

# Prof. Upmanu Lall, Director Water Center

- **Climate & hydrologic risk**
- **Applied statistics & machine learning**
- **Water sustainability, security, resilience, systems**
- **Floods and droughts**
- **Nonlinear dynamics**

(link: <https://eee.columbia.edu/faculty/upmanu-lall> )



## Prof. Upmanu Lall, Director Water Center

- **The Global Water Sustainability Initiative addresses global water scarcity and risk.**
- **The Global Flood Initiative is motivated by the need to predict, mitigate and manage floods at a global scale recognizing their climate drivers, and supply chain impacts.**
- **America's Water seeks to develop sustainable water management and infrastructure design paradigms for the 21st century recognizing the linkages between urban functioning, food, water, energy and climate.**
- **These programmatic initiatives are backed by research on systems level modeling of hydrology, climate, agronomy and economics.**

## Prof. Pierre Gentine, Associate Professor

- **Hydrologic cycle**
- **Land-atmosphere interactions**
- **Soil moisture**
- **Artificial intelligence**
- **Computational engineering science**
- **Data science**
- **Imaging modeling & simulation**
- **Sensing**



(link:<https://eee.columbia.edu/faculty/pierre-gentine/>)

Remote sensing



Physics

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \bar{U}) = 0$$
$$\frac{\partial \rho \bar{U}}{\partial t} + \nabla \cdot (\rho \bar{U} \bar{U} + P \bar{I} - \bar{\tau}) - \rho \bar{G} = 0$$
$$\frac{\partial \rho(e+k)}{\partial t} + \nabla \cdot \left( \rho \bar{U} \left( e + \frac{P}{\rho} + k \right) - \bar{\tau} \cdot \bar{U} + \bar{Q} \right) - \rho \bar{G} \cdot \bar{U} = 0$$

Machine learning



Understanding the  
terrestrial carbon and  
water cycles



### Bio

- Ph.D., Chemical and Environmental Engineering, Yale University, 2014
- Faculty since 2015 (tenure-track)
- Email: [n.y.yip@columbia.edu](mailto:n.y.yip@columbia.edu) | Website: [yiplab-h2o-e-env.eee.columbia.edu](http://yiplab-h2o-e-env.eee.columbia.edu)
- Accolades (selected): CH2M Hill/AEESP Outstanding Doctoral Dissertation Award (2015), *ES&T* Best Papers of 2013, C. Ellen Gonter Best Paper Award (2013)

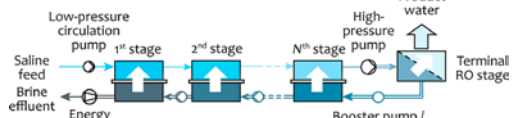
Research interest: advanced physicochemical technologies for *sustainable* production of water and energy; addressing challenges at the interfaces of water-energy-environment

### Focus of current research activities

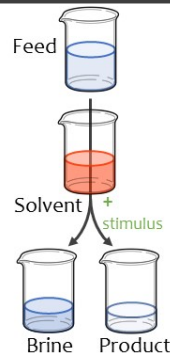
- desalination of ultrahigh-salinity brines
- low-grade heat utilization and conversion
- nutrient recovery from anthropogenic wastes
- energy-efficient electro dialysis desalination
- transport principles in membranes
- thermodynamics of environmental processes

# Research Projects (selected)

Technologies for ultrahigh-salinity desalination: **COMRO** (cascading osmotically mediated reverse osmosis) and **TSSE** (temperature swing solvent extraction)

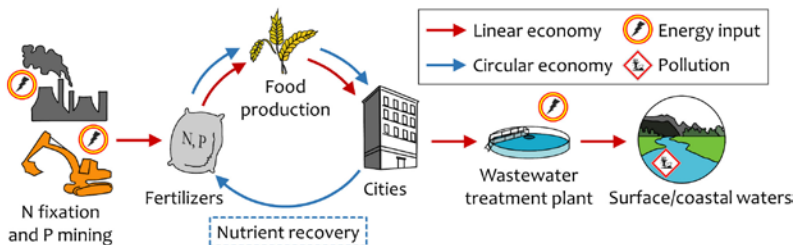


*ES&T*, 2018, 52, 2242

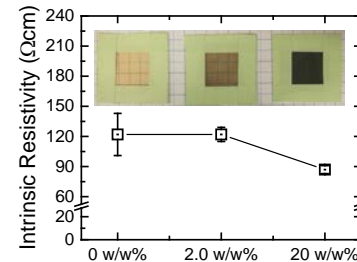


*ES&T Letters*, 2019, 6, 359

Sustainable N and P recovery from high population density urban centers utilizing waste and low-cost resources

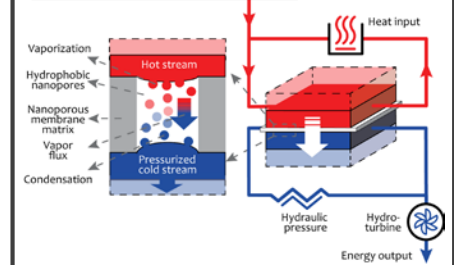


Nanocomposite ion-exchange membranes for enhanced energy-efficient electro dialysis desalination

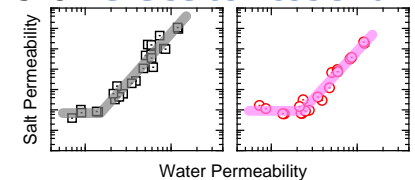


Energy production from low-temperature heat using vapor-pressure driven membrane technology

*Technology* 2016, 1, 16090  
*JMS*, 2019, 588, 117181



Fundamental understanding of transport in salt-rejecting and charged polymeric thin-films for reverse osmosis and ion-exchange membranes



