Exemplars in Engineering Research

Moderated by:
Dr. Frank A. Gomez
Executive Director, STEM-NET
Office of the Chancellor

https://www2.calstate.edu/impact-of-the-csu/research/stem-net

Exemplars in Engineering Research

Speakers

John “Chris” Bachman , Cal State LA
Electrochemical Energy Storage for Sustainable Technologies

Perla Ayala, Cal State Long Beach
Engineering Models for Tissue Repair

Sankha Banerjee, Fresno State
Design and Fabrication of Electro and Photo-active Materials for Applications in Biomedical Devices and Water Purification

Christy Dykstra, San Diego State
Resource Recovery Using Bioelectrochemical Systems (BESs)

Christopher Heylman, Cal Poly San Luis Obispo
Vascularized Human Tumors on a Chip for Drug Screening

Dahyun Oh, San Jose State
Making Nonflammable Lithium-Ion Batteries

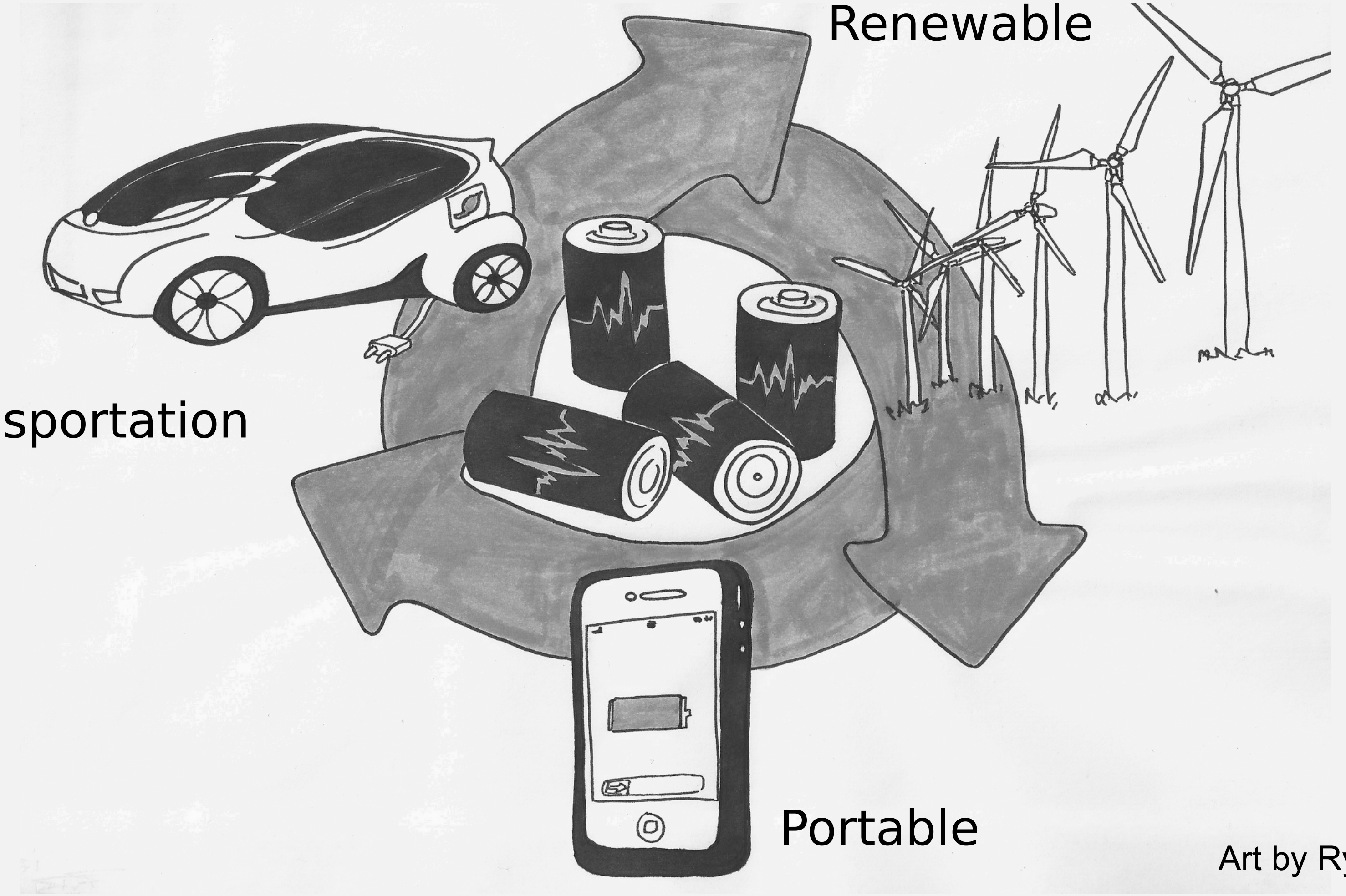
Subhradeep Roy, CSUN
Study of Interactions in Complex Dynamical Systems

Electrochemical Energy Storage for Sustainable Technologies

Dr. John “Chris” Bachman – Cal State LA

Dr. John “Chris” Bachman, Assistant Professor,
Mechanical Engineering Department
John.Bachman@calstatela.edu

Enabling new technologies



Art by Ryan Boulanger (WIT '17)

Solid Batteries and Improved Performance

Janek and Zeier, Nature Energy 1 (2016) 16141

Lithium-Ion Battery

Stability issues, low conductivity, **processing, and microstructure control**

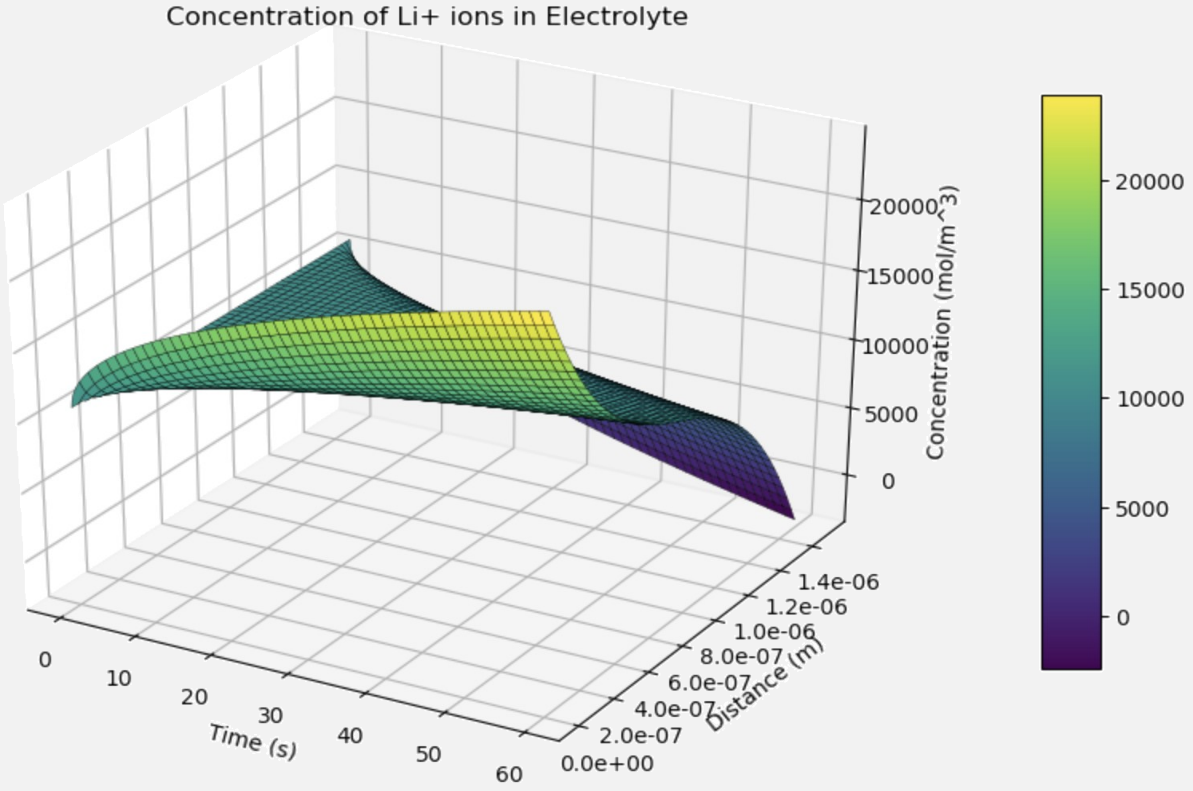
Partnership with Draper

DRAPER | APOLLO 50

Designing and building solid-state batteries but need model to predict performance to limit amount of iterations.

Motion of Li^+

$$\frac{\partial c}{\partial t} = \overline{D}\frac{\partial^2 c}{\partial y^2} + r$$



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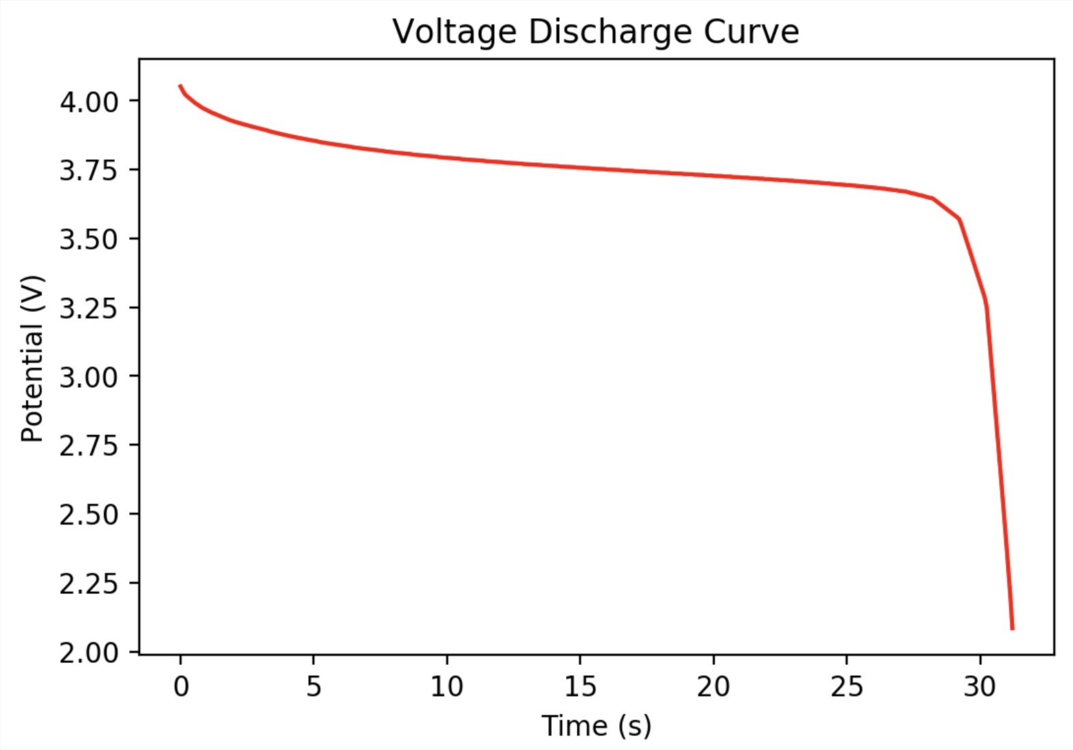
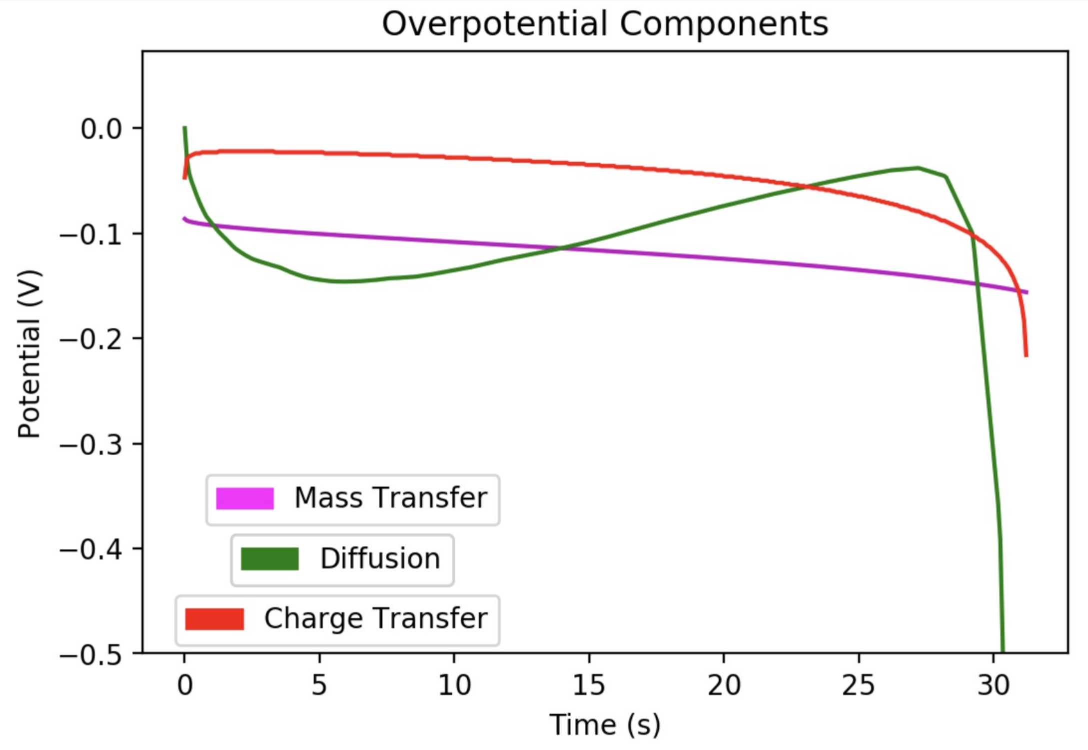
Electrochemical Energy Storage for Sustainable Technologies

Performance Prediction





Allows for design decision making to limit experimental iterations

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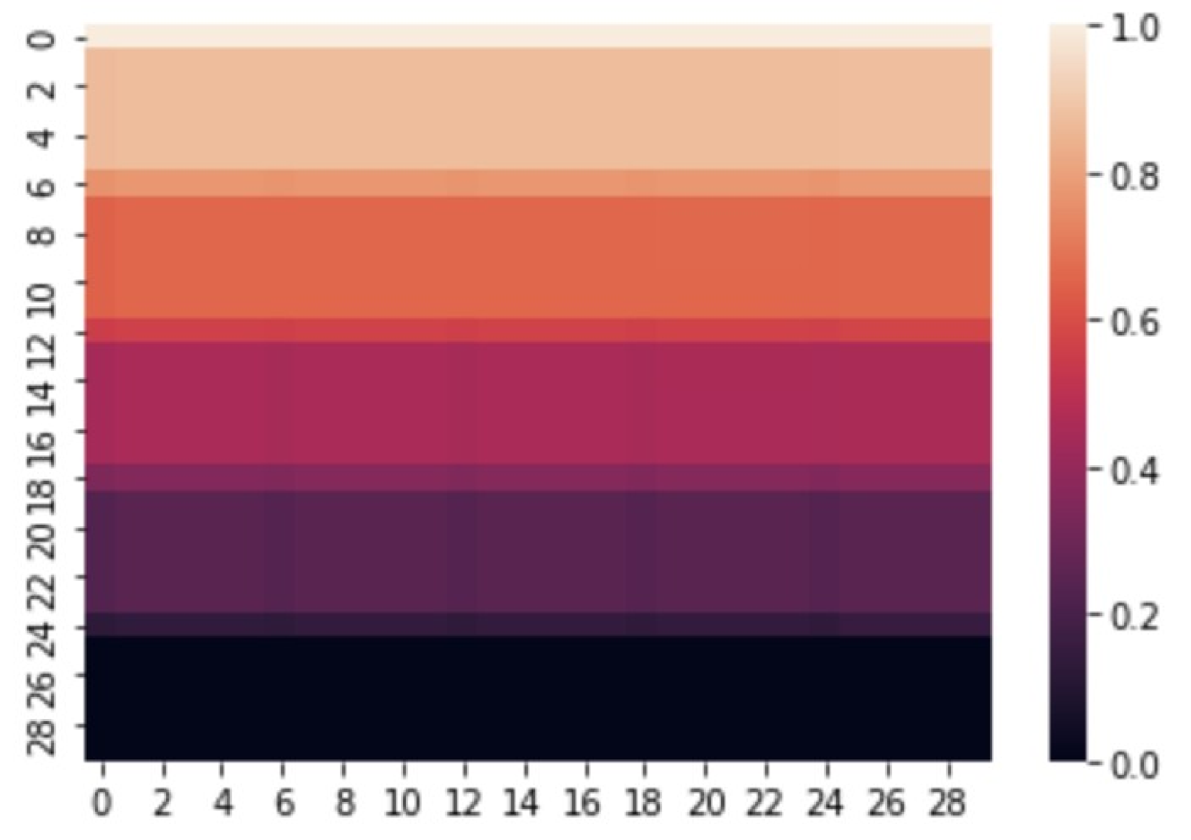
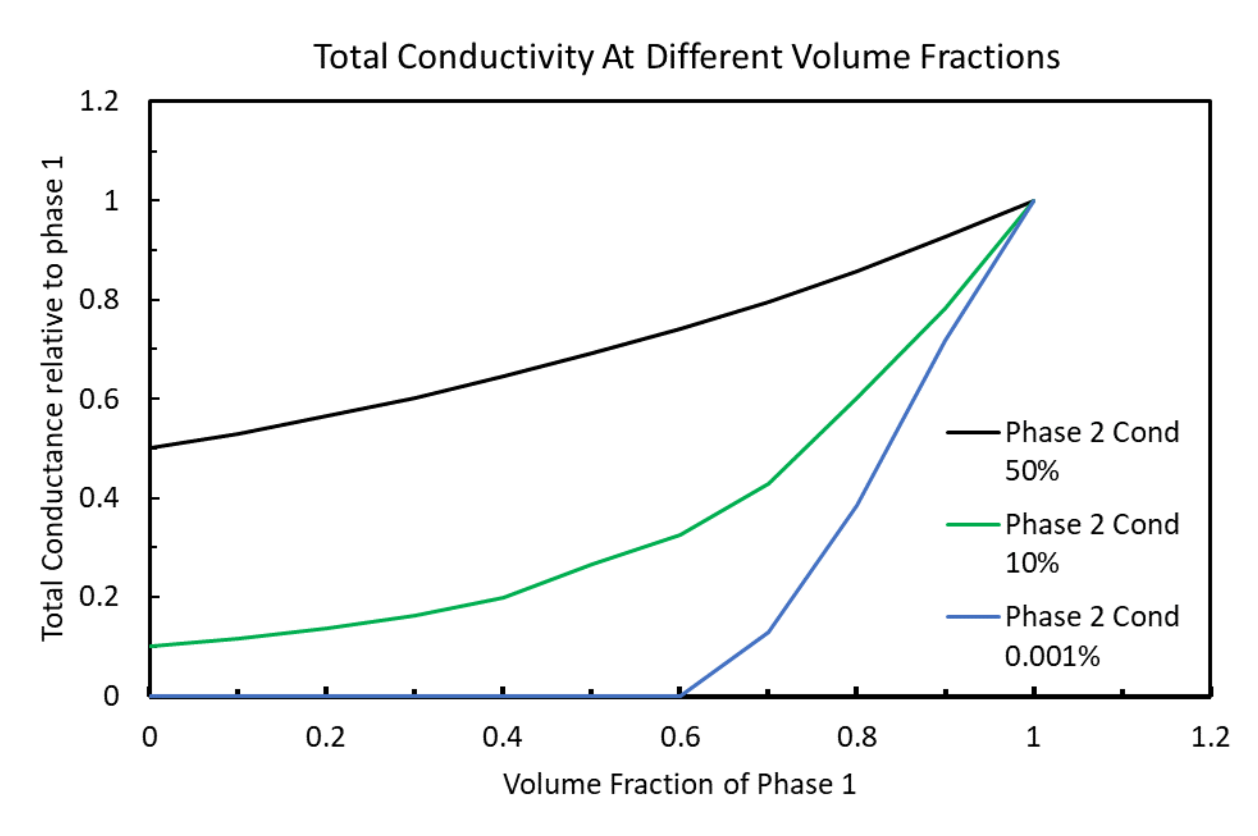
Predict Performance for Varying Microstructure





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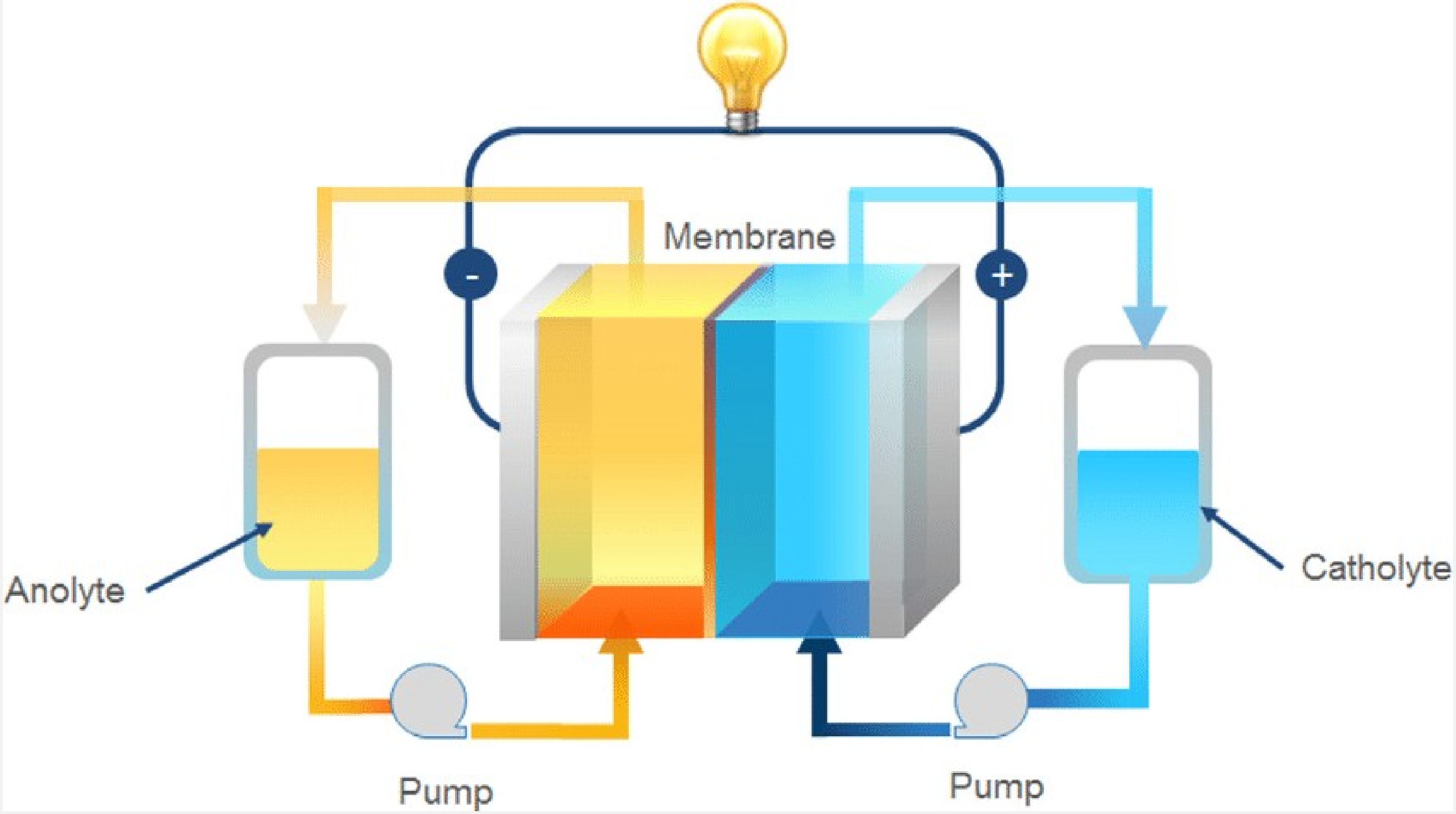
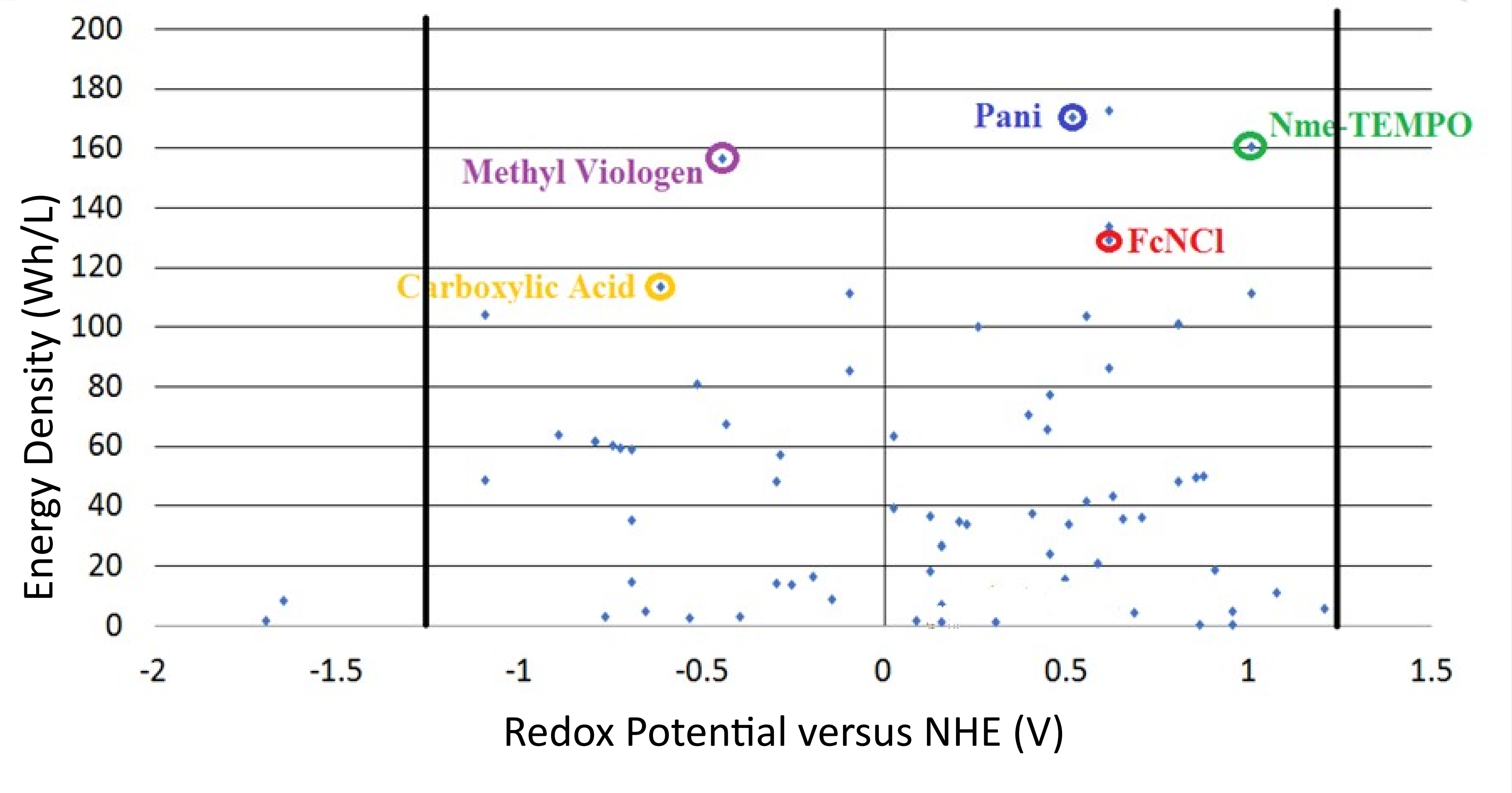
Neutral-Ph Flow Batteries



Can be made from inexpensive, non-toxic, and non-corrosive materials.

