Climate Research, Development, Demonstration, and Deployment Road Map:

Buildings Sector

Prepared for Bart Croes, California Air Resources Board (CARB)

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Supporting Material
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Introduction

While in the vanguard of delivering energy-efficiency and renewable energy in built environment—with three decades of concerted effort, and many successes from research to deployment—California buildings sector has a significant remaining greenhouse-gas (GHG) footprint. This stems from the combination of the state's sheer size, demanding climates, and prevalence of particularly energy-intensive building types. Upward pressures on energy demand from the California buildings sector—driven by an expanding building stock and the intensity of energy-using activiteis therein—have historically been roughly offset with energy-efficiency gains (Figures 1 and 2). To achieve significant reductions, such as the targets called for in AB32, thus requires much more significant efforts than have been marshaled up to this point.

Fortunately, opportunities to reduce GHG emissions associated with California buildings are not only significant but are also among the most cost-effective of those found in any sector.[1] In fact, a portion of the overall US-wide potential—10% to 25% according to a review of studies by McKinsey and Company[2]—comes at a zero or negative net cost in

[1] ~~IPCC Fourth Assessment Report.~~ 2007. Levine, M., D. Ürge-Vorsatz, K. Blok, L. Geng, D. Harvey, S. Lang, G. Levermore, A. Mongameli Mehlwana, S. Mirasgedis, A. Novikova, J. Rilling, H. Yoshino. 2007. "Residential and commercial buildings." *In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[2] This is the conclusion of a recent review of 250 GHG abatement programs across the US by McKinsey and Company. *Reducing US greenhouse gas emissions: how much at what cost?*, US Greenhouse Gas

the sense that the up-front investment required is recouped many times over the lifetime of the measure, and, in some cases has negative or negligible up-front cost. Similar cost curves were developed for the California buildings sector more than two decades ago.[3]

Reaching and even surpassing the AB32 emissions goals within the buildings sector is possible, as illustrated in the case of commercial buildings in Figure 3. Very aggressive efficiency gains combined with renewable energy production and offsets can ultimately yield buildings that provide the desired services to their occupants without generating GHG emissions. Identifying and capturing opportunities requires taking an end-use perspective, as illustrated in Figure 4.

This white paper lays out a roadmap for reducing the greenhouse-gas emissions from energy use in the California buildings sector. A series of companion papers commissioned by the California Air Resources Board address other sectors and crosscutting issues such as land-use planning and energy supply. For example, changing the albedo of roofs and roadways in cities will mitigate urban heat islands, which, in turn, will reduce air-conditioning energy use and associated greenhouse-gas emissions in buildings. The nexus of water, energy, and buildings provides another example not treated in this paper – improvements in end-use water efficiency will reduce buildings-related emissions associated with pumping, heating, and cooling as well as upstream savings in the water production, treatment, and treatment processes.

Other roadmapping exercises have treated the issues in far greater depth, although in most cases with a narrower scope (e.g. technology development only[4]) and/or a broader geographical scale.[5] The California Public Utilities Commission is currently in the process of preparing a Strategic Energy Efficiency Plan,[6] which includes elements with direct relevance to GHG reductions in residential and commercial buildings as well as HVAC systems. Some California roadmapping has been done in the past for specific "high-stakes, high-potential" segments of the buildings sector such as cleanrooms, laboratories, and datacenters.[7,8] Many of these other works focus primarily on energy,

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Abatement Initiative, December 2007, by McKinsey and Company. http://www.mckinsey.com/clientservice/ccsi/pdf/Greenhouse_Gas_Emissions_Executive_Summary.pdf

3 Meier, A., J. Wright, and A.H. Rosenfeld. 1983. "Supplying Energy Through Greater Efficiency: The Potential for Conservation in California's Residential Sector." University of California Press.

4 USDOE. <no date> "Building Envelope: Technology Roadmap". Developed by representatives of the building envelope industry, facilitated by the Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, U.S. Department of Energy. www.eere.energy.gov/buildings/info/documents/pdfs/envelope_roadmap.pdf

5 USDOE. <no date> "High-Performance Commercial Buildings: A Technology Roadmap." Developed by representatives of the commercial buildings industry, facilitated by the Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, U.S. Department of Energy. http://eetd.lbl.gov/emills/projects/buildings-roadmap/roadmap_lowres.pdf

6 California Public Utilities Commission. 2008. "2009 – 2020 Strategic Energy Efficiency Plan." http://www.californiaenergyefficiency.com/stakeholder_summary.shtml

7 Tschudi, W.F., D. Sartor, E. Mills, and T. Xiu. 2002. "High-Performance Laboratories and Cleanrooms: A Technology Roadmap." LBNL-50599. http://eetd.lbl.gov/EMills/PUBS/PDF/High_Tech_Roadmap.PDF

8 Tschudi, W.F., Xu, D. Sartor, and D. Stein. 2003. "High Performance Data Centers: A Research Roadmap." LBNL-53483 http://hightech.lbl.gov/documents/DataCenters_Roadmap_Final.pdf

with the associated GHG emissions representing a parenthetical consideration in most cases. The CARB Economic and Technology Advancement Advisory Committee (ETAAC) is developing an assessment that focuses on economic and GHG emission reduction technology advancements across all major sectors.[9] Recent studies have evaluated the potential for savings in California.[10]

Background

Globally, energy used in the buildings sector is responsible for 11 billion tonnes per year of greenhouse-gas emissions, or about a third of all emissions from human activity.[11] Buildings contribute a similar share to total emissions in California (and nearly 70% of all emissions from the power sector), divided roughly equally between households and commercial buildings (Figure 5), with a total of 122 million tonnes CO_2-equivalent in 2004.[12]

California's emissions remained essentially unchanged between 1990 and 2004, despite substantial growth in population, building stock, the intensity of activity within buildings. During this period, remarkable strides were made in reducing underlying energy-intensities (consumption per unit of value added), with 34% reductions in universities and schools, 26% in restaurants, 12% in hotels and motels, 11% in healthcare, and 8% in offices. Reductions in per-unit energy consumption in household energy were 29% for electric space heating, 19% for gas space heating, 18% for central cooling, 17% for refrigerators, and 4% for water heating.[13] Absolute energy use grew in both sectors, but less than economic output, employment, *or* floor area for the non-residential sector and less than population or number of households in the residential sector.

Thanks to initiatives born in the 1970s, California is distinguished as a world-class innovator in the development and application of energy efficiency and renewable energy in the buildings sector and elsewhere, attaining savings at a far greater rate than the rest of the country (Figure 1). Voluntary efforts such as utility programs contributed in similar proportion to mandatory standards (Figure 2), the savings were delivered at one-half to one-sixth of the cost of new supply alternatives. Over this timeframe, public policies motivated over $5 billion in utility investment in energy efficiency programs,

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[9] California Air Resources Board. 2007. Economic and Technology Advancement Advisory Committee (ETAAC). Discussion draft report (untitled), dated December 21. http://www.arb.ca.gov/cc/etaac/etaac.htm

[10] For an overview on existing residential and non-residential buildings, see CEC. 2005. "Options for Energy Efficiency in Existing Buildings", CEC-400-2005-039-CMF http://www.energy.ca.gov/ab549/index.html

[11] IPCC Synthesis Report, Figure SPM-3. Aside from CO_2, of the buildings sector total 2 GT CO_2-equivalents in nitrous oxide, methane, and halocarbons. See IPCC Fourth Assessment Report. 2007. op cit.

[12] Excludes sinks and sequestrations. Data from the Draft California Greenhouse Gas Inventory, with additional analysis by Jamesine Rogers. http://www.arb.ca.gov/cc/ccei/emsinv/emsinv.htm <accessed January 14, 2008>

[13] Murtishaw, S. 2007. "Energy Consumption in California's Buildings since 1990: An Indicators Assessment of Key Factors." California Energy Commission, PIER Energy-Related Environmental Research Program. CEC-500-2007-077.

most of which has been targeted at the buildings sector, and an additional $2 billion is slated for the next three years.[14]

California's success to-date owes itself in no small part to an effective fusion of science and public policy. Scientific reasoning was convincingly applied in the late 1970s to help planners understand the equivalences (and differences) between energy supply and demand through models such as "supply curves" of conserved energy.[15] This helped establish energy end-use efficiency as a legitimate part of the energy resource mix, paving the way for policy initiatives ranging from utility rebate programs driven by utility regulators to equipment and building standards enabled by the Warren-Alquist Act of 1975. In the flagship example, California appliance standards (later emulated at the national level) trimmed refrigerator energy use by 75%, even as the size increased by one-third.

