
Efficient Anaerobic Membrane Bioreactors through Low-Fouling Membranes

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Nano Terra

- Founded by Professor George Whitesides of Harvard University in 2006
- Staff of 30 world-class scientists and engineers
- Main labs in Cambridge, MA, including:
 - Synthesis labs
 - Analysis and characterization equipment
 - Rapid prototyping facilities
 - Small-scale cell biology and biochemistry facilities
- Additional biological labs in Salem, MA
- Develop new technologies and products for both government and commercial partners



Harvard University



SBIR Phase I Overview



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Nano Terra is developing a coating for PVDF ultrafiltration membranes to reduce biofouling in anaerobic membrane bioreactors (AnMBR) at least 90% during biobutanol production.

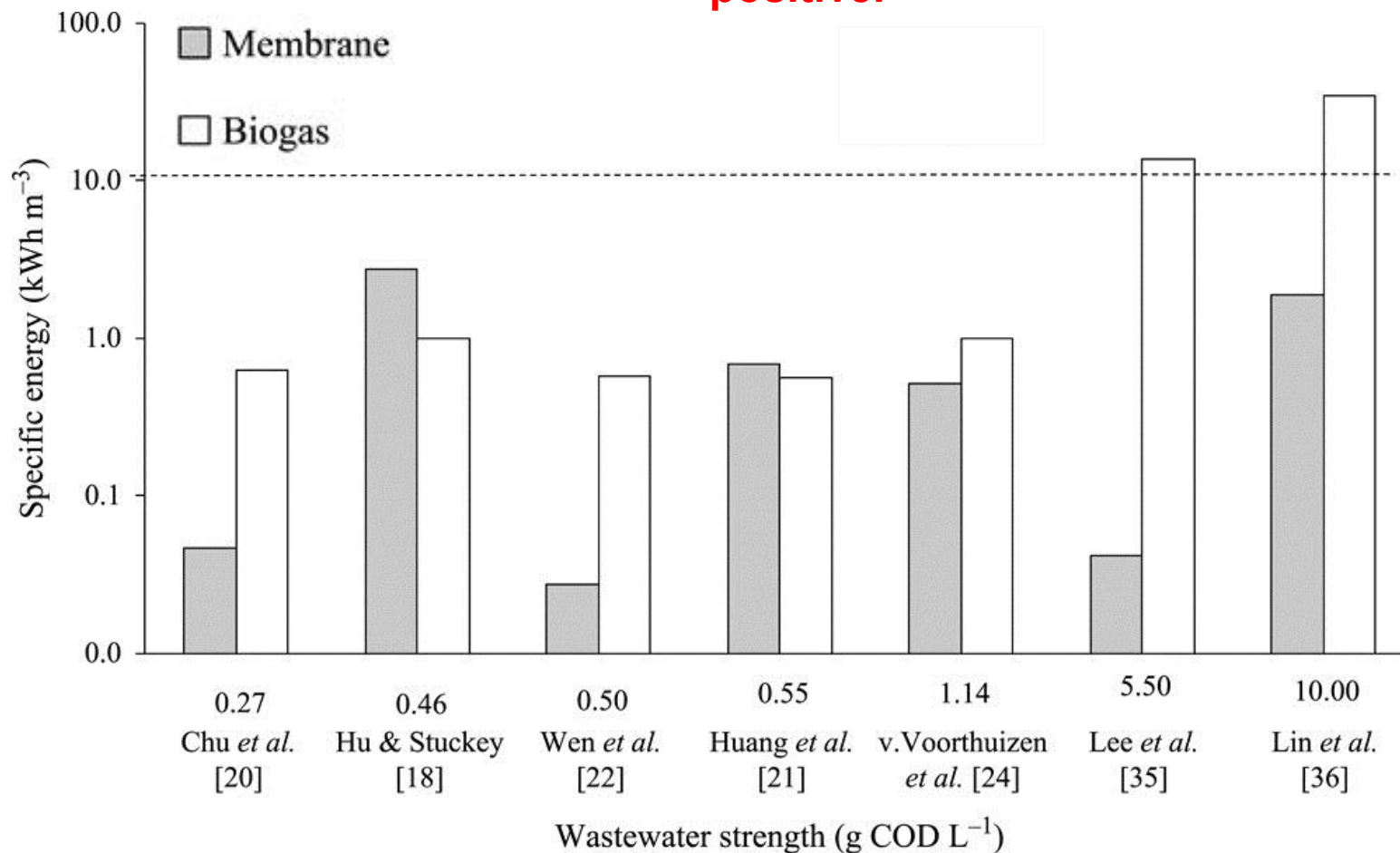
Nano Terra has partnered with Pentair X-Flow to achieve maximal relevance in the MBR market in this project.