Identifying Potential Materials

Energy Density = FnCV/2 [J/L]



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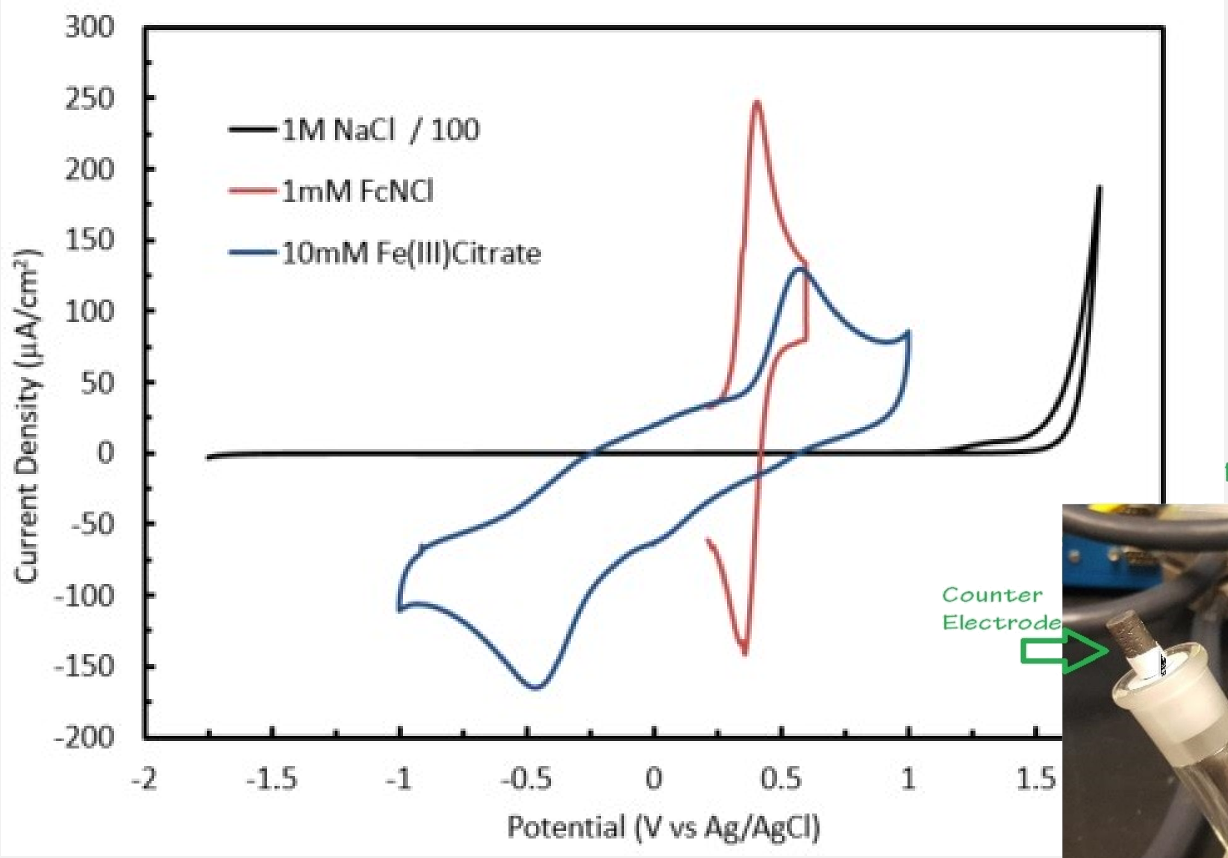
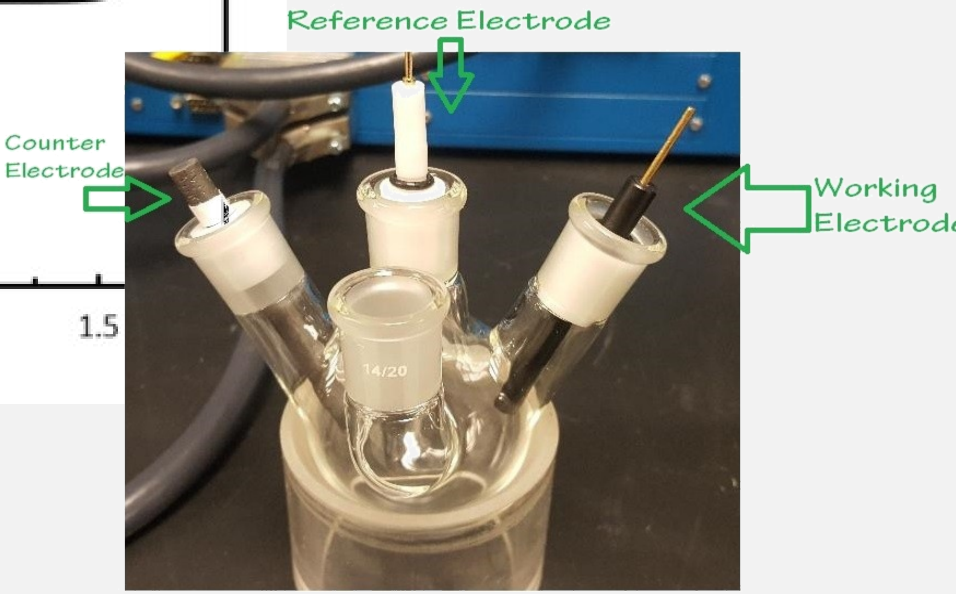
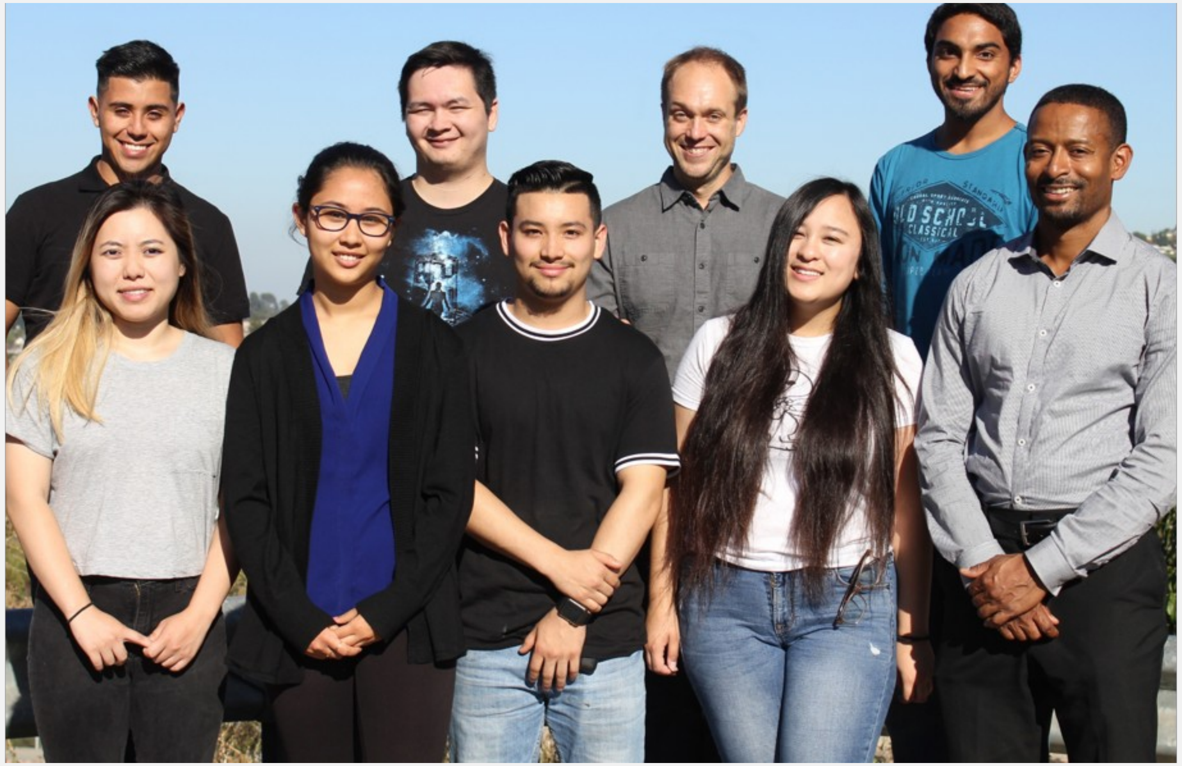
Testing the Materials in our Systems





Thank You

Look forward to questions in Q&A



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Engineering Models for Tissue Repair

Perla Ayala, Ph.D. – California State University Long Beach

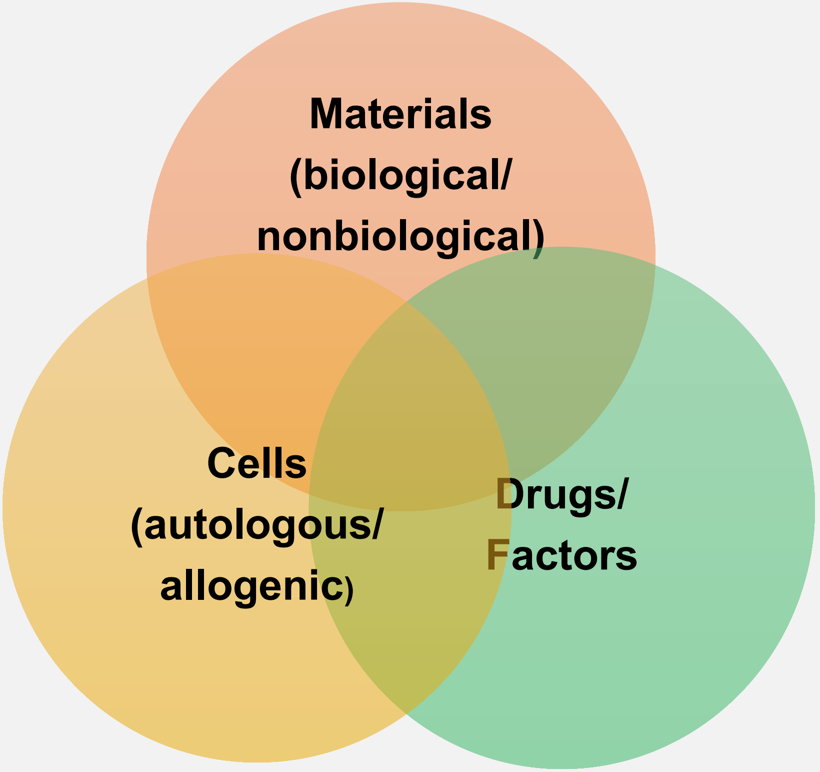
Perla Ayala, Assistant Professor

Cal State Long Beach, Department of Biomedical Engineering

perla.ayala@csulb.edu

Project Overview

Tissue Engineering



The field of tissue engineering focuses on the development of methods and technologies to regenerate, repair, or replace tissues.

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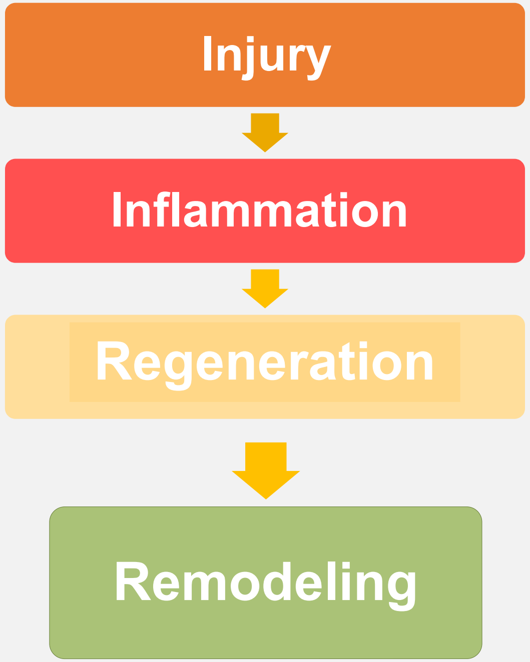
Tissue Repair Process

Tissue Repair Process



- Pathological fibrosis: overproduction of extracellular matrix as a response to tissue damage.

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Therapeutic & Regenerative Systems @CSULB

GOAL: Translate mechanisms of tissue regeneration into feasible therapies that will promote optimal healing.

Objectives:

- Design scalable implantable biomaterials for tissue repair and regeneration.
- Develop functional 3D models of normal and diseased tissues.

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Volumetric Muscle Loss

- Severe muscle tissue damage can result on volumetric muscle loss (VML) which commonly results in significant fibrosis.
- Inadequate recovery of muscle results in long-term disability and contributes to an economic burden of ~$400 billion in the US annually.
- **Objective:** Design biomimetic scalable/implantable scaffold to increase and direct skeletal muscle regeneration.

J Orthop Res 2015;33(1):40-46

Physiol Rep 2017;5(7)

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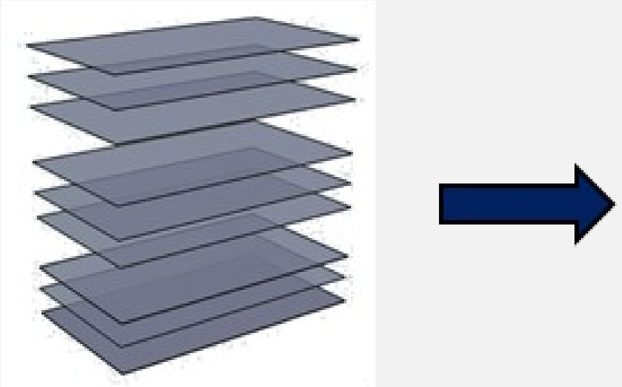
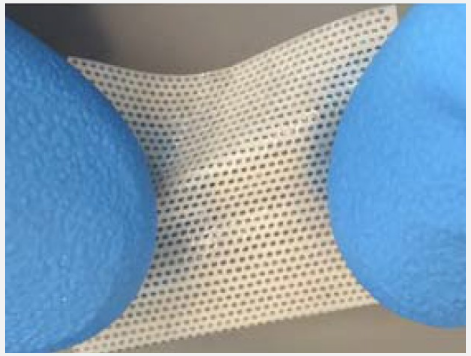
Fabrication of Mechanically Robust Constructs





Layered-patterned collagen construct.

Acta Biomaterialia 26 (2015) 1–12

J Biomed Mater Res Part B: Appl Biomater, 106B: 2345-2354, 2018.

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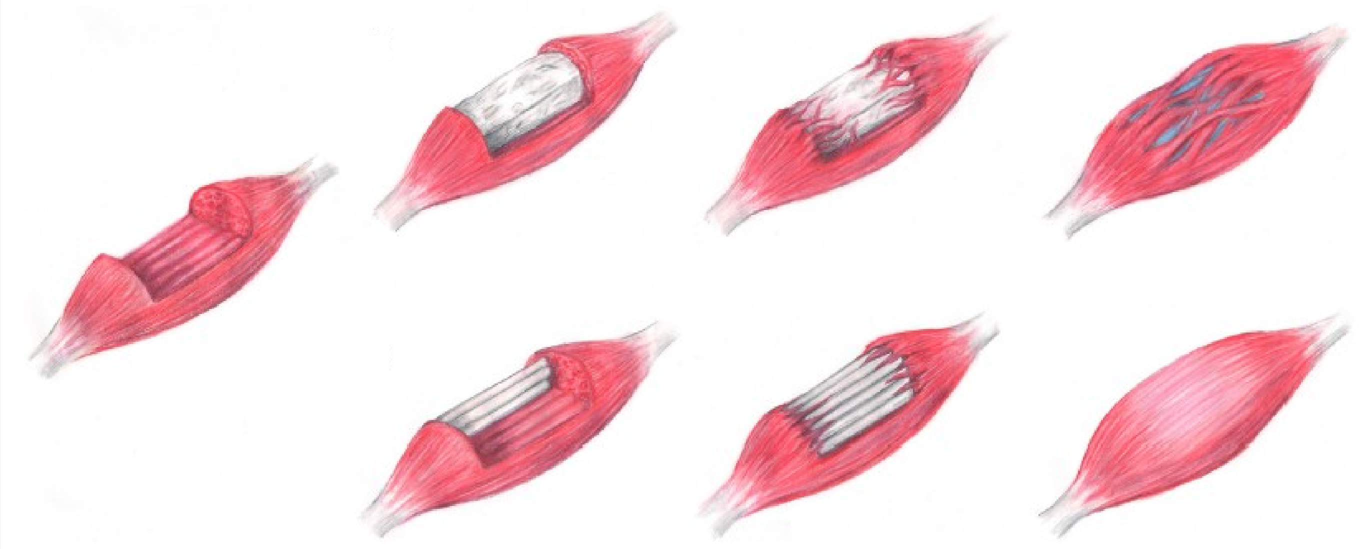
Schematic Representation of Scaffold Mediated Repair of VML



Acta Biomater. 2015 October 1; 25: 2–15. doi:10.1016/j.actbio.2015.07.038.

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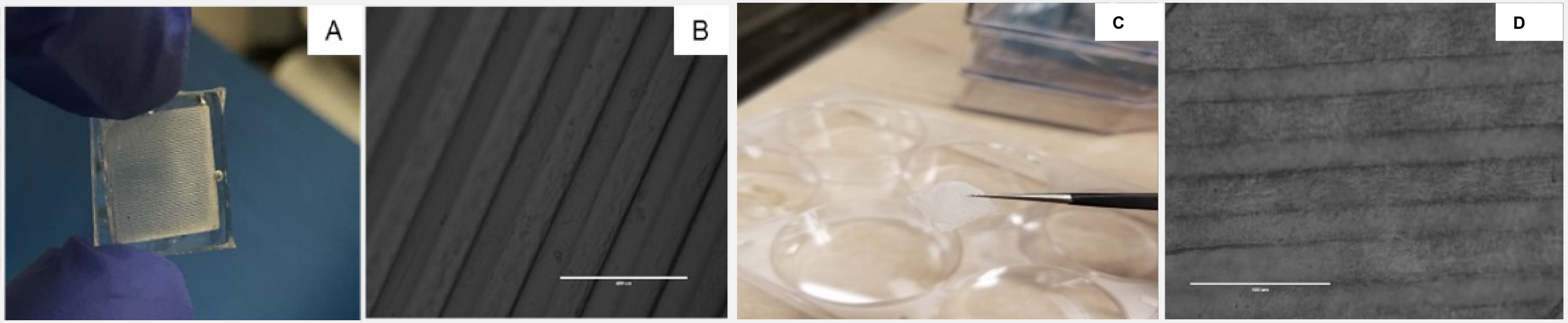
Collagen Films with Micro-Channel



A) PDMS (polydimethylsiloxane) mold with imbedded micro-channels.
B) B) Microscopic image of channels on PDMS mold.
C) C) Collagen sheet extracted from PDMS mold.
D) D) image of collagen sheet with microchannels (right).
Scale Bar= 400μm.

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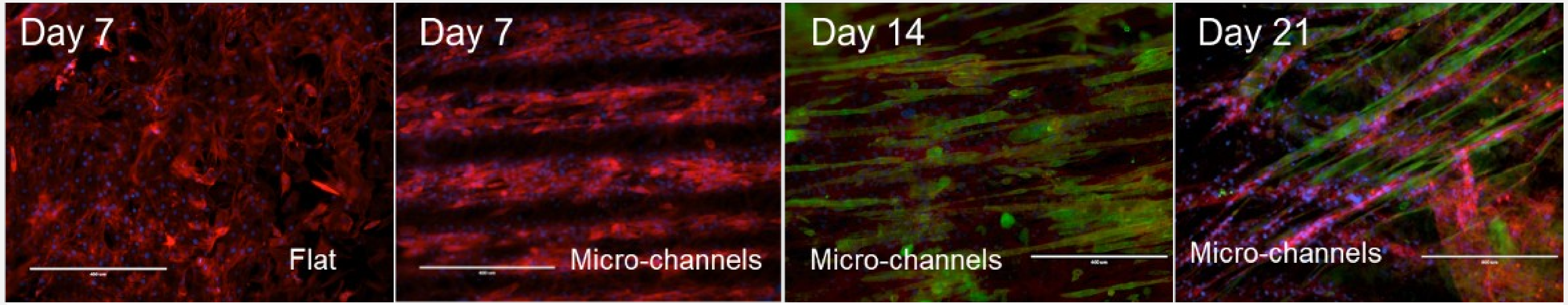
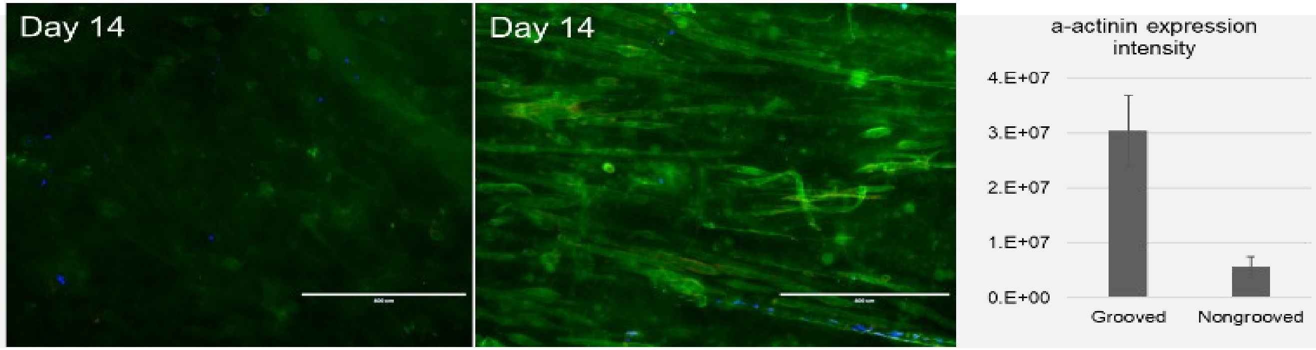
Myoblast Align on Micro-Channeled Collagen Films



Myoblasts on flat and micro-channeled collagen films. F-actin (red), sarcomeric α-actinin (green), and nuclei (blue). Scale bar =400um.



Myoblasts on flat (left) and on micro-channeled (right) collagen films. Immunostained against sarcomeric α-actinin (green). Graph shows relative intensity analysis (<u>$p < 0.001$, n=10, t-test</u>). Scale bar =400um.

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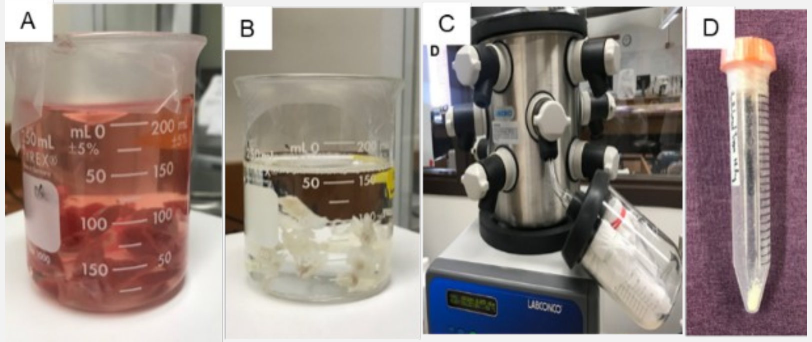
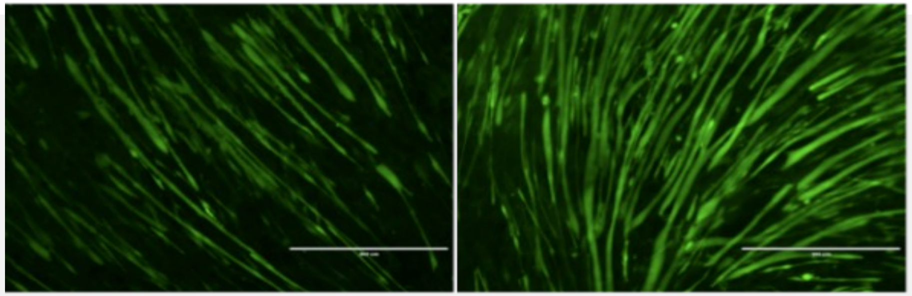
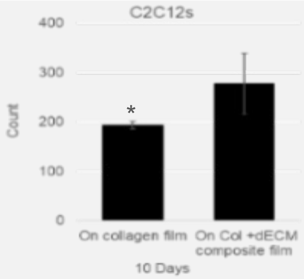
Myoblast Proliferation on Collagen-dSMM Scaffolds



Tissue ECM decellularization. The tissue is placed in 1% (w/v) SDS for 4-5 d. After processing the final tissue is a sterile powder that can incorporated with other materials.





Myoblasts growing on collagen only (left) and collagen with dSMM (right) for 10 days ($p < 0.045$, n= 4, t-test). Staining of live cells (Calcein AM). Scale bar =400µm.

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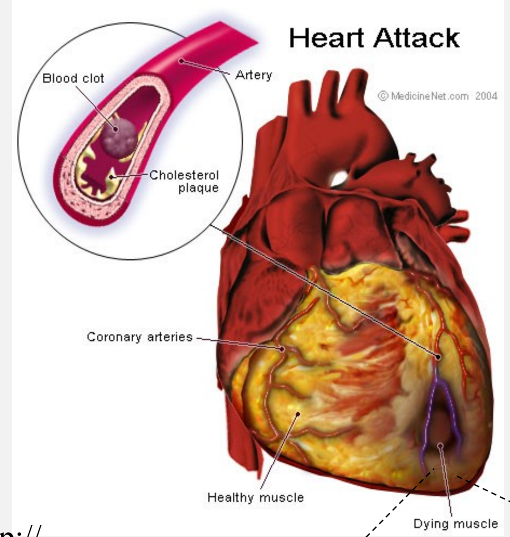
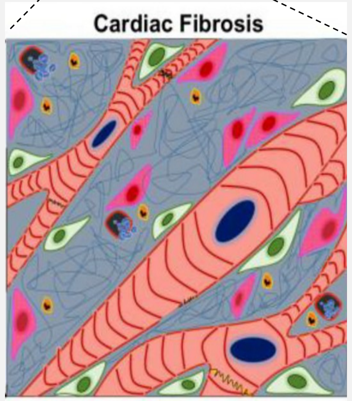
Cardiac Fibrosis



http://www.medicinenet.com/heart_attack/article.htm



- 1M Americans have coronary attack every year.
- MI is a major cause of heart failure, and currently 5M Americans suffer from this condition.

Objective: Establish an engineered model of cardiac fibrosis to investigate the role of critical players.

Adv Healthc Mater. 2017 June ; 6(11): . doi:10.1002/adhm.201601434.
American Heart Association

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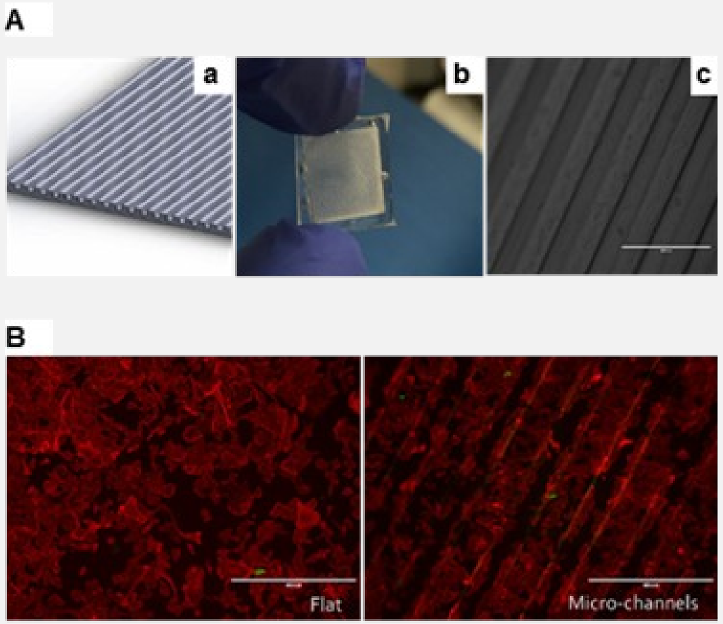
3D Model of Tissue Fibrosis Cell Organization



A) a) 3D printer is used to print the Solid Works model. b) PDMS (polydimethylsiloxane) mold with imbedded micro-channels. c) Microscopic image of channels on PDMS mold. Scale bar 400μm.

B) Cardiac myocytes (HL-1 cells) cultured on collagen scaffold without micro-channels and on collagen scaffold with micro-channels (Day 1, red=F-actin, scale bar 400μm).

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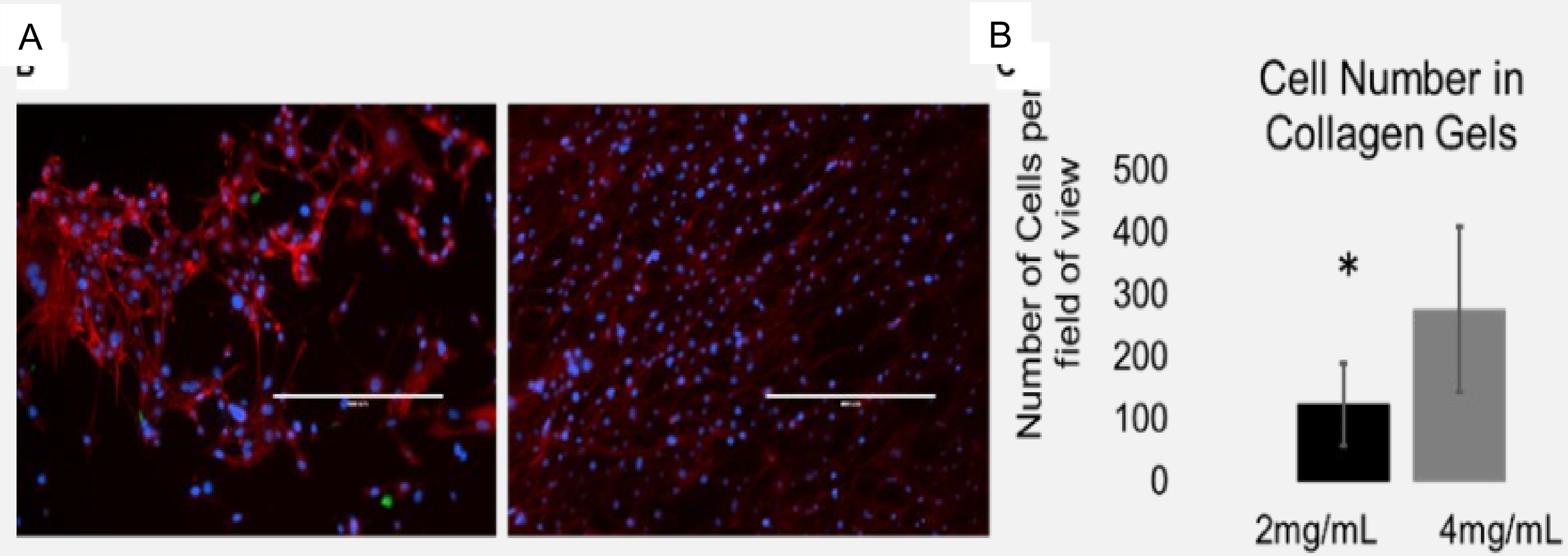
3D Models of Tissue Fibrosis, ECM Density



A) Fibroblasts in 2mg/mL collagen (left) and fibroblasts in 4mg/mL collagen, day 5 (right).

B) Number of Fibroblasts on day 5 in 2mg/mL collagen gels (black) and in 4mg/mL collagen gels (gray) (* $p < 0.02$).