Important public-policy conceptual frameworks such as "Least Cost Utility Planning" and "Integrated Resource Planning" were also born out of research methodologies, but rapidly became established within the framework of policymaking. Later, research institutions served as neutral brokers in convening the so-called "Collaborative Process" that led to fundamental reforms that decoupled utility profits from sales volumes, allowing a leveling of the playing field such that a utilities least-cost plan to be its most profitable plan. The collaborations involved the utilities, environmental groups, consumer groups and yielded consensus proposals to California policymakers.

Consumers have also shown that they can play a decisive role. Assessments showed that in the heat of the state's energy crisis of 2001, consumers contributed substantially to averting many hours of blackouts[16] – an important lesson that behavior can be just as important as technology in achieving energy or GHG goals.

Going forward, California is superbly positioned to address its GHG footprint. The state possesses a wealth of resources reflected in its substantial network of research institutions, advanced educational infrastructure, architecture and engineering practitioners, sophisticated utilities and energy service companies, considerable depth in the energy policymaking community, venture capitalists, advocacy groups, consumers and businesses who are increasingly motivated to address climate change, and political and legislative leadership that is committed towards attaining deep reductions in GHG emissions.

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[14] CEC. 2005. "Options for Energy Efficiency in Existing Buildings", CEC-400-2005-039-CMF http://www.energy.ca.gov/ab549/index.html

[15] Meier, A., J. Wright, and A.H. Rosenfeld. 1983. *op cit.*

[16] Goldman, C.A., G.L. Barbose, and J.H. Eto. 2002. "California Customer Load Reductions during the Electricity Crisis: Did They Help to Keep the Lights On?" *Journal of Industry, Competition and Trade,* 2:1/2:113–142.

Current Efforts

Scores of initiatives are currently underway,[17] which span the following domains:

- End-use technology development
- Systems integration, operations, diagnostics, commissioning
- Advanced metering and its role in enabling dynamic energy pricing
- Demand response, on-site generation, and microgrids
- Building-integrated solar photovoltaics
- Demonstration projects
- Design tools, benchmarking protocols, and best-practices guidelines
- Market data collection and analysis[18]
- Modeling (operations, energy demand, air quality, emissions scenarios)
- Voluntary programs (incentives, design assistance, information)
- Standards for buildings and equipment
- Training and capacity building
- Energy conservation ordinances
- Green-buildings initiatives at the state and local level
- Innovative financing from banks, utilities, cities
- Policy analysis and program evaluation
- Human dimensions, program design, and evaluation

Climate-relevant research and development directed at buildings energy issues is conducted at most universities in the state, national laboratories, and in the private sector. The research community has visualized the various domains of research that are needed to achieve fundamental improvements, as illustrated in the case of windows research in Figure 6.

The single-largest in-state R&D efforts involve the CEC's Public Interest Energy Research (PIER) program and California Institute for Energy and Environment (CIEE), while additional resources come from out of state by way of other state energy offices and federal agencies (USDOE and USEPA, DHS, and others). Foundations (e.g. the Energy Foundation) play an important role as sponsors of buildings energy research and policy-relevant studies in the State.

California also benefits from ongoing national initiatives from USDOE and EPA (R&D, efficiency standards, EnergyStar), Low-income Weatherization, Federal Trade Commission product labeling for appliances and equipment, and multi-state collaborative research and coordination through entities such as the National Association of State

[17] For a more detailed review of current programs and future potential, see CEC. 2005. *op cit.*

[18] California has state-of-the-art building stock surveys such as the California Commercial End Use Survey (CEUS). See Itron. 2006. "California End Use Survey." Prepared for the California Energy Commission, Report CEC-400-2006-005, 339pp. http://www.energy.ca.gov/2006publications/CEC-400-2006-005/CEC-400-2006-005.PDF

Energy Officials (NASEO)[19] and the Association of State Energy Research & Technology Transfer Institutions (ASERTTI).[20]

As a reflection of pervasive market failures as well as the recognition that energy-efficiency at the margin is often less expensive than expanding supply, both natural gas and electricity utilities have mounted significant "demand-side" programs. These include a multiplicity of strategies, including incentives, education/training, design assistance, research, demonstrations, and support of emerging technologies. Recently utilities have begun to offer some customers the ability to purchase offsets for their homes and vehicles.[21] Importantly, the utilities have developed and participated in substantial joint initiatives—some of which draw in other stakeholder groups--which pool talent, unify the message received by consumers, and minimize redundant efforts, etc. Current examples include Savings by Design,[22] the California Commissioning Collaborative,[23] and the Emerging Technologies Coordinating Council.[24] The California Public Utilities Commission and the California Energy Commission have been driving forces in these activities.

New multi-stakeholder initiatives are integrating public and private and well as technical and business dimensions, as exemplified by the Commercial Buildings Initiative whose goal is a carbon-neutral commercial buildings stock by the year 2030. Collaborting institutions include the Alliance to Save Energy, American Institute of Architects, American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE), Lawrence Berkeley National Laboratory, US Green Building Council, and the World Busienss Council for Sustainable Development.[25]

Efficiency and energy-performance standards for buildings and equipment are recognized as among the highest-impact and cost-effective means of managing energy use in the buildings sector. The key standards in California are standards Title 10 for appliances and equipment, and Title 24 for buildings.

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[19] See http://www.naseo.org/

[20] See http://www.asertti.org/

[21] For more information, see http://www.pge.com/about_us/environment/features/climatesmart.html

[22] This program is funded by California utility customers and administered by Pacific Gas and Electric Company, San Diego Gas and Electric, Southern California Edison Company, Southern California Gas Company and the Sacramento Municipal Utility District. For more information, see http://www.savingsbydesign.com/

[23] The California Commissioning Collaborative is a non-profit 501(c)3 organization committed to improving the performance of buildings and their systems. The CCC is made up of government, utility and building services organizations and professionals who have come together to create a viable market for building commissioning in California. For more information, see http://www.cacx.org

[24] The ETCC smoothes the path from the laboratory to the marketplace for promising technologies that help Californians save money and energy. It provides a collaborative forum for the five stakeholder organizations (the investor-owned utilities) to exchange information on opportunities and results from their Emerging Technologies activities. The CPUC finances ETCC operations out of IOU ratepayer Public Goods Charge funds, and provides regulatory guidance. The ETCC meets four times each year. For more information, see http://www.etcc-ca.com/

[25] For more information, see http://buildings.lbl.gov/CBI

The public sector has also begun to focus on the energy and GHG footprint of its own facilities. In December 2004, Governor Schwarzenegger signed Executive Order S-20-04, establishing California's Green Building Initiative (GBI). The Green Building Initiative commits the State to a series of actions that will result in a 20 percent reduction in the energy use of State-owned buildings by 2015 and calls for a 20 percent reduction in the energy use of privately owned commercial buildings. Public efforts to improve energy efficiency are being focused on the educational sector by the CPUC program for the UC/CSU campuses, the Collaborative for High-Performance Schools,[26] and in state government and private buildings by the multi-agency Energy Benchmark Work Group.[27] Private industry is also increasingly active, as illustrated by the Silicon Valley Leadership Group coordinating a portfolio of energy-savings demonstration projects in data centers throughout the state.