Reduced biofouling will lead to

1. Decreased operational and capital costs for an AnMBR plant,
2. More positive energy balance.

Energy balance in AnMBR biofuel production

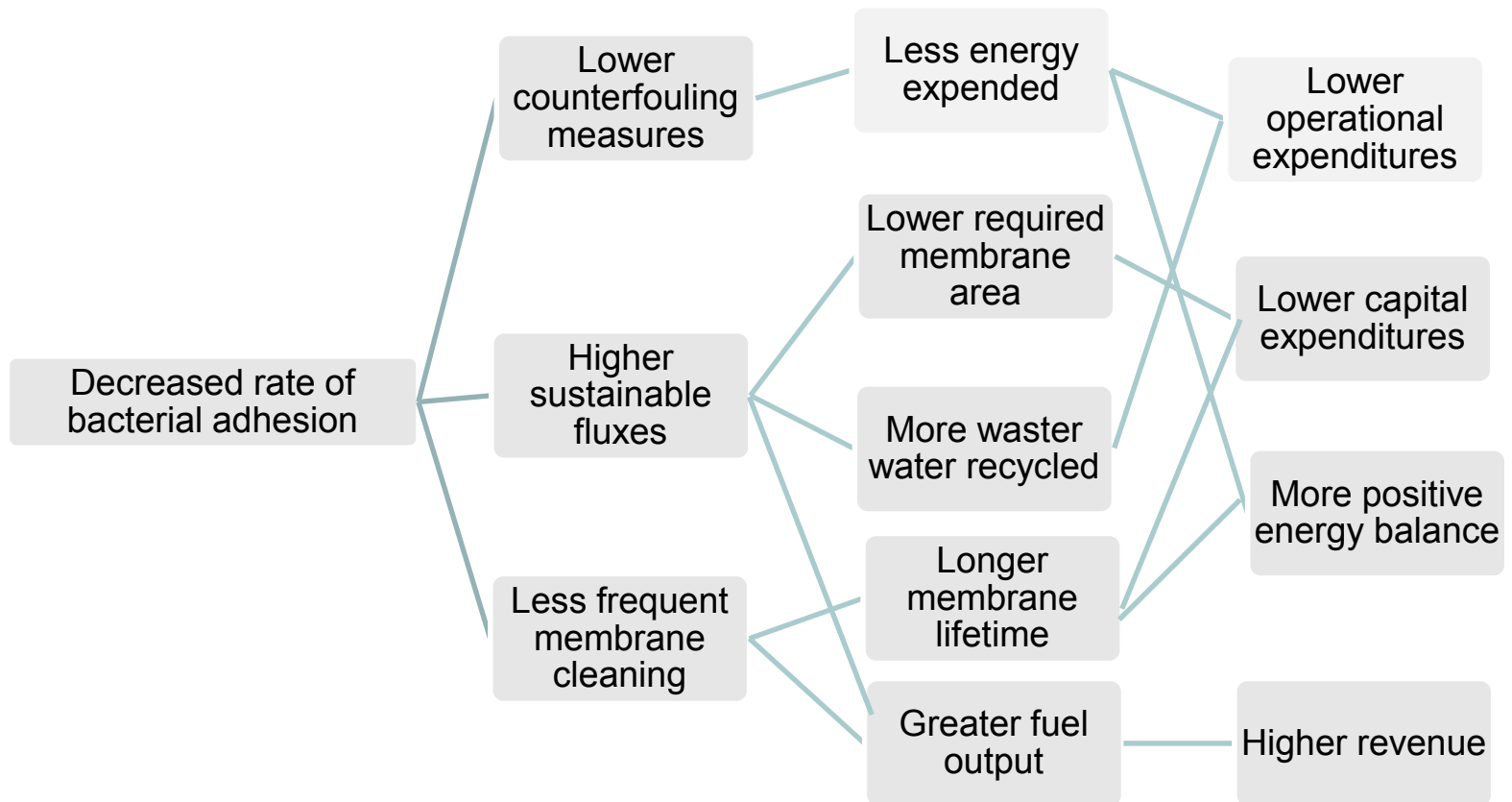
Biofuel production in AnMBRs requires *efficient membranes* to be energy positive.