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Engineering Models for Tissue Repair

Acknowledgements

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- ORSP
- COE RSCA Small Faculty Grant
- CSULB UROP
- CSULB RISE
- CSULB LSAMP

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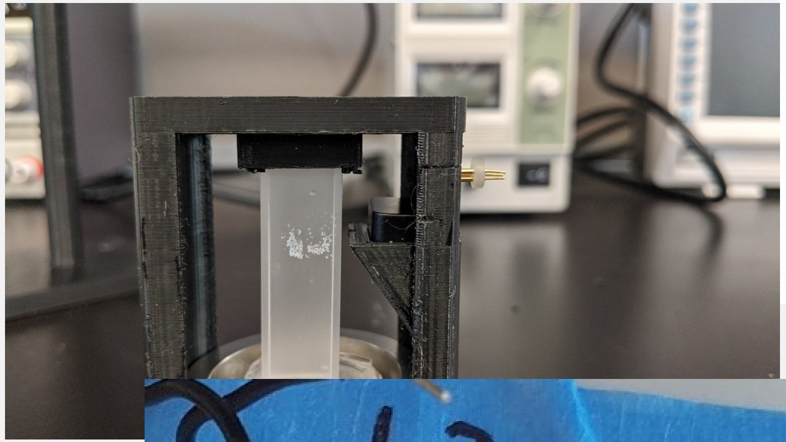
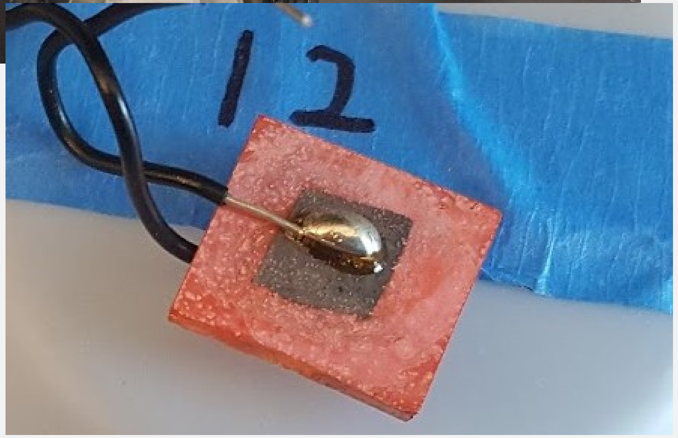
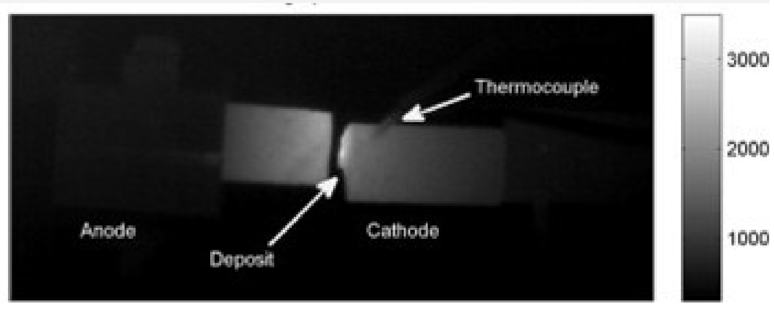
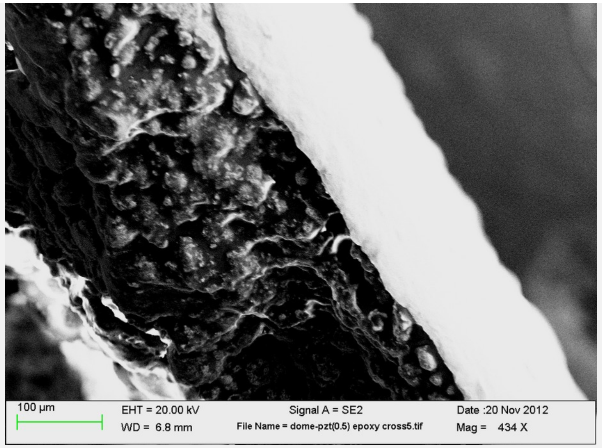
FRESNO STATE Discovery Diversity Distinction

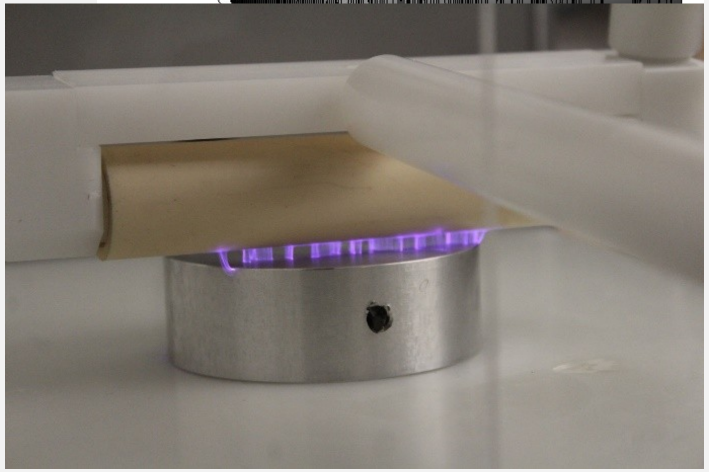
Design and fabrication of electro and photo-active materials for applications in biomedical devices and water purification











Sankha Banerjee, PhD
Assistant Professor/Graduate Program Coordinator
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Laboratory Focus Areas

- Materials Fabrication, Processing, and Characterization
- Wastewater Purification and Desalination
- Biomedical Devices and Applications

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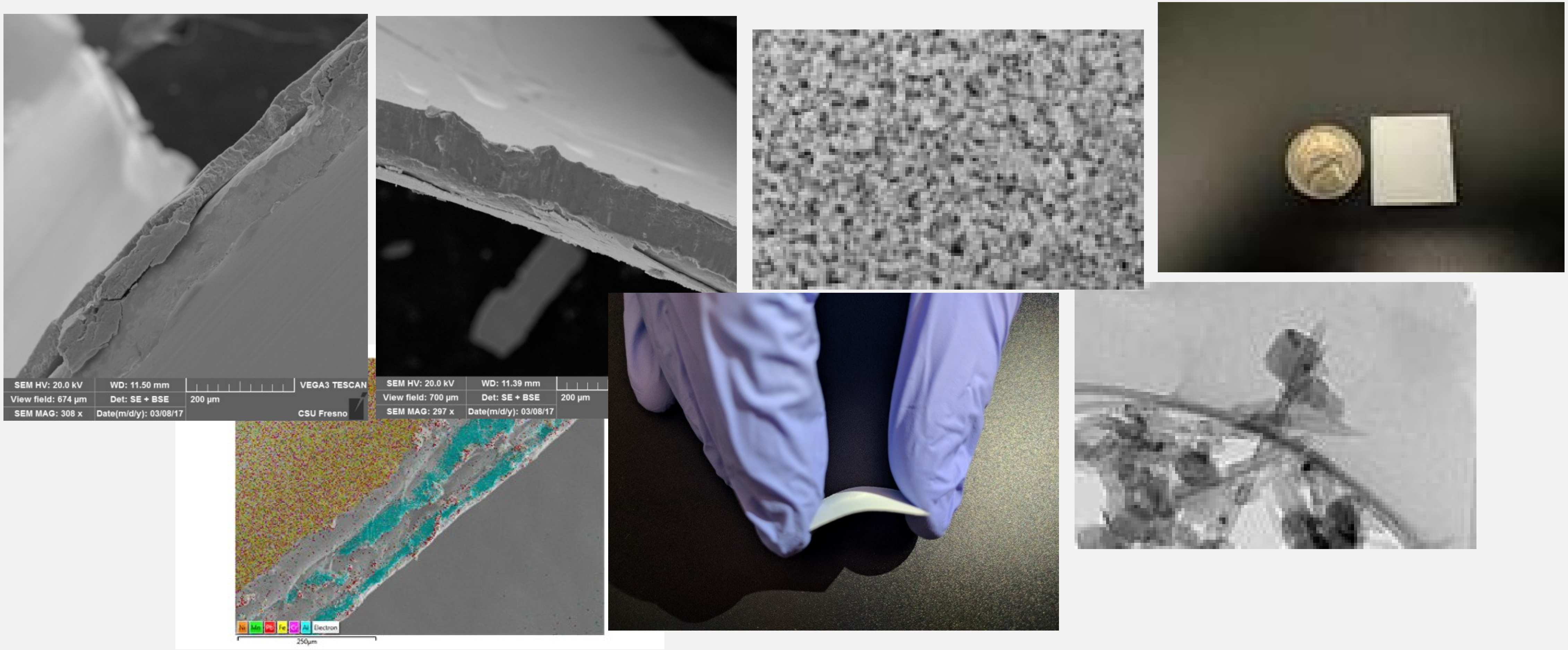
Flexible Multiphasic Electro-Active Thin Films Towards Development of Energy Harvesting Devices



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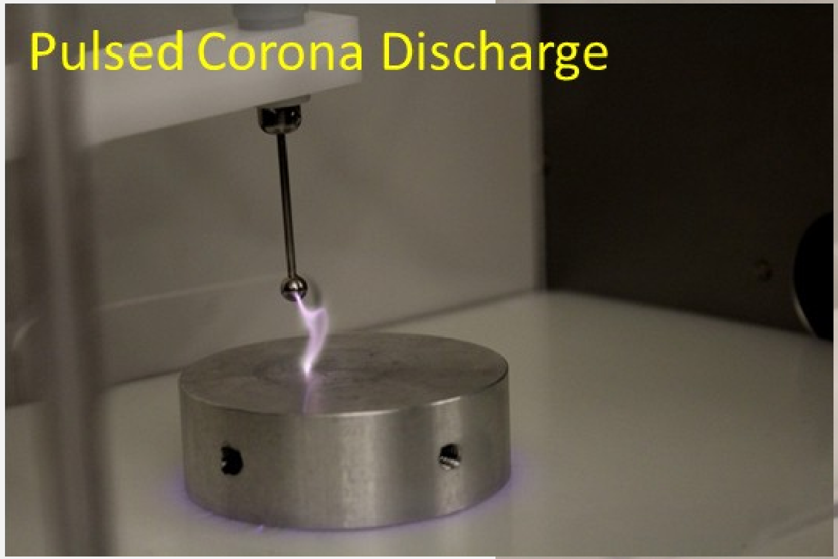
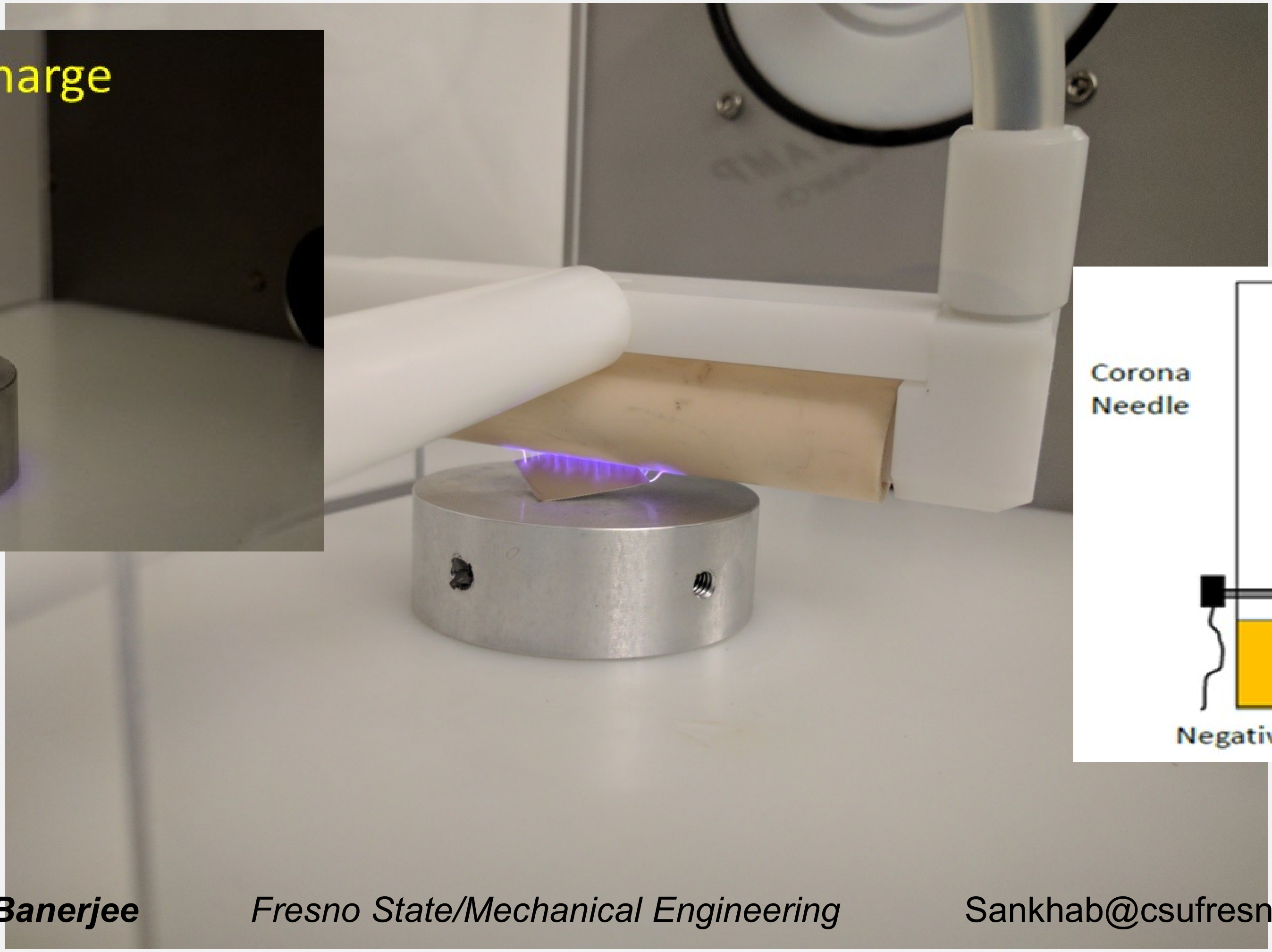
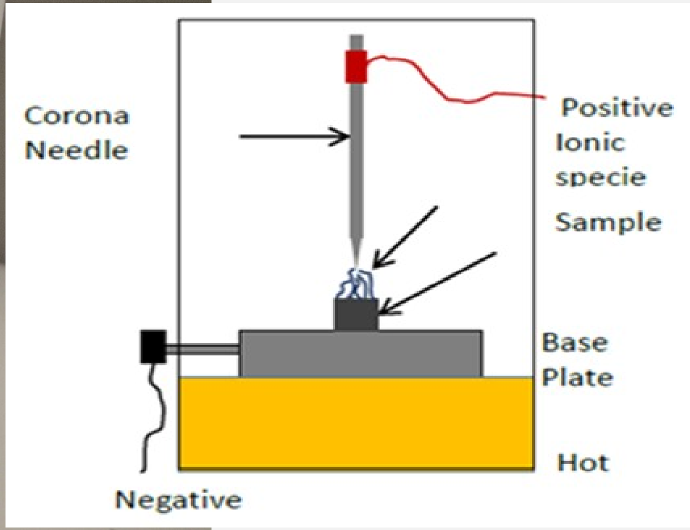
Plasma Micro-Discharge Based Processing & Surface Modification of Organic Matrix Based Flexible Electro- Active Composites







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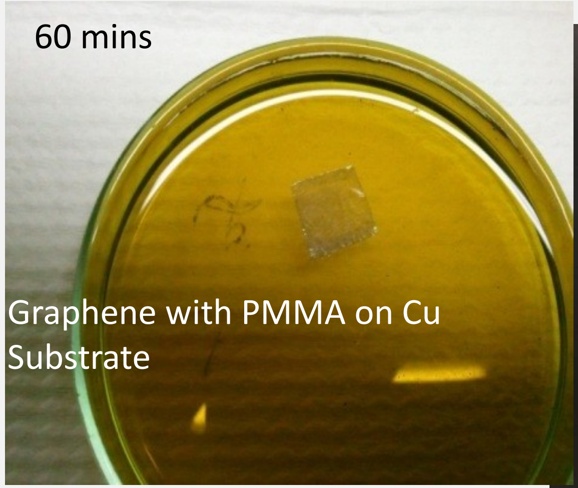
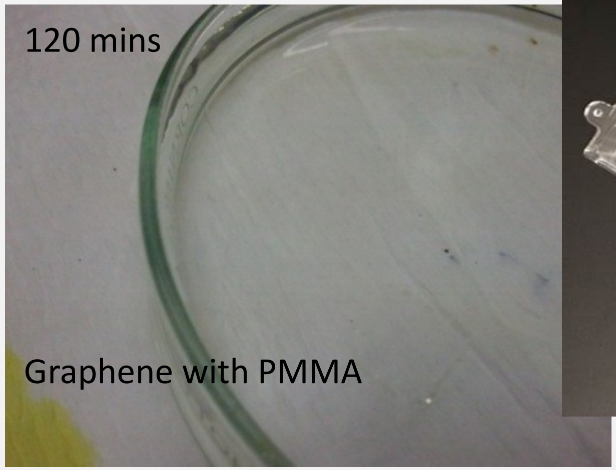
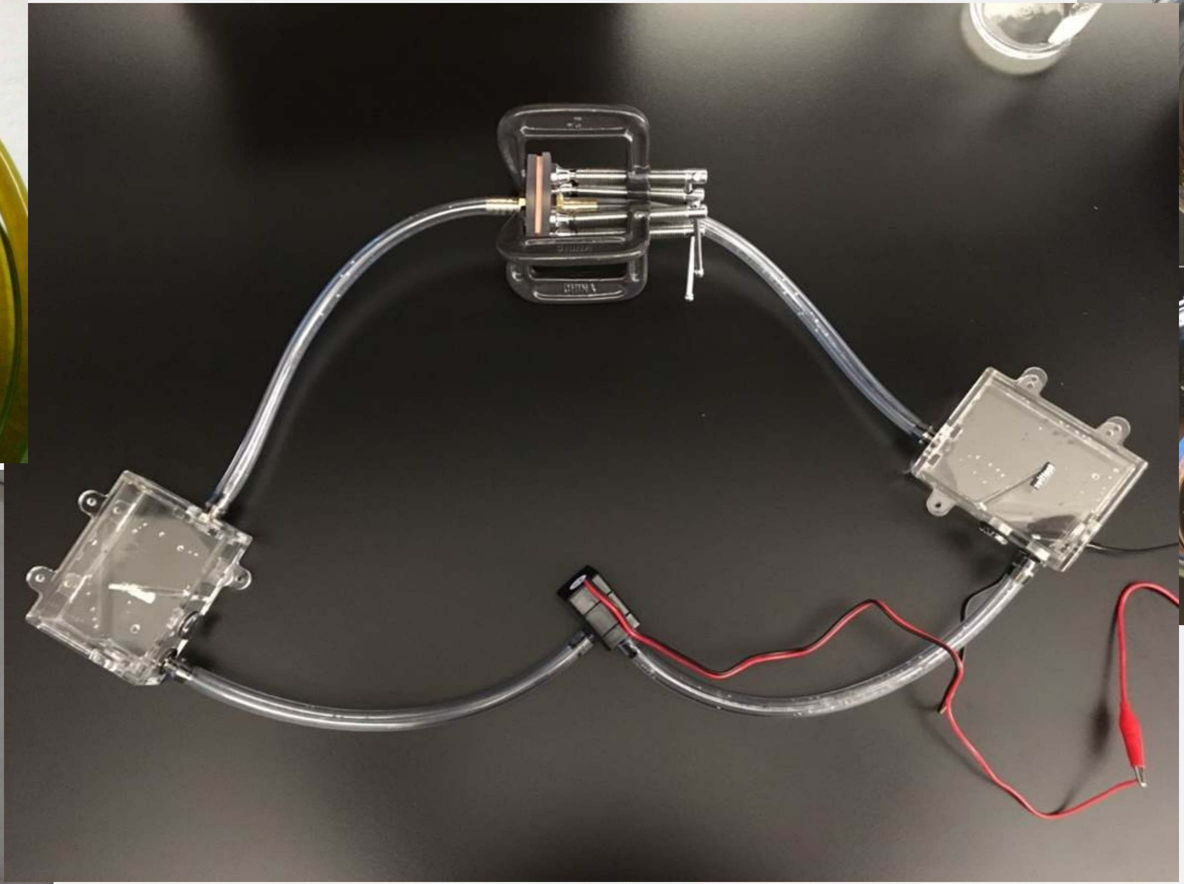
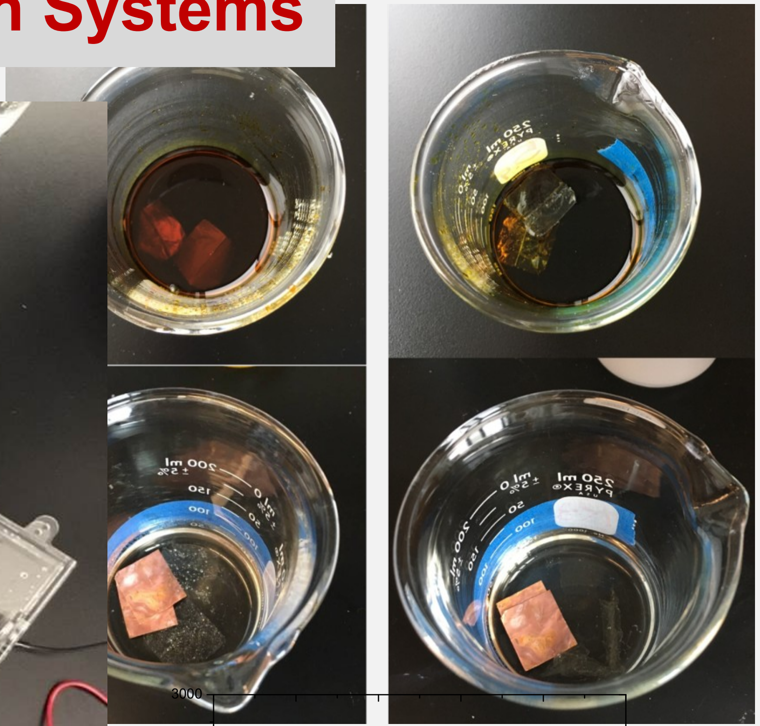
Design and Fabrication of Electro and Photo-Active Materials for Applications in Biomedical Devices and Water Purification

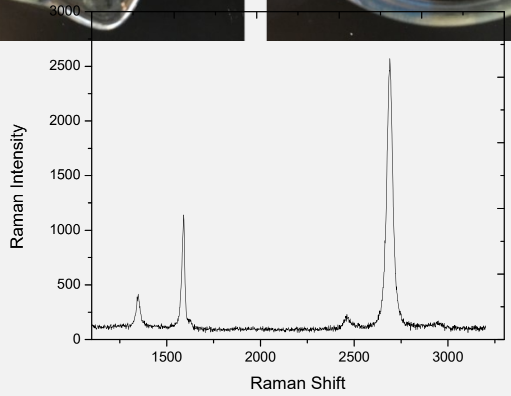
Fabrication of Graphene-based water Purification Systems











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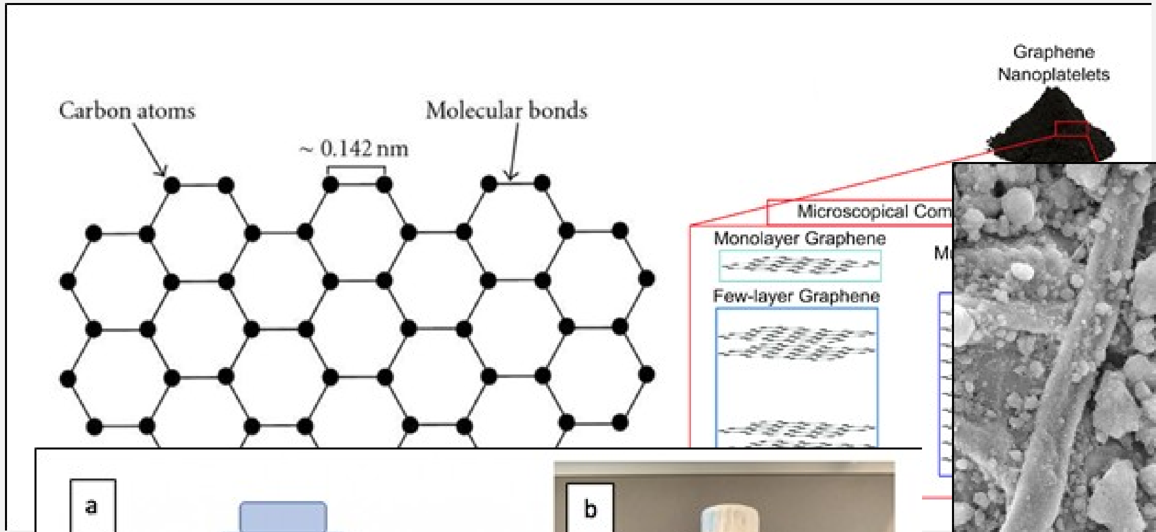
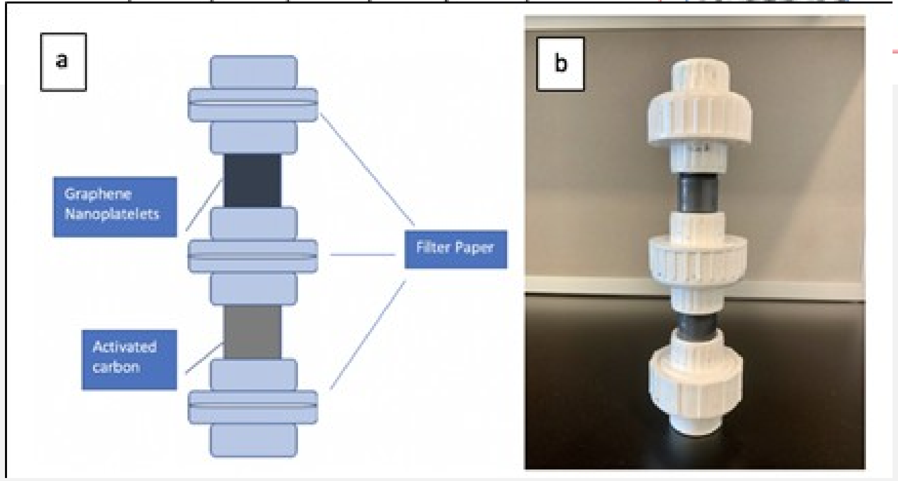
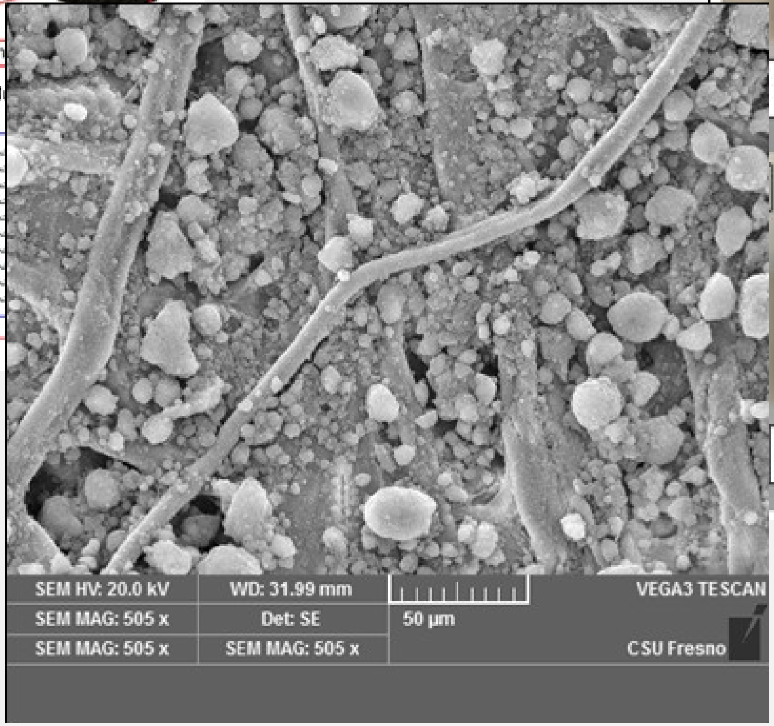
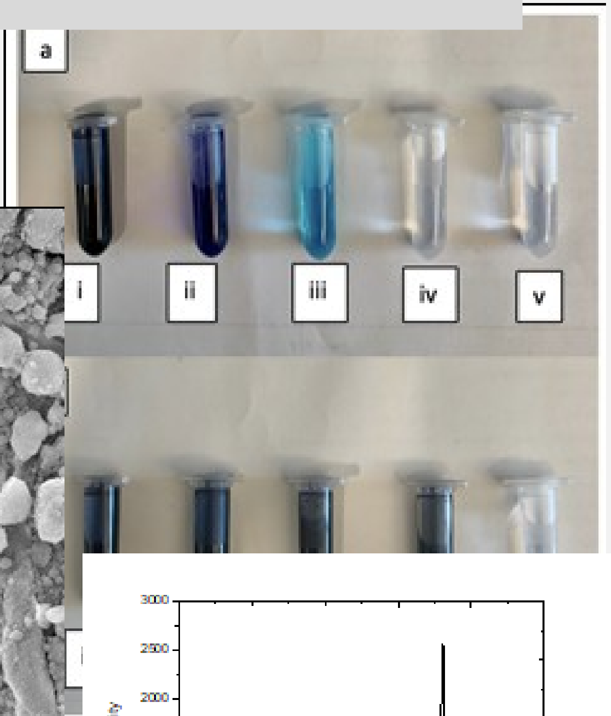
Design and Fabrication of Electro and Photo-Active Materials for Applications in Biomedical Devices and Water Purification

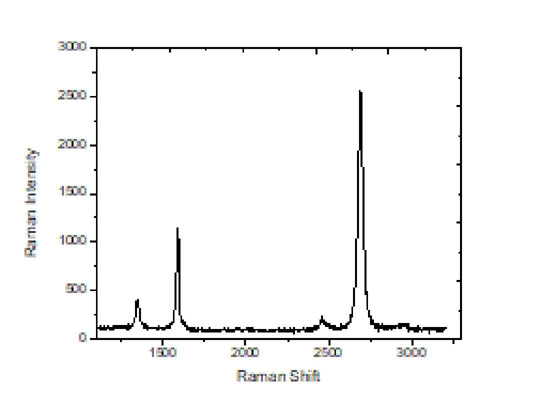
Fabrication of a Hybrid Graphene and Activated Carbon-based Water Purification System