*JMS*, 2019, 573, 668

**Prof. Alissa Park,  
Associate Director Lenfest Center for Sustainable Energy**

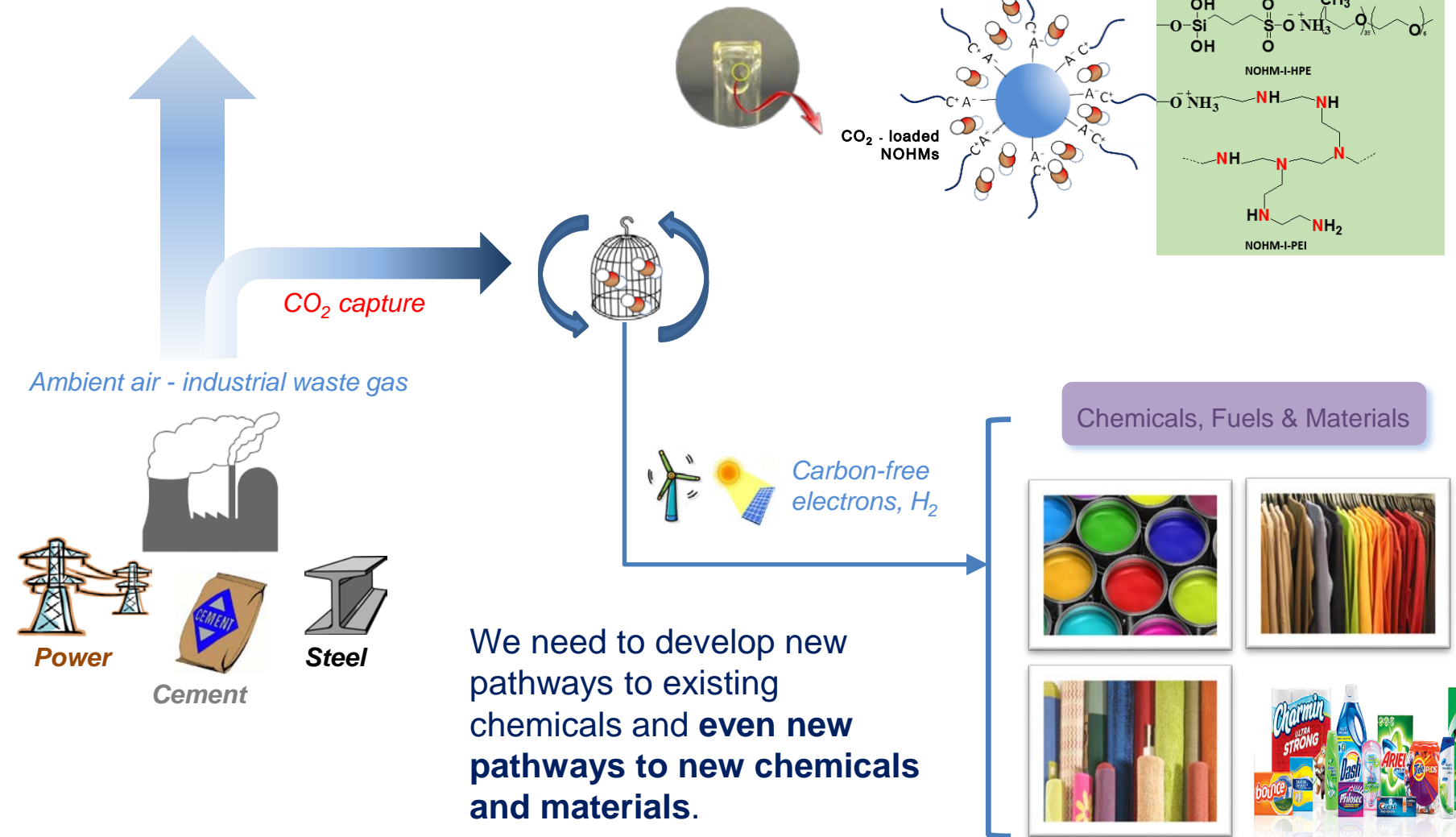
- **Sustainable Energy and Environment**
- **Carbon Capture Utilization and Storage (CCUS)**
- **Particle Technology**
- **Clean fossil energy conversion systems**
- **Alternative energy production**
- **Electrostatic tomography**
- **Multiphase flow systems**



(links: <https://cheme.columbia.edu/faculty/ah-hyung-alissa-park>; <http://energy.columbia.edu/>)

# Innovative Nanomaterials for Combined CO<sub>2</sub> Capture and Conversion

We need to decarbonize all the sectors including power plants and chemical industries

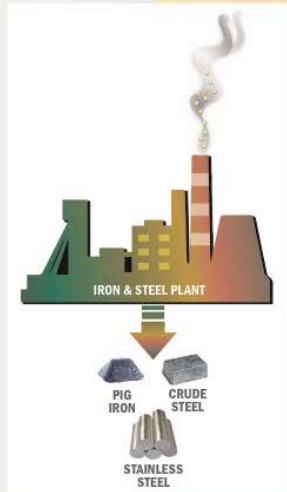




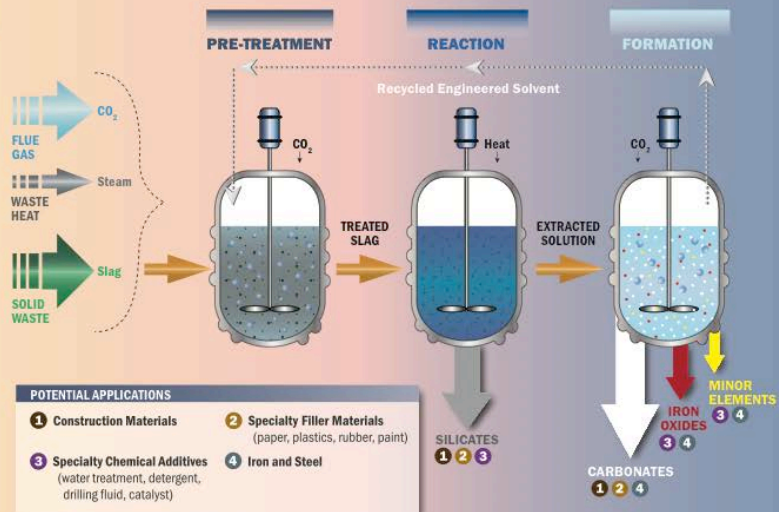
*A.-H. Alissa Park, Director of the Lenfest Center for Sustainable Energy*

