Carbon Neutrality
UC’s Goal to Achieve Zero CO$_2$ Emissions by 2025

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Executive Director
The Institute for Energy Efficiency
The University (all 10 campuses) will achieve zero net greenhouse gas emissions (scope 1 & 2 emissions) in its operations by 2025 (zero scope 3 emissions will be achieved in 2050)
Europe Leads the Way

No-carbon electricity generation share in Europe and the United States (2012)

- percent of total generation

- Iceland
- Switzerland
- Norway
- Sweden
- France
- Austria
- Slovakia
- Finland
- Belgium
- Slovenia
- Denmark
- Spain
- Hungary
- Portugal
- Czech Republic
- Germany
- Italy
- United Kingdom
- Ireland
- Netherlands
- Luxembourg
- Greece
- Poland
- United States

Legend:
- nuclear
- hydro
- geothermal
- solar, tidal, wave
- wind
- biomass and waste

29 October 2014
U.S. per capita emissions = 17 MT CO$_2$e per year
UC System GHG Emissions

2020 Policy Goal

Scope 1 (Natural Gas, Campus Fleet, Fugitive)
Scope 2 (Purchased Electricity)
Scope 3 (Campus Commute, Business Air Travel)

2025 Neutrality Goal

UC Greenhouse Gas Emissions Compared to Climate Goals (Millions of Metric Tons CO₂e)

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UC Energy Efficiency Savings

- $151,000,000 kwh/year savings
- ~9,000,000 therms/year savings
- ~$22M/avoided cost/year (before loan debt of ~$8.6M/year)
- ~99,700 mTons CO2e/year reduction
- Cost of Carbon/ton: ~$87/ton (over 20yrs)

481 Projects

EE Project Total 2009 - 2012 (excluding UCLA)
Co-gen: Combined Heat & Power
## Co-Generation Facilities at UC Campuses

<table>
<thead>
<tr>
<th>Facility Name</th>
<th>Op Year</th>
<th>Prime Mover</th>
<th>Capacity (kw)</th>
<th>Fuel Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCB</td>
<td>1987</td>
<td>Combined Cycle</td>
<td>28,500</td>
<td>NG</td>
</tr>
<tr>
<td>UCLA</td>
<td>1993</td>
<td>Combined Cycle</td>
<td>48,000</td>
<td>NG + biogas</td>
</tr>
<tr>
<td>UCD Med Center</td>
<td>1998</td>
<td>Combustion Turbine</td>
<td>28,000</td>
<td>NG</td>
</tr>
<tr>
<td>UCSD</td>
<td>2001</td>
<td>Combustion Turbine + fuel cell</td>
<td>32,800</td>
<td>NG + Biogas</td>
</tr>
<tr>
<td>UCSF</td>
<td>1998</td>
<td>Combined Cycle</td>
<td>13,500</td>
<td>NG</td>
</tr>
<tr>
<td>UCSC</td>
<td>1985</td>
<td>Combustion Turbine</td>
<td>33,100</td>
<td>NG</td>
</tr>
<tr>
<td>UCI</td>
<td>2003</td>
<td>Combined Cycle</td>
<td>22,060</td>
<td>NG</td>
</tr>
</tbody>
</table>
UC Carbon Neutrality Strategies

Climate Neutral by 2025

Large-Scale Biomethane Development

On-campus Energy Efficiency and Renewables

Off-campus Renewable & Carbon-Free Electrical Supply

Biomethane Development
Transition from natural gas to biomethane to fuel UC’s efficient electrical plant facilities

On-Campus Demand
Invest in energy efficiency and renewable generation to reduce campus load

Off-Campus Electrical Supply
Enter the wholesale electrical market to control our supply
UC 80 MW Solar Contract

- Two Power Purchase Agreements - 60 & 20 MW
- Third Party Provider: Frontier Renewables
- 25 year contract
- Power for UCI, UCM, UCSD, UCD, UCSF, & UCSC.
- In Fresno county - construction in 2015 & online in 2016
- Largest solar project of any U.S. university.
Levelized Cost of Solar Electricity

Source: Lazard’s Levelized Cost of Energy Analysis – Version 8.0 August 2014
Levelized Cost of Electricity (Unsubsidized)

Source: Lazard’s Levelized Cost of Energy Analysis – Version 8.0 August 2014
Wind & Solar Power Variability (30 days)

Barnhart et al: “The energetic implications of curtailing versus storing solar- and wind-generated electricity”
Net Demand ("Duck Curve") - CA
Grid Storage Technologies in Use & Planned in U.S.