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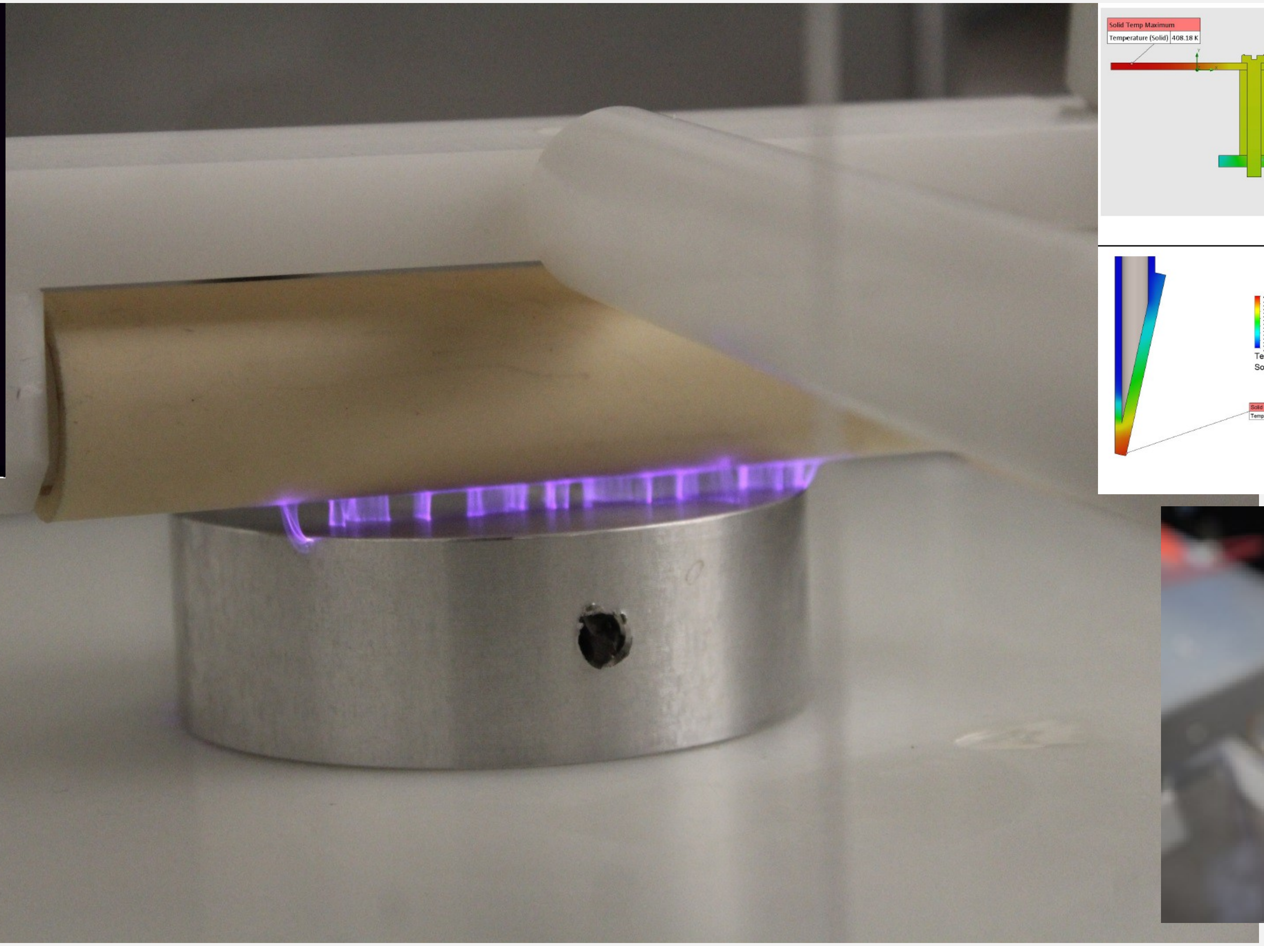
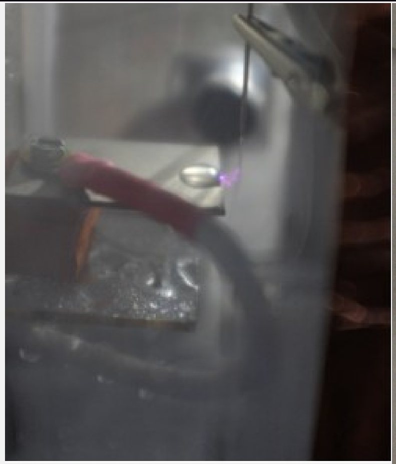
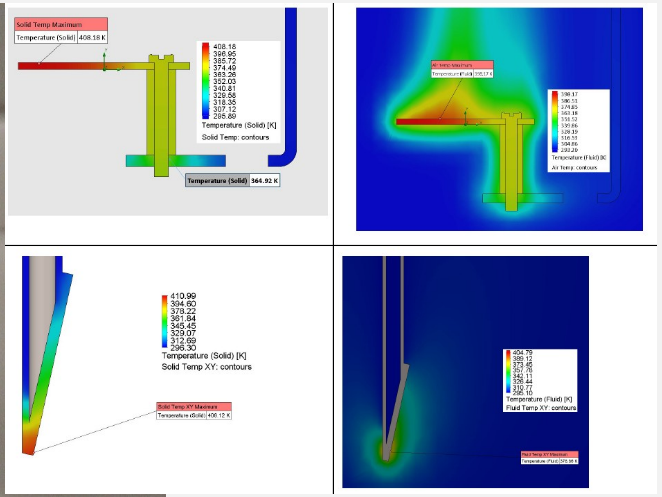
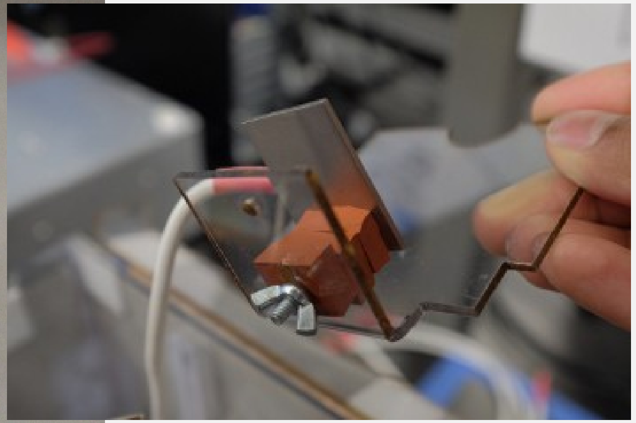
Design and Fabrication of Electro and Photo-Active Materials for Applications in Biomedical Devices and Water Purification

Plasma Micro-Discharge Based Water Purification & Non-Toxic Removal of Organic Contaminants in Wastewater









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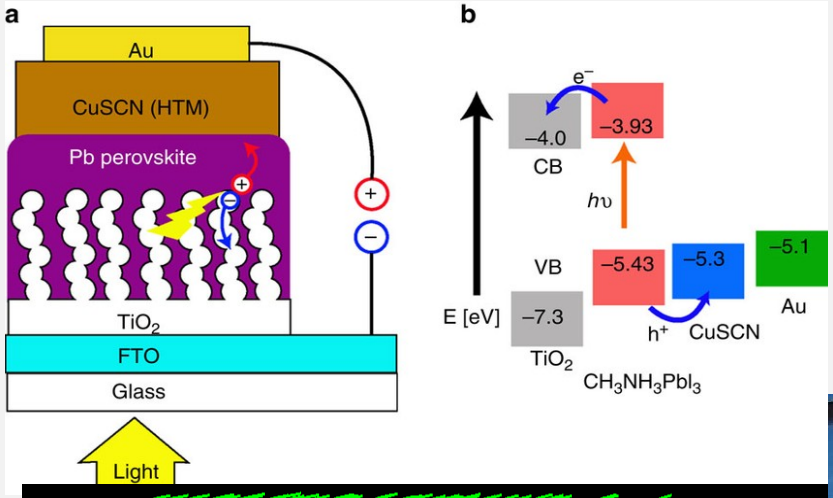
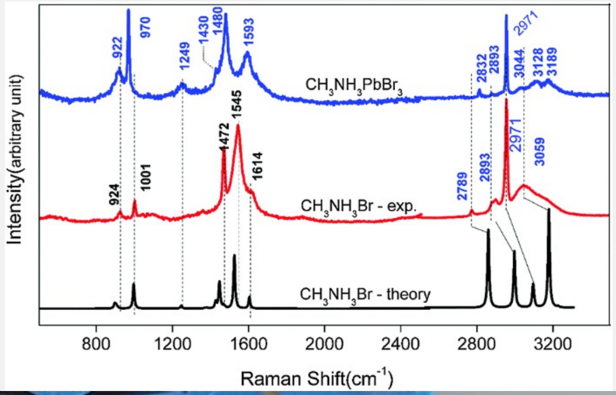
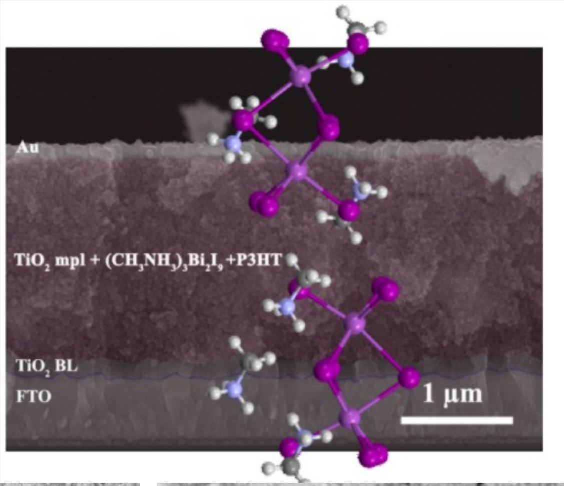
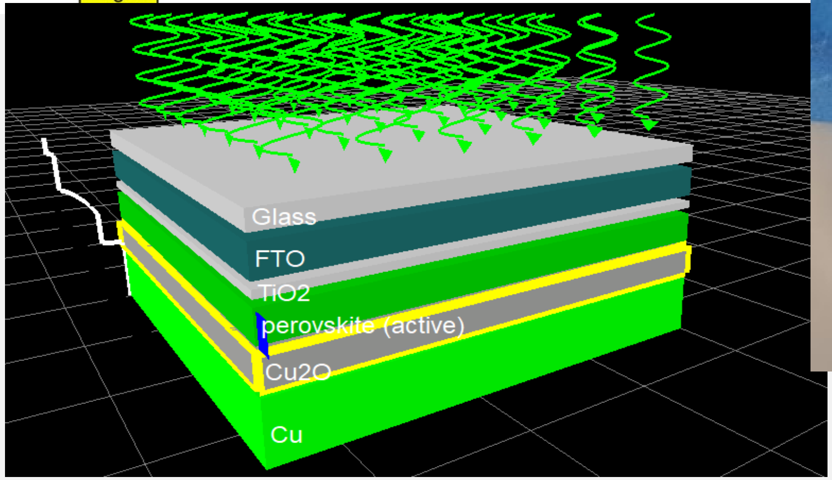
Design and Fabrication of Electro and Photo-Active Materials for Applications in Biomedical Devices and Water Purification

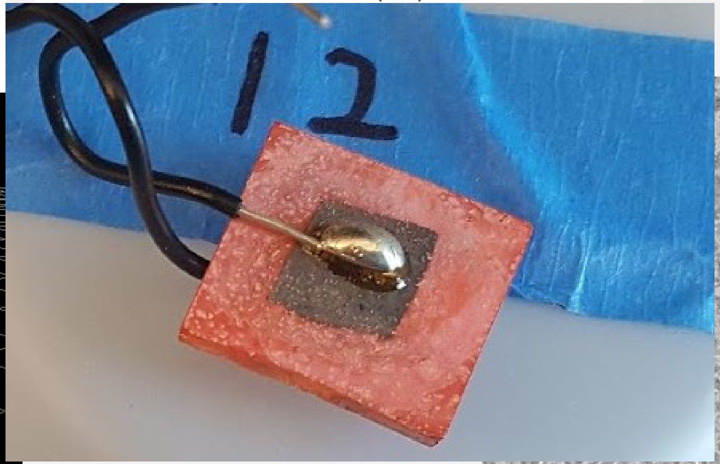
Fabrication/Simulation of Perovskite Cells and Biomedical Sensors

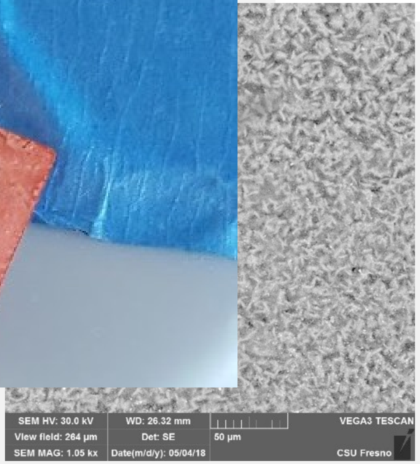


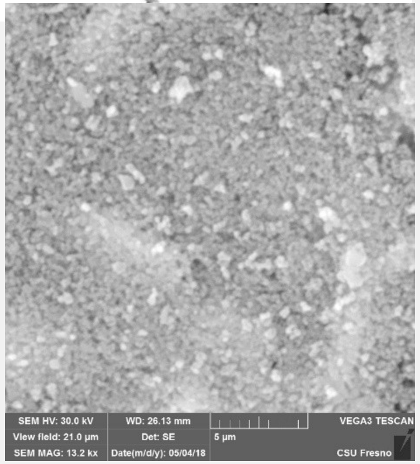








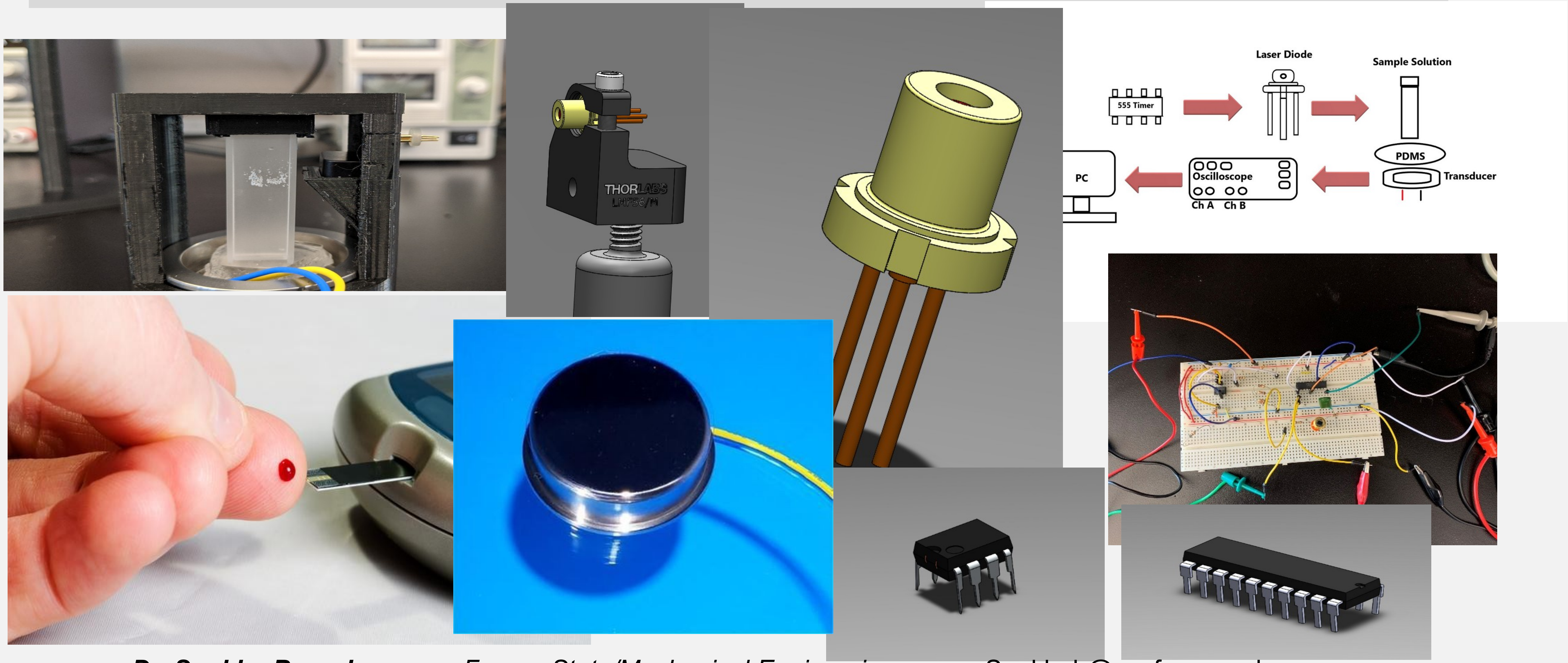




Dr. Sankha Banerjee *Fresno State/Mechanical Engineering* Sankhab@csufresno.edu

Design and Fabrication of Electro and Photo-Active Materials for Applications in Biomedical Devices and Water Purification

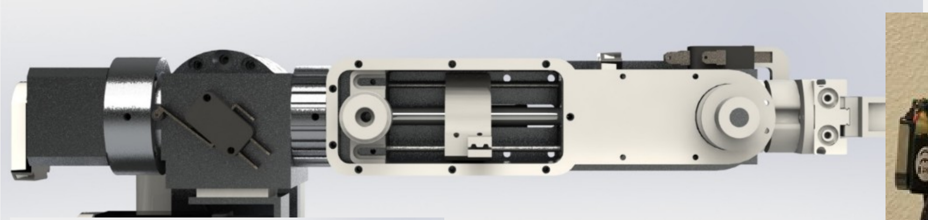
Integration of Plasma based 3D Printing: Towards development of Cell-selective Surfaces

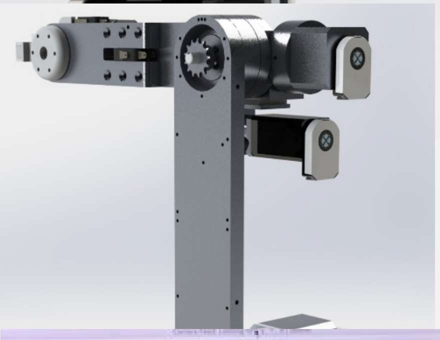


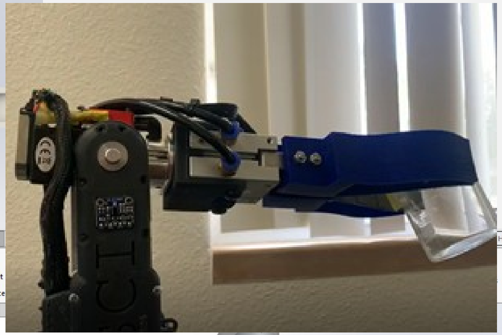
Dr. Sankha Banerjee *Fresno State/Mechanical Engineering* Sankhab@csufresno.edu

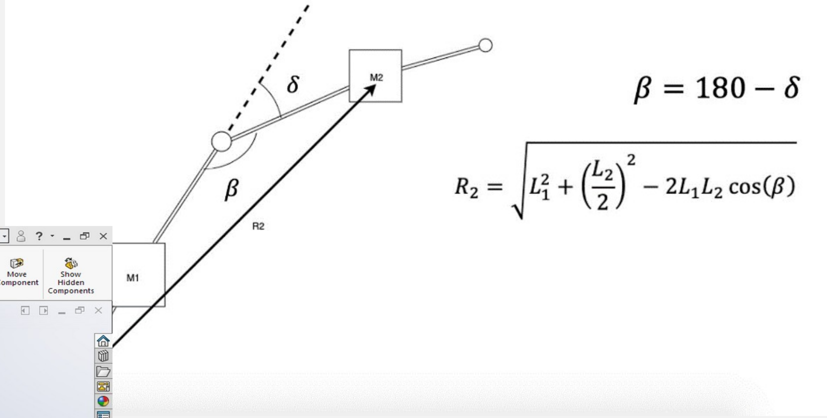
Design and Fabrication of Electro and Photo-Active Materials for Applications in Biomedical Devices and Water Purification

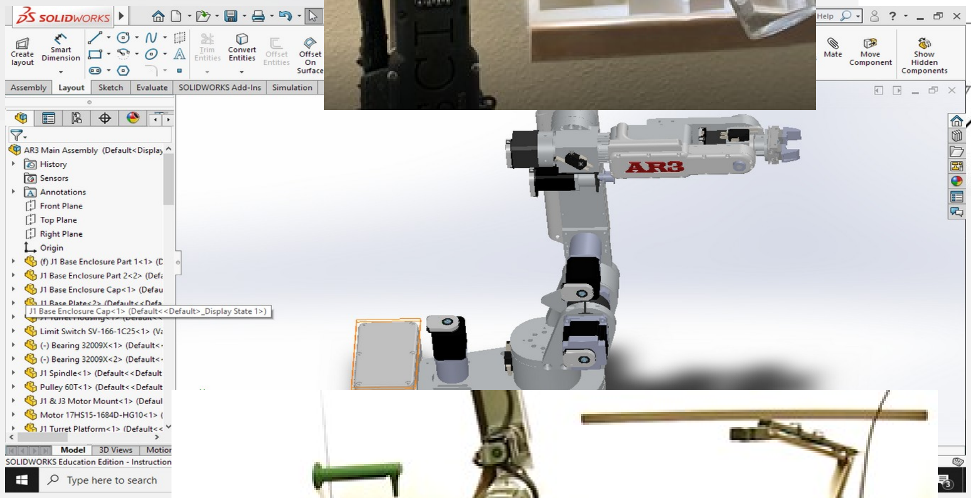
Robotic Arm Based Materials Handling: Towards Development of AI Machines for Semiconductor Fabrication and Biomedical Applications

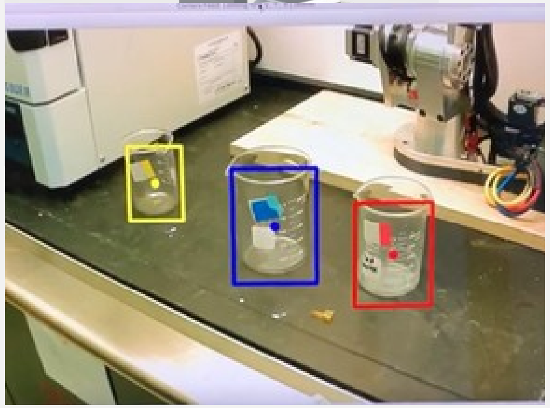


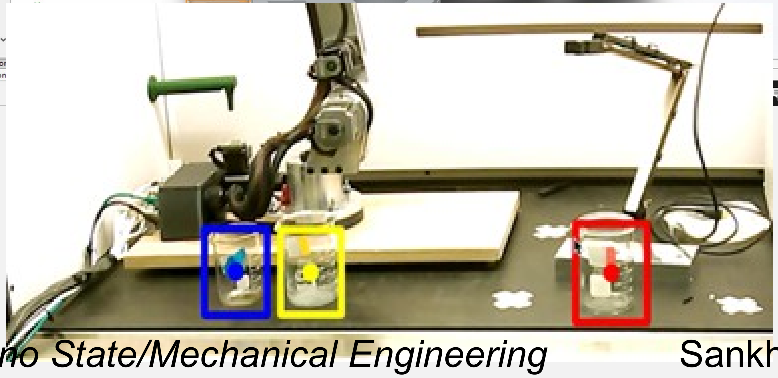












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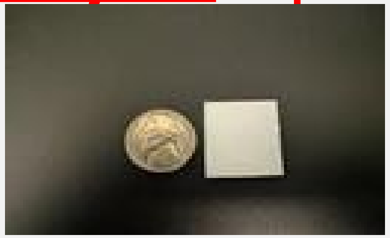
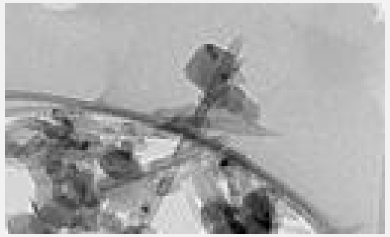
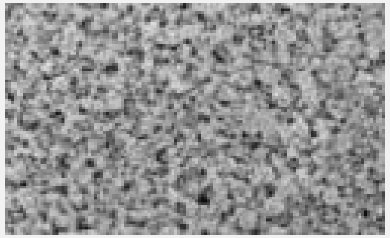
FRESNO STATE Discovery Diversity Distinction

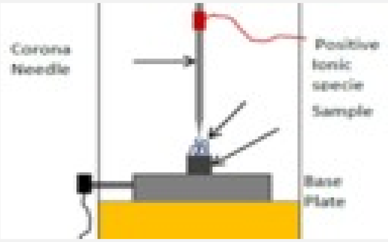
Design and Fabrication of Electro and Photo-Active Materials for Applications in Biomedical Devices and Water Purification

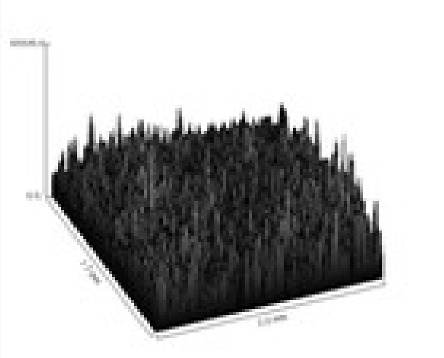
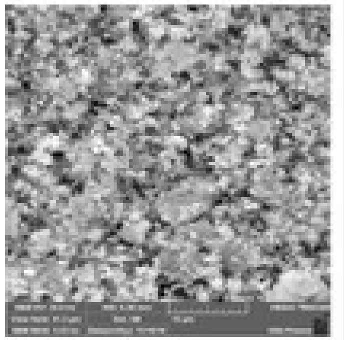
Current Projects

Current Projects: http://www.energyandplasma.com/research.html





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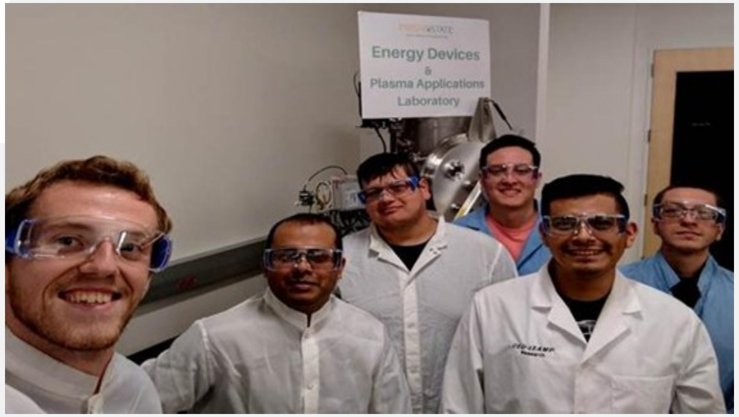
Design and Fabrication of Electro and Photo-Active Materials for Applications in Biomedical Devices and Water Purification

Acknowledgments

Current Group Members
- Gustavo Silva Hernandez (Research Engineer)

Graduate Students
- Mandeep Singh *(LCOE Graduate Fellow)*
- Noah Haworth *(LCOE Graduate Fellow)*
- Mai Tser Yang *(Graduate Equity Fellow)*

Undergraduate Students
- Jack Luong
- Riley Wells
- Faheem Shaikh



Lab Alumni

Jalen Harris (Connell University - PhD student starting in Fall 2020)
Walker Tuff (University of Notre Dame - PhD student starting in Fall 2020)
Daniel Apuan (UC Boulder - PhD Candidate)
David Martinez (UCLA - PhD Candidate)
Harlavpreet Brar (Project Engineer at West-Mark)
Yanan Gao (Faculty at Inner Mongolia University of Technology)
Sanjeev Kumar (Design Engineer at Processtec)
Adithya Katakam (Design Engineer at McLellan Industries)
Jaspreet Badesha (Mechanical Engineer at MEC)
Siddharth Mageshkumar (Mechanical Design Engineer at AB Welding Inc.)
Joshua Lor (Engineer at City of Fresno)
Attar Gill (Mechanical Engineer at MEC)
Shelby Sturgeon (Engineer at B-K Lighting)
Navtaj Sudan (Process Engineer at Virginia Transformer Corporation)
Tatiana Overturf-Tullock

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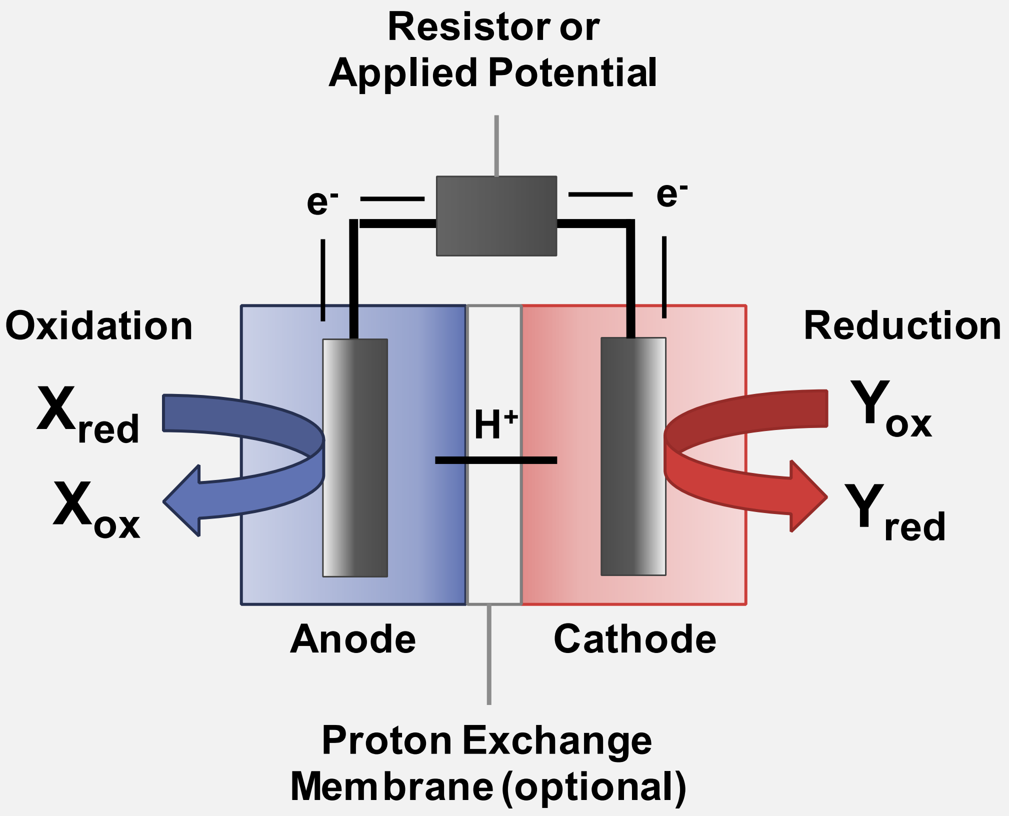
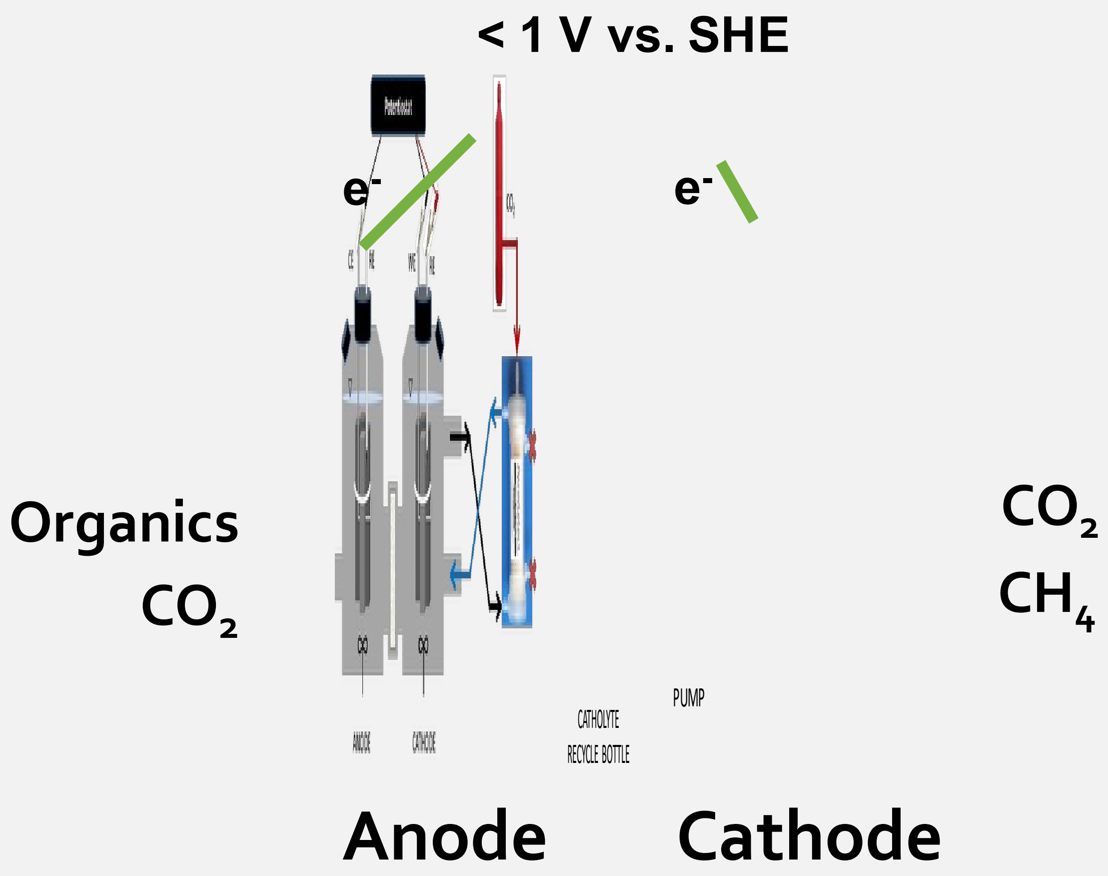
Resource Recovery using Bioelectrochemical Systems (BESs)

