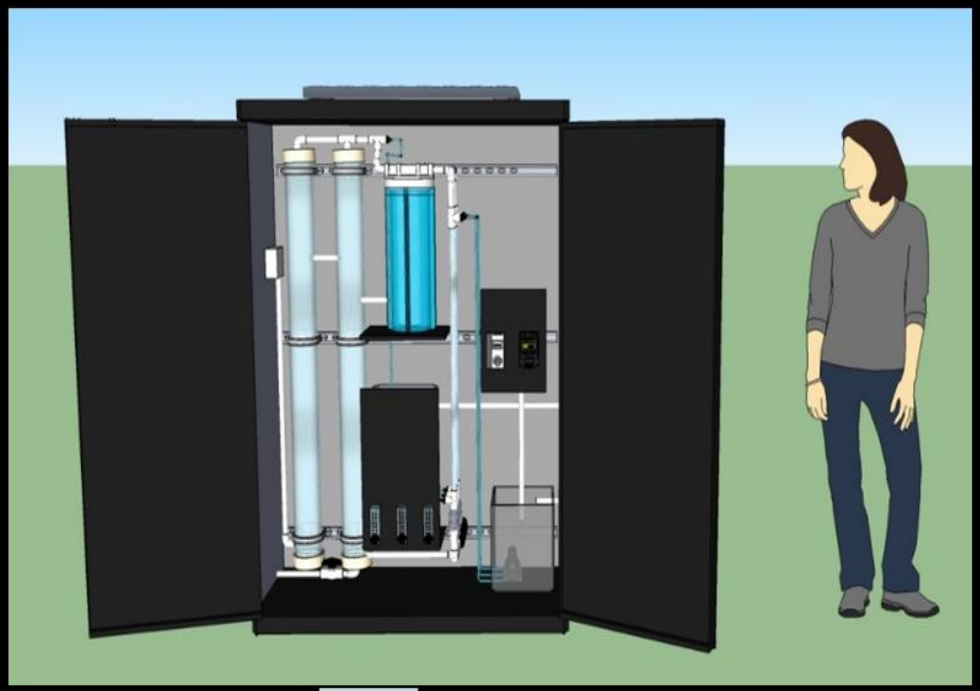
TRL6

Pilot-scale system (TRL6)



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FSM4

TRL6

THE BIORECYCLING/BIOENERGY RESEARCH AND TRAINING STATION (**BBRATS**)

BioFertilizer Farm (horticultural reuse of water and fertilizer via aquaponics)

NEWgenerator (inside shed, power from PV panels on roof, input is from septic tank)

Algae photobioreactors (recovered water/nutrients from NEWgen used for biofuel production)

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TRL6

Beneficial uses for agriculture (profit)

Microalgae (animal feed, biofuel)

