# Photothermal Solar Cell

**DOE Phase II SBIR DE-SC0015924**
**Aquaneers Inc./ New York University**
**07/31/2017-07/30/2019**

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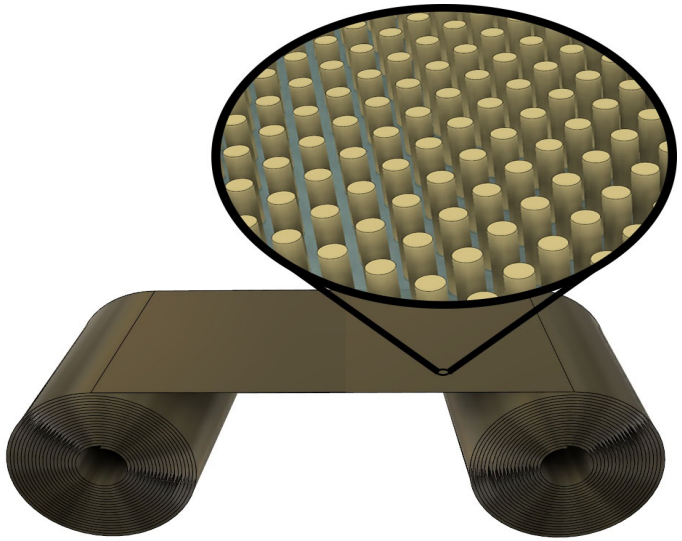
# Overview

## Timeline & Budget

- Phase I Start Date: June 13 2016
- Phase II Start Date: July 31 2017
- Project End Date: July 30 2019
- Project Budget: $1,150,000
- Costs as of 3/31/19: $1,014,503

## Focus

Aquaneers Inc. is developing advanced roll-to-roll processing techniques for large-scale manufacturing of its Plasmonic Ribbon™ nanomaterial product. Photothermal energy conversion is quantified through solar steam generation and applied to desalination devices.



Plasmonic Ribbon™ is comprised of metallic nanorod arrays fabricated on flexible Corning® Willow® Glass.

## Collaborators

NYU TANDON SCHOOL OF ENGINEERING

CORNING

BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK

BROOKHAVEN NATIONAL LABORATORY

# Objectives

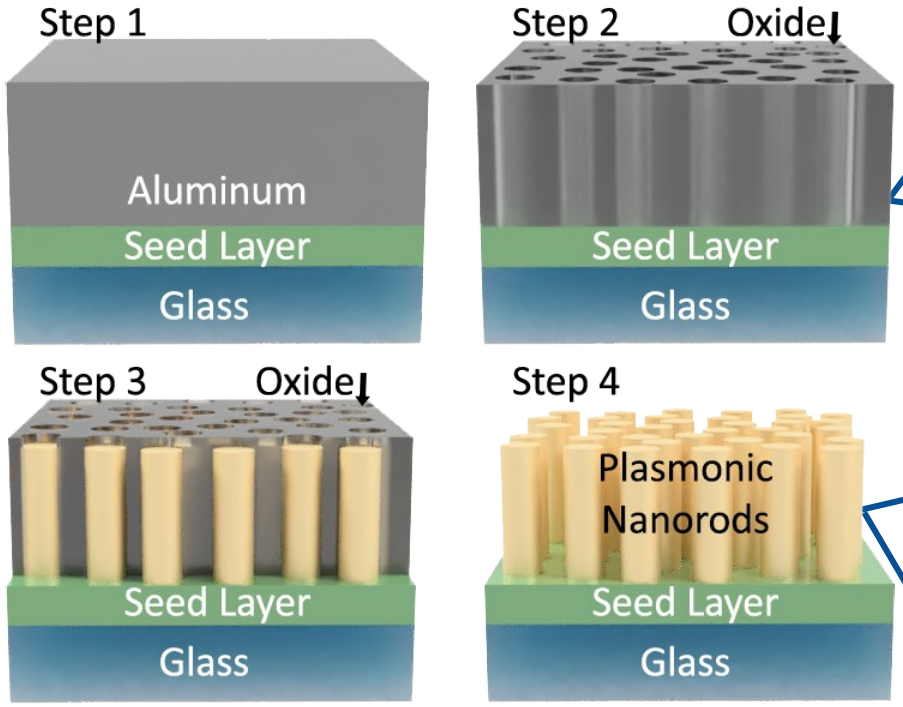
- Develop advanced nano-manufacturing capabilities and commensurate intellectual property.
- Perform analysis for roll-to-roll manufacturing of Plasmonic Ribbon™ to determine feasibility and cost.
- Advance applications for plasmonic materials in energy conversion and renewable energy.
- Quantify the optical energy conversion properties of Plasmonic Ribbon™.
- Determine commercially viable applications within the energy-water nexus and research the market dynamics.
- Look for opportunities to apply Plasmonic Ribbon™ to other technologies in the sustainable energy space e.g. photocatalysis.

