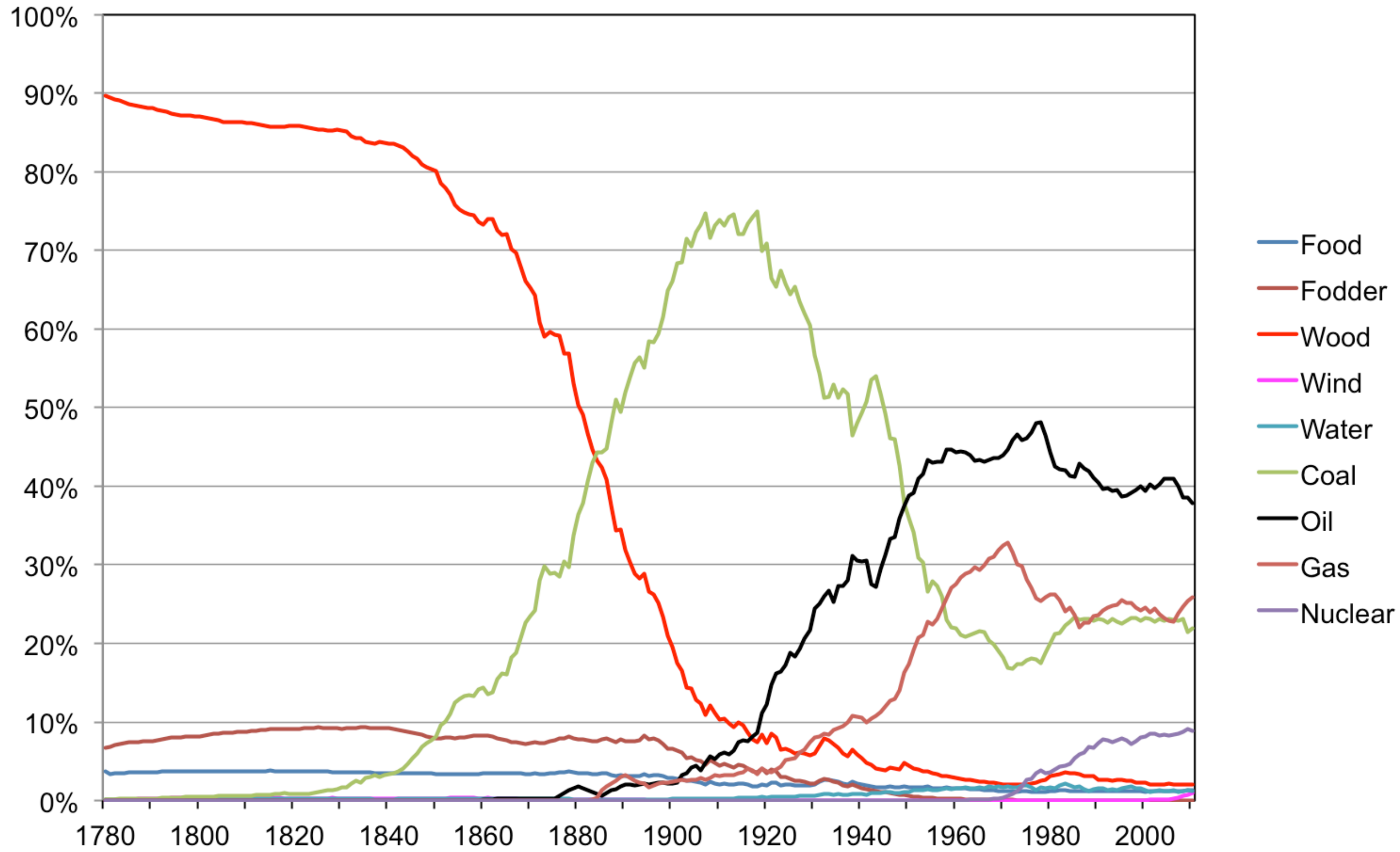
Research on Tap:
Sustainable Energy Research

Questrom School of Business

Cutler Cleveland

Professor, Department of Earth & Environment
College of Arts & Sciences

Energy Transitions in the United States, 1780-2010



Source: O'Connor, Peter A. and Cutler J. Cleveland. 2014. *U.S. Energy Transitions 1780–2010*. ***Energies*** 2014: 7955-7993

Ian Sue Wing

Associate Professor, Department of Earth & Environment

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Enrica De Cian

Senior Researcher

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Global Energy Demand in a Warming Climate

We econometrically model the long-run temperature sensitivity of demand for 3 fuels in 5 sectors, and couple the resulting estimates with earth system model simulations of climate circa 2050.