- **Pumped Hydro**: 95%, 23.4 GW
- **Compressed Air**: 35%, 423 MW
- **Thermal Storage**: 36%, 431 MW
- **Battery**: 26%, 304 MW
- **Flywheel**: 3%, 40 MW

Source: DOE
Hydrogen Storage

- Electricity Generated by Excess Wind Power
- Hydrogen Generator
- Hydrogen Generated by water electrolysis
- PEM Fuel Cell Station
- Transformer
- Grid
- Hydrogen Storage
Biomethane from Organic Waste

- Dairy Waste
- Municipal solid waste
- Landfill
- Food processing
- Wineries/Agriculture
- Others
2.8 MW Project with City of San Diego and BioFuels Energy Inc. to generate methane gas from the Point Loma Wastewater Treatment Plant to generate electricity in a fuel cell.
Approximately 50 tons of mixed waste will be used for the facility daily, half from campus dining commons, animal facilities, olive oil production and winery & half from local commercial food companies and restaurants. Coming online in early 2015, it will generate approximately 1 MW of electricity to power campus buildings.
Located 3 miles from campus, it produces 300 million ft\(^3\) per year of low grade biomethane that is fed to the UCLA campus and mixed with natural gas in their 43 MW co-gen plant. Biomethane is 17\% by volume, 9\% by energy.
Anaerobic Digestion

How it works...

Air-Tight Digester Vessel

First Phase: Liquefaction
Complex Organic Material (Manure) → Simple Organics (Volatile Acids)
Acid-Forming Bacteria

Second Phase: Gasification
Methane-Forming Bacteria

Methane and Carbon Dioxide (Biogas)
Low Odor Nutrient-Rich Liquid

5 – 20 Days, Temperature dependent
Currently, natural gas accounts for approximately 63% of UC’s energy consumption.
## Biomethane Production in Europe

<table>
<thead>
<tr>
<th>Country</th>
<th>Biogas Plants</th>
<th>Biogas Upgrading Plants (Fed In)</th>
<th>Upgrading Capacity in m³/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>137</td>
<td>1 (1)</td>
<td>1806</td>
</tr>
<tr>
<td>France</td>
<td>256</td>
<td>3 (2)</td>
<td>5406</td>
</tr>
<tr>
<td>Germany</td>
<td>9,066</td>
<td>120 (118)</td>
<td>72,000</td>
</tr>
<tr>
<td>Italy</td>
<td>1,264</td>
<td>1 (0)</td>
<td>5406</td>
</tr>
<tr>
<td><strong>Sweden</strong></td>
<td><strong>187</strong></td>
<td><strong>53 (11)</strong></td>
<td><strong>168,006</strong></td>
</tr>
<tr>
<td>Switzerland</td>
<td>600</td>
<td>16 (16)</td>
<td>n.d.</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>211</td>
<td>16 (16)</td>
<td>6,5406</td>
</tr>
<tr>
<td>U.K.</td>
<td>265</td>
<td>3 (3)</td>
<td>12,606</td>
</tr>
<tr>
<td>USA</td>
<td>2,000</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
</tbody>
</table>

# 3 Swedish Aerobic Biodigesters

<table>
<thead>
<tr>
<th></th>
<th>Laholm Plant</th>
<th>Boras Plant</th>
<th>Linkoping Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste processed (tons/day)</td>
<td>14</td>
<td>82</td>
<td>148</td>
</tr>
<tr>
<td>Total solids content (%)</td>
<td>10</td>
<td>30</td>
<td>10 – 14</td>
</tr>
<tr>
<td>Waste composition</td>
<td>33% pig manure; 27% dairy manure; 40% slaughterhouse &amp; potato peels</td>
<td>restaurant food; household food; food processing; slaughterhouse</td>
<td>75% slaughterhouse; 15% food processing &amp; pharmaceutical; 10% manure</td>
</tr>
<tr>
<td>Production (million ft$^3$/year)</td>
<td>160</td>
<td>120</td>
<td>420</td>
</tr>
<tr>
<td>Biogas quality (% methane)</td>
<td>75</td>
<td>No data</td>
<td>70-74</td>
</tr>
</tbody>
</table>
Total flux of three large seeps is estimated to be 125 million ft$^3$ per year (Washburn, Clark & Kyriakidis 2005).
The key principal is heat recovery - capturing waste heat from the chilling system to produce hot water for the heating system. It will reduce campus greenhouse gas emissions by 50% & save 18% of campus potable water.

