Creating a Digital Twin of an Electric Utility

Reimagining building energy modeling in a world of high performance computing, big data, imagery, and advanced metering infrastructure

Presented at:

Argonne National Laboratory

Chicago, IL

Presented by:

Joshua New, Ph.D., C.E.M., PMP, CMVP
Building Technologies Research & Integration Center
Subprogram Manager, Software Tools & Models
Oak Ridge National Laboratory

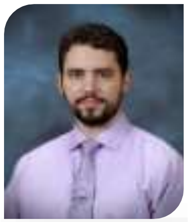
September 25, 2018

OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

Overview

- Jim Ingraham's vision for Utilities of the Future
- Introduction and Context
- 2 Nation-Scale Use Cases
  - Climate zone assessment
  - GEB market creation
- Urban-Scale modeling
  - Automatic Building detection and Energy Model creation (AutoBEM)
- Virtual EPB project (Electric Power Board of Chattanooga, TN)
  - Utility-prioritized use cases
  - Developed capabilities
  - Preliminary results

Virtual EPB – bios

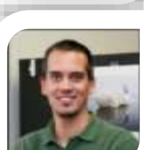


- Joshua New, Ph.D., C.E.M., PMP, CMVP
  - BTRIC "Software Tools & Models" responsible for development of DOE's building simulation tools, HPC, and AI for big data mining.
  - Led 62 projects (9.4/year) totaling \$10M/\$28M (\$1.3M/yr)
    - 133/133 deliverables (44/yr) on-time and on-budget; 100+ publications (13.8/yr)

- James (Jim) Ingraham, B.S. Finance
  - EPB, VP of Strategic Research; electric utility and broadband communications; market research and data modeling

- William (Bill) Copeland, B.S. Economics, MBA
  - EPB, Director of Business Intelligence, EPB business systems, visual analytics

- Hsiuhan (Lexie) Yang, Ph.D. Civil Engineering
  - Computer vision specializing in aerial imagery
  - Machine learning for large data: NASA, AIST, NSF, DOE



- Mark Adams, M.S. Ag&Bio, Mechanical Engineering
  - Building simulation expert, EnergyPlus/OpenStudio developer

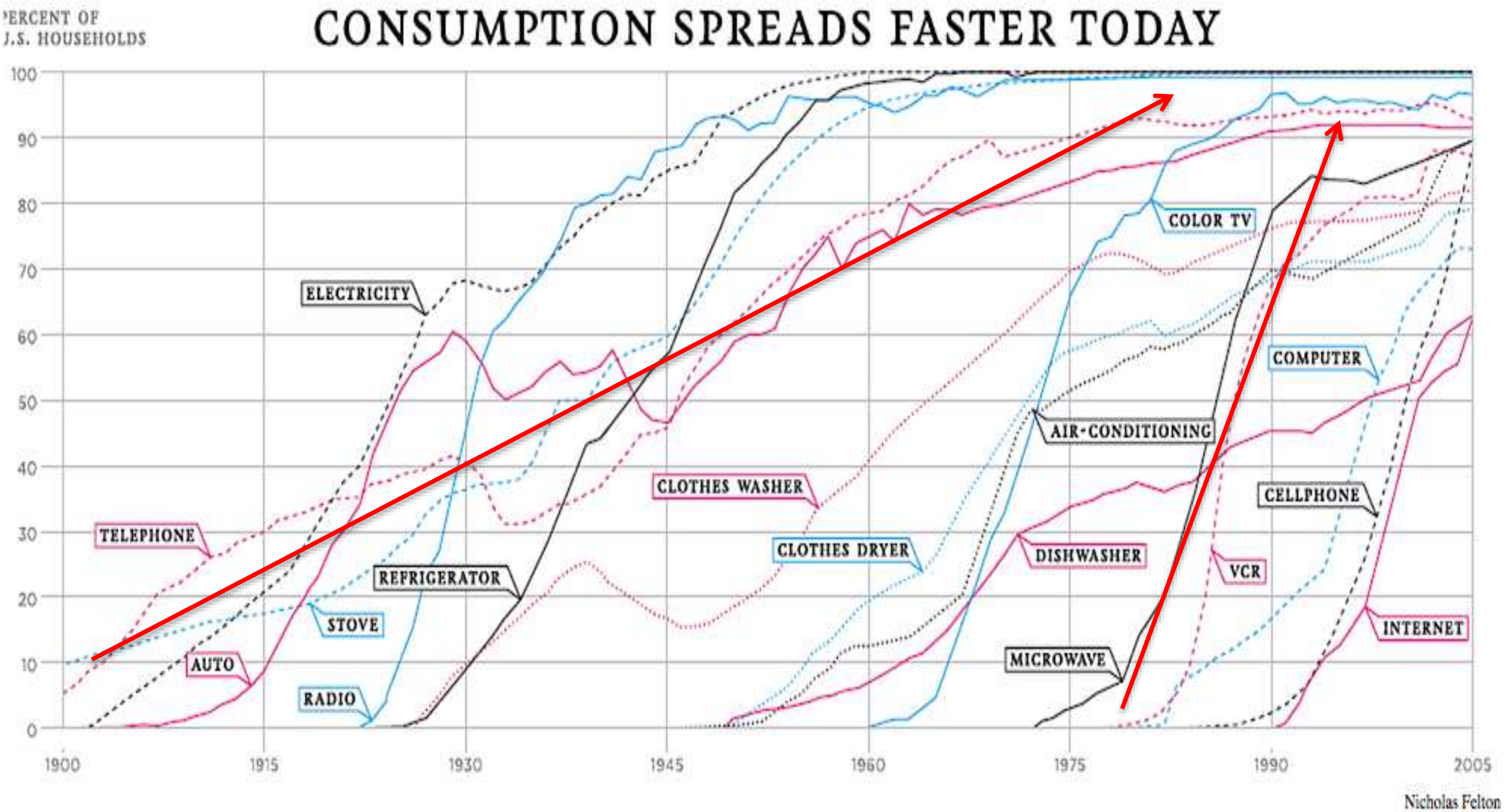
Strategic Research

AUTOBEM: New Age Energy Security You Can Trust

Jim Ingraham: EPB Vice President Strategic Research

A 21st Century Crossroads

Technology Adoption Rates Accelerate



Strategic Research

Wireless Broadband IoT Age Is Upon Us

Papal Conclave 2005

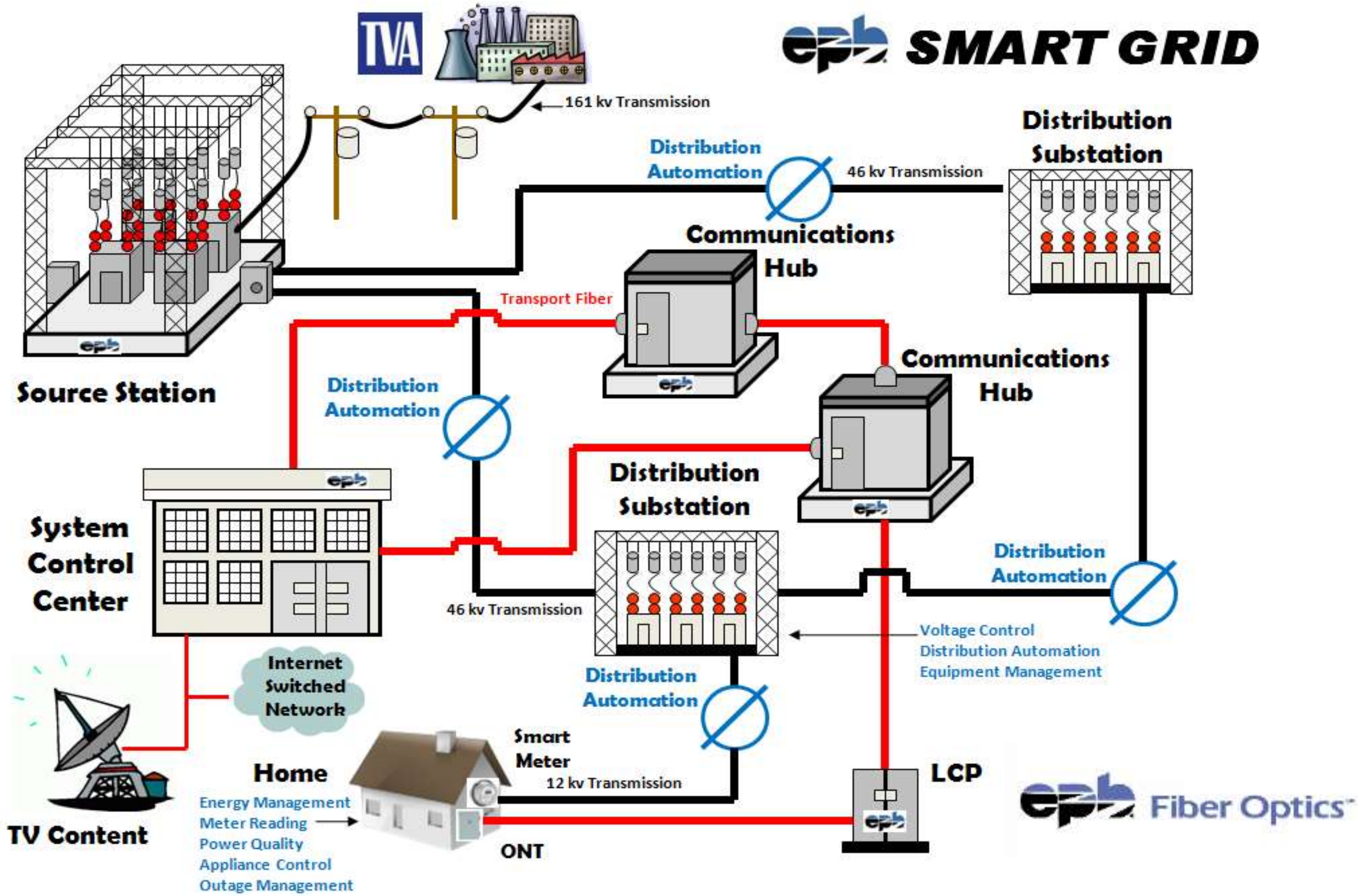
Strategic Research

Gigabit Speed Wireless Broadband Coming Soon in 2018-2019

Papal Conclave 2013

epb Strategic Research

ENERGY and INTERNET NETWORKS



A New Generation of Smart Energy Appliances

Strategic Research

2011

$250
Artificial Intelligence

2015

$5000
5KWh

Commercial Customer Net-Zero That Works

Strategic Research

OATI Microgrid Technology Center

Residential Customer November 2016 Surprise

Why Tesla's new solar roof tiles and home battery are such a big deal

New Residential Customers Rising

The The Fortune 500 Is All In - Customer Demand

CORPORATE RENEWABLE ENERGY BUYERS' PRINCIPLES:
INCREASING ACCESS TO RENEWABLE ENERGY

65 COMPANIES

48 MILLION MWH OF DEMAND FOR RENEWABLE ENERGY

$5 TRILLION IN MARKET CAP

Bloomberg, BD, Sprint, ebay, VOLVO, Etsy, Microsoft, AMD, PEPSICO, Facebook, 3M, ARUP, Hewlett Packard Enterprise, adidas GROUP, P&G, LinkedIn, EQUINIX, Saunders Hotel Group, novo nordisk, Adobe, DIGITAL REALTY, STAPLES, Walmart, intuit, HILTON WORLDWIDE, Gap Inc., TD Bank America's Most Convenient Bank, MARS, REI, Johnson & Johnson, IKEA, YAHOO!, McDonald's, DUPONT, LOCKHEED MARTIN, IRON MOUNTAIN, KAISER PERMANENTE, Unilever, AUTODESK, io, GM, TARGET, starwood Hotels and Resorts, amazon, vf, COX ENTERPRISES, Marriott INTERNATIONAL, Google, Starbucks, workday, Kellogg's, intel, Genentech A Member of the Roche Group, Sealed Air Re-imagine, vmware, Symantec, AVERY DENNISON, EMC², cisco, salesforce, Nestlé Good Food, Good Life, ADITYA BIRLA NOVELIS, switch, Akamai FASTER FORWARD, hp

WWF | RENEWABLE ENERGY BUYERS' PRINCIPLES | WORLD RESOURCES INSTITUTE

www.buyersprinciples.org

Strategic Research

Some Partner With The Electric Company

amazon

Dominion Energy

Strategic Research

Some Do It On Their Own

SIGNAL ENERGY
CONSTRUCTORS

WE HARNESS CREATIVE ENERGY

Strategic Research

Or Hire An Energy Service Company

TENASKA®

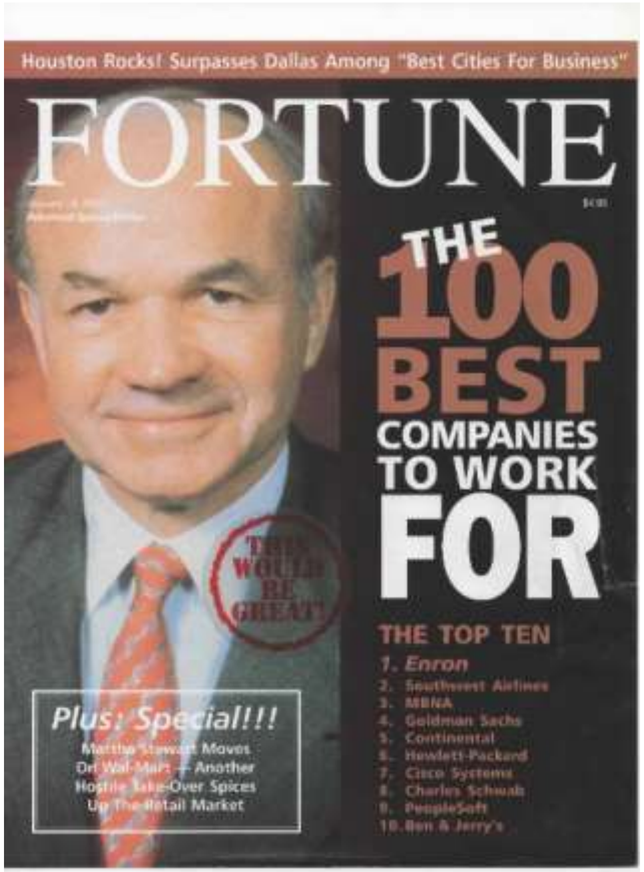
CAESARS ENTERTAINMENT®

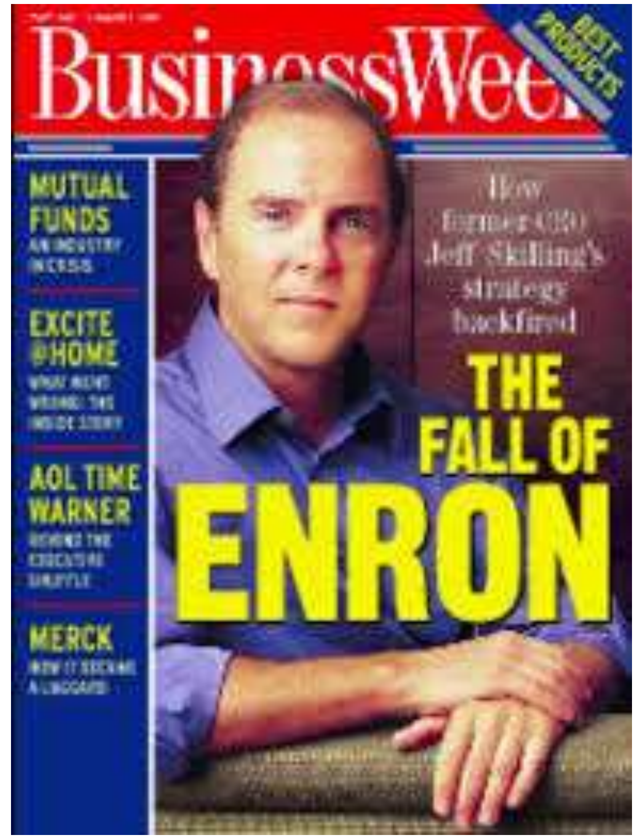
MANDALAY BAY®
RESORT AND CASINO, LAS VEGAS

