UC SANTA BARBARA
Institute for Energy Efficiency

WELCOME TO UC SANTA BARBARA

INSTITUTE FOR ENERGY EFFICIENCY'S 15th ANNIVERSARY EVENT!

IEE: THE FIRST 15 YEARS AND THE NEXT 15 YEARS

FRIDAY, NOVEMBER 3rd 2023

UC SANTA BARBARA
Institute for Energy Efficiency

WORKSHOP AGENDA

1:00 Welcome: Chancellor Yang UCSB, Dean Mishra CoE, Jeff Henley, Oracle

1:15 IEE: "The First 15 Years and The Next 15 Years"
John Bowers, UCSB

1:35 Data Centers and the Future of Energy Efficiency:
Chris Malone, META
Eric Masanet, UCSB

2:20 Towards Green Artificial Intelligence:
Vivienne Szu, MIT
William Wang, UCSB

3:05 Energy Efficient Materials and Quantum Computing:
Steven Denbaars, UCSB
Galan Moody, UCSB

3:45 Climate Change and Energy Efficiency:
David Victor, UCSD
Matto Mildenberger, UCSB

4:30 Reception in Henley Hall Atrium + Courtyard:
Poster Sessions + Tours

UC SANTA BARBARA
Institute for Energy Efficiency

THANK YOU 15th ANNIVERSARY SPONSORS!

transphorm
Highest Performance, Highest Reliability GaN

ChallengerCableSales
Competitive Dependable Direct

Hewlett Packard Enterprise

Nexus Photonics

QUINTESSENT

FREEDOM PHOTONICS
a Luminar company

UC SANTA BARBARA
Institute for Energy Efficiency

WELCOME

Chancellor Yang, UCSB

Dean Mishra, CoE

Jeff Henley, Oracle

UC SANTA BARBARA
Institute for Energy Efficiency

THE FIRST 15 YEARS

2008 Chancellor Yang met with Jeff Henley, Dan Burnham, Fred Steck, Mark Bertelsen
Bowers appointed and met with faculty and organized IEE into six research themes.
Donor support: Henley, Burnham, Bertelsen, Duvall, Steck, Marren, Duca, Byers, Duggan, Holbrook, Macfarlane, and more – THANK YOU !!!

2009 Energy efficiency summits, workshops, internships, exciting research…

2010 Awarded a 5 year DOE EFRC grant for $19M funding research in solid state lighting, polymer solar cells and thermoelectrics.

2016 Awarded the American Institute of Manufacturing (West Coast lead) for >$10M at UCSB

2019 Faculty re-organized research into 3 new cross-disciplinary research themes

2020 IEE moves into new home in Henley Hall!
Data center partnership, industry grant from Facebook/Meta

2022 2035 Initiative launched to address climate change

Rod Alferness Herb Kroemer

Alan Heeger Shuji Nakamura

National Geographic, 2006

The High Cost of Cheap COAL

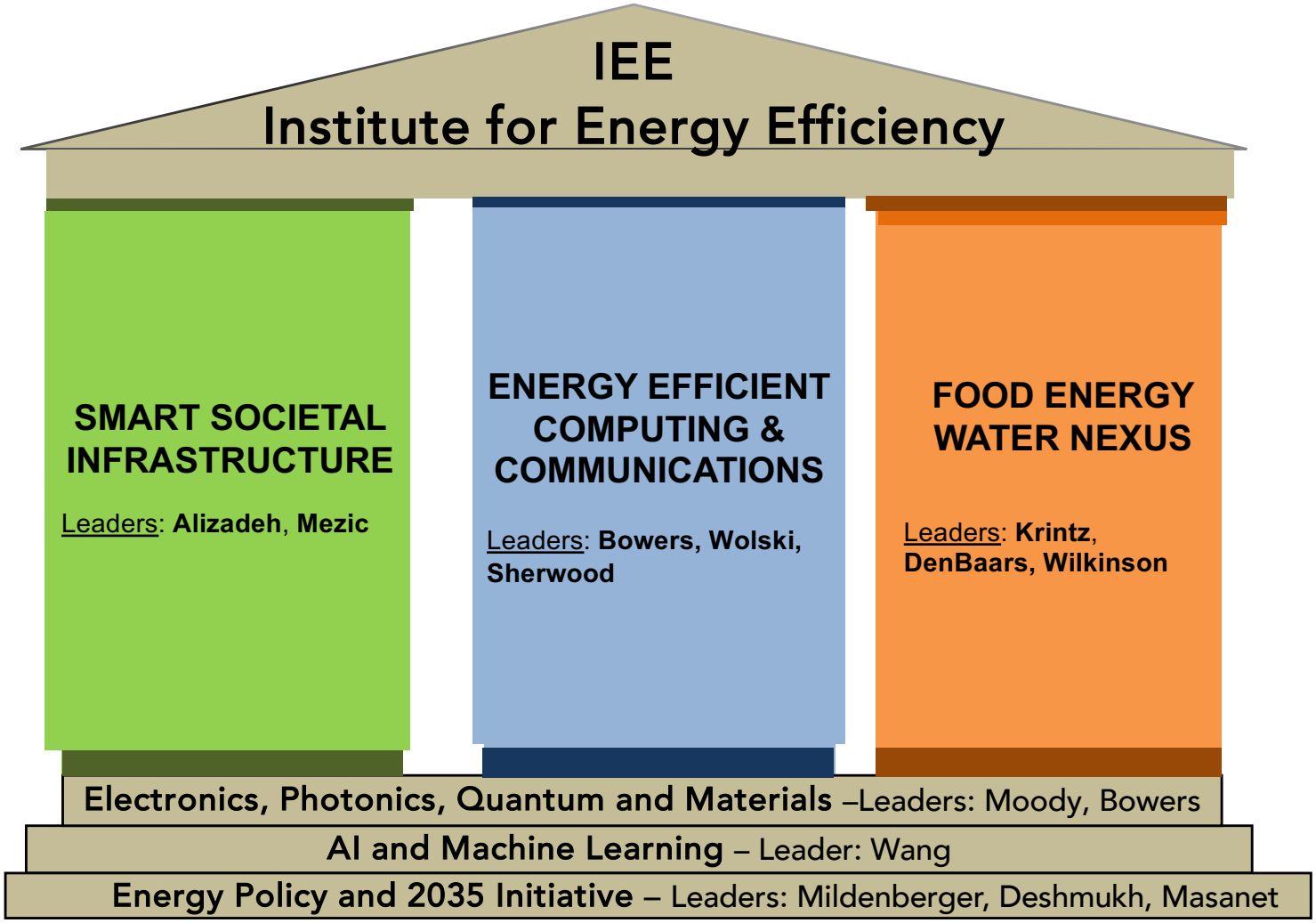
Coal is king again. Oil supplies are tight and natural gas prices are spiking, but coal could light our houses and power our factories for centuries. The price of this energy abundance could be high, however, as two stories on the following pages show. **The Coal Paradox** surveys the threat to global climate that legions of new coal-burning power plants would pose—a threat that new technologies could blunt. **When Mountains Move** describes a different hurt, for which there is no cure: landscapes and communities ravaged by our hunger for cheap coal.

RAW POWER | **Utah's Hunter plant burns 14,000 tons of coal daily, generating enough electricity for a small city. Steam wafts from 600-foot stacks along with tens of thousands of tons of climate-warming CO_2 a day.**

LESTER LEFKOWITZ, CORBIS

96

The cleanest power plant is the one you don't build.
IEE Focus: Energy efficiency


IEE
Institute for Energy Efficiency
SMART SOCIETAL INFRASTRUCTURE
Leaders: Alizadeh, Mezic
ENERGY EFFICIENT COMPUTING & COMMUNICATIONS
Leaders: Bowers, Wolski, Sherwood
FOOD ENERGY WATER NEXUS
Leaders: Krintz, DenBaars, Wilkinson
Electronics, Photonics, Quantum and Materials –Leaders: Moody, Bowers
AI and Machine Learning – Leader: Wang
Energy Policy and 2035 Initiative – Leaders: Mildenberger, Deshmukh, Masanet

THANK YOU TO IEE LEAD FACULTY

Chandra Krintz
Computer Science

Steve DenBaars
Materials

John Bowers
ECE

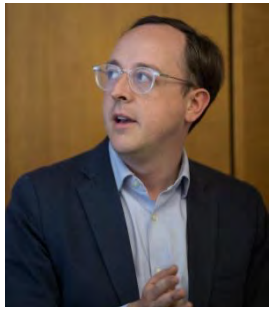
Rich Wolski
Computer Science

Igor Mezic
Mechanical Engineering

Eric Masanet
Environment &
Sustainability

Phil Christopher
Chemical Engineering

William Wang
Computer Science



Matto Mildenberger
Political Science

Ranjit Deshmukh
Environmental Science

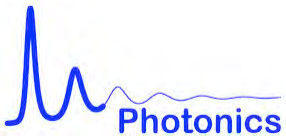
Tim Sherwood
Computer Science

Bob Wilkinson
Water Policy

Galan Moody
ECE

Mahnoosh Alizadeh
ECE

THANK YOU TO IEE INDUSTRY PARTNERS !!!



SUMMITS ON ENERGY EFICIENCY

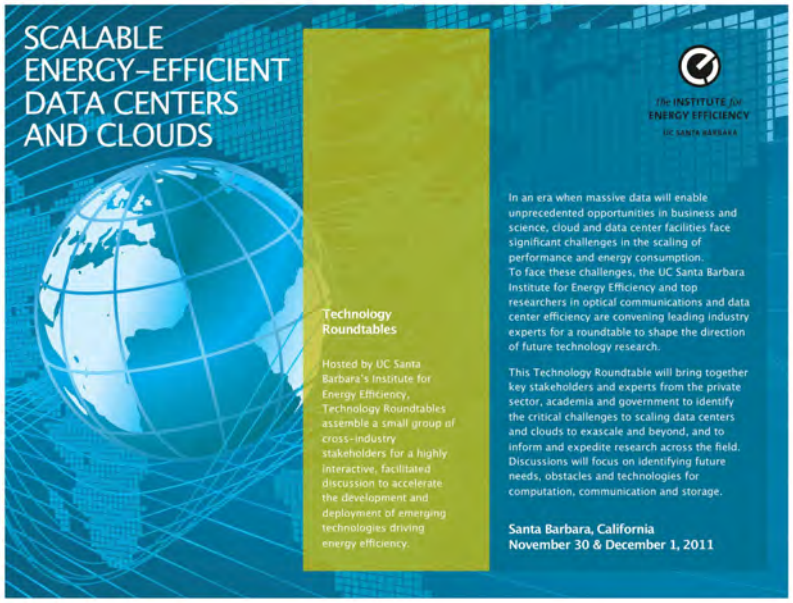
Jeff Henley Steve Chu

Bill Brinkman

Matt Tirrell

FOCUSED TECHNOLOGY ROUNDTABLES

Data Centers, Solid State Lighting, Water, Renewable Energy, Photovoltaics…



DOE EFRC

Center for Energy Efficient Materials

CEEM

John Bowers, Director

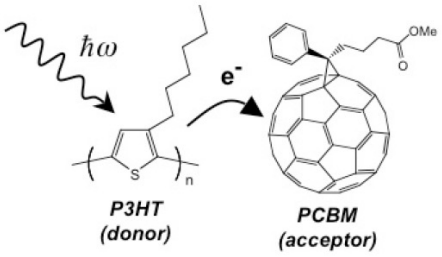
$19M Funded over 5 years:

Solid state lighting: Steve Denbaars, Shuji Nakamura, Jim Speck, Chris Van de Walle, Claude Weisbuch,

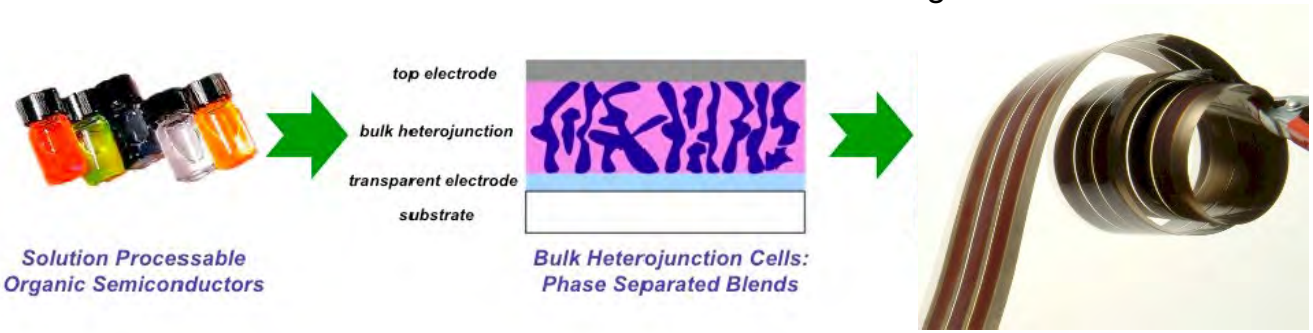
Polymer solar cells: Alan Heeger, Gui Bazan, Quyen Nguyen, Fred Wudl,…

