

Green Technology as a Campus Initiative

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and Byron Washom
UC San Diego

*Presentation at the
INAOE
Puebla, Mexico,
September 23, 2016*

Outline of Presentation

1. Historical overview
2. Green Campus wide Projects
 - Retrofitting
 - Microgrid – solar forecasting, PV, re-use of waste gases
 - LEED building
3. Related Nanotechnology Projects
 - Artificial Photosynthesis
 - Energy Storage
4. Conclusion

An aerial photograph of a tropical island, likely in the Maldives, featuring a long, straight runway and taxiway. The island is surrounded by shallow turquoise water with visible coral reefs, transitioning into deeper blue ocean waters. The sky is filled with soft, white clouds. The overall scene is serene and picturesque.

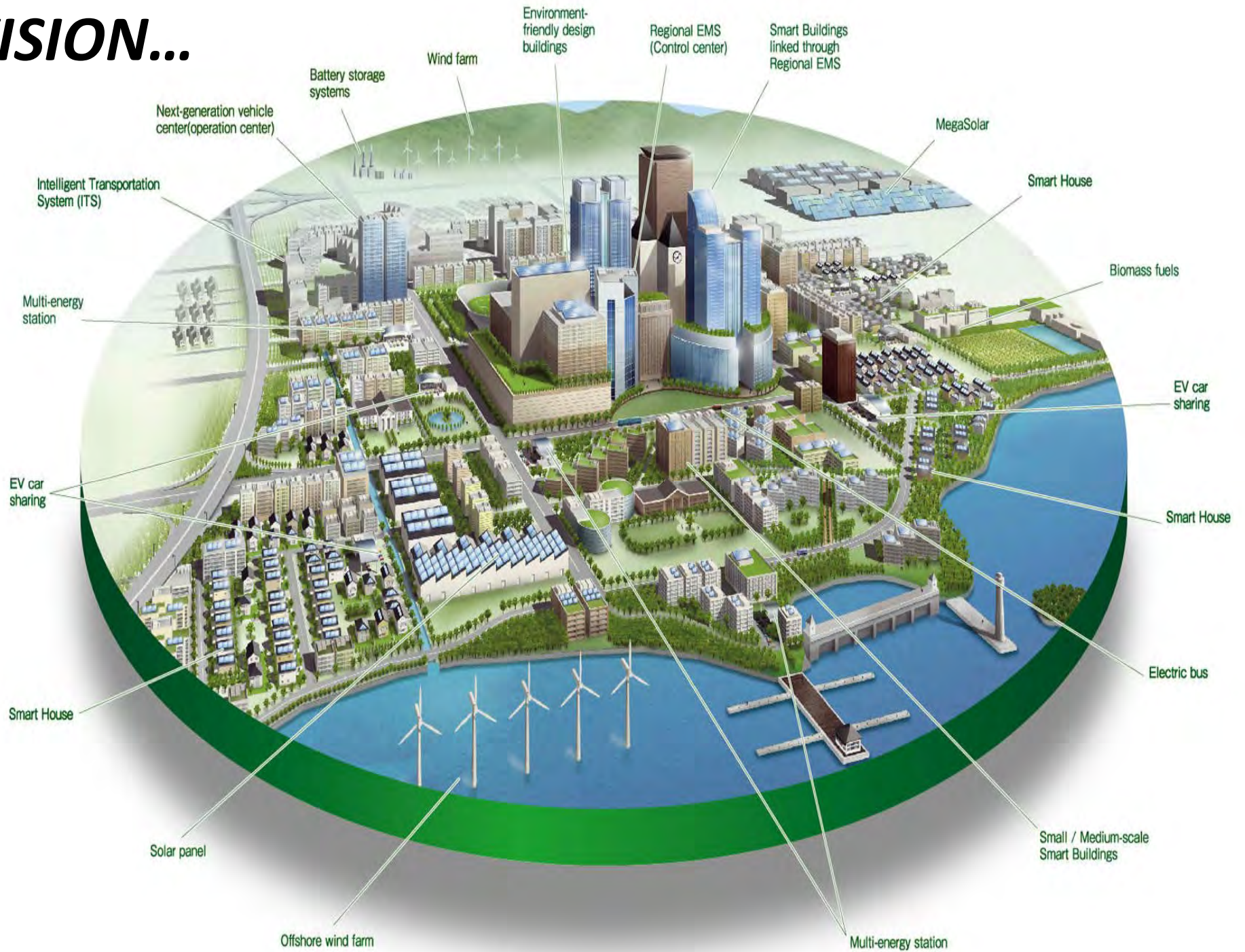
“You learn to live within rather than to live without.”

CA's future electricity system will consist of near zero net energy buildings, highly efficient businesses, low- carbon generation, sustainable bioenergy systems, more localized generation, and electrification of transportation, supported by a highly flexible and robust distribution and transmission infrastructure. – CA Energy Commission, EPIC Funding Vision

Oslo is recognized as the EV capital of the world. In March 2014, Norway became the first country where over one in every 100 passenger cars on the roads is a plug-in electric, and the segment's market penetration rose to 2% in March 2015. Norway ended 2014 as the top selling European country in the light-duty all-electric market segment, and the country accounted for a third of all European all-electric car sales. Norway's fleet of electric cars is one of the cleanest in the world because almost 100% of the electricity generated in the country comes from hydropower

How About San Diego?

VISION...

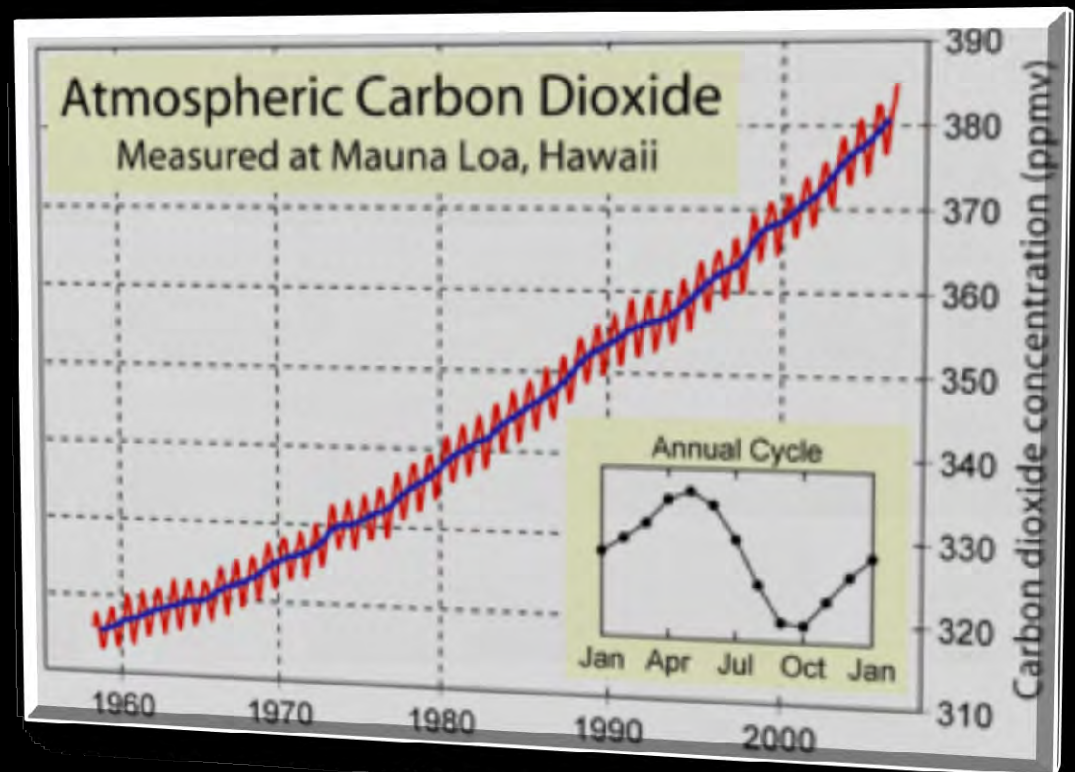


A History in Climate Research

UC San Diego and its Scripps Institution of Oceanography has long been internationally recognized for *pioneering research* in global climate change.

We feel it is imperative to have commensurate leadership in the sustainability of UC San Diego's *operations*.

As a *living laboratory* for climate solutions, UC San Diego will be an early adopter for real-world tools and leading-edge technologies for California and global marketplace.





Courtesy of Birch Aquarium, UC San Diego

UCSD Campus 2015



UCSD Campus Quick Facts

With a daily population of close to 50,000, UC San Diego is the size and complexity of a small city.

As a research and medical institution, we have two times the energy density of commercial buildings

16+ million sq. ft. of buildings,
\$500M/yr of building growth

Self generate 92% of annual demand...still one of SDG&E's largest customers

3rd largest water user in City

UC San Diego Operates a 42 MW_{peak} Microgrid



Outline of Presentation

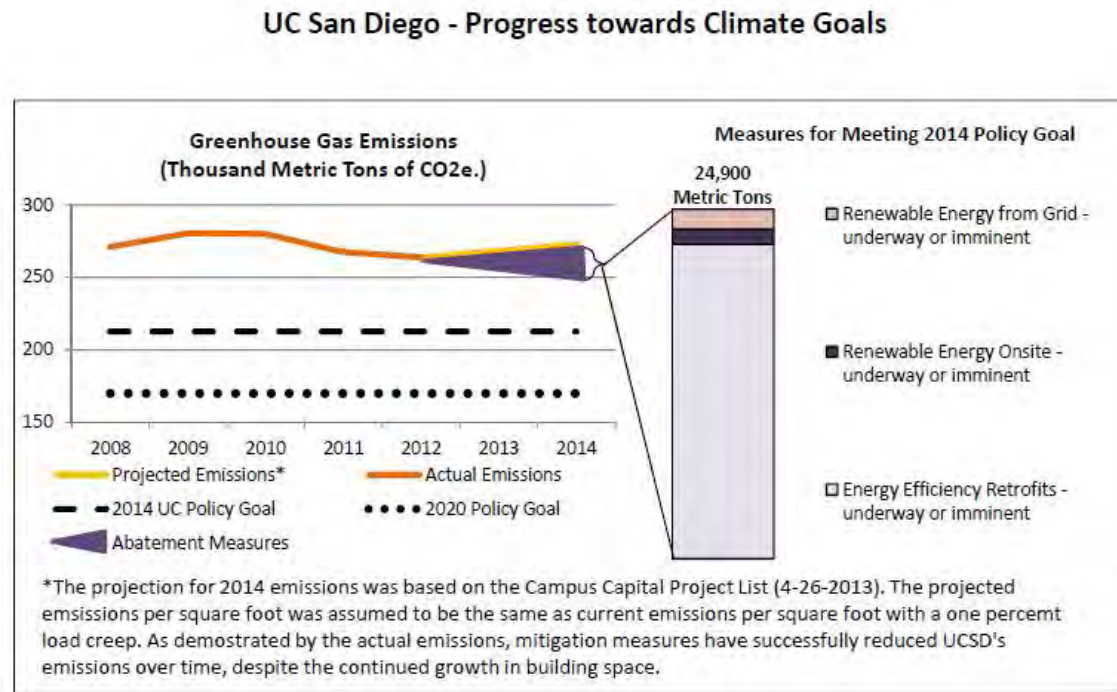
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Energy & Climate Goals vs. Growth

Continue to be a Leader in [Carbon Reduction and Energy Efficiency](#)

By 2015 will have completed \$100M in Energy Retrofit Projects – offsets all new construction since 2000!!

New Construction continues, while viable projects dwindle



Energy & Climate Goals vs. Growth

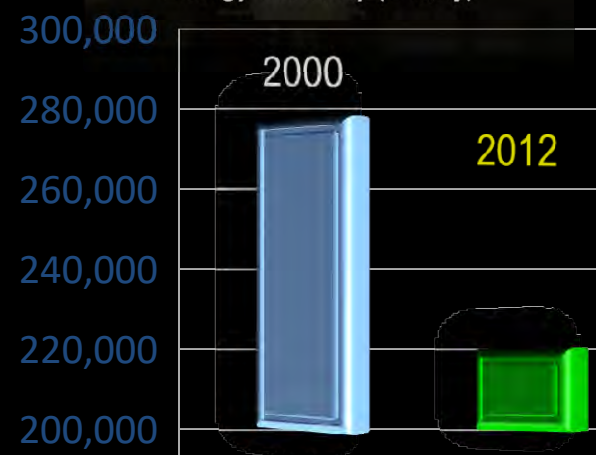
Continue to be a Leader in [Carbon Reduction and Energy Efficiency](#)

We have completed \$100M in Energy Retrofit Projects – offsets all new construction since 2000!!

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Energy Intensity (Btu/sf)



Microgrid ...