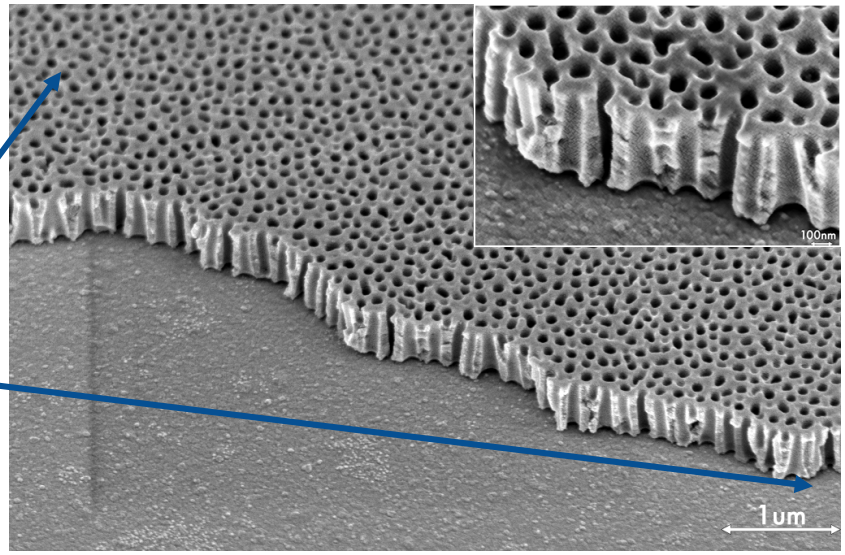
# Technical Innovation and Approach

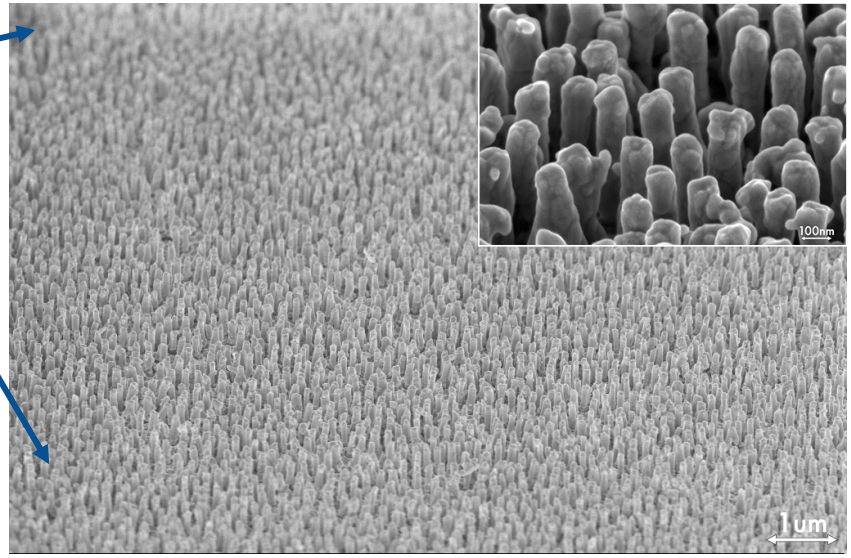
- Problem: Plasmonic nanostructures have tremendous technological potential but limited commercial applications.
- Limitations:
  - Plasmonic materials are typically deployed as nanoparticle dispersions that are hard to manipulate, handle, and use.
  - When fabricated on substrates the materials don't scale for manufacture, require clean rooms, and are costly.
- Approach: Develop nanomaterials fabrication techniques on novel substrates that scale and don't require expensive processes or infrastructure (clean rooms).
  - Batch manufacturing of Plasmonic Ribbon™ on flexible glass is established and being scaled up.
  - Product produced using various materials that yield a range of performance attributes and potential applications.
  - Development of roll-to-roll manufacturing methodologies has been initiated with Binghamton University.