Christy M. Dykstra – San Diego State University

Christy M. Dykstra, Assistant Professor
San Diego State University (SDSU), Department of Civil, Construction and Environmental Engineering
cdykstra@sdsu.edu

Bioelectrochemical Systems (BESs)





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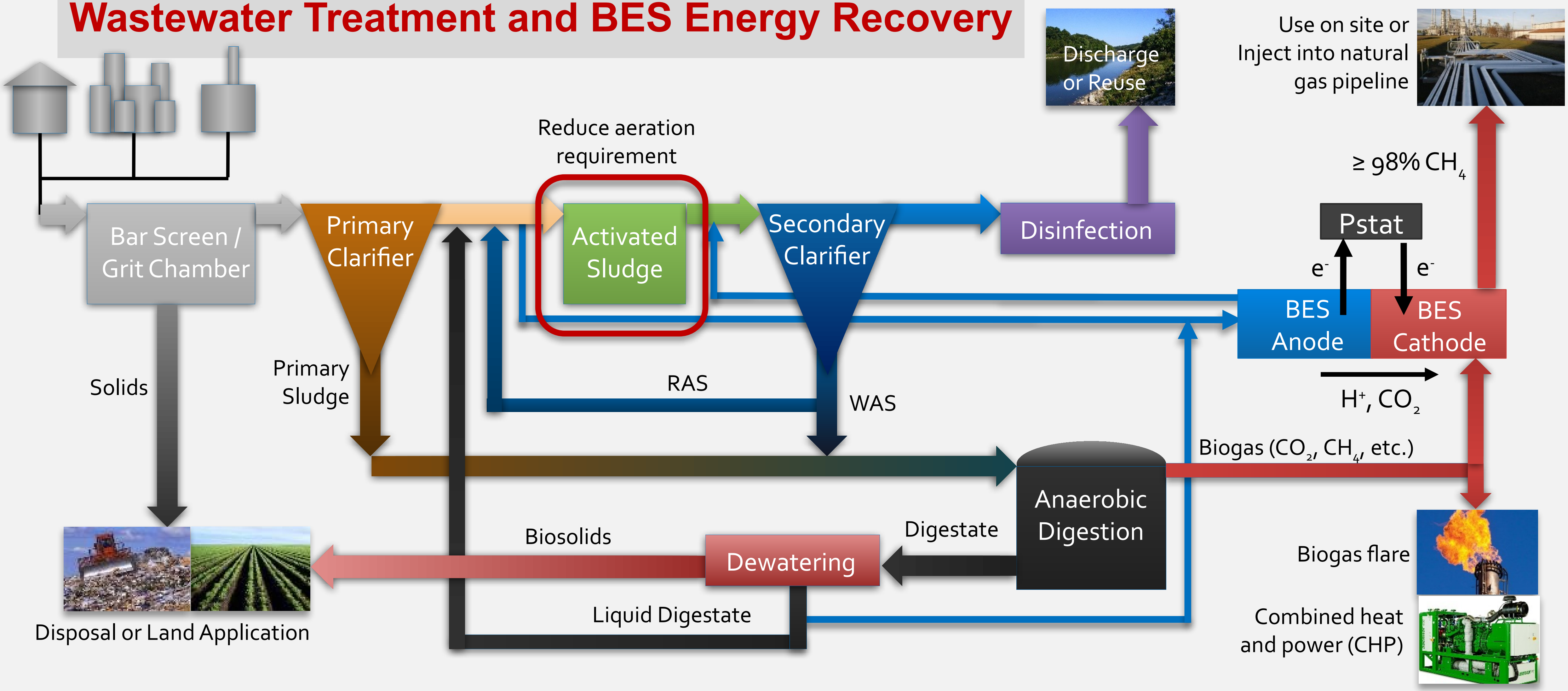
San Diego State University

Resource Recovery using Bioelectrochemical Systems (BESs)

Wastewater Treatment and BES Energy Recovery



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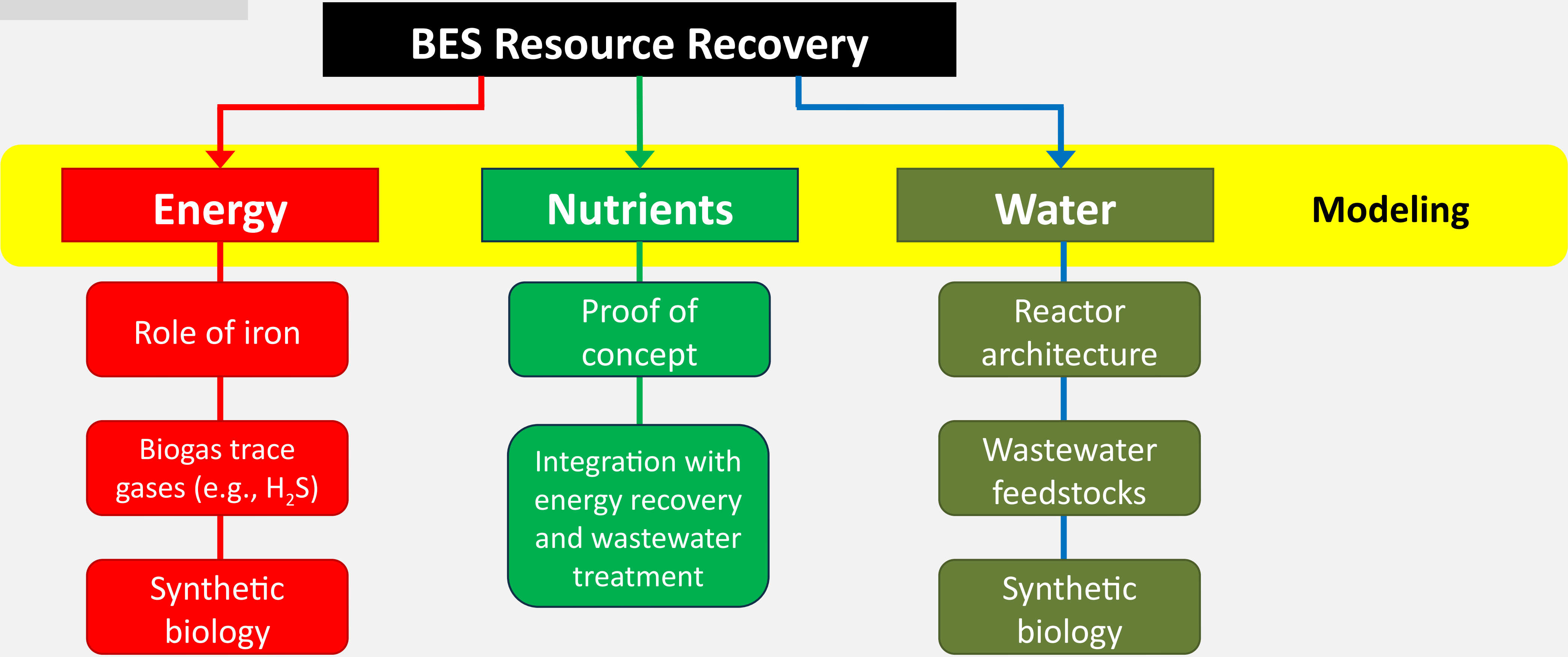
San Diego State University

Resource Recovery using Bioelectrochemical Systems (BESs)

Project Overview



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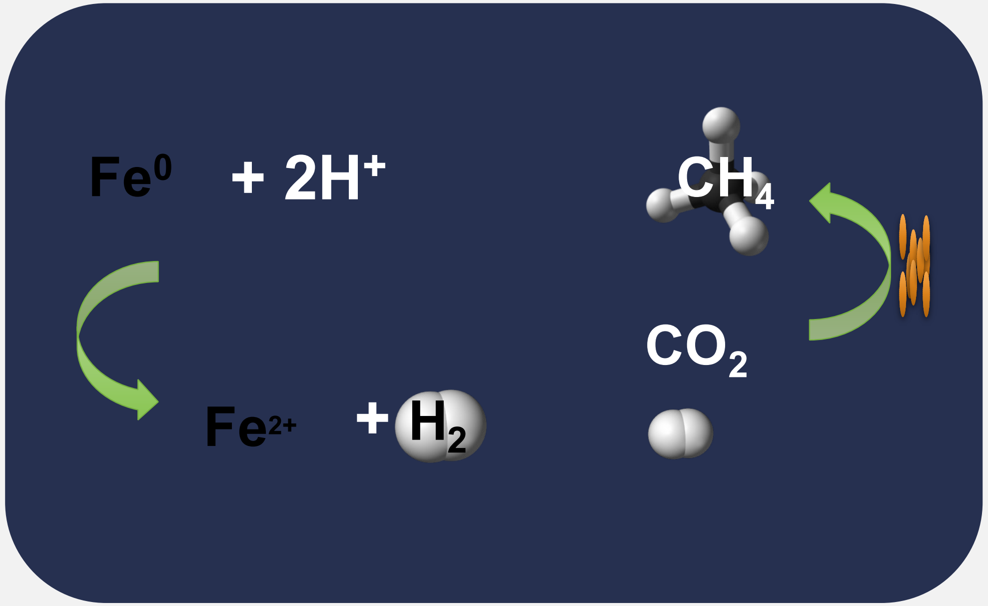
Resource Recovery using Bioelectrochemical Systems (BESs)

Activities

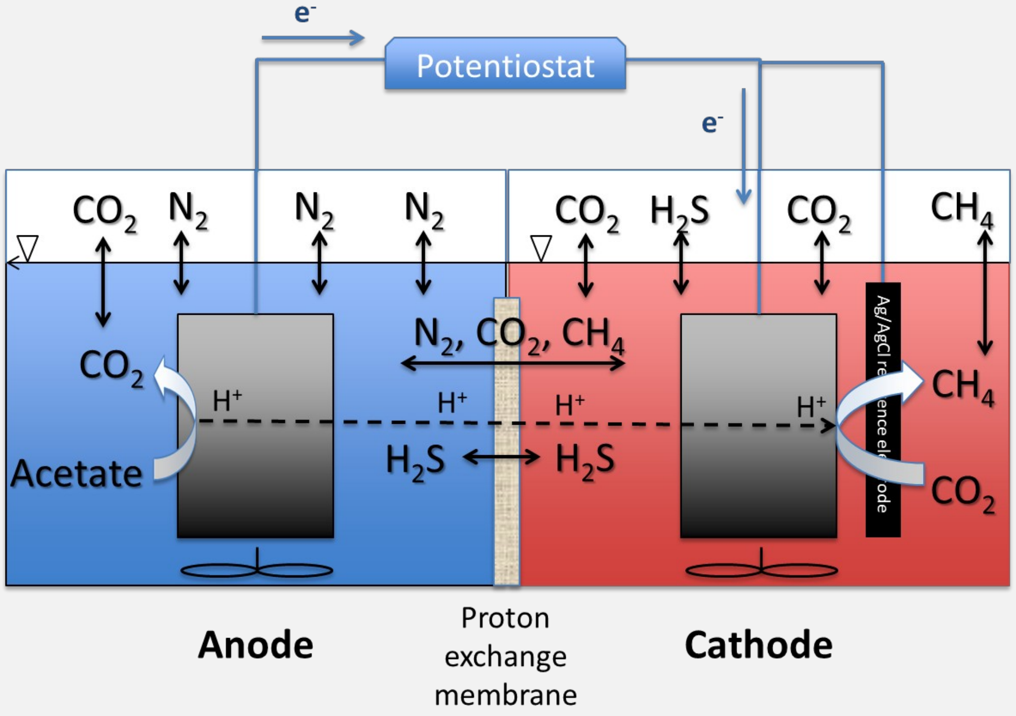
Zero Valent Iron- (Fe^0 -)Amended Biocathode



ZVI anaerobic corrosion

Hydrogenotrophic methanogenesis

Hydrogen Sulfide (H_2S) as a Trace Gas in the Biocathode



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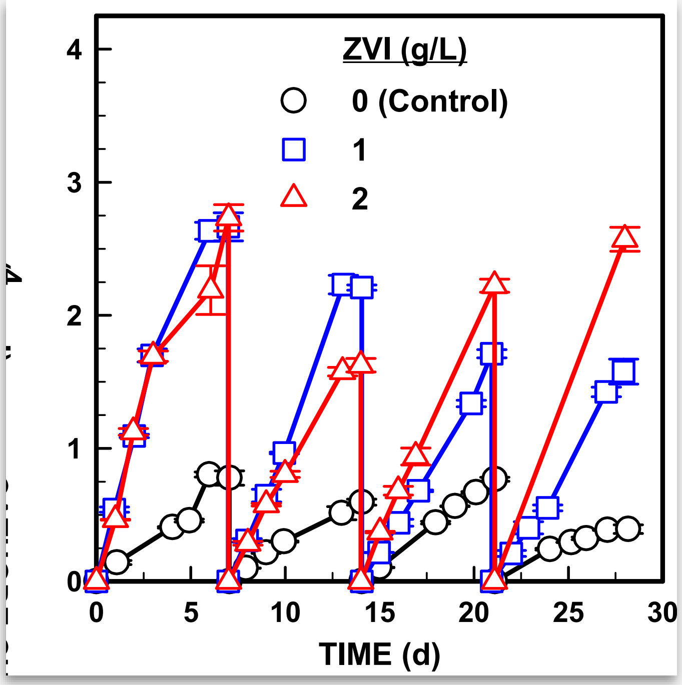
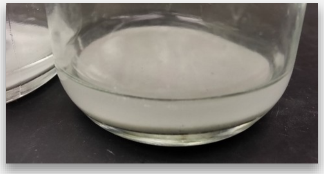
Resource Recovery using Bioelectrochemical Systems (BESs)

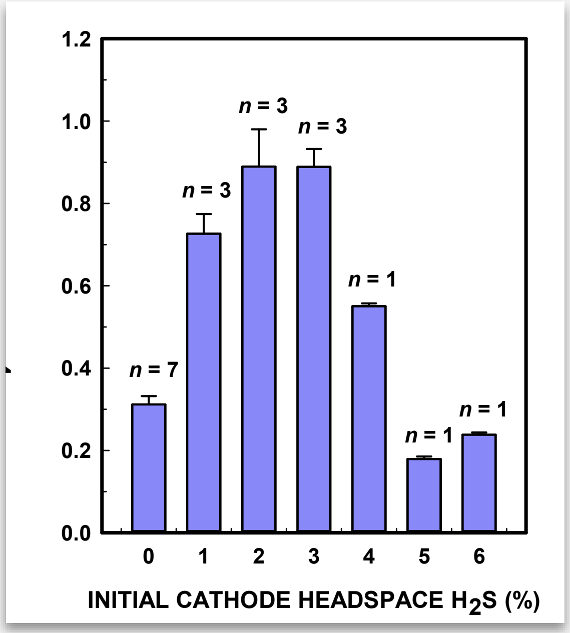
Results

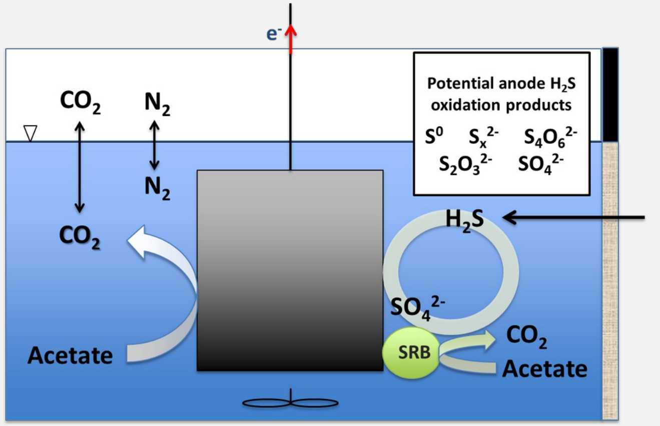
Zero Valent Iron- (Fe^0 -)Amended Biocathode





Hydrogen Sulfide (H_2S) as a Trace Gas in the Biocathode





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Lessons Learned

- Biocathode iron addition can significantly improve BES energy recovery
- Trace gases in anaerobic digester biogas (i.e., H_2S) can improve the rate of BES energy recovery
- Mechanisms for improvement in energy recovery from iron and sulfide need further investigation
- Anaerobic digestion biogas is a beneficial biocathode feedstock for BES energy recovery

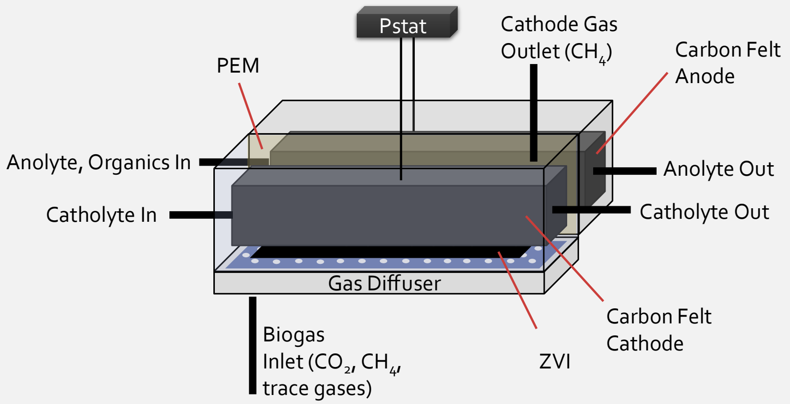
*A lot of fascinating questions remain in this **exciting, interdisciplinary work** to develop bioelectrochemical systems for resource recovery from wastewater.*

San Diego State University

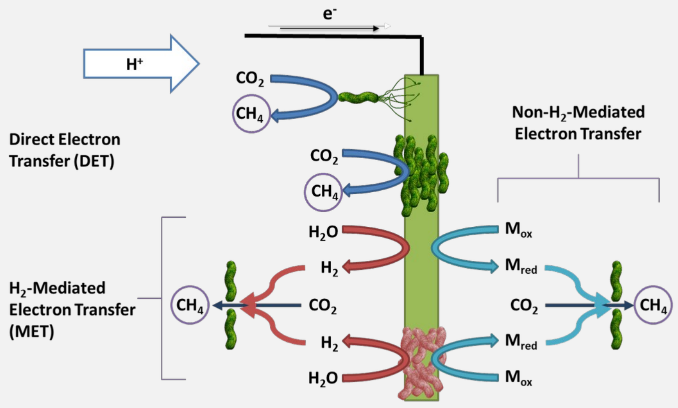
Resource Recovery using Bioelectrochemical Systems (BESs)

Next Steps

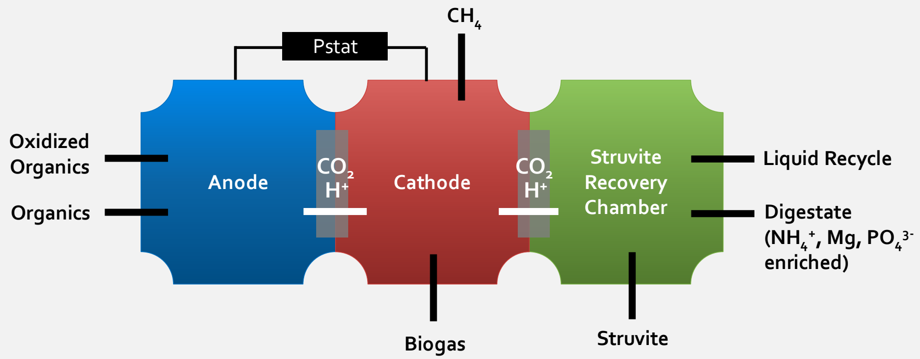
Improve reactor architecture



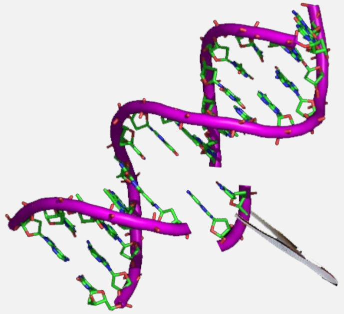
Investigate mechanisms



Integrate nutrient recovery



Increase energy efficiency with synthetic biology tools



Scale-up and pilot test

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Resource Recovery using Bioelectrochemical Systems (BESs)

Summary

Interdisciplinary Opportunities for Collaboration

- Biochemistry
- Bioengineering
- Biology
- Electrochemistry
- Environmental Engineering
- Environmental Sciences
- Materials Science
- Mechanical Engineering
- Modeling

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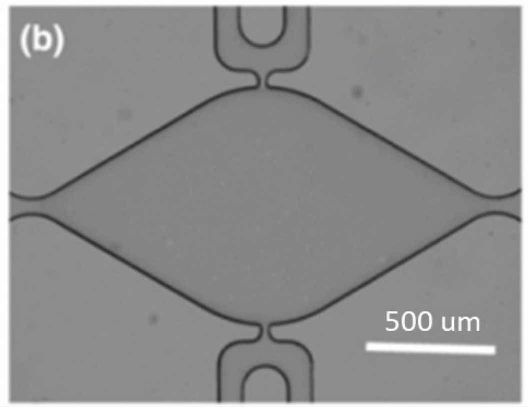
Vascularized Human Tumors on a Chip for Drug Screening

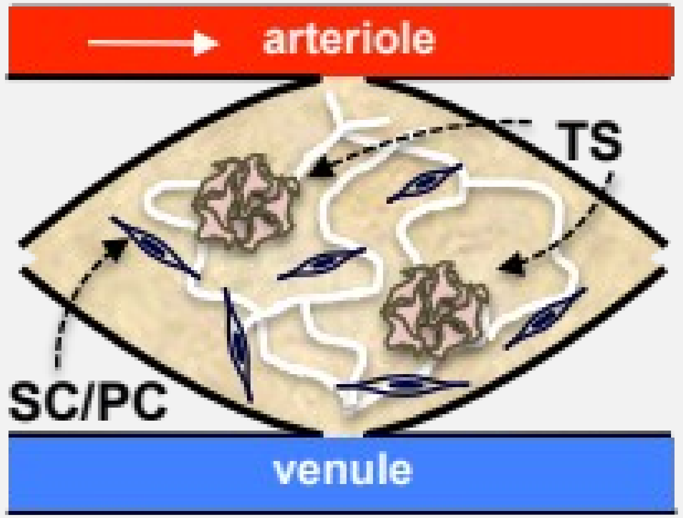
Christopher Heylman – Cal Poly, San Luis Obispo

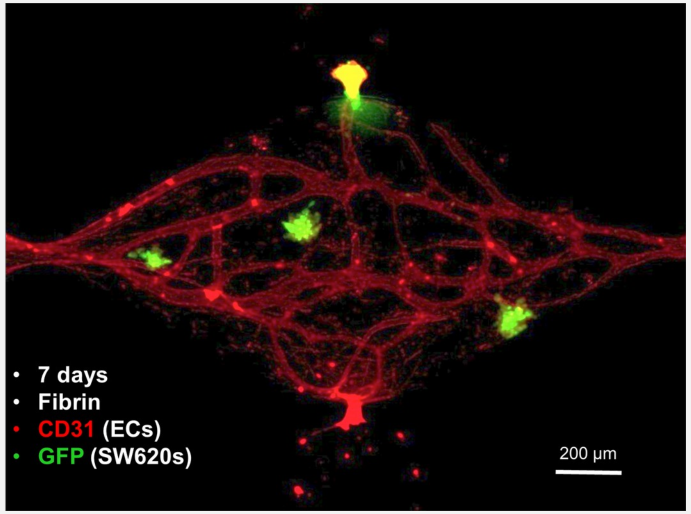
Christopher Heylman, Assistant Professor
Cal Poly San Luis Obispo, Department of Biomedical Engineering
cheylman@calpoly.edu

Project Overview

- 3D Microphysiological Systems
  - Perfused microvasculature
  - ECM / Stromal cells
  - Interstitial flow
  - All human cells
  - 3D tissue
- Drug Discovery & Development
  - Better tissue response info
  - Fail faster







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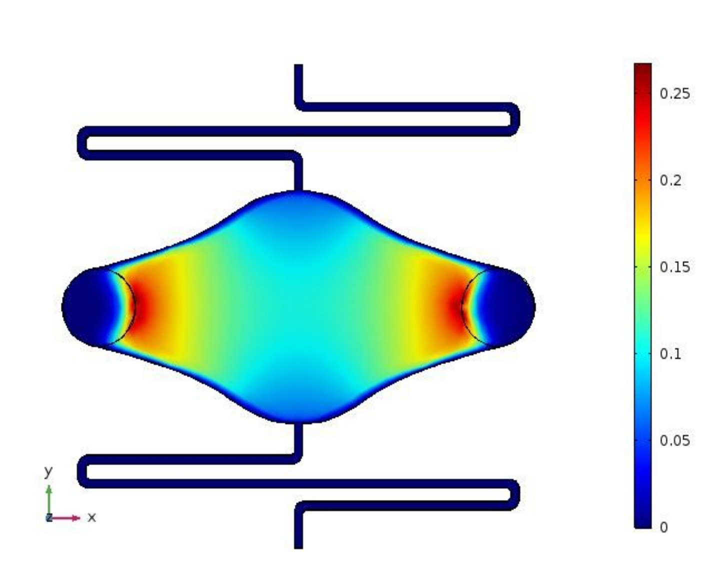
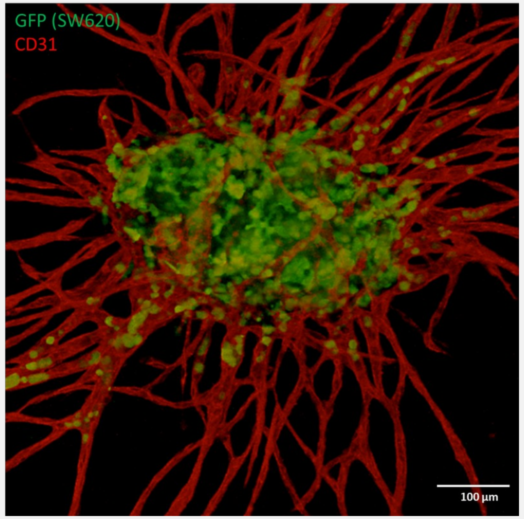
Activities

- 3 Core Projects

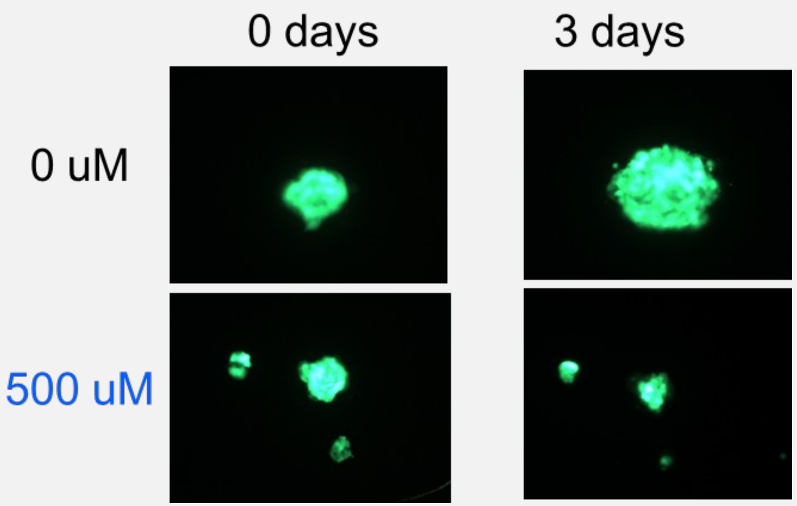
Microfluidic Device Design and Testing



Injectable 3D ECM / Cell Solution



Tumor Drug Response



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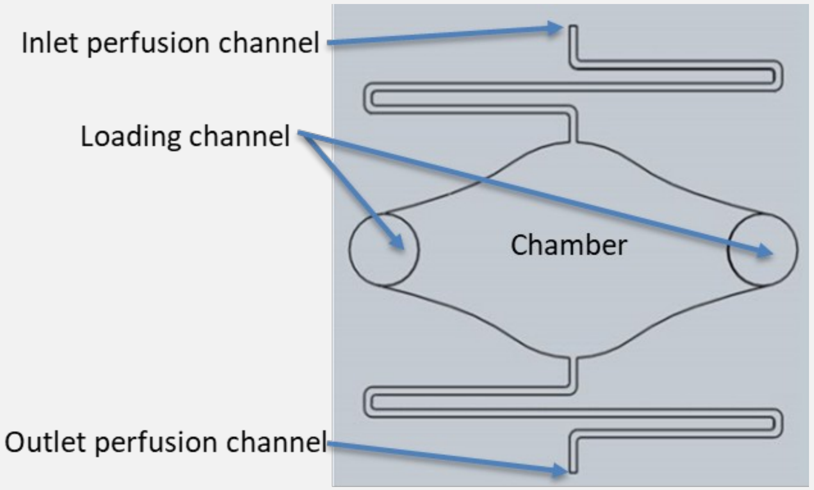
Vascularized Human Tumors on a Chip for Drug Screening