# React CO<sub>2</sub> with Solid Wastes to produce Green Construction Materials

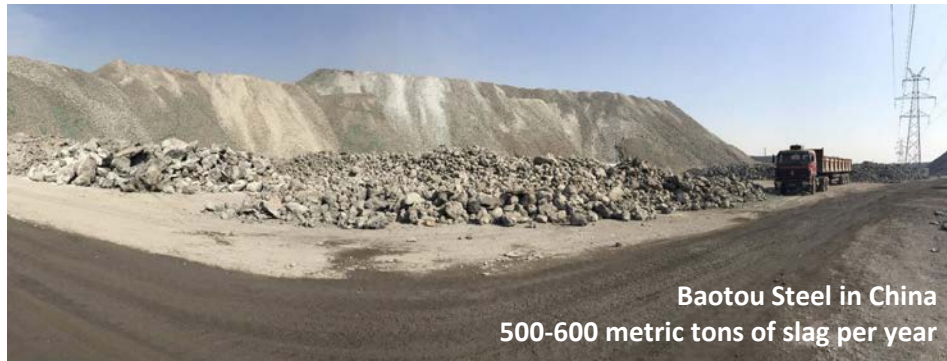
## CURRENT TECHNOLOGY



## COLUMBIA ENGINEERING TECHNOLOGY

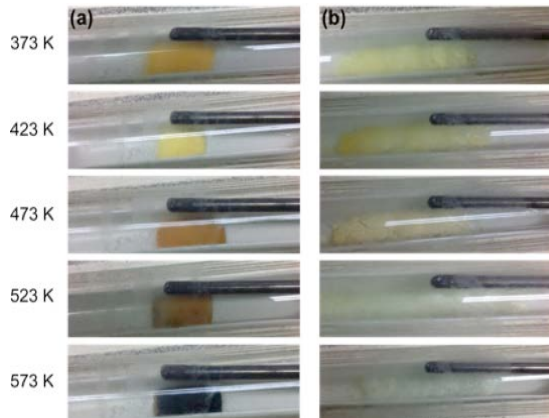
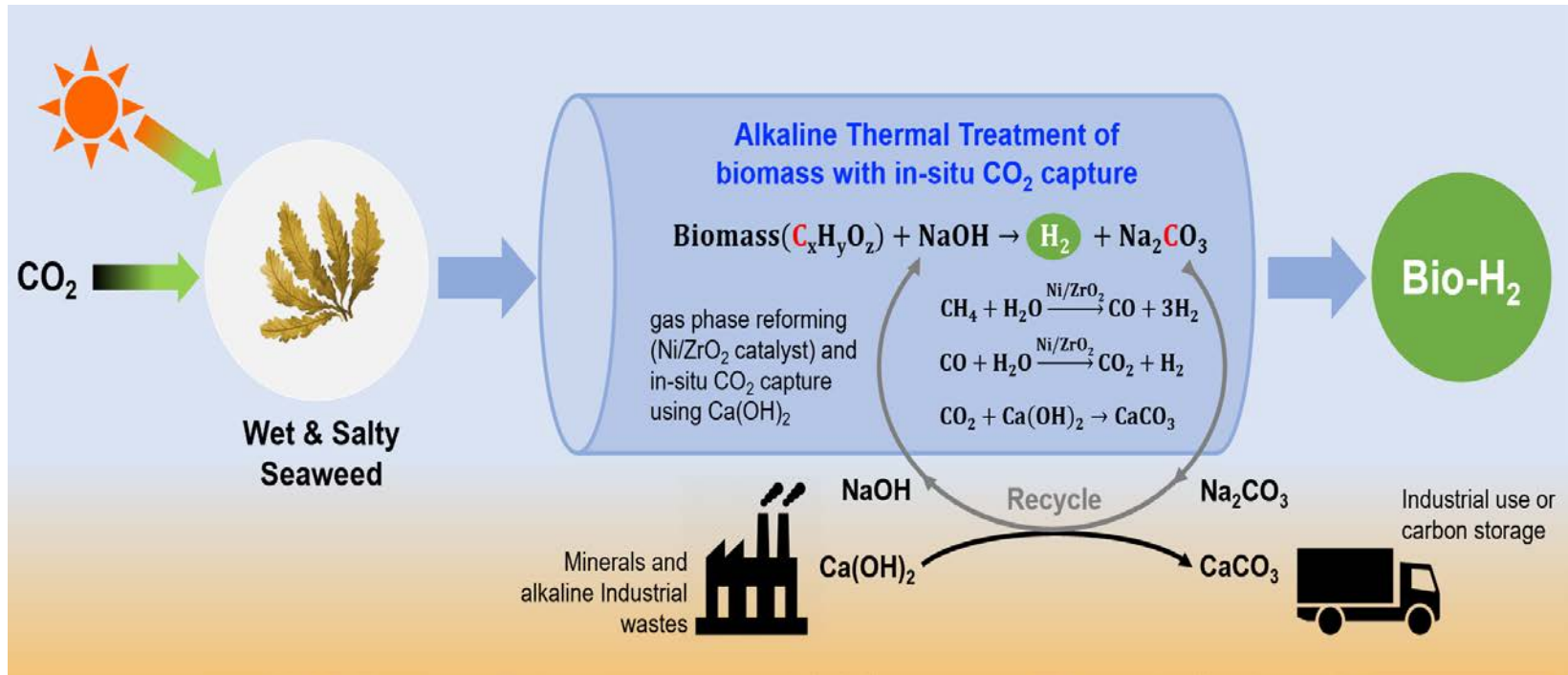


**Columbia's GreenOre technology** is capturing CO<sub>2</sub> using industrial solid wastes while recovering rare earth elements.

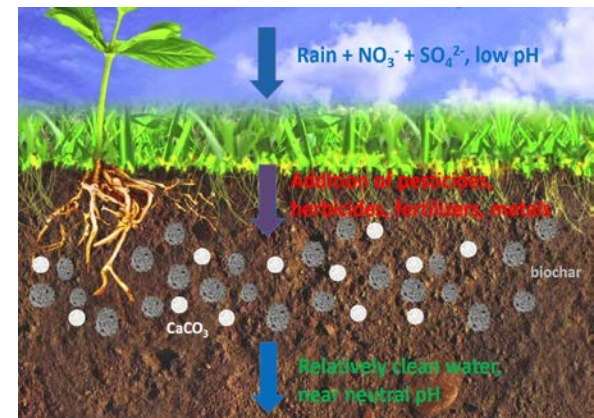


*One steel plant in China generates slag that can cover 1/3 of Tribeca every four years.*

*A.-H. Alissa Park, Director of the Lenfest Center for Sustainable Energy*  
**BioEnergy with Carbon Capture and Store (BECCS): Negative Emission Technology**



The conversion of **wet and salty** biogenic wastes to high-purity H<sub>2</sub> with CO<sub>2</sub> capture can provide opportunities for **carbon neutral or even negative energy production**. Produced carbonates can be used for soil remineralization to improve crop yield and protect groundwater.