Hydroponics for crops

Aquaponics

Urban greenscape

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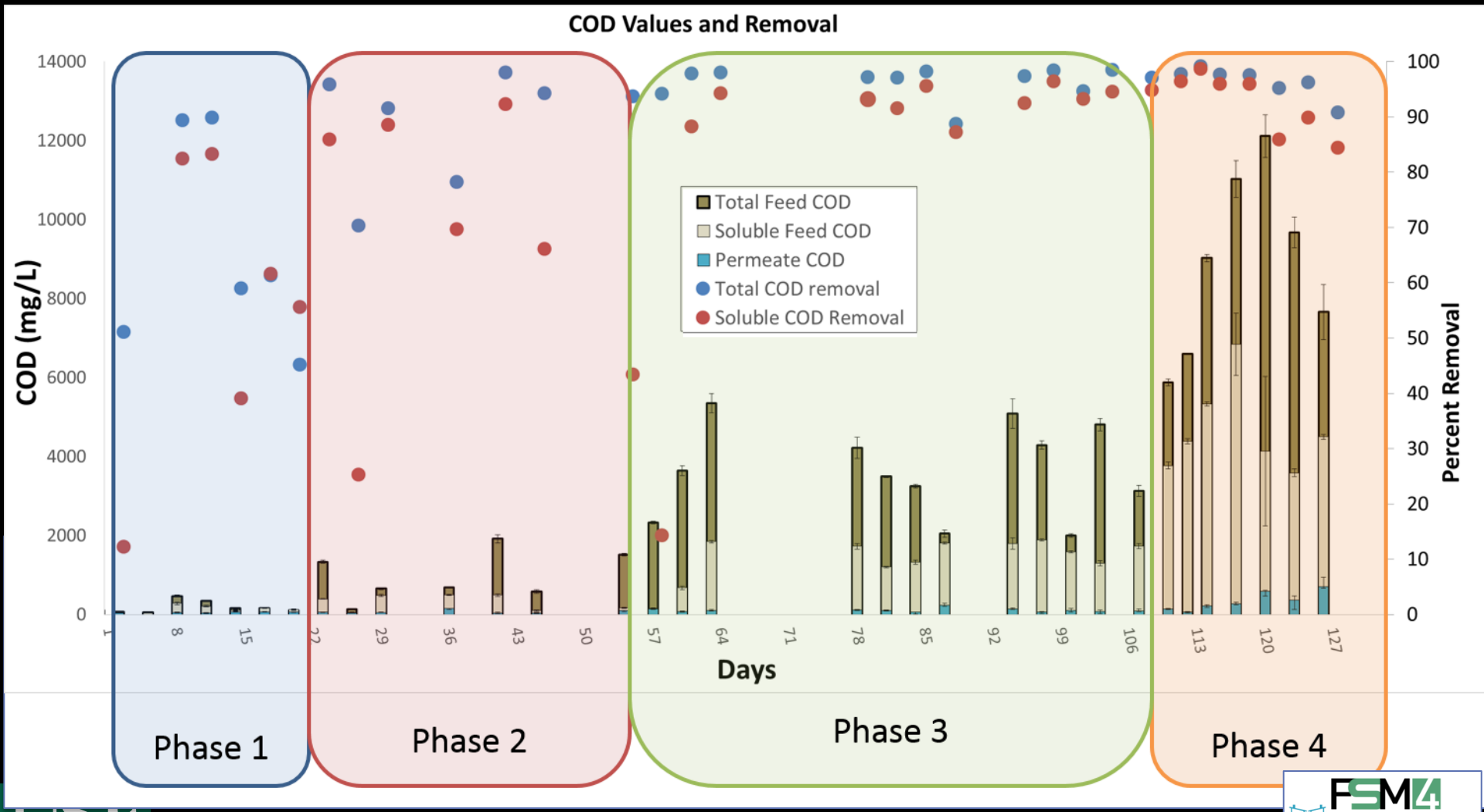
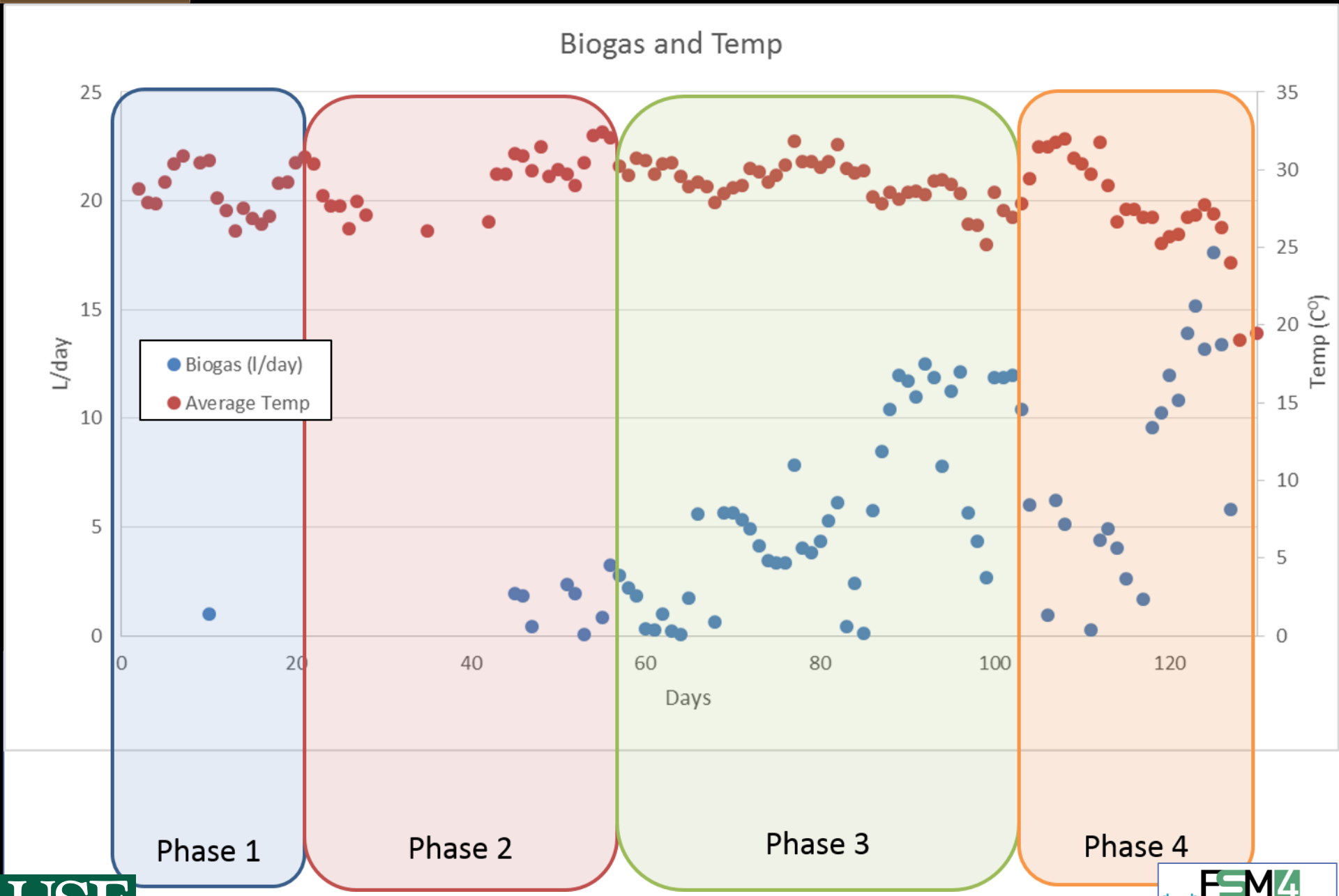
TRL6 System testing for baseline treatment efficiency at increasing feed concentrations (system in Florida on a septic tank)