Model

i = country, t = year

$q_{i,t}$ = log per capita fuel x sector energy consumption

$\mathcal{E}^{T}_{j,i,t}$, $\mathcal{E}^{H}_{k,i,t}$ = days exposed to j population-weighted temperature bins, k population-weighted humidity bins

$\boldsymbol{X}$ = vector of controls

$$\Delta q_{i,t} = \alpha_i + \left[\Sigma_j \beta^T_j \Delta\mathcal{E}^T_{j,i,t} + \Sigma_k \beta^H_k \Delta\mathcal{E}^H_{k,i,t} + \Delta\boldsymbol{X}_{i,t}\boldsymbol{\eta}\right] + \theta\left\{q_{i,t-1} - \Sigma_j \gamma^T_j \mathcal{E}^T_{j,i,t-1} - \Sigma_k \gamma^H_k \mathcal{E}^H_{k,i,t-1} + \boldsymbol{X}_{i,t}\boldsymbol{\lambda}\right\} + u_{i,t}$$

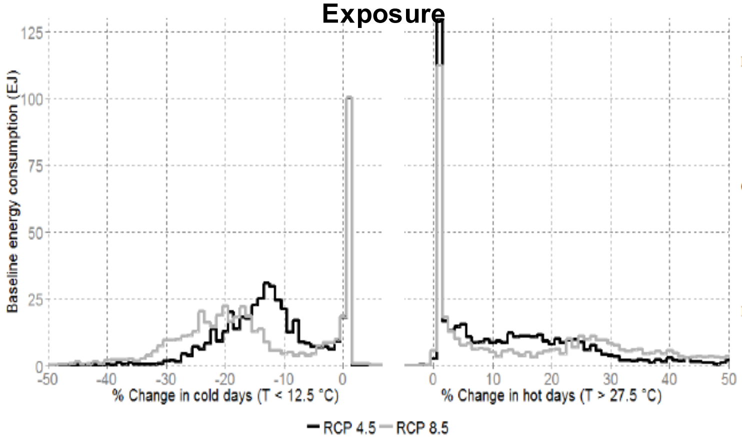
Data

Balanced panel of 29-48 countries (depending on fuel-sector combination), 1978-2010, stratified into tropical/temperate by Koeppen-Geiger classification

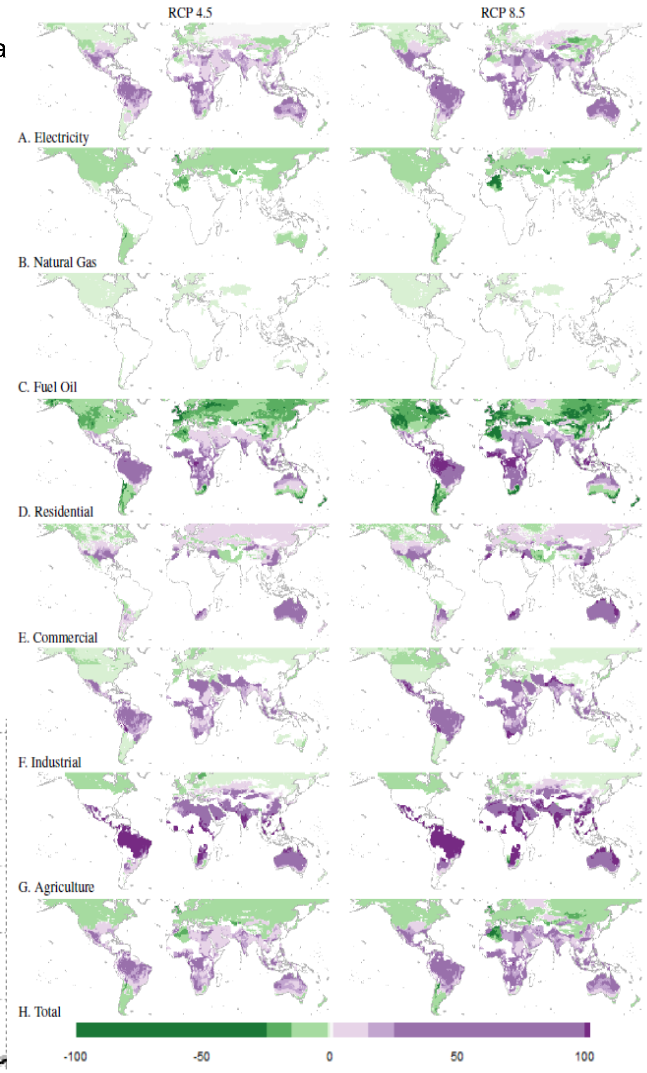
q: final energy (International Energy Agency World Energy Balances)

$\mathcal{E}^T$, $\mathcal{E}^H$: derived from gridded 3-hourly historical temperature and humidity fields from the Global Land Data Assimilation System