Results

- Microfluidic Device Design
  - CAD
  - Flow simulation (COMSOL)
  - Fabrication (soft lithography)
  - Flow validation

Iterate



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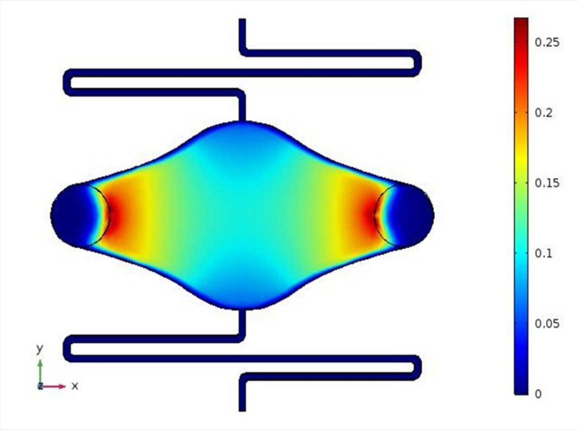
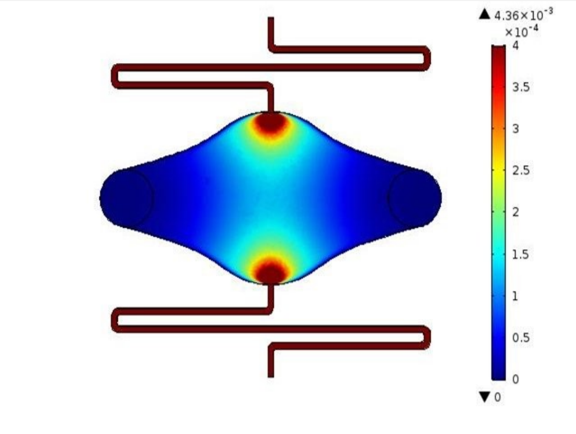


Perfusion



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Vascularized Human Tumors on a Chip for Drug Screening

Results

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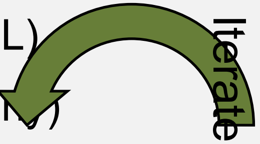
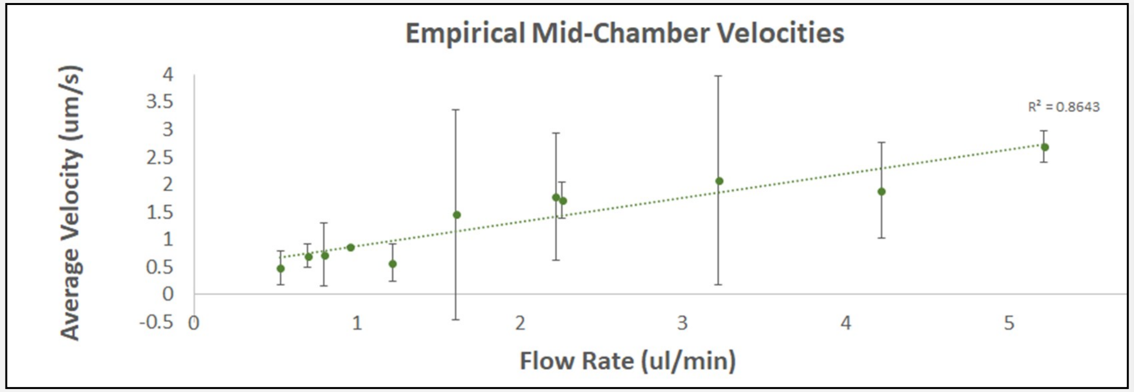
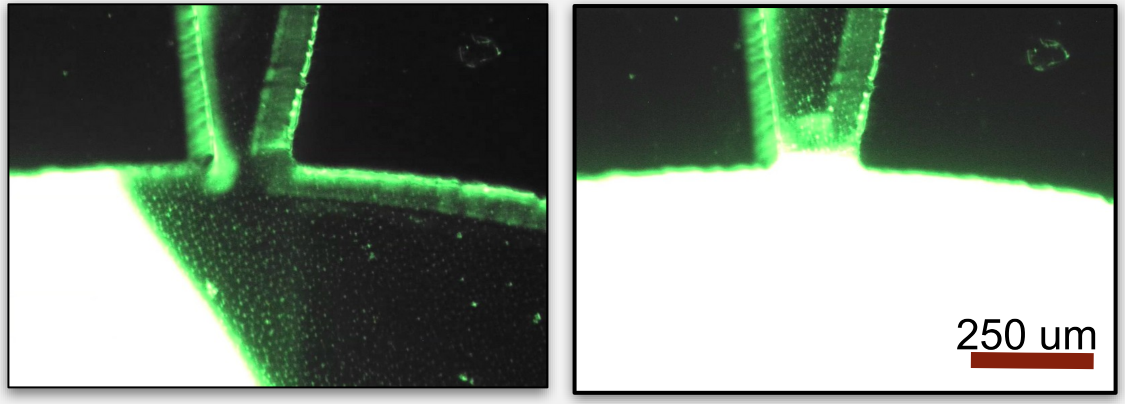




ECM Loading



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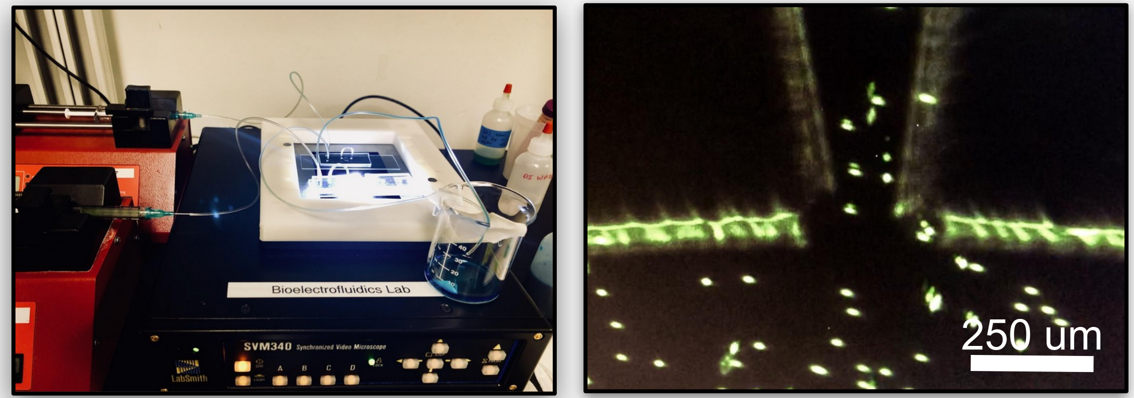

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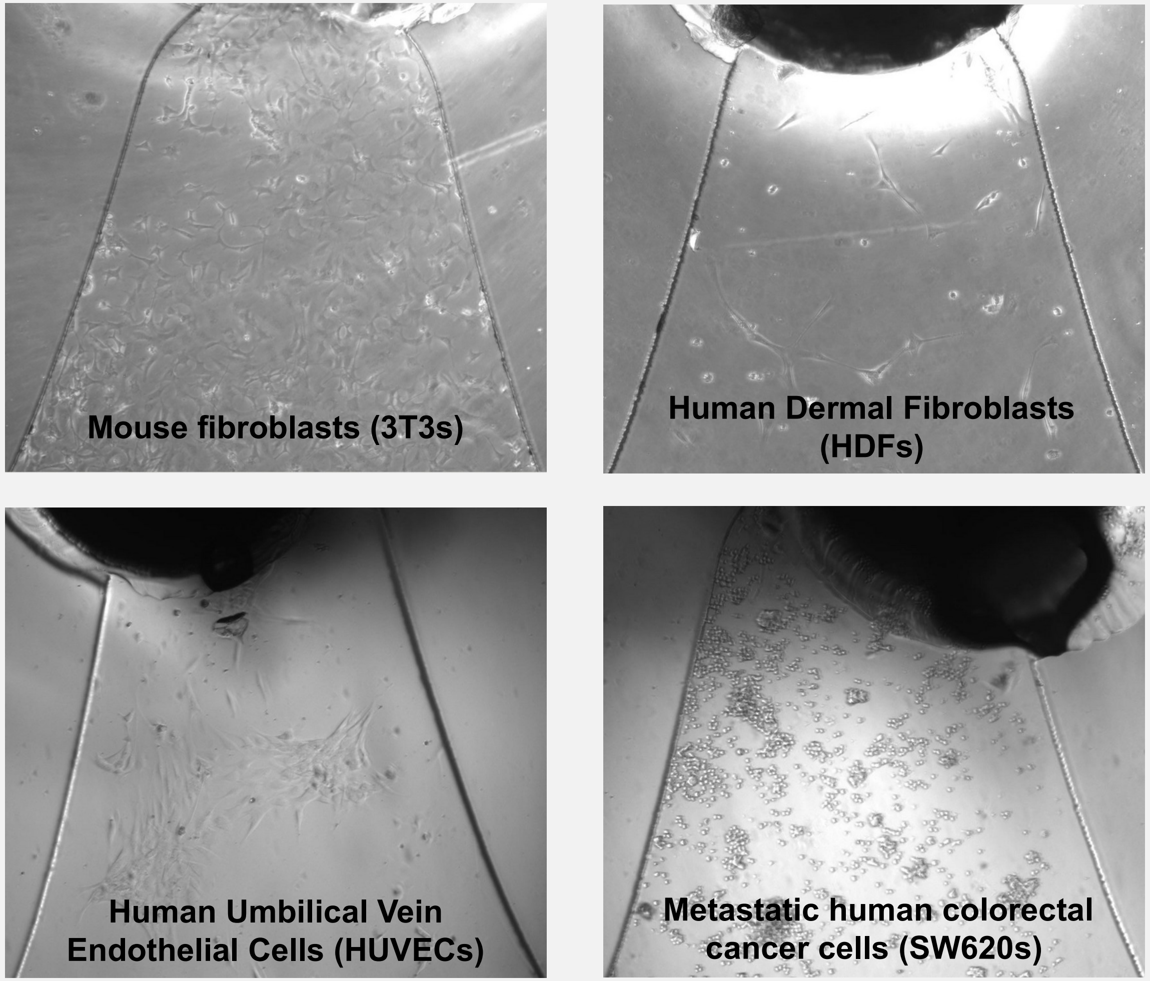
Results

- Cell Loading
  - Load
  - Perfuse for 24 hours
  - Viability and retention



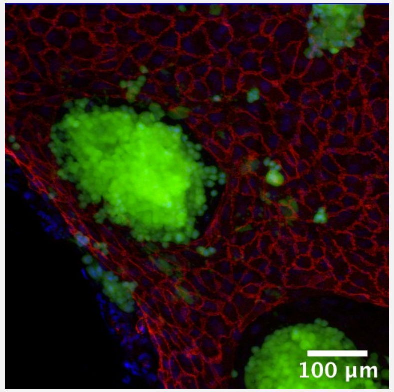
Christopher Heylman *Cal Poly San Luis Obispo / Biomedical Engineering* *cheylman@calpoly.edu*

Vascularized Human Tumors on a Chip for Drug Screening

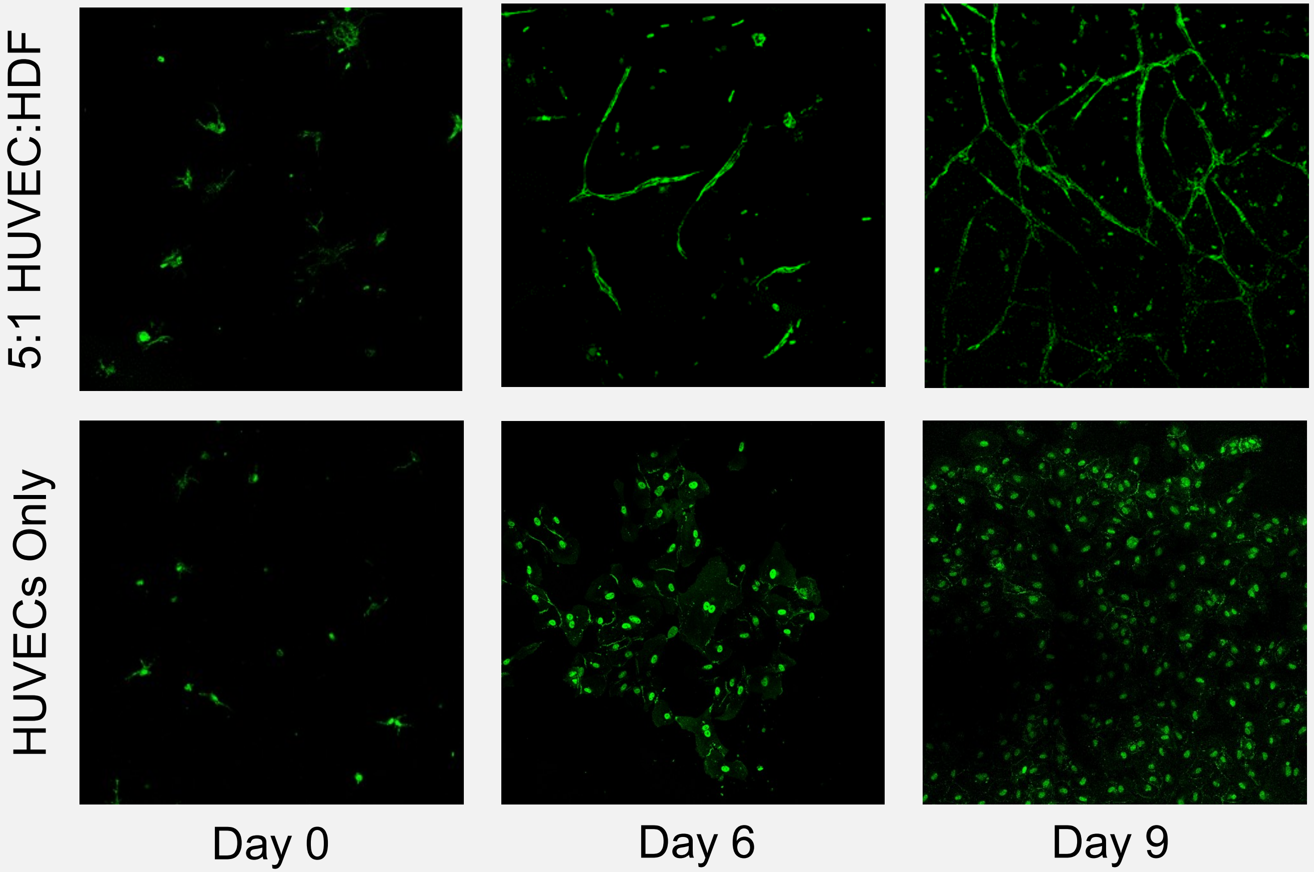
Results

- Injectable 3D ECM / Cell Solution
  - Cells suspended in liquid fibrinogen
  - Thrombin + Fibrinogen → Fibrin (gel)
  - Suspends cells in 3D
  - ***HDFs needed to form vessels***

Tumor / EC / HDF
SW620 (Tumor)
HUVECs (PECAM)
Hoechst (Nuclei)



HUVECs (VECAD)



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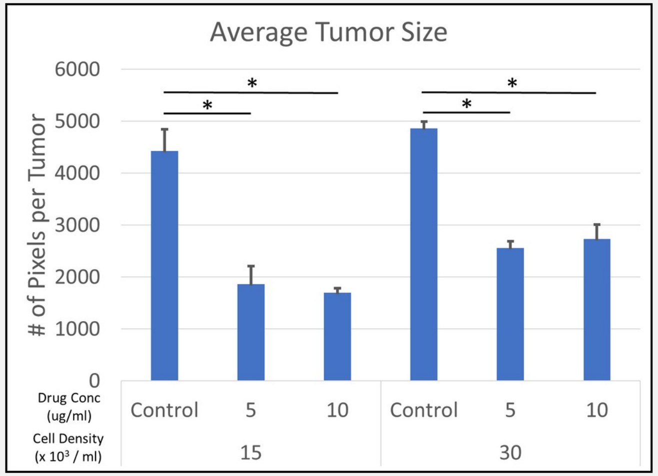
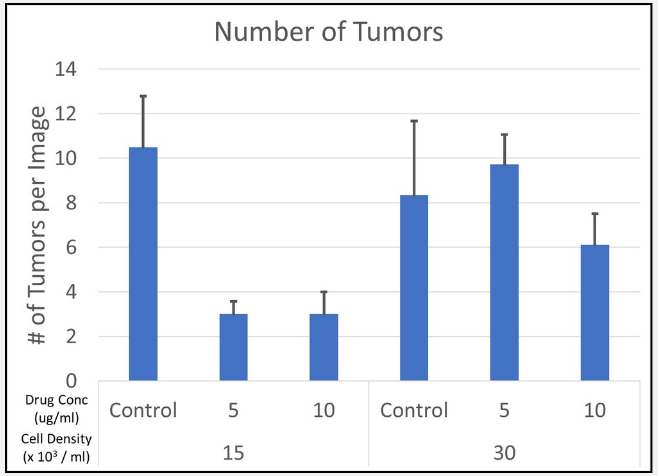
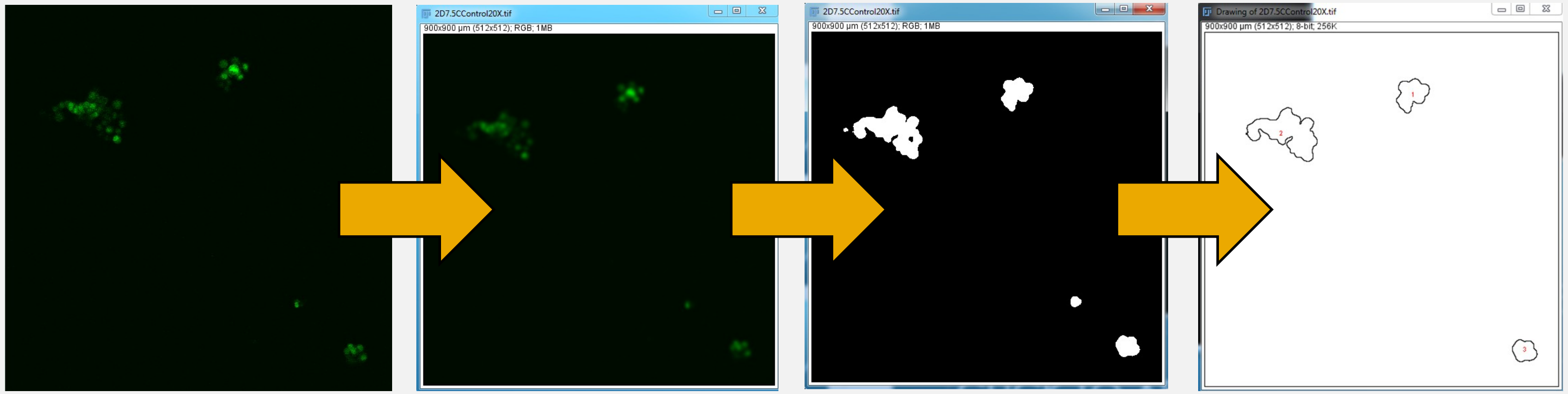
Vascularized Human Tumors on a Chip for Drug Screening

Results

- Tumor Drug Response
  - 5-fluorouracil (5-FU)
  - Chemotherapeutic
  - IV treatment of colorectal cancer







Original Image   Gaussian Blur   Color Thresholding   Output Metrics

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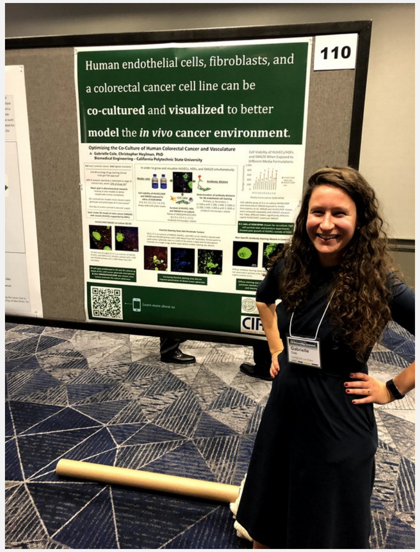
CAL POLY

Vascularized Human Tumors on a Chip for Drug Screening

Lessons Learned

- It takes a village!
  - Undergraduates, graduate researchers
    - BMED, BIO, CHEM, ME
  - Collaboration and shared resources
  - Cell culture, microfabrication, microscopy
- Incremental success
  - Small, achievable projects
  - Packaged for theses and SURP
- Institutional support
  - SURP, CIRM, RSCA, CSUPERB



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Next Steps/Long-Term Plans

- Iterate to Optimize Tissue Model
  - Device design
  - ECM / cell solutions
  - Loading and perfusion parameters
- Combine Tracks
  - Load ECM / cell solutions into devices
  - Assess effects of perfusion on vessel and tumor formation
  - Deliver drugs with know effects to validate
- Test Novel Drugs for Efficacy
  - Industry partners from pharmaceutical and biotech industry

Seeking Collaborators

Tissue Engineering
Microfluidics/Microfabrication
Vascular Biology
Tumor Biology
Pharmacokinetics

Christopher Heylman *Cal Poly San Luis Obispo / Biomedical Engineering* *cheylman@calpoly.edu*

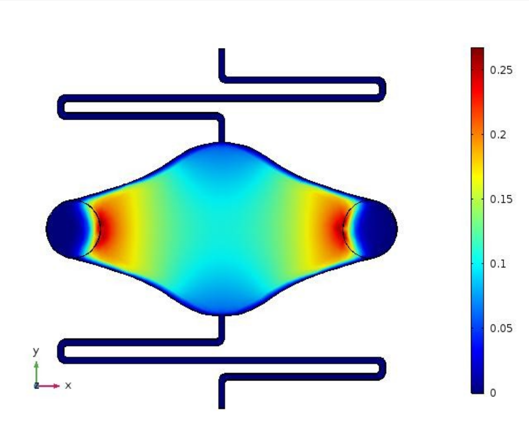
CAL POLY

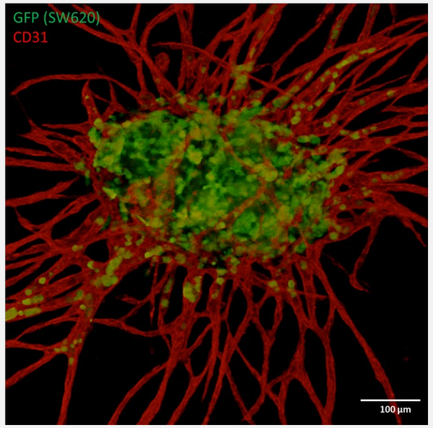
LEARN BY DOING

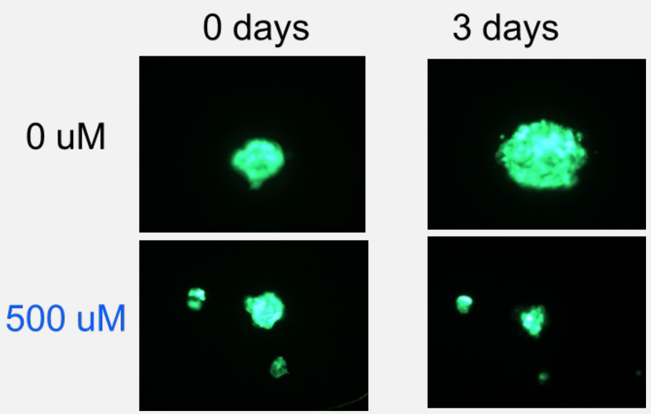
Vascularized Human Tumors on a Chip for Drug Screening

Summary

- Mimic a vascularized human tumor on a chip
  - **Microfluidic Device Design and Testing**
  - **Injectable 3D ECM / Cell Solution**
  - **Tumor Drug Response**
- Multidisciplinary
  - Across majors and colleges
- Enabled by unique combination of resources
  - Cell culture, microfabrication, microscopy
- Impactful for pharmaceutical / biotech industry of California and beyond







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Vascularized Human Tumors on a Chip for Drug Screening

Acknowledgement

Graduate Students

- Kendyl Cohn
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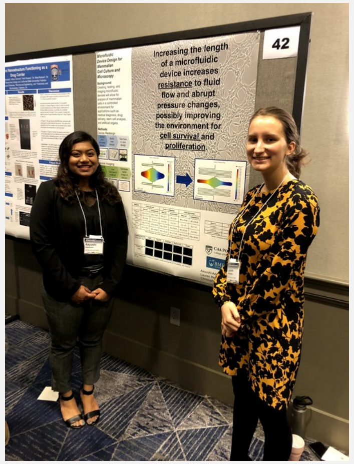
- Allison Rabin
- Amanda Almada
- Lauren Henigman
- Aayushi Adettiwar
- Mia Pinedo
- Sabrina Nelson
- Michelle Leclere
- Leah Torres



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- Cal Poly M.S. Regenerative Medicine Program (CIRM)
- Cal Poly CENG SURP
- Cal Poly RSCA
- CSUPERB New Investigator Grant
- CSUPERB President's Commission Scholar Grant

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Making Nonflammable Lithium-ion Batteries

Dahyun Oh, Ph.D.– San José State University

LG Chem

BERKELEY LAB

Dr. Dahyun Oh, Assistant Professor
San Jose State, Department of Chemical & Material Engineering
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Project Overview

1. Introduction
2. Carbon-based Artificial SEI Layers for Aqueous Lithium-ion Battery Anodes
3. Solid-state Batteries
4. Future work

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What is the next target Battery?

https://www.natlawreview.com/article/lithium-battery-explosion-shuts-down-orlando-airport

Enhancing Energy and Power density with superior safety:
Alternative electrolytes

Solution 1: Aqueous Lithium-ion Batteries

1. Low cost (no inert environment requirement for battery fabrication)
2. Safety
3. Challenge: instability of water

Solution 2: Solid-state Lithium-ion Batteries

1. Safety
2. High energy density
3. Challenge: low ionic conductivity, low wettability, and chemical instability of solid-state electrolyte

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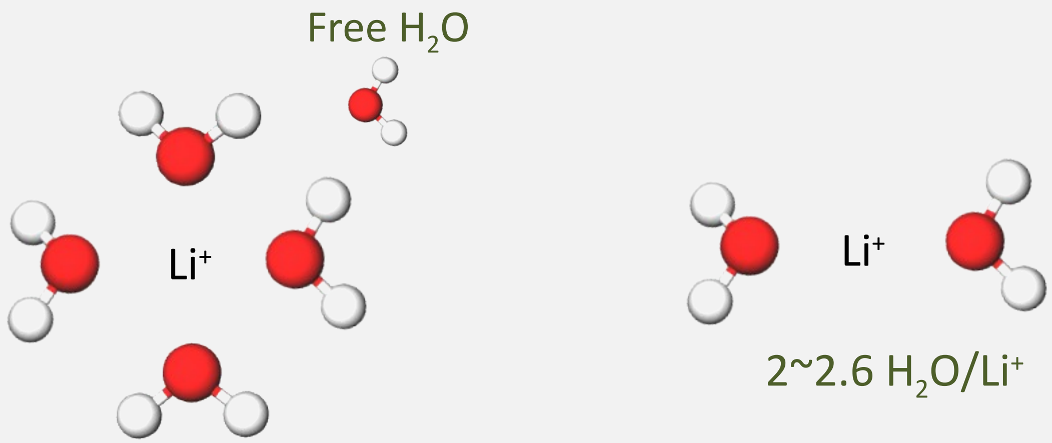
Making Nonflammable Lithium-ion Batteries