# Plasmonic Ribbon™ Fabrication

## Four-Step fabrication process.

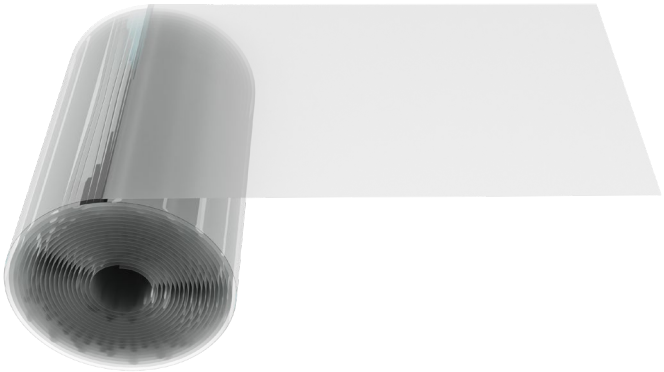



1) Coat glass with seed and Al layers.
2) Anodize Al layer entirely through forming a nanoporous oxide template.
3) Electrodeposit metal into oxide template.
4) Remove oxide exposing nanorod array.

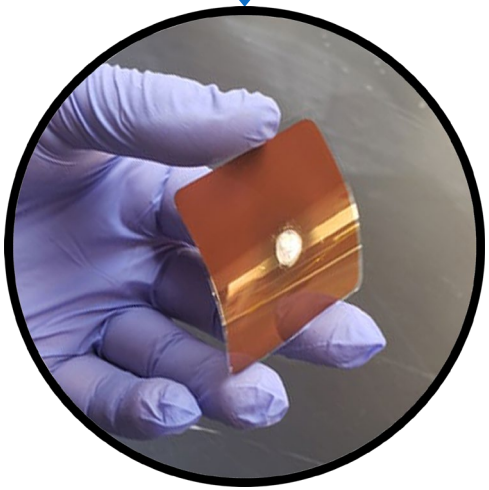
# Corning® Willow® Glass Processing



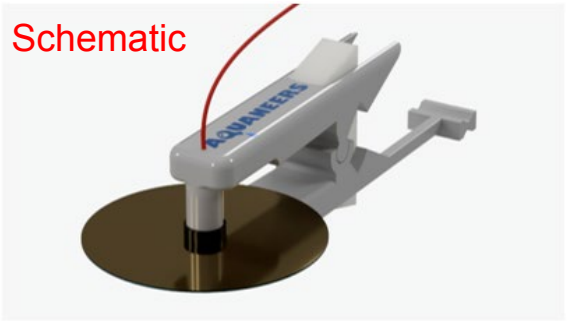
Corning® Willow® Glass
100 microns thick

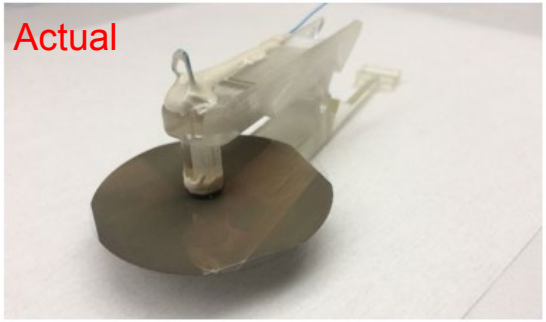

Laser cut coupons

Fabricate Plasmonic Ribbon™



Nanofabrication Process Cell

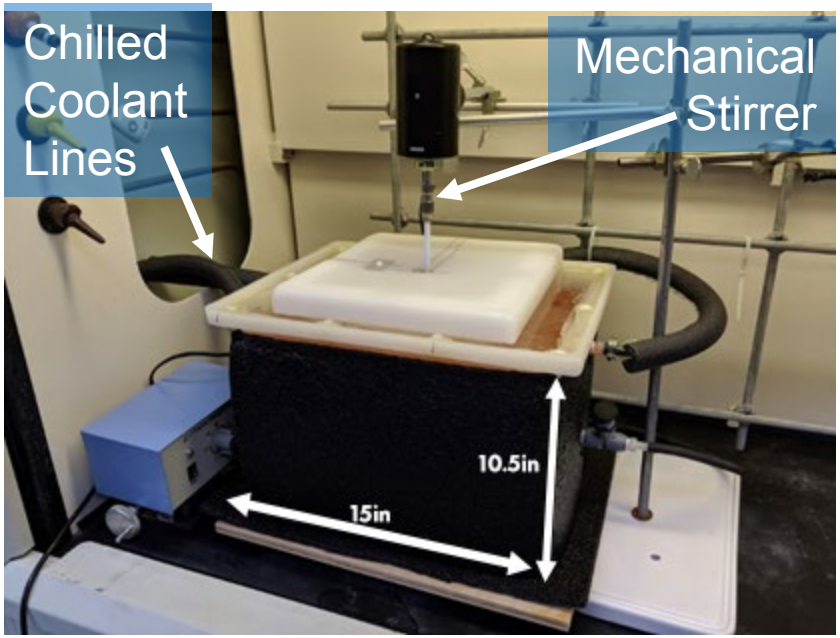



Novel electrochemical processing cell with clip-on submersion electrode design for large area batch sample fabrication. Accommodates multiple substrate geometries.