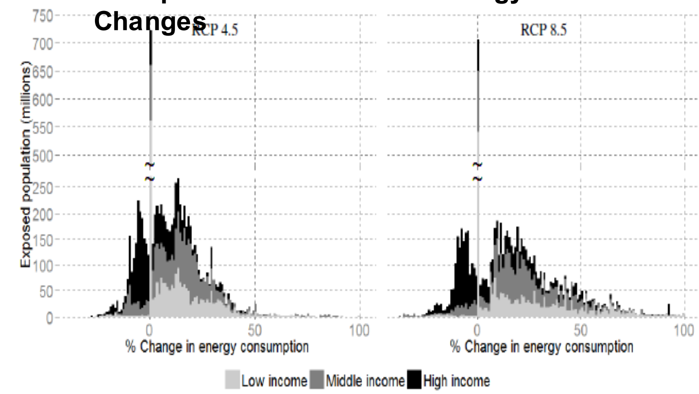
A. Energy Consumption Temperature Change Exposure

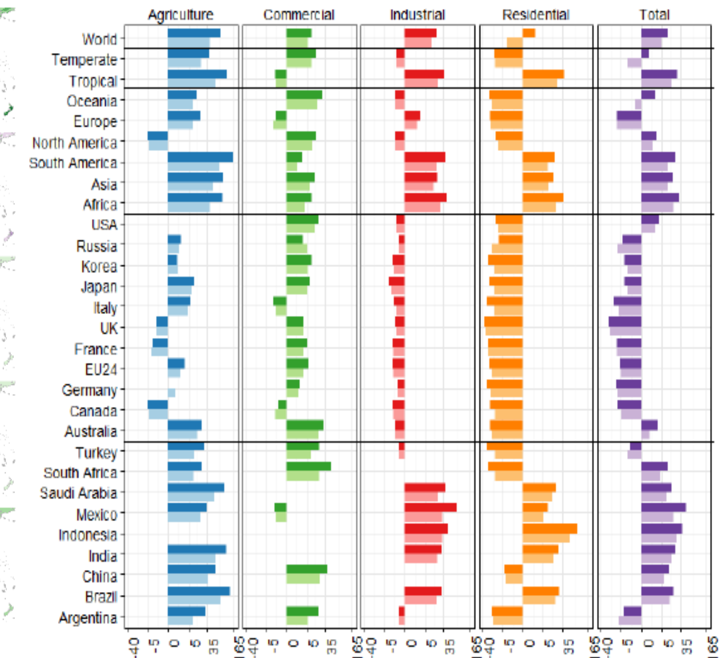


B. Change in Energy



C. Population Incidence of Energy Demand Changes





D. Change in Energy Consumption (%)

Kevin Gallagher

Professor of Global Development Policy/Research
Director, Center for Finance, Law & Policy
Frederick S. Pardee School of Global Studies

Greening the Bi-Polarization of Global Economic Governance

Boston University Office of the Vice President and Associate Provost for Research

BOSTON UNIVERSITY

Laurence Kotlikoff

William Fairfield Warren Distinguished Professor/Professor, Economics
College of Arts & Sciences

When Should I Pump?

Why the Paris Accord May Be Worse Than Nothing

Boston University Office of the Vice President and Associate Provost for Research

Henrik Selin

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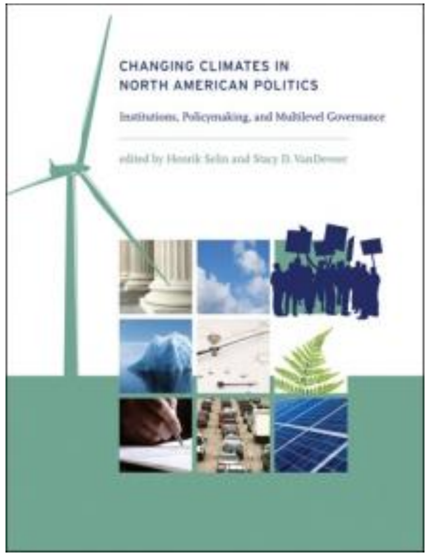
Frederick S. Pardee School of Global Studies

Governing the Environmental Impacts of Energy



Madhu Dutta-Koehler

Associate Professor of the Practice/Program Coordinator, Department of City Planning & Urban Affairs
Metropolitan College