Robust across a large range of influent conditions



TRL6



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TRL7

NEW GENERATOR™

Technology for the global sanitation challenge

- Decentralized, onsite
- Safely sanitizes wastes
- Modular, P&P, Off-Grid (renewable energy)
- Compact design
- Autonomous
- Water recycling
- Energy harvesting
- Fertilizer recovery

PCT patent-pending

Turning waste into profit

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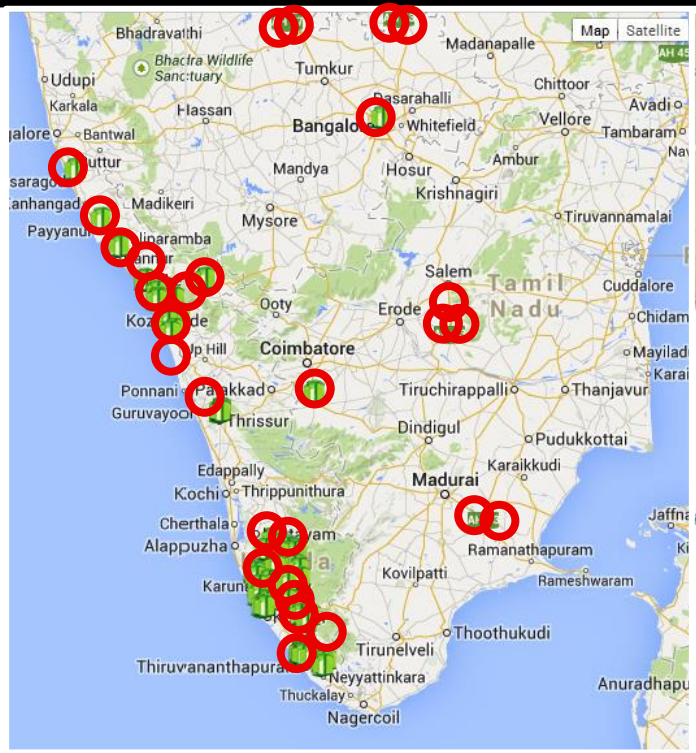
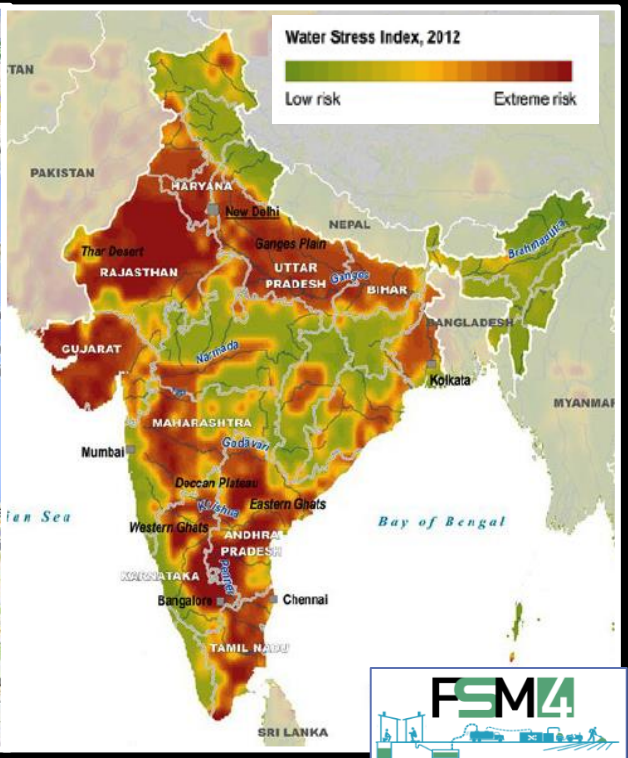
TRL7

Partnership in India

ERAM Scientific Solutions

- Over >2100 units of eToilet installed throughout India→ public sanitation coverage
- Expansion to additional regions in India not possible due to water and energy scarcity
- Coupling with NEWgenerator will enable expansion in India and elsewhere





