New Commercial Buildings—Market Transformation Research Needs:
A scoping report prepared for the California Institute for Energy Efficiency

(9-28-98)

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CIEE
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SUMMARY

New market connectivity and market transformation (MT) approaches to energy efficiency require a much better under standing of the dynamics of markets for energy-using goods than has been required by energy analysis and efficiency programs in the past. While a number of literatures provide MT-useful insights into market functioning, none are comprehensive. The design of effective MT interventions will require new mid-range theory and research on specific aspects of market that are now poorly understood.

This report presents the results of a scoping study that examined the state of knowledge about new commercial buildings markets and related MT research needs. The scoping team surveyed published work that might apply and conducted a series of key informant interviews with industry observers. While relatively little research has been done on commercial buildings markets to date, we found promising theory and research in several literatures, including those of sociology, organizational analysis, institutional economics, science and technology studies, and social science energy analysis. Further research of an interdisciplinary nature will also needed, however, before well-designed MT interventions can be supported in this area. We also identified special problems in interdisciplinary research that need to be addressed when planning MT research agendas.

Prior to presenting such an agenda for commercial buildings MT research, the report sketches an orienting perspective drawn from the literature and our interviews—one that sees these markets as complex, evolving networks of organizations and actors. Such market systems are characterized by multiple interests and perspectives (e.g., of owners, architects, builders, financiers, regulators) that interact in complex ways in the negotiation of designs and the production of buildings. We offer a simplified model of the design and construction process—one that distinguishes four primary phases (pre-construction, design, construction, post-construction), each of which significantly affects the energy efficiency characteristics of the final product.

We identify a series of specific market transformation issues and potentials in four key areas: (1) knowledge and risk, (2) negotiation and regulation, (3) evaluative approaches (building commissioning and post occupancy evaluation), and (4) trends in business, government and innovation. In each area, we sketch some important market characteristics and identify some of the network dynamics likely to affect efficiency innovation. For example, a key hypothesis for MT research might be a “default” design solution as a common industry practice that results in buildings that fall far short of performance potentials. This practice (if true) ought be contrasted with processes resulting in exemplary buildings that can significantly outperform conventional designs.

A wide range of research needs are identified in each of the four target areas. Questions are posed about the potential MT-relevance of: professional training, information flows, the riskiness of innovation, potential effects of differences in the design process on efficiency outcomes, the role of regulations and standards (in both encouraging and inhibiting efficiency innovation), the function of exemplary buildings in the market, the potentials for building commissioning and post occupancy evaluation to shift the balance of power toward owners and occupants, how changes in business organization may affect building needs and future demands for commercial space, and related topics.

In a methodological discussion, the limits of secondary data analysis, focus groups and surveys are discussed, and the approaches required for the study of complex market systems (e.g., ethnographic field studies and detailed case-comparison methods) are described. Before MT research can be undertaken on a large enough scale to support widespread MT intervention, however, a strengthened interdisciplinary research infrastructure is required. Several examples of problem-centered publicly-funded research networks in the natural sciences and energy analysis are offered as models.

1.0 INTRODUCTION

With increased interest in "market connectivity" of energy efficiency programs and new policy mandates to pursue "market transformation" (MT) approaches to energy efficiency and environmental benefits, a new set of research and policy problems take center stage.

The strategic "transformation" of markets in the direction of greater energy efficiency is a fairly new idea (see Geller and Nadel 1994) and represents a quite different undertaking from the resource acquisition programs developed under "demand-side management" (DSM) in the 1980s-90s. MT is aimed at creating fundamental changes in energy-using technologies and energy use patterns, largely by intervening "upstream" from the consumer. In order for this approach to be successful—particularly under less-regulated conditions—a knowledge of markets well beyond that required for DSM is needed. The social sciences (minor contributors under DSM) must play new roles in providing this knowledge. New forms of qualitative as well as quantitative evaluation are also required, as is careful attention to trends in market evolution that can alter the effects of MT interventions. Under MT, the primary responsibility for program development and implementation shifts from utilities to governments. In this context, a key government role becomes sponsorship of interventions that encourage/enable market actors to pursue efficiency innovation without subsidies (see Blumstein, Goldstone and Lutzenhiser 1998 for a discussion of MT program planning and implementation issues).

Conventional energy analysis has, for the past twenty years, focused largely on technical (hardware) aspects of energy efficiency/technological change. As a result, it provides little help in understanding markets well enough to confidently intervene in them. Some attention has certainly been given by energy analysts and social scientists to the attitudes and choices of consumers (see Lutzenhiser 1993 for a review)—and this knowledge base continues to be of value in MT. But, aside from a bit of work on tax and regulatory policy, relatively little attention has been paid by energy analysts to market-level processes or to changing patterns of energy and technology use at the societal level (Shove et al. 1998). These short-comings are likely to seriously handicap efforts to develop MT in the near future.

Recognizing the need to develop new sources of market-level information to support MT interventions in California and elsewhere, the California Institute for Energy Efficiency (CIEE), in collaboration with the California Energy Commission (CEC), initiated an MT research needs scoping study in the fall of 1997. Its goal has been to explore the existing knowledge base concerning markets for energy-using goods, and to identify gaps in knowledge where research will be needed before effective MT interventions can be designed. The principal investigators (PIs) for the project are Loren Lutzenhiser and Rick Kunkle (Washington State University) and Nicole Woolsey Biggart and Bruce Hackett (University of California, Davis). The PIs have worked closely throughout the process with CIEE and CEC staff, and have made use of the expertise of other leading researchers. This enlarged scoping team has been able to draw upon expertise in: energy analysis, sociology, engineering, economics, business, and science policy.