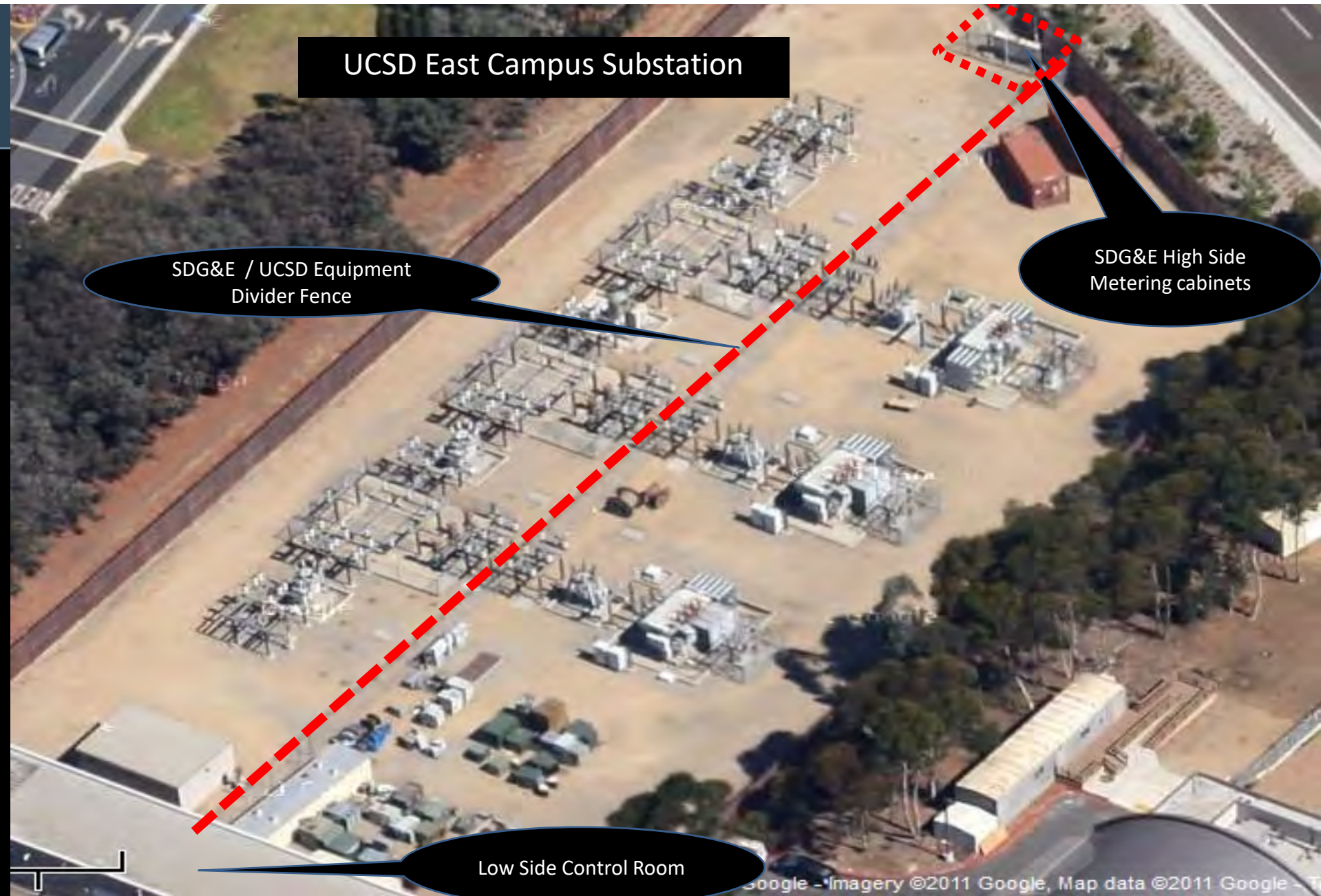
“First light for what the new smart grid architecture will look like is already visible... the ARPAnet moment for the Electrinet is arguably at University of California at San Diego where the 40 megawatt campus is the first fully operational smart microgrid.” *Forbes*



Overview of Microgrid

- Self Gen >92% electricity, 95% heat and cooling (annual)
- 2 Solar Gas fired turbines, with Heat Recovery
 - 13.5 MW each
 - Combined Heat and Power is 66 percent efficient (EPA Energy Star Awardee)
- 3 MW Dresser Rand Steam Turbine
- 3.8 million gallons chilled water storage
- Three (3) steam driven chillers (~10,000 tons capacity)
- Eight (8) electric driven chillers (~7,800 tons capacity)
- 2.8 MW natural gas fired fuel cell (directed bio gas)
- 2.5 MW of Photovoltaics
- 3 MW/6 MWH energy storage
- 75 emergency backup generators

UC San Diego's energy efficiency measures have reduced its imports of electricity by 13.6% over the past four years, but its total utility bill has risen by 23.2% during that same period.



UCSD East Campus Substation

SDG&E / UCSD Equipment
Divider Fence

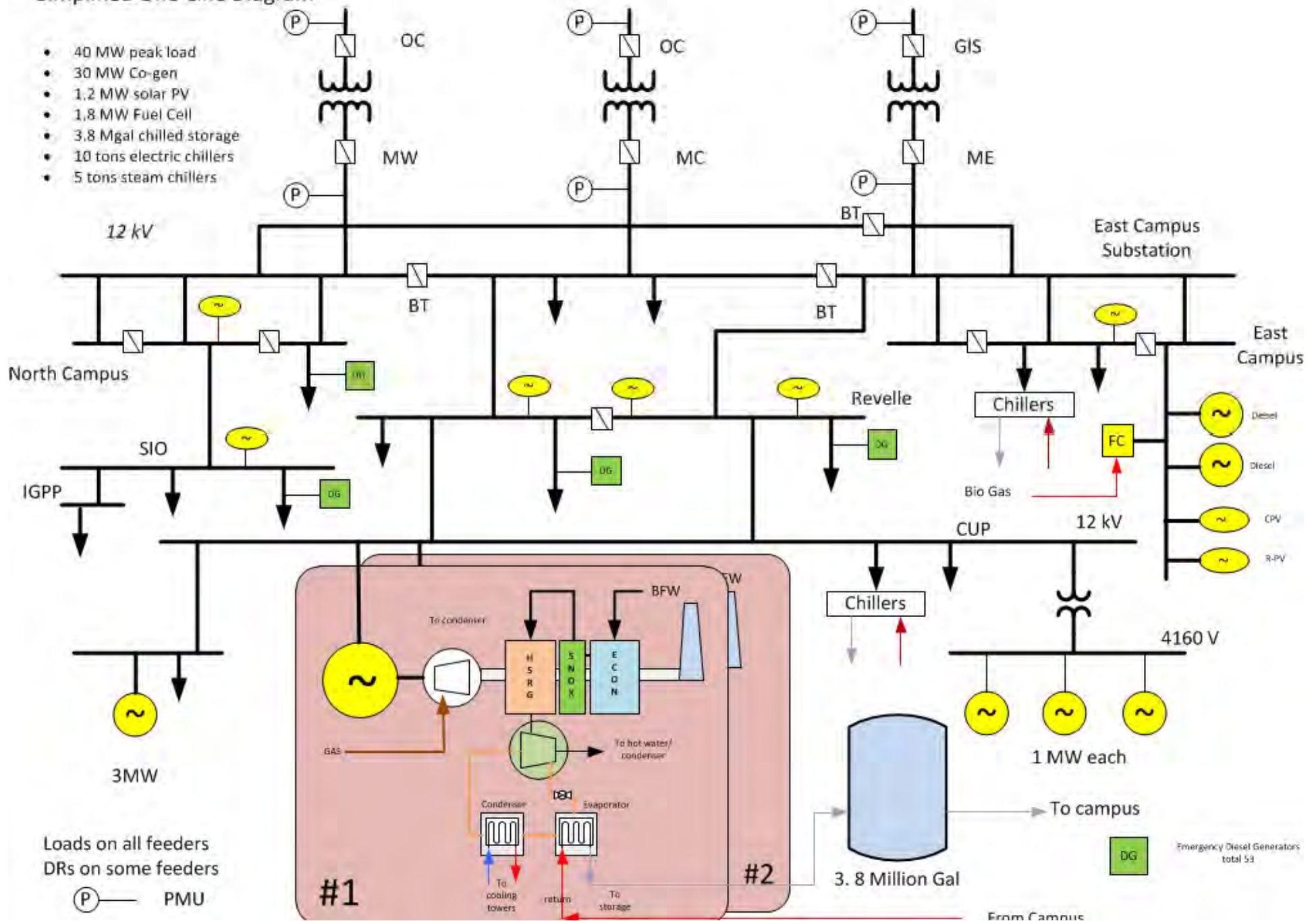
SDG&E High Side
Metering cabinets

Low Side Control Room

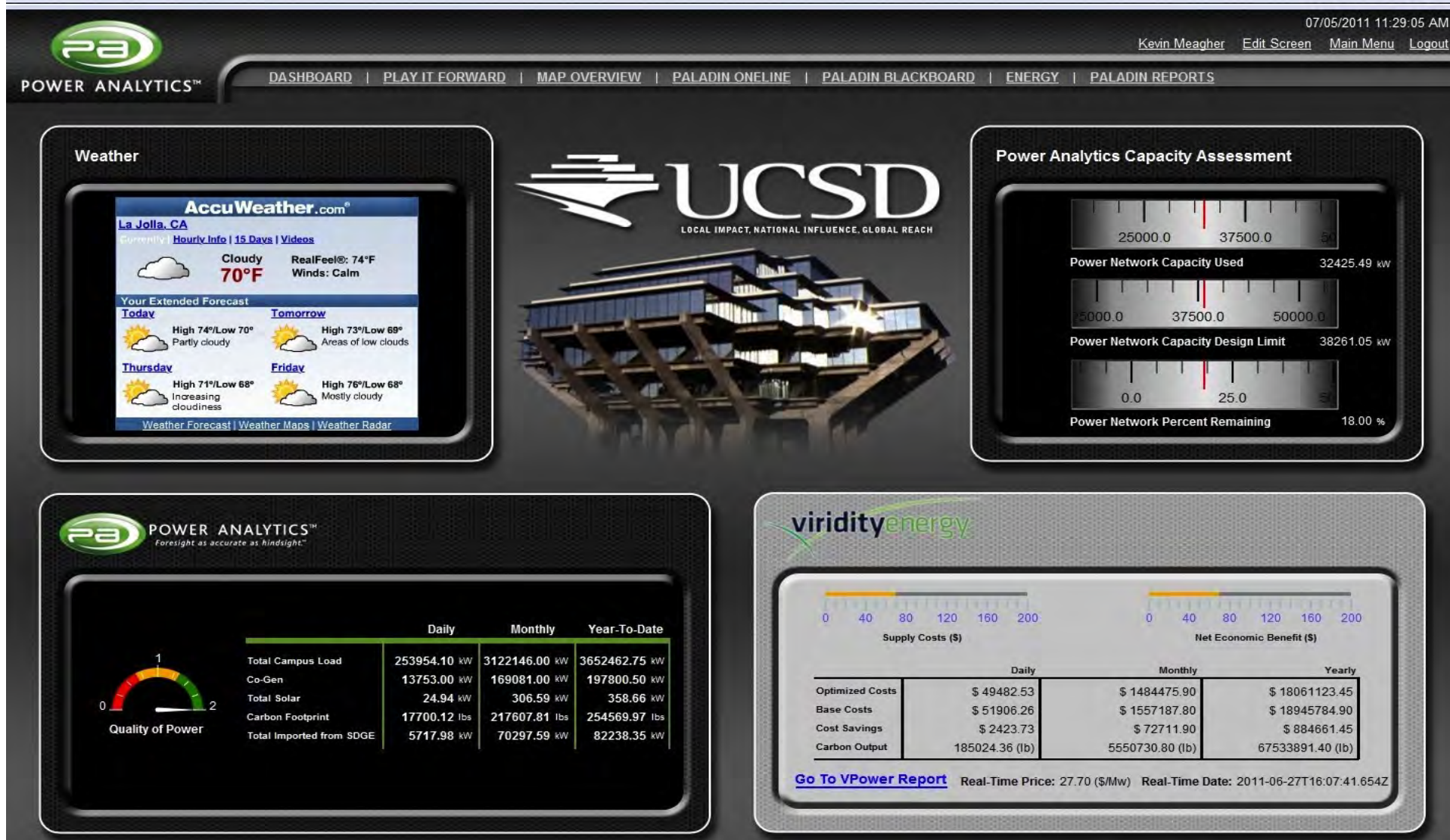
UCSD Microgrid Simplified One-Line Diagram

- 40 MW peak load
- 30 MW Co-gen
- 1.2 MW solar PV
- 1.8 MW Fuel Cell
- 3.8 Mgal chilled storage
- 10 tons electric chillers
- 5 tons steam chillers

69 kV

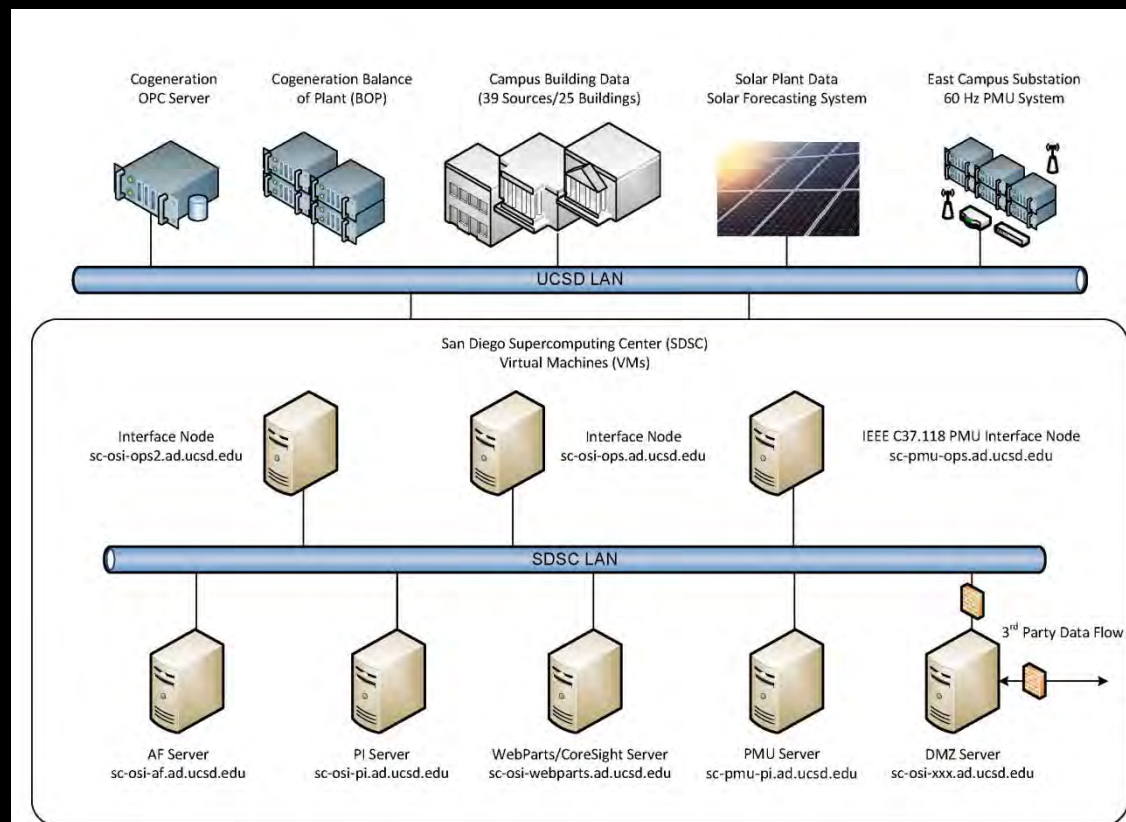


Real Time Control by Power Analytics of Rancho Bernardo CA



OSIsoft PI Software of San Leandro CA

Solution to the Smart Grid dilemma of “drowning in a sea of data, but thirsty for knowledge”.