Lucy Hutyra

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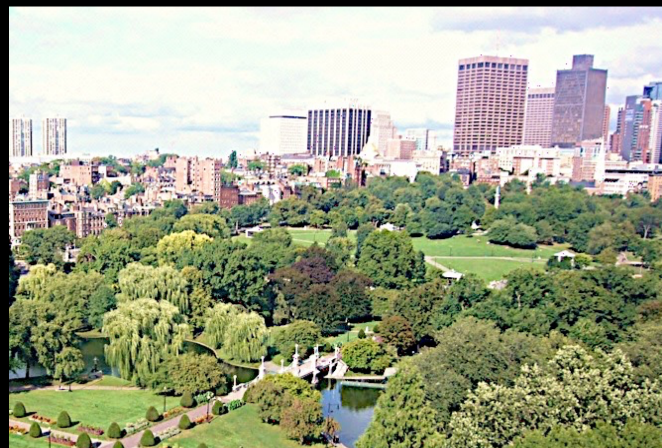
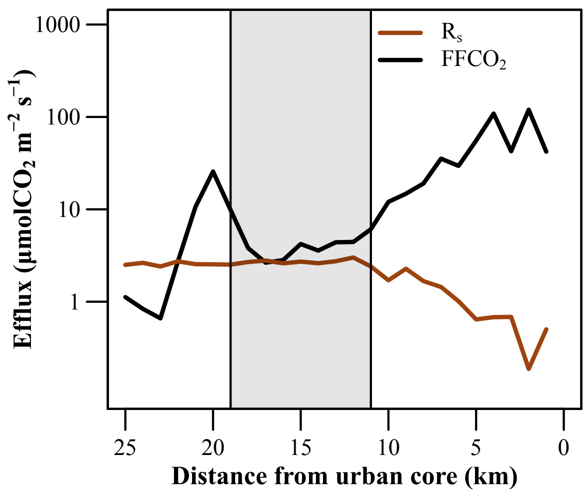
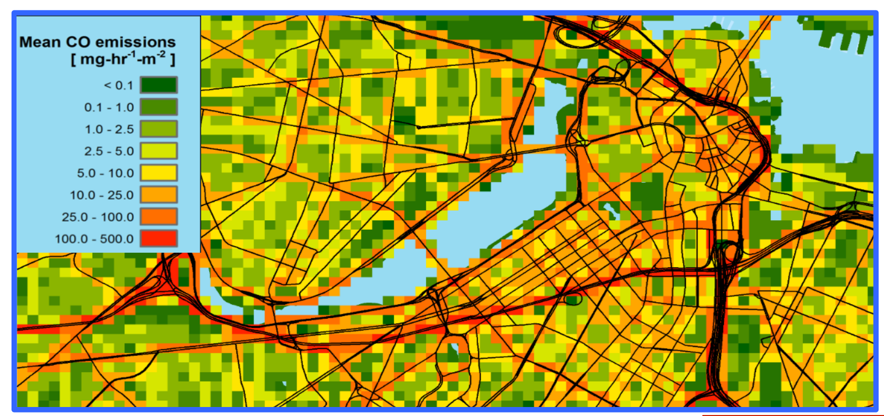
WHERE DOES THE CO_2 IN CITIES COME FROM?



- 70% of CO_2 emissions are attributable to urban areas
- New technologies to measure CO_2, but how do we attribute the sources?
- Does biology in cities contribute significantly?



Forested
Residential
Pavement dominated



Nathan Phillips

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Michael Gevelber

Associate Professor,
Department of
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Improving Performance & Sustainability of Commercial Buildings

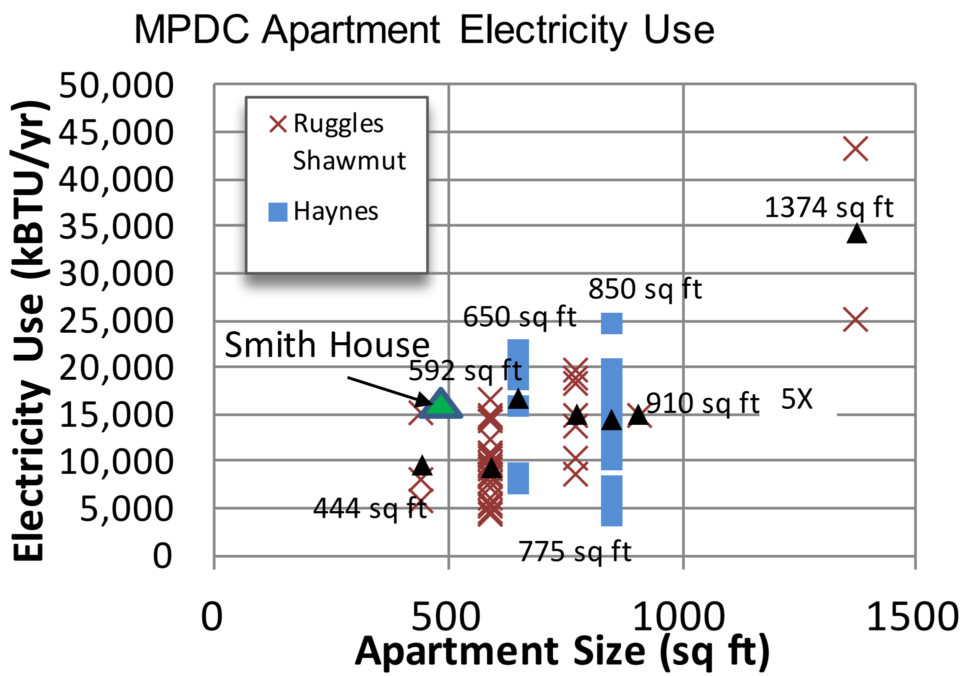
Commercial Buildings: 12% of US energy use, but 37% electricity, & 18% US carbon. **Waste: > 53%!**

Focus: HVAC → 40-60% energy use
- What drives HVAC energy use?
- New HVAC control architecture
- What drives EE decisions & action?