Stanford can recover 65% of the heat now discharged from the cooling system to meet 80% of campus heating demands.
How a Heat Pump works

- **Compressor (3)**
- **Condenser (4)**
- **Evaporator (2)**
- **Expansion Valve (5)**
- **To the Heating System**
- **From Energy Source**
- **Return from the Heating System**
- **To Energy Source**
The Carnot limit determines the theoretical maximum efficiency:

\[ CP = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_C} \Rightarrow \frac{T_H}{T_H - T_C} \]

CP = Coefficient of performance = ratio of heat energy transferred to energy expended to make the transfer.
Electricity consumed: 297,309 MMBTU (87.2M kWh)
Peak electrical demand: 14.6 MW
Natural gas consumed: 290,000 MMBTU (2.9M therms)
Total spent on utilities FY13-14: $11.3 million
Scope I/II GHG Emissions: 48,956 MT CO₂e

Purchased Electricity
27,901 MT
57%

Fugitive Emissions
14 MT
0%

Mobile Combustion
1,230 MT
3%

Stationary Combustion
19,813 MT
40%

29 October 2014
UCSB Purchased Electricity

- Electricity use per square foot was reduced by 36 percent over the past 10-year timeframe

- $2.9 million in annual avoided cost based on 2014 electrical rate
Natural gas usage per square foot has been reduced by over 45% over the past 10-year timeframe.

Compliance with local and state air pollution regulation is now a major driver.
Progress Reducing GHG Emissions (Scope 1 & 2)

Mobile Combustion

On-Site Combustion

Purchased Electricity

2014 Target

2020 Target

Metric Tons CO₂e
UCSB Campus Electrical Demand: October 27-28, 2014
UCSB currently has 5 solar PV arrays that generate 220 kW, the largest of which is at the Multi Activity Center (155kW). A 500 kW PV array (above), funded by UCSB students, will soon be operational on parking structure 22.
UCSB’s Sierra Nevada Aquatics Research Laboratory campus in the Eastern Sierra Mountains is currently completing design of a new classroom facility to become the third building at the site powered by solar PV and heated and cooled by a ground source (geothermal) heat exchanger.
• Established a set of research **grand challenges** that address the goal of carbon neutrality by 2025;

• **Reviewed current research** currently being conducted at the 10 UC campuses and the 3 affiliated national labs;

• **Identified gaps** and/or areas that need to be strengthened in research portfolio,

• Recommendations for **funding** relevant applied research and stimulating **collaborations** within the UC System.

• A 1 ½ day workshop with representatives from 10 campuses and 3 Labs –32 people total.
Why Research Is Important to the Success of the Carbon Neutrality Initiative:

- UC is a rich intellectual resource with a wide range of research activity in renewable energy, energy storage, energy efficiency & relevant economics & policy.

- This initiative presents a special opportunity for the 10 UC campuses, the 3 affiliated National Labs & the ANR to cooperate and collaborate.

- Research is also an important vehicle for engaging each entity and motivating the faculty, students & staff to participate in the initiative.

- The concept of a living laboratory is a unique vehicle for testing and learning about emerging technologies developed by UC and its many partners.

- If successful, the initiative will have impact far beyond UC and will be a model for the state, the nation and the world.
Research Inventory

Basic, Applied, Developmental & Other Research, Q4,FY 09 to Q3,FY13

Federal Agencies (170 awards)
CA State Agencies (156 awards)
UC (77 awards)
Industry (32 awards)
Municipal Agencies (9 awards)
Private Foundations (5 awards)
Other Universities (23 awards)

Total Awards ($ millions)

0 $20 $40 $60 $80 $100 $120 $140 $160 $180

29 October 2014
Site 300 – Renewable Energy Research Facility

Utility scale Research

- Wind, solar energy
- Energy storage
- Micro-grids
- Systems optimization
- ...

Utility scale Generation

- 90 MWs Wind
- 60 MWs Solar

Site 300

Research, Testing, Demonstrations, and Education
Current technology is inadequate and **substantial research investments** are needed to achieve carbon neutrality.

Viable & cost effective **alternatives to natural gas** are needed to provide dispatchable energy to meet varying demand (**Grand challenge #1**).

Solar photovoltaic technology continues to advance and costs decline, but storage and system integration pose important challenges and require additional research (**Grand challenge #2**).