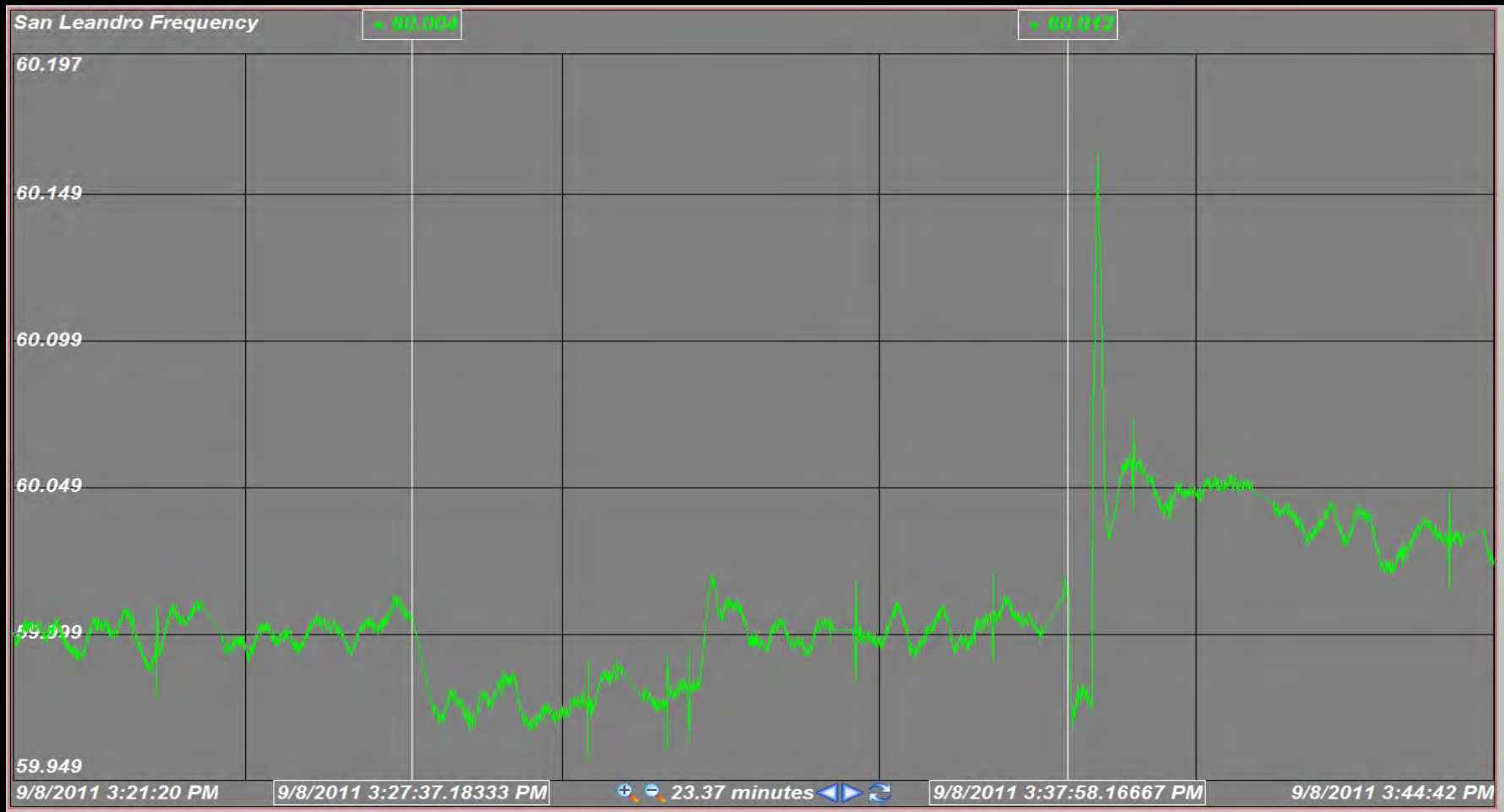


UCSD Microgrid PMU Inventory

- 12 PMUs
 - Six installed
 - 2 SEL 351a
 - 3 Arbiter 1133a
 - 1 FNET (UT)
 - Six under contract to be installed this year
 - Another ten are proposed to the CEC



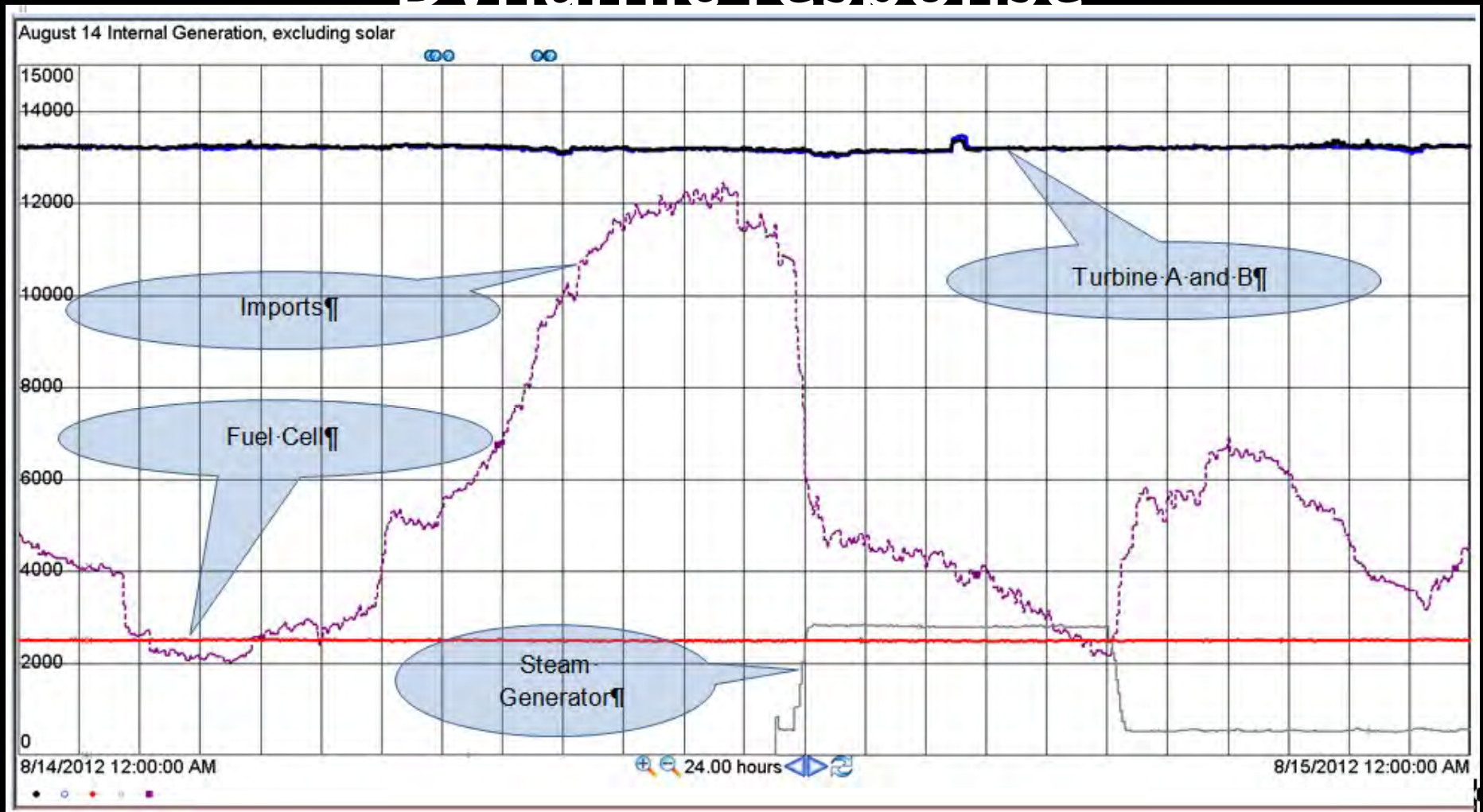
Improved Monitoring Would Have Provided a 10 Minute Warning on the September 8, 2011 Outage



August 14, 2012 Demand Response

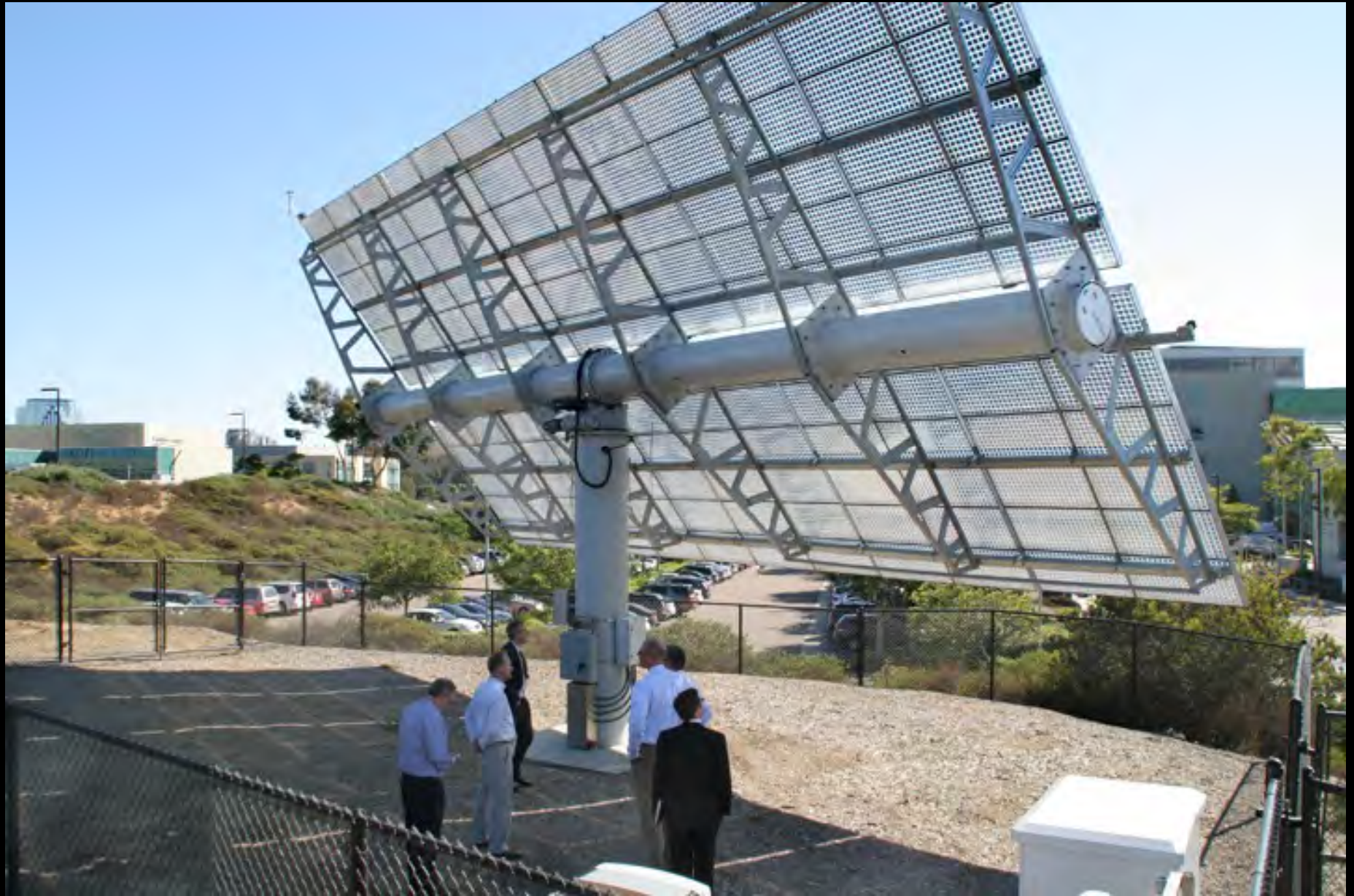
- “SDG&E has notified the campus that energy demand reduction is needed between 1 and 6 p.m. today due to continued high temperatures taxing regional power reserves. Without demand reduction, SDG&E may be required to take actions to stabilize the utility grid.
- “Beginning at 1 p.m. today, Facilities Management will automatically reduce power demand by adjusting campus comfort cooling settings.”
- Heating, ventilation and air conditioning in office areas will go into "unoccupied" mode and spaces will be warmer or cooler than normal, depending on the space. Temperature set points in lab areas will range between 68 and 76 degrees. Airflow will not be affected.”

Dynamic response



Soitec Concentrating PV

- Sparsely known German Concentrix installs at UCSD its 5.5 kW Concentrating PV module, 7/2009
- French Soitec acquires Soitec and begins design of 22 kW Concentrating PV module
- SDG&E enter into a Power Purchase Agreement for 305 MW that are approved by CPUC in 11/2010
- Soitec dedicates San Diego factory for 400 direct and 1000 indirect jobs, 12/2011
- DOE awards Soitec \$25M Manufacturing grant for what is now the world's largest Concentrating PV company



Incubating Innovative Technology and Developing Permanent Local Jobs

- “Soitec already had decided to put the North America headquarters of its solar operation in San Diego. The factory location choice came in part ... because of relationships the company developed with the University of California, San Diego, which allowed space for the demonstration Concentrix panel, and SDG&E.” *NY Times* (7/6/11)

Saturate All Suitable Rooftop PV Sites on Campus



A UC-wide Renewable project ...