Martin, Pidou, Soares, Judd, Jefferson *Environmental Tech.* 2016

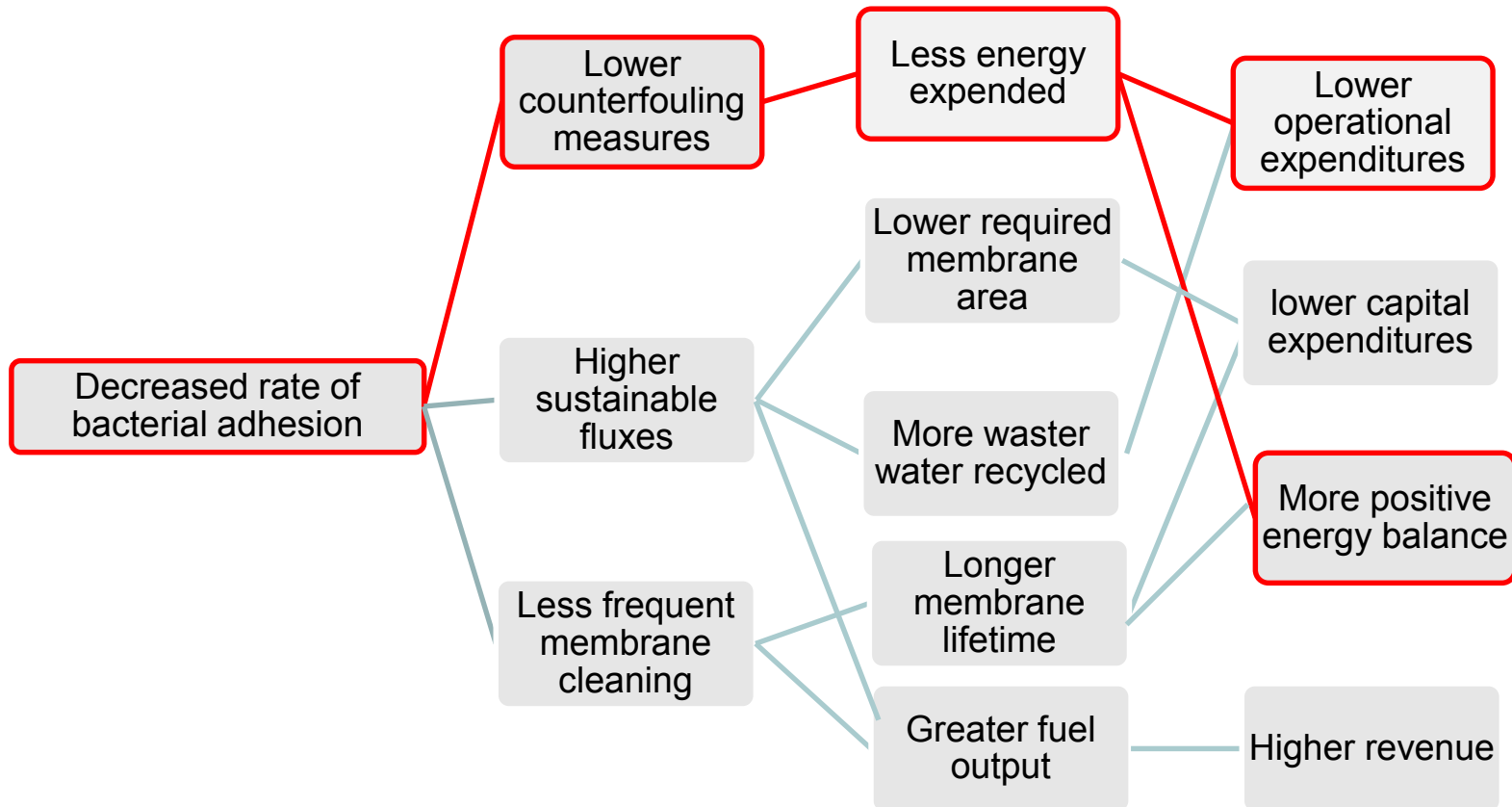
Anti-fouling Approach to Improving AnMBR Business Case and Energy Balance

Control of membrane fouling is central to energy balance and profitability in biofuel production via AnMBR.



