Introduction

The United States faces an enormous challenge centered around providing useful "energy" services in a world with a growing population and growing standard of living. In the short term (next 20 years) resources are constrained; increasingly expensive; impact national and international economic stability; impact lifestyle and political stability; are linked to challenging global security issues; have generally negative local environmental impacts on air quality, water quality, biodiversity; and increasingly are at the center of a global effort to slow climate change by reducing carbon emissions.

To date the primary national focus has been on the supply side-seeking new sources to fuel current energy consumption patterns. This is at best a partial solution and may not be capable of addressing all the issues above on a global basis, in a timely (depending on technology maturity) and cost effective fashion (depending on the load requirements). Numerous recent studies note that the fastest and cheapest approach to impacting this is reducing demand via energy efficiency. (Note- reducing demand via other strategies such as reducing services is also an option but with other socio-economic and political consequences.). It is commonly believed that efficiency gains are limited to small reductions, namely 10-20%. In fact when the focus is on delivering a needed service with the lowest possible energy use, reductions greater than 80% are feasible and have been demonstrated. If this level of demand reduction could be achieved and sustained across the economy it would fundamentally change the energy supply/demand equation.

Aggressive energy efficiency efforts ought to focus on the largest end use and the fastest growing end use. Buildings are the largest end use (40% of total) in the U.S. and the fastest growing. They are also the largest user of electricity (> 70%), which is also the fastest growing energy use and the largest carbon emitter, with the majority of power coming from the use of coal. The electric grid that supplies these energy services today represents an expensive, relatively fragile and inflexible infrastructure and peak electricity needs from buildings are even more disproportionately attributable to buildings. The Energy Usage Index (EUI) profiles of the commercial building stock over the past thirty years (see Fig. 1) is indicative of the status of energy consumption in buildings and the challenge in getting to net zero energy buildings. The anticipated growth in building and industrial loads coupled with new applications such as electric and plug in hybrid vehicles will require significant new base loading generation capacity. The options to provide this capacity are limited and expensive and have serious trade offs between costs and carbon emissions. One part of the solution is aggressive end use energy reductions and demand control in the building sector. This will generate numerous (environmental, societal and economic) benefits that would facilitate achieving national goals on many fronts.

Not for distribution without permission of Arun Majumdar (LBNL) and Clas Jacobson (UTC)

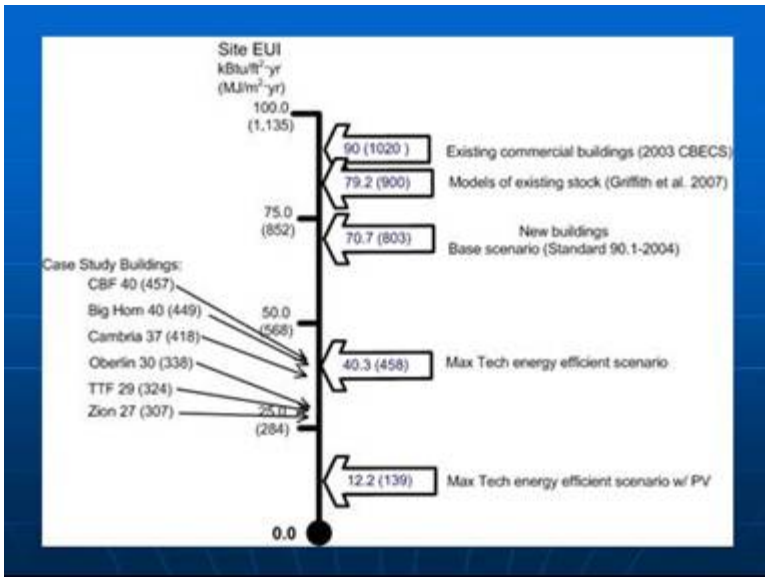

Figure 1. Survey of Energy Use Index (EUI) showing current building stock performance relative to goal for net zero energy buildings (extracted from "The Path to Net Zero Energy Buildings", Harrison, Feb. 2008; http://www.arkansasashrae.org/Speaker%20Slides/0802%20Arkansas%20Chapter.ppt#256,1,The Path to Net Zero Energy Buildings)