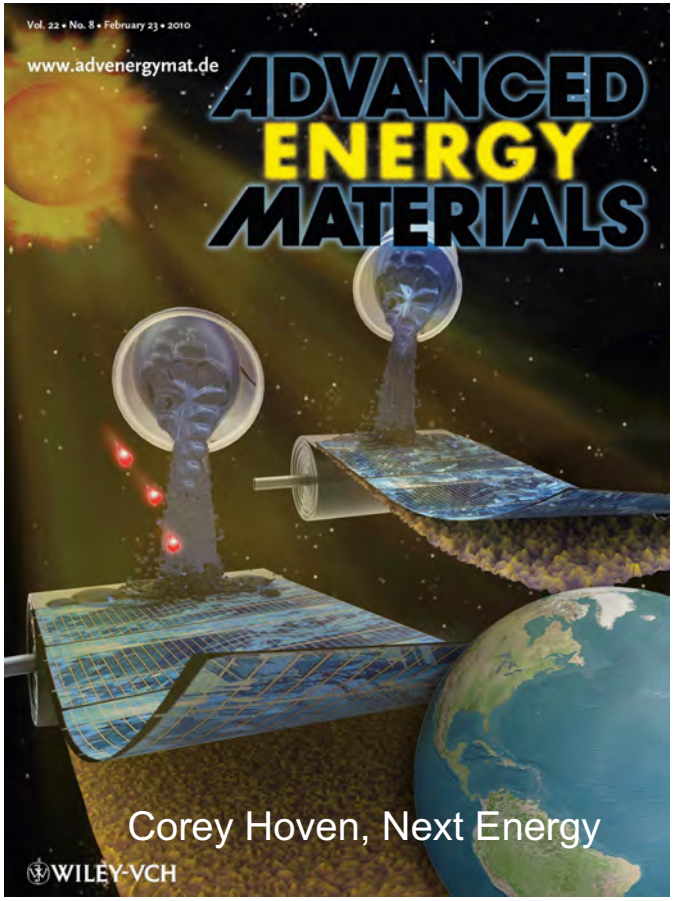
Materials: Art Gossard, Martin Moskovits, Dan Morse, Christopher Palmstrom, Galen Stucky, …

ORGANIC SOLAR CELLS



Alan Heeger

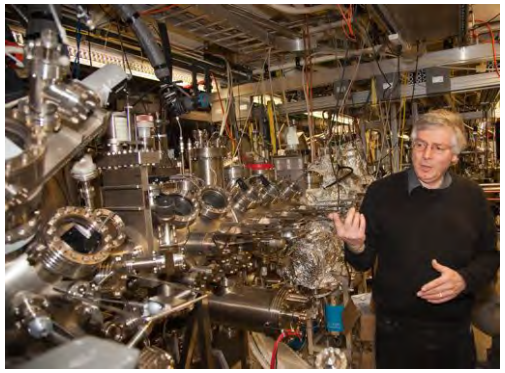




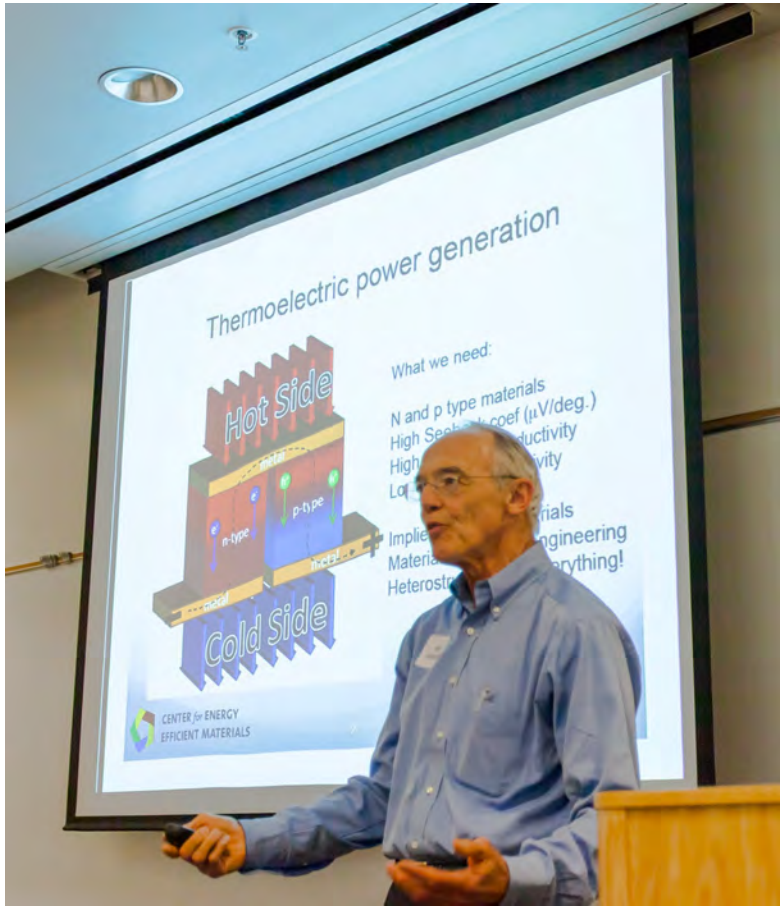
Corey Hoven, Next Energy

THERMOELECTRICS

- **Novel nanostructured thermoelectric materials for improved conversion of heat to electricity**
- **Gossard, Palmstrom, Bowers, Liao,…**
- **Liquid and Immersion cooling more efficient than air cooling being adopted by Oracle, Intel, Cisco, …**

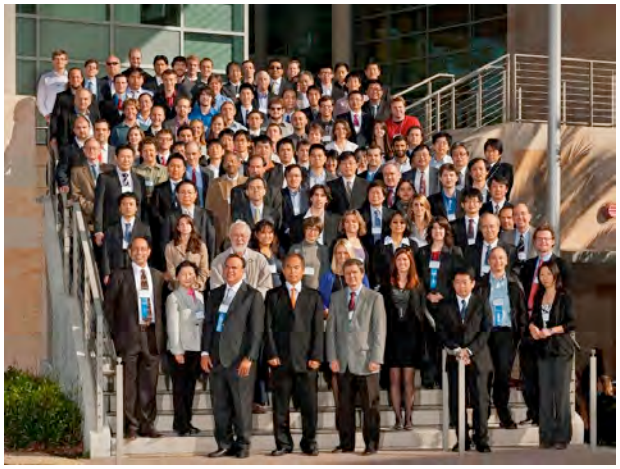


Chris Palmstrom



Art Gossard

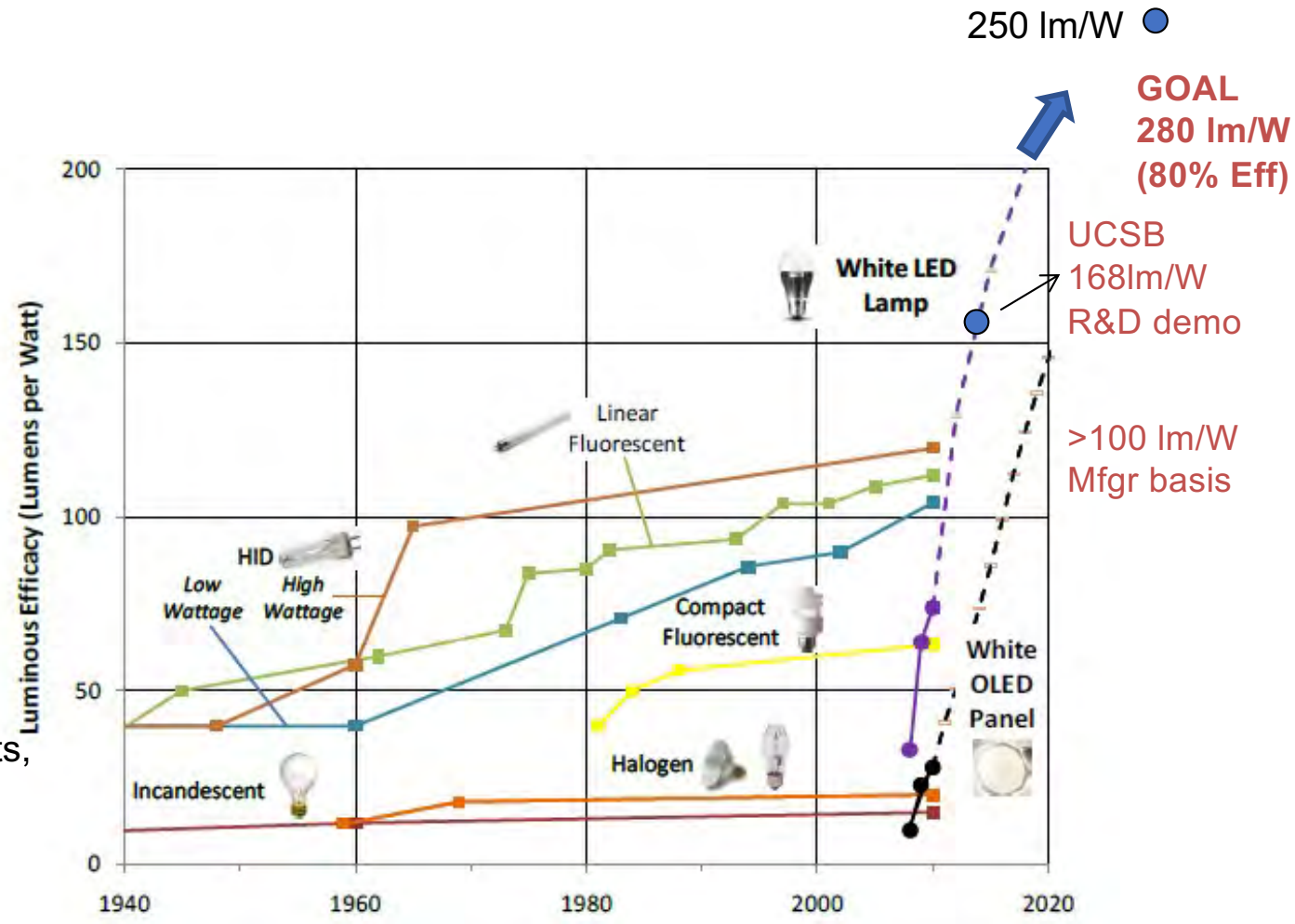
SOLID STATE LIGHTING



SSLEC, 2013

Future Vision

- MicroLED Displays for AR/VR
- High power lasers for headlights, street lights, laser fusion and laser driven chemistry