# Electrolyte Bath Temperature Control

Double walled bath circulates anti-freeze around electrolyte for constant temperature control.



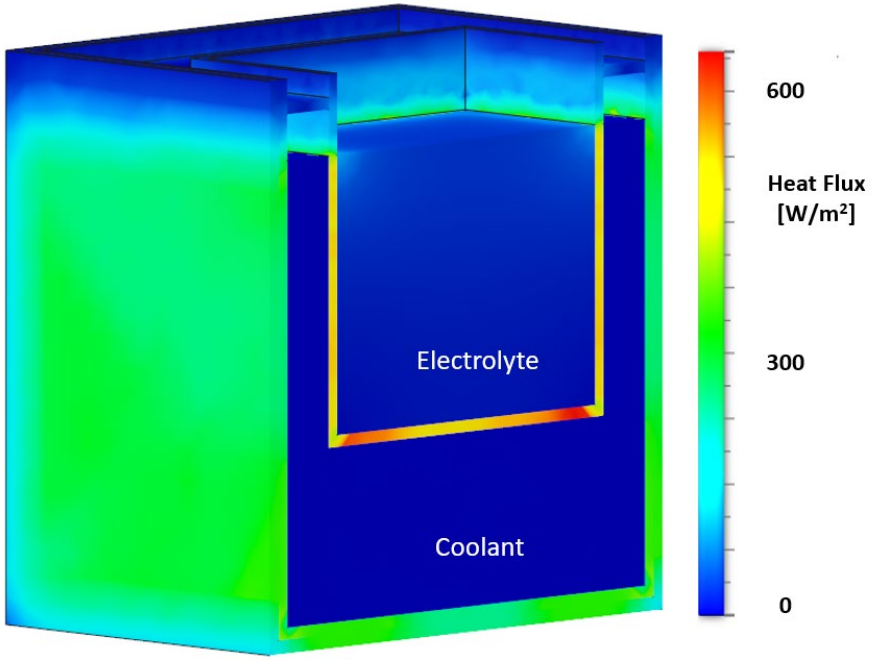



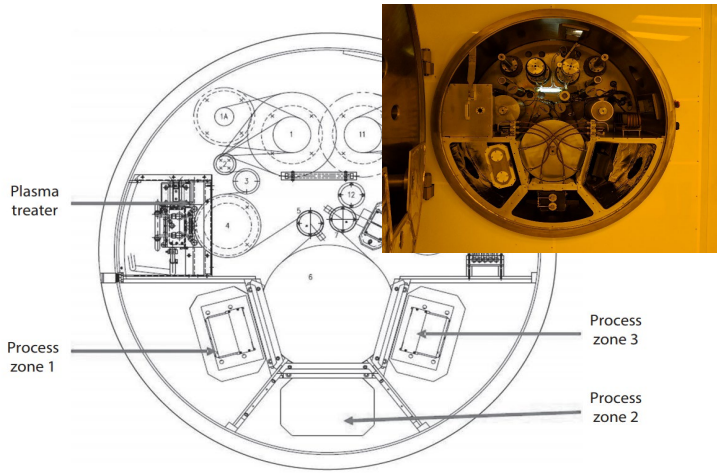

Photo of scaled anodization bath with 7 liter electrolyte capacity. This system can process samples over 15 cm in size, or >10 times larger than the previous system capacity.

Heat flux profile modeled for new double walled bath, showing how heat transfer is largely confined to the wall separating the coolant from electrolyte. Constant temperature can be held indefinitely.

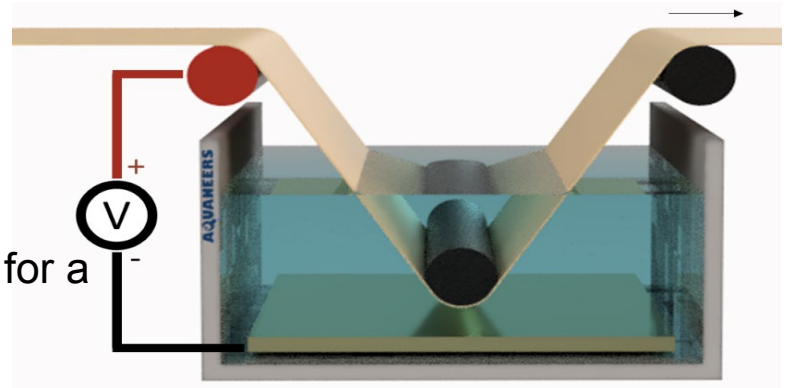
# Roll-to-Roll Process Development

BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK

CAMM
The Center for Advanced Microelectronics Manufacturing




Roll-to-roll vacuum vapor deposition equipment currently being used for continuous sputter coating process development at Binghamton University.