Anti-fouling Approach to Improving AnMBR Business Case and Energy Balance

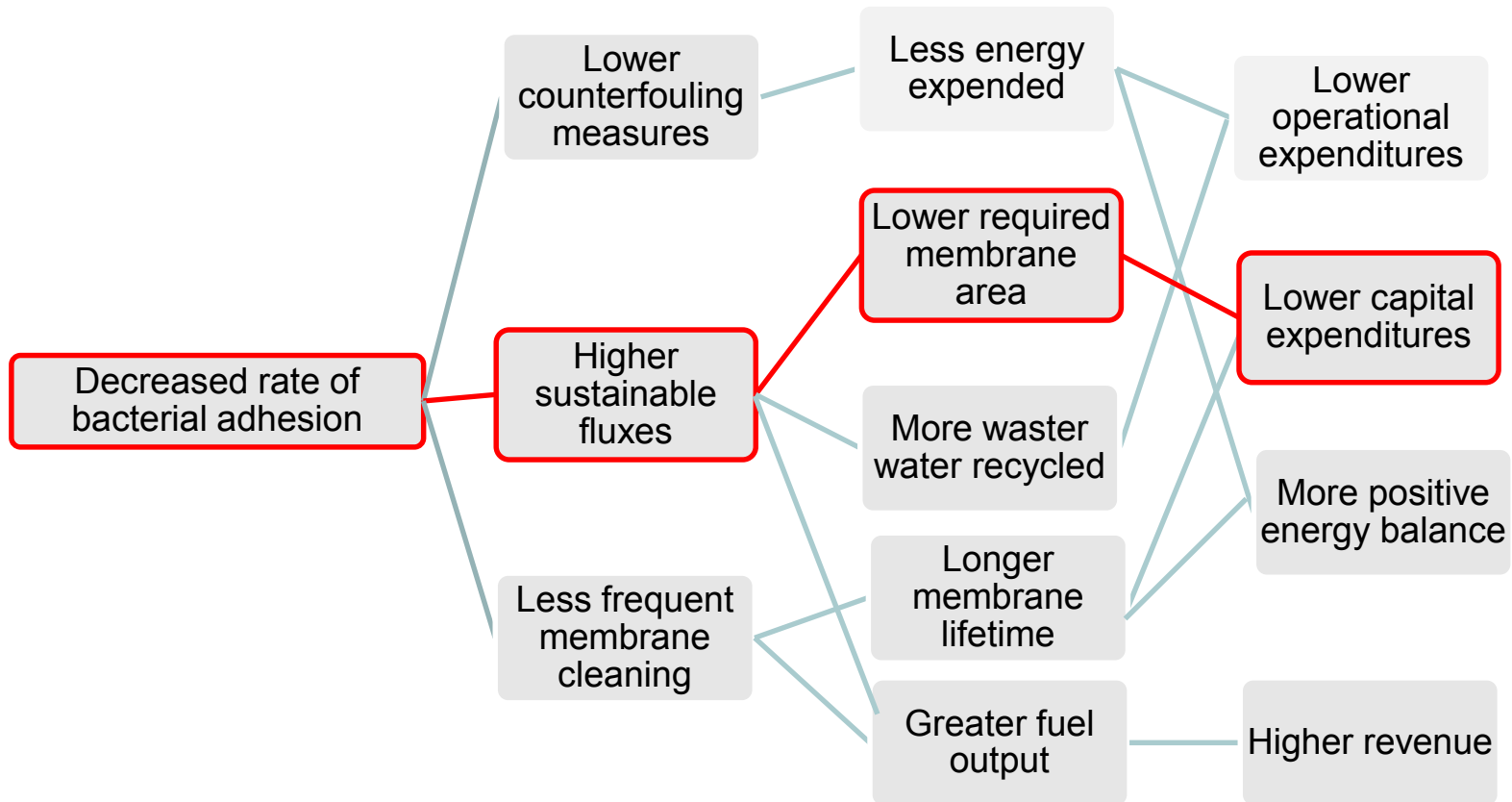
Counterfouling measures account for up to 99% of energy inputs in MBR systems.