WEST COAST HEADQUARTERS OF

AIM PHOTONICS

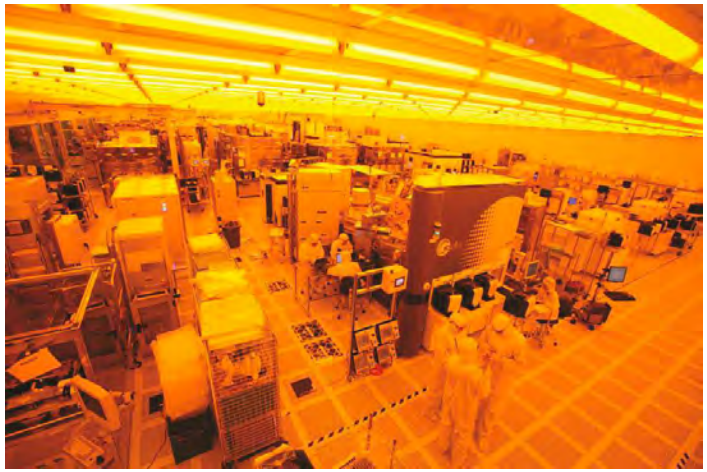
AMERICAN INSTITUTE FOR MANUFACTURING INTEGRATED PHOTONICS

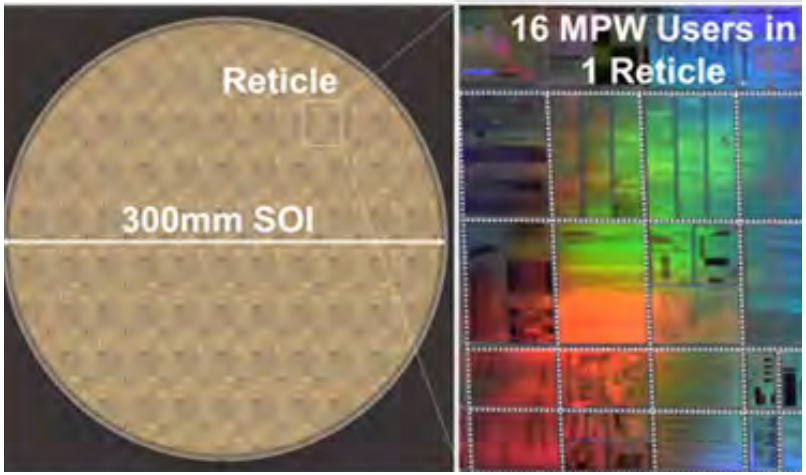
UC SANTA BARBARA

One of 17 Manufacturing Institutes
$110M Federal funding for first 5 years
$270M Federal funding for next 7 years
>$10M UCSB portion

Industrial

Raytheon, Infinera, Boeing, Precision Optical Transceivers, Cadence, Harris, Samtec, Ficontec, PhoeniX Software, Disco, EBARA, IQE, IEC, ESL, LUNA, Yenista Optics, Opto Diode, SunEdison Semiconductor, pwc, SSL Space Systems/Loral, Harmonic





Academic

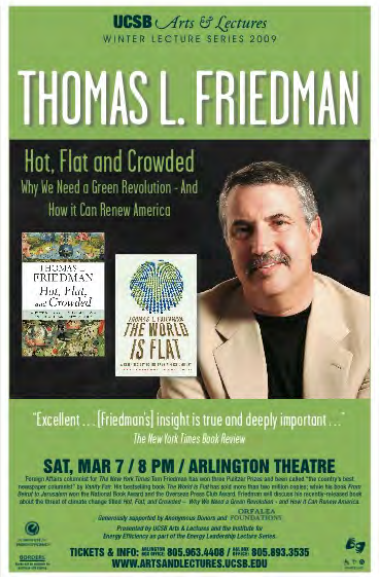
SUNY Polytechnic Institute, UCSB, MIT Massachusetts Institute of Technology, Columbia University, University of Rochester, The University of Arizona, RIT, University of Virginia

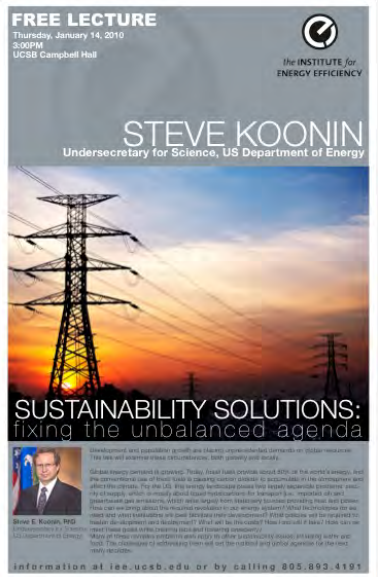
UNDERGRADUATE INTERNSHIP PROGRAMS

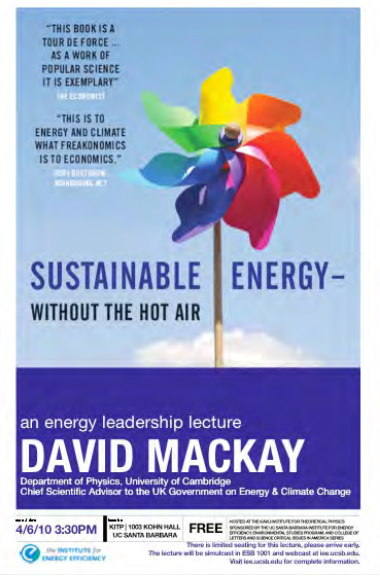
UCSB undergraduates gain first-hand experience in scientific investigation. They are matched individually with Center faculty and graduate student mentors who provide training and support.

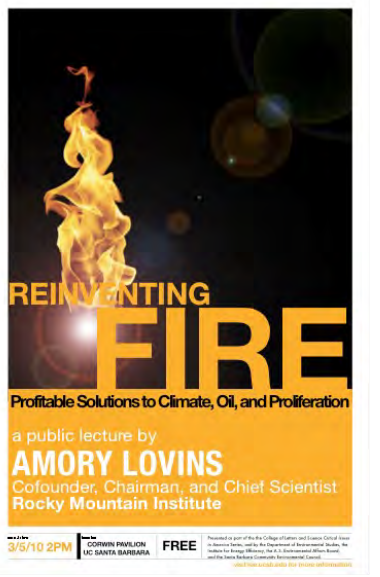
>60 interns in IEE programs

ENERGY EFFICIENCY LEADERSHIP LECTURES









>100 lectures in the past 15 years

the INSTITUTE for ENERGY EFFICIENCY

HENLEY HALL

17 laboratories (AI/ML, LEDs, Quantum Computing, Efficient Chemical Processing, Data Centers,…