The present report on the commercial building sector is the first in a series by the scoping team that will explore research needs in particular areas where strategic energy-efficiency market transformation in California might be possible. In it, we identify a range of poorly understood areas of the market that hold promise for MT interventions—particularly when opportunities are present to build upon developments already taking place that market. In addition to commercial building design/development, we are examining the residential construction market, advanced billing/smart metering, lighting systems, and the research infrastructure needed to support MT.

We don't claim that this is an exhaustive list or that it identifies all of the most fruitful intervention possibilities (either in terms of ease of intervention or magnitude of potential efficiency gains). We do believe, however, that it identifies some particularly promising intervention possibilities in areas where further research is needed before MT intervention potentials can be realistically assessed.

In scoping the knowledge bases and MT research needs related to new commercial buildings, we reviewed the relevant disciplinary and interdisciplinary scientific and

professional literatures, and we conducted a series of scoping interviews with industry observers and energy program operators with commercial building experience (see Appendix A). We also consulted with several researchers who are actively engaged in studies of commercial building design, property development, and the status of energy efficiency in architecture (Appendix B). As noted, we consulted throughout the process with key CEC and CIEE staff, and we conducted a multi-disciplinary workshop at UCD in which commercial building MT was one of several topics discussed by scoping team members, CIEE and CEC staff, and consultants.

The following substantive sections of the report include: (i) a discussion of the literatures examined and their usefulness in MT research, (ii) a summary of key theoretical orientations and hypotheses that derive from those literatures, (iii) an overview of stages in the commercial building development process, (iv) a discussion of MT problems/potentials and research needs in four key areas (knowledge-trust, negotiation-regulation, commissioning-evaluation, and business trends), (v) a discussion of methodological issues and concerns, and (vi) a concluding assessment of available scientific resources with an argument for strengthening the existing research infrastructure.

2.0 LITERATURES EXAMINED

We began the scoping study with a preliminary assessment of the literatures most relevant to the study of energy efficiency, innovation, technological change, and the behavior of actors and firms in markets. Of particular interest were approaches that consider the dynamic character of markets and the evolution of market organization. The embryonic literature on market transformation was a starting point, followed by examination of research in applied energy analysis—including work published in the "gray literature" (i.e., efficiency program evaluation reports, conference papers, etc.). We also examined relevant disciplinary literatures (e.g., in sociology and economics), which are discussed below, and we explored work on the commercial buildings construction process in the literatures on architecture, design and construction management. We also explored work in business technology development, marketing, strategic organizational planning, innovation, and related topics. As noted, scoping interviews were conducted with industry informants and efficiency program professionals and their observations/opinions were compared with the published literature.

As noted above, we found that traditional energy efficiency analysis has tended to focus on hardware, energy flows and comparative costs. Its rendering of the parts played by human actors in energy use and conservation has been notoriously weak (Lutzenhiser 1993)—for the most part limited to notions of consumer/producer rationality, discount rates, market barriers,

free riders, etc. This historically posed little difficulty, since the key DSM policy activity has involved planning and evaluating the cost-effectiveness of technology substitution supported by monetary incentives to energy users. All that was necessary in that context was a calculation of energy savings, costs, an assumption of economic rationality, delivery of an incentive or technology (or a regulation or advertisement), measurement of new consumption levels, and an estimate of net energy savings across the target end use (with sometimes heroic efforts to control for the effects of exogenous changes in the system). Dramatic successes of these efforts have been few, but as long as marginal reductions in consumption were observed, it was not necessary to inquire too deeply into why consumers and producers use energy and technologies as they do—and why they repeatedly fail to adopt more efficient and cost-effective technologies, and why the most careful efforts to achieve "technical potentials" have so often fallen short.

Marginal conservation gains may have considerably less value in deregulated electricity markets, however. And, unfortunately, the original *environmental* and *social* reasons for improved energy efficiency seem to have been largely forgotten by advocates who have learned to make their case in a regulated environment on techno-economic grounds. However, the Kyoto accords that would reduce CO2 emissions to pre-1990 levels may restore an environmental impetus to the energy conservation movement. And, a general turn to markets for policy purposes (e.g., emissions trading markets), coupled with increasingly popular efforts reduce the scale of government-supported services and to make government more "market friendly," support an MT approach to efficiency. These developments particularly support a view (such as that under discussion within the CEC) of government-sponsored MT as involving *cautious, strategic* and *facilitative* action in markets. In meeting these new challenges posed by MT, the techno-economic paradigm inherited from DSM and efficiency hardware R&D is of limited value. The challenge of the present period, then, is to develop a new set of understandings beyond the conventional energy efficiency paradigm—understandings of markets, technologies and the environment that might enable the former to improve the latter.