University as a Laboratory:
~12 million sq ft. Projects in large buildings with advanced HVAC controls as well as brownstones

Public Housing (Madison Park): are operations efficient, where invest? Role of tenants, opportunities for behavior modification?

Extension to Cities: how identify meaningful opportunities for greater EE across the city? What does BERDO data tell us & how use?

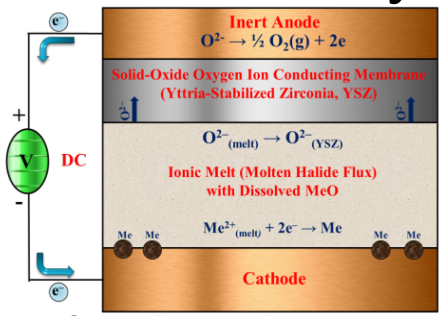


Haynes tenants pay electric bills, while RS do not! 5x variation in use

Uday Pal

Professor, Department of Materials Science & Engineering
College of Engineering

Devices and Processes for Energy and Environmental Sustainability



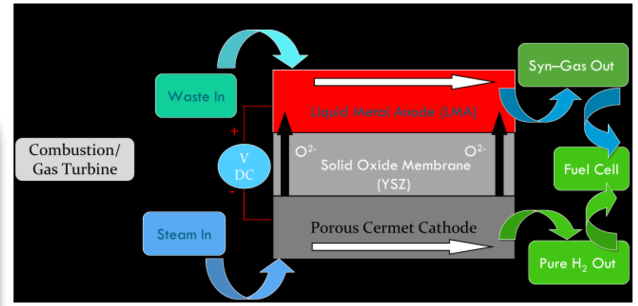
- One unit operation
- Less energy intensive
- Less capital intensive
- Zero direct carbon emission
- Oxygen byproduct
- Non consumable molten salt

Li, Mg, Ca, Ti, Ta, Al, Si, Dy, Nd, Yb

Green Production of Energy Intensive Metals (Pal, Basu, Gopalan)

Annual Energy value
40 billion gallons of gasoline

Waste to Energy Conversion (Pal, Goldfarb, Gopalan)

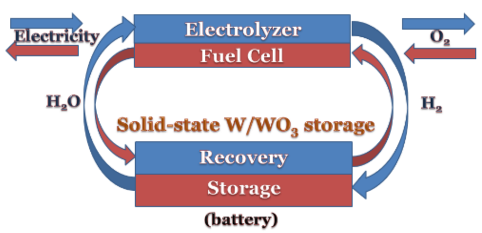


250 million tons MSW generated in 2012
54% Land-filled and 12% incinerated

Other carbon-hydrocarbon waste
(4 lb/person-day)

Solid Oxide Membrane-Based Technologies

Our Proposal: Tungsten/Tungsten Oxide Grid-Scale Energy Storage



- US Generation Capacity (1,100 GW)
- Existing Storage Capacity (22 GW)-Mostly Pumped Hydro

Value proposition

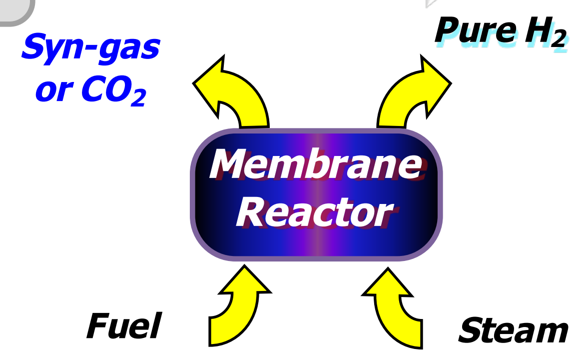
- Novel utility scale rapid response energy storage and conversion system

Energy Conversion and Storage (Gopalan, Pal, Basu, Ryan, Ludwig, Smith)

Fuel Cell and Electrolyzer

Fuel Processing and CO_2 Sequestration (Gopalan, Pal)

Approach: Water splitting combined with reformation of hydrocarbons in two physically separated chambers



- Demonstrated fast heat-up (~15 min) and extreme thermal gradients (~200C°)
- Successful demonstration of H_2 generation at 25W (0.2 l/min) output
- Results repeated after a thermal cycle