An MGM Resorts Luxury Destination

MGM GRAND
LAS VEGAS

Energy Service Smoke And Mirrors Are Back





Who Can You Trust? DOE BTO AUTOBEM Can Be an Answer

Who Will Die

Kodak

BlackBerry

TOWER RECORDS

BORDERS®

circuit city®

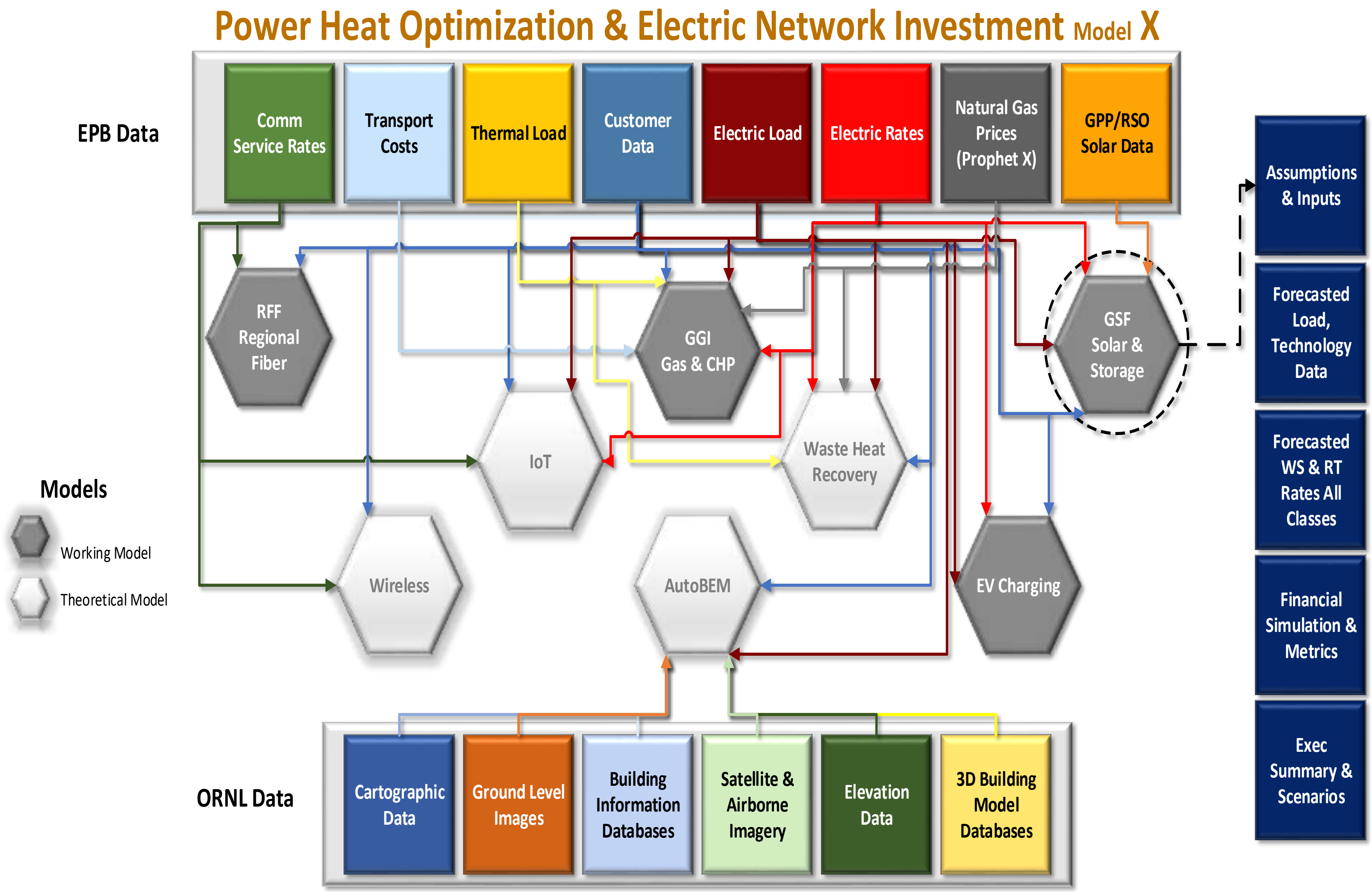
BLOCKBUSTER VIDEO

SEARS

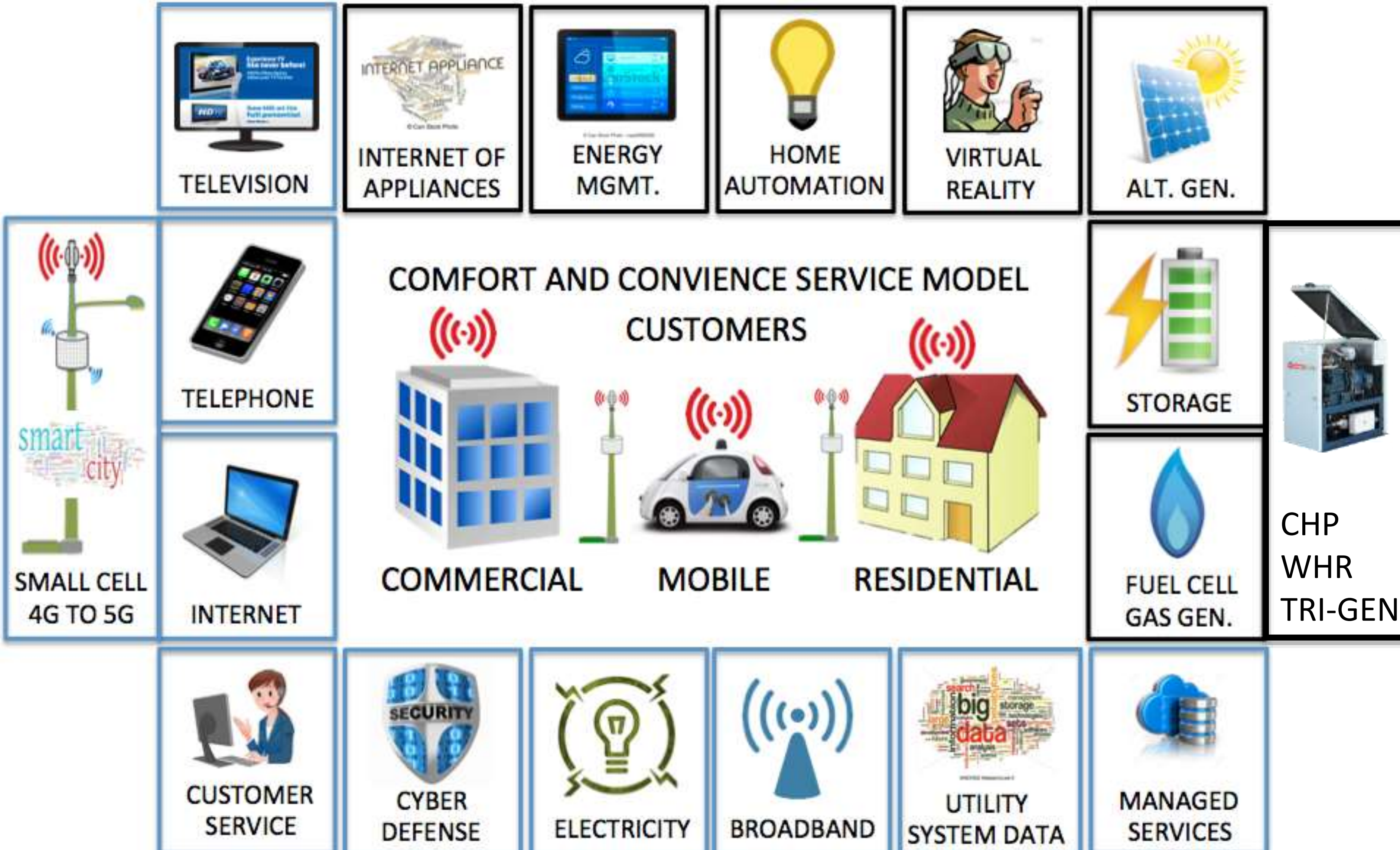
macy's

AUTOBEM Integrated With EPB Appliance Models

Strategic Research



THE UTILITY OF THE FUTURE AT THE CUSTOMER PREMISE

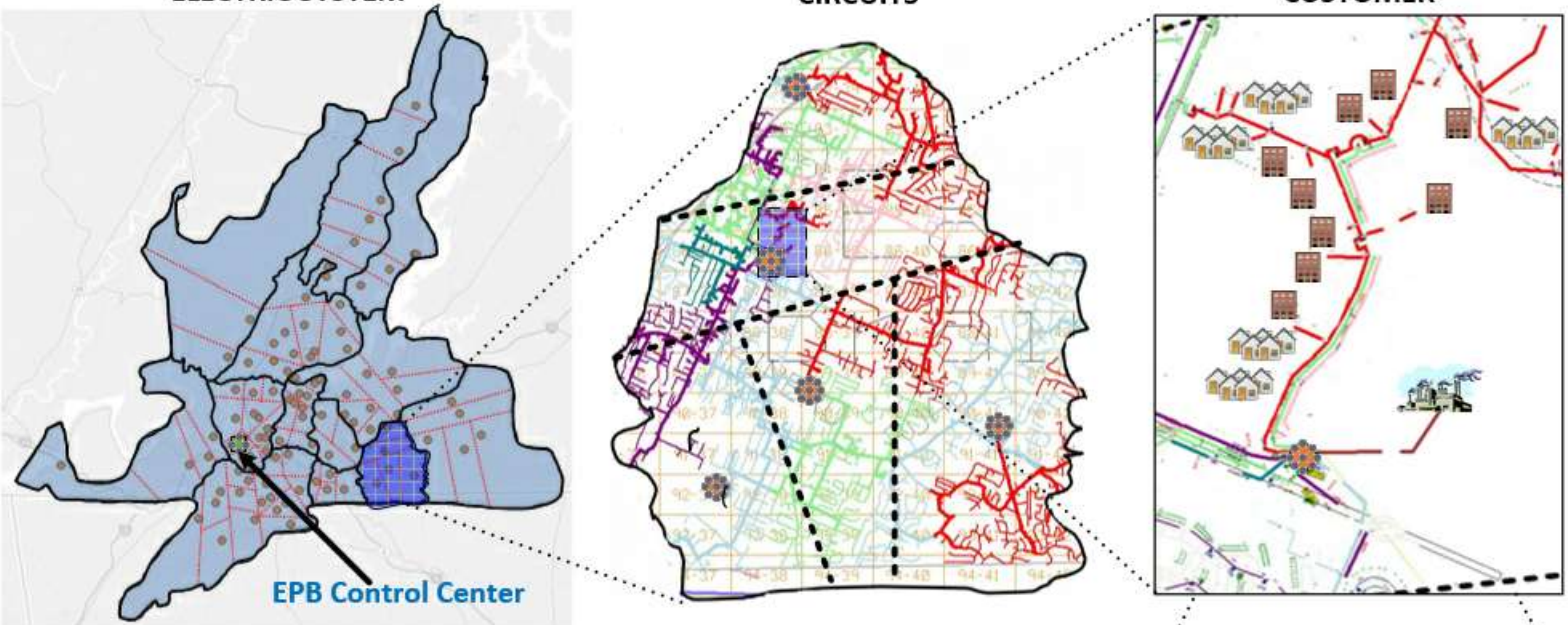


Strategic Research

Control and Manage Load Factor Is The Key

AUTOBEM = MANAGE LOAD FACTOR

ELECTRIC SYSTEM | CIRCUITS | CUSTOMER



111 SUBSTATIONS
336 FEEDERS
166,000 BUILDINGS

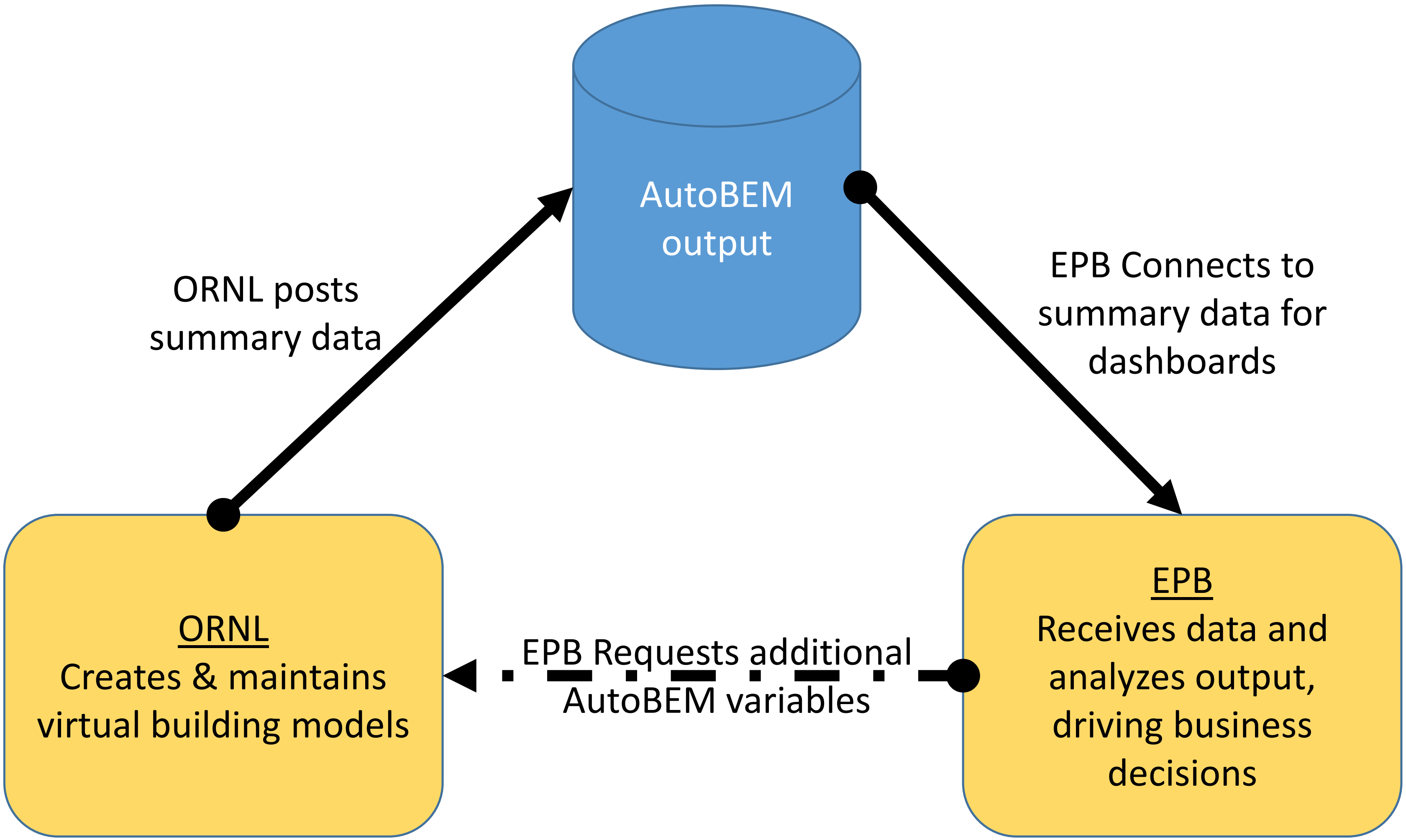
MICROGRID
UTILITY SCALE
GENERATION/STORAGE/
ENERGY EFFICIENCY

Strategic Research

DARPA’S INTERNET CHANGED THE WORLD

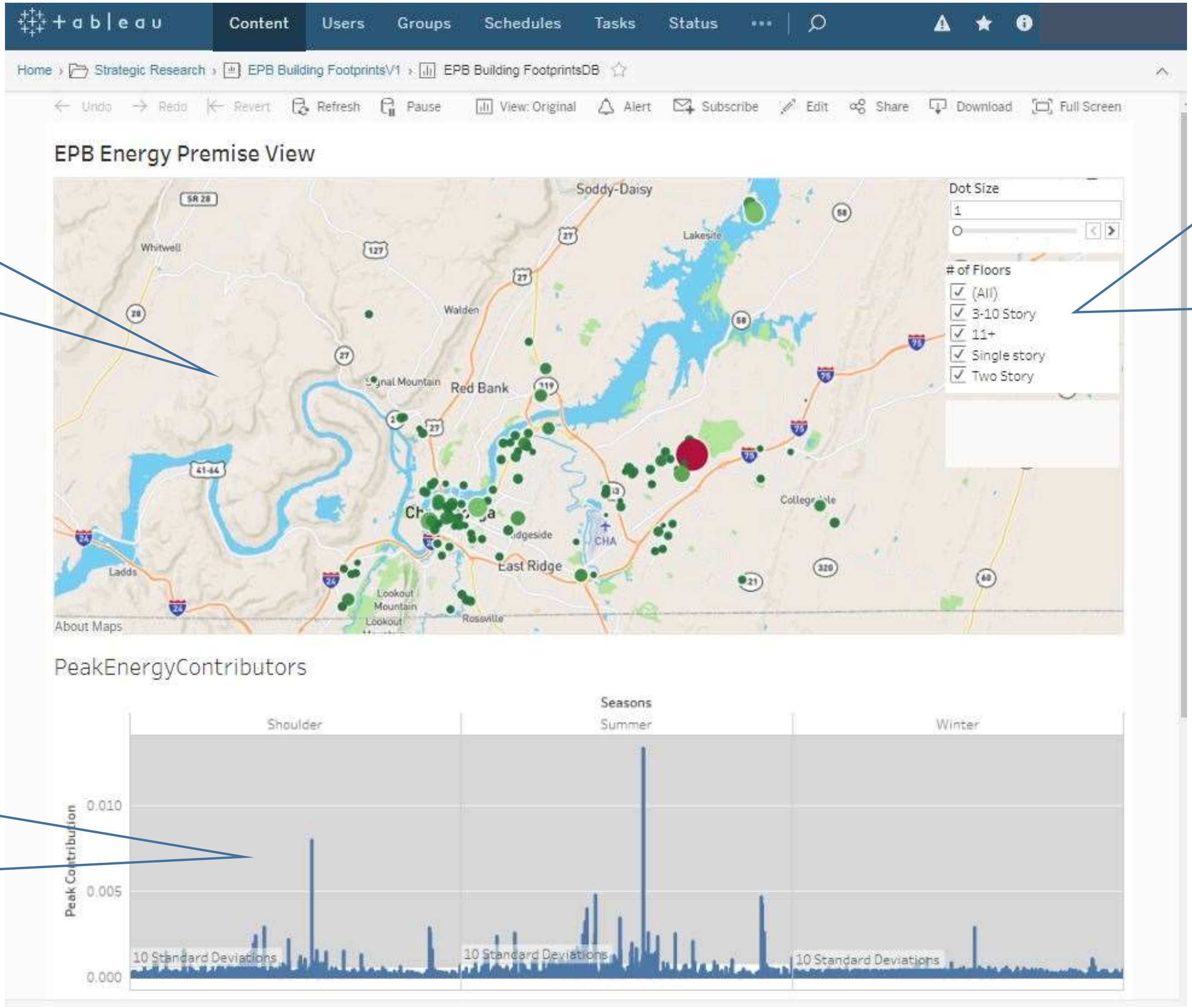
AUTOBEM COULD BE THE NEXT GAME CHANGER

ORNL/EPB Coordination



EPB’s operational systems

Map showing premises, colored by AutoBEM attribute



Use of filters create an interactive experience for business users, driving business decisions

Chart showing same data, in time series format

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Joshua New, Ph.D., C.E.M., PMP, CMVP

- **Career**
  - 2009+ Oak Ridge National Laboratory, R&D staff
    - ETSD, Building Technology Research & Integration Center (BTRIC), Building Envelope & Urban Systems Research Group (BEUSR)
    - Urban Dynamics Institute, Resiliency Team member
  - 2012+ The University of Tennessee, Joint Faculty
- **Education**
  - The University of TN, (2004-2009), Knoxville; Ph.D. Comp. Sci.
  - Jacksonville State University, AL (1997-2001, 2001-2004)