Activities

Superconcentrated Aqueous Electrolyte for LIB

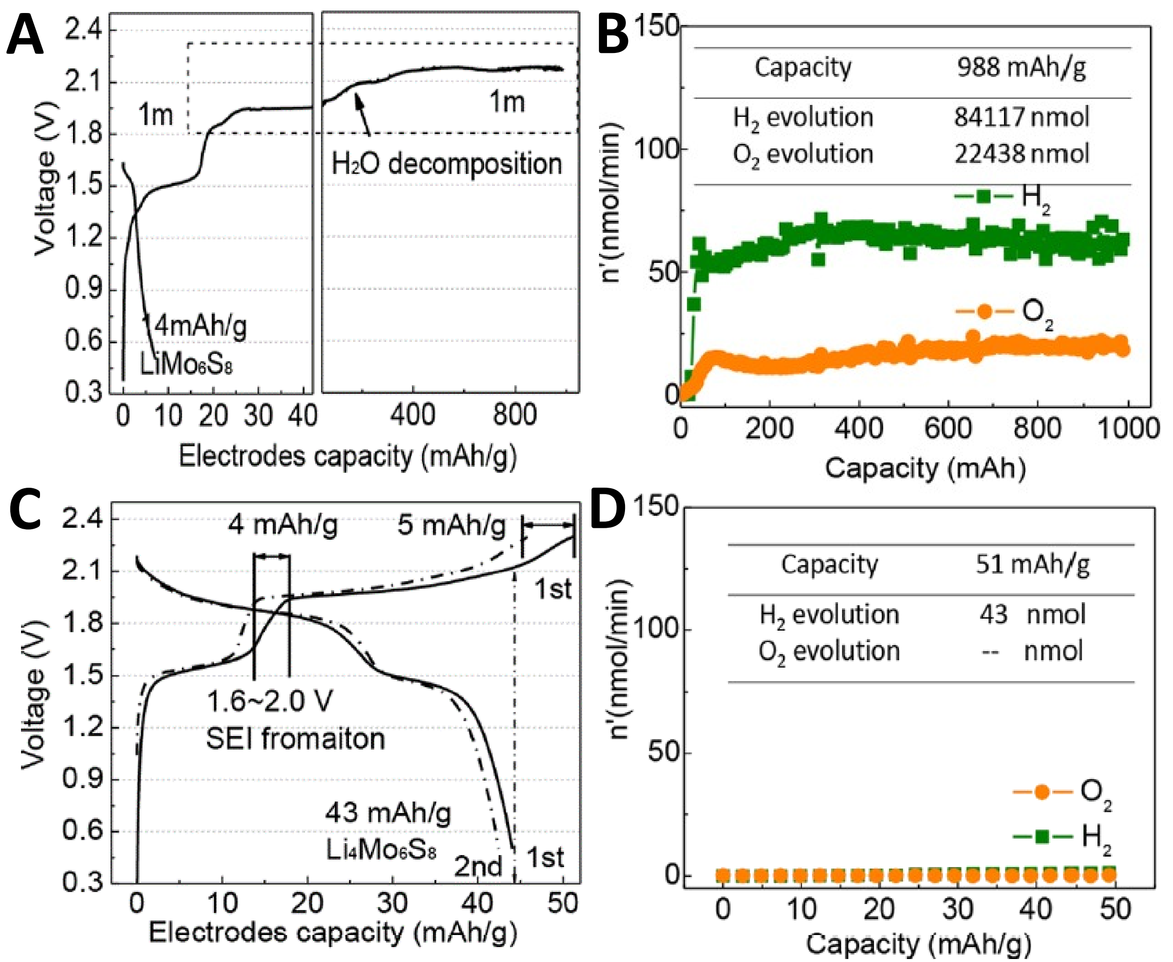
- So called <u>hydrate melt</u> or <u>water-in-salt</u>



Conventional electrolyte

Concentrated electrolyte

L Suo, D Oh et al, **2017** *JACS*



Anode interface formation through salt reduction

Suo et al, **2015** Science
Yamada et al, **2016** Nat Energy

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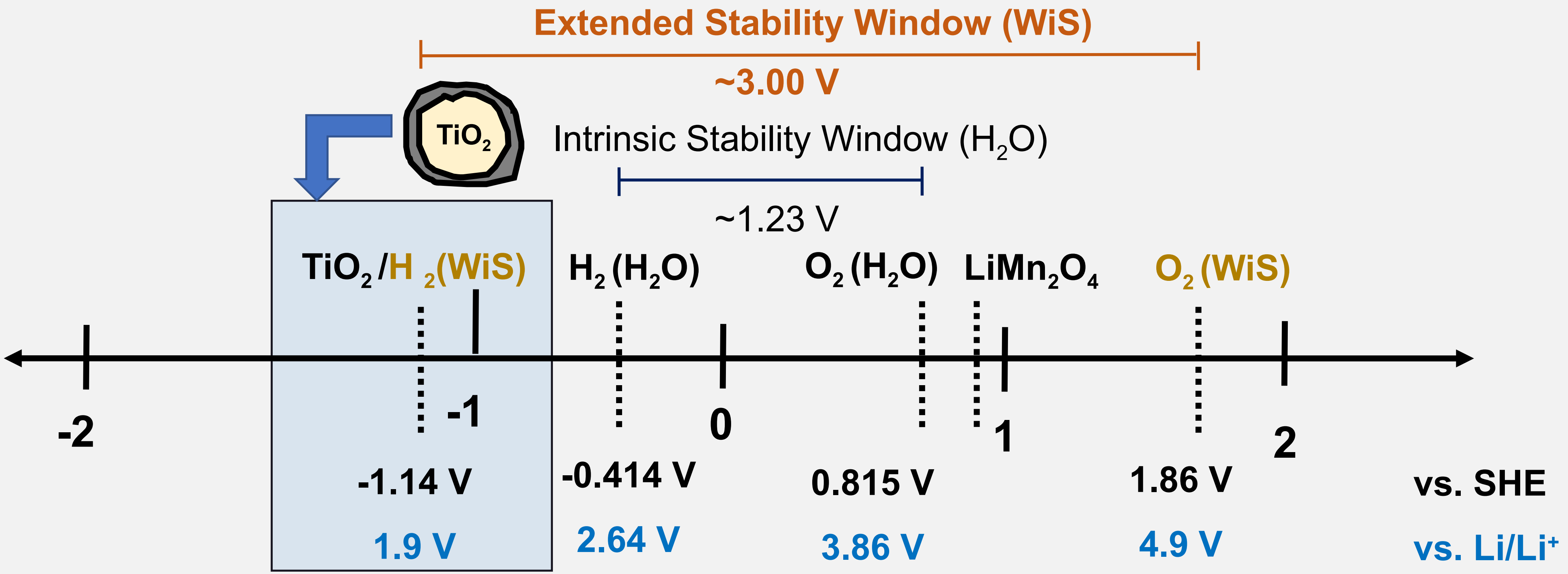
Activities

Redox diagram of WiS electrolytes and electrodes



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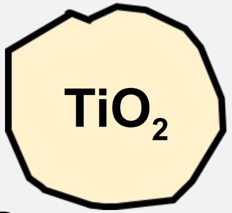
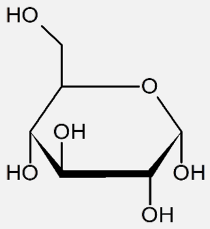
Artificial SEI layers for Aqueous LIB Electrodes

- Carbothermal synthesis

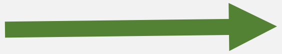


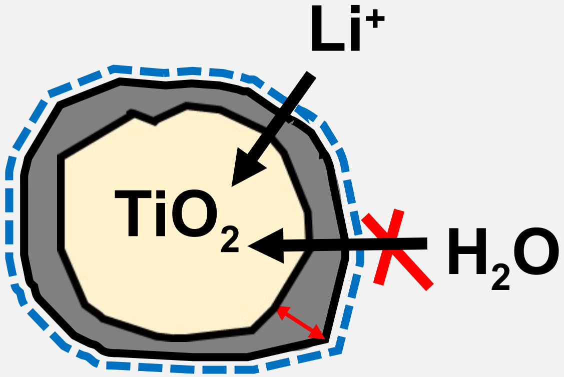
TiO_2 nanoparticles (NP, Sol-gel)



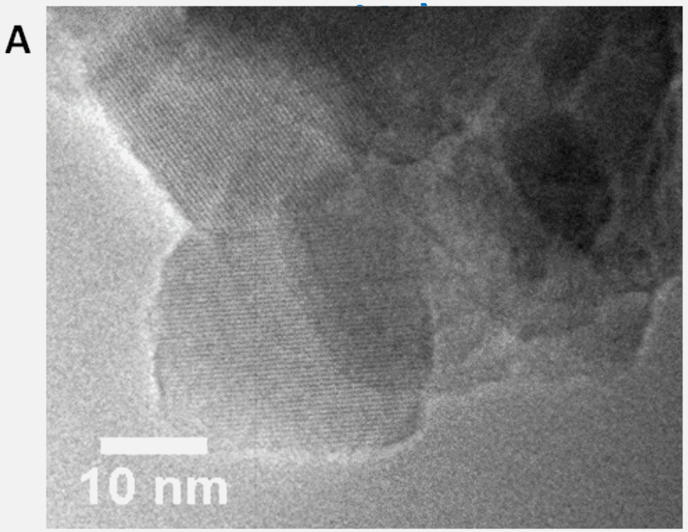
D-Glucose

1. Autoclave (180°C for 12h)
2. Annealing (Ar, 400-900°C)

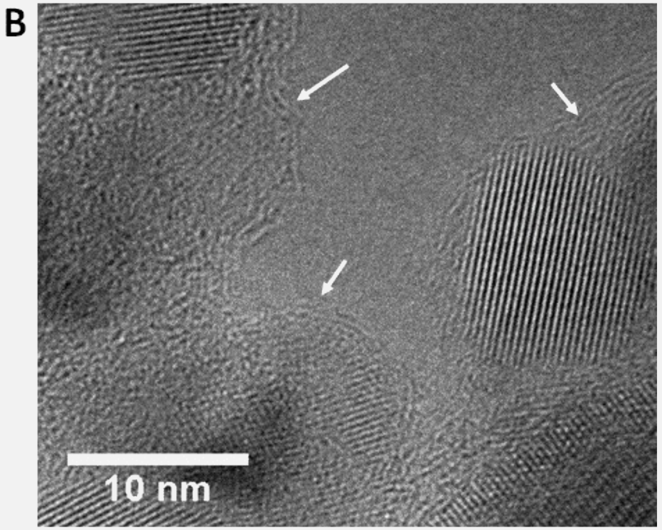




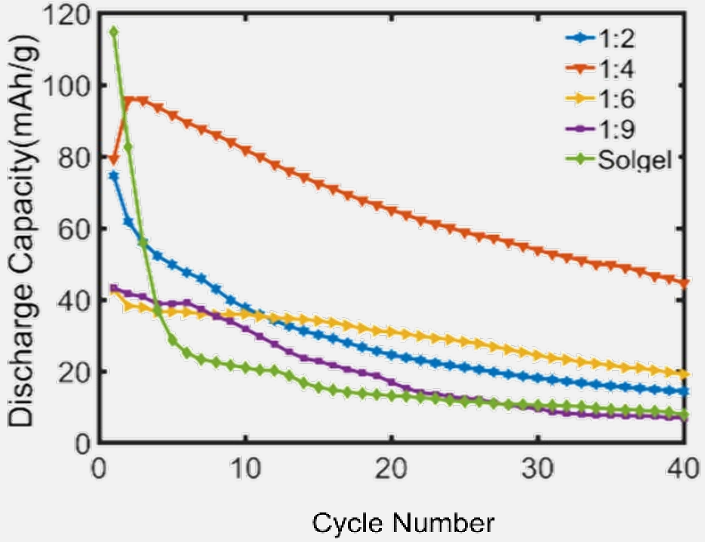
Before coating (Sol-gel



After coating



Subramanya et al., RSC Advances, 2020



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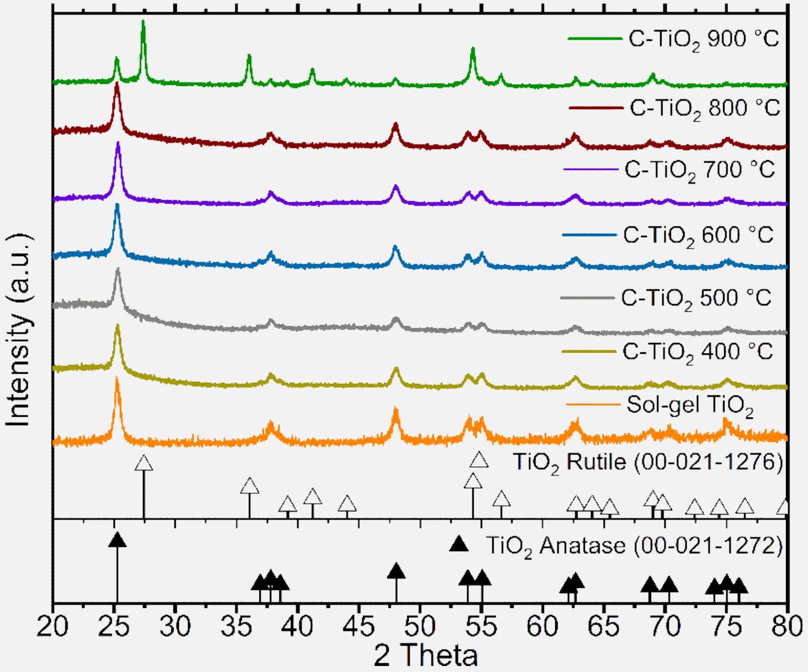
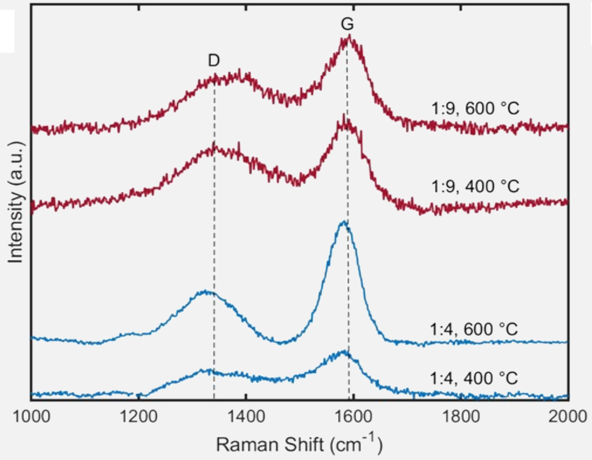
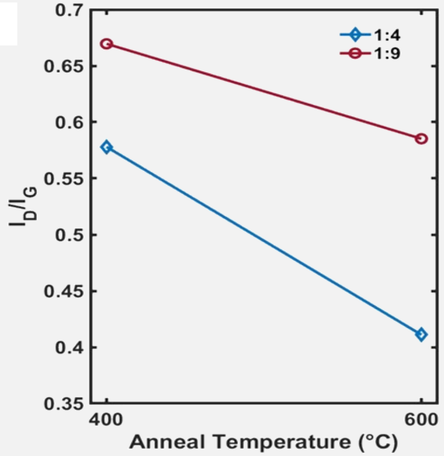
Controlling the composition of graphitic carbon in SEI layers

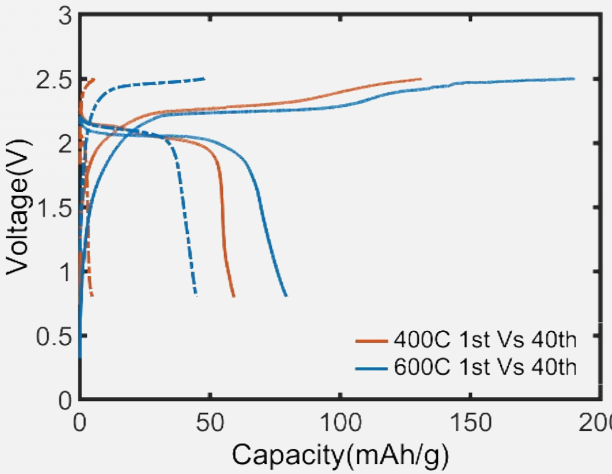
- XRD of C-TiO_2 annealed at different T

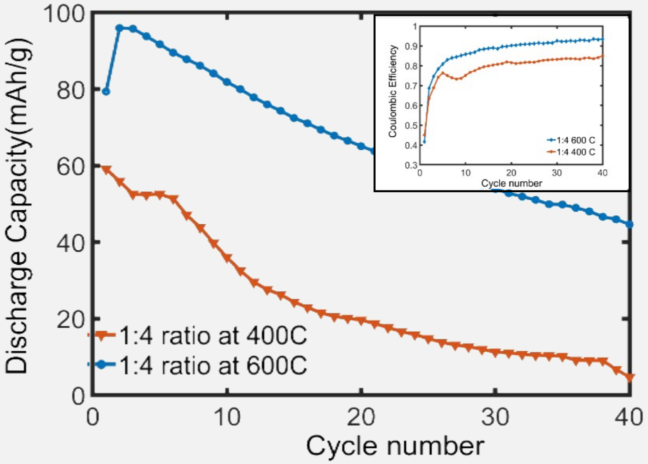


Raman spectra of C-TiO_2 annealed at different T









- C-TiO_2 annealed at 600°C presented the best performance.

Subramanya et al., RSC Advances, 2020

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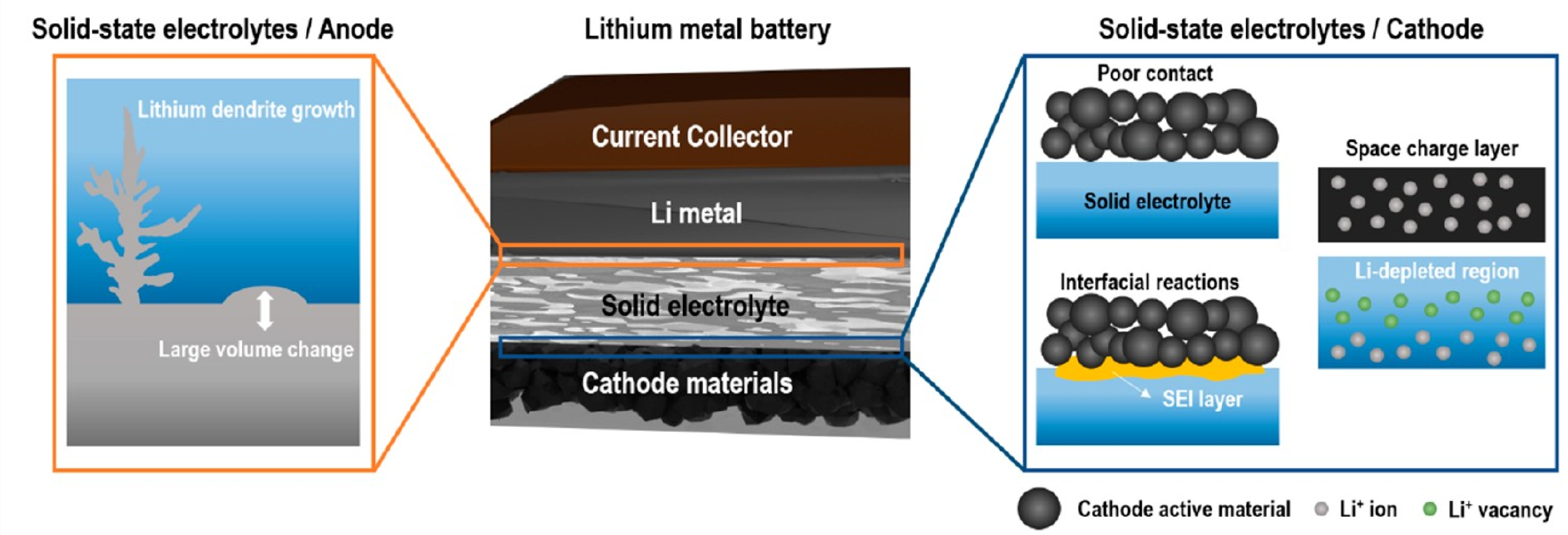
Challenges in solid-state batteries



Yang et al., Applied Sciences, 2020

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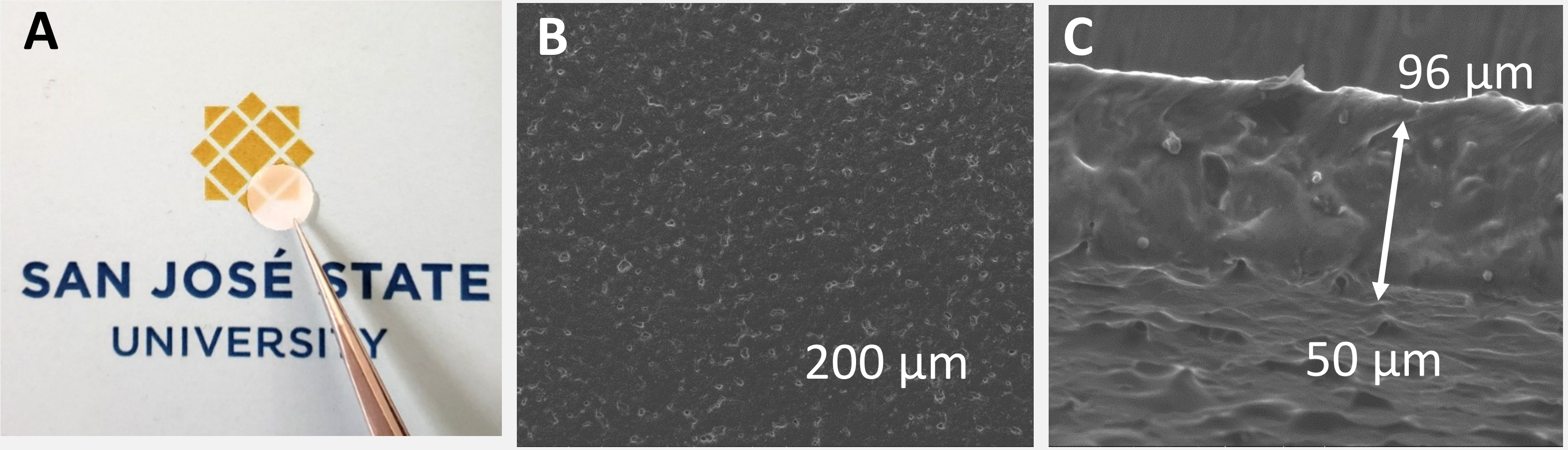
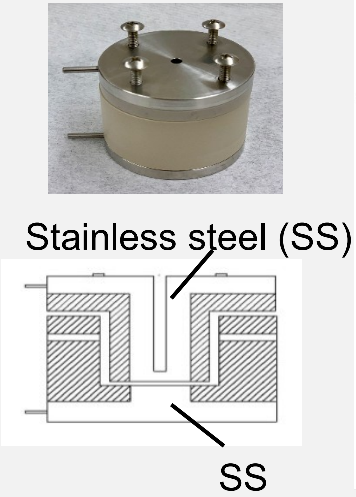
Solid-state Batteries with Composite Electrolytes

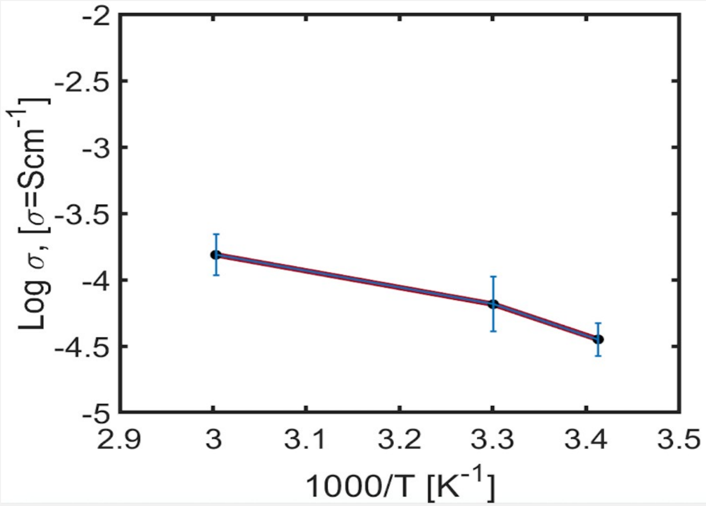
Free-standing Li-ion conducting gel electrolytes



In collaboration with Prof. John Lee (Mechanical Engineering, SJSU)

Ionic conductivity





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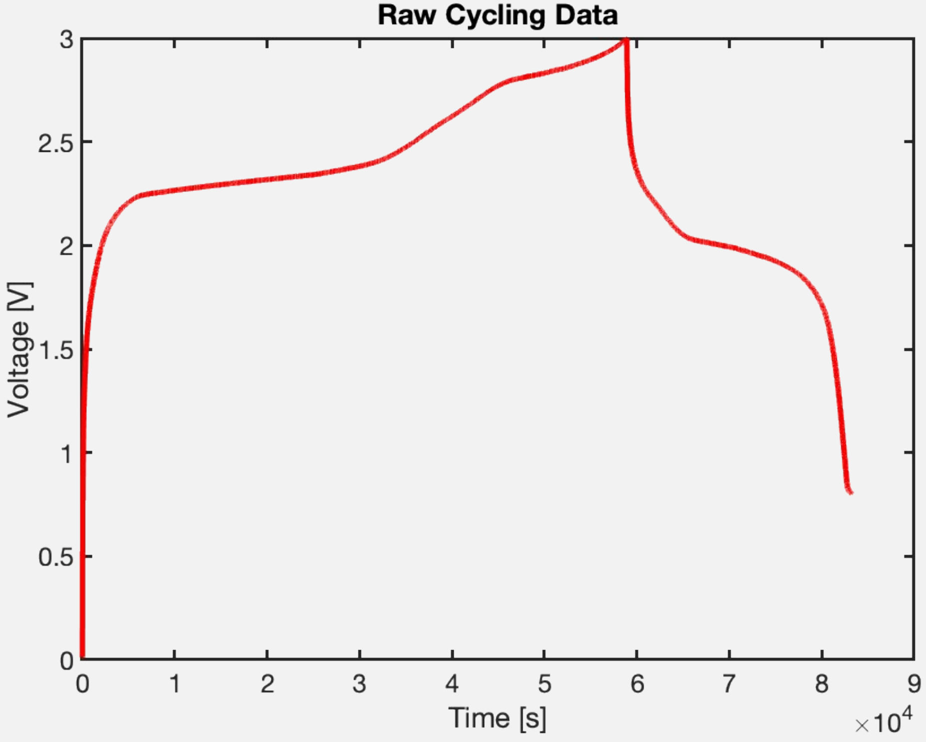
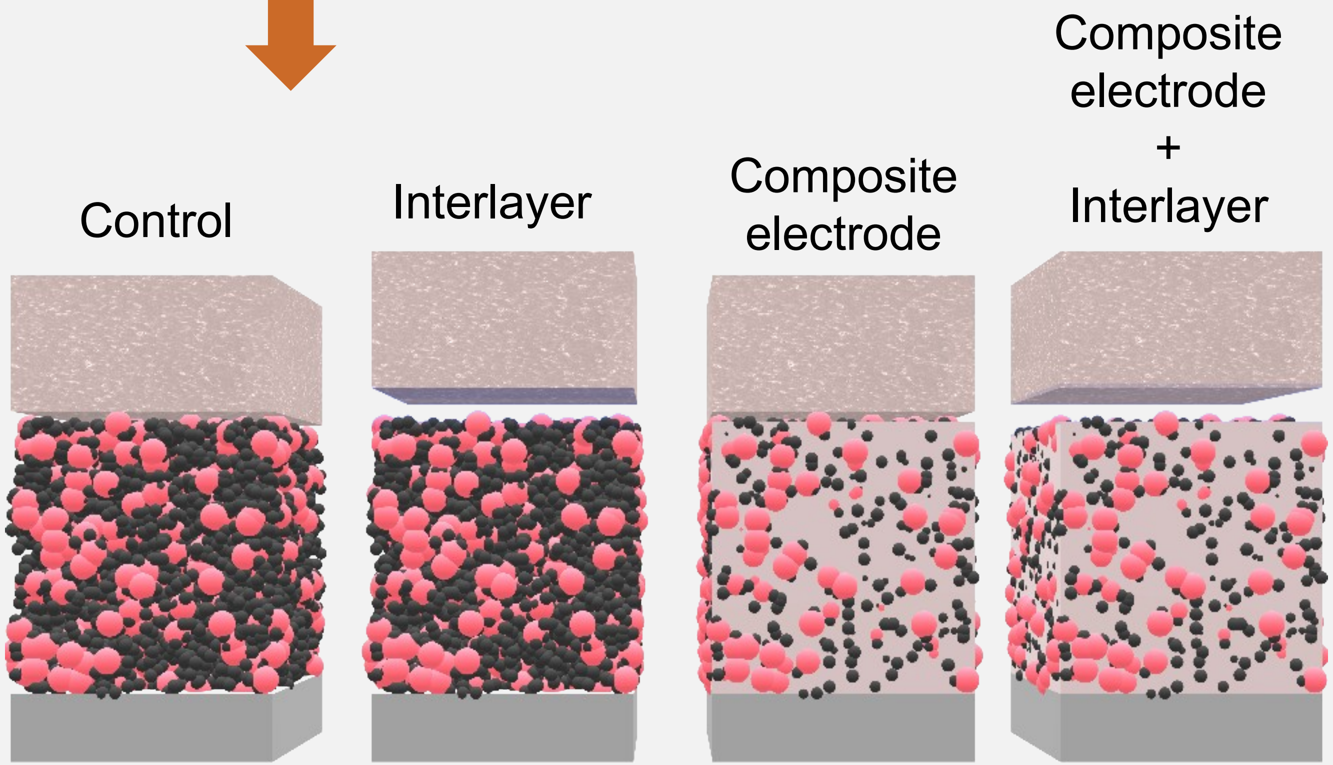
Battery Cells Component

Solid-state Li-ion Battery performance



How to improve the performance?



