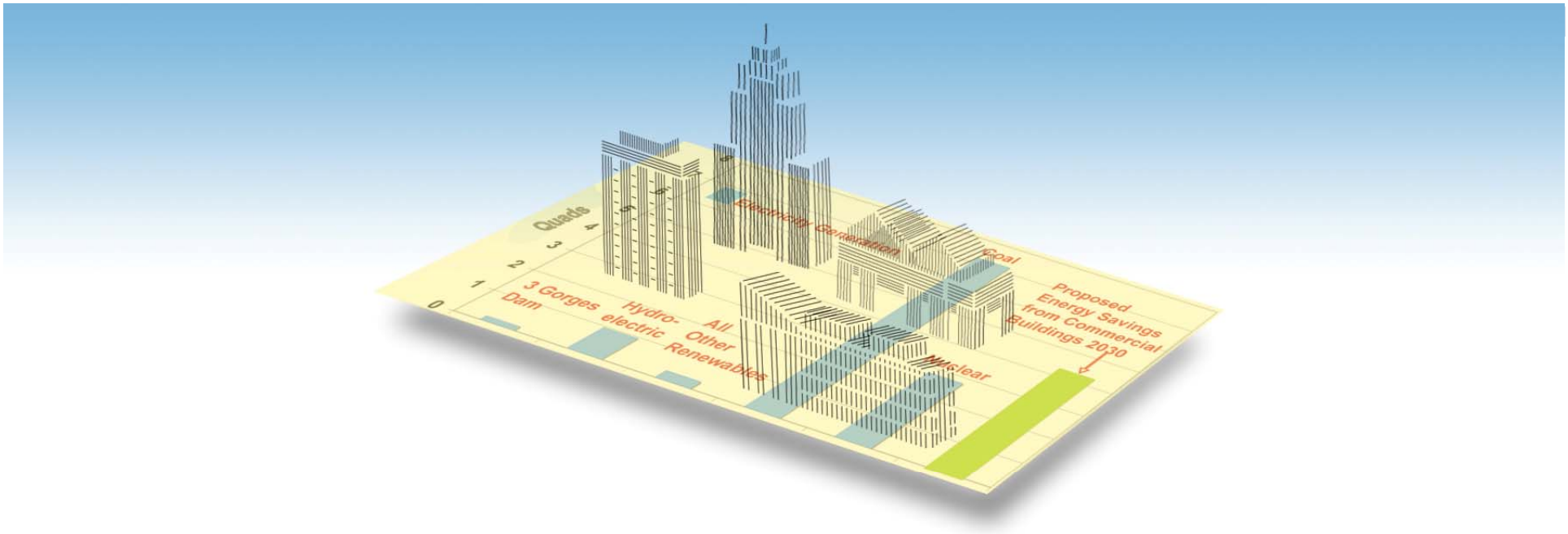
High Performance Buildings Research & Implementation Center (HiPer BRIC)



Energy Efficient Technologies

Matthew Tirrell
College of Engineering
University of California, Santa Barbara
Santa Barbara, CA 93106