Martin, Pidou, Soares, Judd, Jefferson *Environmental Tech.* 2016

Anti-fouling Approach to Improving AnMBR Business Case and Energy Balance

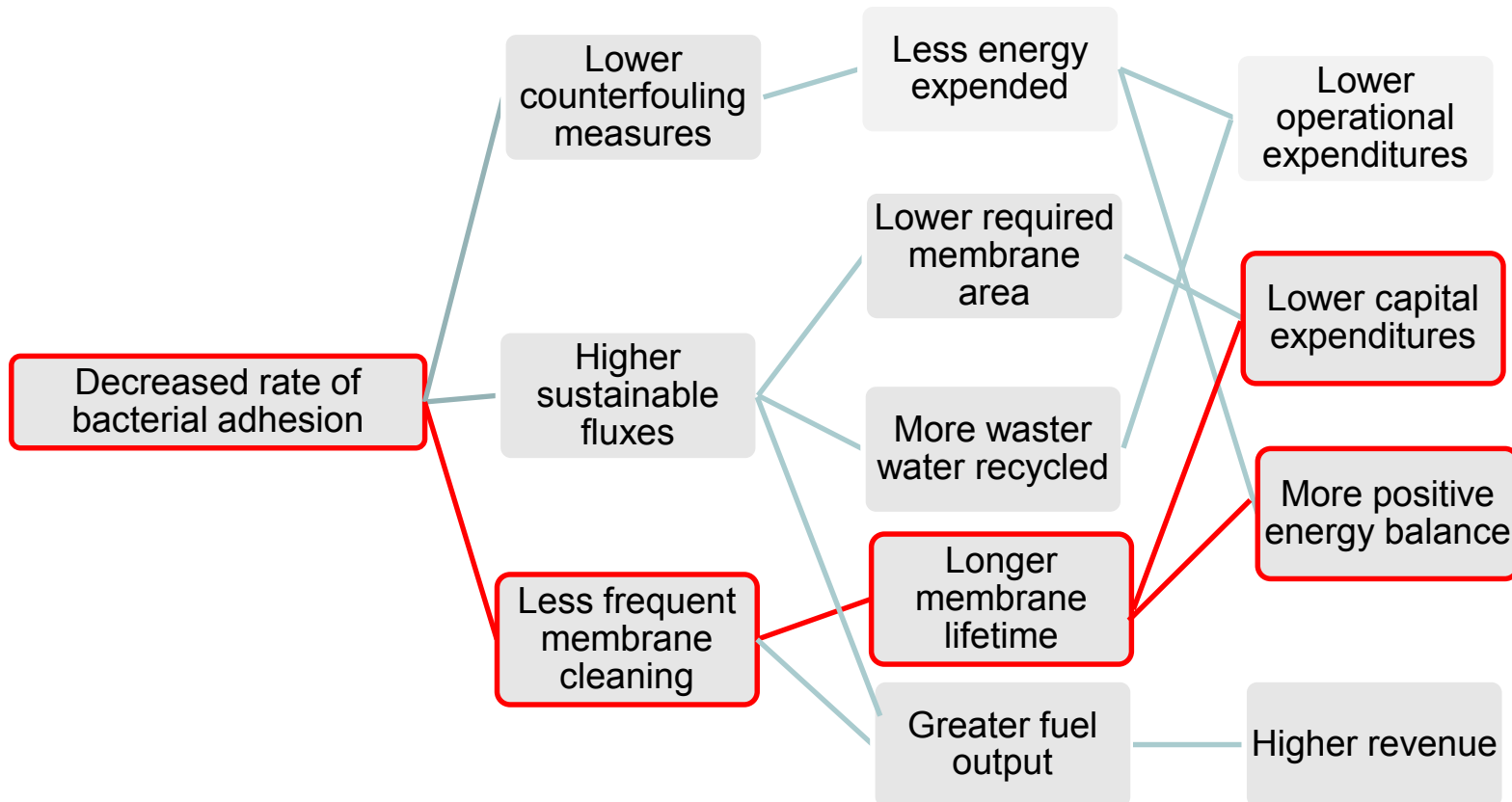
Increased sustainable flux from 15 to 30 L m⁻² hr⁻¹ equates to decreased overall costs by 9%.