Because markets are human arrangements, the "human dimensions" energy analysis literature is certainly relevant to MT program needs. Often overlooked in conventional techno-economic analysis, this literature points to the importance of social and cultural systems, organizational networks, and political/economic institutions in shaping the energy use of persons and firms (see Stern and Aronson 1984, Lutzenhiser 1993, 1994, Shove et al. 1998). Insights from this work allow the problem of market transformation to be seen as a human-centered one, involving persons, networks, firms, and uncertainties (as opposed to stereotyped DSM views of markets as mechanical-rational systems of individuals). If the goal of MT

intervention is to produce long-lasting or sustainable improvements in the efficiencies of products and services available to consumers, then will be necessary to begin MT planning with an understanding of markets as they are currently conceived in social science and management theory—as dynamic and evolving systems of social and commercial relations.

We recommend, then, that CIEE and CEC seriously consider these perspectives along with the results of research on real-world markets when considering the problem of how commercial-institutional buildings can be built in more energy efficient and environmentally sustainable ways. By empirically examining the processes by which large buildings are planned, designed and built, for example, critical system variables (relationships, influences, beliefs, decision heuristics, choice points, etc.) can be identified. Knowing these, policy initiatives can be designed to apply leverage at strategic points in the process/system allowing interventions to be better targeted, more effective, less disruptive to economic systems, and less costly to initiate.

In the effort to understand, for example, how and why particular developer-designer-owner-builder configurations do and do not adopt environmentally beneficial technologies in their building designs, a number of specific disciplinary and interdisciplinary literatures are particularly useful. Organizational analysis and management theory, for example, have over the past half century successfully made the transition from a fairly mechanistic "tool-view" of organizational processes to theories focusing on bounded choice, informal networks, organization-environment interactions, inter-organizational fields/sets and "neo-institutional" and "open systems" views of organizational behavior (Perrow 1986, Powell and DiMaggio 1991, Scott 1998). Recent work in technology and innovation studies also sheds light on how technological choices are shaped in markets (e.g., Hughes 1989, Cowan 1989, Rogers 1995, Bijker, Hughes and Pinch 1989, Dosi 1982). Economic sociology (e.g., Smelser and Swedberg 1994) and several schools of economics, including transaction cost economics (Williamson and Winter 1991) and institutional approaches (Hodgeson 1993), provide other relevant insights into the behavior of actors and groups in market systems. All are likely to be useful in understanding decision-making about commercial buildings in complex organizations.

2.1 Interdisciplinarity Approach Indicated

Taken together, these literatures provide a relatively powerful set of perspectives that enable us to (1) clarify the nature of vague concepts in energy analysis such as market "barriers" and market "failures," (2) gain new insights into how markets actually function, (3) bring new analytic devices (e.g., concepts, approaches, methods) to the study of technology markets, and (4) support innovative applications in energy efficiency programming (e.g.,

strategic MT intervention and enhanced process evaluation). However, the problem of changing technology markets is located in the literature at the fuzzy boundaries between the social sciences and several interdisciplinary and applied areas. While the energy social science, organizations and socio-economic literatures surveyed offer a variety of insights into the nature of technology markets, considerable work remains to be done in synthesizing research scattered across literatures that do not normally interact with one another. There are also significant gaps in our knowledge, requiring significant original empirical research before well-designed MT interventions can be undertaken.

The problems involved in bringing social scientific and applied knowledge to bear on commercial-institutional building design/construction are non-trivial. Different disciplines select different aspects of reality to consider. Sometimes this is simply a business of selecting different sets of variables (e.g., sociology might look at institutional conditions while economics might focus first on price effects). In principle, knowledge in different disciplinary areas could fruitfully be combined to produce a more complete picture of reality (e.g., to see how institutions and prices jointly affect behavior). But sometimes more than different sets of variables are at stake. Different disciplines often advance quite different world views (e.g., that price/cost is the primary determinate of all behavior or that economic choice is a special and relatively unimportant case of social action). The problem with these sorts of narrow disciplinary orientations is that they impose limited theories on complex systems, with a resulting distortion of reality.

In the academic world, this problem is addressed by keeping different disciplines in separate buildings and publishing in separate journals. In the world of policy—particularly in new and difficult areas such as MT where buildings, firms, consumer choice, and the global environment are all involved—this solution isn't very helpful. We believe that the problem should be acknowledged at the outset as an inherently interdisciplinary one. This means that no one discipline can account for the dynamics of technology markets and that the combined insights of several disciplines are required in order to understand well enough how markets for energy-using goods work (particularly large, complex, long-lived systems such as commercial buildings). Without knowledge of this sort, it is hard to imagine how we might intervene intelligently in those markets. In addition to a more systematic examination of the literatures identified above, we recommend that an early task of MT research also be the evaluation of theory and research in other related interdisciplinary problem areas—e.g., socio-economics, science-technology studies, consumption analysis, business innovation studies, communications, economic history, and the history of technology. Insights from applied areas that have no theoretical basis of their own (e.g., energy analysis, marketing, market research, and home economics) may also be helpful, but should be viewed critically. A final word of

caution—among the many literatures that are potentially useful for the development of policy in this area, a number of paradigmatically distinct analytic traditions are represented. Not all are compatible. Some are much more detailed and nuanced in their explanations than others. Some are quite normative—prescribing how the world "ought" to be, rather than helping us better understand how it really is.