    M.S. Systems&Software Design, double-B.S. Computer Science and Mathematics, Physics minor
- **Professional Involvement**
  - IEEE, Senior Member
  - ASHRAE, defines international building codes
    - TC1.5, Computer Applications, Voting member and officer
    - TC4.2, Climatic Information, Voting member and officer
    - SSPC169, Weather Data for Building Design Standards (24% of page count of building code), Voting member
    - TC4.7, Energy Calculations, Voting member and officer
    - SSPC140 and ASHRAE Guideline 14 involvement

Certifications

- AEE, Lifetime Member
  - Certified Energy Manager
  - Certified Measurement & Verification Professional
- PMI, Member
  - Project Management Professional

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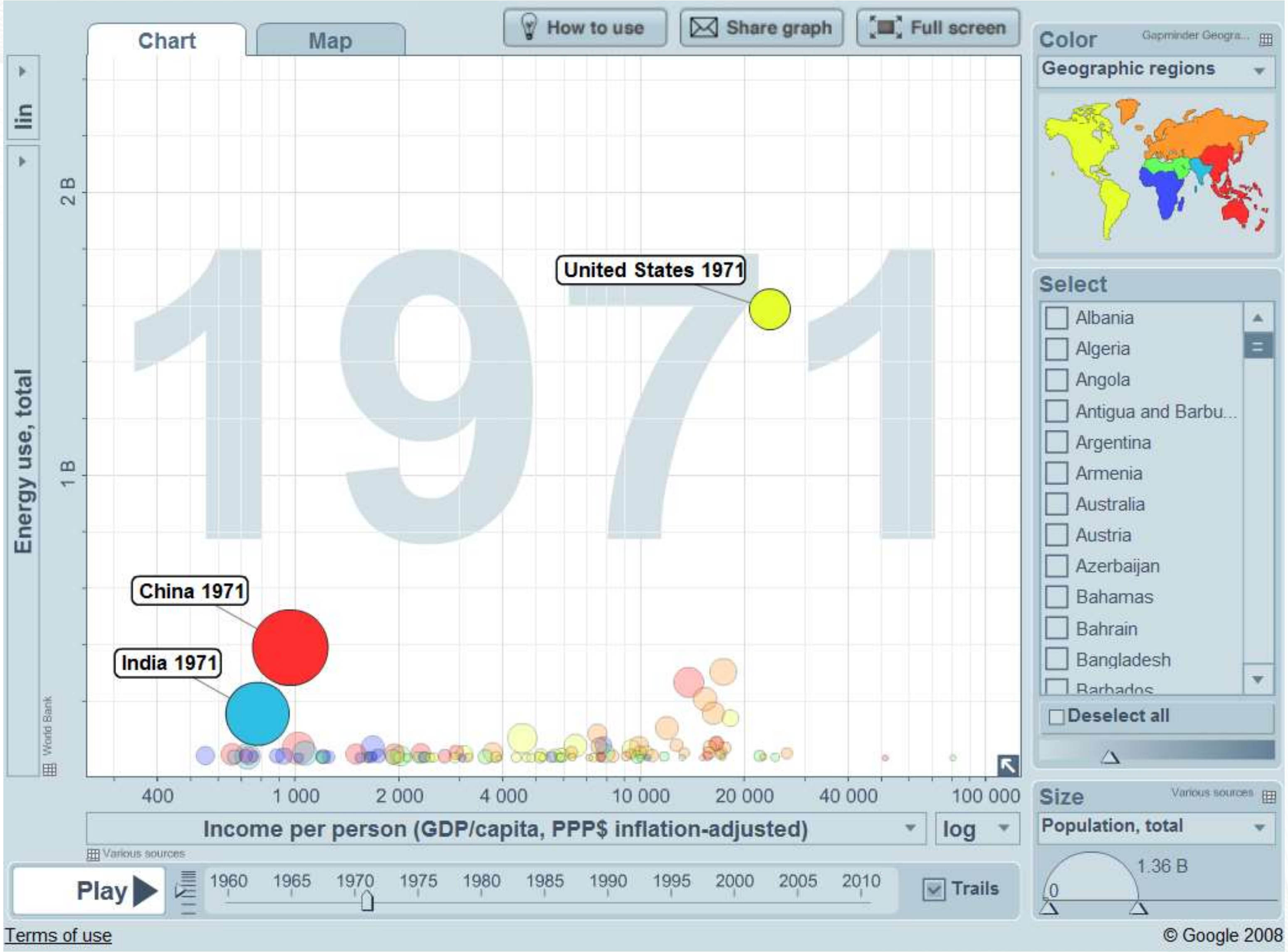
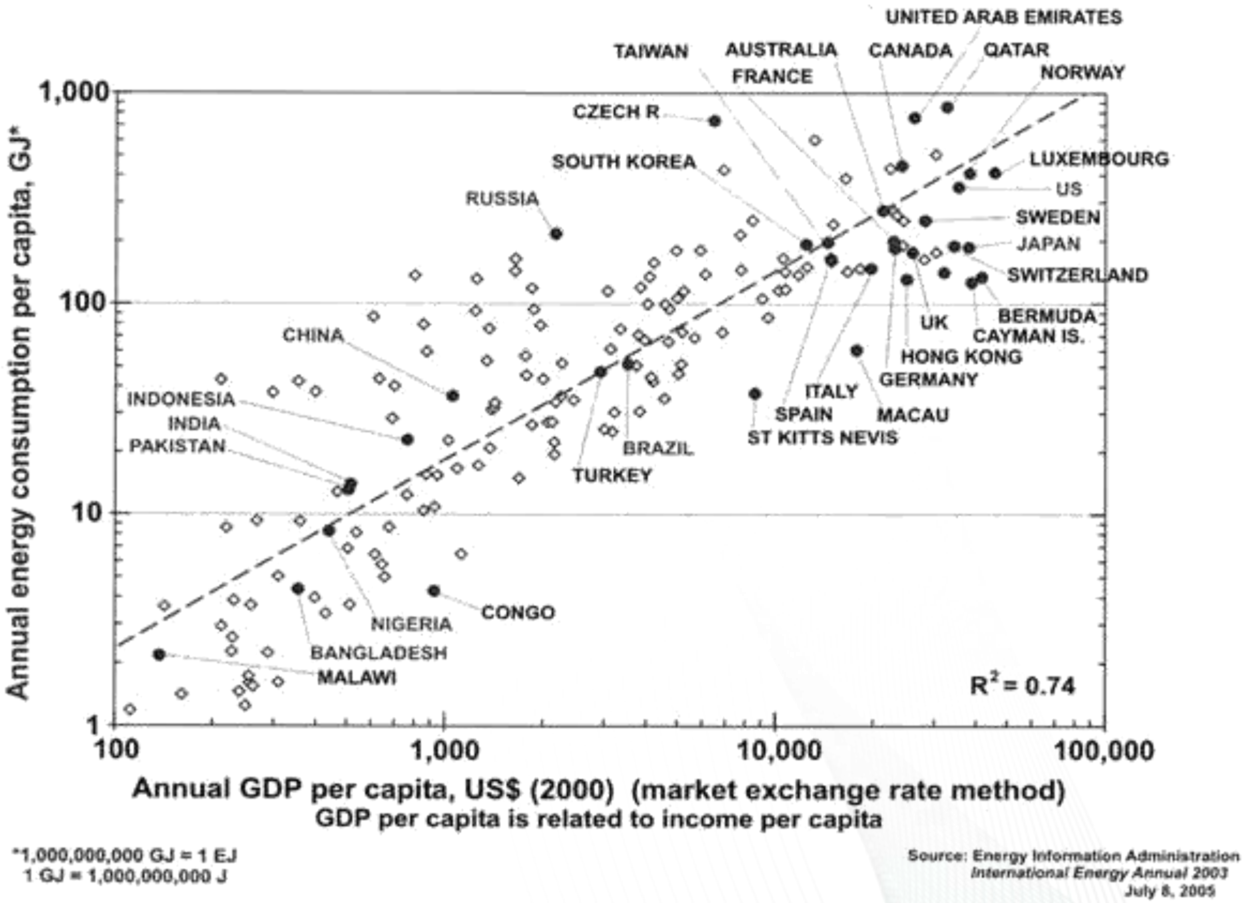
40 Years: Energy and Quality of Life

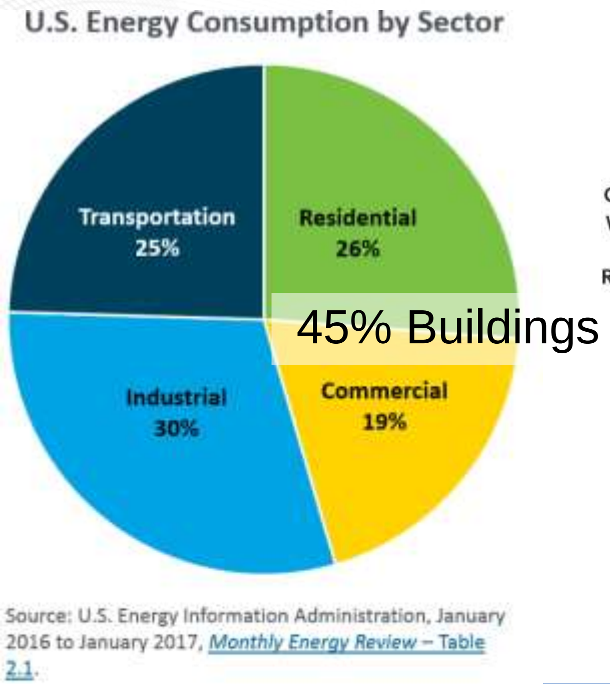


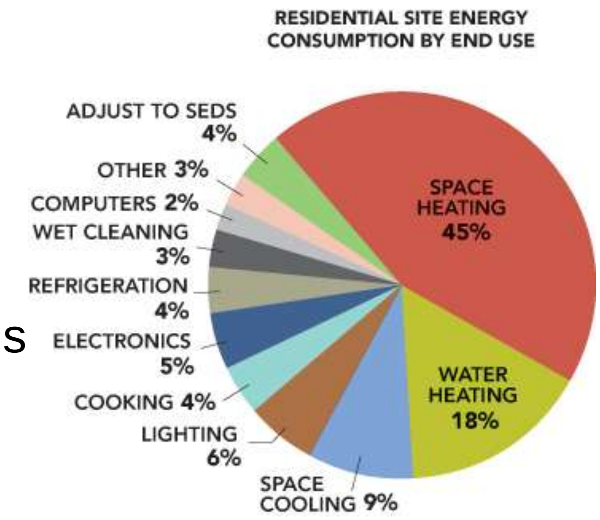
Energy Efficiency and Sustainability - global

- Buildings (China, India, US, UK, Italy) – 39% to 45% of primary energy
- Buildings in U.S.
  - 45% of primary energy & CO_2; 74% of electricity
- Buildings in China
  - 60% of building floor space in 2030 has yet to be built
- Buildings in India
  - 67% of building floor space in 2030 has yet to be built

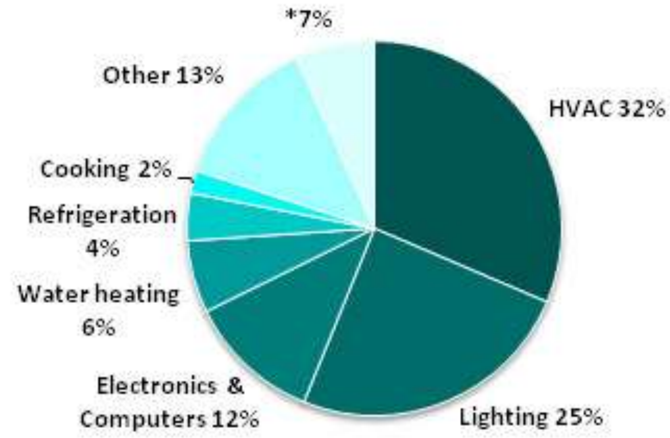


Energy Consumption and Production





Commercial Site Energy Consumption by End Use



Buildings consume 73% of the nation's electricity

124 million U.S. buildings
$395 billion/yr energy bills

Goal of the DOE
Building Technologies Office:
45% energy reduction per sq. ft.
by 2030 compared to 2010 baseline