December 21, 2007

UC SANTA BARBARA engineering

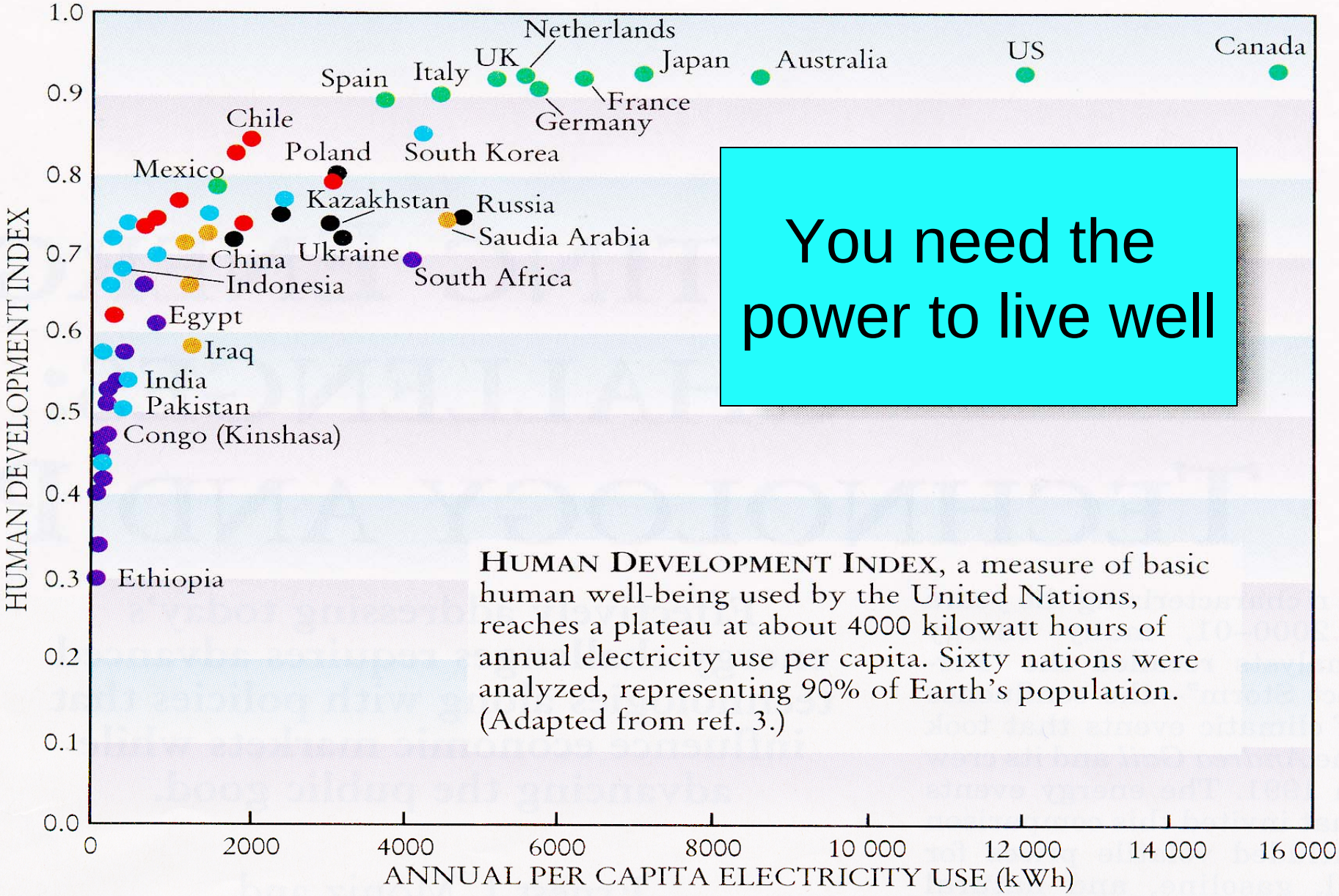
UC SANTA BARBARA
engineering and the sciences

What *distinctive* role can UC Santa Barbara play in the global approach to energy and environmental issues?

The convergence of research and innovation.

The Facts

- **Some facts are undisputed**. The energy "crisis" is more about demand than supply.
- About 80% of energy needs are now supplied by burning hydrocarbons (oil, coal and natural gas).
- Though the annual production rate of hydrocarbons may peak in the next few decades, the duration of the supply is several hundred years.
- The consequences of burning hydrocarbons are what creates the crisis.



HUMAN DEVELOPMENT INDEX, a measure of basic human well-being used by the United Nations, reaches a plateau at about 4000 kilowatt hours of annual electricity use per capita. Sixty nations were analyzed, representing 90% of Earth's population. (Adapted from ref. 3.)

You need the power to live well

UC Santa Barbara is positioned to make a powerful global impact

- UC Santa Barbara has recognized leadership in solid state lighting, energy-efficient electronics, organic photovoltaic materials, dynamical systems analyses applicable to buildings.

Building Energy Demand Challenge

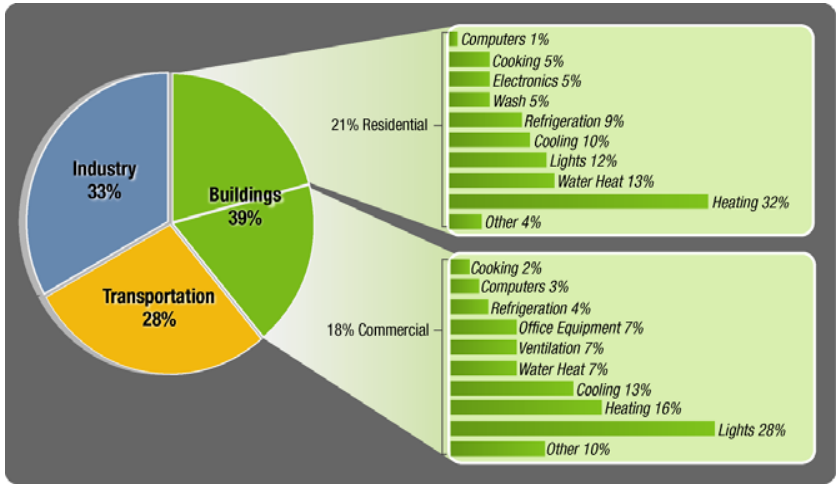
U.S. Buildings consume
- 39% of total U.S. energy
- 71% of U.S. electricity
- 54% of U.S. natural gas