3.0 AN ORIENTING PERSPECTIVE ON COMMERCIAL BUILDING MARKETS

In Sections 4.0 and 5.0 below—the substantive portion of this report—we identify some key organizational features of commercial building markets that are likely to shape the efficiency characteristics of the buildings produced in these markets. We identify four general areas of research and a series of specific research needs in each that follow from our scoping work to date.

In those discussions we assume a perspective drawn from the literature and reinforced by our interviews. It is useful to briefly summarize that view here. We see, for example, the commercial-institutional building markets as multi-faceted and inherently complex social systems. As such, they function to regulate the behavior of participants, regularized interactions, smooth difficulties in the design and construction, and, in the process, serve to limit innovation. We see the design and building process as inherently negotiative—one in which multiple actors work out their interests, governed by informal and professional norms, arriving at compromise solutions that result in fairly conventional designs. One of our key hypotheses is that the result may be a market-dominating "default design" solution that generally replicates earlier tested and approved designs.

Innovation occurs in commercial building design, of course, and understanding the factors that affect energy efficiency during innovation should be a primary goal of MT research in this area. We know, however, that the commercial buildings process confronts would-be innovators with risks as well as rewards. The market functions as a sort of "habitat" that exerts selective pressures on efforts to innovate. Information about efficiency and successful innovation must also flow through these market networks—often with some difficulty. In this environment, laws, standards and regulations play important roles. Codes and standards influence behavior and therefore can have significant transformative effects this market, but also may produce unexpected (even efficiency-frustrating) outcomes. In short, learning does take place and innovation can likely be fostered in this industry, once we better understand how the benefits of energy efficiency can be communicated convincingly.

A key hypothesis points to inherent problems in communication and innovation, resulting from the routine absence of owners, tenants, and other users of commercial buildings from the

design and construction process. Another is that since large buildings are most often "one at a time" and "once in a lifetime" purchases, there is little in the way of effective feedback loops from occupants to architects and builders that might improve future designs. Alternative ways of organizing the design and construction process might result in quite different products, with improved energy and environmental characteristics. Design-build and design-bid approaches, for example, may have somewhat different implications for efficiency innovation. Third party consultants, advisors, evaluators, certifiers, and guarantors also may be able to play a significant role in this regard. But their ability to effectively market their services may be limited by the organizational networks, conventional practices and institutional arrangements that dominate the industry. Finally, emerging trends in business organization, global product and service markets, and patterns of doing work may well affect the building needs of firms and institutional tenants, in turn affecting the design and construction process.

4.0 NOTES ON ENERGY EFFICIENCY AND COMMERCIAL BUILDINGS DESIGN—CHARACTERIZING THE SYSTEM

Commercial (and institutional) buildings represent a large and growing source of energy demand, that also offer many opportunities to significantly improve energy efficiency and reduce pollution impacts. In the world of commercial building design and construction, however, energy efficiency concerns are high on few priority lists. Even where efficiency optimization is best-developed (e.g., under utility and government sponsorship) its practice is inherently problematic. Efficiency potentials have, in fact, been achieved in only a few highly visible and well-funded tests (ACT2, C-2000) (Todesco 1996, Hernandez, Kolderup and Syphers 1997). The DSM program evaluation literature offers some clues to the problem when it points to the importance of actors' non-economic concerns, inability to control the design/construction process, and limited attention to operations and maintenance (O&M) issues in the design stage. While there seems to have been some influence on downstream projects for designers with experience in high efficiency building projects, this is only true in a minority of cases, and the literature offers no clear idea of which designers were effected or why (Janda 1996).

Design and construction decisions are products of multiple actors, made at various stages of a building design process (which we characterize in the following discussion as having four fairly distinct phases). The multiple parties involved can include developers, owner firms, agents, architectural firms, engineering firms, general contracting and subcontracting firms, workers/labor unions, interior designers, systems of finance/appraisal/real estate, building codes/standards and their enforcement agents, community planning processes, ultimate

occupants, customers, and the public. The process involves complex coordination of a large number of multiple parallel and connected systems that come into play at various stages of the process (from early planning to post-occupancy). These include: soils, landscape, drainage, water, sewer, electricity, fuels, structural, envelope/cladding, windows, lighting, finishes, interior divisions, elevators/stairs, HVAC, fire/safety, furnishings, electronic/information, work flow, traffic, materials flow, intra/inter organizational communications, public interfaces, exterior/interior aesthetics, etc. Different actors are responsible for different subsystems, and various professions bring distinctive kinds of expertise, values and interests to the process (superficially these might include: architects–creativity, engineers–performance/specification; builders–ease of construction; bankers–return on investment).

4.1 Multiple Perspectives, Values & Negotiations

The various specialists involved in the system also bring different assumptions about the project and one another's roles in the decision-making process. Each type of actor has a potentially different agenda/conceptualization of the project and of the other participants (e.g., architects' and clients' expectations of one another may not be well understood or agreed upon by either party). This quite naturally reflects different interests, different sorts of expertise, and different strategic ways of seeing the organizational problem of design and construction (Guy 1998). These differences are almost always worked out—buildings get built—but the results can include suboptimal design, miscommunication, tension, and dissatisfaction with the finished project. The challenge, then, is to understand how processes involving multiple professions and interests work.