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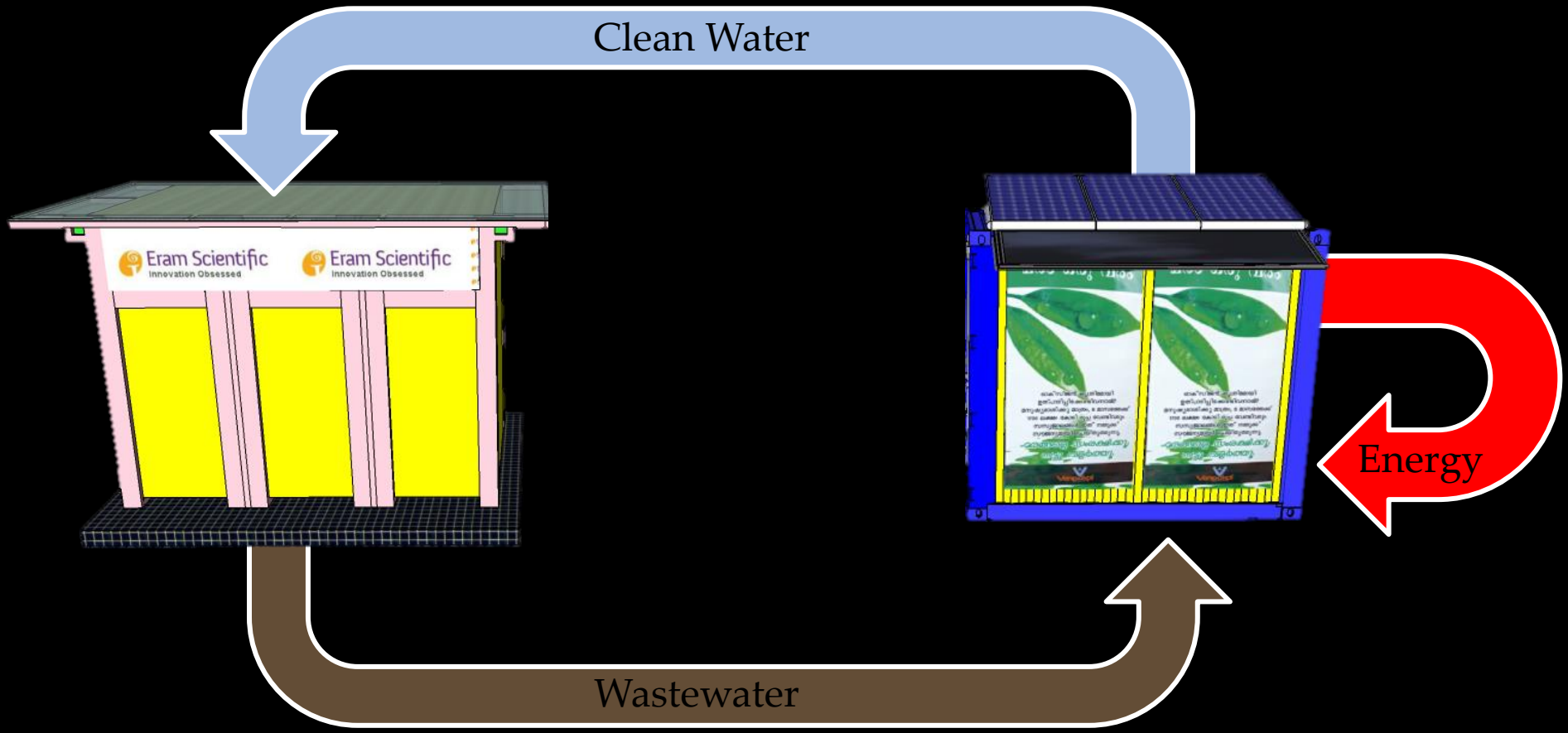
Integration of Toilet with NEWgenerator



FINAL INTEGRATED ETOILET AND NEWGEN AT SITE


NEWgenerator


USF
NEWgenerator


USF
birac
nutrients
energy
water

USF

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USF
UNIVERSITY OF SOUTH FLORIDA
COLLEGE OF ENGINEERING
NEWgenerator
PENTAIR