17 faculty offices

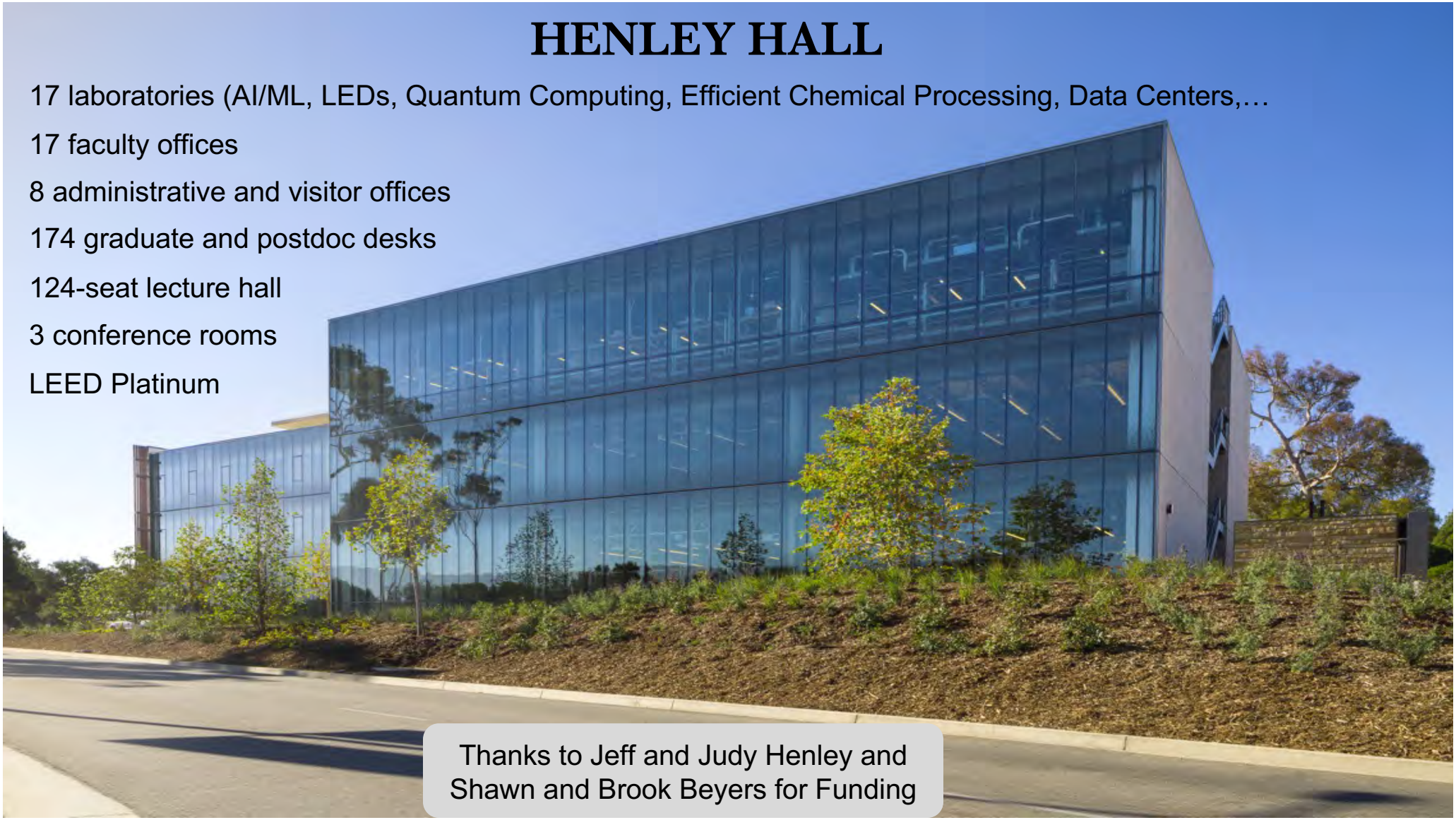
8 administrative and visitor offices

174 graduate and postdoc desks

124-seat lecture hall

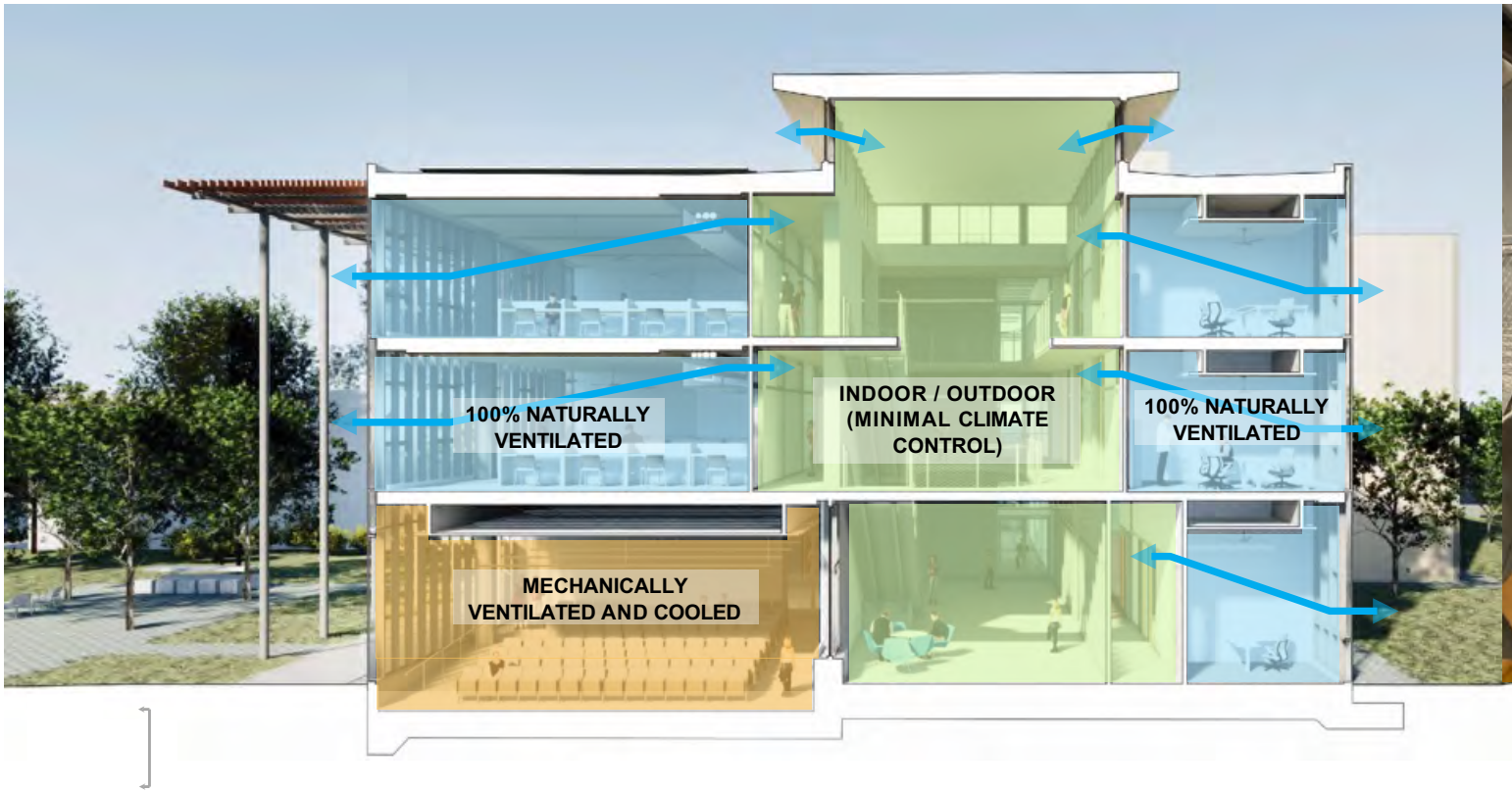
3 conference rooms

LEED Platinum



Thanks to Jeff and Judy Henley and
Shawn and Brook Beyers for Funding

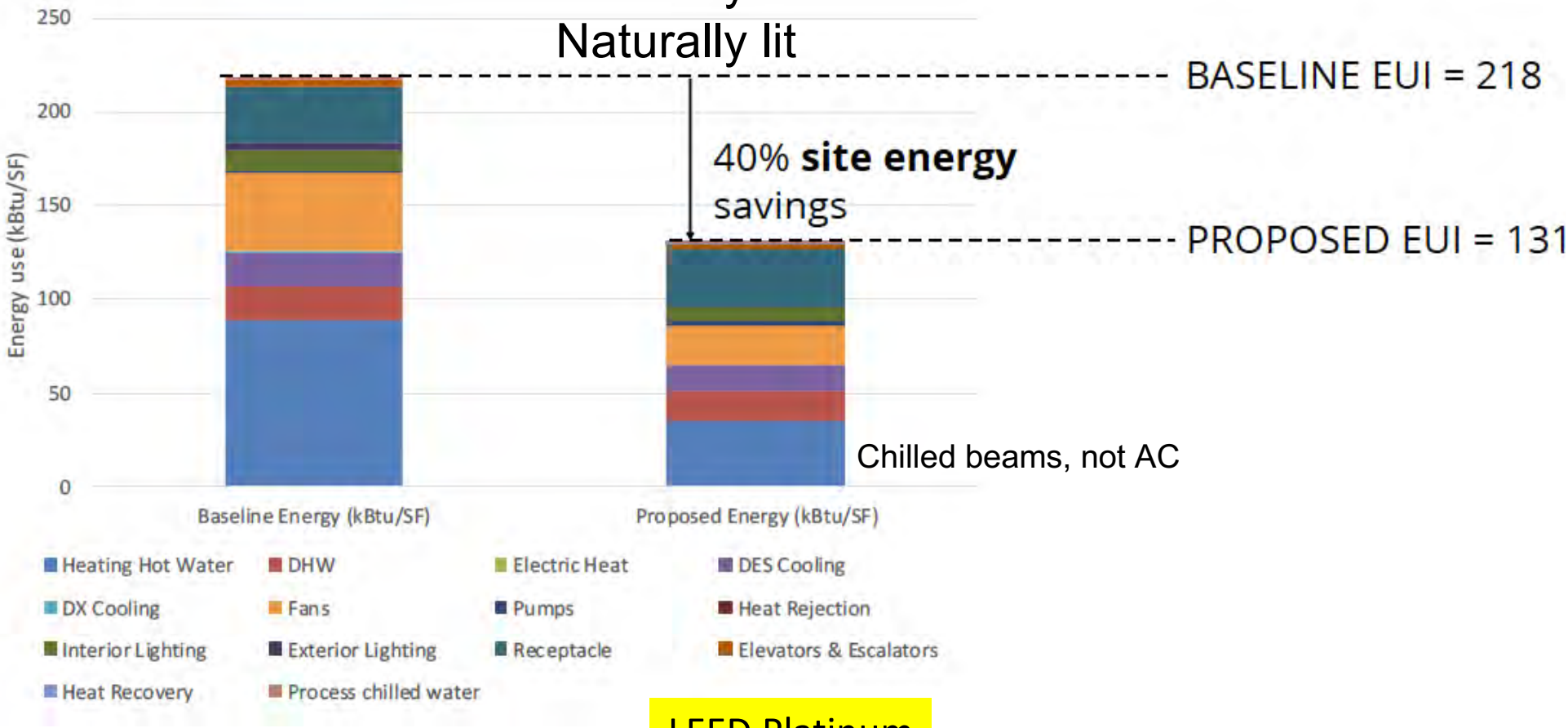
Energy Efficient: Naturally lit and naturally ventilated



Very Efficient Building

Naturally ventilated

Naturally lit



LEED Platinum

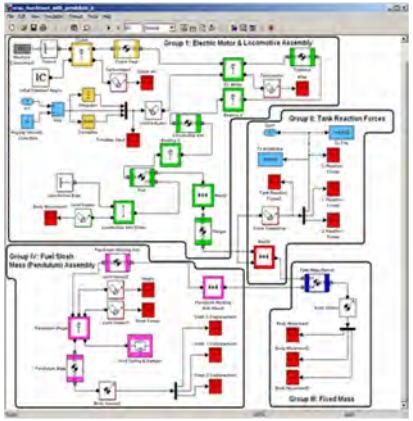
Winner of six architecture awards

AI FOR BUILDING ENERGY EFFICIENCY

We develop Artificial Intelligence algorithms and apply them in societal infrastructure problems. We concentrate on problems of operations and energy efficiency of buildings/power grid infrastructure

Igor Mezic
Mechanical Engineering
Email: mezic@ucsb.edu

- Energy reduction in commercial buildings:20-30%
- Prevent grid destabilization by fluctuating sources.
- Enable zero net energy buildings
- Optimize grid/buildings coupling for operations and energy efficiency.
- AI for operations in retrofits and residential buildings.



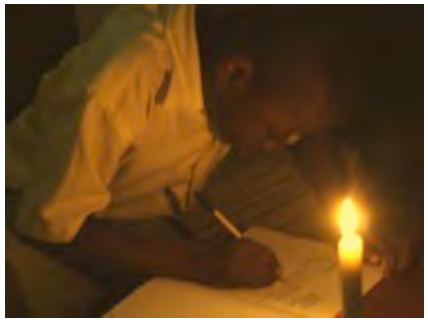
42 million square feet worldwide are controlled by Igor's algorithms. Henley Hall will take this analysis and control to a whole new level.

IEE SEED RESEARCH GRANTS

- IEE seed program kicked off 2019-2020 and IGSB program in 2022-23
- Criteria: new/innovative, likely to lead to external funding, high impact likely
- IEE funded 13 seed grants & 3 IGSB Software impact grants totaling $900K
- Thanks to our philanthropists! – John and Patty MacFarlane, Reece Duca

LED LIGHTING

BRINGING OFF-GRID LIGHTING TO THE DEVELOPMENT WORLD



- Started with visit from Ghana university President asking for inexpensive solar power reading lights
- Kerosene lighting and firewood are used by 1/3 of the world; they cause countless fires and are very inefficient (0.03 lm/watt).
- The average villager spends 10-25% of their annual income on kerosene.

LED LIGHTING

BRINGING OFF-GRID LIGHTING TO THE DEVELOPMENT WORLD

http://www.unitetolight.org/

• Started with visit from Ghana university President asking for inexpensive solar power reading lights

• Kerosene lighting and firewood are used by 1/3 of the world; they cause countless fires and are very inefficient (0.03 lm/watt).

• The average villager spends 10-25% of their annual income on kerosene.

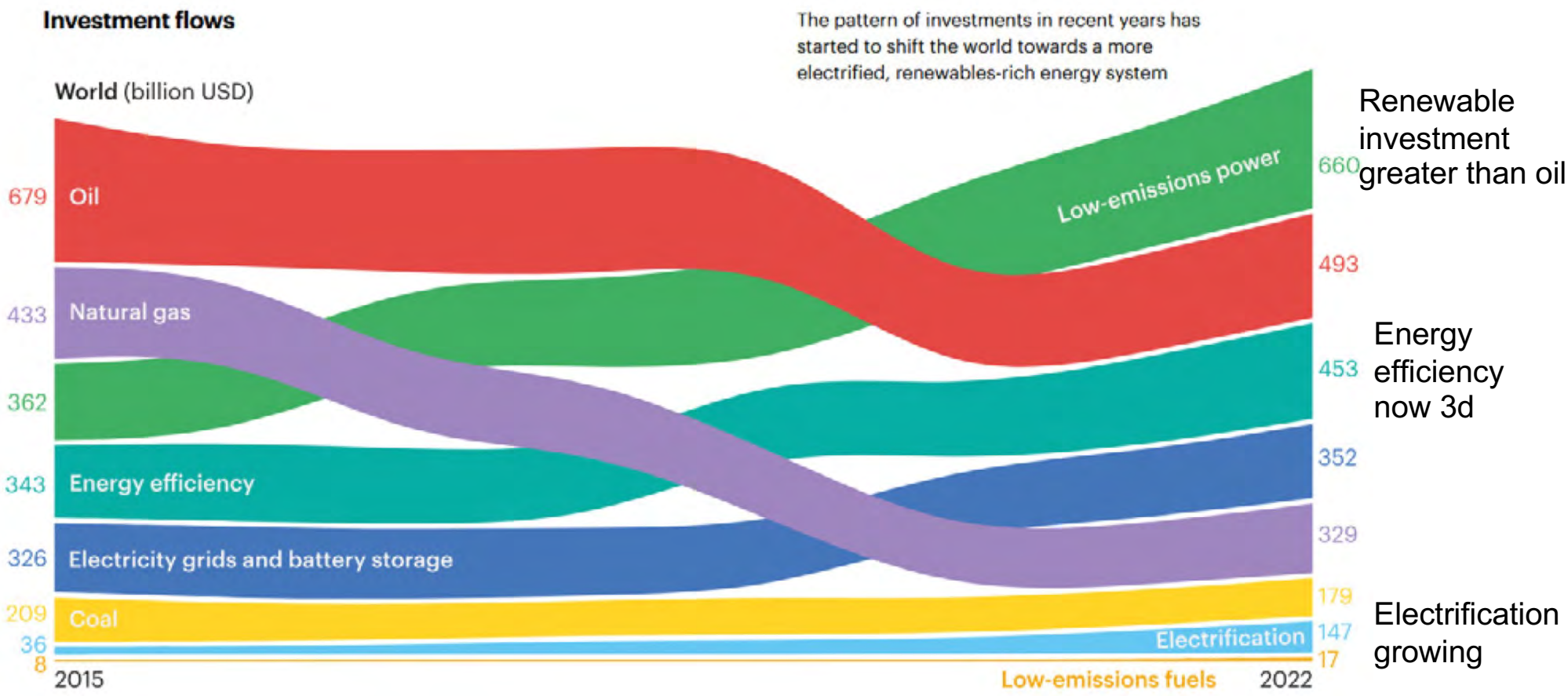
• LED Lighting costs much less on an annual basis and payback period is just 6 months.

•Initial design and demonstration at IEE funded by George Holbrook. Set up and transfer to nonprofit Unite to Light.