# Prof. Dan Steingart, Co-Director Electrochemical Engineering Lab

- **Batteries**
- **Printed electronics**
- **Electrochemistry**



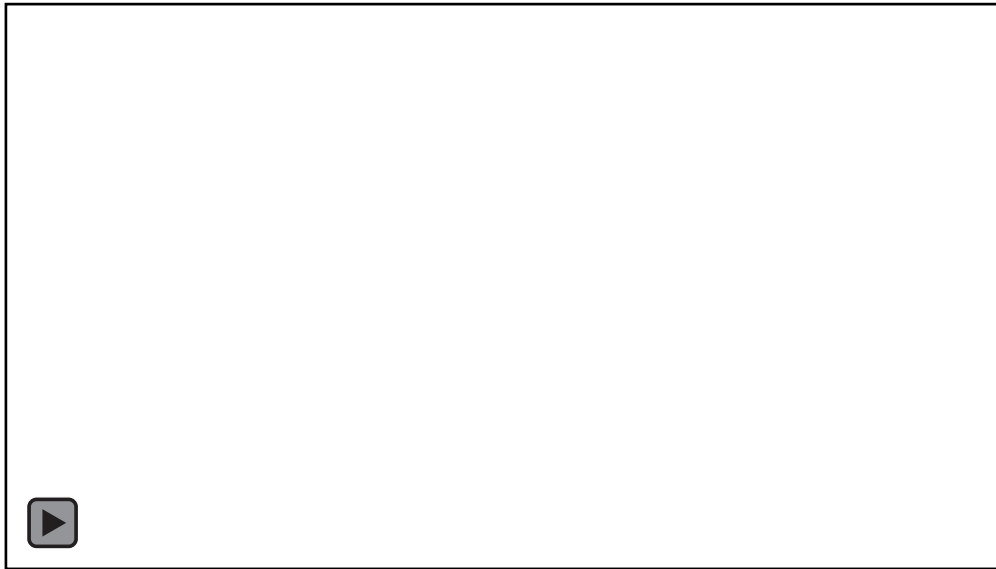
**His group studies the systematic behaviors of material deposition, conversion, and dissolution in electrochemical reactors with a focus on energy storage devices.**

(links:<https://engineering.columbia.edu/faculty/dan-steingart>

<https://ceec.engineering.columbia.edu/people/daniel-steingart> )

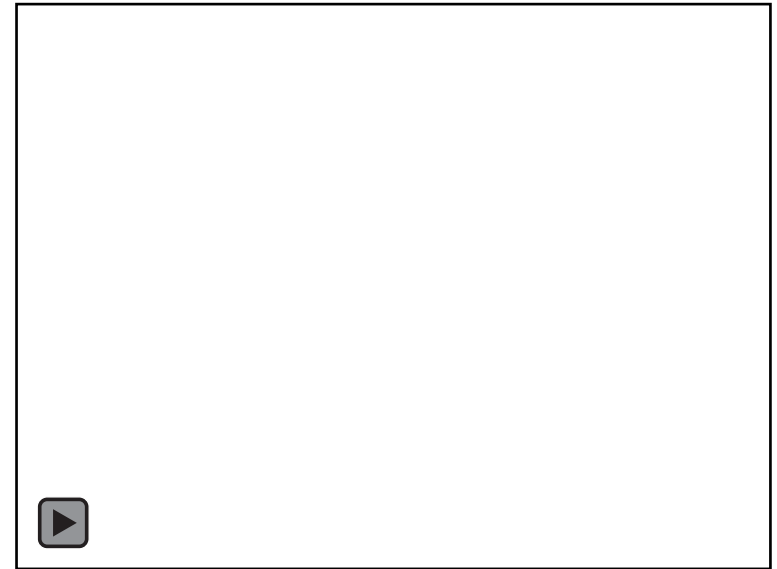
# Steingart Group

*If a battery falls does it make a sound?*



**(Yes and it's really telling)**

*Can a battery constantly short circuit and not kill us?*



**(Yes and it opens up new designs)**

**My group studies and exploits generally unwanted behaviors in elec**

# Prof. Alan West, Electrochemical Engineering Lab

- **Electrochemical engineering**
- **Electrolysis**
- **Electrochemical sensors**
- **Batteries**
- **Fuel cells**
- **Electrodeposition**
- **Energy storage**
- **Energy conversion**

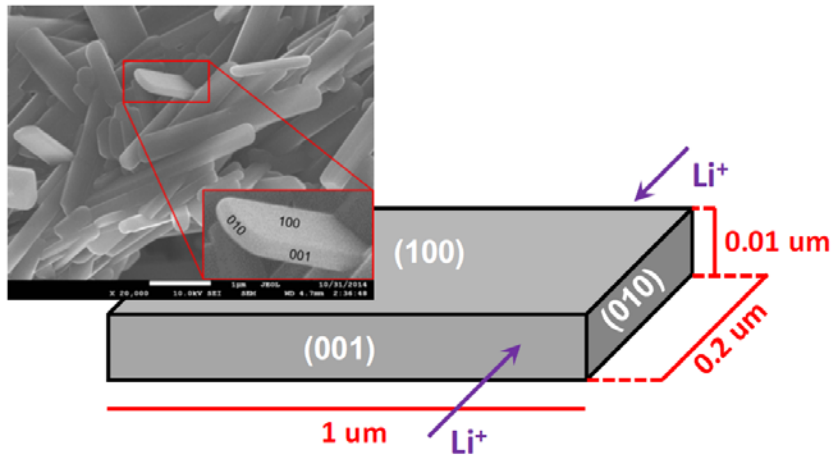


(links: <https://eee.columbia.edu/faculty/alan-west> ; <https://electrochem-lab.cheme.columbia.edu/>)