Pentair X-Flow

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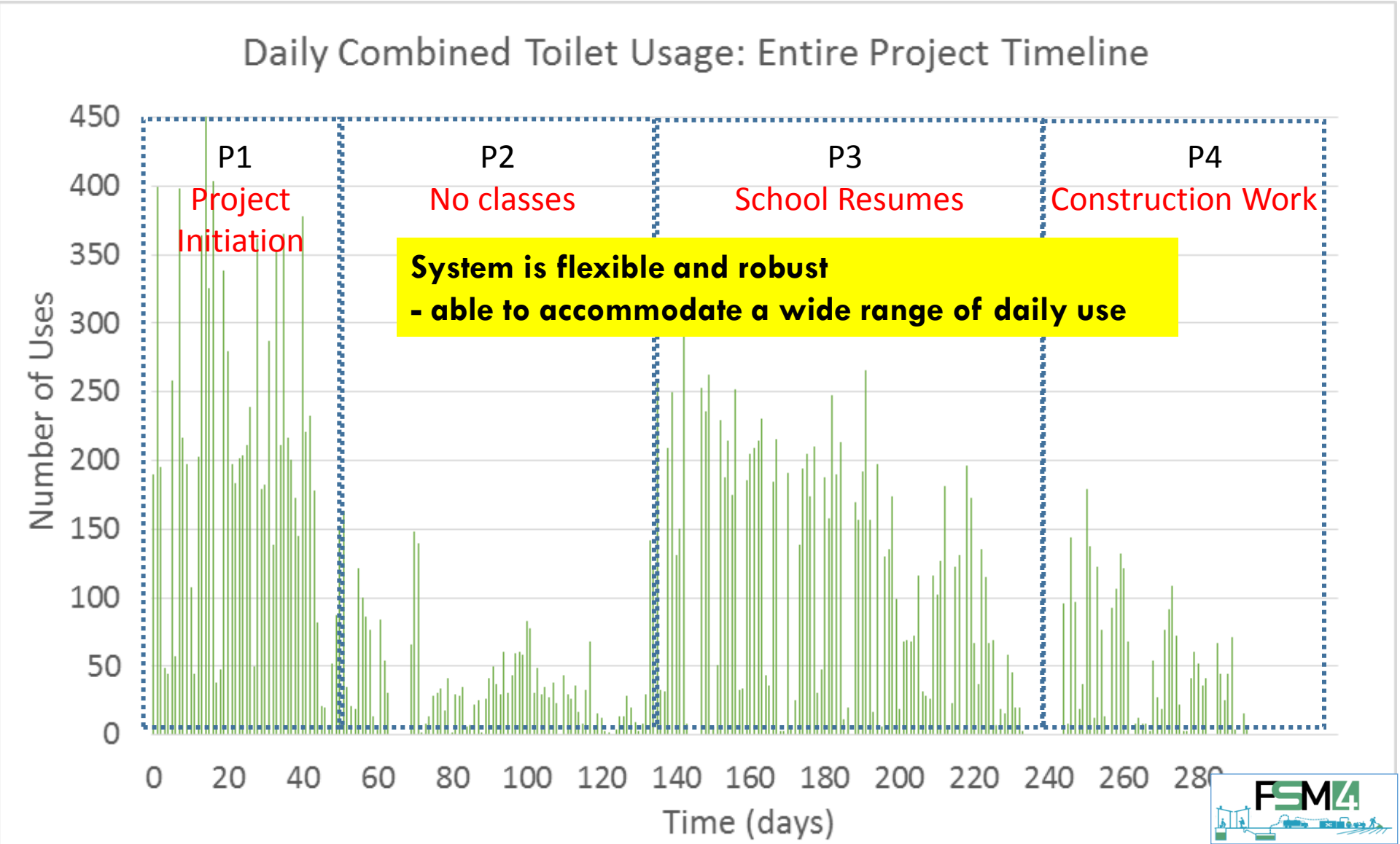
HIGH USAGE FROM SCHOOL AND COMMUNITY