Research, Development, Demonstration, & Deployment Needs

With notable exceptions, the central thrust of buildings energy and climate R&D in California (and elsewhere) can be loosely characterized as emphasizing incremental component-level improvements (Figure 7), with relative underinvestment in systems integration. Integration is generally regarded as the next frontier of gains in energy productivity and emissions reductions (Figure 8). Market and institutional barriers have been well studied (Figure 9),[28] but robust solutions are yet to be achieved. In the demonstration and deployment domain many voluntary and standards-based initiatives have been mounted—with results that California can be extremely proud of—yet our tools for benchmarking and otherwise measuring the impacts, and making "course corrections" are still in relative infancy. Between these two tracks is what is often referred to as the "Valley of Death",[29] i.e. the bringing to market and to scale of innovations devised in the research environment. To its credit, California has become a leader in establishing emerging technologies programs to help bridge this void, but these efforts are still significantly under-resourced compared to the activities they are expected to bridge.

Issues and strategies developed in the past with a focus on energy *per se*, are readily repurposed for obtaining GHG reductions. However, they should be revisited and refined as necessary. Examples could include: (a) different cost-benefit calculations and "optima" for fuel choices, based on valuation of GHGs,[30] (b) bottom-up inventories of GHG-reduction options, (c) co-benefit valuation, (d) understanding end-user price elasticities that can be expected once the cost of GHG reductions is internalized, and (e) addressing non-energy GHGs such as those associated with refrigerants. In this same spirit, efforts made decades ago to make the technical and business case for equating

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[26] For more information, see http://www.chps.net/
[27] For more information, see http://www.h-m-g.com/downloads/EnergyBenchmarking/
[28] See also the discussion in Levine et al., *op cit.*
[29] Mills, E. and J. Livingston. 2005. "Traversing The Valley of Death." *Forbes*. November 18. http://www.forbes.com/2005/11/17/utilities-emerging-tech-cz_1117energy_programs.html
[30] E3 and HMG. 2006. "Time Dependent Valuation of Energy for Developing Building Efficiency Standards: Methodology Report." Energy & Environmental Economics and Heschong Mahone Group, April 1, 34pp.

energy savings on the demand-side to new supply projects need to be mirrored with new efforts to understand and motivate the equivalencies between reducing emissions at the point of end-use with "end-of-the-pipe" strategies. The existing community of energy-management and renewable technologists is well-equipped to undertake these questions. The community of researchers in the arena of human behavior and energy-efficiency is beginning to turn its sights to climate change as well.[31]

Reaching carbon reduction targets requires the attainment of the following objectives:

- A mix of improvements in end-use energy efficiency and zero-carbon energy supply, addressing both new and existing buildings
- Stepwise, rather than incremental technology innovation
- Coordinated public-private partnerships and investment
- A combination of voluntary and mandatory initiatives to mainstream best practices and achieve high market penetration
- An improved information environment so that carbon emitters and intermediaries understand their "footprint" and the opportunities for reducing it
- A shift in consumer and decision-maker values and behavior to lend higher priority than at present to addressing climate change

Following are ten broad strategic goals for continuing California's progress towards reducing buildings-related greenhouse-gas emissions, and associated initiatives that extend or fill gaps in existing initiatives.

1. **Ensuring that new technologies (including information technologies), materials, tools, and processes are continually in the pipeline along with adequate technology assessment for policymakers.**
    - Establish more cross-disciplinary R&D efforts to generate innovation, e.g. applying materials science to the design of advanced sensors, low-albedo roofing materials, solar cells).
    - Simultaneously pursue component and system energy efficiency improvements; incremental (e.g. more efficient HVAC equipment) as well as disruptive innovation and process change (e.g. solid-state lighting; DC circuits for DC loads) (Figure 7).
    - Develop sensors, controls and diagnostics, and predictive algorithms, e.g. embedded within technologies – wired and wireless. Particularly important for fault detection and enabling demand response, i.e. actions to reduce load when there are supply-demand imbalances or economic drivers to shift or save energy at the margin – extend to have emissions determinants (generation mix).
    - Develop network-enabled systems for information collection, management, feedback, control, and decision support.
    - Integrate Energy Management Systems (EMS) and Energy Information Systems (EIS).

[31] *Behavior, Energy, and Climate Change Conference*. 2007. Sacramento, CA, November 7-9. http://piee.stanford.edu/cgi-bin/htm/research_behavior_becc_conference.php?ref=nav4

- Improve building design and operational models/tools, with emphasis on whole-buildings and systems integration and extension/adaptation of energy analysis to emissions.
- More rigorous analyses of decision-support tool interface design and usability.
- Perform uncertainty analysis: technical and economic.
- Quantify and assess trade-offs between embodied energy/emissions in new technologies and emissions avoided in their use.
- Continual technology assessment and demonstration of new technologies and practices to validate initial performance and persistence.
- Harmonize public- and private-sector research activities, ensuring that the highest-risk pre-commercial research is undertaken by the public sector.
- More effectively integrate the investment, finance, and risk-management communities into the R&D process to help scope opportunities, proactively anticipate barriers, and vet their potential for success in the market.

2. **Transcending a "silo mentality" so as to integrate supply- and demand-side strategies (particularly with respect to renewables), while integrating emissions objectives with other agency missions.**
    - Achieve better integration among end-use technologies (windows lighting space conditioning) and between demand and supply (via demand response and building-integrated non-GHG thermal energyor power production). The cost of GHG reductions can be mimized through an improved process of "right-sizing" whereby end-use efficiency is used to help optimize the size and cost of matched energy supply equipment (e.g. devices that use and generate process heat).
    - Deploy GHG-free onsite power, CHP, and microgrids. Operational algorithms and controls needed to manage absence of storage, balancing of heat and electric loads, power quality and reliability valuation, and human/operator behavior.
    - Develop technology and management systems driven with real-time data (weather, energy, occupancy, indoor environmental requirements), and account for anticipated changes in climate and weather on the performance and emissions.
    - Identify and remedy inadvertent tax, policy, and structural deterrents to emissions reductions, e.g.:
        - Allocation of transmission and distribution benefits to on-peak periods rewards load-shifting equally to demand reduction, yet demand reduction may have a larger carbon benefit.
        - CAL/OSHA standards for fume-hoods inadvertently preclude safe and significantly more energy-efficient laboratory fume hoods from the market.

3. **Understanding and maximizing co-benefits of emissions reductions as sources of value and motivation for consumers will increase participation rates and investment in emissions reductions.**
   - Emphasize important additional drivers: occupant productivity, health, comfort, safety, security, disaster-resilience, employment creation, and risk management (physical, legal, financial). The economic value of productivity gains achieved by properly optimizing indoor environmental conditions is 50- to 100-times that of the energy cost savings.[32] Conversely, sub-optimized efforts to maintain comfort can have energy (and GHG) penalties.
   - Better understand and maximize synergisms between buildings efficiency, indoor environmental quality, and resilience to chemical and biological agents.[33] Demand-controlled ventilation and filtration systems provide one example.
   - Enlist involvement of allied sectors, e.g. insurance, banking, health and safety, disaster preparedness, real estate marketing. These entities are increasingly recognizing the risks and opportunities of climate change.[34] For example, insurers have recognized that buildings' GHG emissions pose potential liabilities.[35]

4. **Improving methods for decision-making and understanding social determinants, sources and processes of technological change, and institutions for managing global change.[36]**
   - Develop information channels such as GHG benchmarking tools and ratings/labels to help building owners and operators assess opportunities. Deeper understanding should be gained on how to design and effectively deliver these tools to end users.
   - Improve understanding of the role of lifestyles and behavior (versus tech fixes) in forecasting and potentials studies, e.g. fuel switching, comfort and lighting control. Telecommuting is becoming increasingly common, which shifts energy-using activities from non-residential buildings to residential buildings.
   - Improved understanding and influence of the role of human-based operations, maintenance and other factors in determining persistence of GHG reductions.

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[32] Fisk, W.J.; Seppanen, O.; Faulkner, D.; Huang, J. 2005. "Economic benefits of an economizer system: energy savings and reduced sick leave." *ASHRAE Transactions*, Volume 111, pp. 673-679.