A key insight from the literature on organizational decision-making is that these processes are *negotiative*. By this, we mean that compromises are required and that all decision-making (even about building design) is inherently "political" (i.e., that ambiguity, conflicting interests, competing organizational units/actors, discordant perspectives, misunderstandings, and the tensions that result are sometimes resolved by appeal to authority from outside of the decision-making context). Conflicts between frames of reference and interests (e.g., in terms of aesthetics, packaged systems, building quality, timely completion, energy and resource demands, ultimate occupancy patterns, and user satisfaction) we would expect to be reconciled by appeal to past experience with the actors or solutions, through deployment of external resources/power, linking the design decision to ongoing negotiations about other matters (solutions can be linked, trade-offs devised), the use of unofficial social networks (working power), the employment of charisma, etc. But the bottom line is that, by whatever negotiative process (and there is a large literature on negotiation within and between firms and in the

shaping of technologies), the final product will represent some sort of *compromise* among interests, frames of reference and organizational authorities. For reasons that research will be required to explain, energy efficiency, user interests, and a variety of other building quality features tend to lose out in that compromise—perhaps because they are not well represented in the negotiations, and certainly because they are not compelling concerns in the conventional buildings development process.

4.2 Building Negotiations: Phases and Dynamics

To set the stage for our discussion of research problems and needs in Section 5.0, it is useful to provide an orienting model of the commercial building design/construction process. This model roughly distinguishes four phases of design and construction. Decision makers, actors and influencing factors are somewhat different in each phase, and each has a significant impact on building characteristics and performance. These are the: market context (predesign), design, construction, and start-up phases. Understanding the interactions and motivations of the actors through each phase of the development process is crucial to understanding how energy-efficient technologies and practices do and do not become part of the final product.

4.21 *Market Contexts/Expectations*

This preliminary, but critically important, phase of development encompasses such things as pre-existing real estate market conditions, market standards (expectations about building attributes that define "quality"), regulations/codes, and financial requirements. Different types of financiers and developers enter the game for different reasons at different times with different strategies. Utility tariffs and interventions have shaped the existing building stock and continue to exert influence, just as deregulation will certainly affect efficiency-related decisions in the future. While many technologies are available to the construction industry nationwide, there are legal (state energy codes), educational (the proximity of educational institutions with energy programs), and physical (climate, seismic) factors that ground commercial building markets in geographical areas. The design market from which a development project must draw is competitive in nature and the organization and capacities of design firms may reflect the other kinds of designers working in the area, the kinds of buildings that they do, how they do them, etc. In high growth areas, there may be more small, new firms willing to take chances (perhaps with designers with more recent education) than in older areas with a small number of well-established firms.

4.22 *Project Design*

Historically, most new building energy efficiency programs have taken context largely for granted, focusing on the design stage, where information and/or incentives are provided to encourage the incorporation of improved features/technologies. The design phase itself is a "staged" affair, however, that in the architectural literature is often broken down into: 1) an intelligence stage aimed at understanding the purpose of the whole activity, 2) a design stage in which possible solutions are generated or selected, and 3) a choice stage in which these solutions are evaluated (Lang 1987). Slightly different typologies can be found elsewhere in the literature, and these stages are certainly expanded/contracted in many ways depending on the nature of the project and the architects and clients involved. For present purposes, however, it is important to note that from the very outset of this process, decisions related to project budgeting, building size, appearance, materials/systems, etc. serve to constrain later design choices, with subsequent decisions further narrowing the range of choice. The energy efficiency of the final building—whether this is approached by project designers as an integrated design goal or as the product of adding "energy efficiency measures" (EEMs) onto a conventional design—can be seriously compromised by non-energy decisions made throughout the process.

There has been significant social science attention to the first (intelligence) stage, but virtually none concerning the others. These, however, are precisely the points in the process where any explicit consideration of energy efficiency and associated non-energy benefits (NEBs) (e.g., improved occupant health and productivity) must take place. For example, little research has been done on architect-client relations, and environmental design critics argue that there should be more. Also, research and criticism point out that many architectural firms pay little attention to user needs. Since they are much more concerned with issues of aesthetics, overall design quality and cost, the majority of architects do not list user needs among their most important concerns (Gutman 1988). Certainly understanding building occupants and their behaviors is problematic in practice, but this knowledge might be helpful in identifying and appropriately valuing NEBs. It may be that only smaller firms that deal with individual clients can afford to emphasize user needs (Pressman 1995), or to take these into account in energy-related considerations. Looking at the client side, the research notes that the bureaucratically managed public and private agencies that are the clients for most big projects have an instrumental mentality—with the building being regarded as a capital asset and plans judged significantly on the basis of cost. These organizational clients tend to have a high degree of sophistication regarding building practices—e.g., with in-house departments related to architecture or construction. Gutman (1988, p. 54) concludes that "The domination of the architectural market by large organizations also has produced clients who are reasonably

articulate and explicit in stating the criteria for evaluating buildings and the services of architects, even the procedures and methods according to which a building should be designed." It does not follow, of course, that these clients are similarly sophisticated in their understandings of user/occupant needs and desires, the evaluation of energy efficiency (e.g., lifecycle cost analysis), NEBs, or related matters.