Building Energy Modeling – building descriptions + weather = estimated building energy consumption

$9B/yr – ESCO; $7B/yr – utility EE
$14B/yr – DR management systems
0.3% modified, BEM < 10% of those

Building Energy Modeling
+
Resilience of the Electric Grid
+
ASHRAE’s Changing Climate Zones

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for the US Department of Energy

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ASHRAE Climate Zones

- Based on weather stations, most w/ 18+ yrs of quality data (1961-1990)

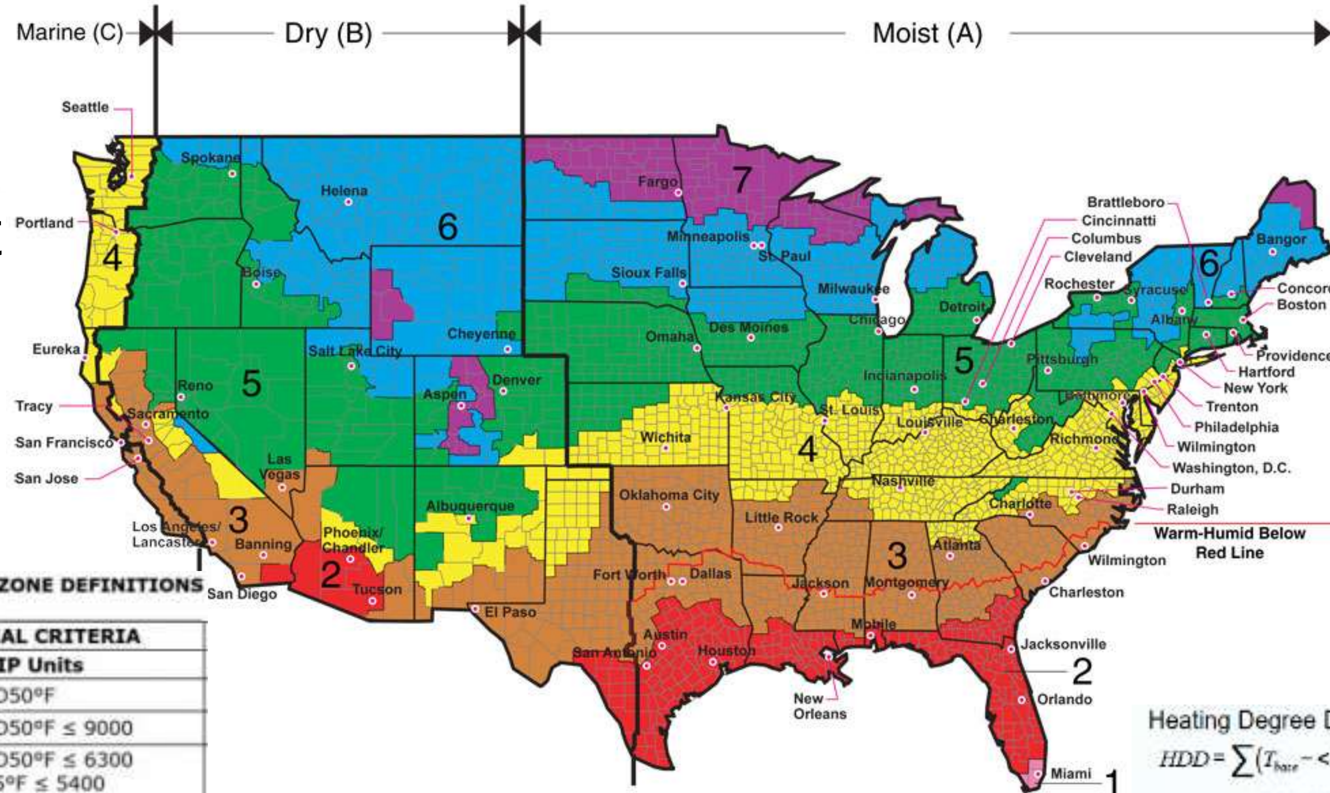

TABLE 301.3(2) INTERNATIONAL CLIMATE ZONE DEFINITIONS

ZONE NUMBER	THERMAL CRITERIA IP Units
1	9000 < CDD50°F
2	6300 < CDD50°F ≤ 9000
3A and 3B	4500 < CDD50°F ≤ 6300 AND HDD65°F ≤ 5400
4A and 4B	CDD50°F ≤ 4500 AND HDD65°F ≤ 5400
3C	HDD65°F ≤ 3600
4C	3600 < HDD65°F ≤ 5400
5	5400 < HDD65°F ≤ 7200
6	7200 < HDD65°F ≤ 9000
7	9000 < HDD65°F ≤ 12600
8	12600 < HDD65°F

Updated every 4 years (2021)

Climate Zone 0 (extremely hot):
10,800 < CDD 50°F
Int'l Energy Conservation Code (IECC) adopts for 2018 code

Heating Degree Days:

$$HDD = \sum (T_{base} - \langle T_i \rangle)^{+}$$

T_{base} = 18°C (65°F)

Cooling Degree Days:

$$CDD = \sum (\langle T_i \rangle - T_{base})^{+}$$

T_{base} = 10°C (50°F)

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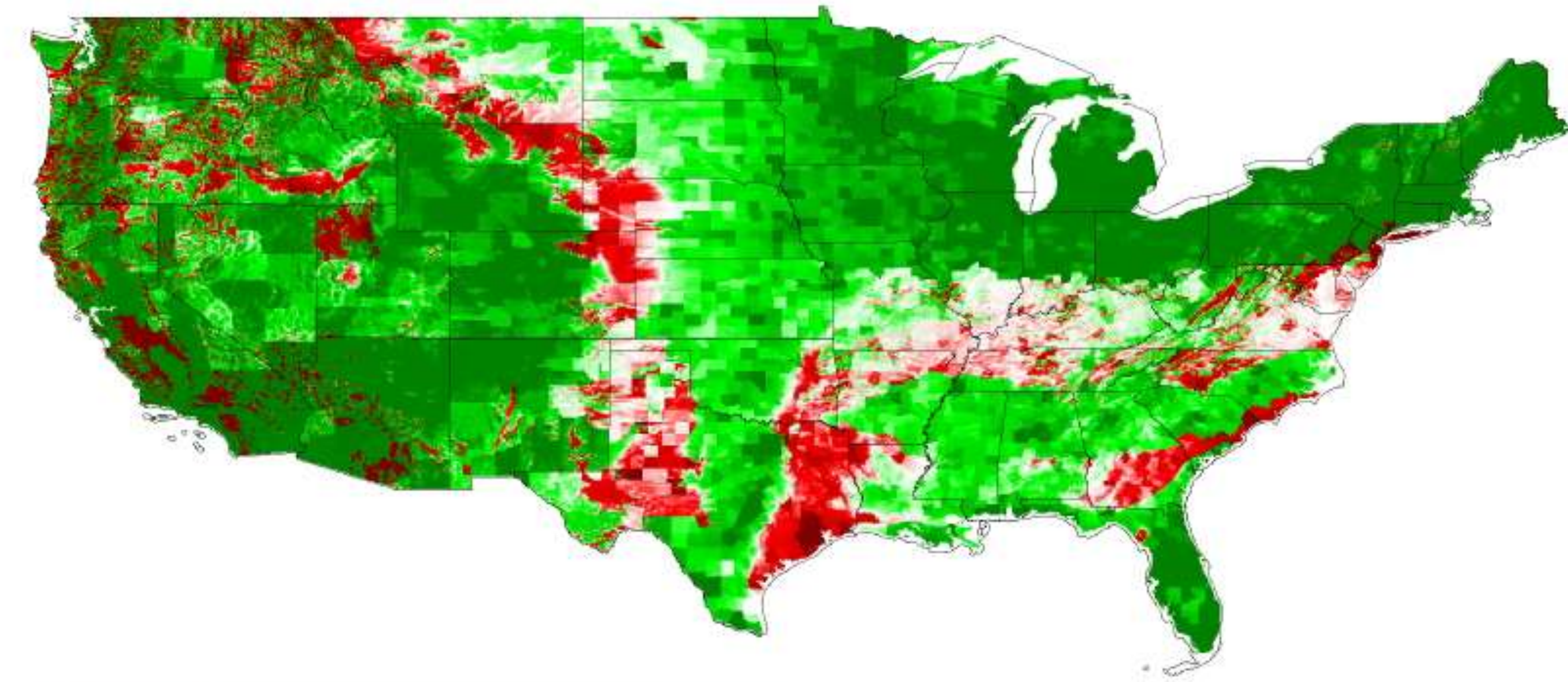
Building-adjusted CZ improvement

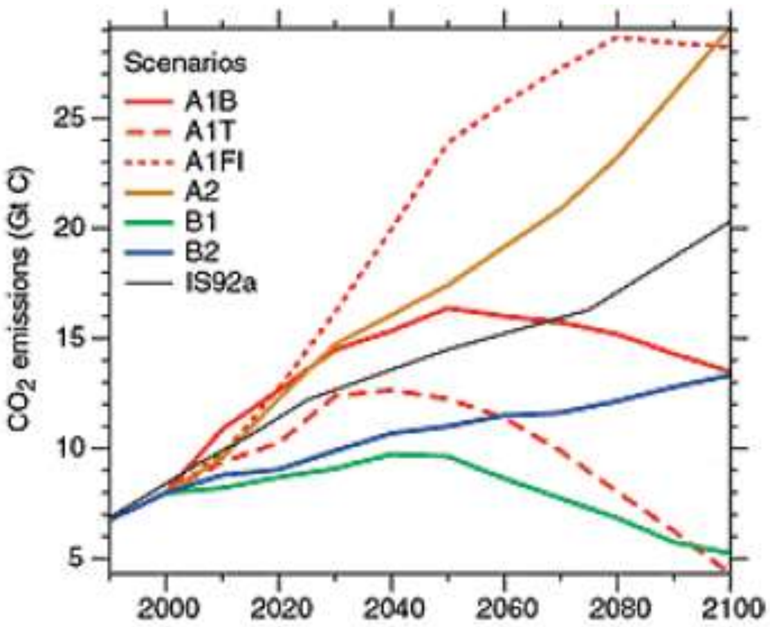
- What other (e.g. political) variables should be included?
- How could the nation's energy security and critical infrastructure resiliency be improved by incorporating future scenarios into the built environment?
- **How much energy and $ could be saved by having a forward-looking climate-aware building code?**

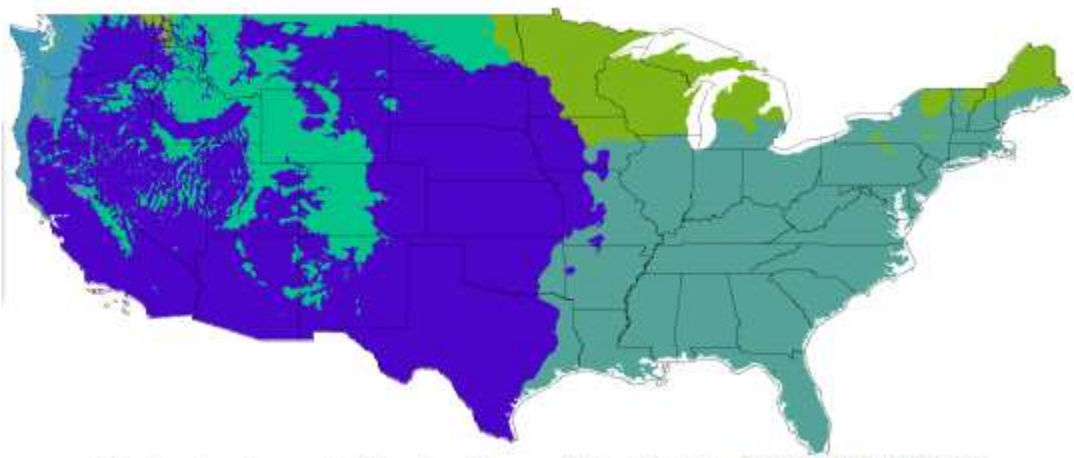


Climate Change Impacts

Contemporary Period

Clustering-based Climate Zones (K=5): HadGCM A1FI 2050





Clustering-based Climate Zones (K=5): HadGCM A1FI 2100

Building Energy Modeling
+
Grid-interactive Efficient Buildings
+
New Energy Market

(save x ± y at confidence level of z,
time-sensitive value trades)

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for the US Department of Energy

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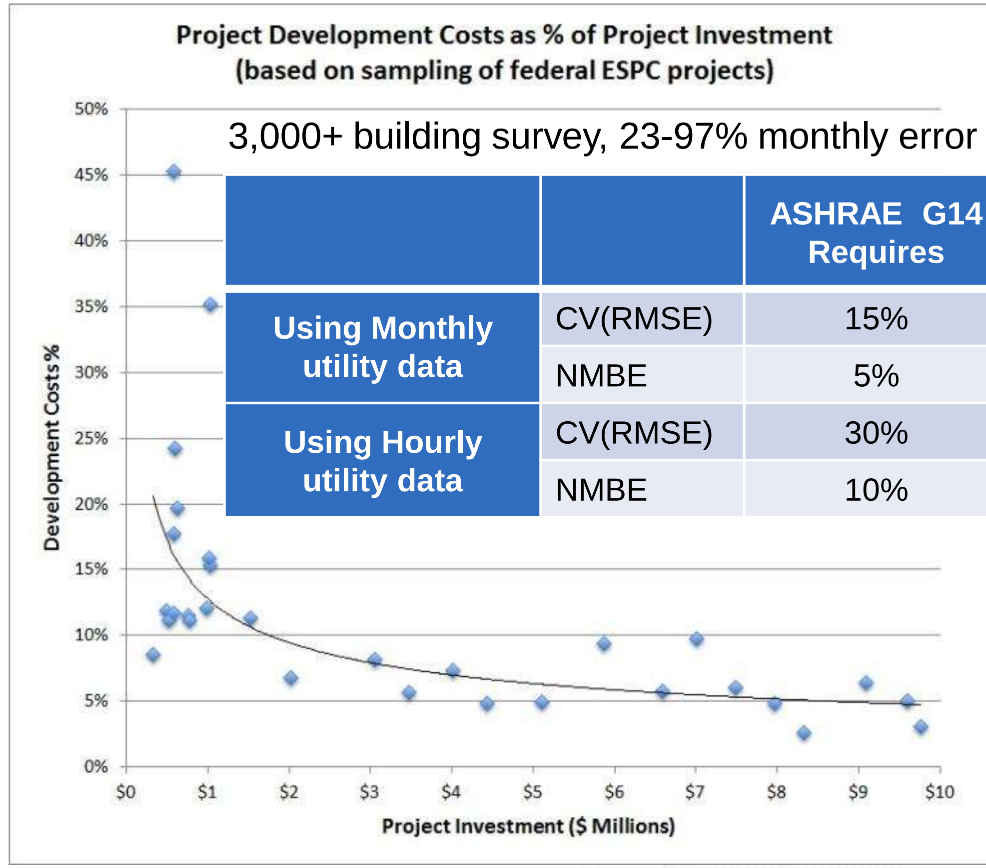
Building Energy Modeling

Optimal Return on Investment
(for building energy savings)

Simulation Engine and Analysis Platform
U.S. Dept. of Energy
$93M, 1995–?