Maere, Nopens, Brepols, Judd Water Research 2010

Anti-fouling Approach to Improving AnMBR Business Case and Energy Balance

Doubling membrane lifetime can decrease costs by 19-46%.



Maere, Nopens, Brepols, Judd Water Research 2010

Nano Terra's Collaboration with our Commercial Partner



Provide commercial membranes for coating and fouling tests

Contribute information on market

Supply relevant testing conditions and reactor operation guidance

Partner with Nano Terra for commercialization



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Synthesize coating material

Apply coating treatment to membranes

Select optimal coatings as evaluated by

- Bacterial adhesion of *E. coli* and *C. acetobutylicum* on membranes
- Membrane permeability
- Coating stability

Operate bench scale AnMBRs with testing for fouling rates, energy input

Perform cost analysis for scale up

A Modular Coating is a Tunable Coating

The coating is:

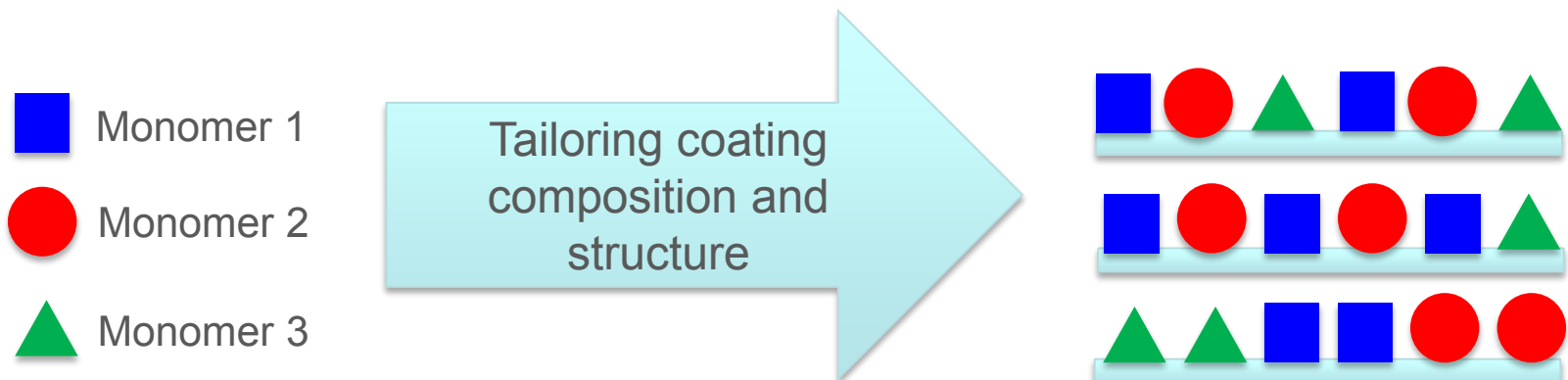
An organic copolymer (non-metal)

Covalently attached to the membrane (non-leaching)

Non-toxic (does not interfere with cell viability in solution)

Non-specific (resists fouling by proteins, sugars, bacteria)

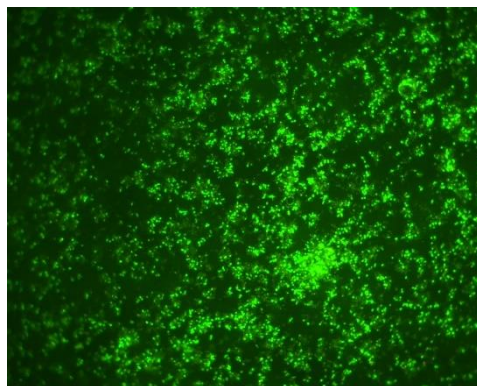
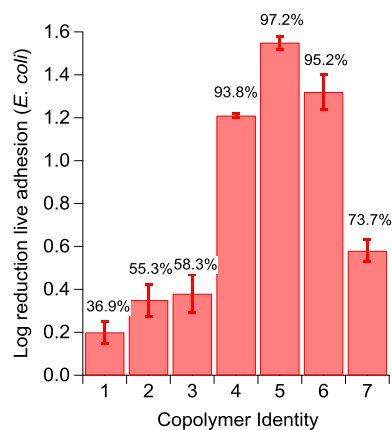
Modular