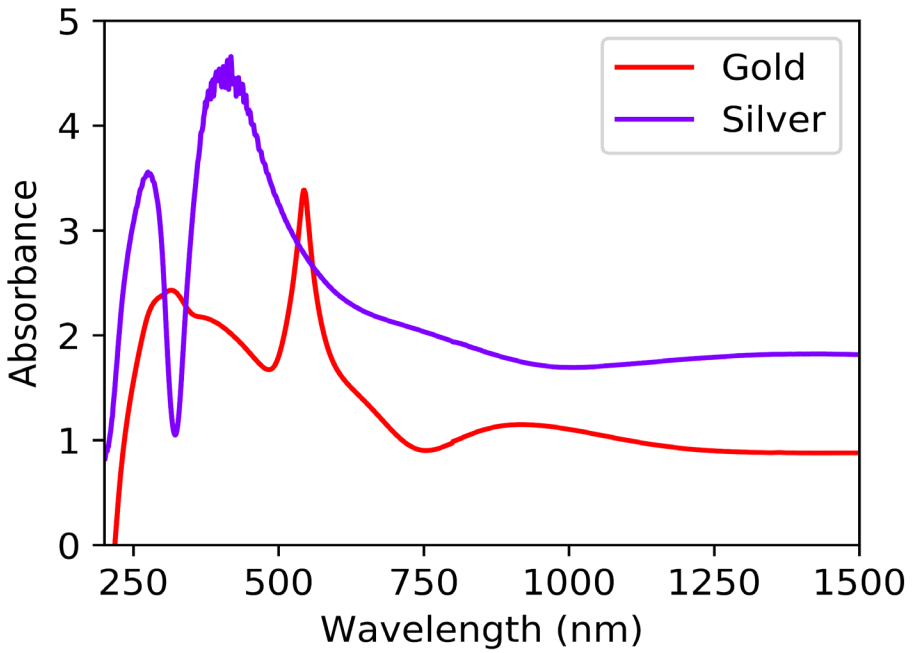



Aquaneers conceptual schematic for a roll-to-roll anodization system.

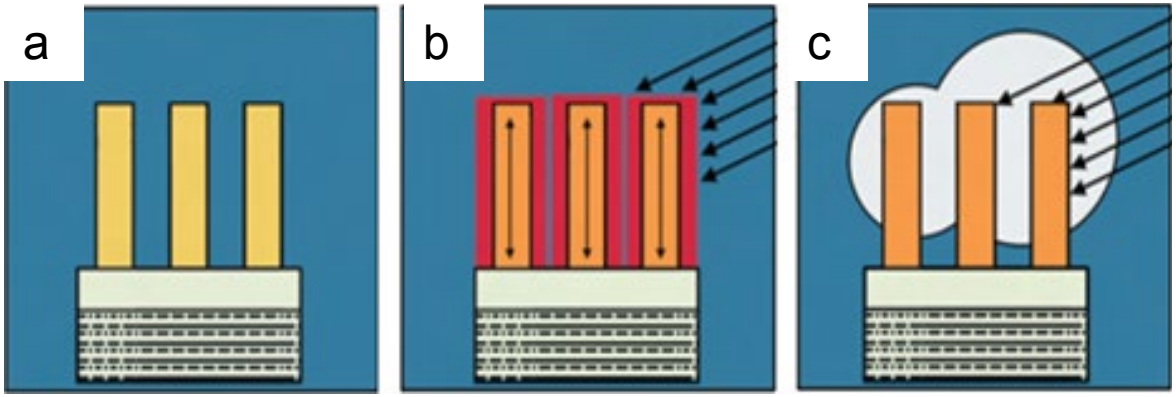
Roll-to-roll electroplating system located at the Binghamton CAMM that will be used for future process development work.

# Plasmonic Properties

Absorbance vs wavelength spectral data shows the pronounced plasmon resonance peaks as measured on gold and silver nanorod arrays. The gold peak is at ~525 nm and the one for silver is at ~ 440 nm.