4.23 *Project Construction*

A new set of actors including the prime contractor and various subcontractors enter the process at this stage. In the "design/build" variation, the contractor and subs are brought into the process earlier, but the value of this form of project organization is disputed by advocates of traditional "design-bid" arrangements. At this stage, factors affecting the energy efficiency of the executed design, and whether hoped-for NEBs are actually secured in that design, may include: the degree of involvement of the design team during the construction phase, involvement of the owner's representative (and how well owners' expectations are represented in specification and construction), contractor-subcontractor dynamics and competencies, project timelines, product availability from suppliers, and a variety of risk/reward incentives. Also, changes are made in the design on the basis of unanticipated site conditions, difficulty in obtaining specified materials and systems, alteration of design elements by subcontractors, mistakes made in installation, etc. All of these factors, individually and collectively, can significantly affect the energy use of the resulting building and diminish non-energy benefits to occupants.

4.24 *Project Start-Up/Shakedown*

When occupied, additional threats to building efficiency arise in the form of operation and maintenance (O&M) practices. The "failure" (in energy efficiency terms) of well-designed and constructed buildings often occurs with occupancy and/or failure to undertake "building commissioning" (Cx) at the start-up or shakedown phase. Cx involves (at a minimum) inspection of installed systems, test operation and optimization, harmonization of related systems, and O&M training. Factors that may affect post-occupancy building performance include: organization of building O&M personnel, functional testing of component systems, O&M training, documentation of technical systems designs, equipment and operating procedures, and other risk/reward incentives. The treatment of this phase seems to be very different in other countries (e.g, Japan and Sweden) where considerable attention is given to Cx, and variations are likely common across the U.S. as well (e.g., with an aggressive commissioning movement in the Pacific Northwest and centers of interest in California, Florida, etc.).

Also, often missing from the development process is a "feedback loop" that would inform early stage work about successes, failure and uncertain outcomes experienced when innovations were actually put into effect in the start-up/shakedown phase. Also frequently missing is documentation of design intent that can inform the choices of actors entering late in the process. This feedback is impeded by the segmented character of the development process and the organizational division of labor involved. "Post-occupancy evaluations" (POEs) to determine user satisfaction have been widely advocated in the environmental design literature (e.g., Rosenheck et al. 1997), but they are, apparently, not commonplace. Building lifecycle information systems (Piette 1998) have also been proposed by energy analysts as a way to track long-term building energy efficiency in order to adjust building performance as needed as well as to inform future building design. At this point, however, these systems are early in their development.

5.0 MARKET TRANSFORMATION RESEARCH ISSUES

Given our theoretical perspective and this phased model of the development process, we have identified MT research needs in four areas. Others certainly exist. But these seem, at this early stage in our thinking, as among the most significant influences on energy efficiency in commercial buildings and potentially the most tractable from a policy point of view. They include: (1) knowledge and risk, (2) negotiations and regulations, (3) evaluative approaches (Cx and POEs), and (4) trends in business, government and innovation.

5.1 Knowledge and Risk

What appear to be clear and obviously good technology/design choices from the point of view of energy efficiency advocates, often don't appear as such to designers in the field. On the other hand, decisions that appear from the energy efficiency point of view to be misguided, may often be considered quite good ones from other perspectives. In fact, all energy efficiency design possibilities do not necessarily represent "good design choices" on non-energy grounds. In the real world, designers consider both the benefits and drawbacks of design elements and technologies—the fact that energy efficient designs have not always "worked" or worked as planned, has not escaped notice. What's more, some efficiency innovations are much easier to use than others, and even "easy" technologies can be poorly implemented (e.g., compact fluorescents in the kitchen vs. in a closet). Because of uncertainties associated with building construction, equipment, installation, and O&M, there can be a significant risk to building designers who adopt energy efficiency innovations. While we might expect to find

individuals and firms who would be willing to take such risk if there is a reasonable prospect for appropriate reward, the experience of these potential risk-takers does not indicate significant rewards—for several reasons. First, a small percentage of total building and operating costs are associated with energy. One study estimates that out of a typical rent of $19.70 per square foot only $1.70 results from energy costs (OTA 1992). And when tenants are responsible for these costs, owners are unlikely to be concerned about them. Second, when compared to other more tangible/visible aspects, energy efficiency improvements are difficult for building owners and users to detect and appreciate. Being unable to appreciate the benefits they are, in turn, generally unwilling to pay enough to cover the builder's risks. If the kinds of significant cost savings, energy efficiency and ancillary benefits routinely reported in *Energy User News* and similar energy services and advocacy outlets are to be communicated convincing to risk-averse builders and designers, then new ways to instill trust in a wary industry must be considered.