The opportunity to save energy in buildings has not gone unnoticed. There have been a wide variety of programs and actions over the last 3 decades with some impacts on energy use. However the overall impact has been to reduce the rate of growth, at a time now when absolute reductions are needed. Furthermore building energy performance differs from energy use in other sectors in several important ways, which must be understood if changes are to be made:

1. The building sector is diverse- by type, size, climate, age, ownership model, and usage.
2. The sector is large but fragmented- with 10% of GDP and $1.5T annual expenditures but a structure very different from other capitol industries or businesses such as auto or aircraft.
3. There are many players and policies, national and local, that influence technical decisions and investment decisions.
4. Decisions that influence energy use permeate the design and construction process- there is no single point of intervention.
5. The building design and construction process is largely non-integrated with many silos and handoffs. This makes the delivery of high performance buildings difficult.
6. Energy use is dominated by 3-5 major end uses, e.g. heating, cooling, lighting but a large fraction of total use is attributable to many smaller functions. This breakdown varies enormously
7. Actual operation of the building is a major determinant of final energy use as well as design parameters. This is both a matter of systems maintenance and actual

Not for distribution without permission of Arun Majumdar (LBNL) and Clas Jacobson (UTC)

operations vs design intent as well as the issue of user behavior.

While there are numerous state, local and utility funded energy efficiency programs these have had a nominal impact on overall usage. A more dramatic, large scale program is required to achieve a goal of "zero net energy performance" by 2030 (ASHRAE ref), with the understanding that this is achieved by a very large reduction in actual energy needs (50-80%) and then supplemented with on site power to get to a net zero level. The technical viability of such an approach is promising - the apparent difficulty in attaining these goals routinely and cost effectively defines the challenge. To date these strategies have been applied largely to new construction; addressing the nations energy challenge requires that this be extended to existing buildings as well.

Addressing the Challenge

New approaches and new actions are needed if these aggressive goals are to be realized. The key challenge is to achieve the very aggressive level of performance (i.e. net zero) that has been reached to date by one of a kind solutions, and make them routine, robust, cost effective and persistent. Furthermore the approach must be sufficiently flexible that it can be applied successfully to all building types, all climates, all ownership models and be applicable to both new and existing buildings.

A new effort, HiPerBRIC, is proposed to create the enabling technologies and systems, design methodologies, processes and tools to accomplish these goals. The goal for this program is to establish a partnership consisting of government, industry, and academia with the goal of conducting the necessary research to deliver on the stated goals of zero energy buildings. The focus will be on the necessary delivery methods, modeling, tools, computational methods and basic science required for the economical delivery of high performance buildings and building technologies enabling broad market adoption. The project will consist of a series of interrelated project tracks. Each of these will focus on core elements necessary for achieving the stated goals in a measurable fashion. The program will define a series of deliverables and milestones for introducing solutions, impacting the design and delivery process and implementation of specific technologies and systems, to industry. The overall focus is intended to be on the more complex, longer term deliverables with the expectations that near term deliverables will be achieved by other programs under the supervision of the Department of Energy, Industry Groups (ASHRAE, AIA, USGBC and others), State and local Government and Utility programs.

Proposed Program Tracks

The HiPerBRIC program is focused on all elements of the process required for the design, delivery and operation of buildings. The realization is that the delivery of high performance buildings requires improvements in all of these areas. Significant improvements are possible in the short term through the sharing of best practices, use of

Not for distribution without permission of Arun Majumdar (LBNL) and Clas Jacobson (UTC)

"best in class" systems and improved operational procedures and tools. However the delivery of the zero net energy goals at a commercially viable, economical level will require further improvements. These will include new tools, methods and systems that are not readily available in the market today. This needs to start with the basic science in areas such as understanding of human comfort and factors, physics and dynamics heat rejection and mass and momentum transfer, and innovative technologies for building heating, cooling, lighting, material and power. A suite of tools, models, and platforms are required to synthesize and optimize implementations of the innovative systems, and for the definition, testing and optimization of the new integrated systems. To achieve this a series of research projects, test beds, pilot projects and collaborations is necessary. Finally methods of readily delivering these in a commercially viable manner must be developed. It is the methods and systems required to deliver these future, high performance systems that HiPerBRIC intends to focus on.