EnergyPlus **OpenStudio**

Free, open-source (GitHub),
free support community (unmethours.com)



3,000+ building survey, 23-97% monthly error

		ASHRAE G14 Requires
Using Monthly utility data	CV(RMSE)	15%
	NMBE	5%
Using Hourly utility data	CV(RMSE)	30%
	NMBE	10%

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HPC scalability for desktop software

Titan is the world's fastest buildings energy model (BEM) simulator

>500k building simulations in <1 hour

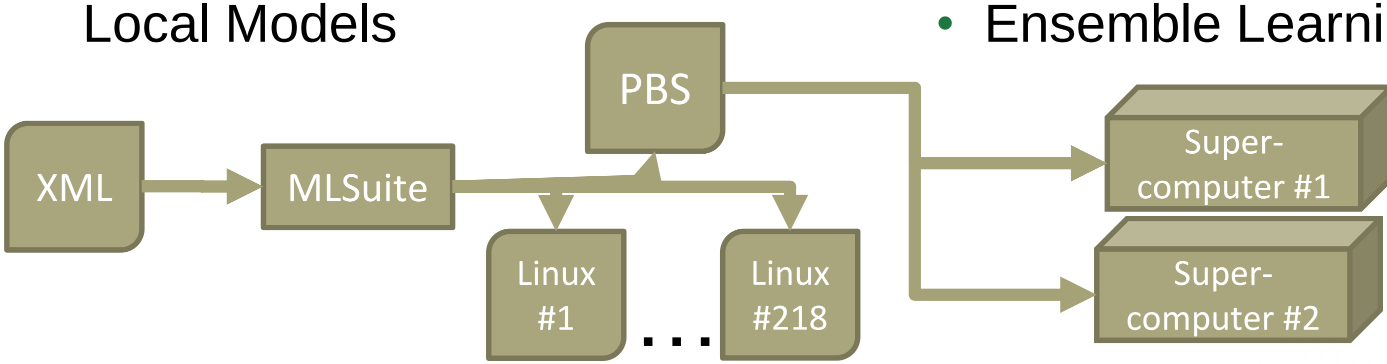
130M US buildings could be simulated in 2 weeks

8M simulations of DOE prototypes (270 TB)

CPU Cores	Wall-clock Time (mm:ss)	Data Size	EnergyPlus Simulations
16	18:14	5 GB	64
32	18:19	11 GB	128
64	18:34	22 GB	256
128	18:22	44 GB	512
256	20:30	88 GB	1,024
512	20:43	176 GB	2,048
1,024	21:03	351 GB	4,096
2,048	21:11	703 GB	8,192
4,096	20:00	1.4 TB	16,384
8,192	26:14	2.8 TB	32,768
16,384	26:11	5.6 TB	65,536
32,768	31:29	11.5 TB	131,072
65,536	44:52	23 TB	262,144
131,072	68:08	45 TB	524,288

MLSuite: HPC-enabled suite of Artificial Intel.

- Linear Regression
- Feedforward Neural Network
- Support Vector Machine Regression
- Non-Linear Regression
- K-Means with Local Models
- Gaussian Mixture Model with Local Models
- Self-Organizing Map with Local Models
- Regression Tree (using Information Gain)
- Time Modeling with Local Models
- Recurrent Neural Networks
- Genetic Algorithms
- Ensemble Learning



***Acknowledgment:* Dr. Lynne Parker (NSF Div. Dir. Info. and Intel. Systems);**
Dr. Richard Edwards (doctoral student, now Amazon's ad analytics)

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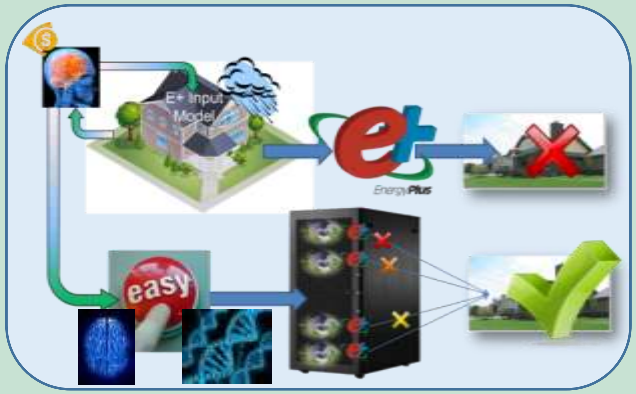
Calibration Performance – automated M&V

National HPC Resources → **Applied Research** → **Industry and building owners**

High Performance Computing

- Different calibration algorithms
- Machine learning – big data mining
- Large-scale calibration tests



Features

- Calibrate any model to data
- Calibrates to the data you have (monthly utility bills to submetering)
- Runs on a laptop and in the cloud
- 35 Publications: `http://bit.ly/autotune_science`
- Open source (GitHub): `http://bit.ly/autotune_code`

Results

		ASHRAE G14 Requires	Autotune Results
Monthly utility data	CVR	15%	1.20%
	NMBE	5%	0.35%
Hourly utility data	CVR	30%	3.65%
	NMBE	10%	0.35%

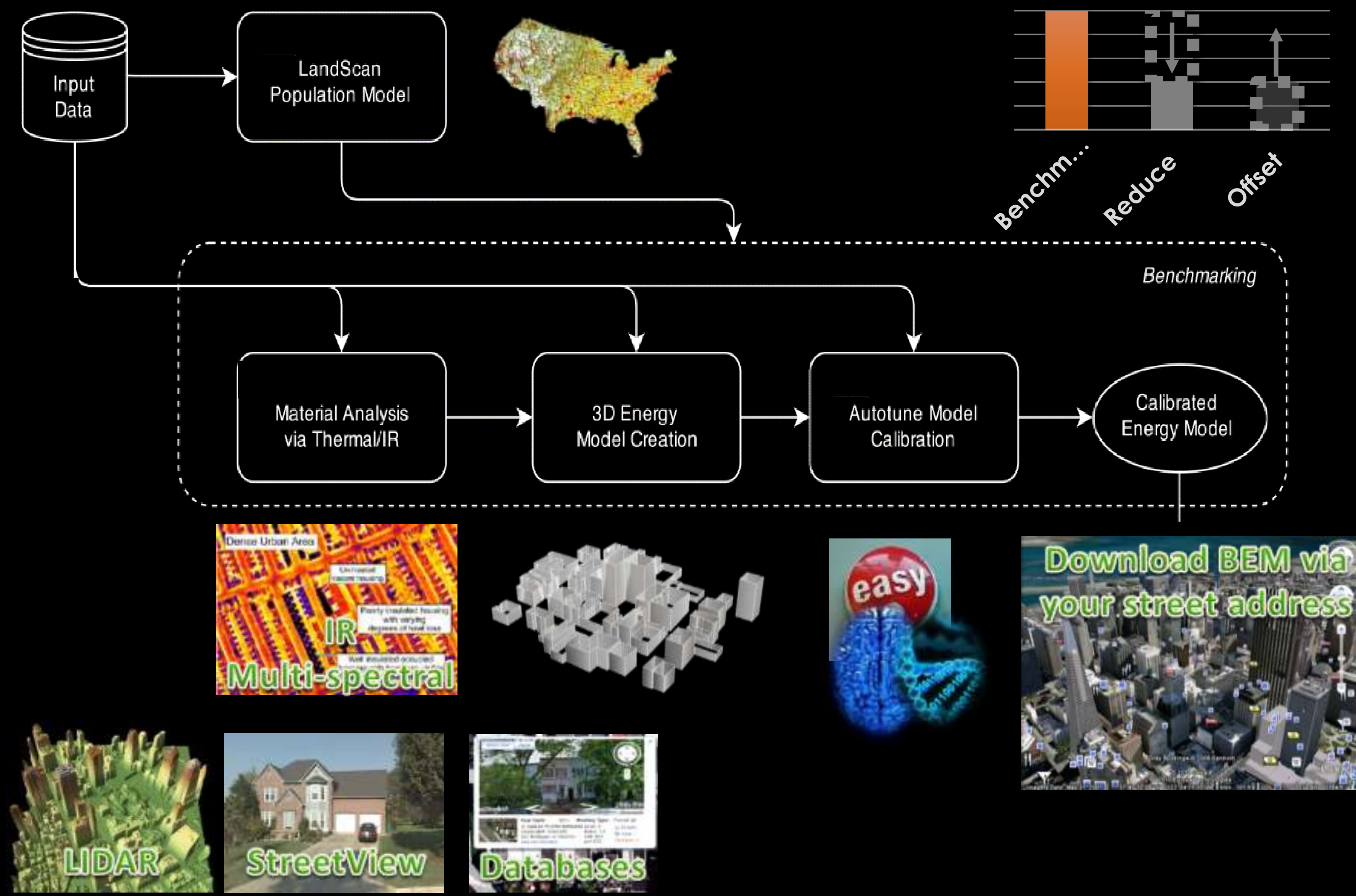
Results of 20,000+ Autotune calibrations
(15 types, 47-282 tuned inputs each)

Other error metrics

Residential home	Tuned input avg. error
Within 30¢/day (actual use $4.97/day)	Hourly – 8% Monthly – 15% 3 bldgs, 8-79 inputs

Leveraging HPC resources to calibrate models for optimized building efficiency decisions

Model America 2020 – BEM for every U.S. building



Acknowledgements

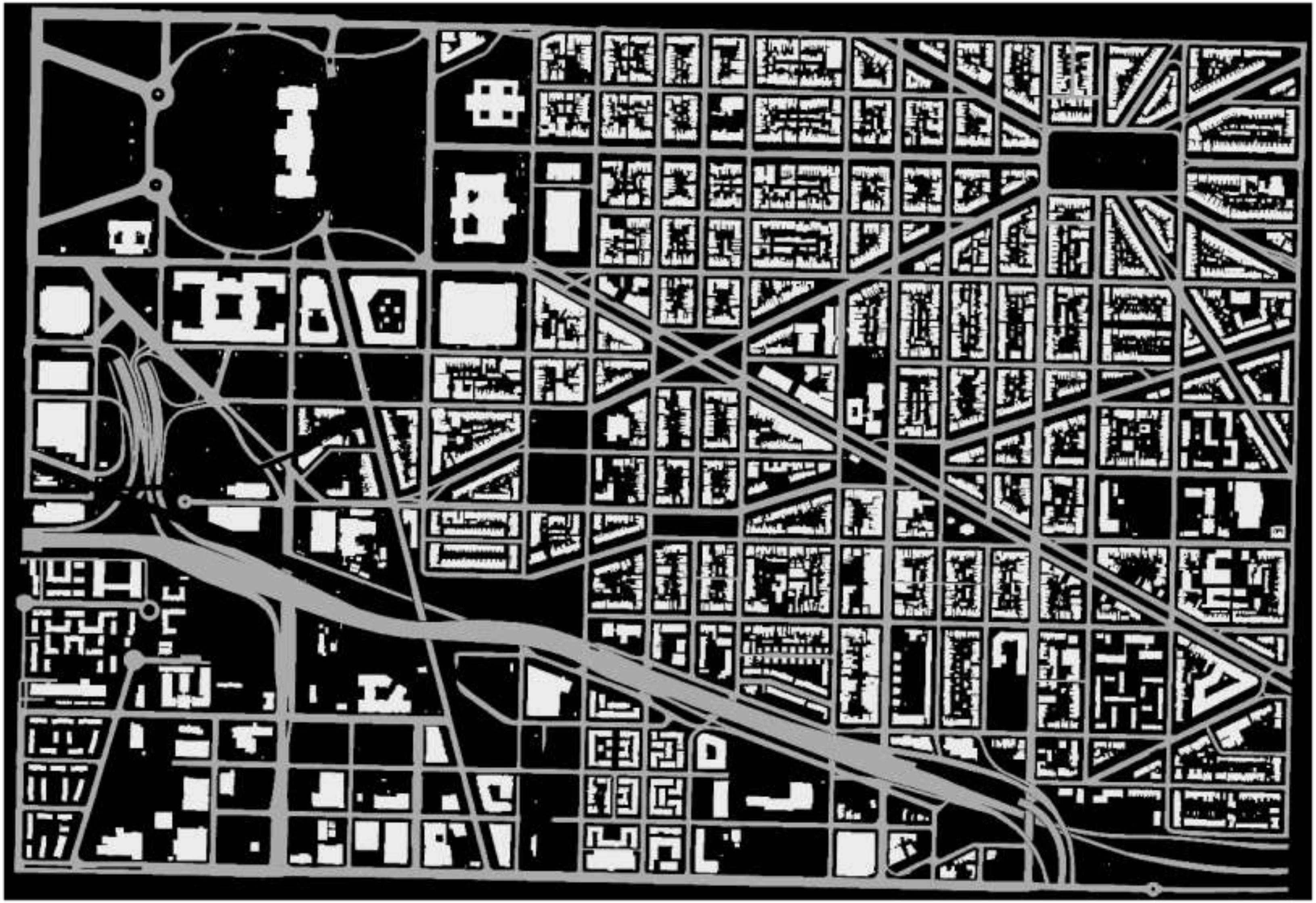
- U.S. Department of Energy
- National Nuclear Security Administration
- Oak Ridge National Laboratory
- Building Technologies Office
- Office of Electricity

Data Sources

- Database and image sources for urban model generation
  - Satellite and airborne imagery
  - Cartographic data
  - Ground level images
  - Elevation data
  - Building information databases
  - 3D building model databases

	Short Title
Summary	Satellite imagery, including panchromatic and multispectral images
Data type	Image
Company	
Website	
Temporal resolution	Cities - 3-11 times per week
Spatial resolution	0.3 m
Measure accuracy	
Cost	$11 per sq. km
Format	GeoTiff
Mapping to building input variables	Building footprints
Mapping to area properties	Vegetated areas, road surface, buildings, parking lots
Mapping to material properties	Road pavement materials (e.g., concrete, asphalt), parking lots (e.g., gravel, soil)
Coverage of US	Over 10 million km^2 of coverage of the contiguous US
Orientation	Aerial
Existing internal software	N/A
Existing expertise	Remote sensing data analysis tool
Restrictions	N/A
Comments	

Manual Segmentation of DC



Automatic Road Extraction

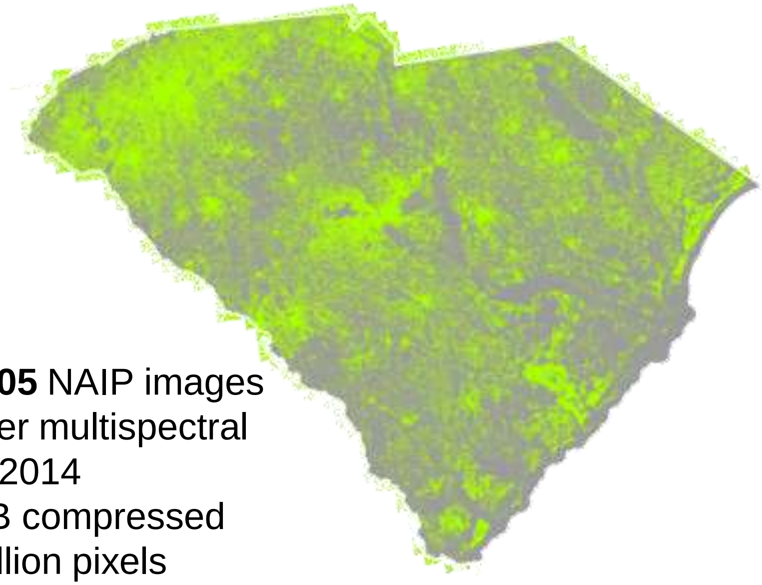
Automatic Building Footprint Extraction

Algorithm: Deep Learning extended and using GPUs for fast building footprint and area extraction over large geographical areas.