[33] See http://securebuildings.lbl.gov/

[34] Washington Post. 2008. "Insurers Paying to Rebuild Green Homes." January 8. http://www.washingtonpost.com/wp-dyn/content/article/2008/01/08/AR2008010802631.html?referrer=emailarticle. See also http://insurance.lbl.gov

[35] Shapiro, S. 2007. "Buildings' Carbon Emissions Pose Potential Liability." *Business Insurance*, October 22, p. 14.

[36] An excellent overview of the issues and research needs is proved by L. Lutzenhiser, "Setting the Stage: Why Behavior is Important". [36] *Behavior, Energy, and Climate Change Conference*. 2007. Sacramento, CA, November 7-9. http://piee.stanford.edu/cgi-bin/htm/research_behavior_becc_conference.php?ref=nav4

- Improve tracking of GHG emissions and GHG reductions from various building types: commercial, residential, schools, industry and government facilities, at the building and end-use levels.
- Improve the validity of behavioral assumptions underlying efficiency program design and projections of impacts: economic rationales, attitudes, actions taken *in lieu* of programs or policies.
- Execute more thorough market segmentation in program and policy design. Given the huge variations among types of buildings and occupants, it is critical to segment non-residential customers and develop tailored strategies, e.g. healthcare, hi-tech, schools, and small business. This also applies to the household sector, not only in terms of building type and demographics, but also with attention to the trend towards home offices and telecommuting, which introduces new technologies and behavioral patterns influencing household emissions.
- Study and enhance decision-making among policymakers, program administrators, and program implementers.
- Study and enhance the dynamics of innovation among producers of energy technologies and services.

5. **Building capacity to deliver technologies and services in a context where demand will otherwise outstrip supply. The need for implementation currently outstrips the available qualified workforce.**
    - Improve and expand training across all relevant discipines: architecture, basic and applied sciences, building operations and management, engineering, real estate, finance, public administration, etc.
    - Improve and expand training at all levels, i.e. K-12, technical/vocational, advanced educational institutions.
    - Improve product and service certification procedures.
    - Improve training of code compliance officials.
    - Establish industrial infrastructure to manufacture necessary technologies

6. **Becoming more sophisticated in designing and targeting deployment efforts to balance voluntary and mandatory measures for achieving sustained market transformation.**
    - Identify opportunities that cannot be predictably captured with voluntary efforts (candidates for standards), and articulation of voluntary programs tailored to extend savings beyond the floor established by standards. Standards for existing buildings may be motivated by these findings.
    - Advance the analysis, development, and deployment of building and equipment energy codes, e.g. through application of time-dependent valuation of energy resources and supply-related emissions.[37]
    - Standards that encompass buildings with own generation.
    - Improve tools, training, and incentives for developers and owners, as well as compliance officials.

[37] E3 and HMG. 2006, *op cit.*

- Improve engagement and coordination among local, state, and federal government initiatives.
- Develop and issue "Beyond-Code" voluntary standards, with links to utility incentive programs.
- Water-efficiency standards that reduce on- and off-site energy use and emissions.

7. **Scaling up the delivery of GHG reductions, managing uncertainties, and minimizing the risks of under-attainment.**
    - Revisit the needs of underserved and hard-to-reach market segments, e.g. low-income and small businesses.
    - Interject GHG-reduction efforts at critical points in a building's lifecycle, e.g. mobilizing information, incentives, and financing; directed specifications, purchasing, and procurement strategies; and efficiency upgrade requirements at the time of sale.
    - Significantly expand the existing programs, standards, and other mechanisms for energy-efficient buildings and equipment. Many proven strategies are available: product labeling, home ratings, tax incentives, performance incentives, utility rebates and support, and energy service companies (ESCOs).
    - Create improved "market pull" by enabling consumers (residential and non-residential) to value and demand high-quality products and services, and a systems-level (rather than piecemeal) strategy.
    - Improve the design process for new buildings and retrofit, operation, and maintenance of existing ones.
    - Improve GHG estimation tools used during the design process
        - Baseline GHG emissions based on meeting Title-24 Energy Code
        - GHG emissions reductions based on % exceeding Title-24 Energy Code
    - Improve quality of GHG emission factors for energy usage based on region/climate zone, utility provider and/or time-dependent[38] valuation of energy (emissions vary depending on hours used and peak demand) rather than annual averages.
    - More fully utilize building tune-ups, commissioning, measurement & verification, and other quality-assurance strategies essential to securing projected benefits, irrespective of the deployment strategy.
    - Evaluate and quantify of GHG-offset products and tradeable certifications, and provide objective information to buyers.

8. **Making buildings more resilient to climate change, while capitalizing on synergisms between emissions reductions and climate change adaptation.**
    - Understand the implications of climate change for building energy systems and their operation (e.g. space conditioning, evaporative cooling).
    - Incorporate climate changes into macro-level models of human settlement patterns (and associated energy demands).

[38] E3 and HMG. 2006. *op cit.*

- Identify and evaluate technologies and practices that simultaneously reduce emissions while enhancing adaptive capacity (e.g., mitigating urban heat islands and distributed-generation strategies to manage the risk of power outages).[39]

9. **Exhibiting leadership by example among public-sector buildings.**
    - Intensify efforts to reduce GHGs from public buildings to help pave the way for private sector implementation.
    - Design comprehensive approaches to go beyond buildings to include transportation, etc. Example: Greening of the U.S. Capitol project.[40]

10. **Improving the timeliness and practice of policymaking and program evaluation (consumer impacts, delivery process, and market effects) with feedback to the research and deployment processes.**
    - Provide more systematic identification of market barriers and failures, and strategies designed to overcome them.
    - Develop more sophisticated experimental design, e.g. nested in-depth evaluation, and tracking of progress towards goals.
    - Extend/modify the methods developed for assessing energy-efficiency programs for GHG-driven programs.
    - Identify best practices in evaluation, creating of guidance documents and frameworks.
    - Minimize perceived adversarial role of evaluators: engage at inception of programs, more interim constructive feedback, improved dissemination of results and lessons learned.
    - Apply and tailor successful efforts and frameworks developed at the national level to the California context.[41]
    - Ensure that due credit is given to individuals and institutions that run successful initiatives.

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California stands to remain a leader in the management of buildings energy use, and now greenhouse-gas emissions. Traditional energy considerations *per se* will be with us into the indefinitely (security, cost, productivity, and non-climate environmental impacts). The addition of GHGs makes an already complex problem even more complex, and the rewards of progress far greater.