U. S. Buildings produce 48% of Carbon emissions

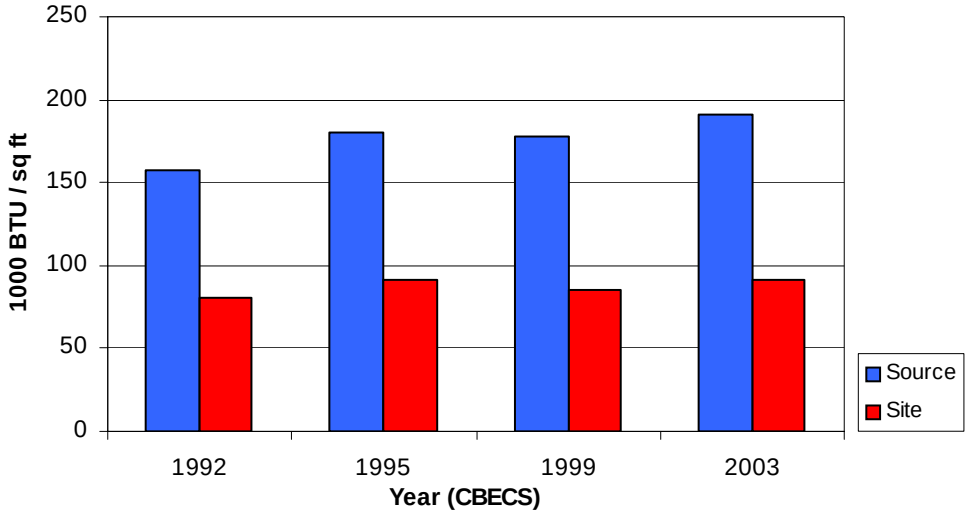
U.S. Commercial Buildings annual energy bill: $107 billion (2003)

Commercial Building Energy Intensities are increasing
- Electrical Energy consumption *doubled* in last 18 years
- 25% growth projection through 2030

Energy Breakdown by Sector



U.S. Commercial Building Energy Intensity

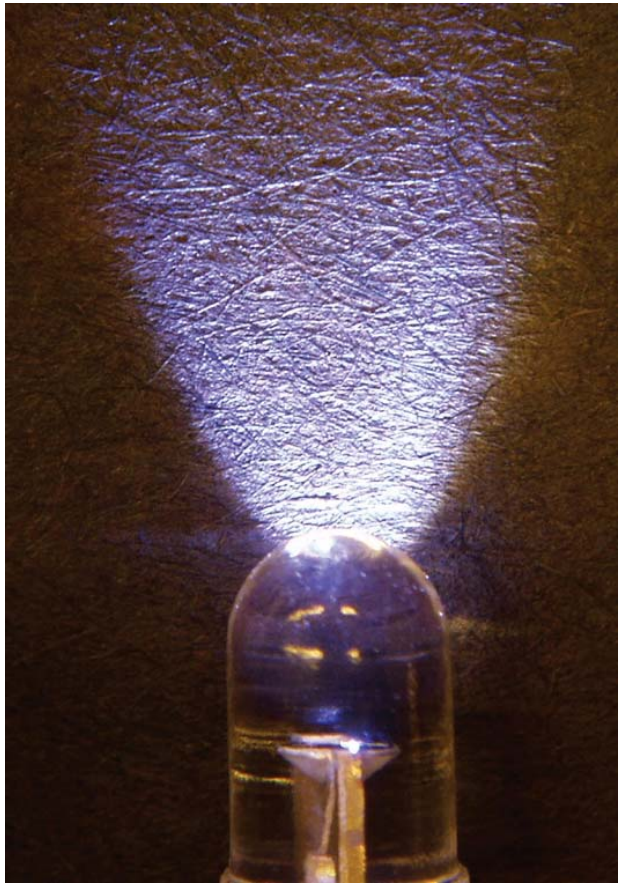


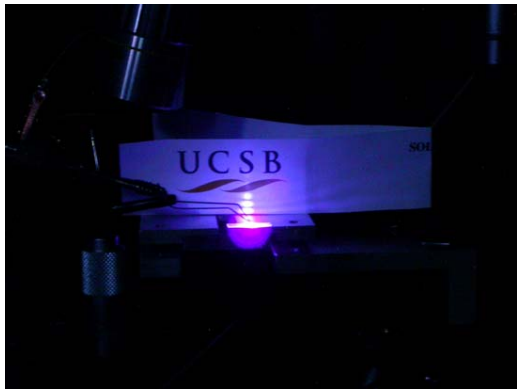
Sources: *High Performance Commercial Buildings: A Technology Roadmap*, U.S. DOE., US GBC, DOE EIA CBECS Database, Table C2A and 5B.

Solid State Lighting and Energy Center

Offers the capability to develop:

- If a 150 lumen/watt LED source were developed, then in the United States alone we would realize **$115 billion cumulative savings by 2025.**
- We would also eliminate the need for 133 new power stations, save 258 million metric tons of carbon and save 273 trillion watt-hours per year in energy.





QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

LED Focus | August 2007

Efficient Semipolar Blue LEDs Created on Freestanding Substrate

by Michael A. Greenwood

Blue LEDs with high quantum efficiency and significantly reduced polarization-related internal electric fields have been successfully fabricated on freestanding semipolar substrates by researchers at the University of California, Santa Barbara.

To improve performance, the team produced devices on recently available high-quality semipolar bulk gallium nitride substrates. The devices consisted of a 1-µm silicon-doped n-type GaN layer, a stack of six multiquantum wells with 20-nm undoped GaN barriers, and 3-nm InGaN quantum wells ending with an undoped 16-nm-thick GaN barrier and a 10-nm undoped AlGaN electron-blocking layer and a 200-nm magnesium-doped p-type GaN layer. The research team was led by Hong Zhong, Shuji Nakamura, Steven P. DenBaars and James S. Speck.

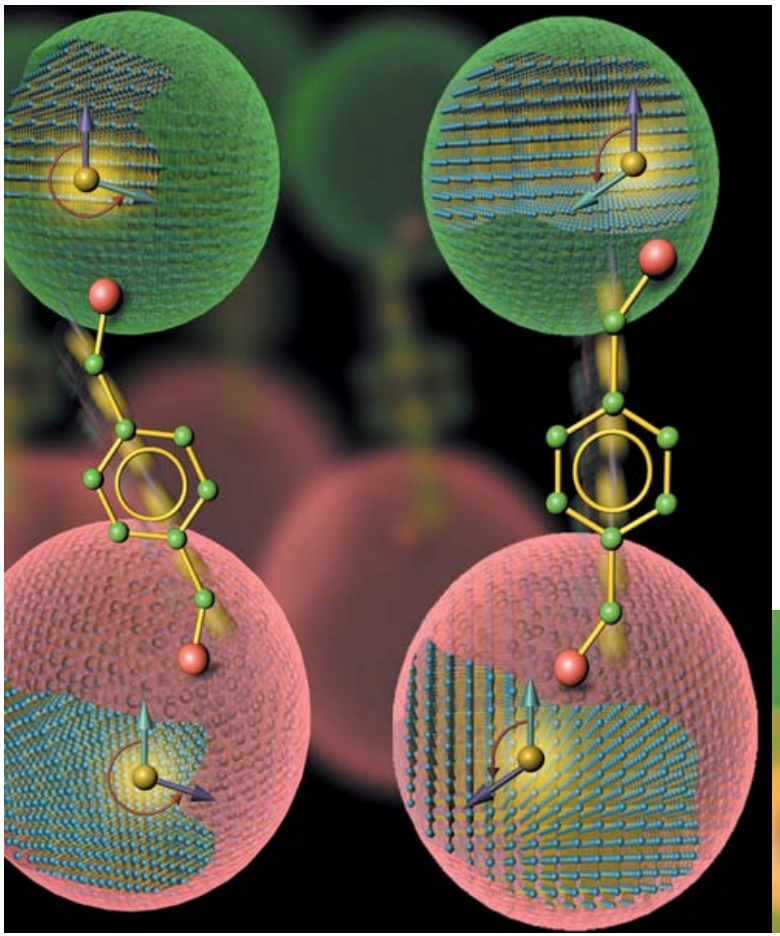
Areas of Leading Strength

- **Solid State Lighting and Energy Center**
- **Energy-Efficient Electronics**
- **Organic Photovoltaic Materials**
- **Dynamical Systems Analyses**

Energy-Efficient Electronics

(Center for Nanoscale Science in Defense; WINS; Center for Silicon Photonics; Station Q)

Exploring and developing:



- All optical circuits
- Silicon photonics
- New chip architectures, to reduce heat generation
- Spintronics and quantum computation

Areas of Leading Strength

- **Solid State Lighting and Energy Center**
- **Energy-Efficient Electronics**
- **Organic Photovoltaic Materials**
- **Dynamical Systems Analyses**

UTRC/University Projects

UTC Power
A United Technologies Company

More Electric Aircraft architecture design

Hamilton Sundstrand
A United Technologies Company

Microgrids: architecture and control

Aircraft Power Systems Control Design

Dynamics and Control

Embedded Systems and Networks

UCSB

CALTECH

Electric Power System Dynamics and Control
Future Electric Aircraft architecture design
• Architecture and Control Design for Building and Aircraft Energy Systems
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Variational Integrators for Electric Power Systems
(Dino Lelic UTRC, Houman Owhadi Caltech)

Cyber-Physical Systems

Building Airflow Dynamics and Control
• Generalized Cartesian Space Partitioning
(Nathan Hariharan UTRC, Fredric Gibou UCSB)
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•Network architectures for distributed estimation and control
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•Stability and Performance of Distributed Control over Networks
(Eelco Scholte UTRC, Joao Hespanha UCSB)