The specific tracks proposed for this project are as follows (and illustrated in Figure 2).

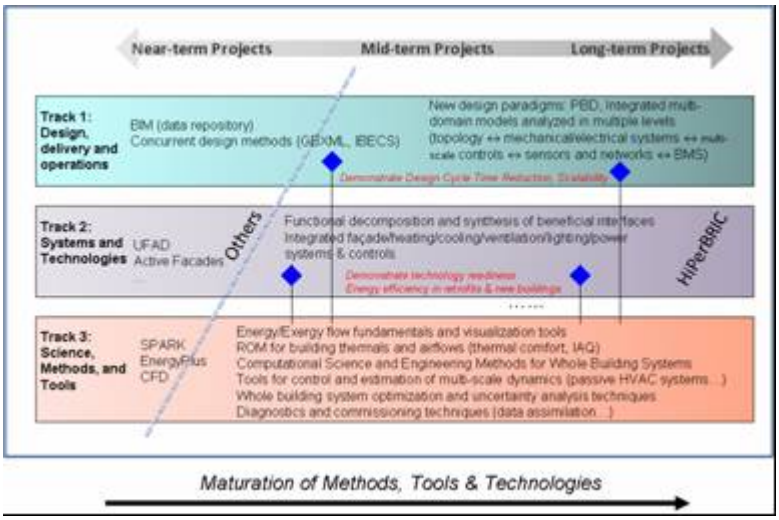

Figure 2. Proposed program tracks for HiPerBRIC, illustrating the key areas for research, development and transformation focus.

<u>Design and Delivery</u>

The design and delivery track is focused on developing and maturing methods used to design and deliver systems for both new and existing buildings. This track focuses on the required tools and methods that architects, engineers, contractors and operators will use for future net zero energy buildings projects. Projects conducted in this track would seek to implement new processes and toolsets in the context of specific low energy building designs and quantify the benefits in design cycle time reduction and improved performance verification capability. The specific advances required in understanding of the underlying building physics and dynamics, the associated models, analysis framework and tools will be the focus on the third track. Examples of methodologies, processes and tools proposed to be developed and matured include:

Not for distribution without permission of Arun Majumdar (LBNL) and Clas Jacobson (UTC)

- Use of digital models (such as BIM) for use in integrated design, construction, and operations
- System-level methodologies to analyze and optimize the configuration and integration of building components and subsystems
- Environment for integration modeling and analysis tools to enable cost-performance trades at various scales of a building and stages of the design and delivery process
- ……

MISSING (pending input from Phil Haves & Steve Selkowitz-LBL): Support of operations (for continuous commissioning, maintenance and regular facility operations) and innovation. Innovation paradigm: Structure systems as collection of components (or subsystems), that are compartementalized the same way as an actual system is compartementalized (eg., a pump only sees states at its flanges and controls signal, similar for packaged unitary equipment). Operations paradigm: Tools and data support for end-user to manage building, diagnose problems quickly and ensure "tuned" building performance (relative to original design intent).

Systems and Technologies

The systems and technologies track is focused on the integrated systems and innovative subsystems that will be required to realize high performance buildings with significantly lower energy usage footprint. These systems include the building envelope, site placement, mechanical, electrical, controls and structure. Each of these systems will need to not only be highly optimized to reduce energy usage (as is being done currently), but will also need to be tightly integrated to take maximize energy efficiency. Just as importantly, they will need to be delivered in a form that is both economical and readily used by current and anticipated future industry players. To do this will require a focus on not just the technology used in these systems but also the proper methods of delivery, serviceability, cost, integration and operability of these systems. Projects conducted in this track would seek to identify, engineer, develop and mature (via demonstrations) innovative systems that result in measurable, non-incremental gains in energy demand reduction in new construction buildings as well as retrofit building. The engineering of these systems will employ and leverage advances made in system synthesis and analysis methods (proposed in the first track) and methods and tools being proposed in the third track (to follow). The project investments needed here include identification of new technology solutions, optimization and scalable designs and prototypes of solutions for which physical implementation is already defined or those for which the implementation strategy is understood but not the implementation details. Examples include:

- Separation of ventilation from heating and cooling
- Optimized VAV, mixed mode and passive/natural ventilation systems
- Radiant heating and cooling systems
- High efficiency lighting systems and controls

Not for distribution without permission of Arun Majumdar (LBNL) and Clas Jacobson (UTC)

- Innovative thermal storage systems
- Combined heat and power
- Optimized on site renewables
- …….