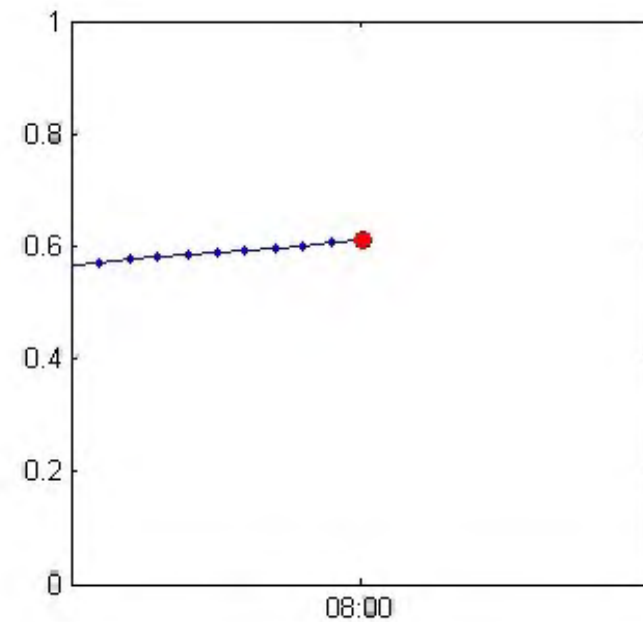


The 60MW Five Points PV facility in Fresno County has begun sending electricity to the University of California (UC) under a 25-year power purchase agreement with developer Centaurus Renewable Energy. - *Recharge*, Aug 23, 2016

Innovate: Solar Forecasting

- Day ahead Solar Forecasting
 - Evaluate forecast performance for California-specific meteorological events (winter frontal system, marine layer clouds, Tule fog)
 - Conduct high resolution rapid refresh simulations to improve cloud resolution
 - Conduct data assimilation of ground or satellite data

The trouble with solar: clouds affect irradiance at the ground level



Time of Day (hh:mm)



Improved Forecast Implementation with the CAISO

- CAISO market test system parallels actual market operations and allows for real world validation of the impacts from improved solar forecasts
- We are in continuous contact with the CAISO staff, and have their full support and commitment for implementing our forecasts into their decision desk
 - Our team has extensive experience in the CAISO market and has close working relationships with CAISO staff
 - Actively supporting CAISO in Long-Term Procurement Planning, Flexible Capacity Procurement and Renewable Integration.
- The forecasting tools from activity B will be configured to continuously upload forecasts into the CAISO test system
 - This functionality is currently being developed by the CAISO



BioGas Recycling



2.8 MW Fuel Cell supplies 10% of baseload power with directed biogas renewable fuel



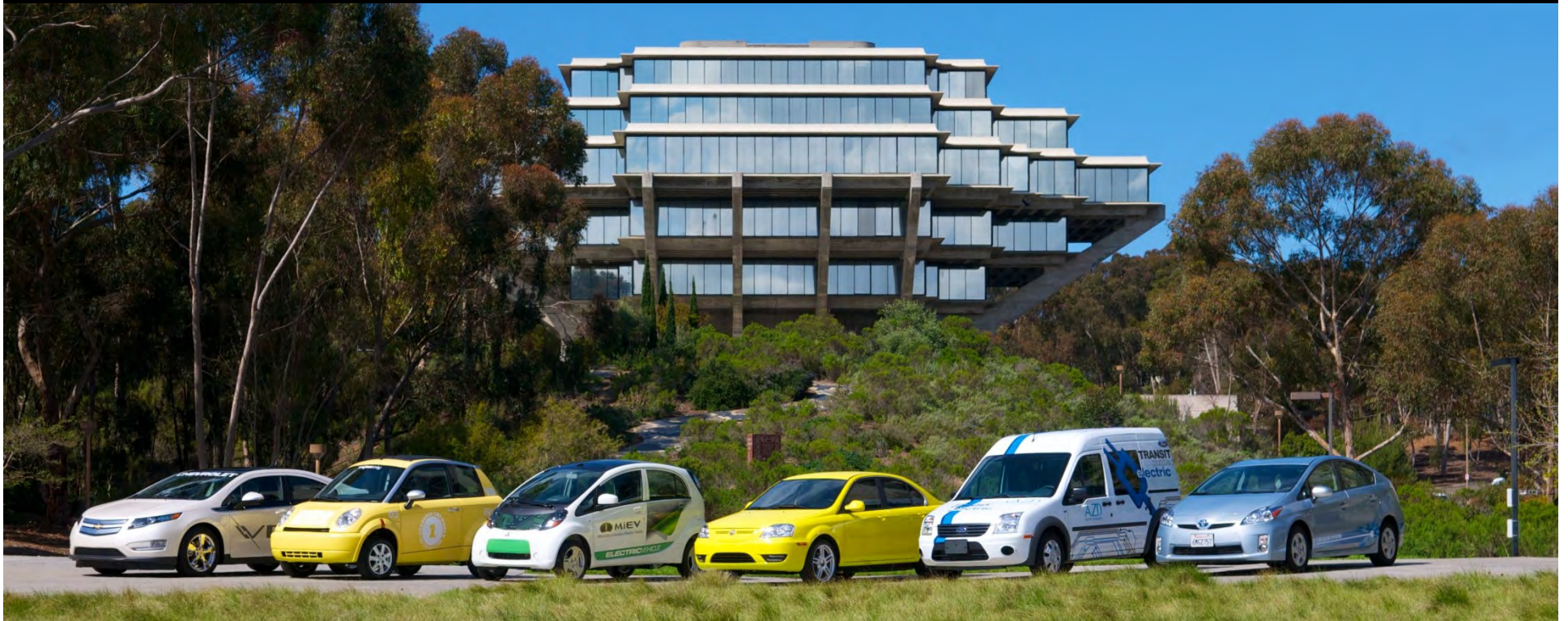
Thus, surplus renewable methane gas that is currently being flared at Pt Loma will be purified and utilized to provide 8% of the UCSD campus electric load, 24 x 7 x 52 for 10 years.

All at a price equal to our cost of importing from the grid.

“San Diego is embracing EVs like no other city, even in electrified California. Some 10 percent of the [Nissan LEAF](#) US reservations are in San Diego, and the university is leading the charge...”

PluginCars (6/17/11)

UCSD's Electrification of the Transportation Sector: “Field of Dreams”





“Tailpipe Endgame”

Renewable Energy Charging of EVs



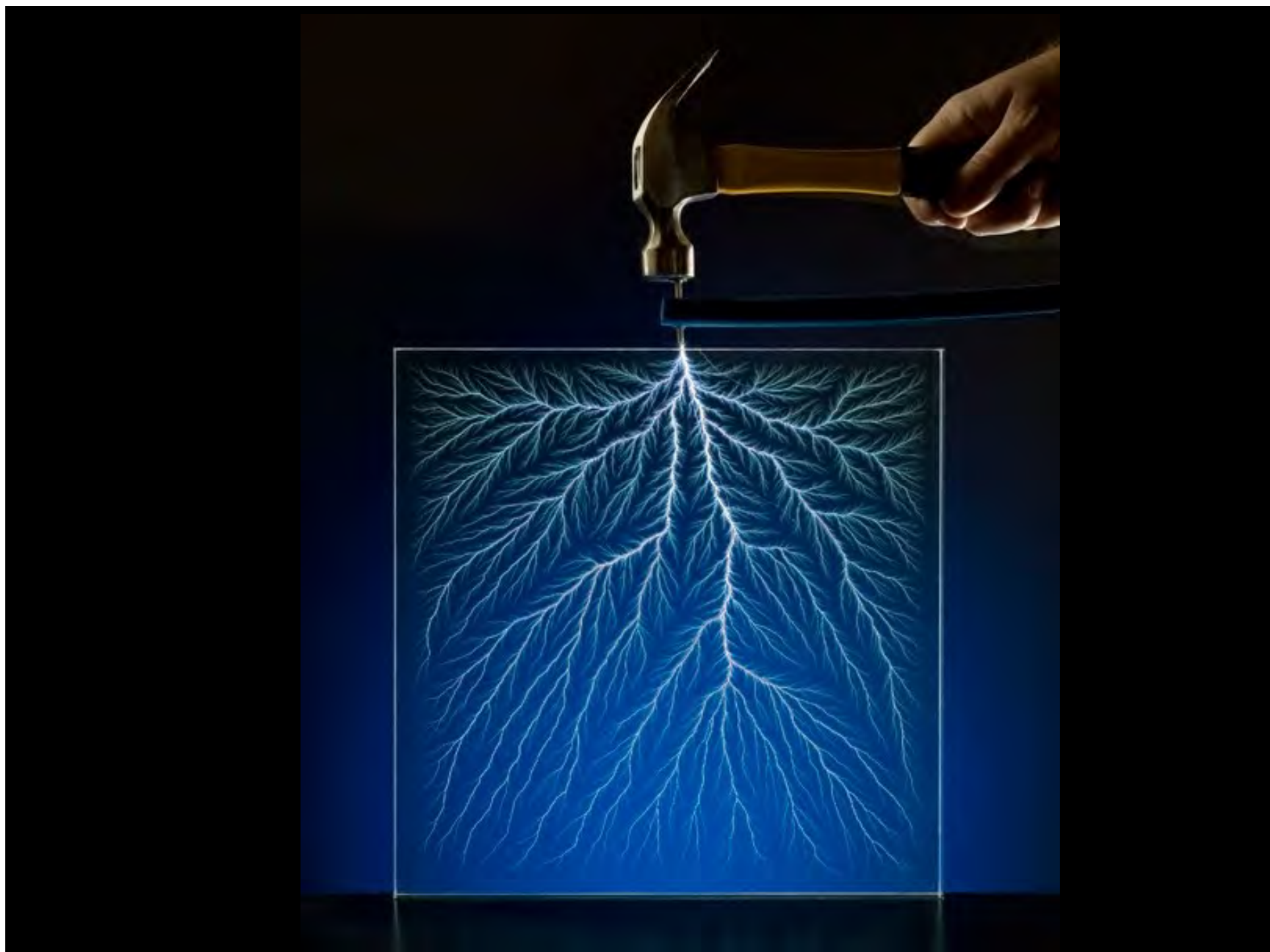
Canopies ready for EVSE

- DC-DC charging of EVs with renewable energy
- Detailed analysis of preferences & patterns
- Evaluate Utility Tariff Rates



UCSD's Microgrid has 4,000 kW of Renewable Energy Available for On-Peak EV Charging





Energy Storage Projects at UCSD

- 30 kw, 30 kWh Sanyo/Panasonic Li-Ion battery energy storage system, integrated with 30 kW PV
- 125 kW, 300 kWh, ZBB Zinc – Bromine Flow Battery – CA Solar Initiative Demand reduction demonstration
- 120 kW / 65 kWh 2nd life EV Battery Test Stand NREL- CCSE
- 108 kW, 180 kWh BMW, demonstration of 2nd use EV batteries, direct DC coupling to PV, and Fast EV DC Charging
- 2.5 MW, 5 Mwhr, SGIP Advanced Energy Storage
- 730 kW, 1460 kwhr SGIP PV Integrated, five off campus sites
- 30 kW, Maxwell Labs, Ultracapacitors, CPV smoothing of intermittency, coupled with solar forecasting
- ARPA-e Energy Storage Test Bed
- 3.8 Million Gallon Thermal Energy Storage
- Second Thermal Energy Storage in design engineering

Governor Designated San Diego as the Latest Innovation Hub

San Diego iHub Now Joins California's Innovation Corridor to Advance State's Economic Innovation and Global Competitiveness

The San Diego iHub is focused on the convergence of three clusters: mobile health, biofuels, and solar energy and energy storage

Sanyo 30 kW Solar PV Fully Integrated with 30 kWh Energy Storage, 1st in US



30 kWh Energy Storage



Central Utility Plant

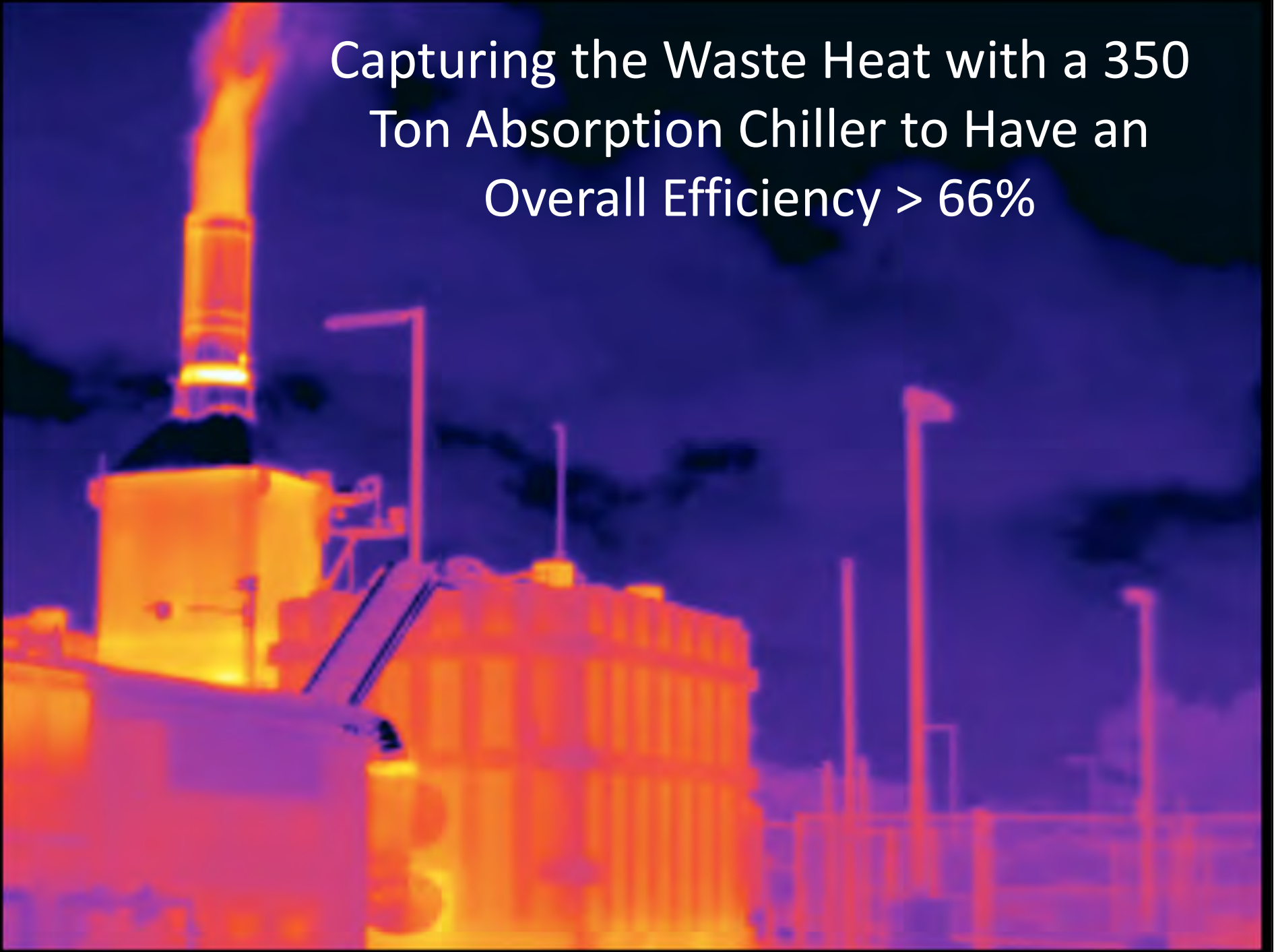
- Provides > 92% electricity and 95% of Heat and Cooling for most of the UCSD Campus
- Cogeneration system consists of two 13.5 Megawatt natural gas-fired turbine generators
- 60,000Lb/Hr of Steam per unit, totaling 120,000 Lb / Hr produced as available waste heat, which provides heating and cooling energy for the Chiller Plant and the Heating Plant.
- Awarded 1 of 3 “Energy Star Awards” by EPA in 2010

Central Utility Plant 2015





Capturing the Waste Heat with a 350
Ton Absorption Chiller to Have an
Overall Efficiency > 66%



The Central Utility Plant Saves the UCSD Campus

\$800,000 Per Month!

Yes, \$800,000 Per Month!