A much greater level of UC-wide cooperation and collaborative research is needed for success of the initiative (**Grand challenge #3**).

All campuses need direct access to wholesale electricity markets.

UC-wide test-beds and research consortia offer a unique opportunity to advance research on carbon neutrality.
Source: International Council for Clean Transportation, Bloomberg New Energy Finance. Note: Figures are normalized to New European Driving Cycle, which is a combination of city and highway cycles. LDV stands for light duty vehicles.
Only 20% of Energy Propels the Average Gasoline Powered Light Duty Vehicle

Source: IEA “Tracking Clean Energy Progress 2013”
Electric vs Conventional Internal Combustion Engine (ICE) Vehicles

![Graph showing fuel price vs battery prices for electric and ICE vehicles.]

- Battery-electric vehicles are competitive above a certain fuel price.
- PHEVs are competitive above a higher fuel price.
- Hybrid-electric vehicles are competitive above the highest fuel price.
- ICE vehicles are competitive at lower battery prices.

Source: US Energy Information Agency; McKinsey Analysis
Cost of Ownership – Honda Civic Gasoline, CNG, HEV

Source Bloomberg - Sustainable Energy in America 2013 Factbook
Car Incremental Cost versus 2010 Baseline ($26,341 Retail Price)

Legend
FCV = Fuel Cell Vehicles
BEV = Battery electric Vehicles
PHEV = Plug in Hybrid Electric Vehicles
HEV = Hybrid Electric Vehicles
CNG = Compressed Natural Gas
ICE = Internal Combustion Engine

Source: Transition to Alternative Vehicles and Fuels – NAS 2013

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LNG --- Heavy Duty Vehicles
An artist's rendition of A123 Systems battery systems at a wind farm. (Credit: A123 Systems)
Storage Technologies Capital costs ($/kW)

- Sodium sulphur batteries
- Advanced lead-based batteries
- Flywheels
- Flow batteries
- Lithium-ion batteries
- Compressed air
- Pumped hydro

Source: Bloomberg New Energy Finance
Beyond Li-ion Storage Concepts

**Multivalent Intercalation**
- \( \text{Li}^+ \rightarrow \text{Mg}^{++}, \text{Y}^{+++}, \ldots \)
- Double or triple energy stored and released

**Chemical Transformation**
- Intercalation \( \rightarrow \) chemical reaction
  - \( \text{Li-O}_2, \text{Li-S, Na-S,} \ldots \)
- All atoms store and release energy

**Non-aqueous Redox Flow**
- Flowable electrodes
  - solutions or suspensions
  - no structural constraints
  - rich horizon of unexplored redox couples
  - Low cost / high capacity

*Source: JCESR*

*Highest potential, least understood opportunities*
### California Energy Storage Procurement Targets (MW)

<table>
<thead>
<tr>
<th>California Investor Owned Utility (IOU)</th>
<th>2014</th>
<th>2016</th>
<th>2018</th>
<th>2020</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern California Edison</td>
<td>90</td>
<td>120</td>
<td>160</td>
<td>210</td>
<td>580</td>
</tr>
<tr>
<td>Pacific Gas &amp; Electric</td>
<td>90</td>
<td>120</td>
<td>160</td>
<td>210</td>
<td>580</td>
</tr>
<tr>
<td>San Diego Gas &amp; Electric</td>
<td>20</td>
<td>30</td>
<td>45</td>
<td>70</td>
<td>165</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>200</strong></td>
<td><strong>270</strong></td>
<td><strong>365</strong></td>
<td><strong>490</strong></td>
<td><strong>1,325</strong></td>
</tr>
</tbody>
</table>

Source: CPUC Rulemaking 10-12-007
- Hybrid electric vehicles will become more widely deployed as new mileage standards are implemented.
- Liquified natural gas will become more widely used to power heavy duty vehicles. However, compressed natural gas is unlikely to be used widely in light duty vehicles.
- Without continued subsidies and or a carbon tax, hybrid and fully electric light vehicles will not become cost competitive with internal combustion vehicles for two to three decades.
- Low cost efficient energy storage, both for transportation and the electric grid, remains the single most important technological challenge limiting the widespread deployment of renewable energy and electric vehicles.
Why On-site Solar Won’t Work for UCSB

Total annual consumption = 90 million kWh

Instantaneous power = 7 to 14 MW

Average rate= $0.11 per kWh

Solar capacity required = 0.55 MWatts per GWh (@ 5 hrs per day) = 50 MW total (with storage @100% efficiency)