Berkeley Lab

Wireless container

First responders decision support

Building Technologies

Indoor air quality control

Evacuation support

Efficient refrigeration

UTC Fire & Security
A United Technologies Company

Contaminant estimation

Carrier
A United Technologies Company

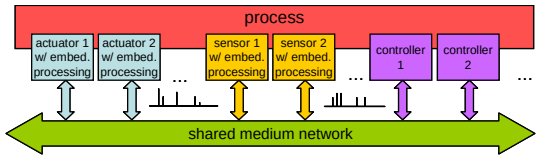
United Technologies

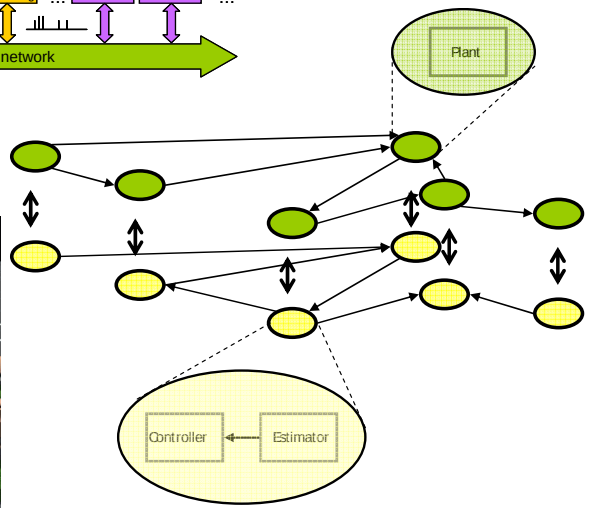
Research Center

Stability and Performance of Distributed Control over Large Networks

UC SANTA BARBARA engineering

Eelco Scholte (UTRC), Joao Hespanha (UCSB)





Objective:

- Development of network protocols and distributed control and estimation algorithms for the integrated design of high performance embedded systems.

Description:

- Application of distributed estimation in integrated buildings, as well as distributed control in aerospace systems requires the use of rigorous methods for stability, convergence and robustness guarantees.
- Application to distributed estimation of people in buildings across wireless networks.

Technical Approach:

1. Development of formal methods to model the dynamics of networks of embedded systems for control and estimation purposes.
2. Development of formal tools for the analysis and design of impulsive systems.
3. Development of high-confidence algorithms and protocols for the interconnection of sensing, actuation, and control nodes.

Impact:

- Capabilities to jointly design complex distributed control algorithms with the network will result in much more efficient and less conservative designs.
- Formal methods for design of distributed control enables guarantees with respect to stability and robustness of complex estimation and control algorithms.

References:

[1] Y. Xu. ***Communication scheduling methods for estimation over networks***. PhD Thesis, University of California, Santa Barbara, CA, USA, Mar. 2006. http://www.ece.ucsb.edu/~hespanha/published/YXu-UCSB-EE-2006-Dissertation.pdf

[2] P. Naghshtabrizi. ***Delay Impulsive Systems: A Framework For Modeling Networked Control Systems***. PhD Thesis, University of California, Santa Barbara, CA, USA, Sep. 2007. http://www.ece.ucsb.edu/~hespanha/published/PayamDissertation-Sep07.pdf

United Technologies

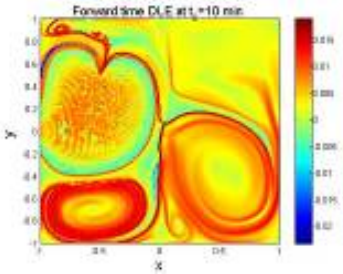
Research Center

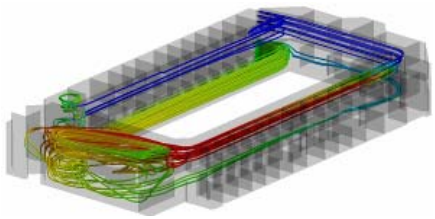
Building Airflow Transport Dynamics & Control with Lagrangian Coherent Structures

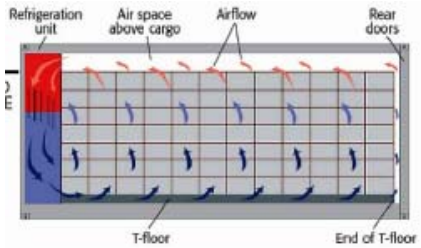
UC SANTA BARBARA engineering

CALTECH

Amit Surana (UTRC), Jeff Moehlis (UCSB), Jerry Marsden (Caltech)







Objective:

- Develop analytical tools, model reduction approaches and control strategies for building airflow and contaminant transport problems that exploit Lagrangian Coherent Structures framework.