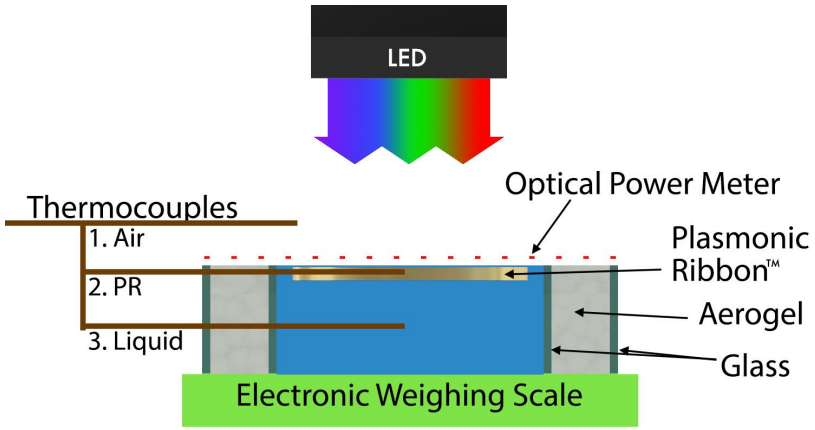



Plasmonic heating and steam generation is shown in the schematic. Frame (a) shows Plasmonic Ribbon™ immersed in water. In (b), the material is illuminated resulting in a plasmonic excitation. The damping of the plasmon results in photothermal heating and the generation of steam in frame (c).