Abraham et al., in preparation

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Future work

1. Mimicking SEI layers observed in superconcentrated aqueous LIB

: in situ surface analysis

2. Using bioinspired materials to develop artificial SEI layers

: Unravel failure mechanism

3. Solid-state Batteries

:inorganic solid-state synthesis

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Thank you

Energy Materials Lab

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Prof. Folarin Erogbogbo (SJSU)
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Dr. Emory Chan (LBNL)
Dr. Rohan Dhall (LBNL)

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Study of Interactions in Complex Dynamical Systems

Subhradeep Roy – California State University, Northridge (CSUN)

Collaborators:
Rolf Muller (biologist), Mechanical Eng. Dep., Virginia Tech
Ben Jantzen, Computer Science Dep., Virginia Tech
Sachit Butail, Mechanical Eng. Dep., Northern Illinois University

Subhradeep Roy, Assistant Professor

CSUN, Department of Mechanical Engineering

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Project Overview

- **Complex systems:** Individual units ***interact*** with other units which lead to ***emergent behavior*** at group level


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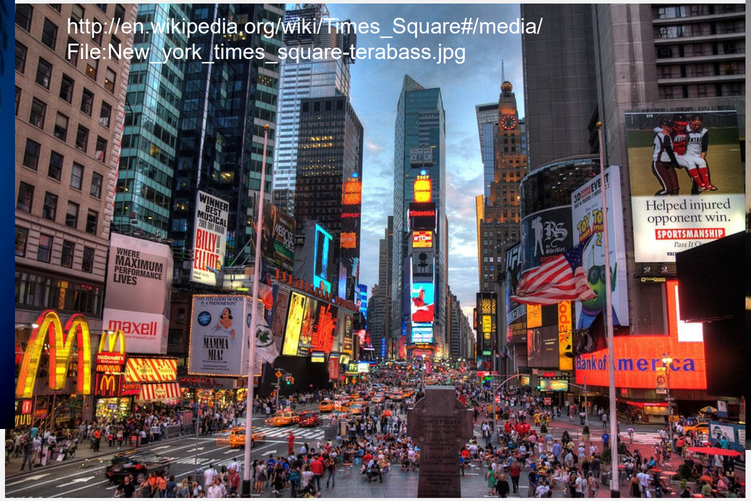

http://en.wikipedia.org/wiki/Times_Square#/media/File:New_york_times_square-terabass.jpg


http://www.tripadvisor.com/Attraction_Review-g30196-d106309-Reviews-Congress_Avenue_Bridge_Austin_Bats-Austin_Texas.html

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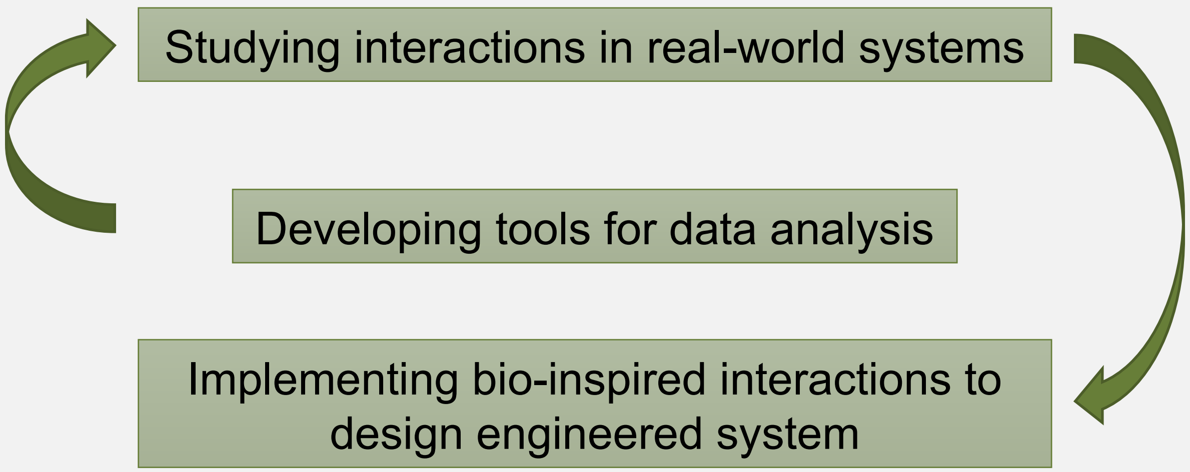
Study of Interactions in Complex Dynamical Systems

Project Overview

- **Complex systems:** Individual units ***interact*** with other units which lead to ***emergent behavior*** at group level
- How I study complex systems?



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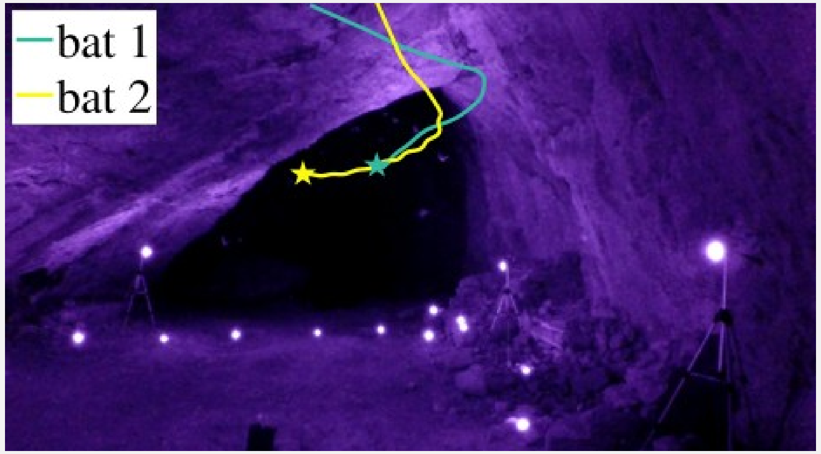
Activities

Studying interactions in real-world systems



- First real-world example: *interactions of flying bat pairs*
- Why bats?
  - Echolocation/ active sensing
  - Information sharing (C. Chiu, W. Xian, C. F. Moss, *PNAS*, 2008)
- Research question: Do a pair of bats share information with active sensing, and if the information sharing is directional?
- Steps:
  i. Collecting data from wild bats
  ii. Tracking: extract 3D coordinates
  iii. Analyze data: using Transfer Entropy (TE) and Convergent Cross Map (CCM)

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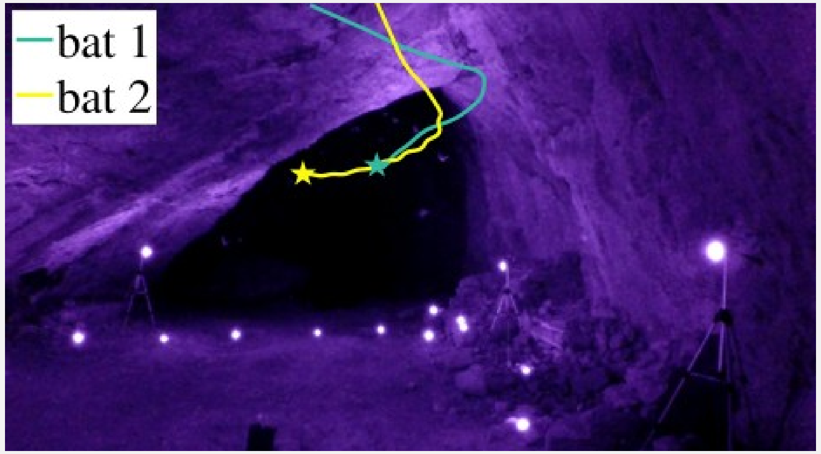
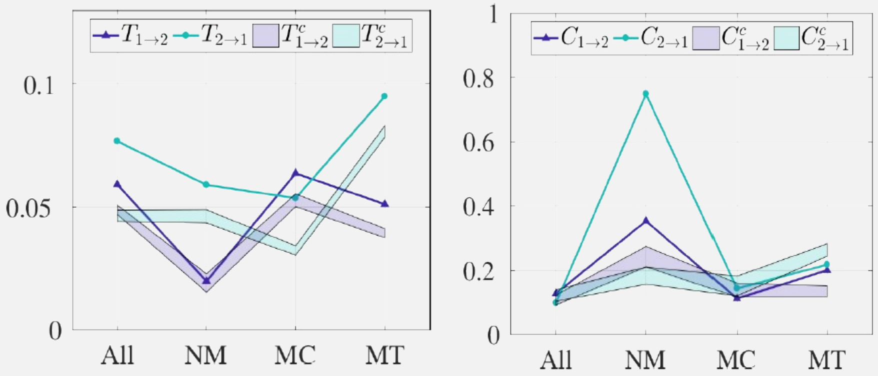
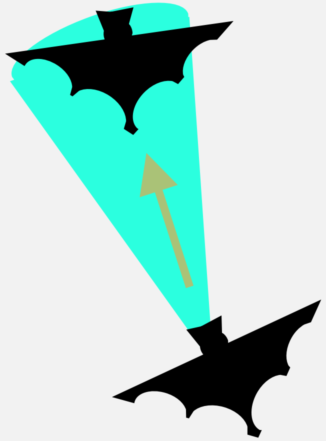
Results



Data analysis techniques
(TE and CCM)





S Roy, K Howes, R Mueller, S Butail and N Abaid
Extracting information flow between flying bat pairs using model-free methods
Entropy, Volume 21(1), 42, 2019

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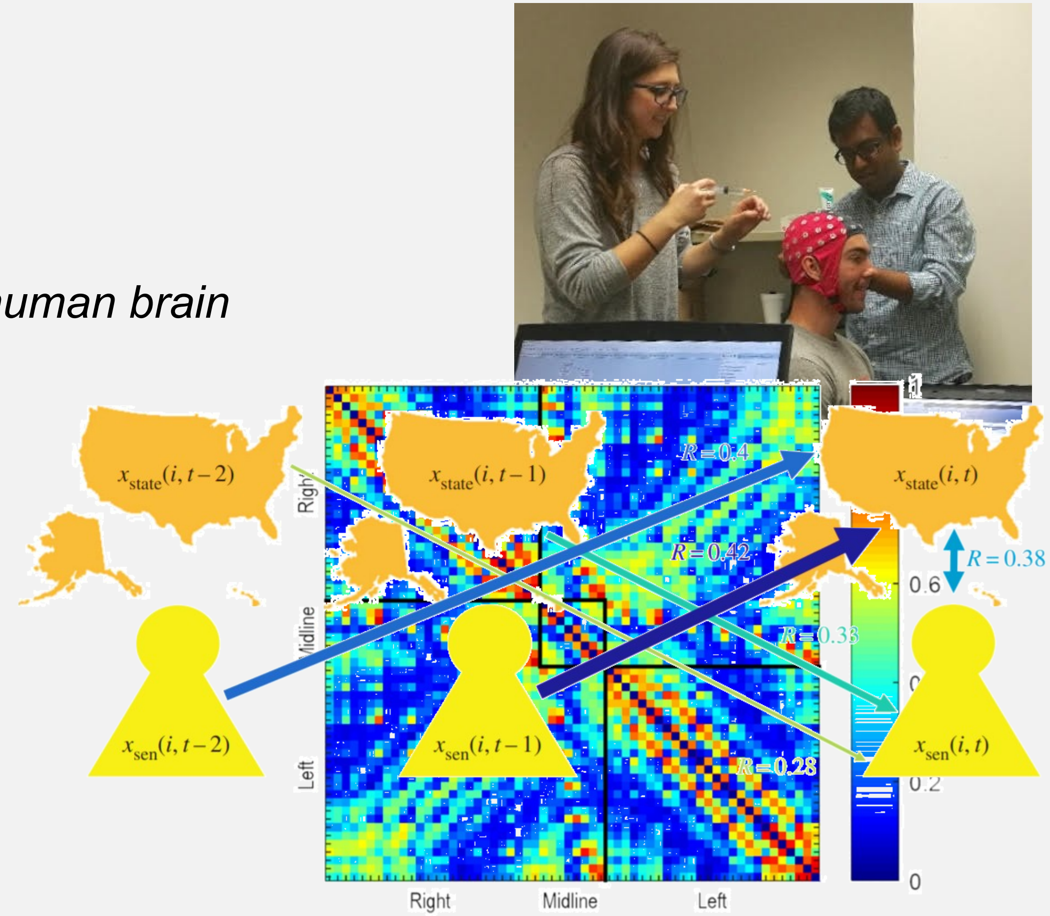
Additional Activities

Studying interactions in real-world systems

- Second real-world example: *interactions of neurons in human brain*
  - Objective: study brain connectivity network
- Third real-world example: *interactions of humans*
  - Objective: study human opinion formation



S Roy and N Abaid
Interactional dynamics of same-sex marriage legislation in the United States
Royal Society Open Science, Volume 4(6), 170130, 2017
Featured in Virginia Tech News

C Beauchene, S Roy, R Moran, A Leonessa and N Abaid
Comparing brain connectivity metrics: A didactic tutorial with toy simulations
Journal of Neural Engineering, Volume 15(5), 056031, 2018

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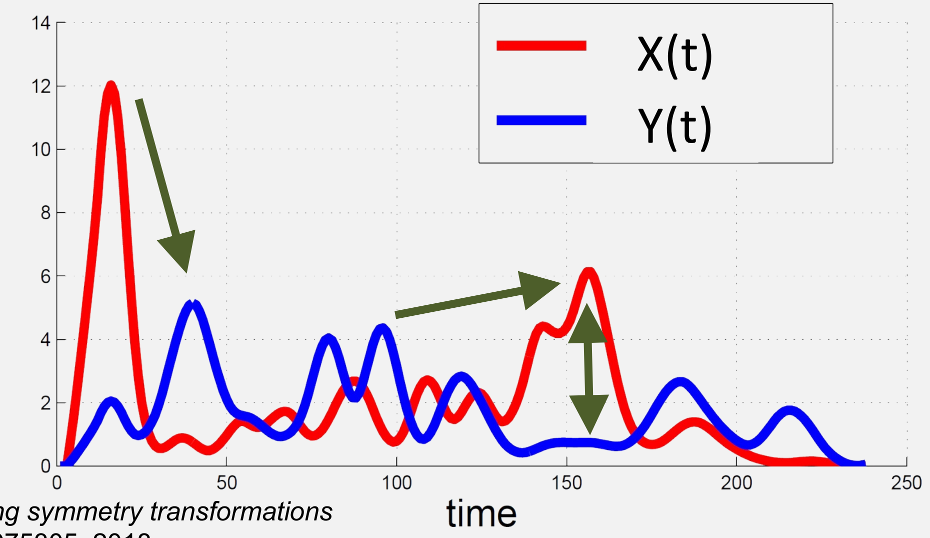
Lessons Learned

Developing tools for data analysis

- Relation between two time series
  - $X(t)$ influences $Y(t)$
  - $Y(t)$ influences $X(t)$
  - Bidirectional
- Causal discovery tools
  - Transfer Entropy (TE)
  - Convergent Cross Map (CCM)
  - Dynamical symmetries



S Roy and B Jantzen
Detecting causality using symmetry transformations
Chaos, Volume 28(7), 075305, 2018

A Hashimoto, S Roy, C Shea-Blymyer, B Jantzen and N Abaid
Differentiation of Collective Behavior Based on Automated Discovery of Dynamical Kinds
ASME 2018 Dynamic Systems and Control Conference, pp. V003T30A008-V003T30A008.

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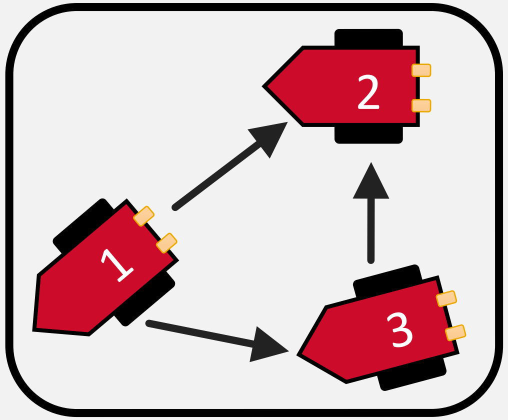
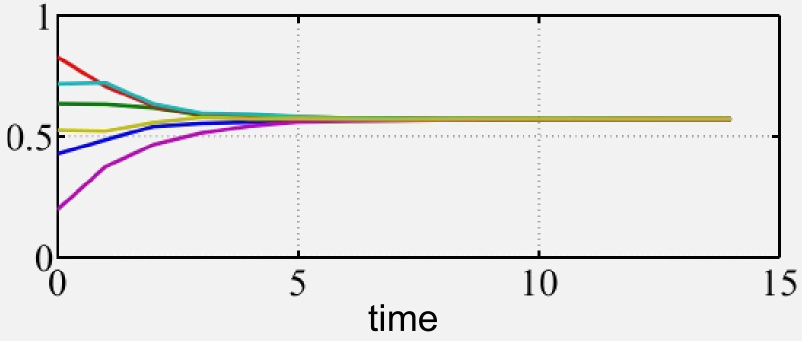
Activities

Implementing bio-inspired interactions

- Model bio-inspired interactions using graph theory
- Approach – modeling interactions using networks/ graphs
  - Vertices/nodes represent individuals
  - Edges represent interactions
- Implement using consensus and synchronization protocols
- Applications in robotic teams





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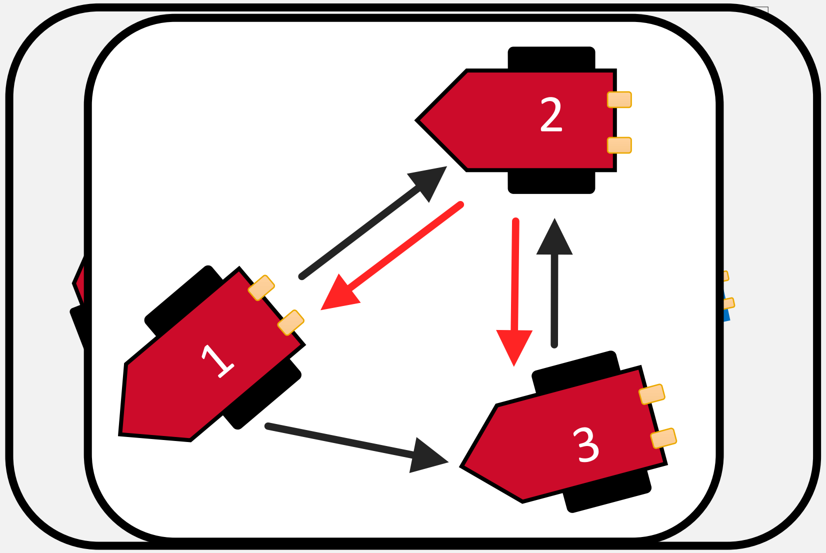
Study of Interactions in Complex Dynamical Systems

Activities

Implementing bio-inspired interactions

- Model bio-inspired interactions using graph theory
- Leader-follower interaction: modify nodes
- Friendly-hostile interaction: modify edges
- Derived closed-form expression for convergence speed in terms of system parameters



S Roy and N Abaid
Leader-follower consensus in numerosity-constrained networks with dynamic leadership
Chaos, Volume 26(11), 116309, 2016

S Roy and N Abaid
On the effect of collaborative and antagonist interactions on synchronization and consensus in networks of conspecific agents
IEEE Transactions on Automatic Control, Volume 61(12), 4063-4068, 2016

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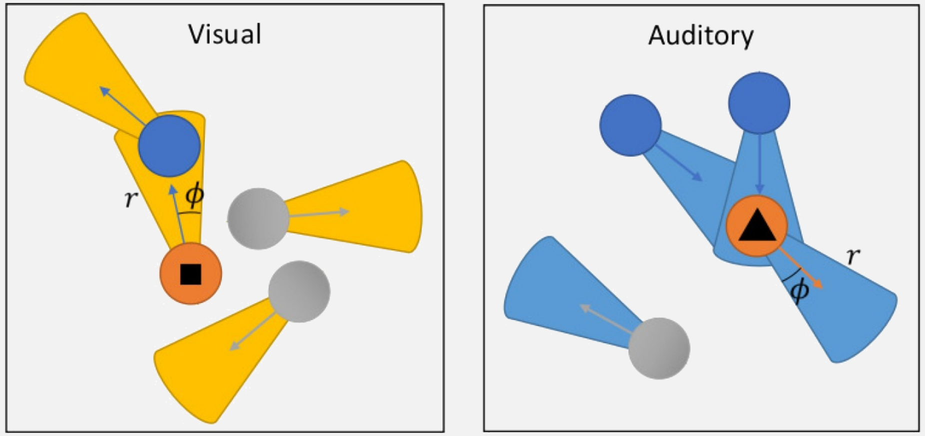
Study of Interactions in Complex Dynamical Systems

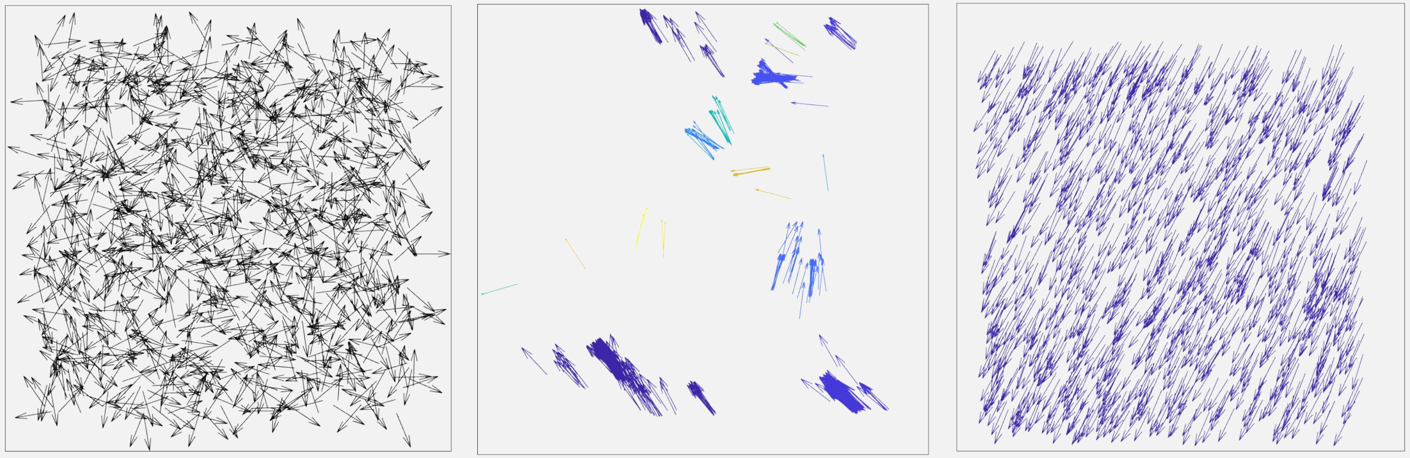
Activities

Implementing bio-inspired interactions

- Model bio-inspired interactions using agent based modeling
- Computer simulation techniques
- Each agent interacts with neighbors and updates position and velocity using a discrete-time protocol



Time = 0sec   Visual; time = 1000sec   Auditory; time = 1000sec



S Roy, M Shirazi, B Jantzen and N Abaid
On the effect of two independent sensing cues on Vicsek model
Physical Review E Volume 100(6), 062415, 2019.

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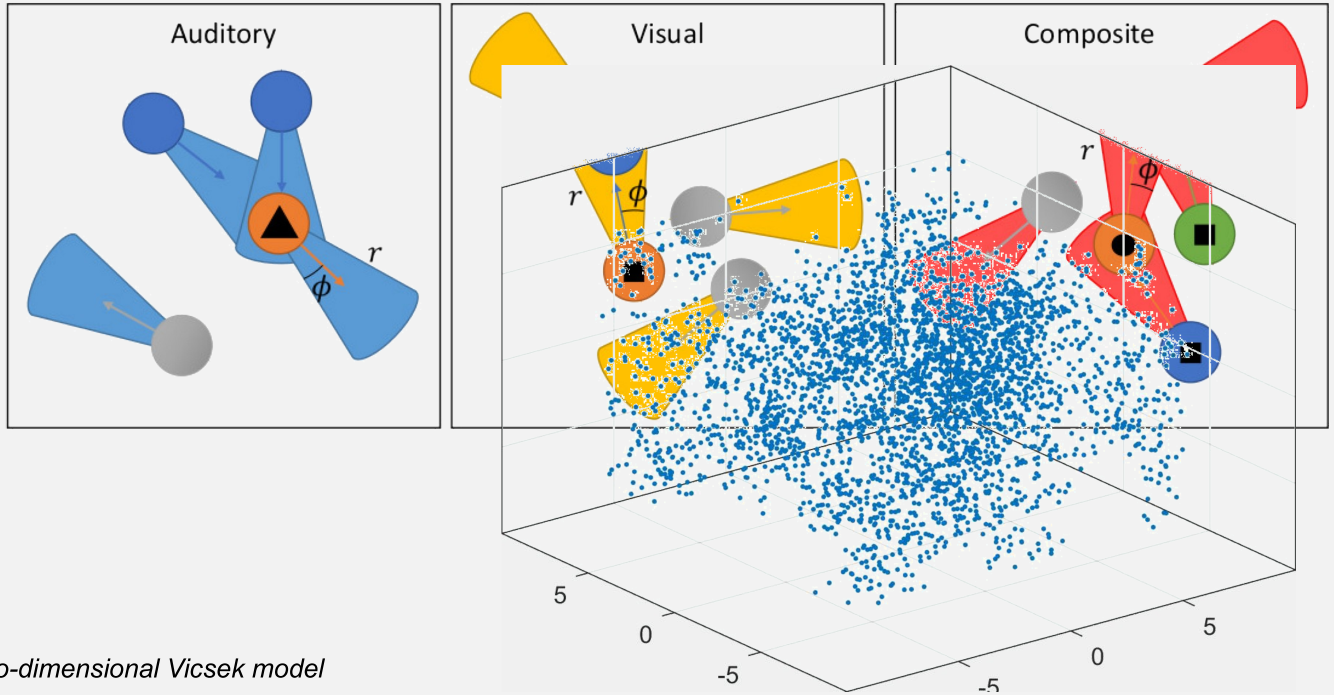
Next Steps/Long-Term Plans

Implementing bio-inspired interactions by incorporating multiple sensing cues

- **Research Objective (1a):**
  - In a 2D model
- **Research Objective (1b):**
  - Extending to a 3D model



J Lemus* and S Roy
The effect of simultaneous auditory and visual sensing cues in a two-dimensional Vicsek model
ASME 2020 Dynamic Systems and Control Conference, (accepted)

*= CSUN grad student

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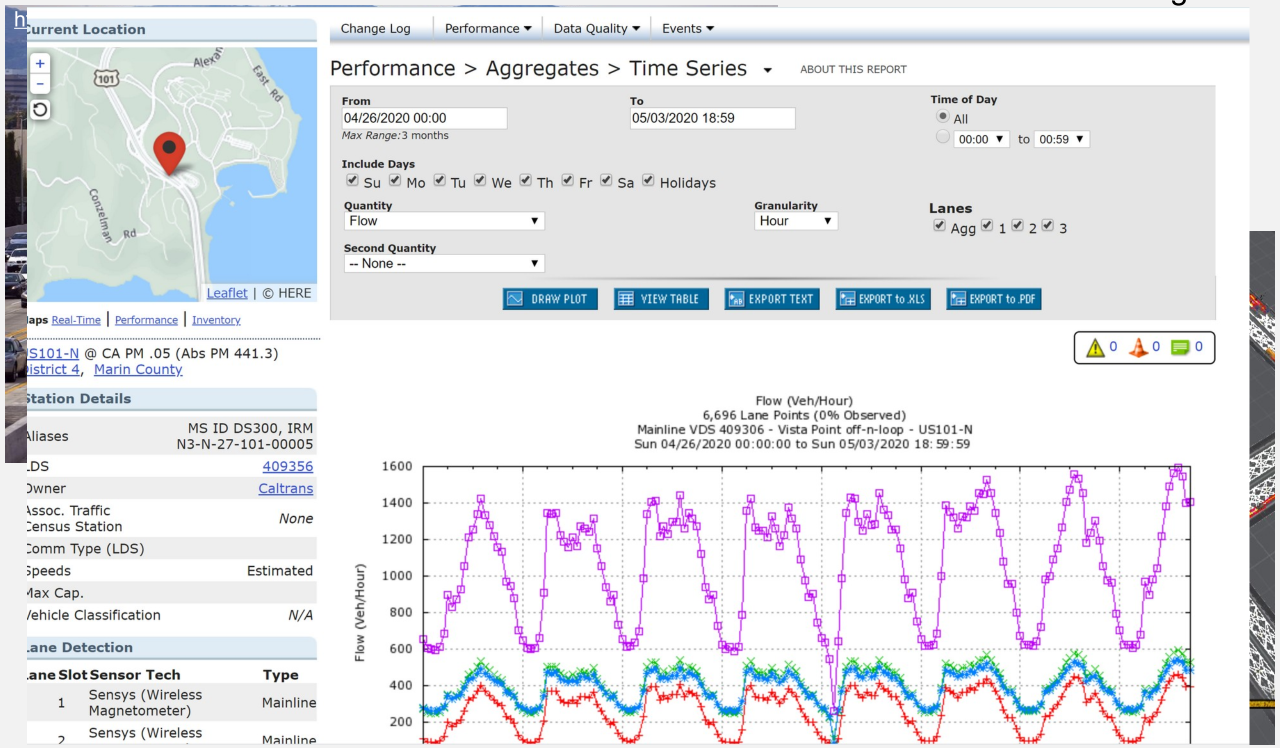
Next Steps/Long-Term Plans

Studying interactions in real-world systems: detecting traffic interaction network

- **Research Objective (2a):**
  - Using vehicle flowrate time-series data collected at each intersection
  - Applications in traffic control and reduce congestion

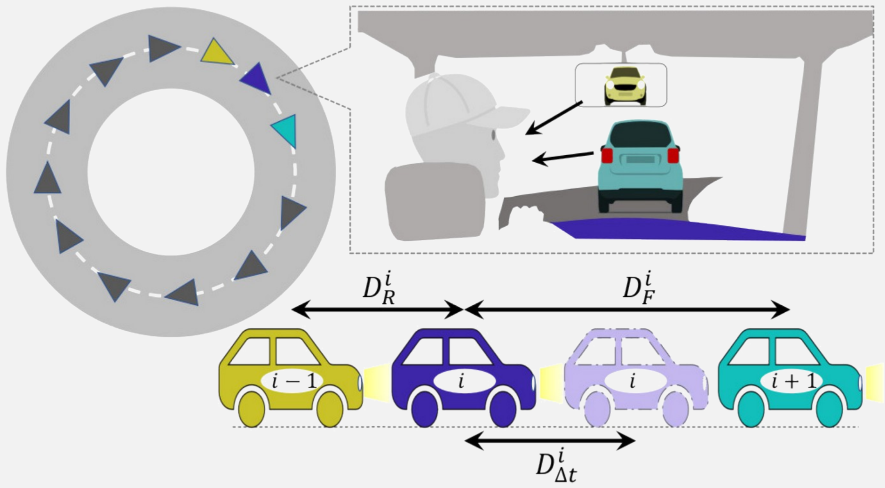
Caltrans PeMS - CA.gov



Next Steps/Long-Term Plans

Studying interactions in real-world systems: understanding interactions among car drivers

- **Research direction (2b):**
  - Quantifying interaction using information theory



S Roy
Quantifying interactions among car drivers using information theory
Chaos (under review)

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Summary

- Complex systems study requires a multidisciplinary and collaborative approach.

Find more:
https://subhradeeproy.weebly.com/

Complex Dynamical Systems Laboratory (CDSL)

- At CDSL, we foster interdisciplinary collaboration to identify and decipher fundamental research questions arising in nature.

Questions & Answers

Exemplars in Engineering Research

Speakers

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Sankha Banerjee, Fresno State
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Next Steps/Closing Remarks

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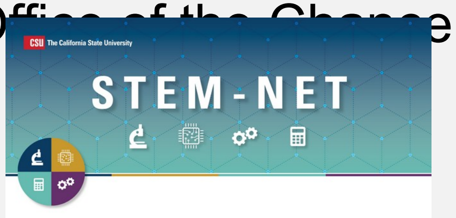

https://www2.calstate.edu/impact-of-the-csu/research/stem-net