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BOSTON UNIVERSITY

Thomas Little

Professor & Associate Dean of Educational Initiatives,
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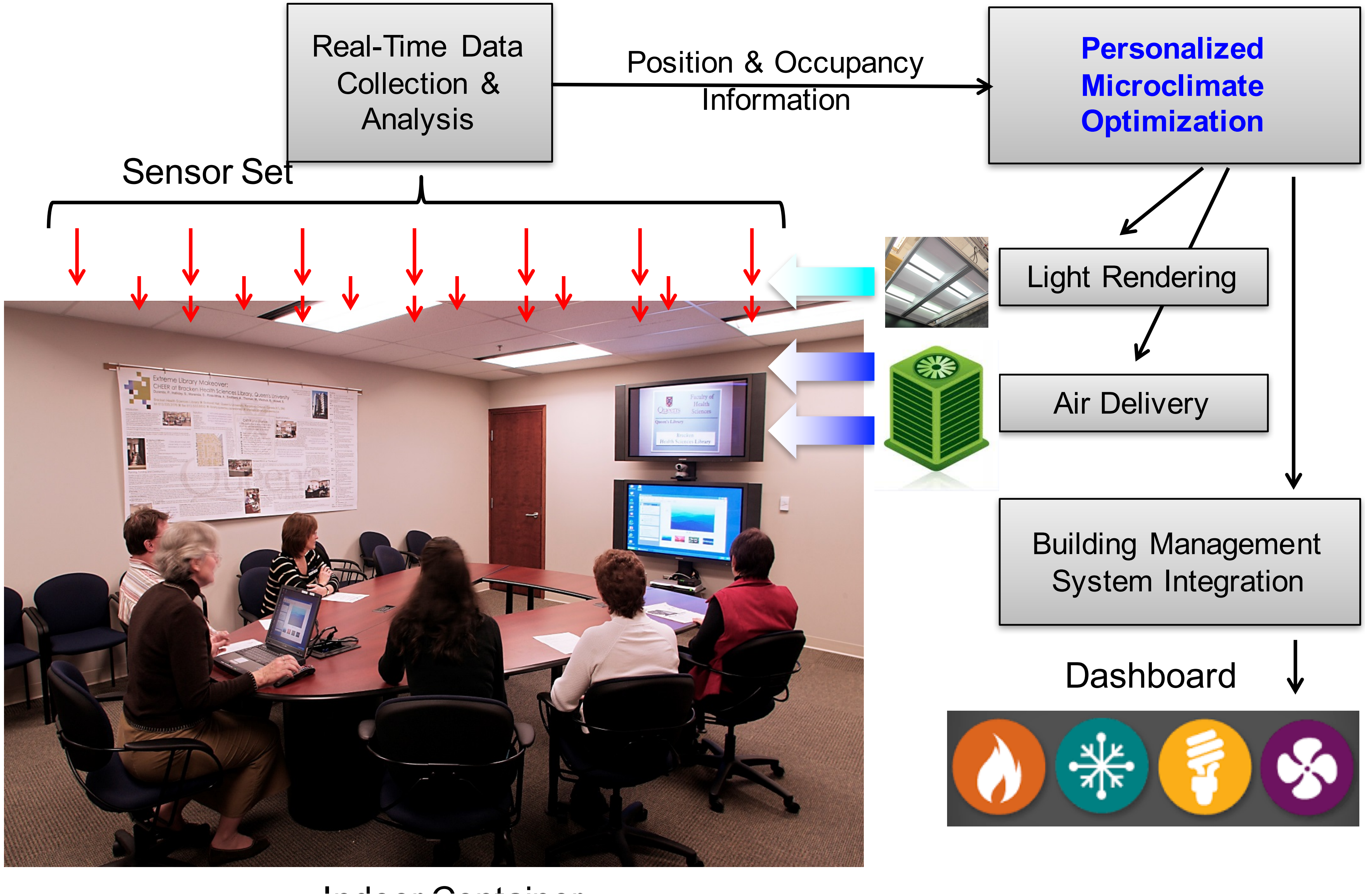
Center for Lighting Enabled Systems and Applications (LESA)



Michael Caramanis

Professor, Department of Mechanical Engineering
College of Engineering

T&D Nodal Location Marginal Cost Discovery for Efficient Demand-Side Provisioning of Reserves and Massive Renewable Generation Integration: A Distributed Computing and Communication Architecture