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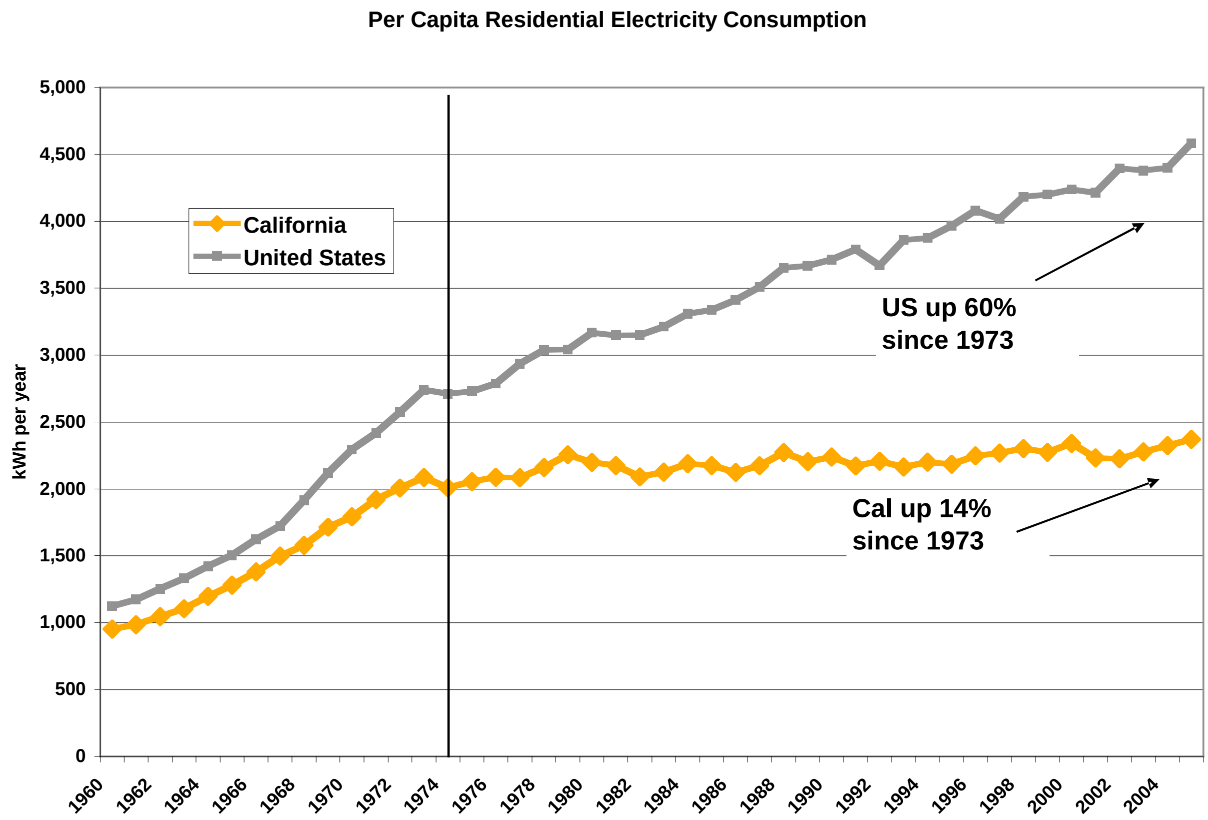
[39] An entire special issue of the journal *Mitigation and Adaptation Strategies for Climate Change,* vol 12, no 5 (2006) assembled a collection of articles to this topic.

[40] Beard, Daniel P. 2007. "Green the Capitol Initiative: Final Report." Washington, DC: U.S. House of Representatives, Chief Administrative Officer. June 21. http://cao.house.gov/greencapitol/green-the-capitol-final-report.pdf

[41] Reed, J.H., G. Jordan, and E. Vine. 2007. "Impact Evaluation Framework for Technology Deployment Programs: An Approach for Quantifying Retrospective Energy Savings, Clean Energy Advances, and Market Effects." U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. http://evalframework.org/Evalframework/Framework_Draft_2_Page_One.html



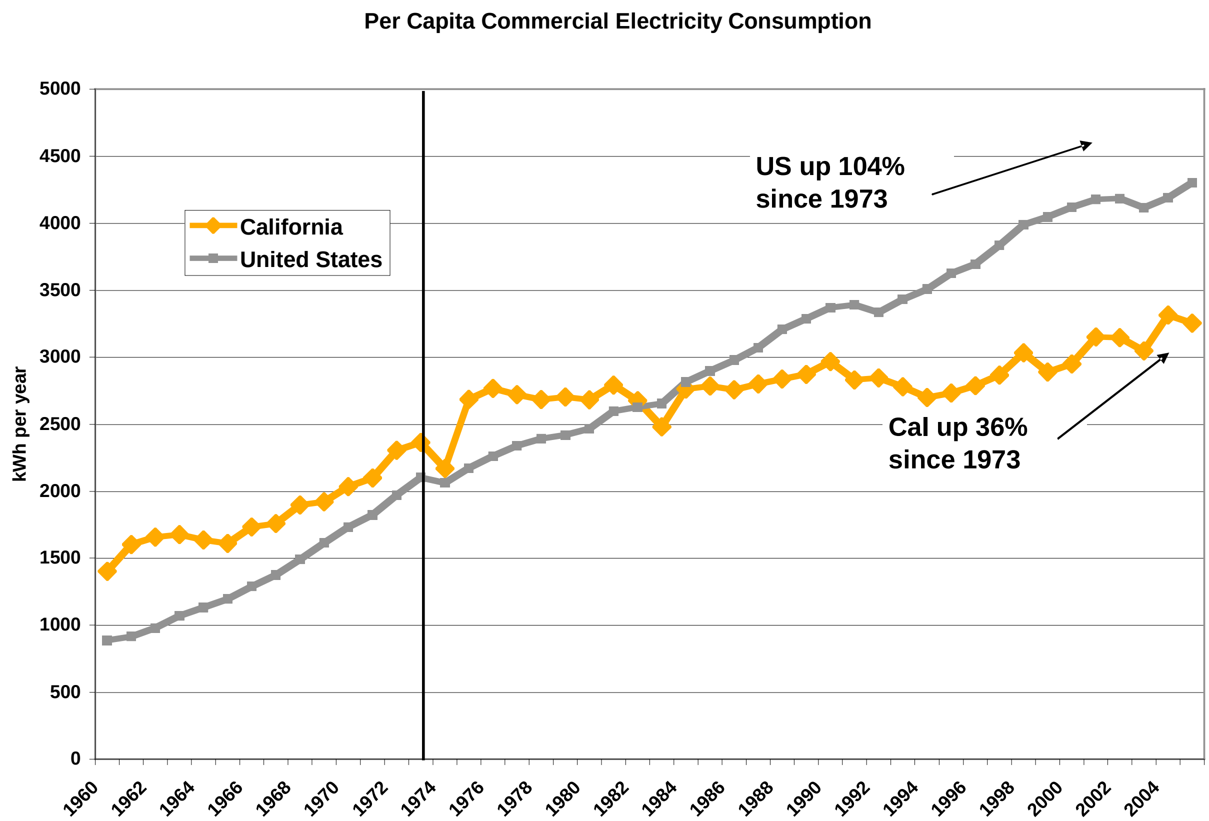


Figure 1. Reductions in energy intensity in California compared to the United States: residential sector (above) and commercial sector (below). Source: Arthur Rosenfeld, California Energy Commission.