Multi-company Competition Precision/Recall – 30/35; Current Precision/Recall – 60+/60+

Automatic Building Footprint Extraction

- **220,005** NAIP images
- 1 meter multispectral
- 2012-2014
- 5.8 TB compressed
- 9.8 trillion pixels



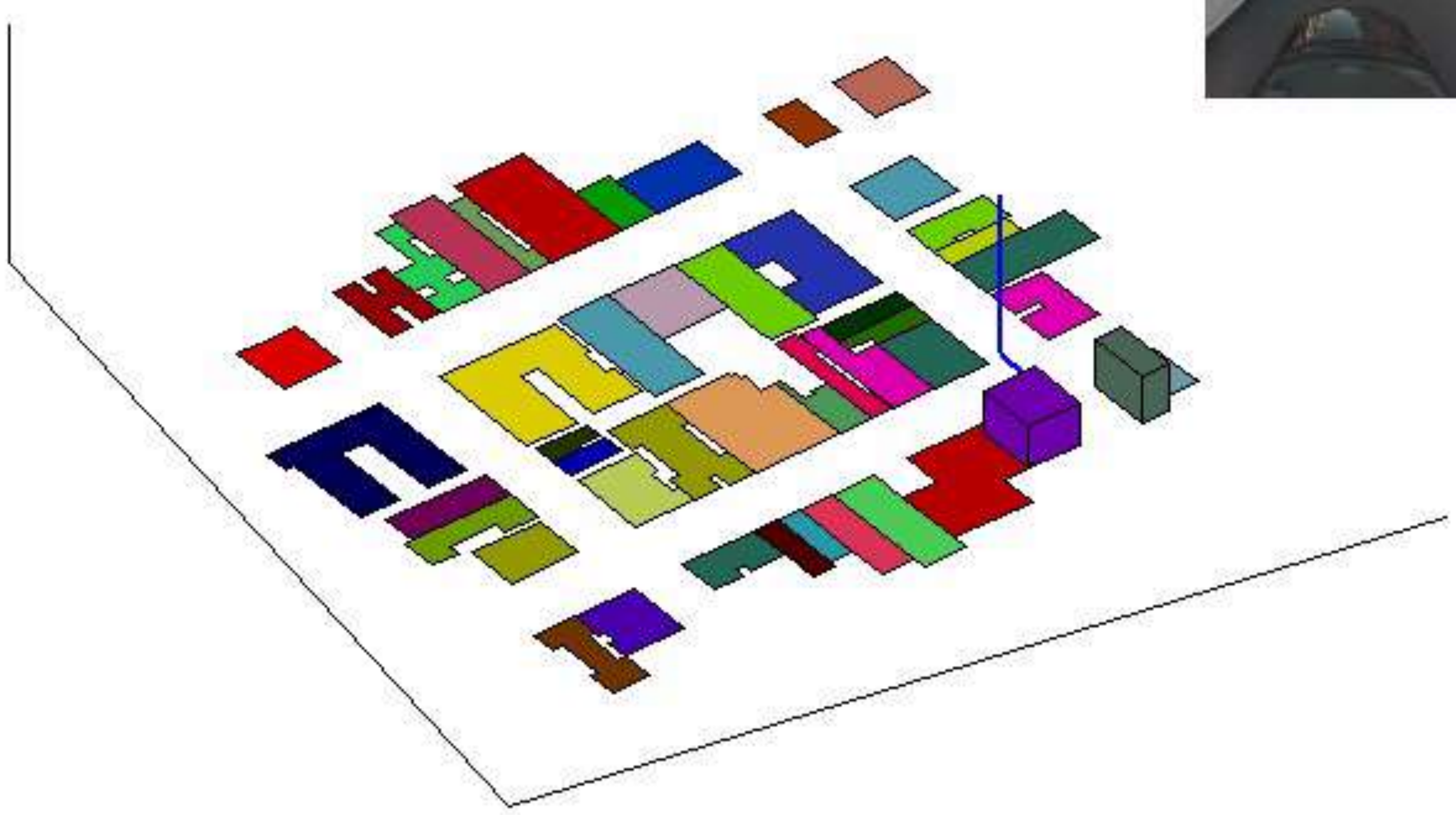
Portland, OR (25,393 m²)
Imagery: June – July 2012
Lidar: September 2010

Frankfort, KY (14,801 m²)
Imagery: June 2012
Lidar: June 2011

Part of Knox County, TN (18,527 m²)
Imagery: June 2012
Lidar: October 2014

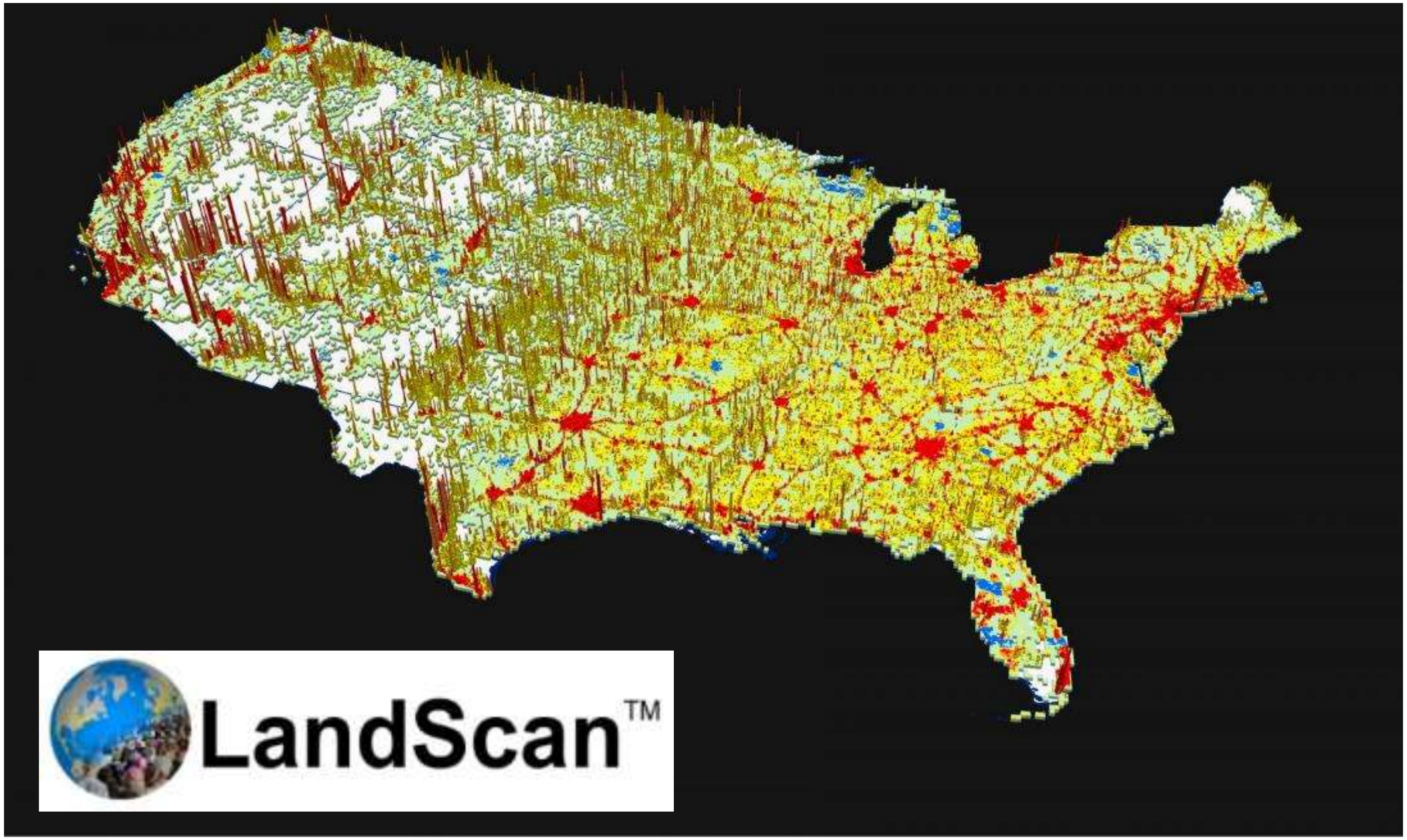
Processing Street-Level Imagery – Jiangye Yuan

3D Building Model Generation



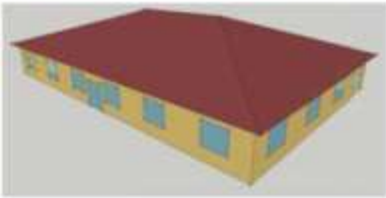
LandScan USA – Amy Rose

- 90-meter grid of daytime (commercial) and night time (residential) population
  - ~14 different data sources (e.g. anonymized cell phone GPS)
  - Building occupancy and schedule adaptation

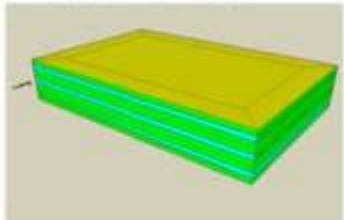


Prototype Buildings

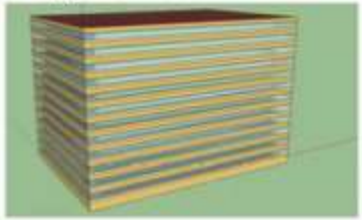
Small Office



Medium Office

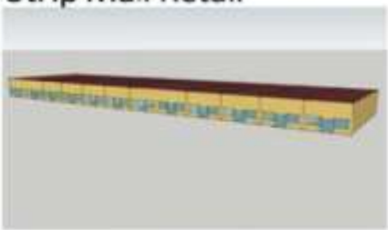


Large Office

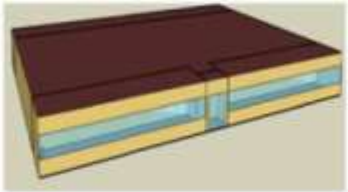


Warehouse

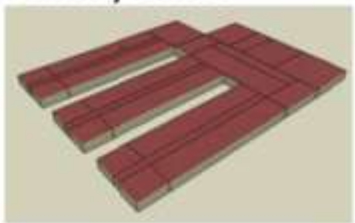
Strip Mall Retail



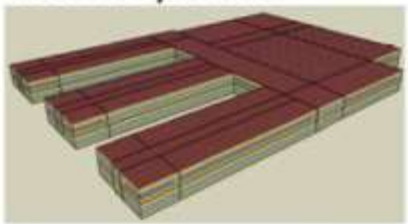
Standalone Retail



Primary School

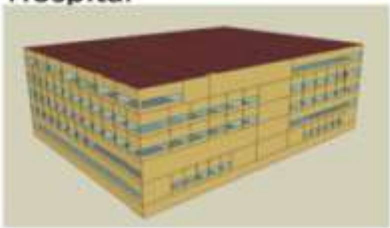


Secondary School



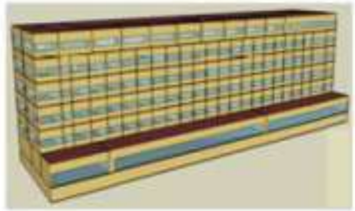
Outpatient Healthcare

Hospital

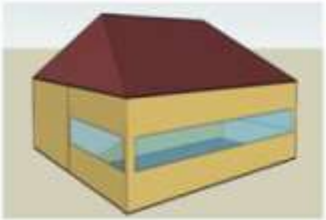


Small Hotel

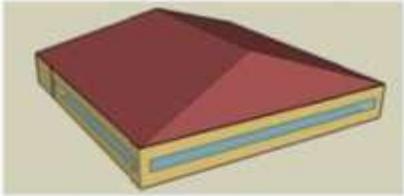
Large Hotel



Quick-service Restaurant

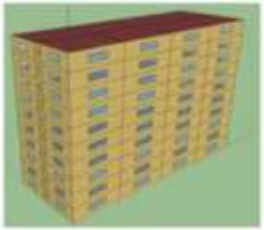


Full-service Restaurant



Mid-rise Apartment

High-rise Apartment

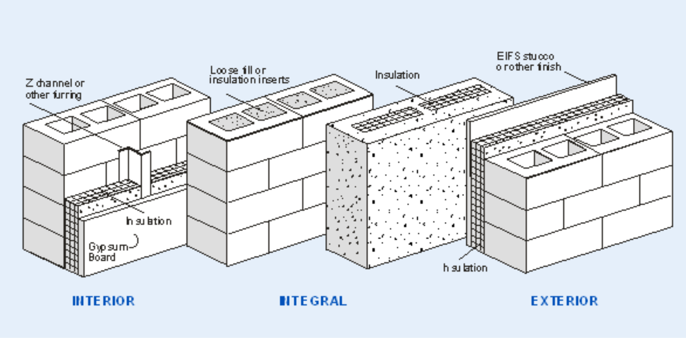


Prototype and Reference Building Updates

- 70, 80 → 90% of U.S. commercial floor space
- 16 types, 16 climate zones, 3 vintages = 768 buildings
  - 17-19+ types, 16-17 climate zones, 5-16+ vintages = 1,360-5,168 models
- ~3,000 avg. parameters per building
  - Square footage, HVAC layout, infiltration (i.e. airflow)
  - Construction (e.g. wall, layers of envelope)
  - Material properties (ASHRAE Handbook of Fundamentals)
  - Equipment and occupancy schedules

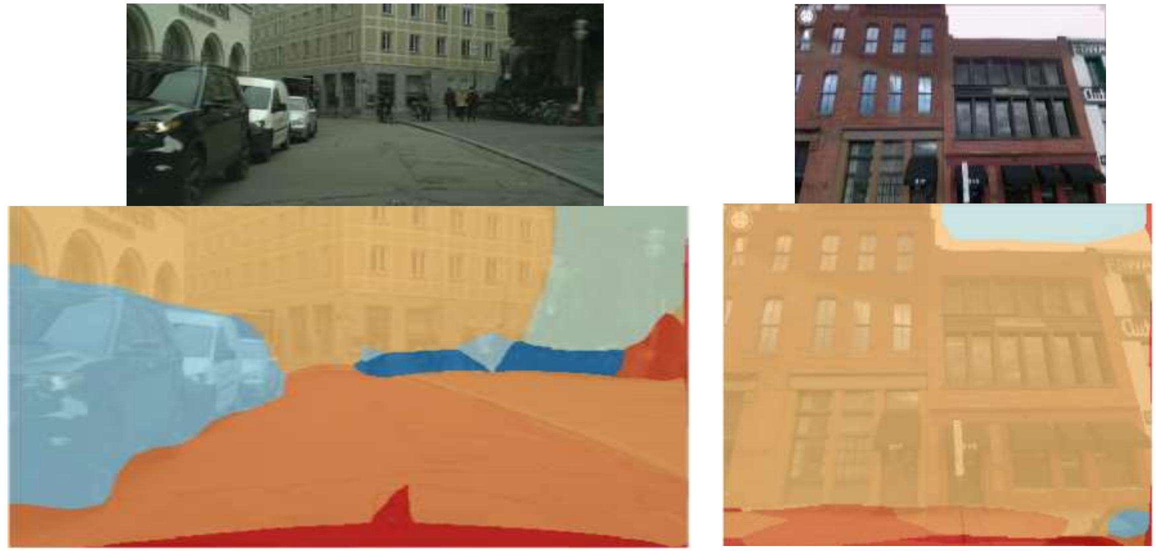
Table 3 Properties of Solids

Material Description	Specific Heat, Btu/lb·°F	Density, lb/ft³	Thermal Conductivity, Btu/h·ft·°F	Emissivity Ratio	Emissivity Surface Condition
Aluminum (alloy 1100)	0.214[b]	171[u]	128[u]	0.09[a] 0.20[a]	Commercial sheet Heavily oxidized
Aluminum bronze (76% Cu, 22% Zn, 2% Al)	0.09[u]	517[u]	58[u]		
Asbestos: Fiber	0.25[b]	150[u]	0.097[u]		
Asbestos: Insulation	0.20[t]	36[b]	0.092[b]	0.93[b]	"Paper"
Ashes, wood	0.20[t]	40[b]	0.041[b] (122)		
Asphalt	0.22[b]	132[b]	0.43[b]		
Bakelite	0.35[b]	81[u]	9.7[u]		
Bell metal	0.086[t] (122)				
Bismuth tin	0.040*		37.6*		
Brick, building	0.2[b]	123[u]	0.4[b]	0.93*	