Research Summary

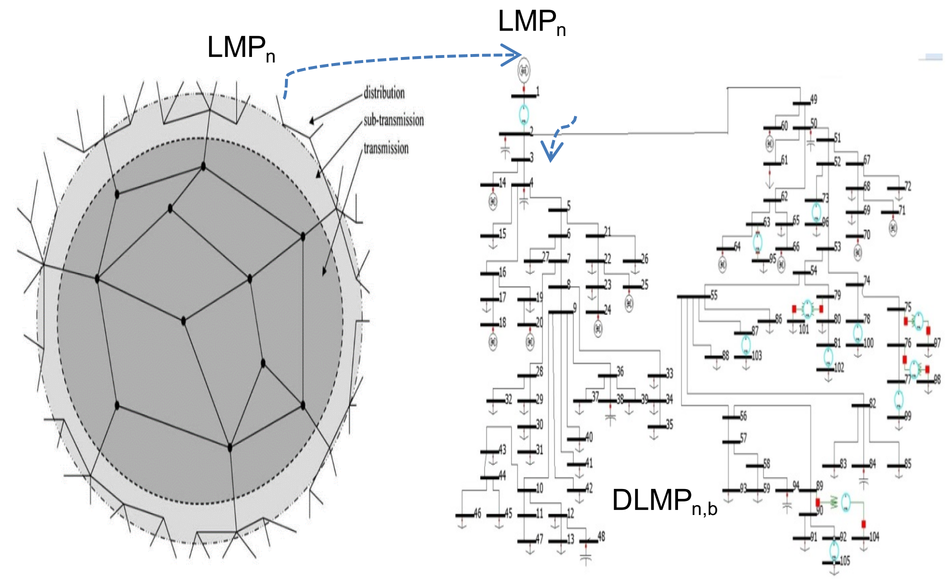
*-Synergy of Volatile Renewable Generation with Flexible Distributed Loads and DERs . Distributed MC based Prices can **Commoditize Demand Response***
*-Hundreds of thousands of **Transmission and Distribution nodes** where DERs are connected modeled in Market Layer where Prices are Cleared for Energy (real and reactive) and Reserves.*
-Deployment Layer handles actual provision of reserves.
*-**Distributed yet Collaborative architecture** based on Proximal Message Passing Algorithms allows detailed DER Preference and Capability modeling. => Customer acceptance enabled!*

Research Impact

-Transformation of Power markets
-DERs to acquire higher value/valuation and revenues
-Significant decline in T&D Utility costs
-T&D networks resilient to growth. Required Investments Delayed
-Production of DERs – including those not yet in the market -- will boom
-High Renewable Generation integration will become Sustainable.

Key Research Features/Objectives

Features	Description
Synthetic Reserves and Ancillary Services	*Non Rotating Assets Can provide Reserves and Reactive Power Compensation to Great Cost Advantage*
Managed DERs	*EV Battery Charging, HVAC and Heat Pumps with Variable Speed Drives, Data Centers, Smart PV Inverters/Converters for Volt/Var control*
Achievable Targets/Benefits	*-Provision of Regulating Reserve exceeding 5% of System Load. – Provision of Faster Reserves with Response time < 1 sec, ,+/-5% tolerance,* *-Reliability of Load side Reserve provision > 95% exceeding conventional generation reliability of 90-93%* *-Storage-like behavior with Duration 10 min to 1 hour from Duty Cycle appliances, Pre heating/pre cooling in HVAC systems*



-Transmission Networks, LMP-> Markets Since 1997
-Extension of Markets to Flexible **Distribution**/Retail Participants/**DERs** who are capable to provide **Storage like behavior** and Fast **Reserves**
-DLMP-LMP discovery possible for large real T&D networks through Dual Decomposition/Distributed Algorithms
-Costs/Congestion in Dist. Nets include: Transformer. Degradation, Voltage limits etc.
-Distributed DERs and Flexible Loads enabled to satisfy intertemporal preferences and complex individual dynamics/constraints (e.g., EV battery Electrochemistry)

Test Plan

-Realistic data on 500,000 node T&D network with several thousand Transmission nodes and several hundred feeder networks.
-Marginal Cost based prices will be simulated on T&D Market clearing distributed architecture.
-Real-time load flow impact of DER on distribution lines.
-Extensive Validation plan with hardware in the loop (100+ PV with smart inverters, Non Intrusive WattsWorth consumption monitors, CHP, DGs.