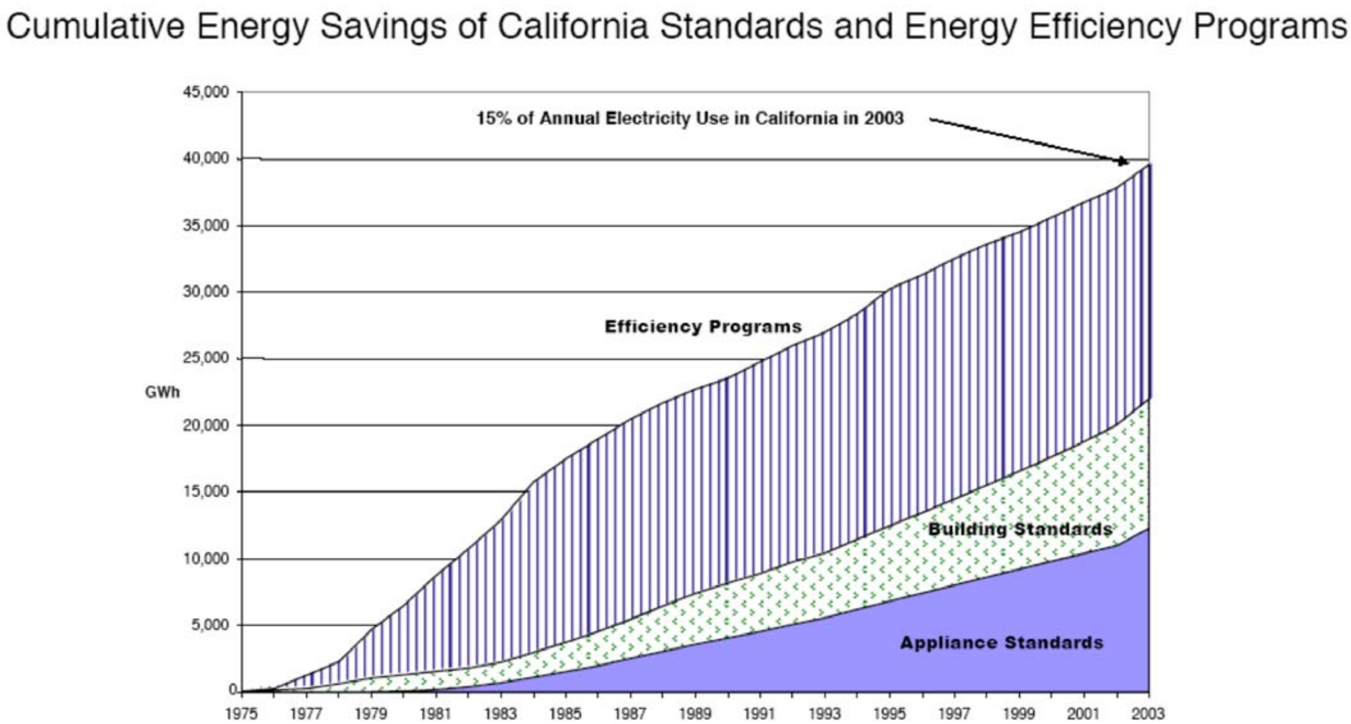
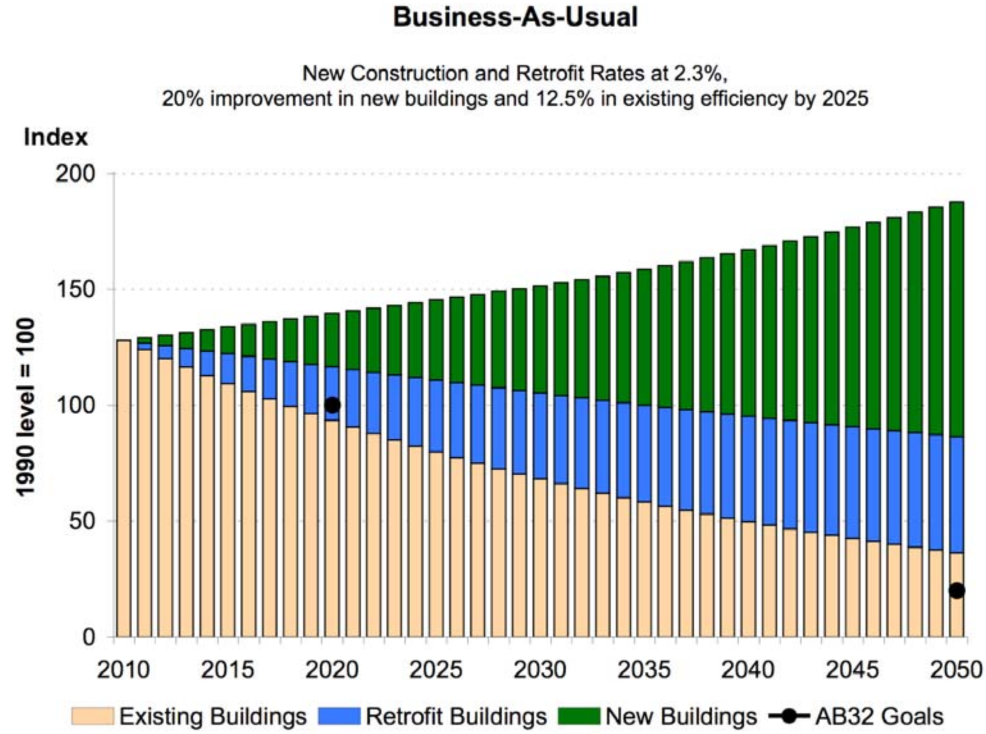


Figure 2. Cumulative buildings energy savings from California standards and voluntary programs. Source: CEC "Options for Energy Efficiency in Existing Buildings", CEC-400-2005-039-CMF, Dec 2005

Carbon Emissions Scenarios for California's Commercial Buildings Sector



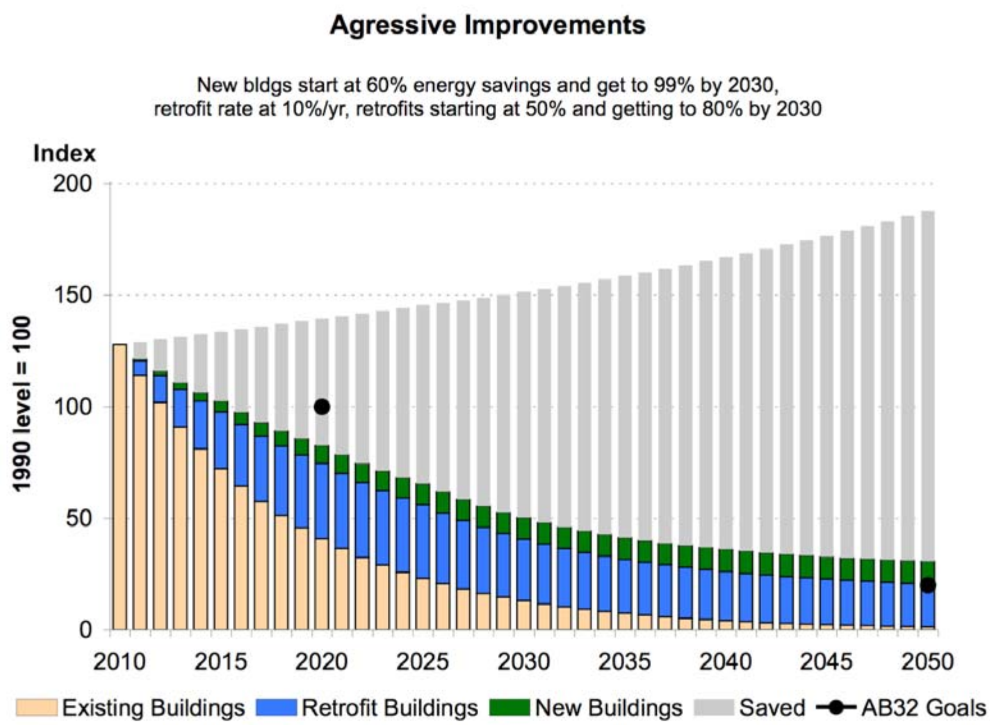


Figure 3. Scenarios of growth in energy use with current rates of efficiency improvements versus with targets for maximum efficiency. Includes only energy used within buildings; excludes associated energy such as that associated with the provision of water. Assumes constant carbon content in energy supply mix. Does not include building-integrated renewables. Prepared by Sam Borgeson and Brian Coffey, LBNL.

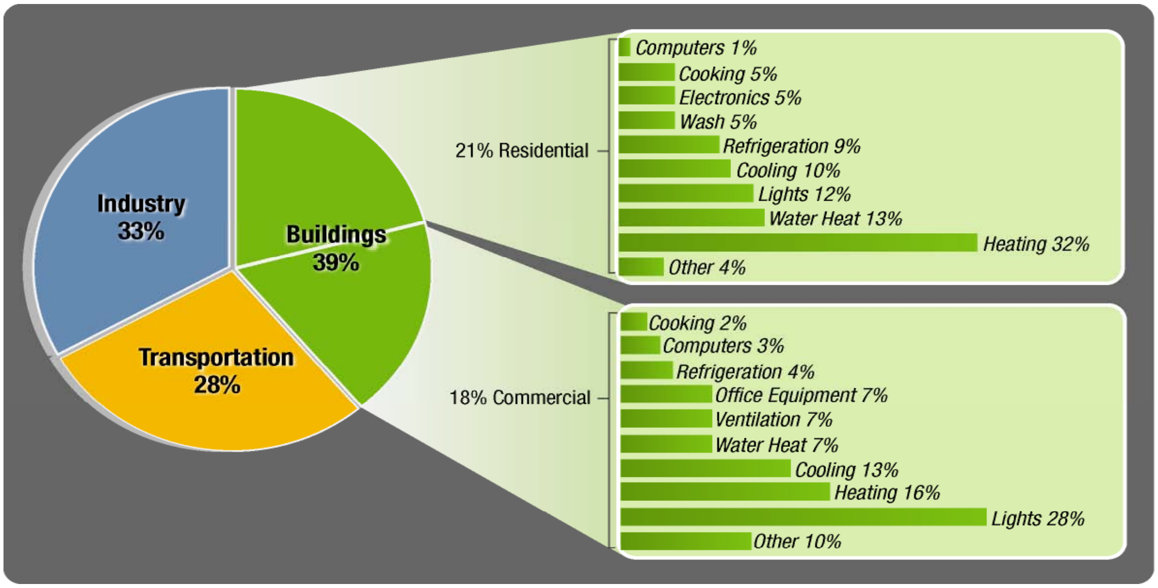


Figure 4. End-use breakdown of carbon emissions in the U.S. buildings sector.