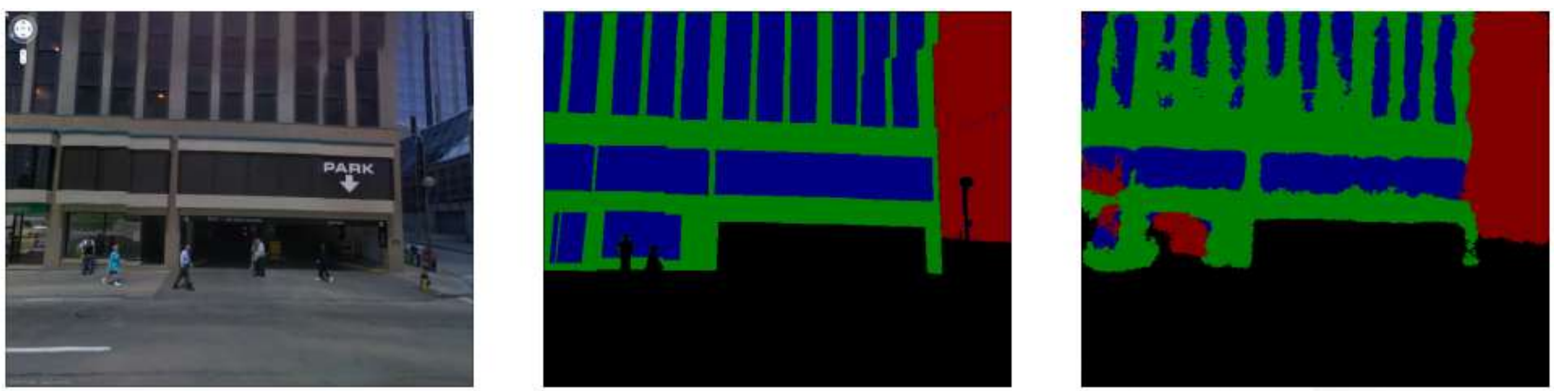


Street-level imagery (Lexie Yang)

Façade Type



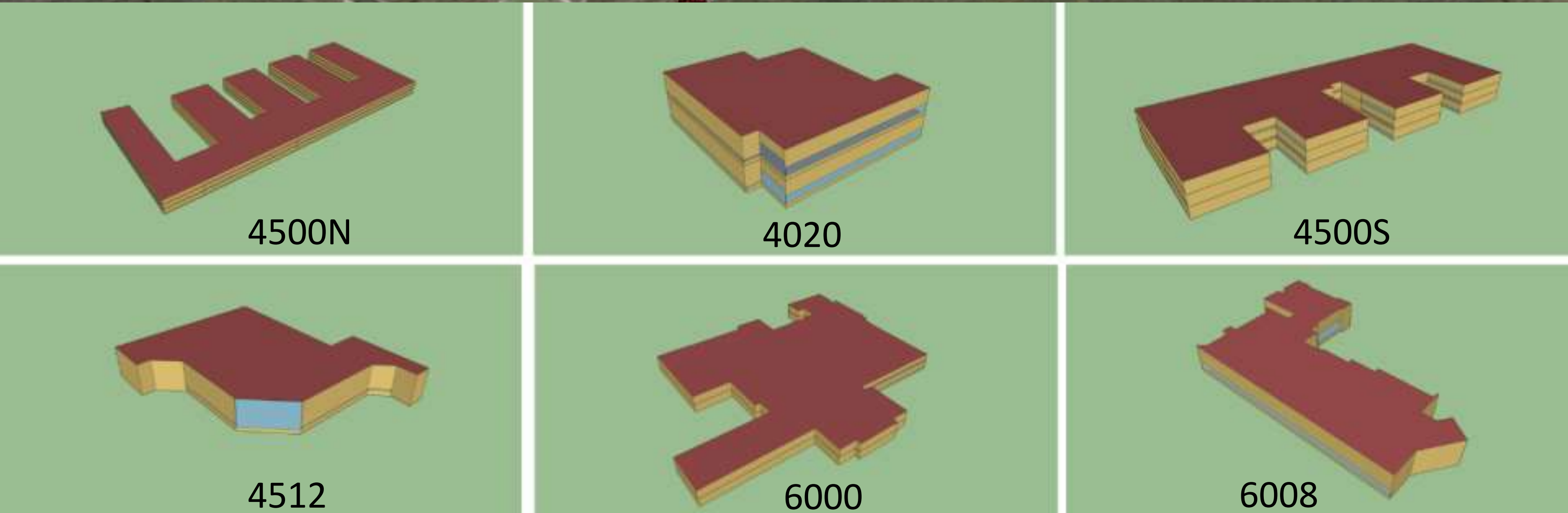
Windows (blue)
Façade (green)
Street/open (black)
Other building (red)



Window-to-wall ratio

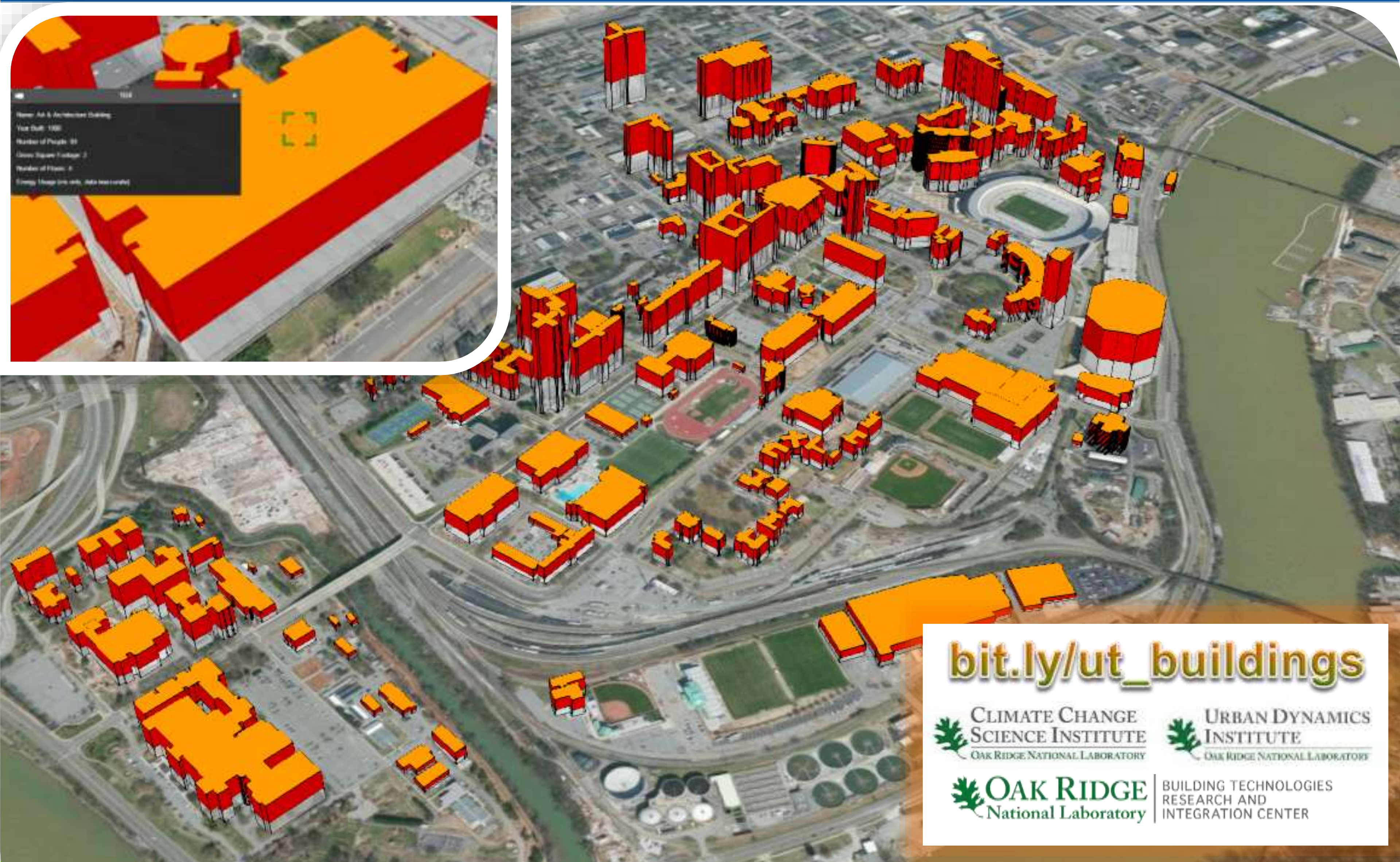
Input image Ground truth Model output

Oak Ridge National Laboratory



Oak Ridge National Laboratory (interactive)

The University of Tennessee (2 days)



bit.ly/ut_buildings

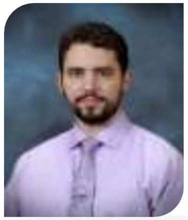
Climate Change Science Institute
Oak Ridge National Laboratory

Urban Dynamics Institute
Oak Ridge National Laboratory

Oak Ridge National Laboratory

Building Technologies Research and Integration Center

Virtual EPB – bios



- Joshua New, Ph.D., C.E.M., PMP, CMVP
  - BTRIC "Software Tools & Models" responsible for development of DOE's building simulation tools, HPC, and AI for big data mining.
  - Led 62 projects (9.4/year) totaling $10M/$28M ($1.3M/yr)
    - 133/133 deliverables (44/yr) on-time and on-budget; 100+ publications (13.8/yr)

- James (Jim) Ingraham, B.S. Finance
  - EPB, VP of Strategic Research; electric utility and broadband communications; market research and data modeling

- William (Bill) Copeland, B.S. Economics, MBA
  - EPB, Director of Business Intelligence, EPB business systems, visual analytics

- Hsiuhan (Lexie) Yang, Ph.D. Civil Engineering
  - Computer vision specializing in aerial imagery
  - Machine learning for large data: NASA, AIST, NSF, DOE

- Mark Adams, M.S. Ag&Bio, Mechanical Engineering
  - Building simulation expert, EnergyPlus/OpenStudio developer

Virtual EPB Summary

- DOE's Building Technologies Office and Office of Electricity
  - Goal: create a digital twin of every building in EPB's service area
  - Final Deliverable: Simulation-informed data and valuation report for energy, demand, emissions, and $ impact to EPB for each building in EPB's service area for 5 prioritized use cases covering 9 monetization scenarios

  - 2 projects, funded and tracked separately
  - Total - $700k (OE-$450k, 41 tasks; BTO-$250k, 15 tasks + BTO: $400k FY19)
  - 56 tasks, 12 milestones, 1 Go/No-Go (passed)
  - On-schedule except for 1 technical input (High-res bldgs) and 1 task (QA/QC)

Utility Use Cases for Virtual EPB

- **Peak Rate Structure** - model peak segment customers in aggregate as disproportionate contributors to electric utilities' wholesale demand charges for more equitable rate structures.
- **Demand Side Management** – identify DSM products and grid services for better distribution grid management that allow both utilities and rate-payers to share in peak reduction
- **Grid stability services** – quantify improved load models
- **Emissions** – accurately account for emissions contributed by each building, providing enhanced abilities for utilities to best comply with national emission policies.
- **Energy Efficiency** – accurate modeling/forecasting of every building energy profile virtually in a scalable fashion allows better follow-up and more targeted energy audits/retrofits.
- **Customer Education** - better understand building's energy usage as a function of weather to provide better information during customer billing enquiries.

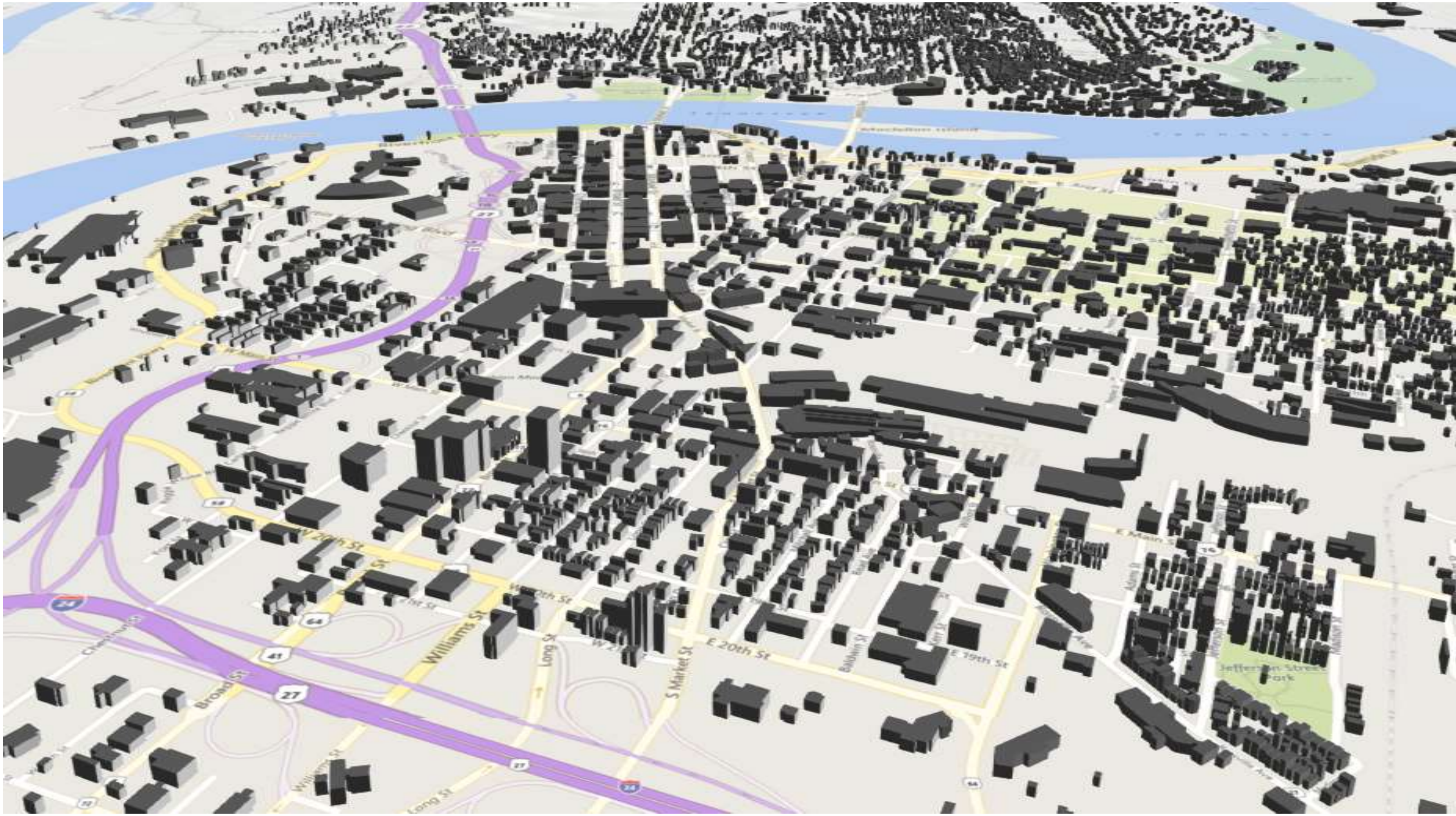
Energy, Demand, Emissions, and $ for 9 scenarios (Customer->EPB, EPB->TVA)

EPB buildings in Tennessee (166,944)

EPB buildings in Tennessee (166,944)

EPB buildings in Tennessee (166,944)

Chattanooga, TN (100,000+ buildings)



Scientific results

- 100+ page internal report NDA/OUO
  - New, Joshua R., Hambrick, Joshua, and Copeland, William A. (2017). "Assessment of Value Propositions for Virtual Utility Districts: Case Study for the Electric Power Board of Chattanooga, TN." ORNL internal report ORNL/TM-2017/512, December 15, 2017, 107 pages.
- Sensitivity analysis for all building types
  - 80% of commercial buildings - 16 climate zones, 16 building types, averaging 5.75 vintages
  - 281-4,617 building descriptors (e.g. thermostat, insulation level) were modified

	Small Office	Outpatient	Large Office	Medium Office	Hospital	Warehouse	Small Hotel	Large hotel
Inputs	458	3483	1072	760	1955	333	1823	887
	Strip Mall	Retail	Quick Service Restaurant	Full Service Restaurant	Mid Rise Apt	High Rise Apt	Secondary School	Primary School
Inputs	800	438	281	286	1464	4617	1621	1051

  - Fractional Factorial (FrF2) resolution IV statistical design of experiments
- Summarize 768 lists of impactful variables
  - 254,544 annual simulations were completed on the nation's fastest supercomputer (Titan)
  - 216 Excel spreadsheets were created listing the energy and demand impacts of each building property
- Quantify Most Important Building Parameters
  - Top 10 annual energy (kWh) and demand/peak-shaving (kW) variables for each of the 16 building types

The AutoBEM technology “axe”

135,481 building models have been created and matched to EPB’s PremiseID

Limitations: limited building types, not calibrated, will improve quarterly

QA/QC: will show how close our simulations are to 15-min data

2.3 million EnergyPlus building energy models using AutoBEM technology, Titan, cloud, and local servers to produce and analyze 13 TB of simulation data.