Description:

- Spatial inhomogeneity in dynamics of mixing in enclosed spaces affects performance and controls (hence efficiency) of building systems (comfort, IAQ and safety applications)
- Lumped airflow and contaminant transport models are inadequate and CFD is not amenable to real-time monitoringn and control

Technical Approach:

1. Develop validated low order models and LCS tools for analysis and real-time estimation of airflow, particulate/gaseous and thermal patterns in enclosed spaces
2. Develop model-based centralized and distributed estimation schemes for spatioemporal flow patterns
3. Verify real-time estimators and control strategies via experiments in sub-scale testbed (e.g. LBNL, Carrier)

Impact:

- Reduced-order models enable robust performance of building systems and controls, enabling higher efficiency HVAC systems and improved emergency and fire safety systems
- Analytical tools for capturing mixing dynamics enable strategies for faster and more accurate detection of airborne threats

References:

[1] Shawn C. Shadden, Francois Lekien, and Jerrold E. Marsden . ***Definition and properties of Lagrangian coherent structures.*** ***Physica D: Nonlinear Phenomena, Volume 212, Issues 3-4, 2005, Pages 271-304***

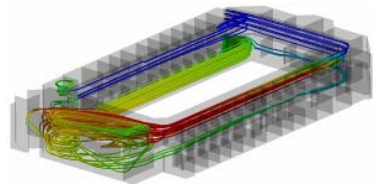
United Technologies

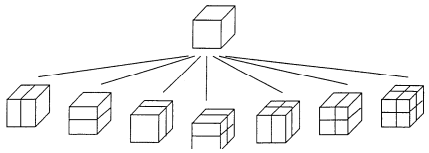
Research Center

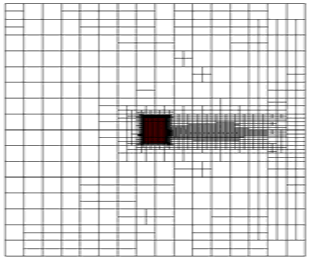
Generalized Cartesian Space Partitioning for Multi-fidelity Airflow Transport and Control

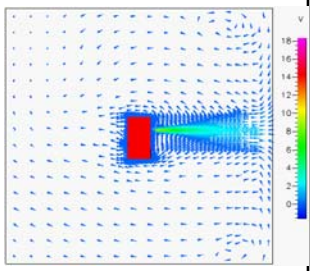
UC SANTA BARBARA engineering

Nathan Hariharan (UTRC), Frederic Gibou (UCSB)









Objective:

- Develop multi-fidelity models for predicting building airflow/contaminant transport and their control, using automated generalized Cartesian space partitioning methodology

Description:

- Spatial inhomogeneity in dynamics of mixing in enclosed spaces affects performance and controls (hence efficiency) of building systems (comfort, IAQ and safety applications)
- Lumped airflow and contaminant transport models are inadequate and CFD is not amenable to real-time monitoring and control
- An automated, unified framework of high fidelity/reduced order/lumped models is required for accurate real-time estimation

Technical Approach:

1. Develop automated octree/ADT binary tree partitioning of space to efficiently represent 1D, 2D, and 3D domains in a network of connected spaces.
2. Develop efficient, distributed computational methods to ensure fast turn around from geometry specification to flow solution (Automated Cartesian gridding from CAD designs, solution, network computation, GPU).
3. Develop mesh refinement strategies to focus on key geometric/flow features.
4. Develop Cartesian space partitioning based reduced order real-time estimation fusing model/sensor data, and optimize sensor placement.

Impact:

- Combined high fidelity/reduced order/network model in a single framework to enable robust performance of building systems and controls, enabling higher efficiency HVAC systems and improved emergency and fire safety systems
- Accurate prediction of airborne threat transport over large connected spaces will enable optimal deployment of expensive sensors
- Analytical tools for capturing mixing dynamics enable strategies for faster and more accurate detection of airborne threats

References:

[1] Hariharan, N., Wang, Z.J., “An Automated Viscous Unstructured Adaptive Cartesian Grid Generation for Complex Geometries,” Final Report for SBIR Phase-II Contract No: N68335 98 C 0233, Naval Air Systems Command, Patuxent River, MD-20670, December 2000.

[2] Aftosmis, M.J., Berger, M.J. and Melton, J.E., "Robust and Efficient Cartesian Mesh Generation for Component–Based Geometry," AIAA Paper No. 97–0196, 1997.

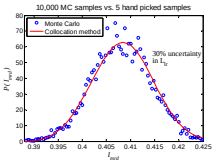
[3] Losasso, F., Gibou, F. Fedkiw, R, “Simulating Water and Smoke with an Octree Data Structure,” ACM SIGGRAPH 2004, Los Angeles, CA, pages 457-462

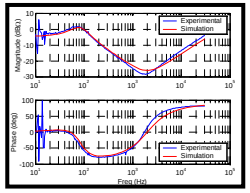
United Technologies Research Center

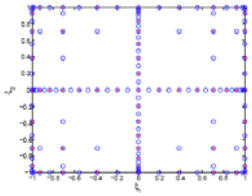
Electric Power System Robust Design and Control