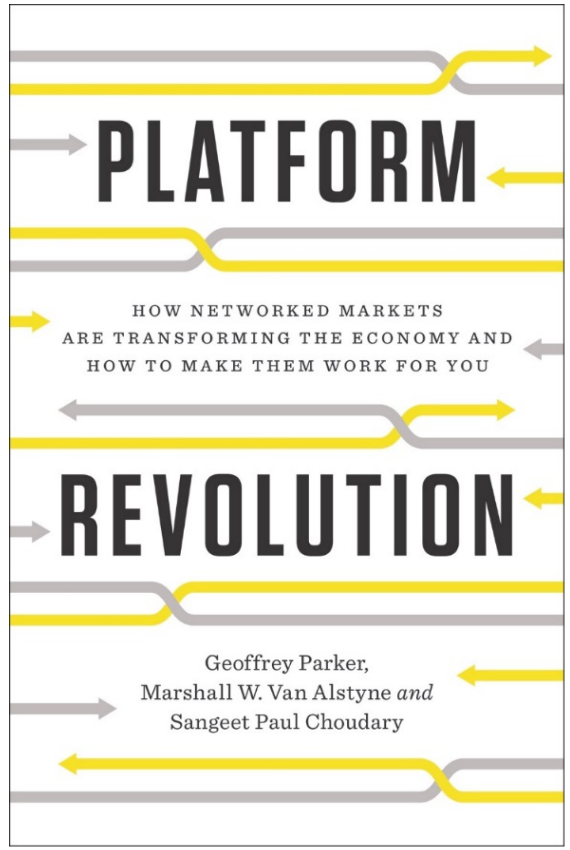
Efficient Distributed Architecture for LMPs at all Smart Grid T&D nodes => Significant Efficiency and Resilience Gains in Power Systems

Marshall Van Alstyne

Professor/Chair of IS Department/Dean's Research Fellow, Department of Information Systems
Questrom School of Business

The transition to platforms in energy is inevitable

FIRM	MARKET CAP
Apple	532
Google	488
Microsoft	402
Berkshire Hathaway	310
Exxon Mobile	308



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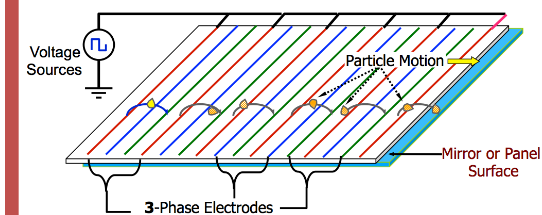
Sustainable Large-scale Solar energy Conversion by Water-free Cleaning of Solar Panels and Mirrors by Electrodynamic Screens

Problem: Dust causes major energy-yield loss and degrades the optical performance of solar panels and mirrors

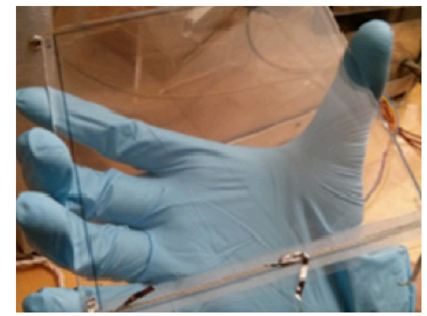
For a 0.3 GW solar plant in Southwest US, more than a million gallons of deionized water is needed per year and cleaning costs > $1M/yr

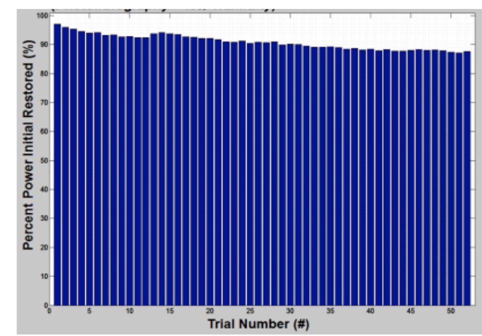
To reach 200 GW (20% of the US power consumption), the deluge water cleaning will require an unsustainable level of water consumption.

Solution: BU, in collaboration with industrial partners and Sandia National Lab, developed a transparent electrodynamic screen (EDS) as a water-free cleaning method, for removing dust, as frequently as needed, from solar collectors



Electrodynamic Screens (EDS)





Results

Research Activities: Established feasibility of the EDS film method for solar fields during 2013-2015; supported by DOE, MassCEC and Industrial Partners

2015-2018: Advancing the EDS technology for commercial production by US-based manufacturing facility for field retrofitting EDS onto solar collectors.

The projects supported graduating 2 PhDs, 6 MS/MEng, 8 BS in ECE, ME, & MSE and 1 Post Doc. Funding from DOE, MassCEC, and Industrial Partners

Kavita Ravi

Director of Strategic Analysis, Innovation and Industry Support
Massachusetts Clean Energy Center

MassCEC's Resources for Universities

Programs supporting research, commercialization and workforce development:

Academic Collaboration	Supports research and other clean energy/water efforts in Massachusetts with matching funding, letters of support, conference sponsorship, clean energy adoption and industry connections.
Catalyst	Early-stage grants for proof-of-concepts
AmplifyMass	Cost-share for Massachusetts ARPA-E awardees
Offshore Wind Research and Development	Supports offshore wind related research

Other programs support early stage clean energy companies.

Contact: Kavita Ravi, Kravi@masscec.com

Since 2015 Program Metrics

27 awards totaling $1.3M

BU received $108k

2 Non-Financial Awards

Universities Awarded in 2015

MassCEC is a publicly-funded agency dedicated to accelerating the success of clean energy technologies in Massachusetts.