2012 Microgrid Goal: Replicate@Scale



U. Hawaii – Maui College, Rural Site



UCSD's Subcontractors Top 5 out of 700 Proposals to DoD for 3 Virtual Power Plants of San Diego Navy Bases



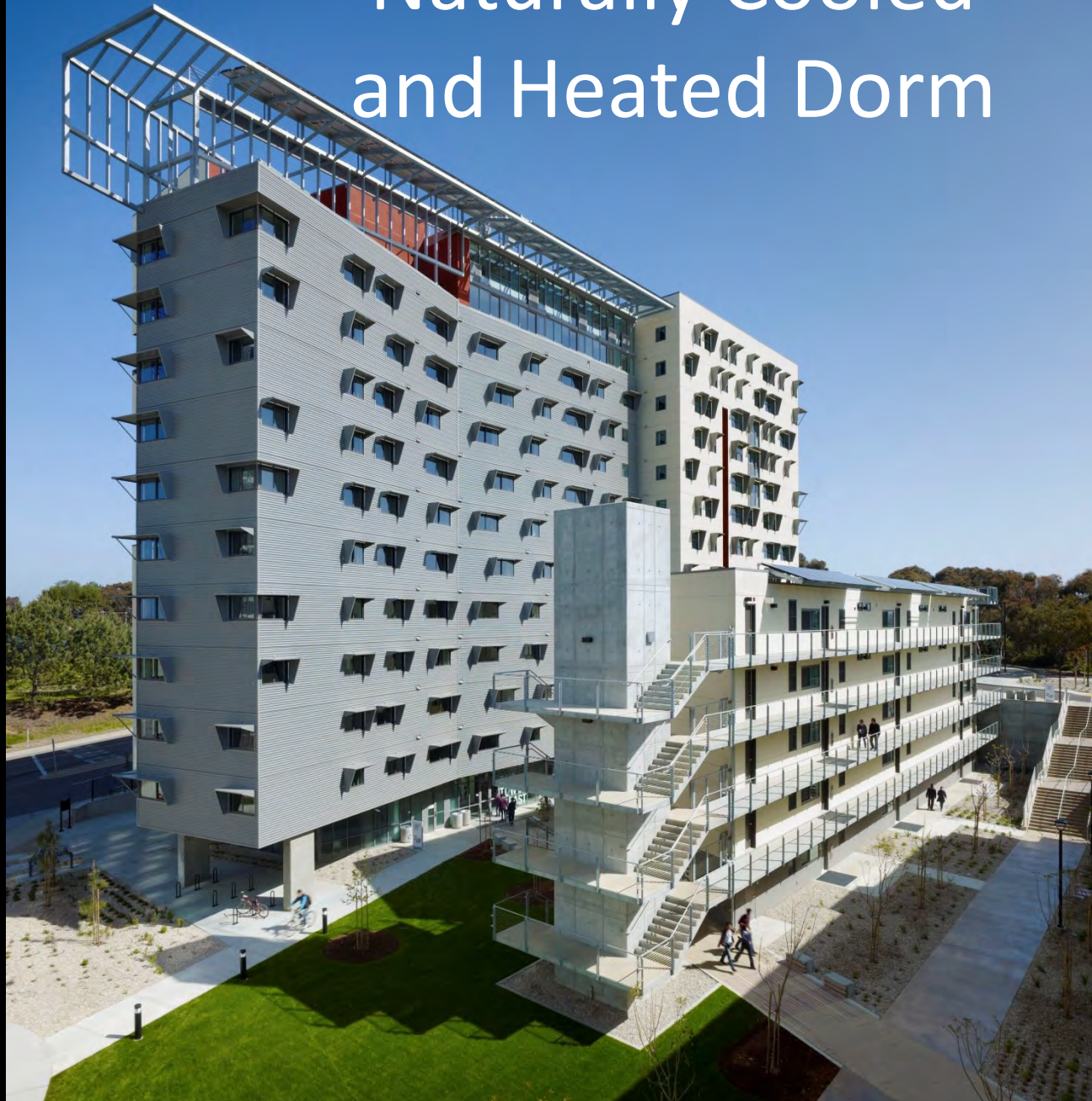
LEED Projects



- Keeling Apts awarded LEED Platinum.
- 14 certified now, 17 in progress.
- UC has most LEED of any university system, just certified 100th building.
- Plan to continue partnering with SDSU and UCSD Associated Students on projects at both campuses.
- Providing presentation on USGBC Student Program at AASHE conference.



Naturally Cooled and Heated Dorm













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Academics & Research

Students Engaged in Sustainability

- 13 educational programs related to sustainability.
- Over 270 courses touch on environmental sustainability.
- Environmental Eng. 70% growth, students working worldwide on projects
- Environmental Economic Courses expanded.

Green Student groups more popular than ever

Net Impact

Engineers for a Sustainable World

BioFuels Action and Awareness Network

Global Environmental Brigades

Human and Earth Rights Organization

One Earth One Justice

The Roosevelt Institute

Student Sustainability Collective

USGBC Student Group

PowerSave Green Campus

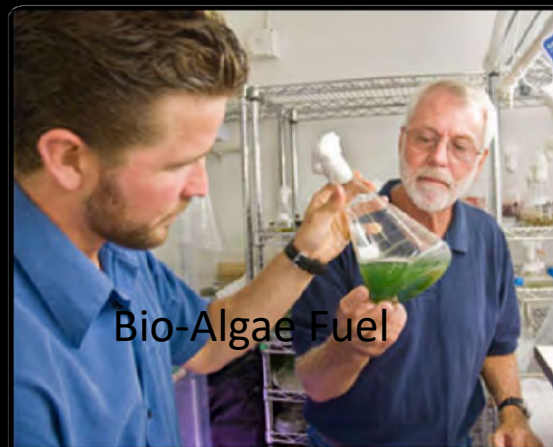
TIES



Academics & Research

Sustainability research has contributed to UC San Diego's ranking in the top-tier of sustainable universities.

- Over 150 researchers from 36 departments engaged in sustainability related studies.
- 20 Greenovation forums connecting researchers to regional businesses.
- Research areas of interest.
 - Climate change
 - Biodiversity & Conservation
 - Societal Transformation
 - Economics of Sustainability



GreenLight
UCSD



*Local Impact,
National Influence,
Global Reach*

**Sunlight + Natural Oils
from Algae**

= Green Crude

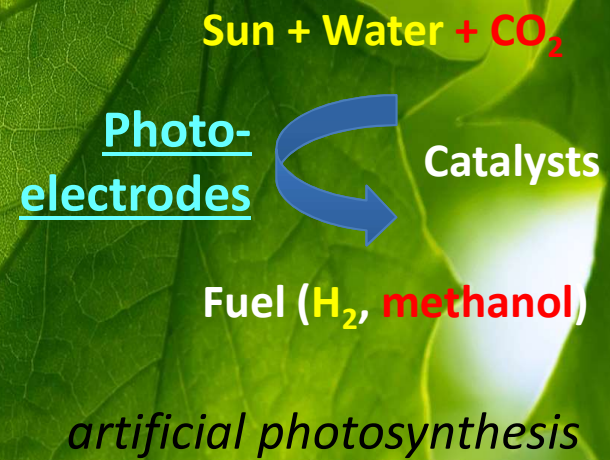
Stephen Mayfield and his team



Natural Oils from Algae → Surf Board



gy in Chemical Fuels



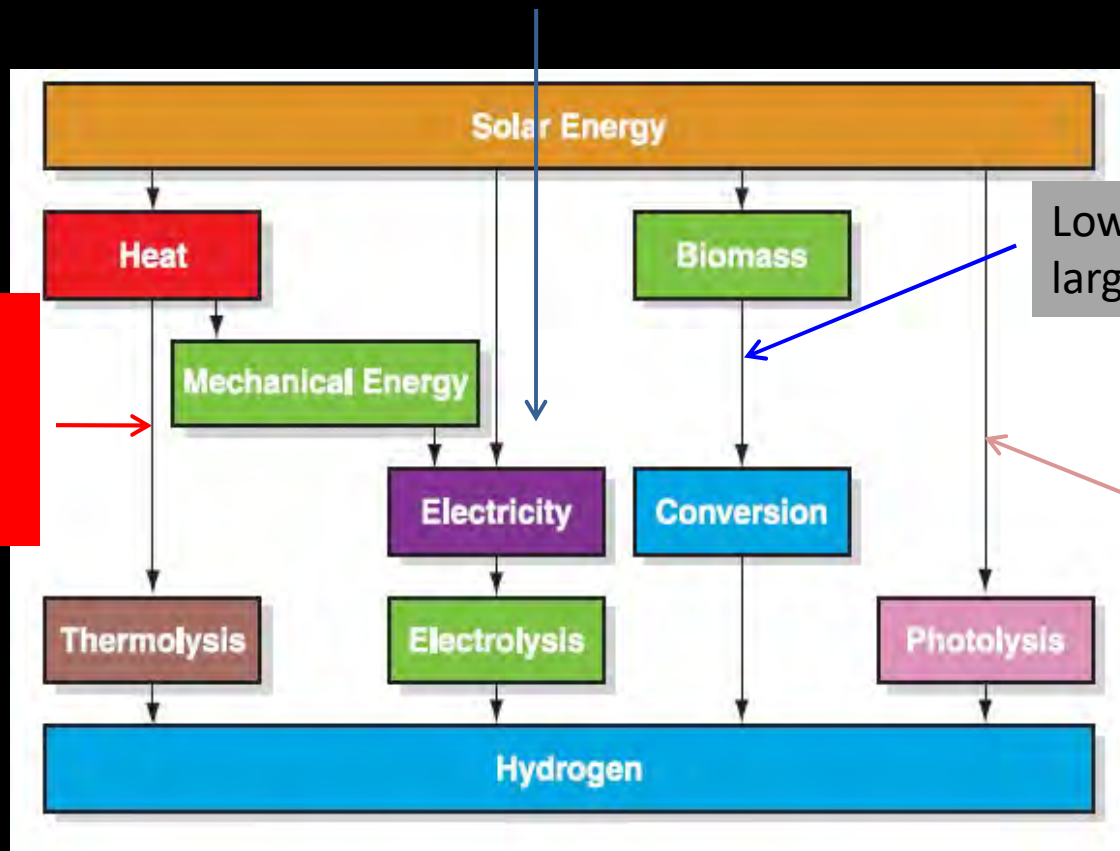
Sustainable Pathway to H₂ Production

Most versatile, commercially available, expensive

Low efficiency and large system

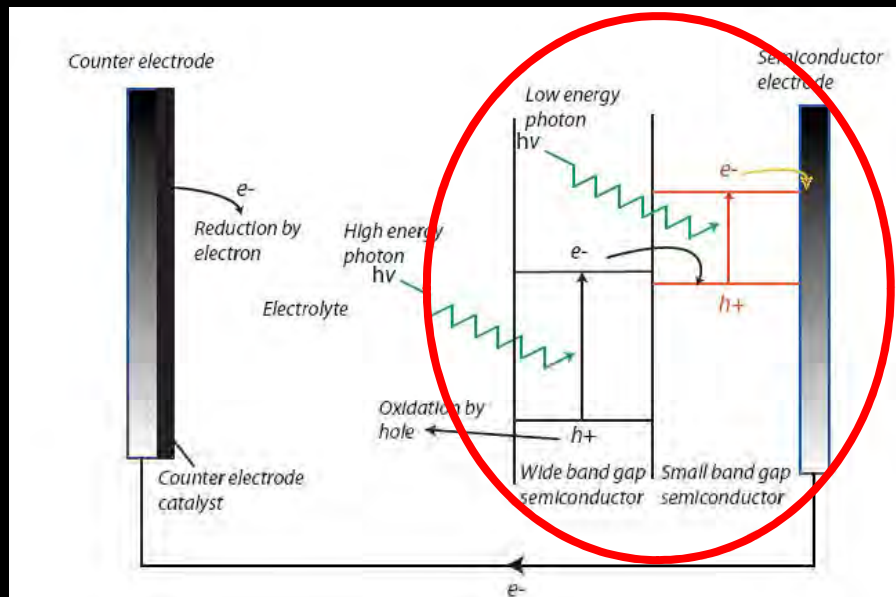
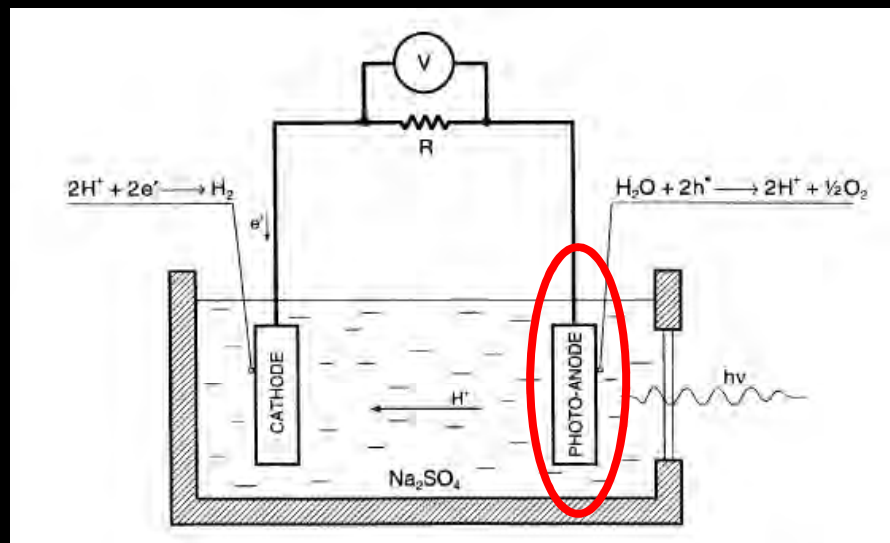
Single step conversion, potentially high efficiency

Severe back reaction @ high temperature



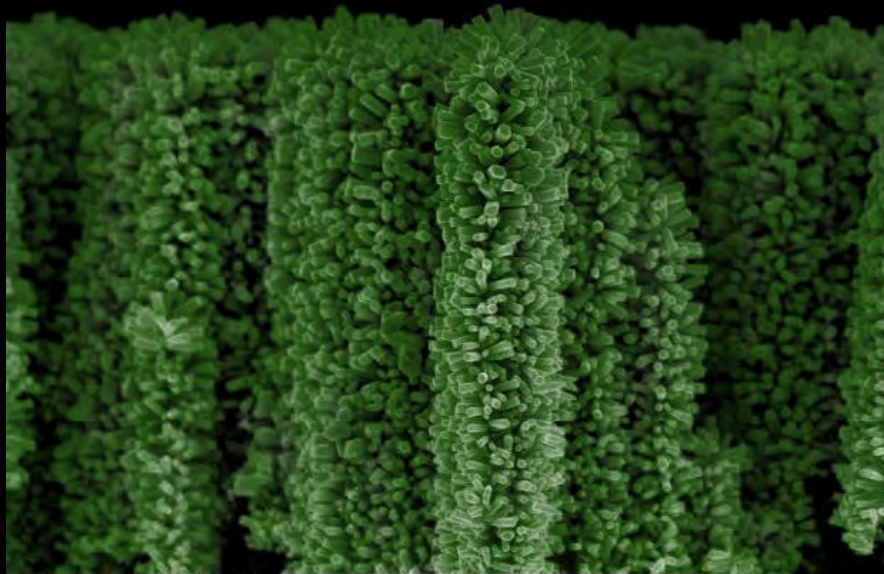
J. A. Turner, Science 1999, 285, 687.