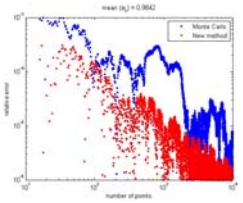
UC SANTA BARBARA engineering

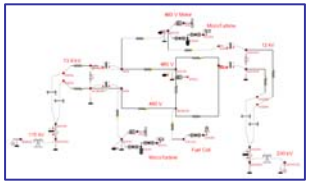
Dino Lelic (UTRC), Mustafa Khammash (UCSB), Joao Hespanha (UCSB)

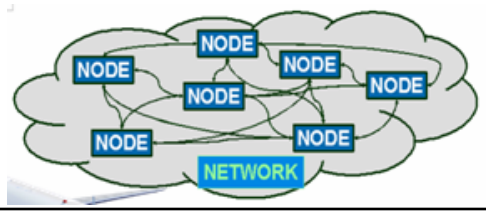












Objective:

- Develop analytical tools, model reduction approaches and robust control strategies for aircraft electric power system.
- Develop tools for analysis and robust design of an electric micro-grid

Description:

- Future more electric aircrafts will have reconfigurable network structure with multiple generators and variable loads. Existing analytical tools are inadequate to capture the complex dynamics to obtain robust design of such systems.
- Analytical tools for integration of variety of power sources on micro-grids in buildings (fuel cells, CHP, small generators) with dynamic load demand and external power grid do not exist

Technical Approach:

1. Develop validated low order models and tools for robust analysis and real-time estimation of power flow, interaction of critical components (generators, loads in various operating conditions with unceratain parameters.
2. Characterize component uncertainty and map the effect of uncertainty to stability margin range
3. Identify critical key parameters and their impact on system stability and develop the tools for robust stability with uncertainty

Impact:

- Improved power system stability, maintainability, reliability/redundancy, efficiency power availability.
- Improved power management, utility and reduced power extraction (resulting in reduced weight/volume)
- Reduced operating (life cycle) cost with positive enviromnetal impact (less emissions and noise)

References:

[1] C. Zhu, M. Khammash, V. Vittal., and W. Qiu, ***Robust Power System Stabilizer design using H_inf Loop Shaping Approach. IEEE Trans. Power Systems, Vol. 18, No. 12, 2003, Pages 810-818***

[2] W. Qiu, V. Vittal, and M. Khammash, ***Decentralized Power System Stabilizer Design Using Linear Varying Parameter Approach, IEEE Trans. Power Systems, 2004, Vol. 19, No. 4, Pages 1951-1960***

[3] P. Prempraneerach, F.S. Hover, M.S. Triantafyllou, C. Chryssostomidis, and G.E. Karniadakis, ***Stochastic Sensitivity Methods and Application to the Shipboard Power System, 2007, IEEE Trans Power Systems (in print)***

UTRC/University Projects

More Electric Aircraft architecture design

Microgrids: architecture and control

Aircraft Power Systems Control Design

Dynamics and Control

Embedded Systems and Networks

Electric Power System Dynamics and Control
Future Electric Aircraft architecture design
• Architecture and Control Design for Building and Aircraft Energy Systems
(Dino Lelic UTRC, Mustafa Khammash UCSB)
• Networked Embedded Controls and Communications for Electric Aircraft
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•Stability and Performance of Distributed Control over Networks
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Wireless container

First responders decision support

Building Technologies

Indoor air quality control

Evacuation support

Efficient refrigeration

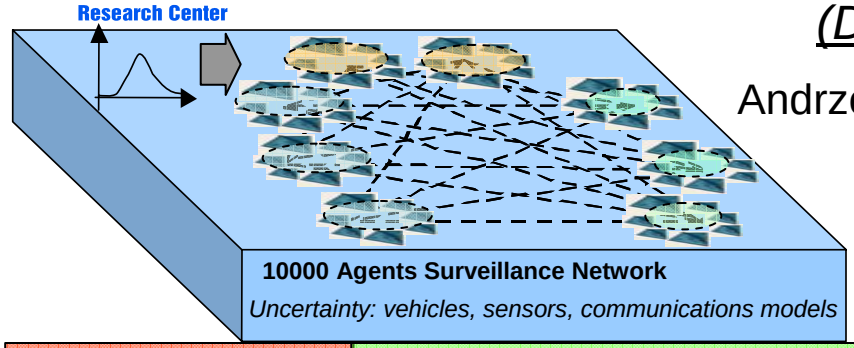
Contaminant estimation

Dynamic Network Analysis for Robust Uncertainty Management

(DYNARUM)

Andrzej Banaszuk (UTRC), Igor Mezic (UCSB)