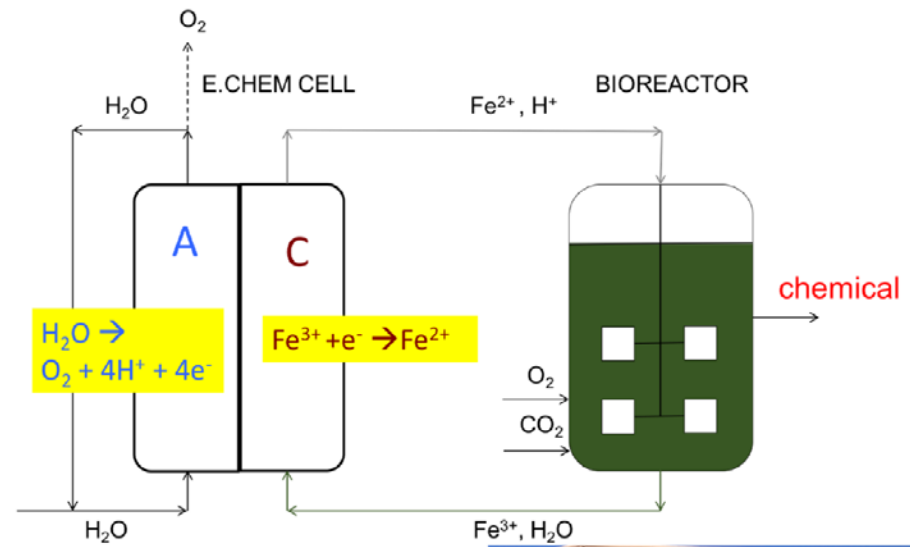
# Alan C. West, ChE and EEE

## Creation, Analysis, and Development of Electrochemical Technologies

### Next Generation Batteries: Rate and Life



### Harnessing Renewable e- for Chemicals



# Prof. Xi Chen, Professor

Carbon dioxide capture, utilization, and storage

Energy storage

Energy conversion

Multi-scale simulation

Soft materials and robotics

Morphogenesis

Mechanobiology

Nanomaterials

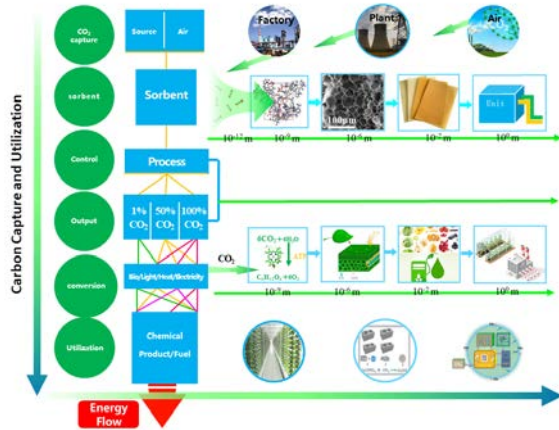
Nanomechanics



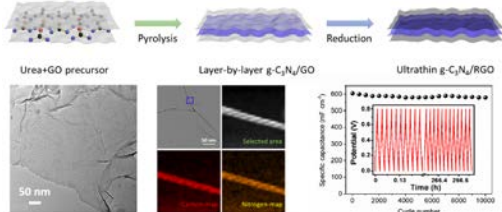
(links: <https://eee.columbia.edu/faculty/xi-chen>; <http://www.columbia.edu/~xc2107/lab.html>)

# Xi Chen, Professor Earth and Environmental Engineering

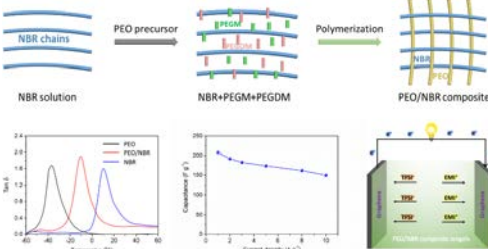
## CO<sub>2</sub> capture and utilization



## Energy storage

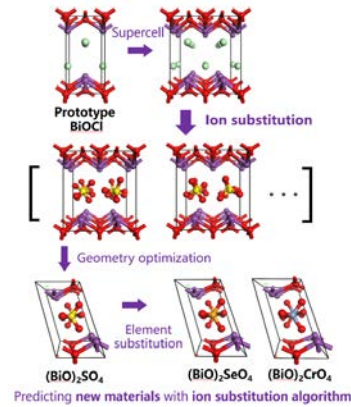


Ultrathin conductive graphitic carbon nitride assembly boosting energy storage

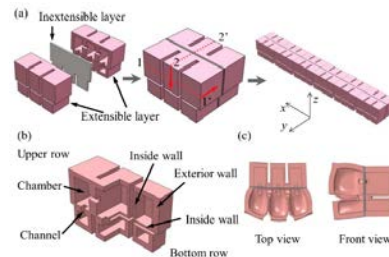
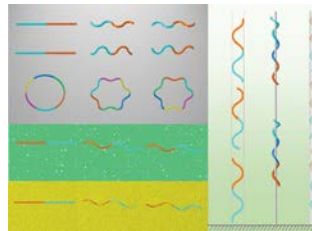