•220,000 lights distributed to 80 countries

•30% improvement in graduation rates when UtL lights are provided to high schools

THE NEXT 15 YEARS: FOLLOW THE MONEY

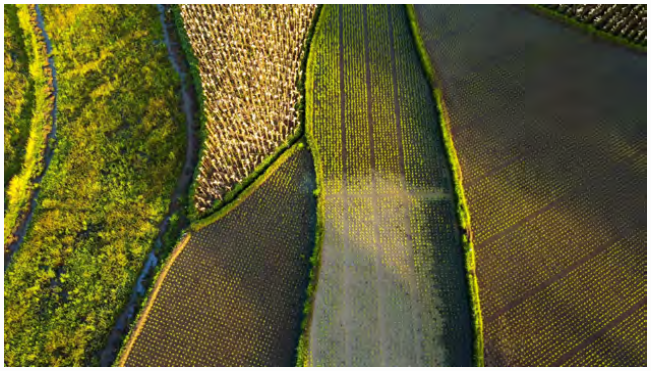


Source: [International Energy Agency]

UC SANTA BARBARA
Institute for Energy Efficiency

THE NEXT 15 YEARS

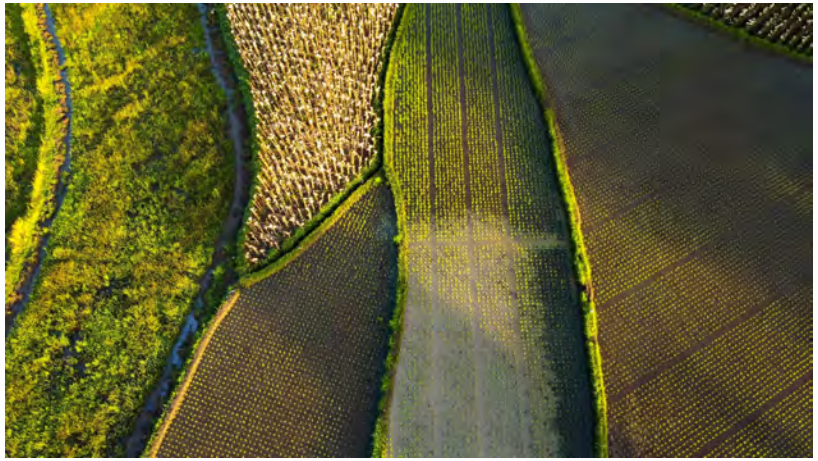
Making every human activity more energy efficient



Driving toward 50% renewable energy integration by 2030 and 99+% by 2050.

Our technology becomes orders of magnitude more energy efficient.

THE NEXT 15 YEARS: Making every human activity more energy efficient



- **Double production of food using less than half the energy and water**
- **Economically viable zero net energy buildings**
- **Electrified transportation**
- **Alternatives like Green Hydrogen for some transportation**
- **More efficient heavy industry production**

THE NEXT 15 YEARS: SMART FARMING



Chandra Krintz & Rich Wolski

Tour second floor lab

- **End-to-end IoT systems for rural communities and remote ecological environments**
  - To instrument our world requires new approaches to providing power “everywhere”
  - Renewable energy sources, battery sustainability, power infrastructure to accompany computational infrastructure

- ***The answer is software***: systems that program remote devices to be power efficient

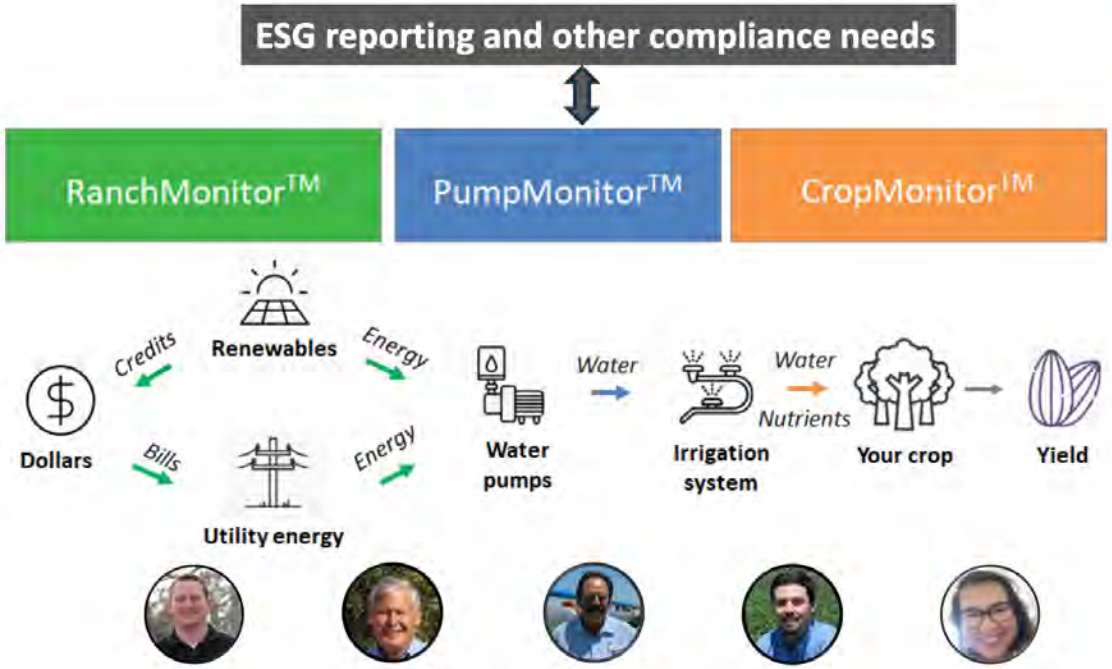
- Example: **UCSB SmartFarm** -- Turning cloud & data analytics into *farm implements*
  - Cloud-style, easy to use, data-driven decision support, actuation, & control for farm operations
    - Automation, ML and AI systems to scale operations, reduce energy consumption, improve ag. outcomes & lower costs
  - Use Cases
    - Precision, data-driven irrigation and pest control
    - Food tracking from farm to fork
    - Efficient frost prevention via microclimate prediction

UCSB

AGRICULTURE: MORE EFFICIENT WATER AND ELECTRICITY USAGE

Olivier Jerphagnon (founder and UCSB grad) spun Agmonitor out of IEE

The solution: decision support tool to improve margins (Operations) and resource efficiency (ESG)

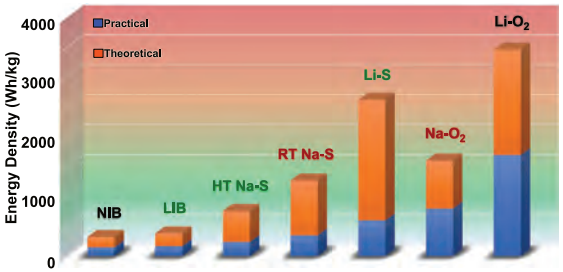


- **Clear metrics for:**
  - Energy transition
  - Water security
  - Food production
- **The whole team works together**
  - Texts (crew)
  - Email notifications (ranch manager)
  - Report and ROI predictions (owner)

AgMonitor

Future of Batteries

Research directions at UCSB

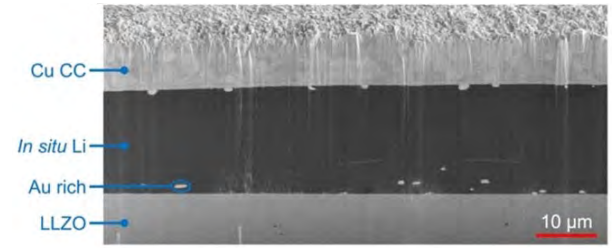


Goikolea et al. Advanced Energy Materials 10, 2002055, 2020

NIB: Na-ion battery, LIB: Li-ion battery
Na-S and Li-S: sulfur chemistries
Na-O2 and Li-O2: Na air and Li air chemistries

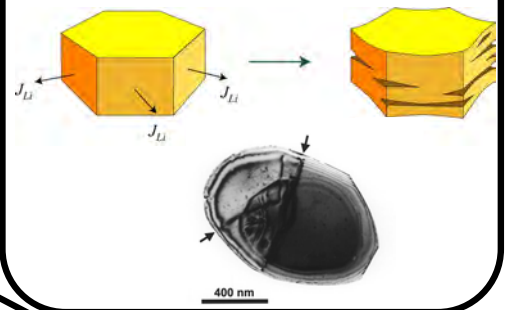
Sakamoto

solid electrolytes + Li anodes



Higher energy: → All-solid-state batteries:
Conversion cathodes: e.g. Li_xFeF_3, Li-Sulfur
New redox mechanisms

Solid Mechanics



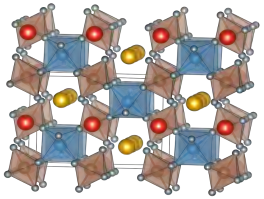
Balakrishna

McMeeking

Higher power:

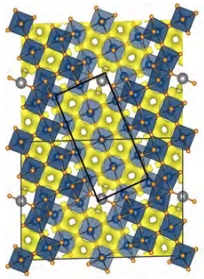
Lower cost, sustainable:

Na-ion batteries



Clément

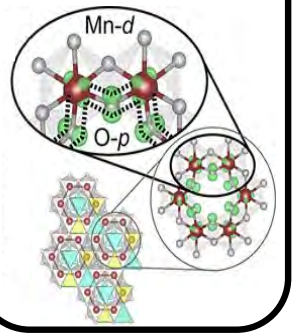
Wadsley-Roth anodes



Seshadri

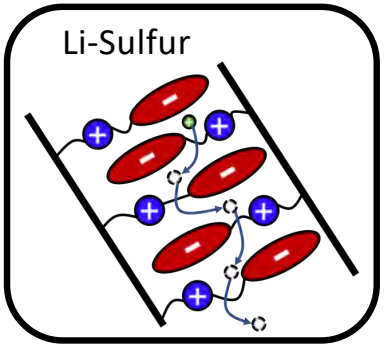
Van der Ven

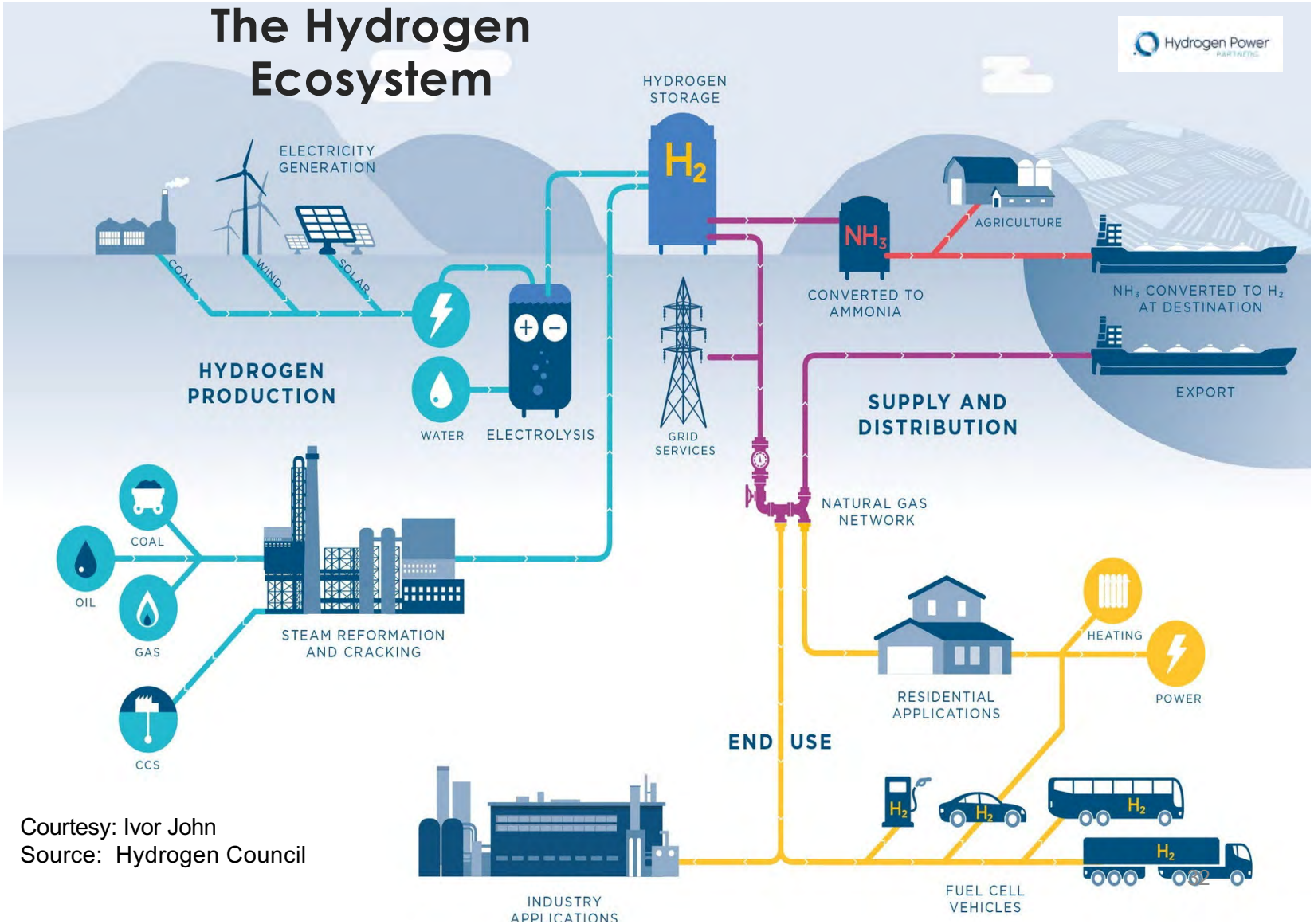
anion redox



Segalman

Li-Sulfur





Courtesy: Ivor John
Source: Hydrogen Council

CONTRIBUTIONS OF CATALYSIS TO ENERGY EFFICIENCY

Tour Phil Christopher's 3d floor lab

Chemical manufacturing (NH_3 for fertilizer, C_2H_4 for plastics, etc.) contributes ~10 % of worlds CO_2 emissions (3.3 gigaton CO_2/yr) and hydrocarbon fuel combustion is >20-30% of worlds CO_2