1. Generate baseline building – OpenStudio (1.5-3h Amazon, 30h internal)
2. Run ECM measures – OS Measure (30 mins AWS, 2h internal), Custom (1m AWS, 5m intl.)
3. Copy data to Titan – 1 min (1.2GB tar.gz)
4. Submit to Titan – 0-2 hours in queue
5. EnergyPlus simulation time – 30-45 mins (5mins/sim = 1.4 years to simulate EPB on 1 core)
6. Data transfer – 40 mins (160GB tar.gz)
7. Uncompress – 10-15 mins
8. Reformat data – 20-30 mins
9. Analysis – 5-10 mins

Time for creation, annual simulation, and analyzing “all” EPB buildings

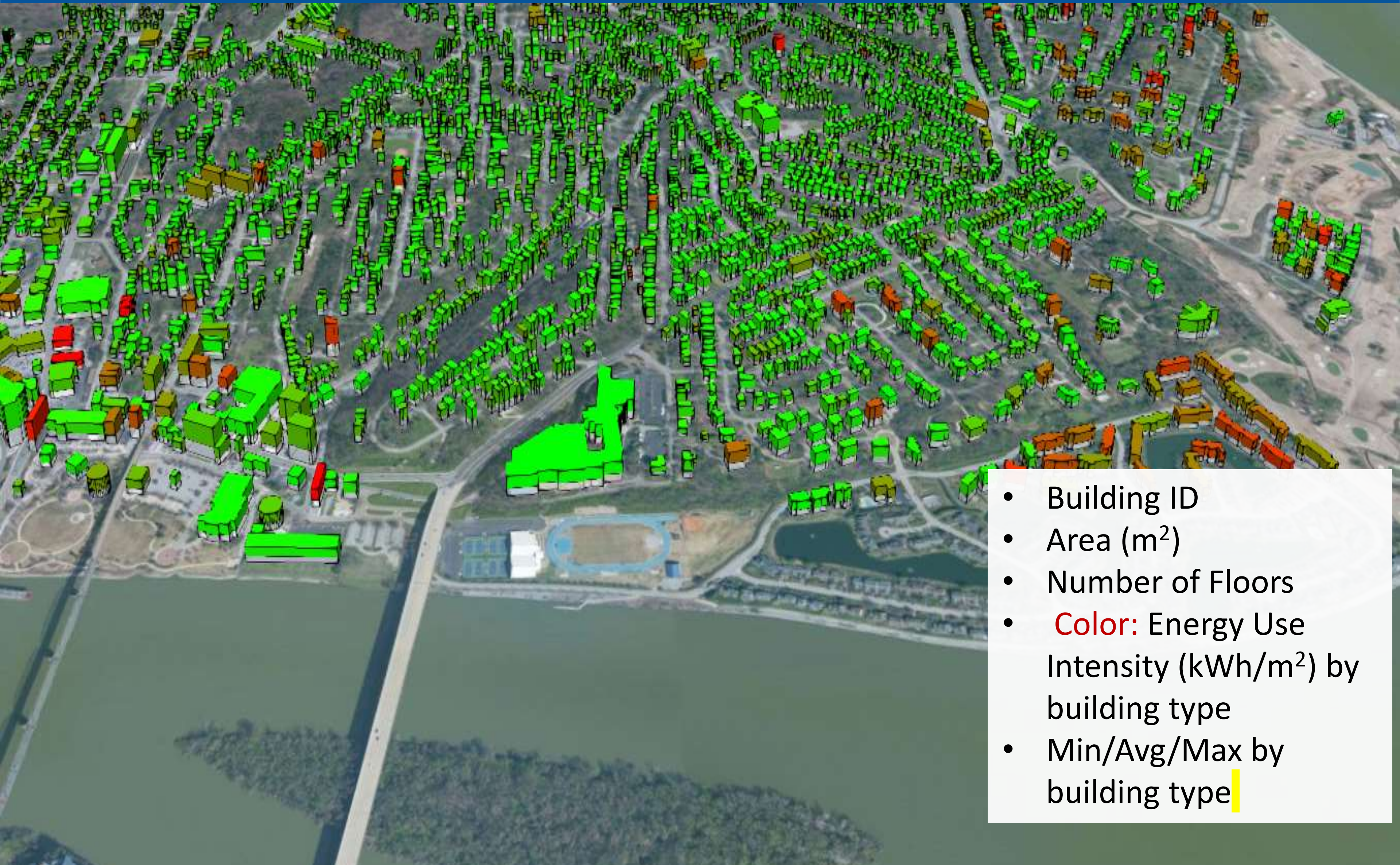
6.5 hours (6.1h –36.5h)

Use Case - Scenarios

- ***Preliminary*** building-specific estimates of energy, demand, and cost savings totaling **$11-$35 million per year** based on 9 scenarios prioritized by EPB.

1. **Peak Rate Structure**
    1. Scenario #1a, Peak contributions for each building
    2. Scenario #1b, Cost difference, in terms of dollars per year, for all building
2. **Demand Side Management**
    1. Scenario #2a, Monthly peak demand savings, annual energy savings, and dollar savings based on rate structure for all buildings.
    2. Scenario #2b, Location-specific deferral of infrastructure cost savings potential
3. **Emissions**
    1. Scenario #3a, Emissions footprints for each building
4. **Energy Efficiency**
    1. Scenario #4a, Optimal retrofit list of independent ECMs
    2. Scenario #4b, Optimal retrofit package of dependent ECMs
5. **Customer Education**
    1. Scenario #5a, Percentile ranking of each building's EUI by building type and vintage
    2. Scenario #5b, Monthly peak demand savings, annual energy savings, and dollar savings based on rate structure for all buildings compared to AMY weather file scenario.

1a – Peak contribution percentile by type

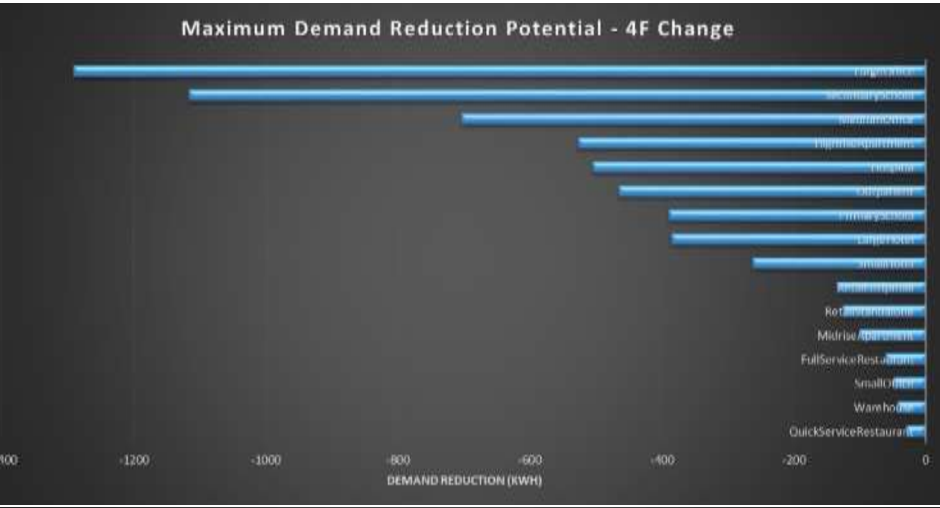


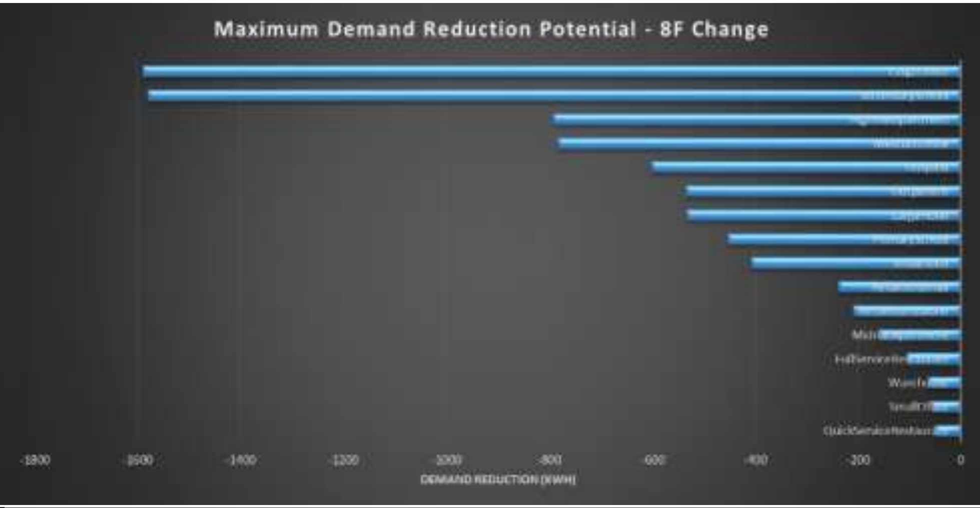
- Building ID
- Area (m^2)
- Number of Floors
- Color: Energy Use Intensity (kWh/m^2) by building type
- Min/Avg/Max by building type

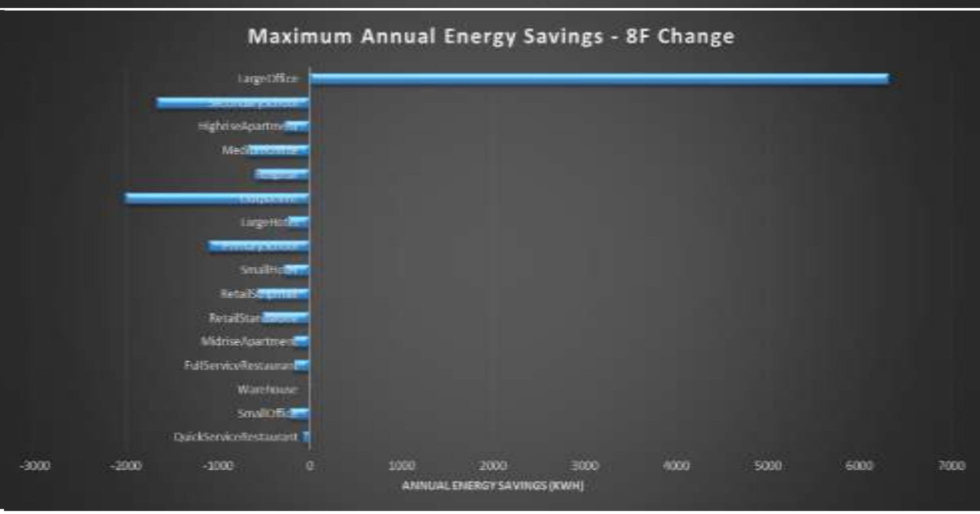
2a - Smart Thermostat

- Pre-heat/pre-cool 2 or 4 hours prior to peak demand hour each month
  - Single Heating or Single Cooling thermostat – up or down 4°F and 8°F
  - Dual Setpoint Thermostat – Average of baseline cooling and heating setpoints with a 0.5°C deadband
- Setback thermostat setpoint by 4°F or 8°F for peak demand hour and 4 hours after peak for each month
- Altered thermostat values affects 38 (1-4 per building type) thermostat schedules in 518 (3-118 per building type) thermal zones for 16 different building types
- The 4°F and 8°F runs are compared to baseline, unaltered simulation to determine demand reduction and energy savings potential

2a - Smart Thermostat: Maximum Demand and Energy Reduction Potential







Resiliency and Emissions Footprints

- **2b: Demand Side Management**
  - **Resiliency of critically-loaded feeders and substations**

Circuit: Customer Information

Circuit: **Circuit Count:**1
As of Date: **XFMR Count:** 146
Meter Count: 703

Circuit ID	Xfmr Structure Number - Compressed	Premise Number	Account Number - Formatted	Premise Service Address	Meter Number

- **3a: Emission Footprint for each building**
  - **Carbon footprint (CO_2)**
  - **Nitrogen oxides (NOx)**
  - **Sulfur Dioxide (SO_2)**
  - ***Methane (CH4)***
  - ***Nitrous Oxide (N2O)***

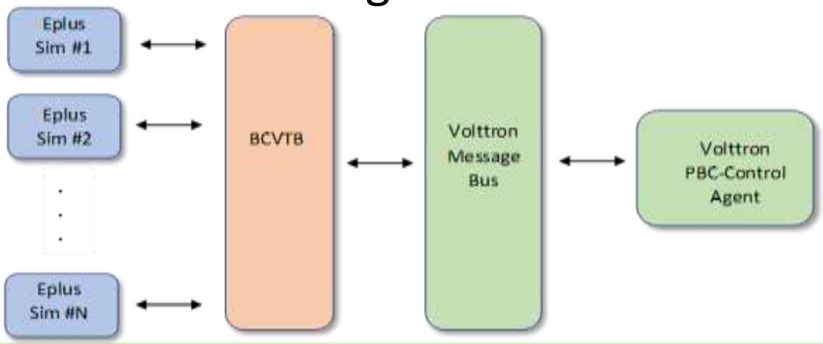
Demand and EE opportunities

- Energy, demand, emissions, savings (customer and utility) for every building every 15 minutes

ECMs	Different Fields Calculated for Each ECM							
HVAC	1.Total	2.Annual	3.Energy	4.Annual	5.Annual	6.Annual	7.Annual	8.Total
Lighting	Cost	Electric	Cost	Electric	Demand	Demand	Demand	Cost
Infiltration	Savings	Savings	Savings		Savings	Cost		Savings
8F setback						Savings		
HVAC Efficiency	$	kWh	$	kWh	kW	$	kW	$
4F setback								
Insulation	9.Annual	10.Energy	11.Annual	12.Percent	13.Annual	14.Annual		
Water heater	Electric	Cost	Electric	Savings	Demand	Demand		
Heat pump	Savings	Savings			Cost Savings			
Smart WH	kWh	$	kWh	$	$	kW		

Related Work

- **Combined Heat and Power (CHP)**
  - Sizing micro-CHP based on heating, cooling, and electrical demands
- **Transactive HVAC Control**
  - EnergyPlus models for transactive control
- **Microgrid**
  - Simplified model replaced with EnergyPlus
  - Run for area within EPB for considering microgrid
- **VOLTTRON Deployment**
  - B2G services deployment of hardware and control strategies



Virtual EPB – interactive results

60246

ID	60246
DOE Building Type	SmallOffice
Num Floors	3
Percentile	87.70 %
Estimated wholesale vs retail cost	$ 9797.07
CO2 emissions	222052.32 lbs/year
Smart Thermostat - 4F cost savings	$ 1316.61
Smart Thermostat - 8F cost savings	$ 2325.84
TMY->AMY Smart Thermostat - 4F cost savings	$ 204.99
TMY->AMY Smart Thermostat - 8F cost savings	$ 103.41
HVAC Efficiency ECM	$ 1291.79
Gas HVAC ECM	$ 4276.69
Gas Water Heater ECM	$ 725.58
Heat Pump Water Heater ECM	$ 476.95
Insulation ECM	$ 736.27
Infiltration ECM	$ 1577.50
Lighting ECM	$ 2898.95

Exascale Computing Project

- Coupling:
  - Transportation (CommuterSim)
  - Weather (WRF, Nek5000)
  - Buildings (OpenStudio/EnergyPlus)
  - Population (LandScan)
  - Socio-economics
- Individual-person, agent-based models, fully-coupled simulations running on the fastest computers in the world

Argonne NATIONAL LABORATORY

OAK RIDGE National Laboratory

BERKELEY LAB

NREL NATIONAL RENEWABLE ENERGY LABORATORY

ECP EXASCALE COMPUTING PROJECT

Titan (ORNL), when the world's fastest 27 petaflops, world's 7th (top500.org)

Summit (ORNL), world's fastest in June, 207 PF

Aurora (ANL), Frontier (ORNL)

Exascale…

Discussion

HPC Tools for Modeling and Simulation
Capturing building energy consumption

Joshua New, Ph.D., CEM, PMP, CMVP
BTRIC, Software Tools & Models
Oak Ridge National Laboratory

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