Information about innovation (e.g., related to efficiency design features and associated NEBs) enters the industry through a variety of channels, including professional training (in schools of architecture, engineering, construction and facilities management), continuing education programs, trade associations, professional societies and their publications, special purpose professional/research groups, government and utility intervention programs, consulting firms, and so on. All sources are not equally trusted, not all provide equally timely information, and frequently competing claims are made. Innovations take place in a competitive (sometimes hostile, always somewhat risky) environment in which the costs of failure are high and the value of routine processes is well established. There are also costs involved in admitting lack of knowledge, in having been discovered to have produced a less than optimal design, and in being associated with failed "experimentation." For the efficiency design features that aren't "easy," the lack of trained professionals is an important aspect of design/construction systems often overlooked by energy efficiency advocates. Koomey (1990, p.78) notes that "...it has been estimated that less than one percent of the architects and engineers in the U.S. are qualified to design and construct buildings that employ state-of-the art efficiency strategies, and gaining this kind of expertise may take as long as ten years." Because some efficiency design alternatives are easy, there is a fairly widespread taken-for-granted belief among efficiency advocates that all can be implemented successfully by simply distributing information outlining their benefits. In reality, sometimes special actors (e.g., "project facilitators") are necessary for packaging, distributing and interpreting efficiency information in the design process. Without an institutionalized presence in design negotiations and construction practice of efficiency, owner and end-user interests (e.g., by appropriately trained architects and engineers), such "facilitation" may be crucial.

Making the case for efficiency innovation increasingly relies on the claim of non-energy

benefits (improved worker productivity, happiness, air quality, more healthful conditions, less absenteeism, etc.). Mills and Rosenfeld (1994) do a nice job of identifying potential NEBs and we would add to their list other benefits, including: enhanced firm reputation, competitiveness, growth, and profitability. A key problem with the present NEBs formulation, however, is that it is unlikely than anyone in the design community (in fact anyone outside of the energy efficiency community) would think of design problems as having a "non-energy benefits" dimension. It might be useful if the NEBs problem were turned on its head so that designers might consider something like the "energy benefits of user-sensitive design." It is also important for the energy efficiency community to recognize, and for MT researchers to take very seriously, what we might term the "non-energy drawbacks" of efficiency alternatives—e.g., knowledge and behavior changes that might be required of users.

5.11 *Research needed to better understand industry knowledge, risk and trust factors*

We would want to know how professional education treats energy, efficiency and commercial building design in theory and practice. What skills, knowledge, and biases (or lack of same) do architects and engineers bring to the design process? What is the status of energy efficiency in professional continuing education? Is the rapidly growing interest in sustainable design and green buildings within the architectural community (e.g., in the AIA) having any effects on the content of technical training or architectural practice? How do various industry actors perceive, assess and act upon the risks of innovation? How, where and why have efficiency facilitation efforts been undertaken, either as ventures by entrepreneurs, additions to architectural and engineering consulting practices, or services provided by non-profits, utilities or governments? What (if any) impacts on technical knowledge, trust and design practice have followed from utility and government efforts to demonstrate state-of-the-art practice/technology in commercial building design/construction?

5.2 Negotiation and Regulation

Beyond knowledge limits and the riskiness of innovation, several other sets of factors are likely to influence efficiency decisions in commercial building design and construction. As we have noted, this is a quite complex negotiative process, in which costs, profits, organizational capacities, financing constraints, technical expertise and so on interact in arriving at a preferred solution among competing interests. Decision-making under these circumstances could be quite difficult, since opportunities for breakdown are constantly present. Successful negotiation is the norm, rather than the exception, however. Work on design in other contexts suggests that successful design decision-making under conditions of complexity, ambiguity,

contradictory aims, and time constraints, is likely to settle into routine negotiative patterns that produce fairly predictable "default solutions" (Shove 1997). Rather than work out every compromise anew in each design negotiation, parties learn what to expect from one another (individually and professionally) and build on past compromises in their current designs. As in other spheres of social life, these professional relationships are governed by shared norms and conventions, which are rooted in tacit common knowledge and stable organizational cultures. Relatively predictable relationships between architectural, engineering firms and contracting firms may serve to stabilize negotiations—institutionalizing a system of routine compromises that don't really fully "satisfy" any of the parties' interests, and in fact may deoptimize the effectiveness of all in the process.

Since these compromises reflect constraints encoded in regulations, performance standards, building/zoning codes, specification guidelines, etc., it is possible that the default solution largely involves professional efforts to fit a set of site, budget and time constraints to regulatory standards using a design template that has routinely satisfied the tests of code compliance, professional liability, insurability, etc. in the past. Codes and standards seem to be routinely invoked as barriers to the incorporation of features and innovations requested by owners and occupiers. And it is undoubtedly the case that codes, standards, procurement requirements, financing conditions and indemnifications are problematic and likely routinely conflict to some degree with one another. Whether codes/standards are so inflexible and complexly interactive that only a few standard compromises are possible (or cost-effective), or whether they are, in fact, routinely open to negotiation and interpretation in commercial construction, are unknown. In *all* other bureaucratic/legal contexts (e.g., in government agencies, large firms, universities, policing, medicine, etc.) complex and contradictory systems of rules that potentially constrain actors are routinely used in partial and selective ways, allowing issues to be reframed and regulations to be variously interpreted (and sometimes overlooked or discarded). The potential physical, human and legal consequences of this sort of creative "rule-work" in the construction of large buildings are certainly more serious than is, say, deciding how to finesse a travel claim that lacks a meal receipt through the accounting system. But it is doubtful that the professional application of regulations and standards in commercial building is really less artful. In the process of design, it is not clear what role regulations play in negotiation dominated by considerations that include cost, profit, risk, utility, professional and corporate values, and—sometimes—energy efficiency.