TRL7

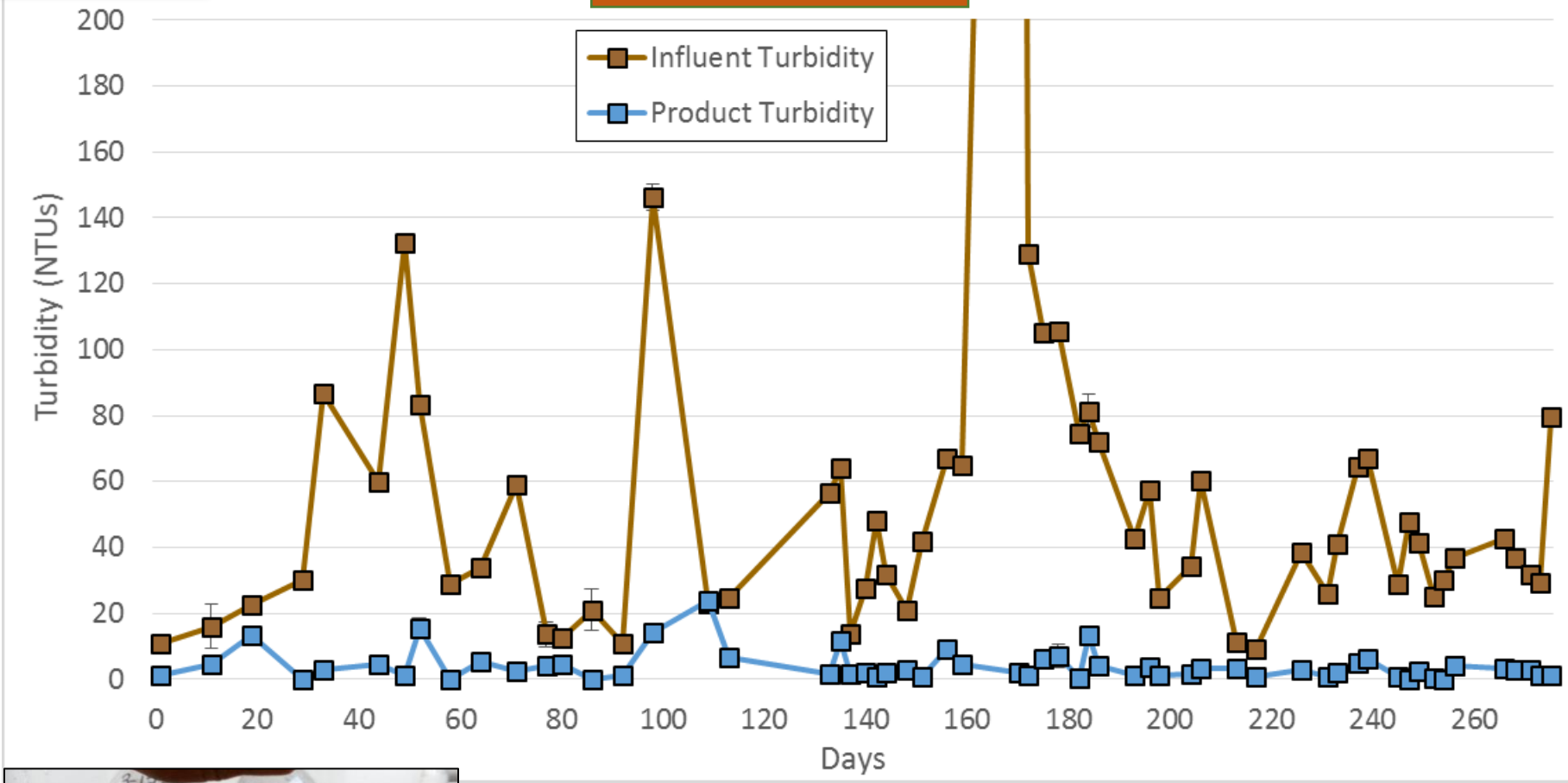
System Usage

#Uses	P1	P2	P3	P4
Avg.	220	47	120	40
Max	454	163	314	179



TRL7

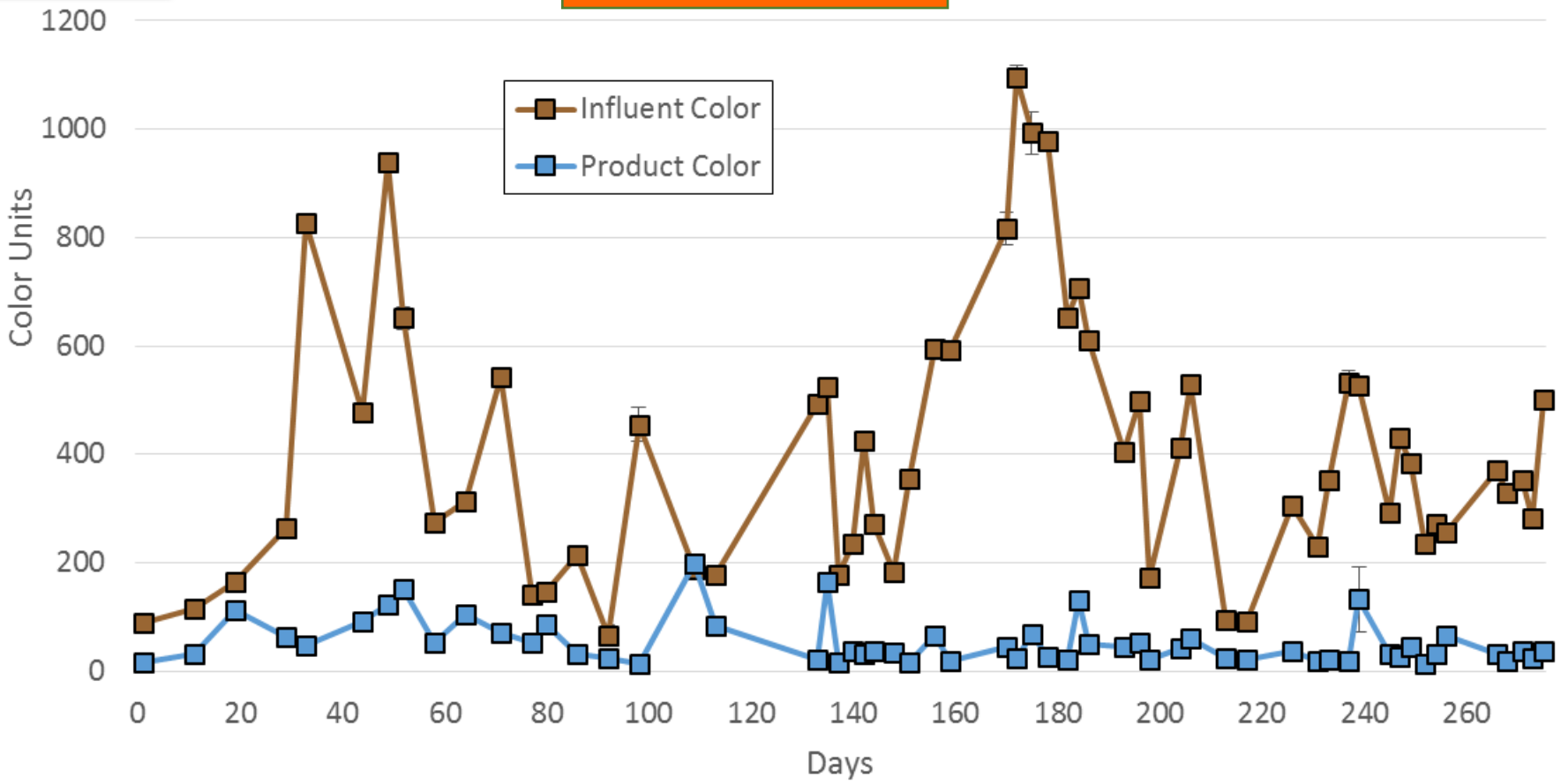
Turbidity



Parameter	Influent	Post Membrane	Product