UCSB EFFORTS TO ADDRESS THESE ISSUES

CO_2 emissions associated with H_2 production (used as a fuel or reagent)

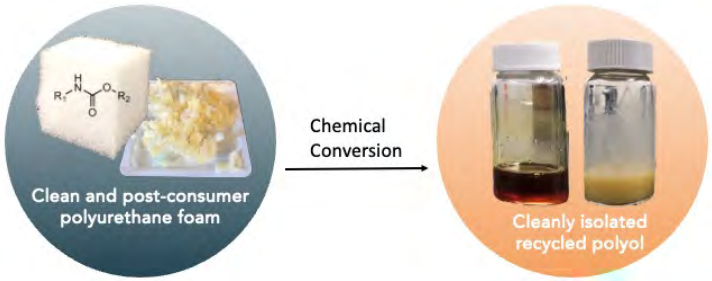
(McFarland, Gordon, Christopher)

Novel materials and processes for CO_2 free H_2 production

"Waste" reuse for chemical synthesis

(Scott, Abu-Omar, Christopher, McFarland, Segalman, others…)

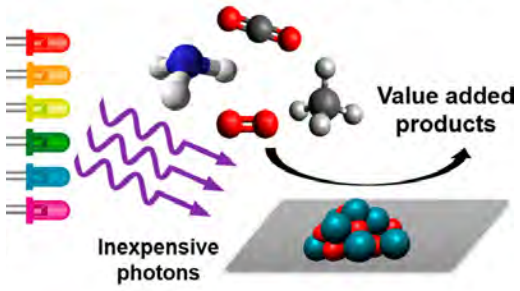
Plastics, CO_2, waste as C/energy source



New catalysts and processes for improved efficiency

(Scott, Abu-Omar, Christopher, McFarland, Sepunaru, DenBaars, …)

Photons/electrons as energy source, and catalyst design



ZERO CO_2 HYDROGEN

Mike Gordon

Phil Christopher

Eric McFarland

Incumbent technology for H_2 production used in industry:
Steam Methane Reforming $CH_4 + H_2O \leftrightarrow CO + 3H_2$ (~6 Ton CO_2/ton H_2)

Alternative Chemistries for H_2 production WITHOUT CO_2

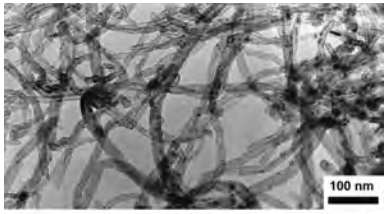
Methane pyrolysis enables H_2 and high value C production

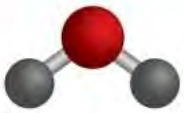
$$CH_4 \rightleftharpoons C + 2H_2 \qquad > 6\ \frac{kWh}{kgH_2}$$

High value secondary product

Plasma- based processes

Carbon Nanostructures

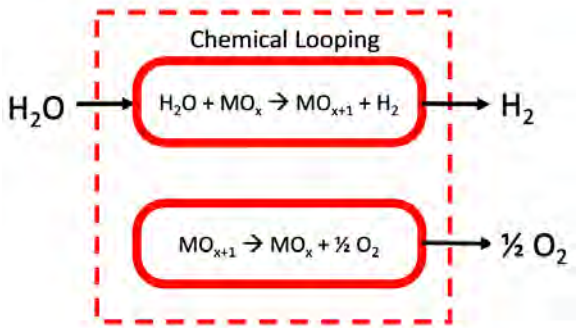




Thermochemical H_2O splitting through chemical looping driven by resistive heating can be competitive with electrolysis

$$H_2O \rightleftharpoons \frac{1}{2}O_2 + H_2 \qquad > 50\ \frac{kWh}{kg\ H_2}$$

Thermochemical



THE NEXT 15 YEARS: Renewable Energy Integration

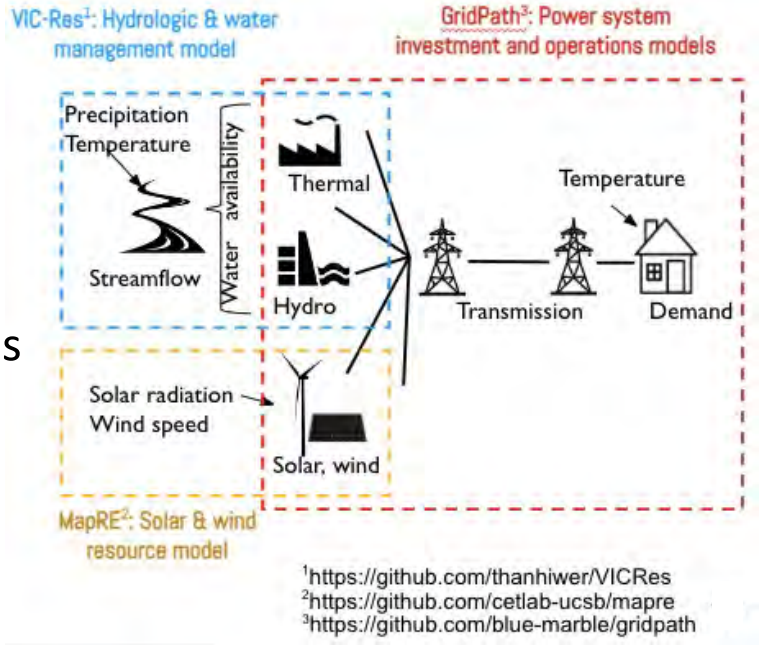
- Energy storage solutions make renewables a “first class energy source”
- AI/ML and other SW manage and plan the power grid all the way to the user

SOFTWARE TO PLAN AND OPERATE EFFICIENT AND EQUITABLE ENERGY SYSTEMS

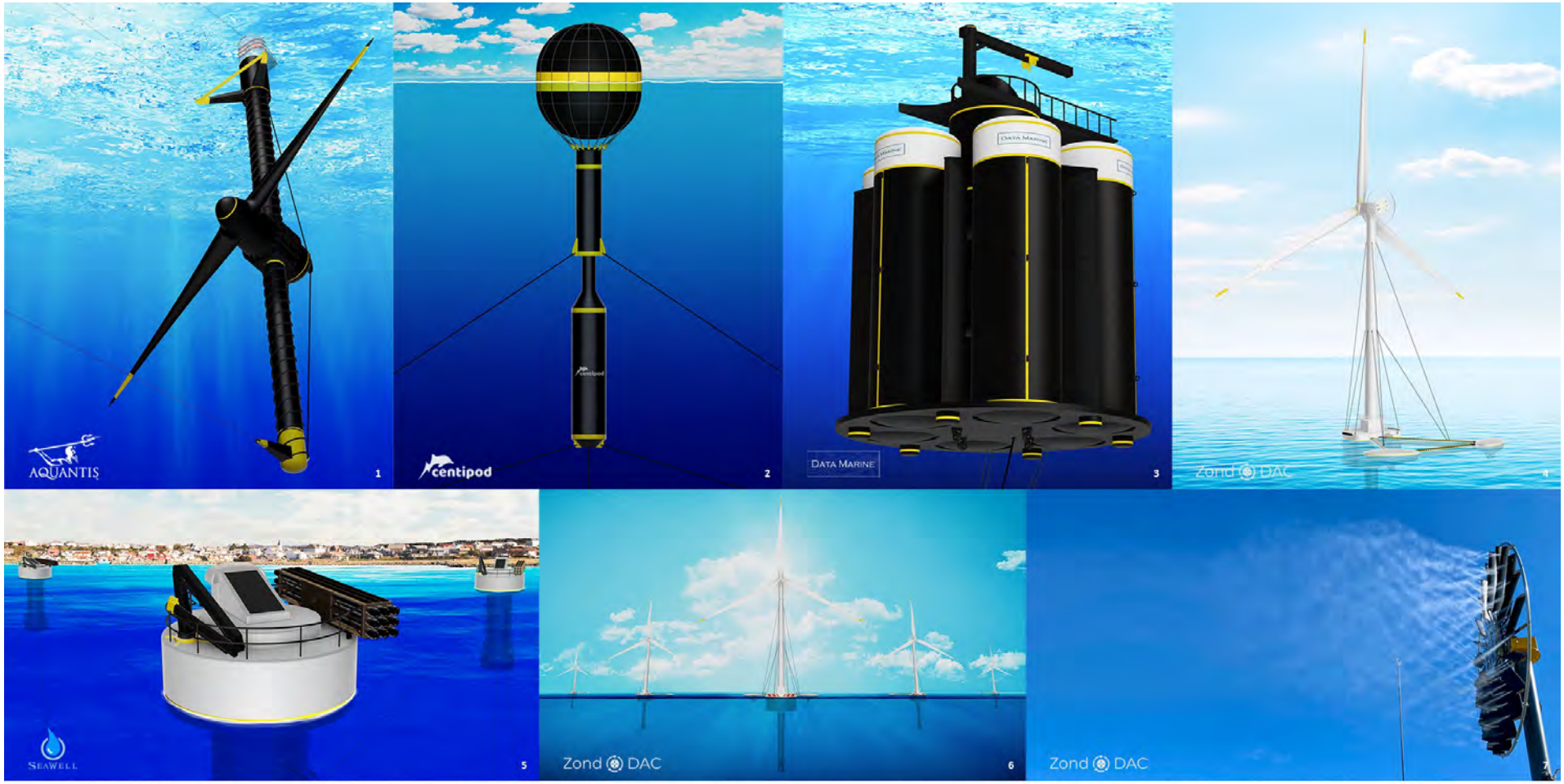
Clean Energy Transformation Lab CETlab

Ranjit Deshmukh
Environmental Studies
and the Bren School

- Software tools for renewable energy integration and planning generation, storage, and transmission assets
- ML for forecasting of renewable energy and demand for efficient power systems operations
- Models to analyze decarbonization policies for equitable economic, health and employment outcomes



WIND OR TIDAL DRIVEN ENERGY AND DESAL WATER



From top left: 1) Aquantis 1.25MW Ocean Current Turbine, 2) Centipod 180kW Wave Power Converter, 3) Data Marine 7.2MW Offshore Data Modules, 4) ZONDDAC 15m (D) Precipitor (4,200T/YR CDR), 5) SeaWell 450kW 150m³/hr Desalination, 6) SeaHawk 3MW Offshore Wind Turbine with 15m (D) Precipitor, and 7) Test 4m (D) Precipitor (320T/Y CDR)

ECOMERIT TECHNOLOGIES

UC SANTA BARBARA
The 2035 Initiative

UC SANTA BARBARA
Social Sciences

UC SANTA BARBARA
Institute for Energy Efficiency

Accelerating the Clean Energy Transition

Phasing Out Fossil Fuels

Adapting to Climate Change

Current flagship policymaking projects at The 2035 Initiative include:

- Leveraging the success of the Inflation Reduction Act (IRA) to craft climate and energy policy roadmaps at the US state-level and internationally
- Developing an equitable roadmap for methane regulation
- Creating a global climate observatory to measure climate impacts and response strategies in developing countries
- Creating pathways for school electrification to cut climate pollution and boost community resilience
- Developing the first high-resolution global maps of climate concern, including the first effort to systematically survey climate-vulnerable populations in small-island regions

UC SANTA BARBARA
The 2035 Initiative

UC SANTA BARBARA
Social Sciences

UC SANTA BARBARA
Institute for Energy Efficiency

Electrification: Plugging into a key climate solution

- Replacing fossil-fueled cars, household appliances, and industrial technologies with clean, electric alternatives is one of the greatest opportunities to address the climate crisis, slash pollution, and jumpstart the clean economy.
- If paired with a clean electricity grid, nationwide electrification would cut 90% of U.S. carbon emissions.
- It's also a great investment – a fully electrified home can save the average household more than $2,500 per year on its energy bills.
- The Inflation Reduction Act spends billions to support and subsidize electrification, and the market is responding. For example, annual investment in U.S. EV and battery manufacturing has increased 9-fold since the IRA passed last year.
- Electrification is a primary focus of *The 2035 Initiative*, with several ongoing projects aimed at promoting a speedy transition to clean, cost-saving electric technologies.