Flexible and highly-conductive composite ionogels for soft electronic devices

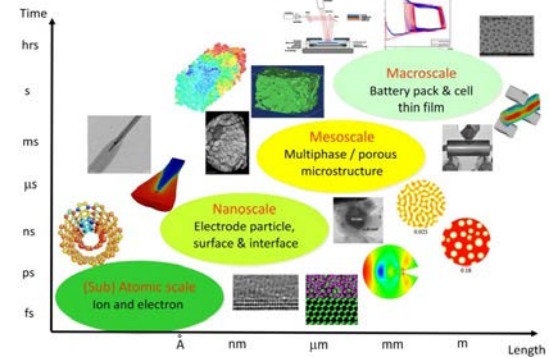
## Material genomics



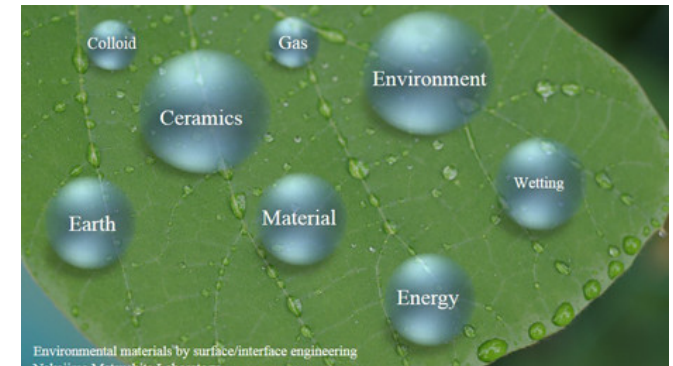
## Soft materials



## Multiscale mechanics of materials



## Materials for energy, earth & environmental engineering

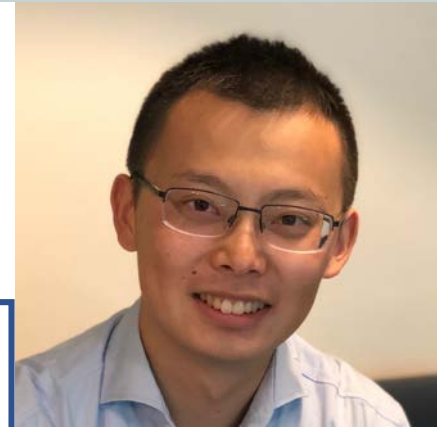
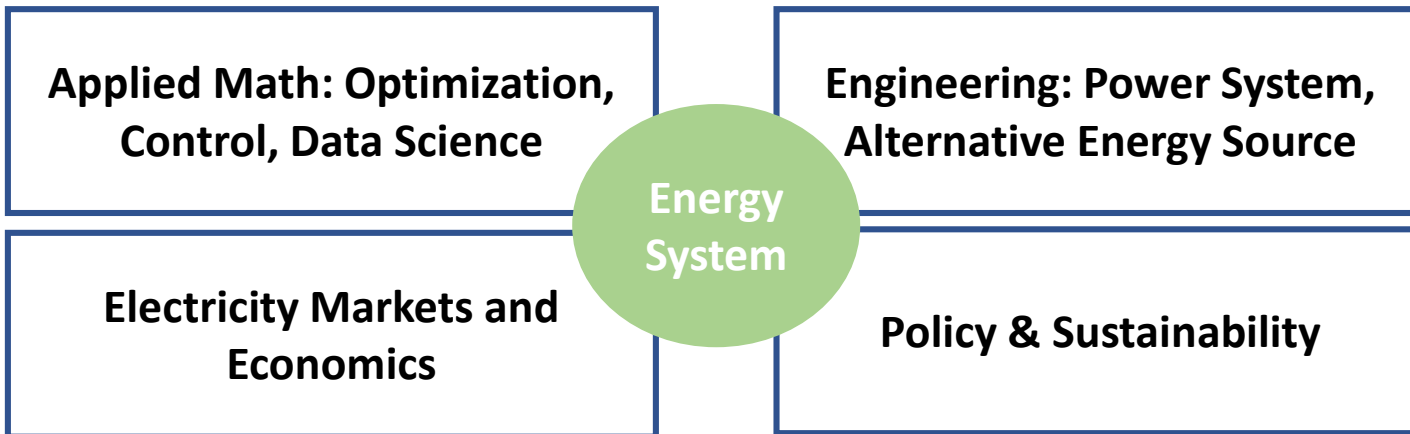


(link: <https://eee.columbia.edu/faculty/xi-chen>)



## Bolun Xu, Ass. Professor

- Research: Sustainable Energy System



- Projects:
  - Data-driven energy system and market analysis
  - Energy analysis for transportation electrification
- Courses:
  - Energy System Economics and Optimization
  - Environmental Data Analysis and Modeling(links: <https://bolunxu.github.io/>)

# Research Example: Determining location and size for energy storage projects US West-Coast

## Engineering

WECC power system model:

- 240 nodes; 448 lines; 71 gen.; renewables.

Operation data for one year:

- Demand, renewable, fuel cost.

## Economics

Cost of different storage technology

- Lithium-ion battery energy storage (Li-BES)
- Compressed air energy storage (CAES)

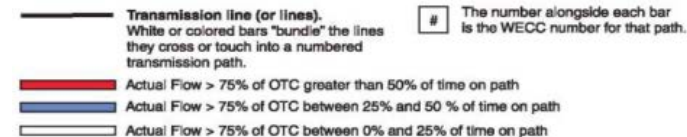
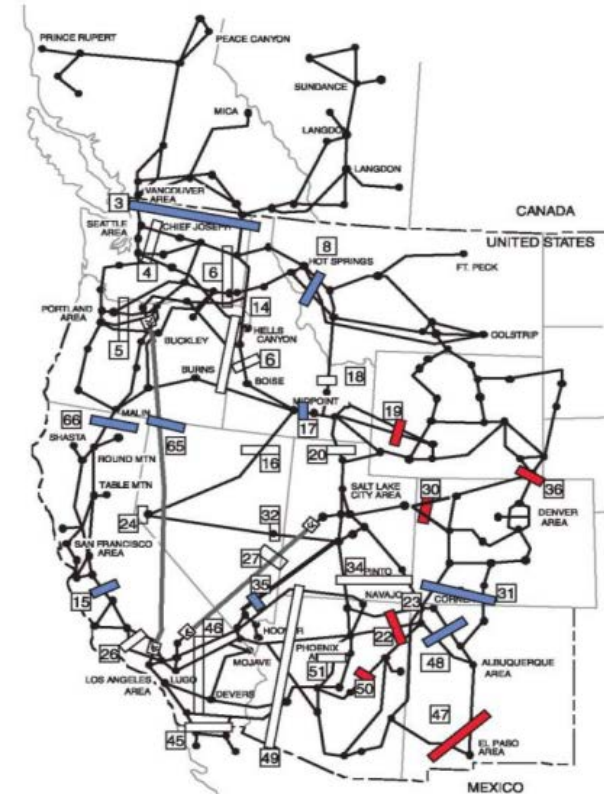
Objective to minimize social cost:

- Location to build storage
- Technology and configuration

## Operation research

Problem size:

- ~10 million variables and constraints
- (Almost) impossible to solve directly
- Use mathematics techniques!



**Results be used for policy recommendations...**

# Prof. Vasilis Fthenakis, Adjunct Professor, Director Center for Life Cycle Analysis

- Renewable energy systems integration
- Solar forecasting
- Life cycle analysis
- Solar water desalination
- Photovoltaics recycling
- Mining/mineral systems analysis



(links: <https://eee.columbia.edu/faculty/vasilis-fthenakis>; <http://www.clca.columbia.edu/>)

# Center for Life Cycle Analysis: Prof. Fthenakis, Director

## Investigating Big Solar: Challenges and Opportunities

---

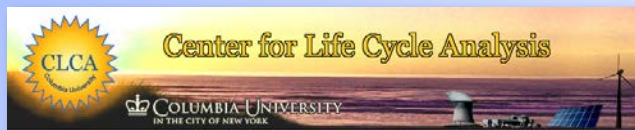
### Challenges

- Operational Challenges
  - Variability, Transmission, Grid Reliability/Stability
- Perceptions on Environmental Impact

### New Business Opportunities

- Solar Energy-Water Desalination
- Energy Storage
- Solar Energy Water Nexus in Mining
- Solar Fuels and Chemicals

**Course:** E4190 Photovoltaics Systems Integration and Sustainability



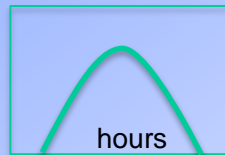
# Renewable Energy Systems Integration

## Solar Variability Solutions: Cost Optimization

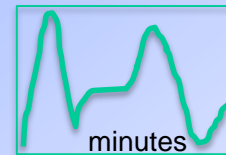
Seasonal



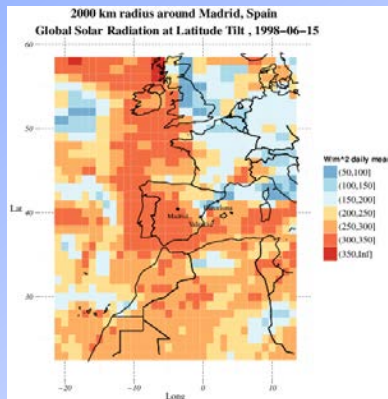
Diurnal



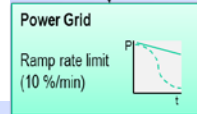
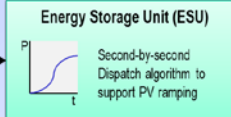
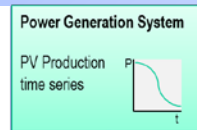
Cloud-induced