Photoelectrochemical Splitting of Water



Advantages of PEC cell (vs. solar cells)

- ❖ No complicated technology required for making rectifying contact
- ❖ Light can reach space charge region without essential losses
- ❖ Flexibility to utilize different band gap materials
- ❖ Two photon system is more efficient for light absorption



Acc.V Spot Magn Det WD
5.00 kV 2.0 20000x TLD 4.3
SIS XL.TIF 1 μm

1. 3D branch Nanowire (platform)

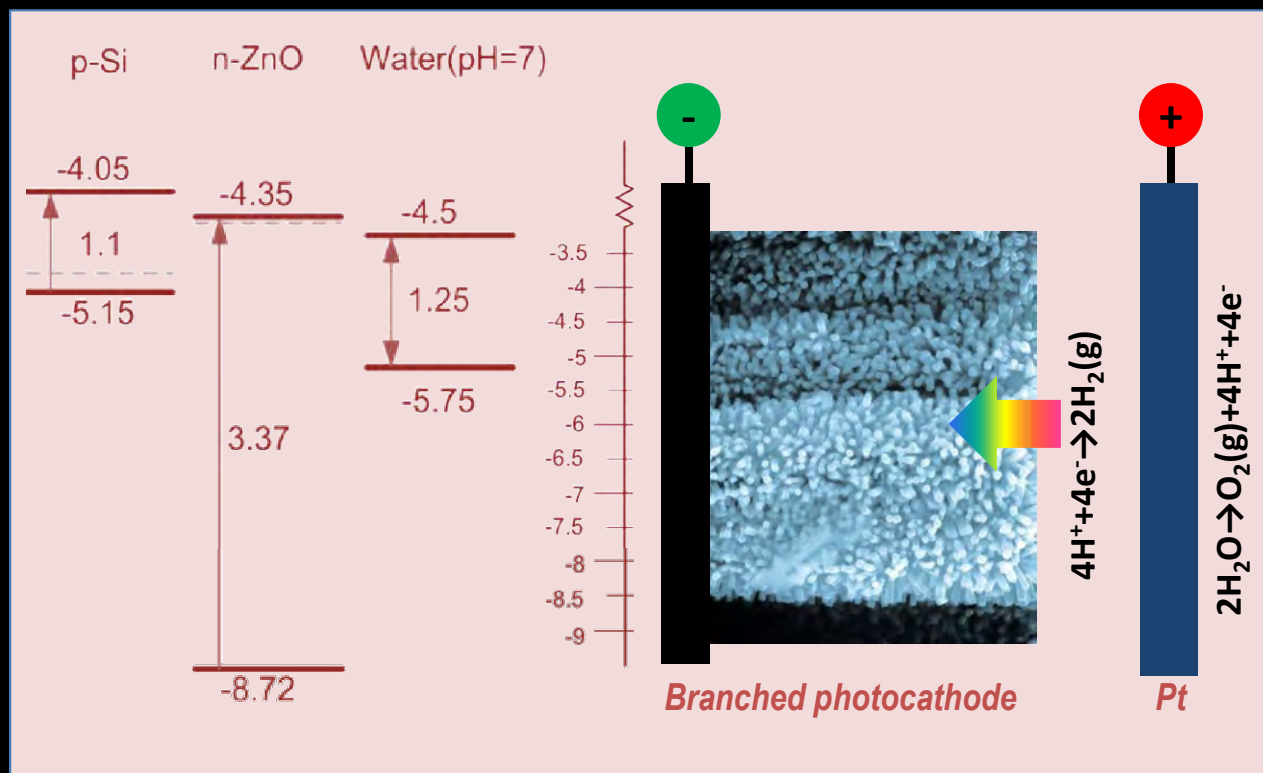
- ❖ Low cost
- ❖ Nanoscale integration (single crystal, epitaxial)
- ❖ High efficiency
- ❖ Large surface area for chemical reactions

2. Si solar cells

- ❖ Low cost
- ❖ Largely deployable
- ❖ High efficiency
- ❖ Long device lifetime



3D Branched Nanowire Heterojunction Photoelectrodes



- ❖ Cheap, earth abundant materials
- ❖ Low cost process

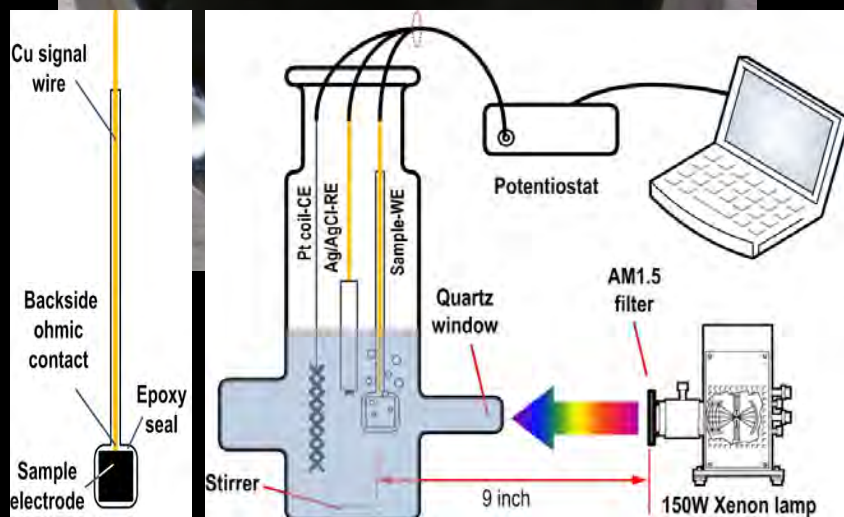
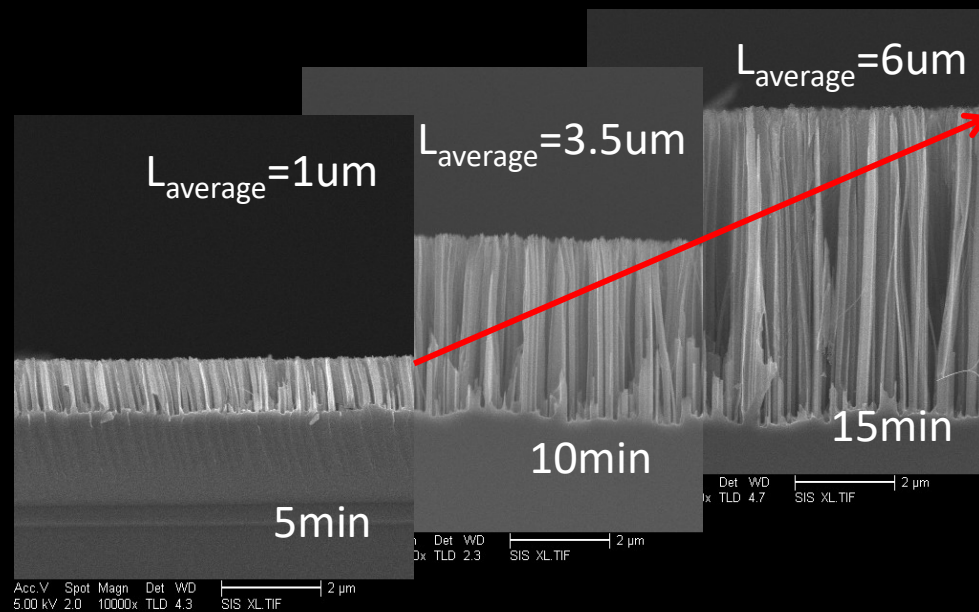
- ❖ Vertical Nanowire arrays enhance light absorption
- ❖ Large junction area enhances the minority carrier generation, separation, and transport
- ❖ Functional integration of different band gap materials at nanoscale
- ❖ Much enlarged surface area for chemical reaction
- ❖ Large surface curvature increase gas evolution

Branched Nanowire Photoelectrode Fabrication

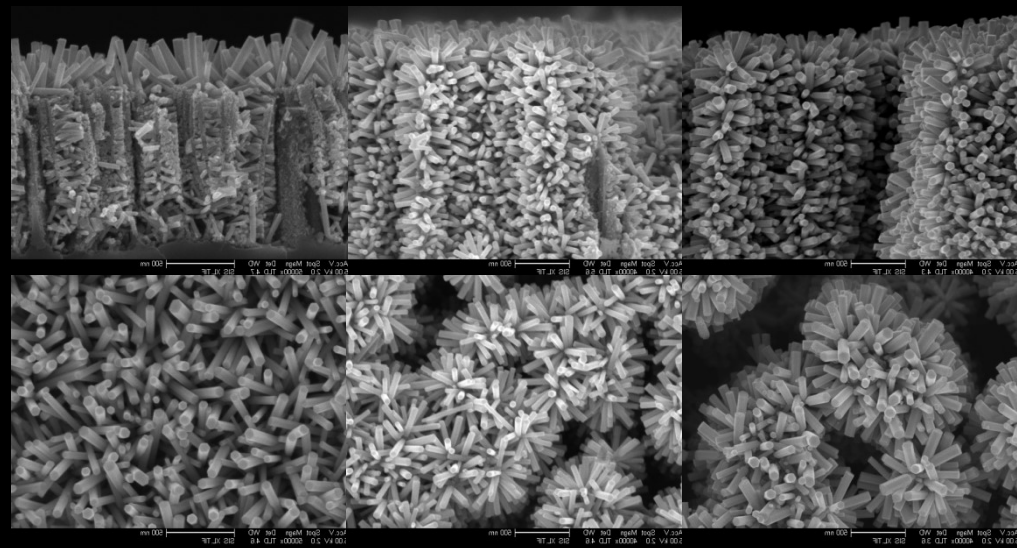
❖ **Wafer scale**

❖ **Solution processes**

- Wet etching of SiNWs / ZnO NW synthesis



K. Sun, et al., Nanoscale, 2012.

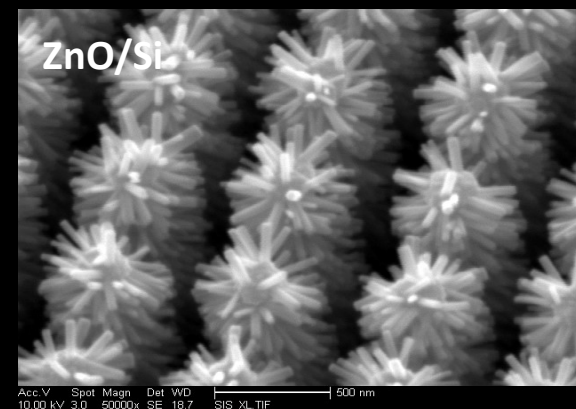
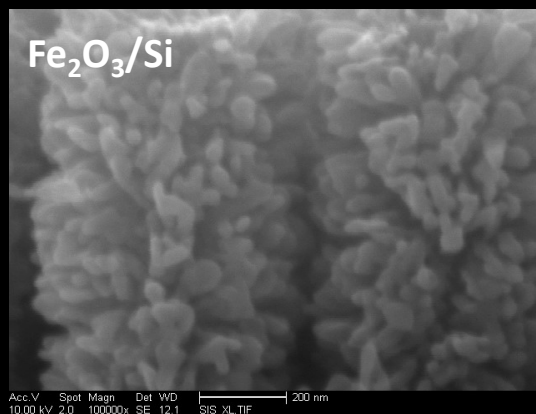
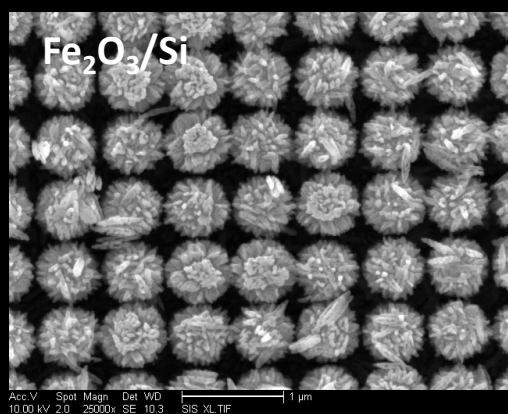
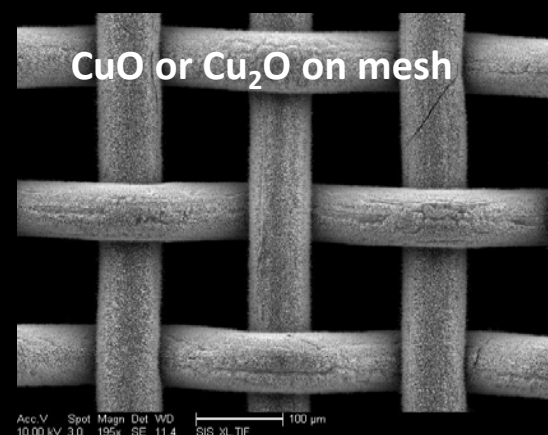
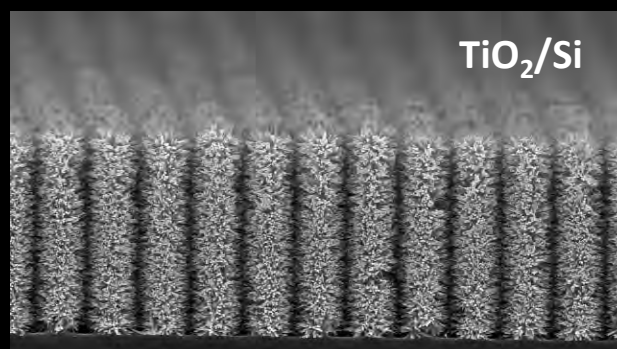
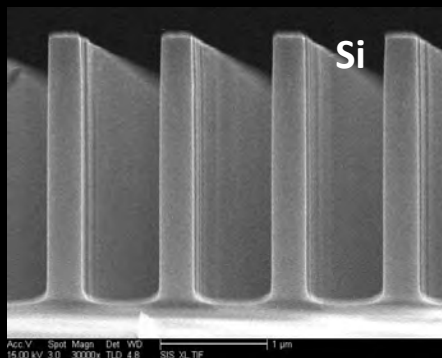


5min etched SiNW

10 min etched SiNW

15 min etched SiNW

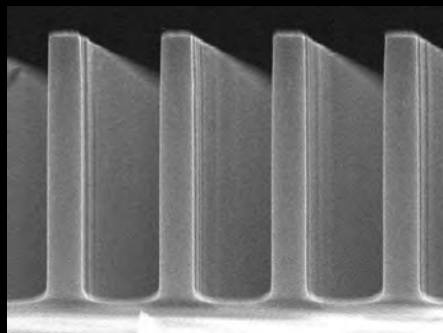
3D Nanowire Platform: Versatile, Flexible, Transparent, ...