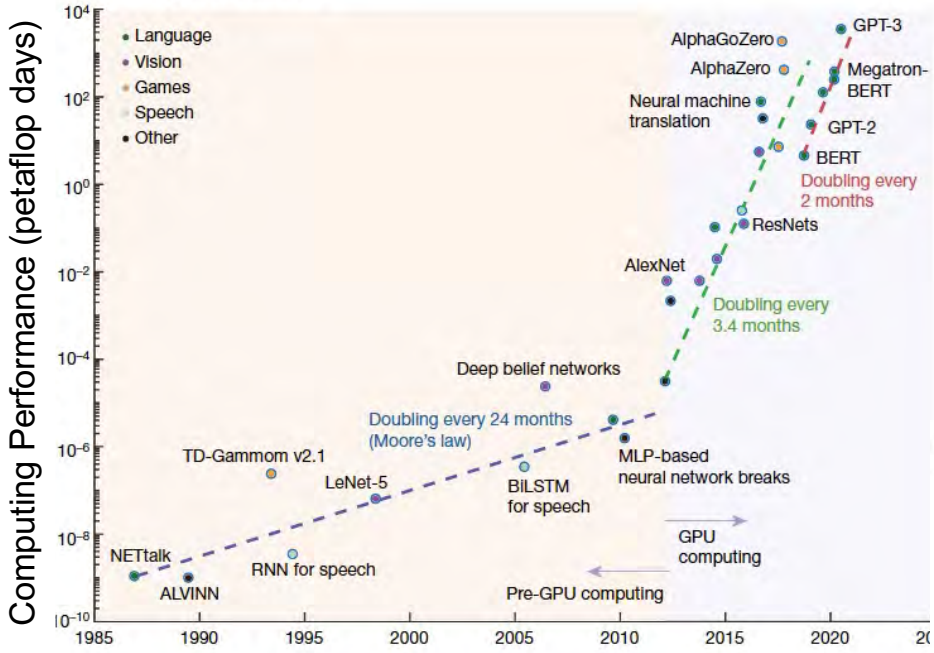
Image: NREL

THE NEXT 15 YEARS: Data Centers and Technology

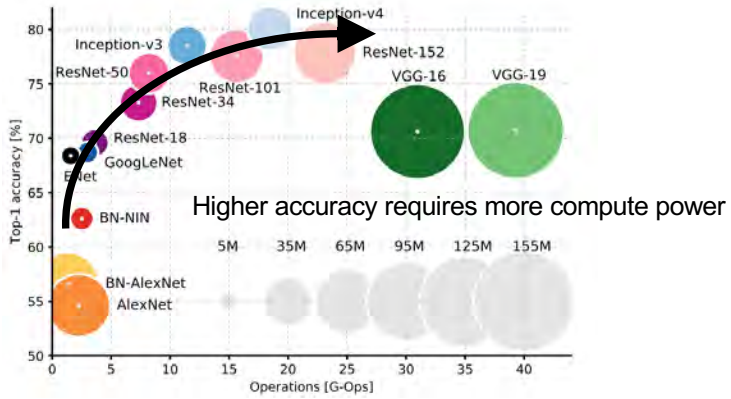
- **Multiple orders of magnitude improvement in Data Center Energy Efficiency**
- **1000X improvements in AI/ML Energy Efficiency**
- **Quantum >10,000X energy efficiency improvements & outperforms classic**
- **Continued Photonics interconnect, comms energy efficiency improvements**

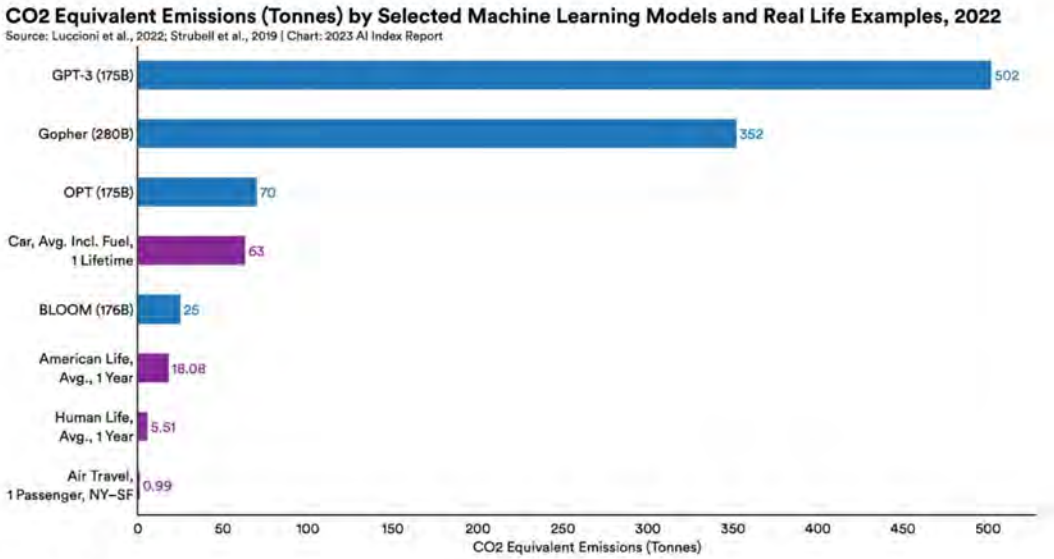
RISING DEMAND FOR AI AND COMPUTE POWER

Number of programs which use deep learning has *doubled* every 3.4 months, much faster than Moore's Law



Mehonic et al., "Brain-inspired computing needs a master plan"





Abbas, Ali, et al. "Micro Activities Recognition in Uncontrolled Environments," *Applied Sciences* (2021).

GREEN AI/ENERGY EFFICIENT AI PROJECTIONS


William Wang

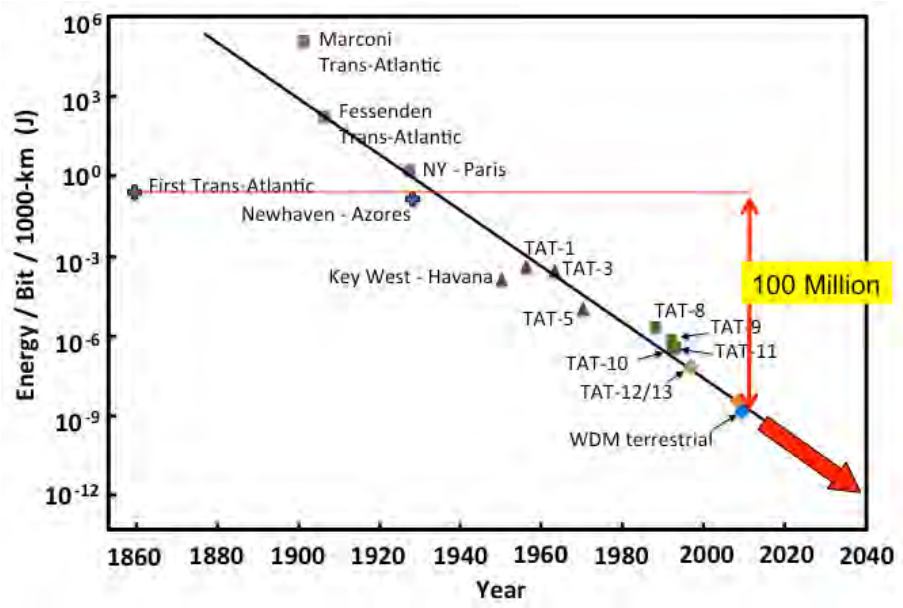
- 2023-2027: **Initial Steps to Sustainability**
  - Enhanced Efficiency: Optimized algorithms for lower power consumption.
  - Sustainable Hardware: Transition to recyclable & renewable chip materials.
  - Dynamic Scaling: AI computation adapts in real-time for energy conservation.
  - Carbon-neutral Data Centers: Shift to 100% renewable energy sources.

- 2027-2032: **Breakthroughs in Green Tech**
  - Quantum Computing: Quantum algorithms reduce power needs dramatically.
  - Neuromorphic Chips: Brain-like structures in silicon for low-power operations.
  - AI-assisted Design: AI tools develop more energy-efficient AI systems.
  - Localized Computing: On-device computations reduce energy in data transmissions.

- 2032-2038: **Mastery of Sustainable AI**
  - Self-optimizing Systems: AI cloud models that refine their own energy efficiency.
  - Advanced Cooling: Generative AI-designed materials enable near-zero energy cooling.
  - Green AI Certification: Global standards for eco-friendly AI solutions.
  - Energy Harvesting: AI powered by ambient energy, minimizing traditional power usage.

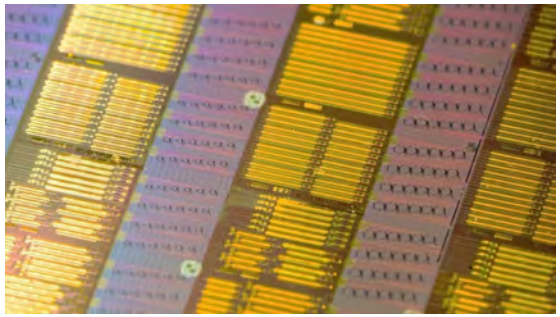
REDUCING THE ENERGY TO COMMUNICATE

Fiber Optics is very efficient!
Transport a bit across the ocean

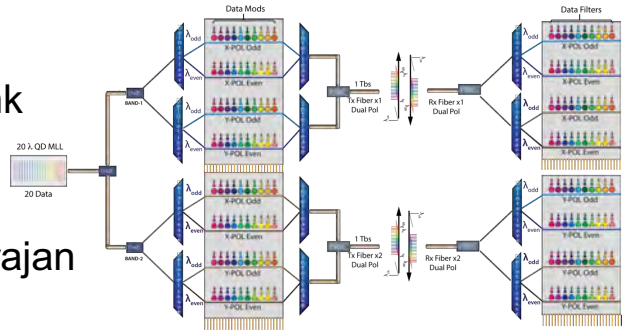


Clint Schow, Dan Blumenthal, John Bowers

- Data Centers are limited by interconnects: processors waiting for data
- Increasing interconnect bandwidth can make them more efficient.
- UCSB focused on silicon photonics to solve this problem



10 Tbps link



Luke Theogarajan
John Bowers

Intel® Silicon Photonics – at scale

- Technology developed through extensive device research at Intel Labs over the past 20 years
- Hybrid silicon laser technology licensed from Bowers UCSB
- Pluggable silicon photonics successfully scaled and shipping in volume to multiple cloud and networking equipment customers