Science, Methods and Tools

In the buildings area there has been relatively little research conducted over the last 50 years on basic areas related to the delivery of building services including comfort, safety, and indoor environment. The purpose of this track is to propose investments in understanding the basic physics and dynamics of heat, mass, momentum and information transfer that underlies the building performance and the essential delivery of building services. Research issues to be tackled in this track include physics of building thermals and airflow transport and models to capture relevant behavior, analytical techniques to explore multi-scale dynamics, controls and estimation required to exploit and manage integration and coupling of energy and information flow among building subsystems, and methods to compute multi-physics and multi-scale dynamics of coupled building phenomena and systems. The proposed investments will be instantiated via projects to impact the systems and technologies and design and delivery tracks for the delivery of new system solutions and optimized designs. Examples include:

- Building performance issues related to human thermal comfort, optimized delivery of lighting, heating, ventilation, cooling, and power
- Physics of heat transfer and rejection
- Methods for delivery of daylighting
- Reduced-order models for rapid analysis and optimization of new control strategies
- Methods for analysis and optimization of multi-scale control strategies
- Uncertainty and sensitivity analysis techniques for use in design of integrated systems, controls and other automation systems
- Information theoretic methods for assimilation of building performance data to be delivered to operators and end users
- ……..

HiPerBRIC Program Description

The HiPerBRIC program is intended to consist of a series of interrelated projects in parallel tracks that comprise a comprehensive research program. The projects will be implemented by dedicated teams from national labs, industry, and academia. The intent is to execute a comprehensive national research program focused on the viable delivery of high performance buildings and associated technologies. The program will have a series of intermediate industry deliverables, focused on specific advances to design systems and tools and to technologies and systems. The concept is that these deliverables will be able to be readily used by industry for the implementation of building projects at progressively

Not for distribution without permission of Arun Majumdar (LBNL) and Clas Jacobson (UTC)

improved performance levels at an economically viable cost. Deliverables will be in the form of research papers, tools, models, design paradigms, intellectual property (i.e. patents, idea records, etc.), building technologies and systems. HiPerBRIC will work with the building industry including suppliers, architects, engineers, contractors, utilities, government, owners, and academia to deliver this to the industry. The intent of these deliverables are to fundamentally change the industry so that they can readily and effectively deliver increasingly higher efficiency building projects, dropping the overall energy use index of the built stock and as a result reducing electrical demand and carbon usage.

The overall mission of this project is to achieve a complete market transformation. Elements of this transformation include:

- Use of integrated design practices
- Broad use of digital models
- Performance based project construction and delivery
- Optimized building operations
- Improved occupant experience and indoor environmental quality
- Reduction in EUI
- Reduction in source energy usage and carbon output related to buildings

HiPerBRIC shall focus on the research elements of this transformation. This includes, but is not limited to:

- Basic building science and physics research
- Computational science and methods
- Modeling and analysis tools
- Pilots, small scale implementations and test labs
- Recommendations for commercialization

It is also important to state what **HiPerBRIC will NOT do**. The intent is that the commercialization and delivery of the systems and methods identified and proven by this project will be done by others. This will include the delivery of near term market transformational elements using best practices and products available today Examples of these partners and programs include:

- ASHRAE standards and advanced energy design guidelines
- New Building Institute guides and programs
- University and trade school programs for architects, engineers, technicians and operators
- Energy efficiency programs such as LEED and Energy Star
- State and local energy codes and requirements
- Utility programs for energy efficiency

Not for distribution without permission of Arun Majumdar (LBNL) and Clas Jacobson (UTC)