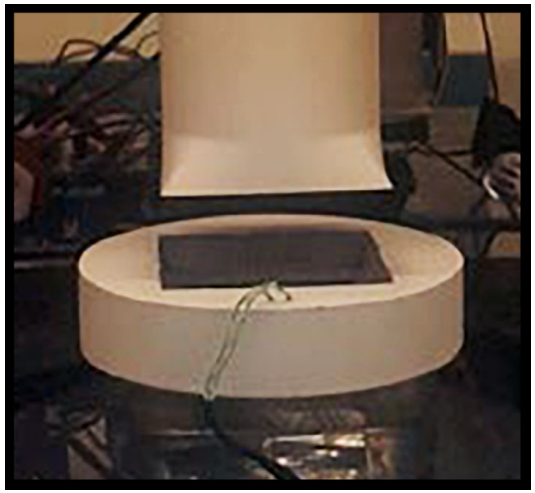


# Photothermal Steam Generation

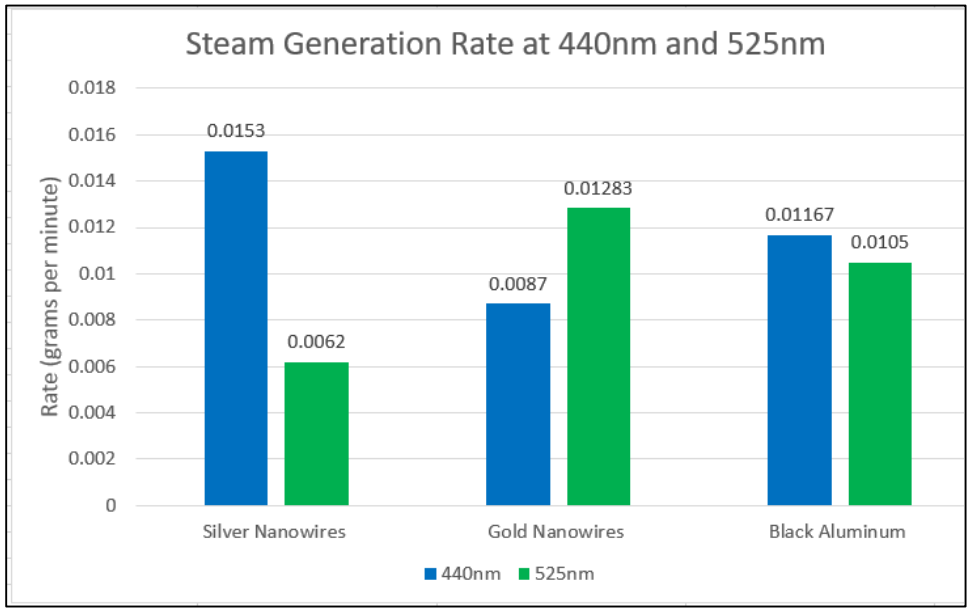
## Experimental Method




Schematic



Photo

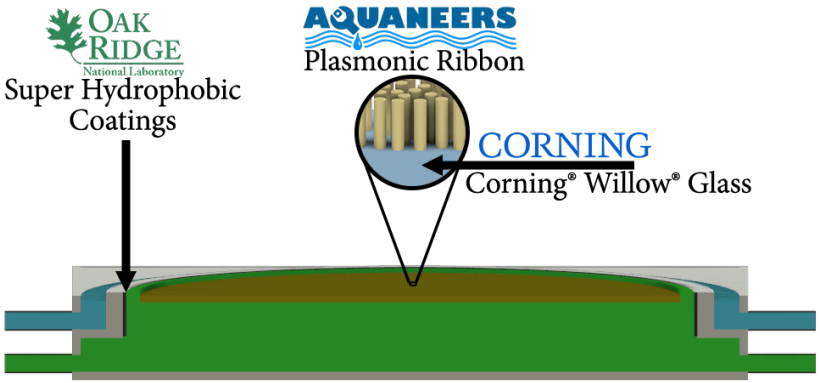



The steam generation results compares the rates obtained with the gold and silver Plasmonic Ribbon™ to that obtained on a blackbody absorber when illuminated at 440 nm and 525 nm respectively. When illuminated on resonance, the photothermal effect is more pronounced in the Plasmonic Ribbon™ than the blackbody, while off resonance the blackbody is superior.