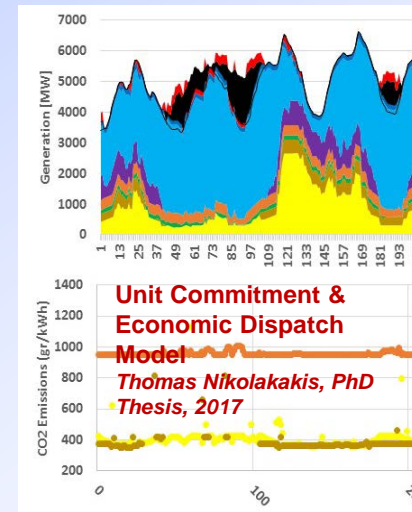
### Model development at the Center for Life Cycle Analysis (CLCA)



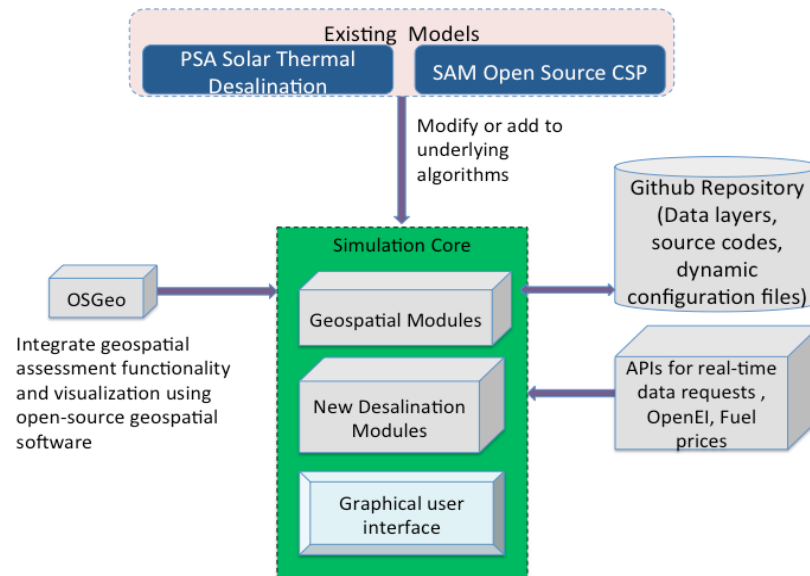
**PV Generation, Curtailment, Transmission and Storage Optimizer**  
*Marc Perez, PhD Thesis, 2014*



**PV Energy Storage Optimization for Ramp Rate Control**  
*Rob van Haaren, PhD Thesis, 2014*



# GIS-based graphical user interface tool analyzing solar thermal desalination systems and high-potential implementation regions



- **Reference Desalination models: MSF, MED, MED-TVC, RO**
- **New Technologies & Potential Hybrids: MD, RO-MED, RO-MD, crystallization for ZLD.**
- **The analysis tool design will be Open Access, Expandable, using a Modular Architecture**

**US-DOE Award, 2018-2021**

**PSA: Plataforma Solar de Almeria**

**SAM: NREL System Advisory Model**

# Prof. Robert (Bob) Farrauto, Catalysis for a Sustainable Environment Lab

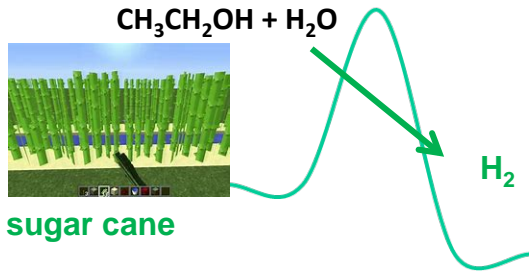
- **Heterogeneous catalysts and process for a sustainable environment**
- **Air pollution abatement**
- **Dual function materials for CO<sub>2</sub> capture and conversion to fuels**
- **New catalysts and processes for catalytic hydrogen generation**

(links:<https://eee.columbia.edu/faculty/robert-farrauto>;

<http://www.columbia.edu/cu/catalysis-environment/>)

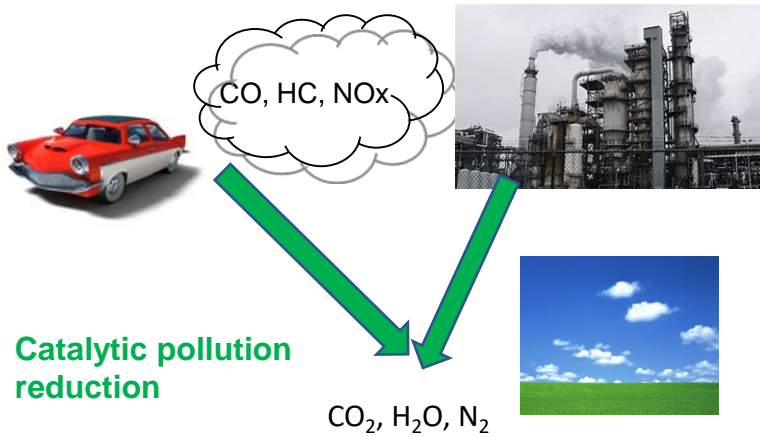
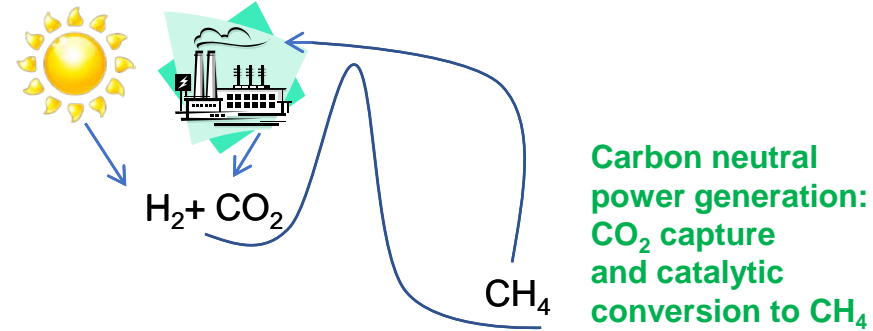