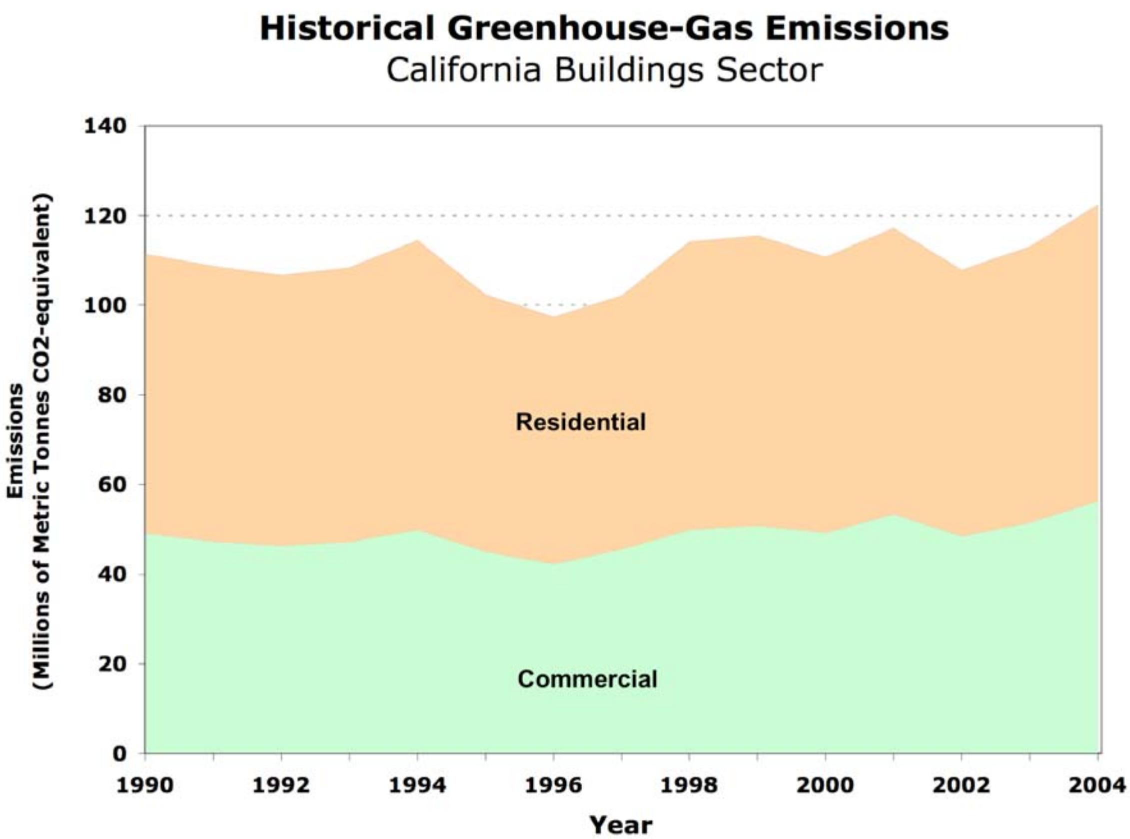


Figure 5. Trends in greenhouse-gas emissions from the buildings sector. Includes both "direct" emissions from fuel combustion in buildings and "indirect" emissions from the production of electricity used in buildings. Data source: Jamesine Rogers, California Air Resources Board.

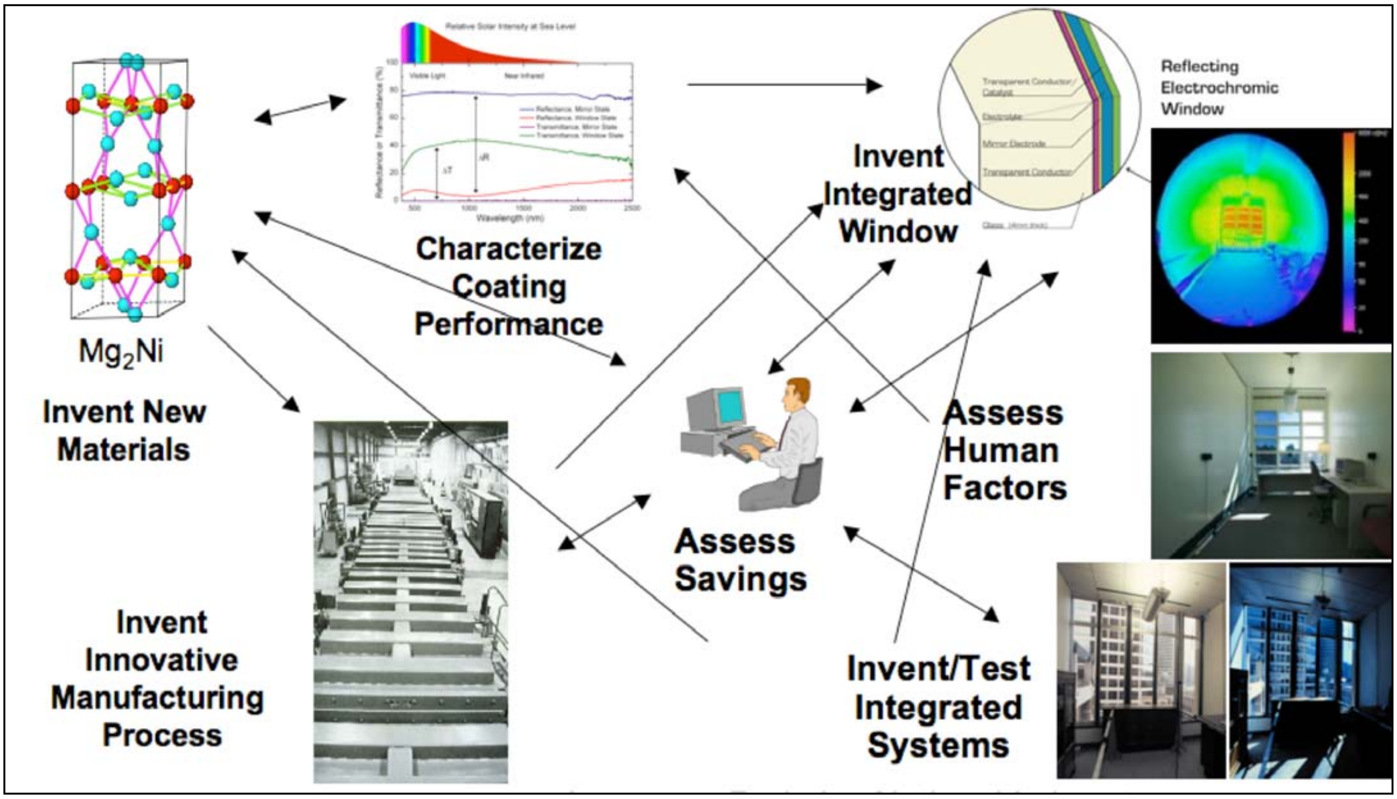


Figure 6. Example of integrated R&D needs in the case of windows.