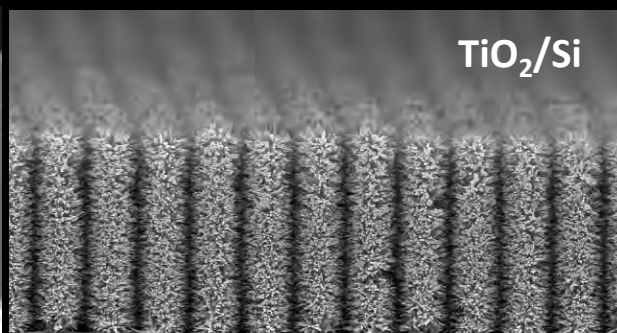
- ❖ 3D nanowire heterostructures provide unique and versatile integration of different materials at nanoscale
- ❖ Low cost processing
- ❖ Flexible substrate
- ❖ Transparent PEC for advanced integration possible

S. Noh, K. Sun, et.al. *Nano Energy* 2012.
A. Kargar, S. et.al. *Nano Lett.* 2013.
A. Kargar, S. et.al. *ACS Nano* 2013.
A. Kargar, S. et.al. Submitted. 2014.

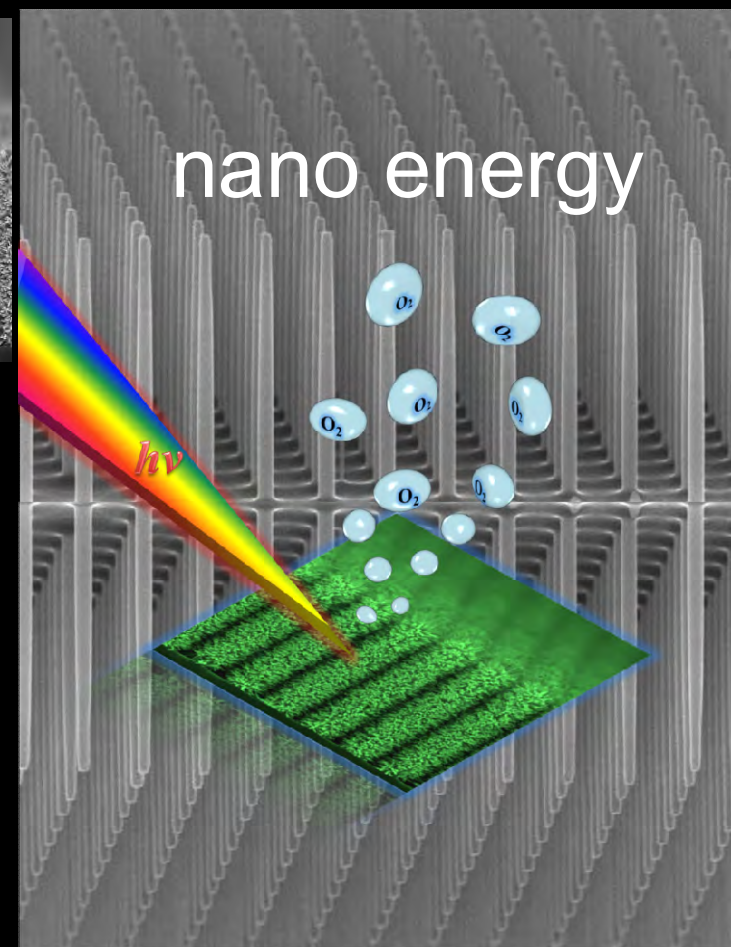
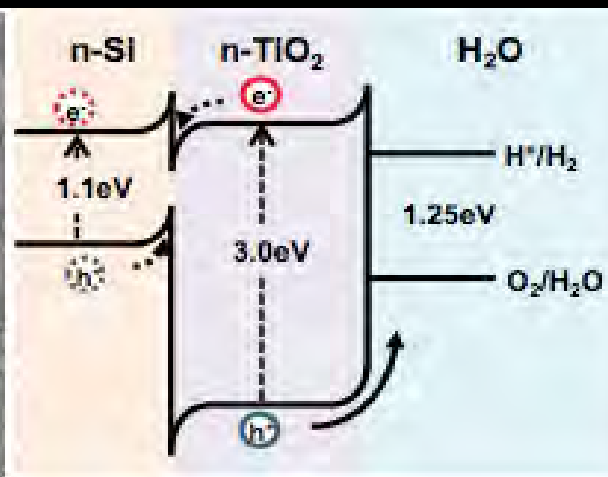
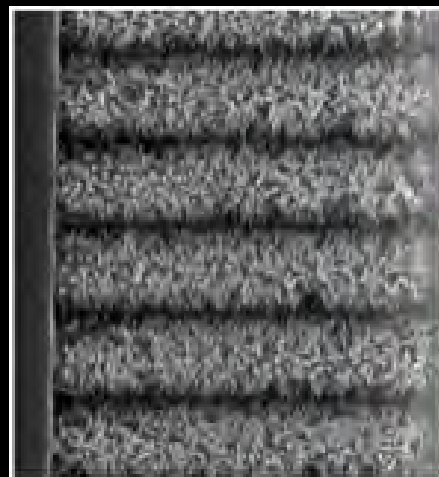
Branched n-TiO₂/n-Si Nanowire Photoanodes



Acc.V Spot Magn Det WD
15.00 kV 3.0 30000x TLD 4.8
SIS XL TIF



TiO₂/Si



- ❖ Low cost processing
- ❖ Robust, earth abundant materials
- ❖ Tunable structures

Energy Storage Research

Priority Research Directions

**Solid State
Batteries**

**Conversion
Type**

**Na & Mg
Intercalation**

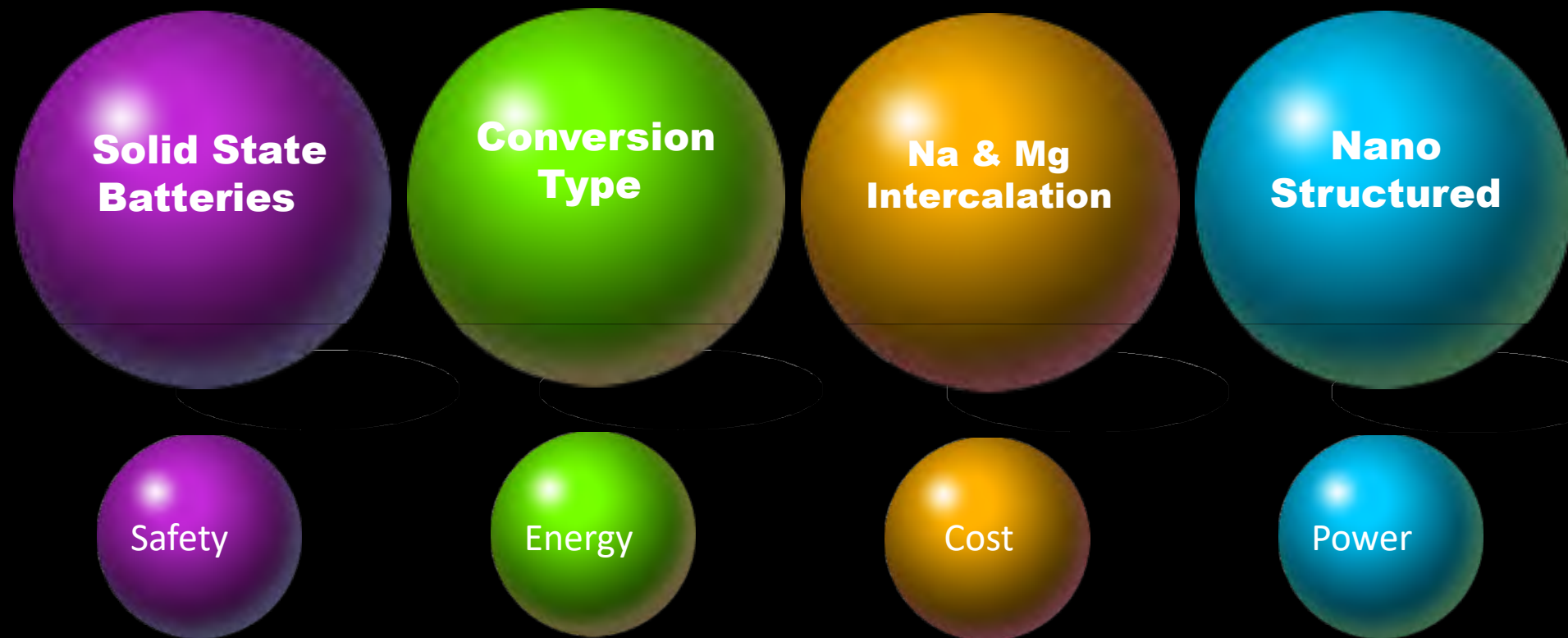
**Nano
Structured**

Safety

Energy

Cost

Power



Nanostructured Electrodes

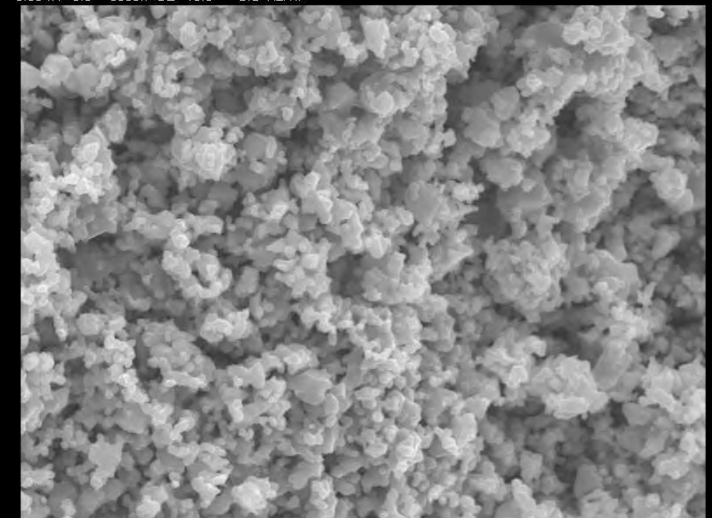
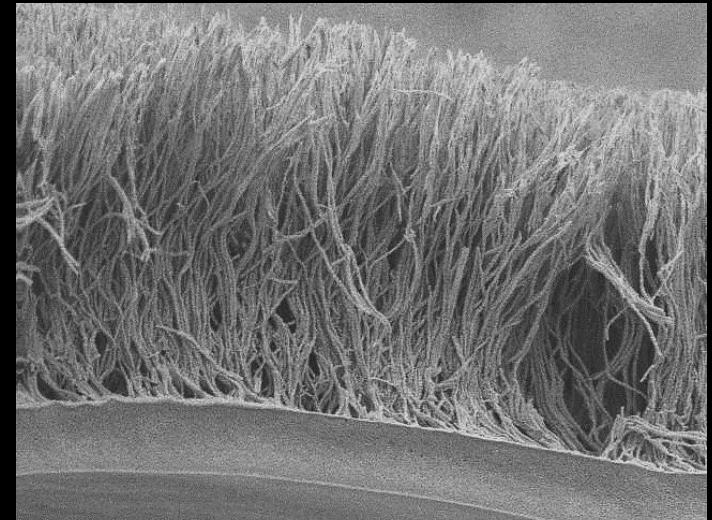
Understanding BULK builds a solid foundation towards Nano

Go For Nano

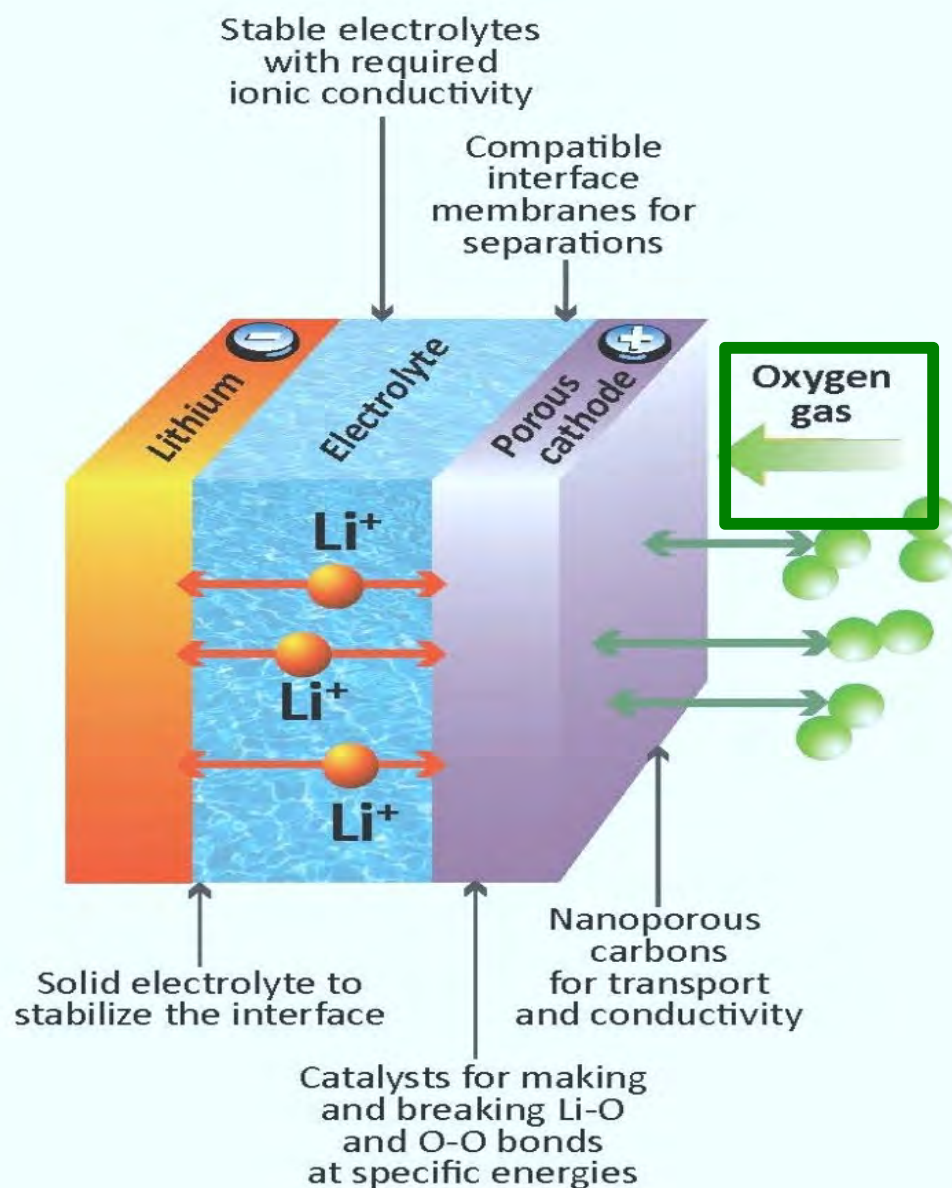
- ☺ Minimize diffusion distance
- ☺ Phase stability change
- ☺ Defect tolerance
- ☺ Enable new chemistry