Avg.	60	14	4
% Removal			**91**
Max	725	80	24

TRL7

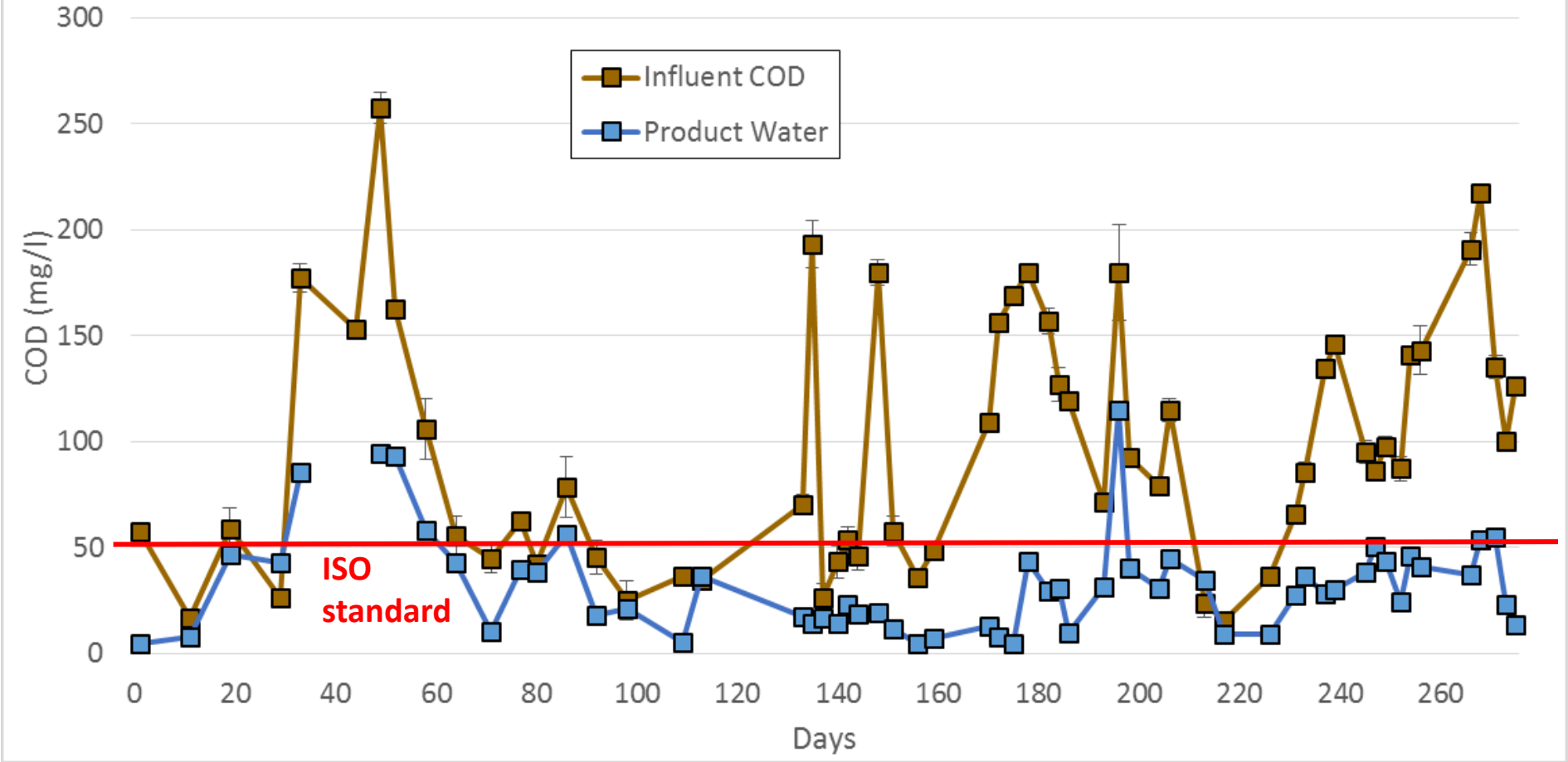
Color



Parameter	Influent	Post Membrane	Product
Avg.	407	132	52
% Removal			**85**
Max	1096	479	197