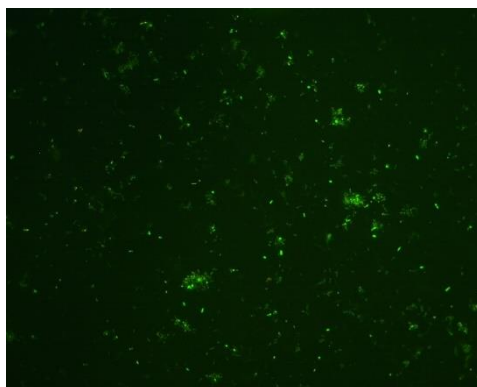
Coating Screening for Adhesion Reduction

Reduction in live cell *E. coli* adhesion reduced up to 97% (1.55-log). Adhesion reduction in *C. acetobutylicum* is expected to be as good or better.

Reduction of adhesion by live cells

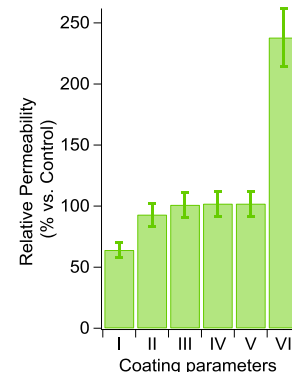
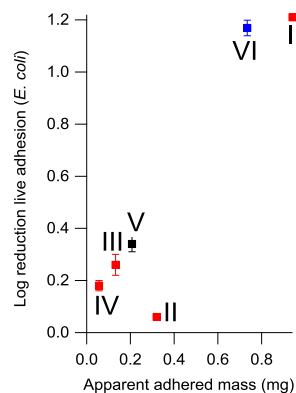
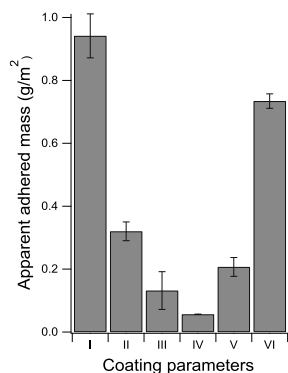


Fluorescence microscope image of *E. coli* of untreated PVDF substrate



Fluorescence microscope image of *E. coli* on PVDF substrate treated with antifouling coating

Characterization of Coated Membranes



Apparent adhered mass of coating on membranes as measured by fluorescence spectroscopy

Bacterial adhesion reduction for coating vs. apparent adhered mass

Relative water permeability of coated membranes compared to untreated membranes

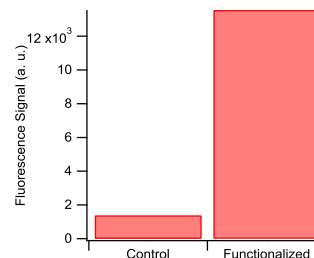
~0.2-0.9 g/m² of coating on the membrane depending on the deposition parameters.

Preliminary Coating of Commercial Membranes

- Coat tubular ultrafiltration membrane from Pentair
- Demonstrated coating attachment membrane by monitoring fluorescence
- Further work will include:
 - Characterization of adhesion, permeability and rejection
 - Process automation
 - Incorporation into AnMBR for biobutanol production
 - Determination of coating stability



Functionalized piece of membrane by Pentair X-Flow



Conclusions

- Control of membrane fouling is central to energy balance and profitability in biofuel production *via* AnMBR.
- Nano Terra's preliminary screening shows multiple coatings that reduce fouling by >90%.
- The screening results are expected to translate to decreased fouling rates, decreased energy inputs and greater profitability in AnMBRs



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Thank you!