Need to Take Care of

- ☹ Safety due to interface
- ☹ Packing density (vol. density is key)
- ☹ Scalability

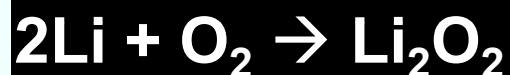


Metal Air Batteries – Open Systems



Lithium anode and an “Air” cathode made of a porous material that draws in oxygen

Discharge:



Charge:



Truly Interdisciplinary Research

Basic Research Needs

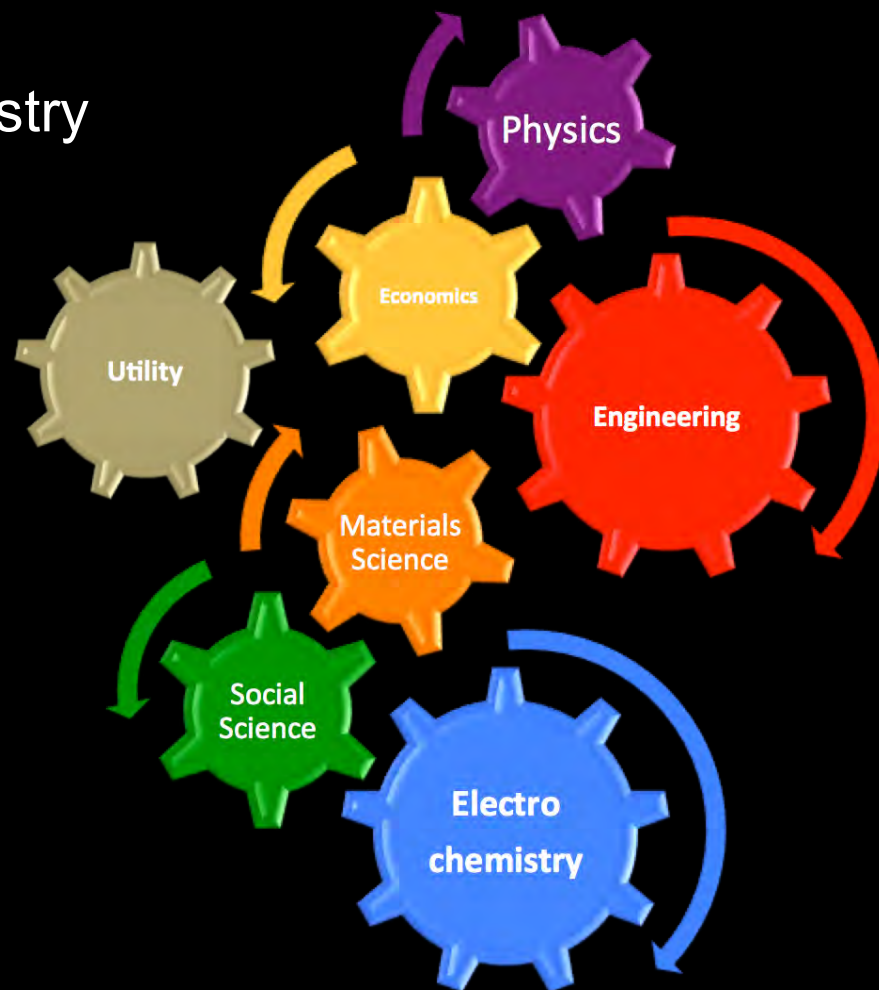
Enable multielectron electrochemistry
Solve ORR/OER challenge
New metal-air battery design

Applied Research Needs

Close the gap in intercalation
Better safety design
Smart control (power electronics)

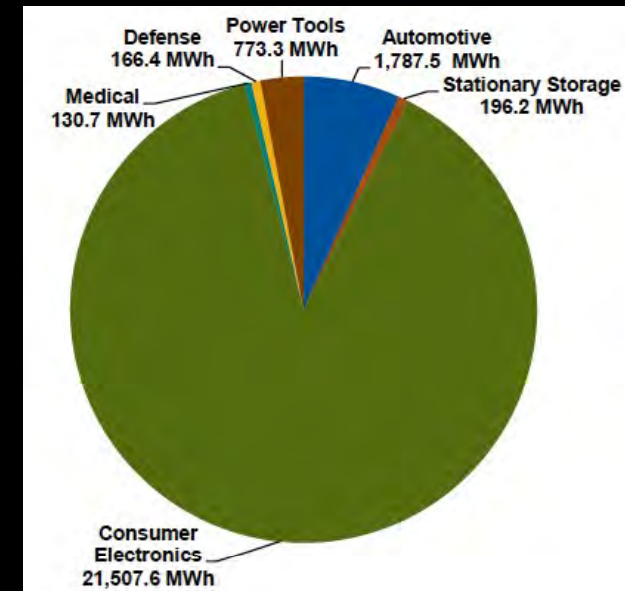
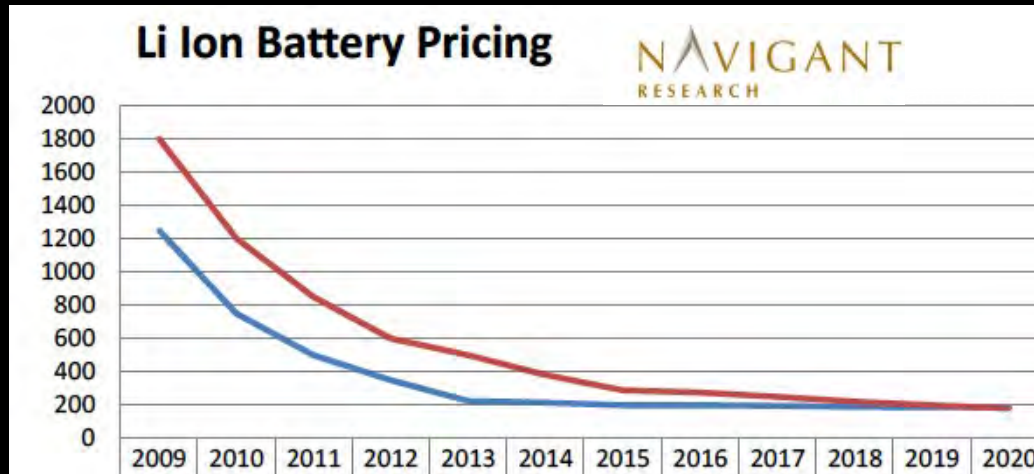
Forecast and Operation

Live monitoring of battery health
Optimization of battery valuations
Big data and predictive model



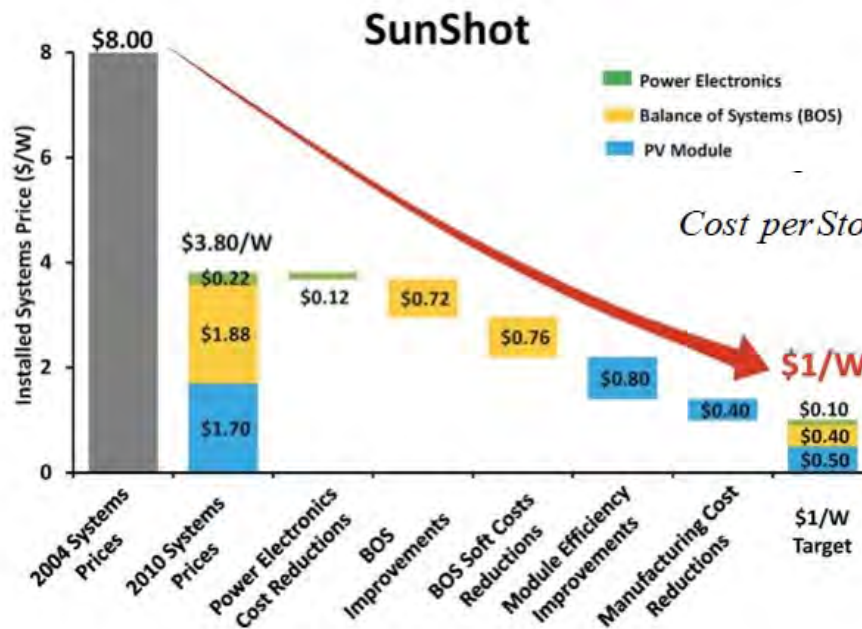
Good News from the Market

\$/KWh



Today, more than 20GWh Battery Are Produced (Li Ion Only)

Electricity in CA 15 cents/kWh



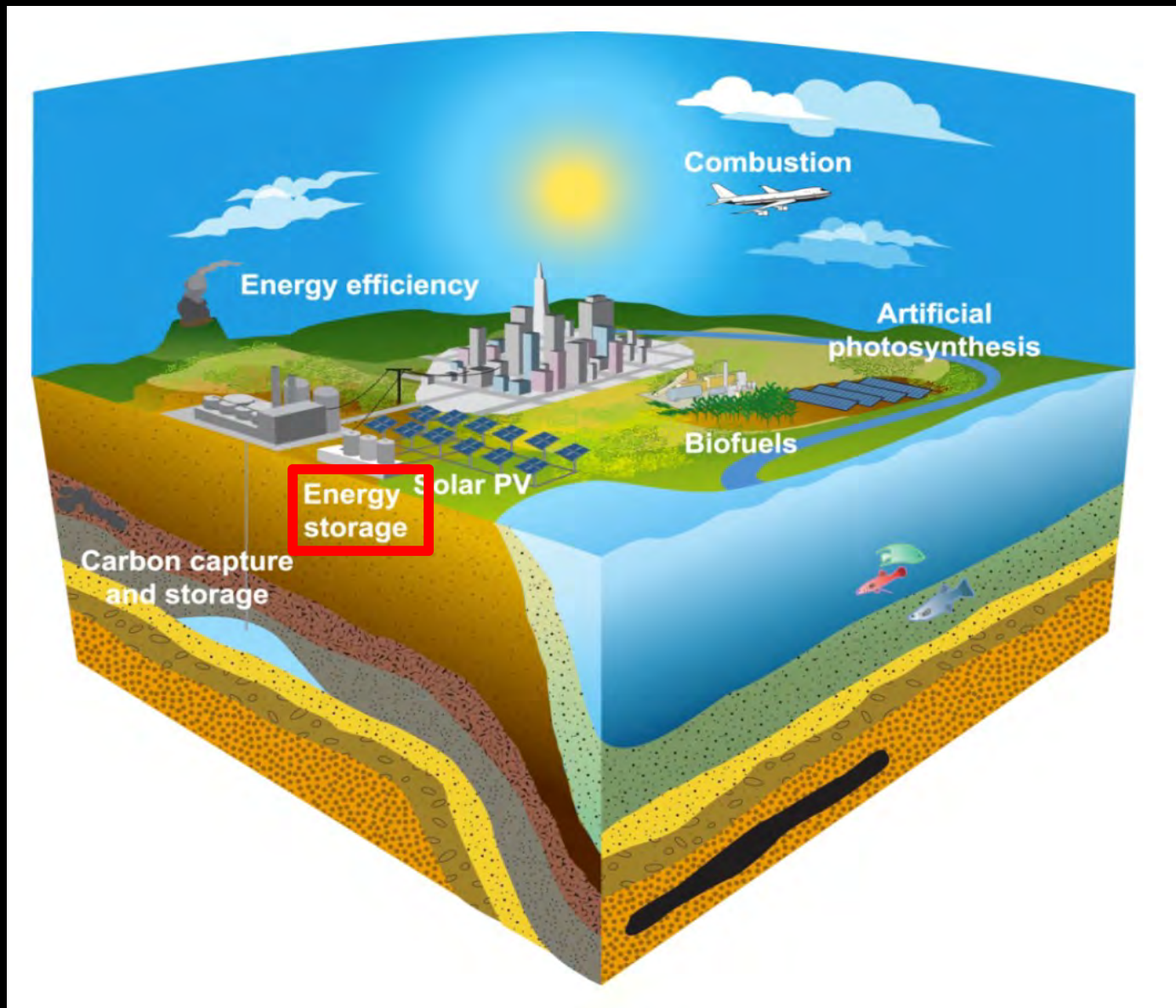
SAFETY MUST BE HANDLED with Reasonable Cost

Market Adoption

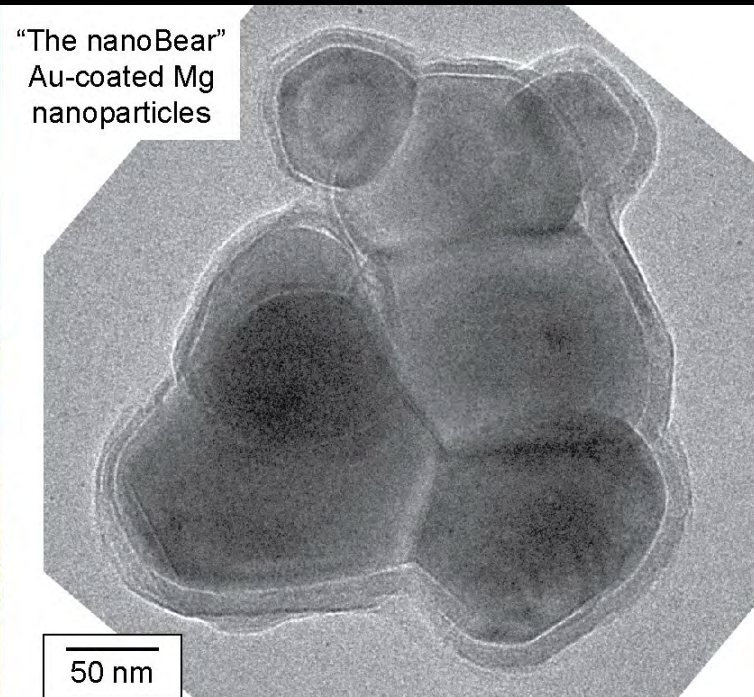
Smart Grid Operation

Social Acceptance

Energy Storage for A Sustainable Future



Have some fun with ... NanoBear



Olivia Graeve et al. <http://graeve.ucsd.edu/>

THANK YOU