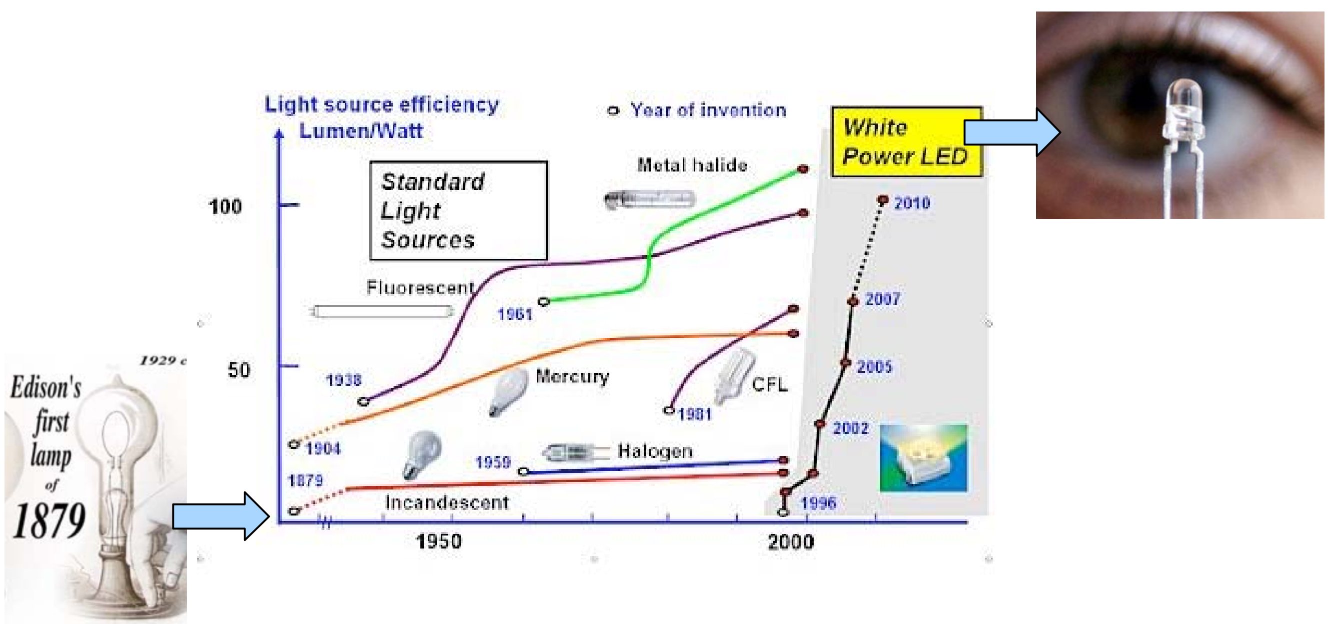


Figure 7. A century of electric lighting technology, with the "disruptive" entry of solid-state white lighting ("LED) in the past decade.

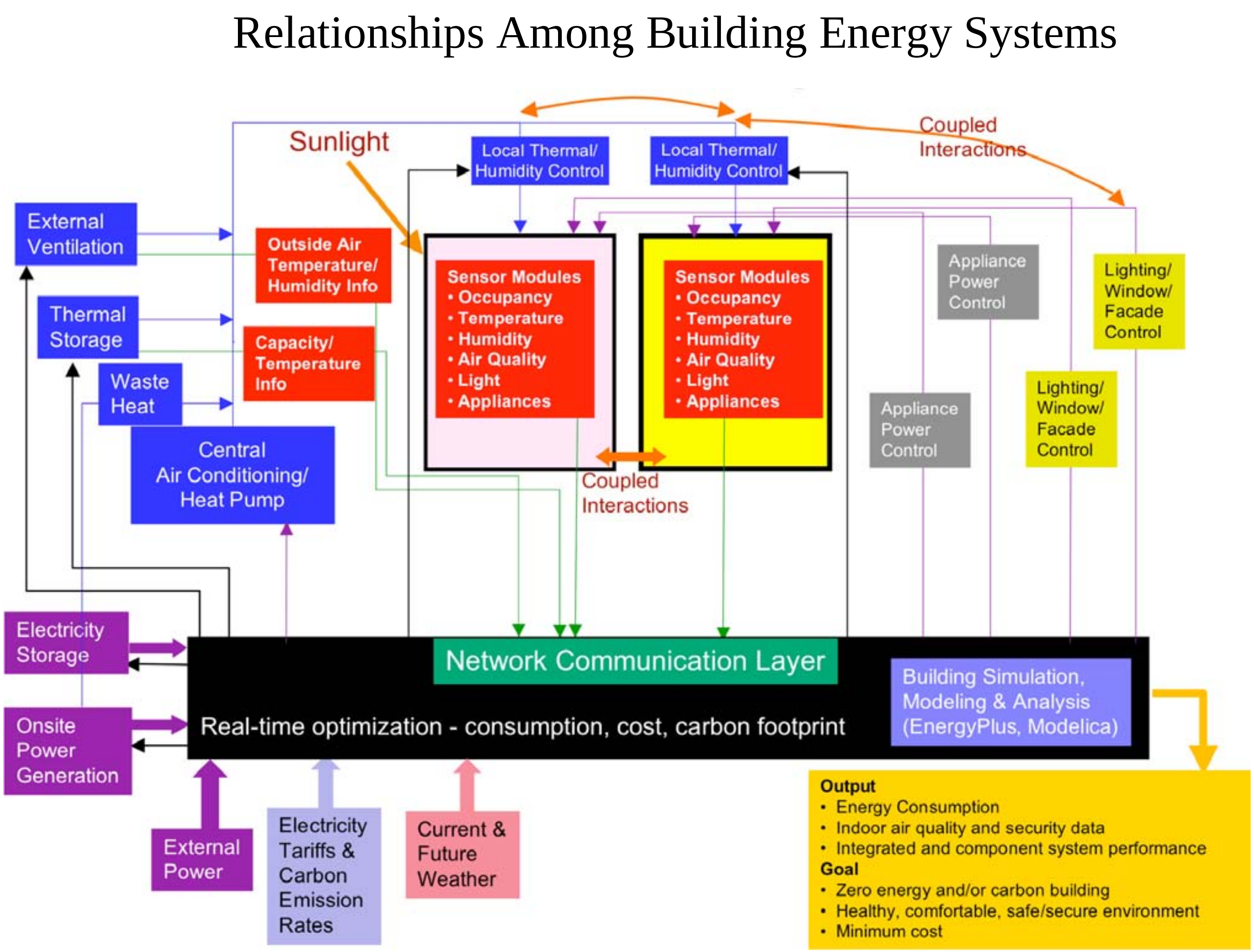


Figure 8. Source: Lawrence Berkeley National Laboratory

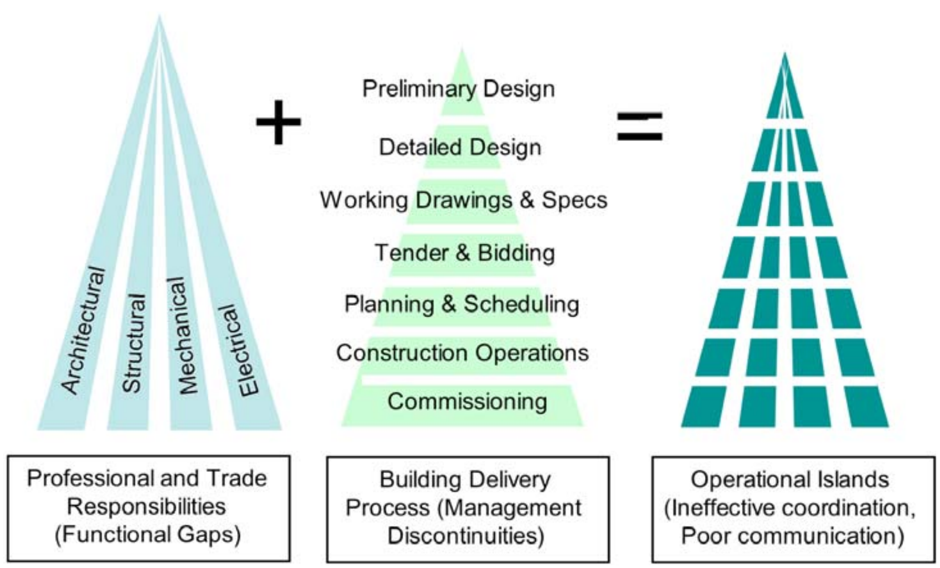


Figure 9. Source: World Business Council for Sustainable Development, project on energy efficiency in Buildings