TRL7

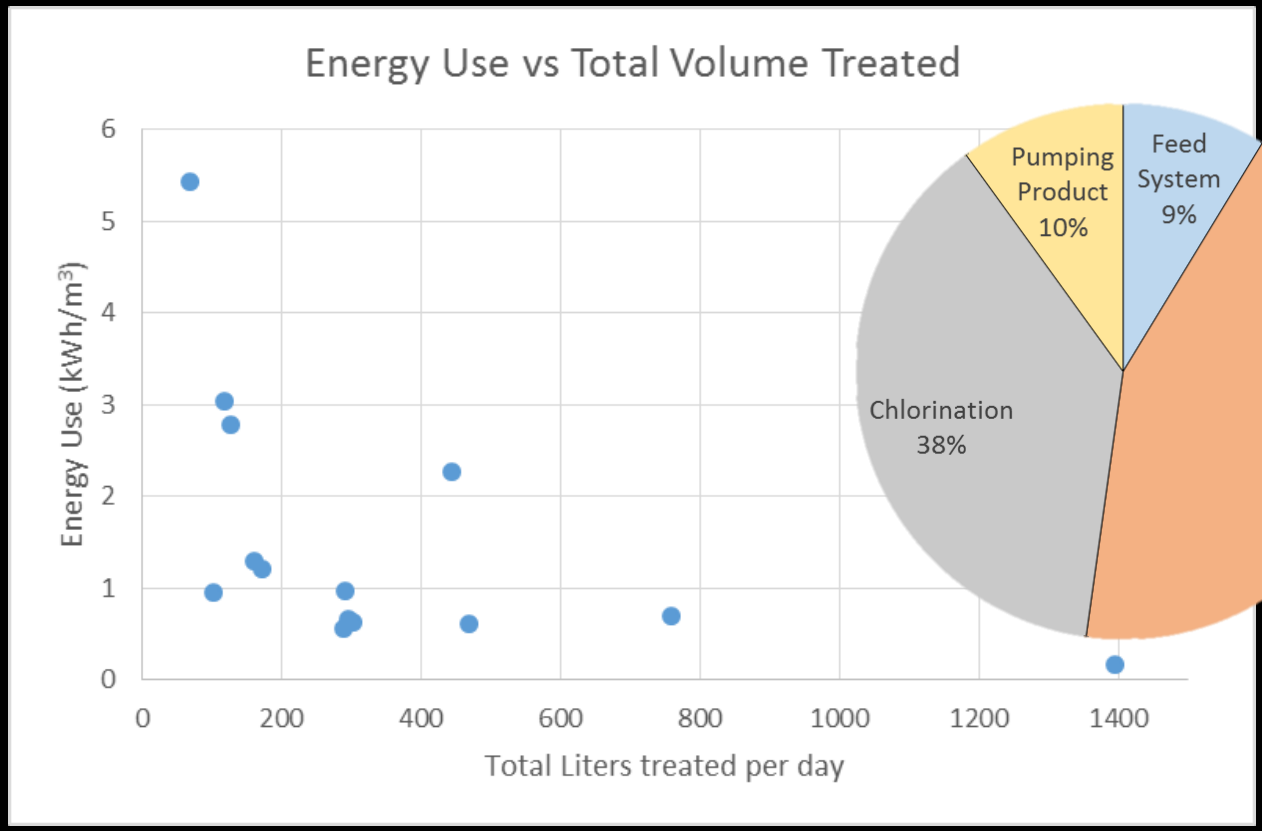
Chemical oxygen demand (COD)



*Average removal throughout trial period. When influent COD increases above 100 mg/L – the removal increases to 86%

Parameter	Influent	Post Membrane	Product
Avg.	98	38	32
% Removal			**72%***
Max	258	86	107

Energy consumption



- Low-energy fouling management strategies allow for **9 months** operational TMP of **0.14 bar** (design flux 5 LMH).
- When **>200 liters** were produced per day, the specific energy use was **0.83 kWh/m³** (and this is all clean and free solar energy)

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Remaining challenges

- Permeate polishing for ammonium + residual organics (improve energy and performance)
- Biogas utilization beyond burning
- Further miniaturization, physical footprint reduction
- Further process intensification, increase service density and hydraulic throughput (developing approach for 8-10X increase)

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Remaining challenges

- Further develop automation & user interface
- Continue FMEA and reliability/resilience assessment
- Testing over wide range of conditions (wastewater and fecal sludge characteristics, cultural and site characteristics)
    - Other countries and sites under discussion
- Certify NEWgenerator in accordance with ISO standard (non-sewered systems)

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FSM4

THANK YOU

NSF
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
cade museum creativity + invention
BILL & MELINDA GATES foundation
birac Ignite Innovate Incubate
USF
Eram Scientific

For more information

Prof. Daniel Yeh
dhyeh@usf.edu

Twitter @dhyeh
http://NEWgenerator.tumblr.com

TEDx talk
http://tinyurl.com/TEDxUSF-DanielYeh1

USF Membrane Biotechnology Lab
http://mbr.eng.usf.edu/

Graphics: A. Prieto