# R. Ferrauto, Director Catalysis for A Sustainable Environment

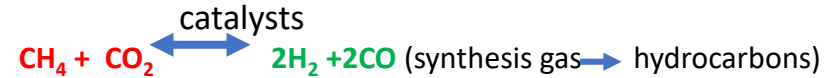


Catalysts for the  $\text{H}_2$  economy:  
Reforming ethanol

Ferrauto Research  
Catalysis for a  
Sustainable Environment



$\text{CO}_2$  Utilization: Utilizing  $\text{CH}_4 + \text{CO}_2$  green-house gases



Catalysis for a Sustainable Environment  
<http://www.columbia.edu/cu/catalysis-environment>





- **Surface/colloid chemistry of materials/nanoparticles**
- **Greener chemicals**
- **Biosurfaces**
- **Sustainability in underground resources exploration, e.g. extraterrestrial mining**
- **Molecular interactions at interfaces using advanced spectroscopy**
- **Polymers/surfactants/protein absorption, flocculation/dispersion**
- **Sunlight powered photosynthesis of fuels from CO<sub>2</sub>/water**

(link: <https://eee.columbia.edu/faculty/ponisseril-somasundaran> )

# Columbia National Science Foundation Center for Particulates Polymer & Surfactant Systems

- Develop **novel green surfactants/polymers/bio-reagents** for interfacial applications
- Investigate particle-Surfactant-Polymer-Protein **static and dynamic** interactions for optimal performance
- Select schemes for **synergy** among chemicals
- Carry out **long term basic research** for new technological and intellectual paradigms
- Supply a venue for **industry-academic interactions** for relevant research

(link: <http://blogs.cuit.columbia.edu/iucrc/>)

# Recent Success Story

## Breakthroughs

Prototype Greenness Index,

Greener Molecules for Frothing. Nanogels, tissue engng

Time lapse understanding of polymer-surfactant dancing

Catalysis by doped nanoparticles for CO<sub>2</sub> to Alcohols

**New programs:** Hydraulic fracturing, Ebola

## Public Awareness

Stephen Hawking's Brave New World: Discovery Chan

New York Times, National Geographic, New Yorker

Globo TV



## Publications and Patents

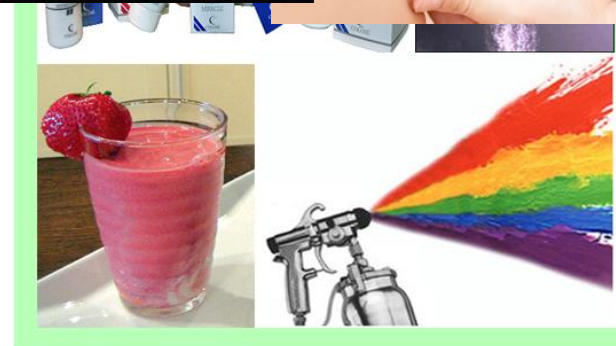
JACS, PNAS, Nature Nanotechnology, JPCC, JCIS, Langmuir,

IJMP, C&S: A, J. Catalysis, PCCP,.....

## Collaborations

NTNU, Tulane, CUNY, Poly, ISU, LSU,

UNY, IITM, Chalmers U JHU, University of Bern, IAB companies



# Prof. Kartik Chandran, KC Laboratory

- **Engineered systems for resource recovery**
- **Microbial N-cycling**
- **Sustainable sanitation and wastewater treatment**
- **Reactors**
- **Novel molecular based biokinetic estimation tools**
- **Bioprocess modeling**
- **Global climate impacts of engineered wastewater treatment practice**
- **Microbial ecology of engineered biological waste and water treatment**
- **Elucidation of microbial biochemical degradation pathways**
- **Parameter identification for complex biotransformations**



(Links: <https://eee.columbia.edu/faculty/kartik-Chandran>; <https://kchandranlab.wixsite.com/kclab>)

## Prof. Nickolas Themelis, Emeritus Professor

- **Data science**
- **Design, and modeling**
- **Waste to energy**
- **Mining**
- **Technology, policy, economic tools that will reduce landfilling in the U.S. (Currently 90% of post recycling wastes are disposed in landfills), Latin America, and Asia.**



(link:<https://eee.columbia.edu/faculty/nickolas-themelis>)

# Prof. Thanos Bourtsalas, Lecturer

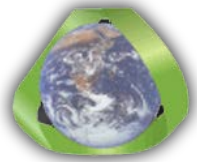
- **Circular Economy**
- **Sustainable Management of Resources**
- **Process engineering**
- **Design and modelling of urban development**
- **Life Cycle Environmental and Cost Analysis**
- **Public policy for sustainable development**
- **Economics for sustainable development**

([link:https://eee.columbia.edu/athanasios-bourtsalas](https://eee.columbia.edu/athanasios-bourtsalas))



# Circular Economy

*Advisors: Dr. Thanos Bourtsalas; other faculty*



COLUMBIA UNIVERSITY  
EARTH ENGINEERING CENTER

## **Urban development:**

- Feasibility studies on the deployment of sustainable development projects, e.g. transformation of contaminated open dumps to eco-industrial parks
  - Technical, environmental, economic and financial, and policy components
- Formulation and monitor of Public and Private Partnerships
- Results-based (blended) financing schemes to minimize the construction, operation, and counterparty risks, incl. environmental, in infrastructure investments

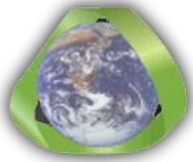
## **Industry:**

- Redesign of processes for minimum loss of resources, and of products to last longer and to be easily repaired/reused;
- Remanufacture of products to be used in primary production;
- Recycle of products or its components for materials production.
  - *Recycling should ideally produce high added value materials.*

*Applies to both areas: Industrial Ecology/Life Cycle Analysis (LCA) studies to understand the effect of any adjustment on the economy and the environment*

# Sustainable Management of Urban and Industrial Residues

*Advisors: Dr. Thanos Bourtsalas and Nickolas Themelis; other faculty*



COLUMBIA UNIVERSITY  
EARTH ENGINEERING CENTER

## **RECOVERY OF MATERIALS:**

- Recycling of metals, paper, plastics, glass
- Composting
- Use of ash in civil works

## **RECOVERY OF ENERGY AND FUELS:**

- Electricity from Waste-to-Energy (WTE) power plants
- Industrial and residential (district) heating
- Chemical recycling to recover fuels from mixed plastic materials
- Use of alternative fuels in cement manufacturing
- Desalination

**Societal objectives: Conservation of non-renewable resources and land; mitigation of climate change.  
For examples of past M.S. EAEE theses link to [gwcouncil.org/publications/research-projects](http://gwcouncil.org/publications/research-projects)**