Land required = 400 acres (@ 8 acres per MW).
# Biomethane Production from 1000 Cow Farm

<table>
<thead>
<tr>
<th></th>
<th>18d</th>
<th>24d</th>
<th>28d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumed Total Solid %'s</td>
<td>8.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co-feed - Gallons</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biogas Production per year - cft</td>
<td>70,080,000</td>
<td>76,650,000</td>
<td>78,840,000</td>
</tr>
<tr>
<td>Biogas Flowrate - cft / minute</td>
<td>133</td>
<td>146</td>
<td>150</td>
</tr>
<tr>
<td>cft of methane per year</td>
<td>38,544,000</td>
<td>45,990,000</td>
<td>48,880,800</td>
</tr>
<tr>
<td>MMBTU's per year (millions)</td>
<td>38,852</td>
<td>46,358</td>
<td>49,272</td>
</tr>
<tr>
<td>MMBTU's per hour</td>
<td>4.4</td>
<td>5.3</td>
<td>5.6</td>
</tr>
<tr>
<td>CFT CH4 PER DAY</td>
<td>105,600</td>
<td>126,000</td>
<td>133,920</td>
</tr>
<tr>
<td>Farm usage only MMBTU's factored for</td>
<td>14,640</td>
<td></td>
<td></td>
</tr>
<tr>
<td>conversion efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm Usage % of Energy generated</td>
<td>38%</td>
<td>32%</td>
<td>30%</td>
</tr>
<tr>
<td>Energy generated % of farm usageage</td>
<td>265%</td>
<td>317%</td>
<td>337%</td>
</tr>
</tbody>
</table>

Source: Questar Technologies
Council Membership

Art Rosenfeld (Honorary Chairman)
Nathan Brostrom, EVP-Business Operations (co-chair)
Wendell Brase, UCI Vice Chancellor for Administration (co-chair)
Barbara Allen-Diaz, Vice President Agriculture and Natural Resources
David Auston, Professor of Electrical & Computer Engineering (UCSB)
Roger Bales, Professor of Engineering (UCM)
Matt Barth, Professor of Engineering (UCR)
Carl Blumstein, Director, California Institute for Energy and Environment (UCB)
Sandra Brown, Vice Chancellor for Research (UCSD)
Ann Carlson, Vice Dean and Professor, School of Law (UCLA)

Peggy Delaney, Vice Chancellor for Planning and Budget (UCSC)
Council Membership (cont’d)

Rollin Richmond, President, Humboldt State University
Michael Siminovitch, Professor/Director of the California Lighting Technology (UCD)
Kira Stoll, Co-Chair, UC Climate Change Working Group (UCB)
Elaine Swiedler, Undergraduate Student, (UCD)

Regent TBD

External Advisors:
   Bob Fisher, former CEO, Gap Inc.; co-founder and trustee, Pisces Foundation
   Lisa Jackson, EPA Administrator, 2009-2013
   Ren Orans, Managing Partner, E3
   Derek Walker, Associate VP, Climate and Energy Program, EDF
Some (Speculative) Concluding Remarks

- The recent development of unconventional sources of oil and gas will spur the continued use of fossil fuels.
- The U.S. will become less dependent on imported sources of energy.
- Renewable sources of energy, especially wind and solar will continue to grow, but will remain a relatively small fraction of total electrical energy for the next decade or two.
- Natural gas will gradually replace coal in the U.S. assuming methane leakage and groundwater contamination can be properly managed.
- Natural gas will become more widely used to power heavy duty vehicles, but is not likely to impact light duty vehicles.
- Low cost efficient energy storage, both for transportation and the electric grid, remains the single most important challenge limiting the widespread deployment of renewable energy and electric vehicles.
- Although the U.S. has the capacity to comply with the 2 degree scenario, it is much more challenging for China and India to do so.
Carbon Intensity --- a Measure of Clean Energy

Source: shrinkthatfootprint.com

Carbon intensity of electricity: g CO2/kWh

Note: 2010 figures for direct combustion emissions only (IEA 2012)
Per Capita GHG Emissions by State

SOURCE: The Vulcan Project, ASU
The average cost of these end-use energy savings is $4.40 / MMBTU: 68% below the weighted average across all fuel types.
Levelized Cost of New Electric Power in U.S. ($/kWh)

Note: These are costs for new generation that would come online in ~2018; exclusive of subsidies

Source: US Energy Information Agency
Coal versus Natural Gas