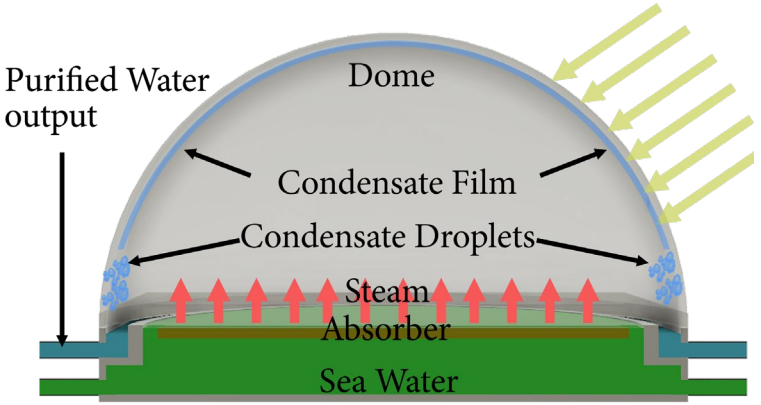
# Solar Desalination

## AquaSol System

Technical Innovation

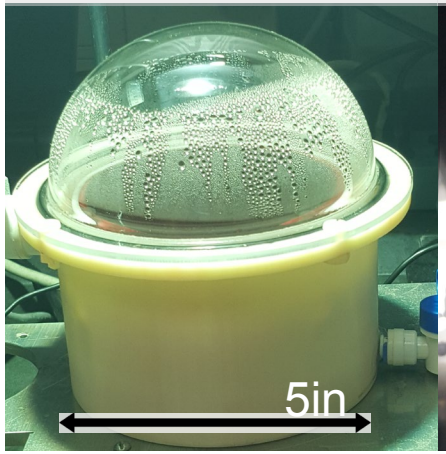



Operational Schematic

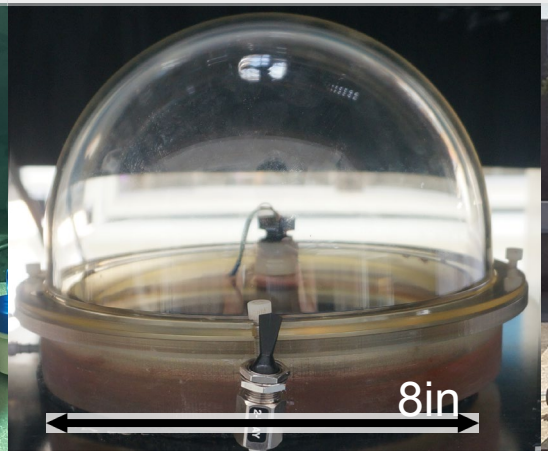



## AquaSol Evolution

Bench Model
4” Absorber




Bench Model
6” Absorber




Bench Model
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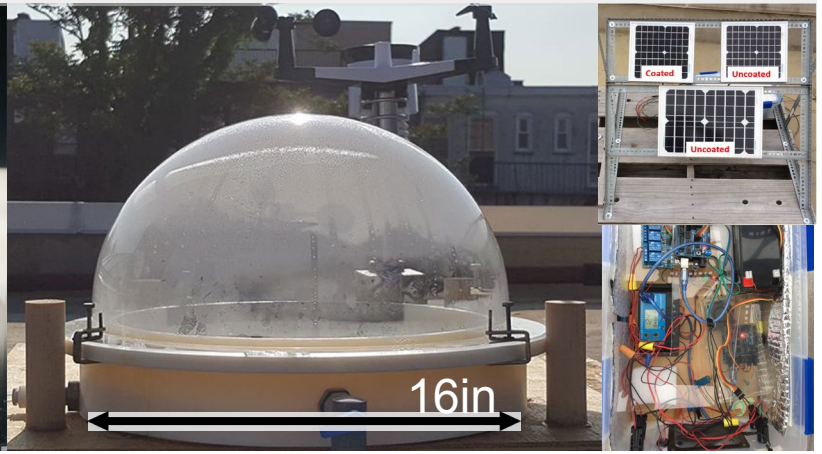
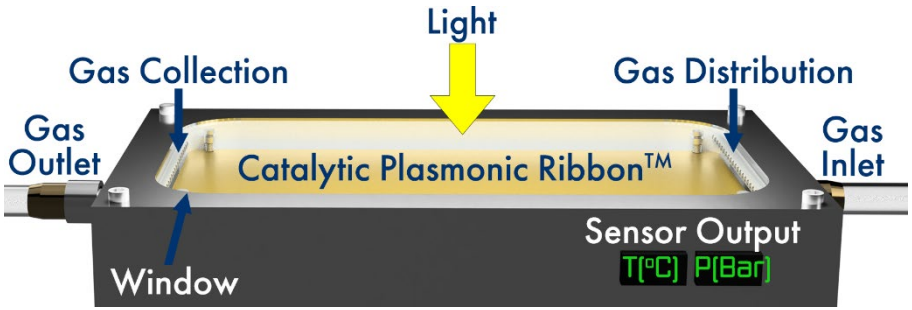


# Future Applications

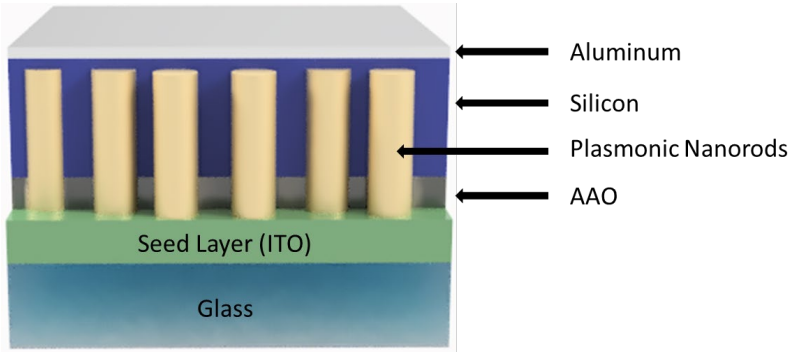
The optical excitation of a plasmon in a nanostructure and its subsequent damping results in transfer of the energy to heat and energetic charges (electrons and holes). The heat can be used for photothermal applications, while the energetic charges can enable photochemistry and photodetector applications.

## Catalytic Plasmonic Ribbon™




In this DOE Phase I SBIR (DE-SC0019657) project, a catalytically active Plasmonic Ribbon™ is made by coating silver nanorods with a bimetallic layer. The goal is to demonstrate the photocatalytic synthesis of methanol from carbon dioxide and hydrogen in an optical flow reactor.

## Metamaterials for Sensing




In this proposed NASA Phase I STTR project, roll-to-roll manufacture of a metamaterial format of Plasmonic Ribbon™ will be undertaken, with the goal of demonstrating a Schottky barrier type photodetector as shown above.

# Results and Accomplishments

- Reliable fabrication of Plasmonic Ribbon™ on Willow® Glass substrates.
- Nanorods produced from gold, silver and copper on ITO and silver seed layers.
- Transition from batch to continuous nanomaterial manufacture initiated with coating depositions at Binghamton University.
- Custom steam generation test and measurement apparatus designed and built to quantify plasmonic photothermal effect.
- Lab and field solar desalination systems implemented.
- Superhydrophobic coating research and development performed.
- US utility patent application, *Plasmonic Energy Conversion Device for Vapor Generation* (15/810,341), filed November 2017.
- US provisional patent application, *Catalytic Plasmonic Nanomaterial* (62/809,996), filed February 2019.

# Transition Next Steps

- Fully process roll-to-roll coated Willow Glass®.
- Expand and fund work at Binghamton through NY State and Federal grants.
- Expand Plasmonic Ribbon™ customer base.
- Demonstrate the plasmonic enhancement for catalytic synthesis.
- Analyze commercial market opportunities for photocatalytic materials and chemical synthesis.
- Pursue equity investment.