12.5 mil in DARPA funding

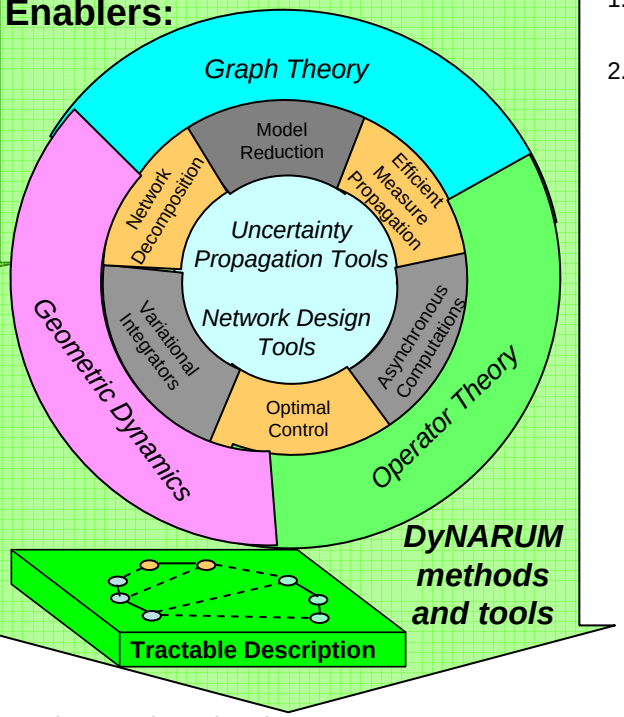


Barriers

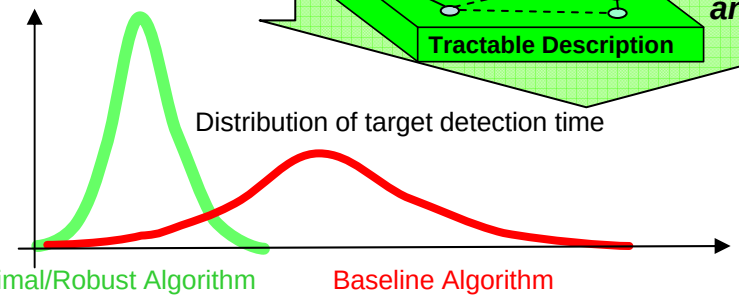
- **Large Scale**
- **Multiscale**
- **Uncertainty**
- **Nontrivial Dynamics**

Uncertainty Propagation Intractable With Current Methods

Enablers:



DyNARUM methods and tools



DyNARUM program objectives:

1. Develop analysis and design tools for Uncertainty Management in large Dynamical Systems
2. Demonstrate tools in a surveillance problem with > 10,000 agents

Program metrics in terms of detection time distribution

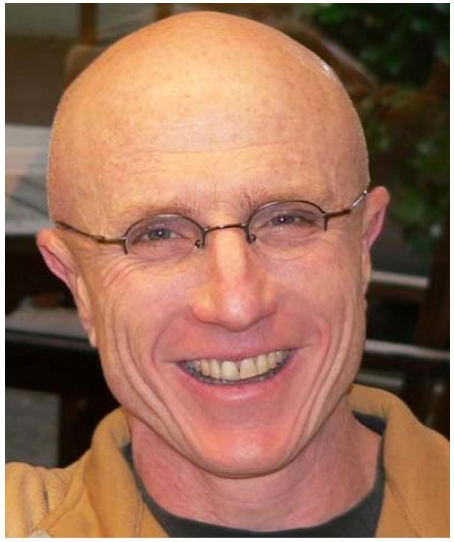
	Reduce computation time	Reduce average	Reduce standard deviation
Phase 1	10x + validation on linear problem with Gaussian inputs	-	-
Phase 2	100x + validation on linear problem with non-Gaussian inputs	10x	-
Phase 3	100x + validation on nonlinear surveillance problem	100x	10x

DyNARUM Team

A World Gone Green

"KPCB has been scouring the globe looking for promising energy innovation projects. By and large we have seen a number of impressive generation and storage projects, but few on the demand side. The demand side, as you allude to in your description, offers huge challenges of scale that cannot be addressed by the supply side alone.

"UCSB has the opportunity to put a stake in the ground on the demand side and to promote the invention of efficient energy technologies in a more concerted way. Given that many of the solutions involve system overhauls, USCB's interdisciplinary approach to addressing basic research promises further innovation dividends." **Randy Komisar,** *personal communication*

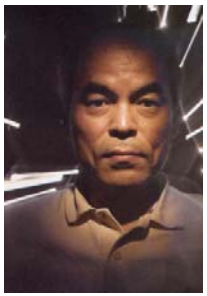


Kleiner Perkins partner: Randy Komisar

Member, UC Santa Barbara, COE International Advisory Board

Proven Track Record

- We are uniquely able to make a significant impact in increasing global energy efficiency with several well-developed programs and centers on our campus with the necessary talent and track records.



Shuji Nakamura
Working in obscurity, a researcher creates the ultra-high-efficiency descendants of Edison's incandescent lightbulb

"The world is a brighter place because Shuji Nakamura is not easily discouraged." *Time*

UC Santa Barbara
Engineering
THANK YOU!