2016
100G PSM4 release

2017
100G CWDM4 release

2018
1M units shipped

1M

2019
2M units shipped

2M

2020
4M units shipped

4M

2020
400G release

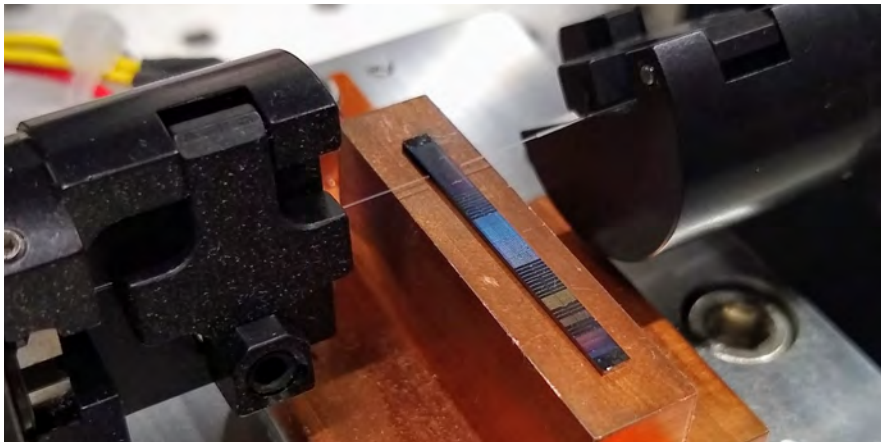
2021
>5M units shipped

5M

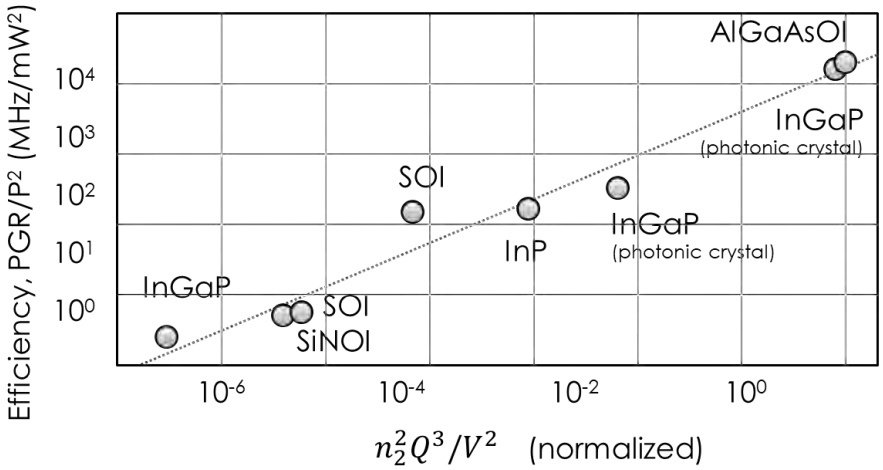
2022
>8M units shipped

8M

PHOTONIC QUANTUM COMPUTING: ULTRA EFFICIENT

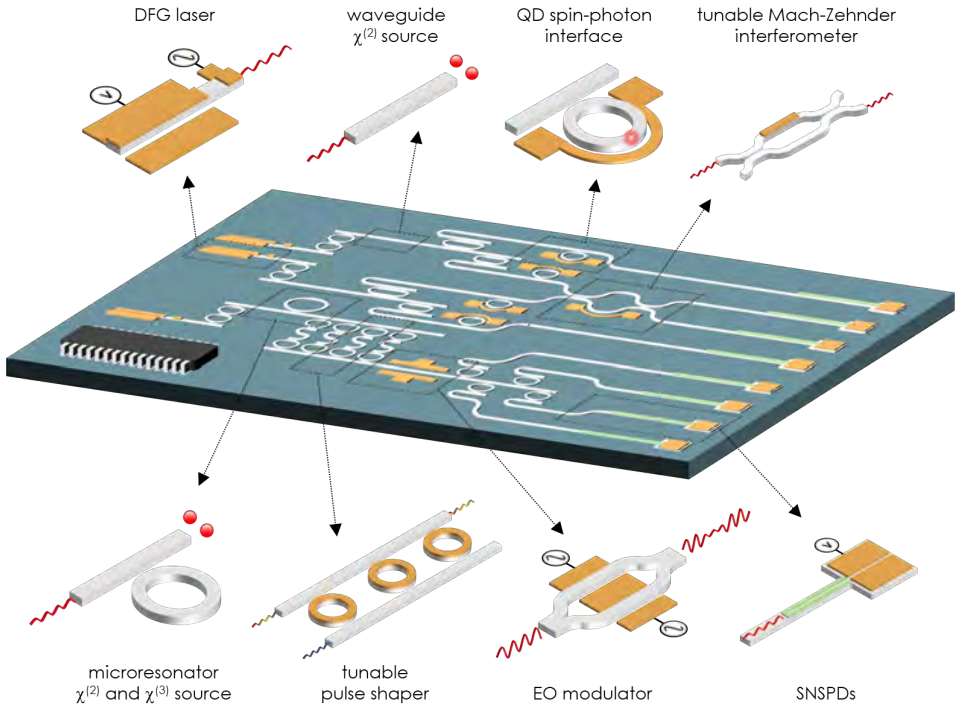


PRX Quantum **2**, 010337 (2021)



Efficient photonic circuits, lasers, quantum sources, and detectors are key enabling technologies for future computers, networks, and communications

Galan Moody
John Bowers



Optica **10**, 917 (2023)

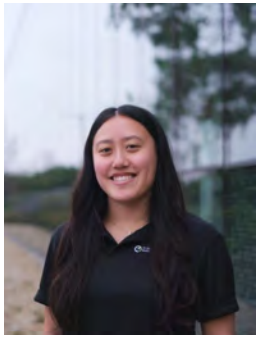
IEE STAFF

Mark Abel,
Associate Director

Jenna Craig,
Assistant Director

Elliott Hong,
Financial Manager

Amanda Miller,
Contract & Grant Analyst



Cassandra Tai,
Personnel Analyst

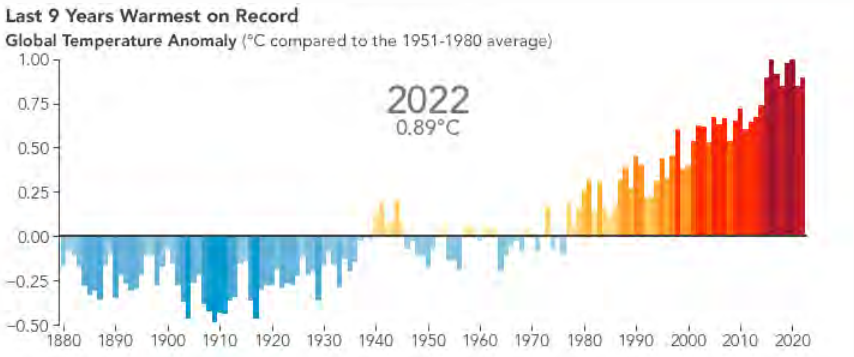
Suryaansh Dongre,
Admin Student Assistant

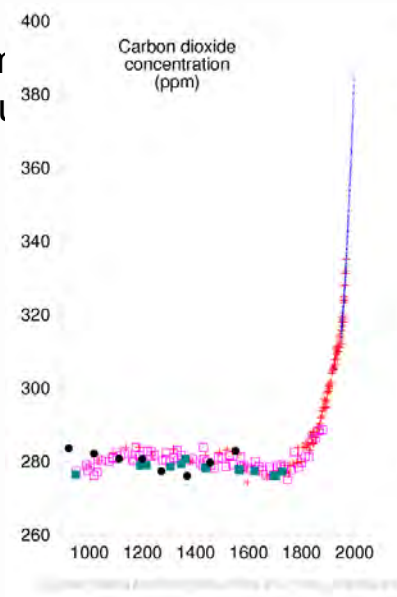
Brooke Grazda,
Admin Student Assistant

UC SANTA BARBARA
Institute for Energy Efficiency

SUMMARY

- Over the past 15 years, there has been significant progress in
  - Solid state lighting: Higher efficiency, Lasers with higher brightness (See Denbaars' talk)
  - Chemical processing, hydrogen generation (Christopher lab tour, CZero)
  - Data center efficiency (See Malone and Masenet's talks)
  - Silicon photonics: Higher efficiency, higher capacity, use in data centers
  - AI algorithms and AI technology (See Szu and Wang's talks)
  - Quantum computing (See Moody's talk)
  - Electrification (See Mildenberger's talk)
  - Efficient farming (Krintz, Wolski tour, Agmonitor)
- Over the next 15 years, significant advances are needed and possible in all of these
- Many companies spinning out to address these problems (Next Energy, Czero, Mixm Pseudolithic, Blue Laser Fusion, Soraa Laser Diode, Monde Wireless, Agmonitor, Qu Nexus, Mirios, Lucidean, Spero Renewables, Mentium)
- Climate change is real, painful and progress in energy efficiency is essential





UC SANTA BARBARA
Institute for Energy Efficiency

WORKSHOP AGENDA

1:00 Welcome: Chancellor Yang UCSB, Dean Mishra CoE, Jeff Henley, Oracle

1:15 IEE: "The First 15 Years and The Next 15 Years"
John Bowers, UCSB

1:35 Data Centers and the Future of Energy Efficiency:
Chris Malone, META
Eric Masanet, UCSB

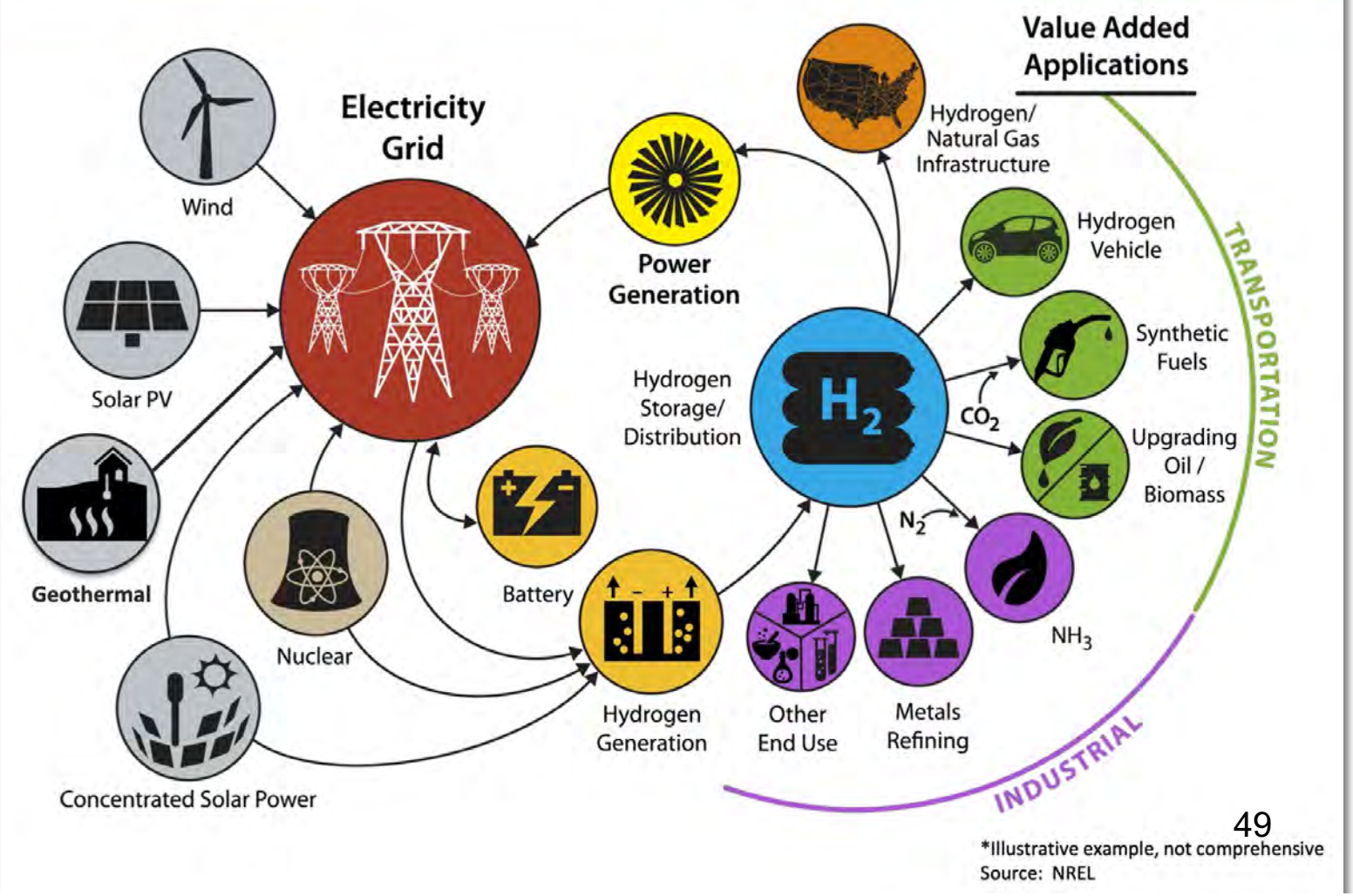
2:20 Towards Green Artificial Intelligence:
Vivienne Szu, MIT
William Wang, UCSB

3:05 Energy Efficient Materials and Quantum Computing:
Steven Denbaars, UCSB
Galan Moody, UCSB

3:45 Climate Change and Energy Efficiency:
David Victor, UCSD
Matto Mildenberger, UCSB

4:30 Reception in Henley Hall Atrium + Courtyard:
Poster Sessions + Tours

Hydrogen Basics (2/2)



*Illustrative example, not comprehensive
Source: NREL