Exemplary buildings are sometimes, however, built—buildings that may look quite different from dominant designs, that use novel materials, and/or that take innovative approaches to energy and resources efficiency. Because these cases are relatively rare, they are frequently given design awards, receive the acclaim of architectural critics and generate

considerable publicity within industry organizations. However, all of these buildings have also been the product of design negotiations, under constraints similar to those faced by the designers of default structures, and facing the same array of regulations.

What accounts for the difference? Conventional wisdom might suggest that owner demands, coupled with sufficient funding to overcome the additional costs of research, design innovation, and increased capital investment required to reap future lifecycle cost savings are at work. There is undoubtedly something to that hypothesis. But there is likely more to the story. Some motivated owners have reported frustration with inflexible code-interpreters. Many well-funded demonstrations designed to exceed codes have failed to achieve projected performance levels. And certain sorts of occupant behavior may be required in order to optimize hardware/design performance (e.g., shutting down computer equipment when not in use, checking lights before leaving the building, not working late at night or on weekends). At the same time, projects with tight financing constraints have used conventional materials and techniques in creative ways to produce high performing low-energy buildings that come in under budget. And some very large scale demonstrations in the U.S. and Europe designed to simultaneously optimize energy, environmental, organizational, and social benefits and amenities, claim to have been complete at market cost, with little regulatory difficulty, while meeting or exceeding performance goals. An architect might argue that the difference involves "good design." But the conditions under which "good design" by this definition can be accomplished may be strongly influenced by regulations, standards and legal constraints—and particularly by the interactions of designers with regulators, risk managers, insurers and other "secondary" actors positioned to either facilitate or limit design innovation.

5.21 Research needed to better understand industry negotiation processes and the role of regulation and related institutional constraints

To know more about negotiation and regulation in the design process, we would first want to better understand some baseline processes: the role of budgeting (and the process of budget construction or resource allocation), how design teams are selected, what sorts of communication ordinarily take place between the design team, the owner firm and the regulatory context, the nature of interaction on the design team (among architects, civil, structural, mechanical, and electrical engineers, lighting and interior designers, etc.), the distribution of risk/reward incentives across the team, and variations in division of labor among parties. From a policy point of view, we would want to ask how incorporation of outside expertise (e.g., from an energy consultant or utility project team) might fragment or enhance the normal process and how it might affect the likelihood of innovation. Investigation of the default solution hypothesis would allow us to ask how, when faced with time pressures and

other considerations, the "simplest solution" or "easiest outcome" is reached. More importantly, we would want to answer the question "Why is *this* the default case and what role does regulation play in favoring that solution?" Does regulation play a different role in different building contexts (e.g., less flexibility where children are concerned than when the design goal is to housing documents or inmates)? Do differences in regulatory environments (e.g., between states) potentially make a difference in how markets function (and the sorts of buildings that result)?

Taking the cases of exemplary buildings, we would want to know how those exceptions happened, what role regulation played, and how "successful" they really are in terms of energy efficiency, user values and as models from which elements could be transferred to more conventional practice (i.e., can particular negotiation techniques, regulatory solutions or professional interactions from exemplary cases be readily applied to the default case, or is an entire "package" of novel organizational approaches needed?). Are the achievements of exemplary designers and builders more applicable to some industry sectors and types of building than others (e.g., to office towers more than suburban office campuses, to courthouses more than university classroom buildings)? Are they of more importance to certain types of actors in the process? To certain types of clients or firms?

5.3 Building Commissioning and Post Occupancy Evaluation

A key factor in the relatively low status of energy efficiency in commercial building design involves the frequent absence of the occupant organization(s) from the design process. In the cases of speculative development, the owner (who may not be the occupant, but whom we might expect to have some interest in long-term operating costs) isn't present either. Even where an owner is involved in the planning stages, they may not have the expertise to press for operational efficiency or they may not have the incentive to do so (e.g., in the case of a pension fund investing in a pre-leased building in which the tenant will bear the operating costs). In all of these examples, the interests of those who will consume the energy and pay the bills (and their long-term O&M considerations) are effectively excluded from the design negotiations.

The efficiency of building systems is governed by code, however, providing the owner or tenant some confidence that at least conventional energy consumption rates might be assured. Few new buildings operate as planned, however, with performance being affected by a number of factors, including: design weaknesses that go unnoticed, changes made during construction altering the integrity of the design, equipment being installed that varies from specification, errors and omissions made in installation, unanticipated interactions between systems, and less than optimal operations and use of the building. The practice of "building commissioning"

(Cx) outlined above seeks to remedy performance short-falls that result from these sorts of problems, through detailed inspection, testing, tuning, and training. Cx as a movement is a fairly recent arrival on the energy efficiency scene and in commercial buildings markets. As such, it is generally imagined to be a new practice that takes place mostly in the shake-down phase. Actually, Cx is an old practice that, ideally, begins to influence the design/construction process from the earliest planning stages. Some trace its disappearance to government contracting practices that discouraged paying for the participation/presence of design engineers on the construction site (Brown 1998). In present industry practice, Cx can be ordered by the architect, builder or owner to assure that buildings operate more or less as designed. While certainly benefiting building operation and energy performance in existing buildings, Cx also offers a potential to shape future owner expectations and designer/builder liability. Serious design, installation, systems, and performance problems discovered in the course of Cx by reputable professionals would place owners and/or occupants in a much stronger legal position than they are today vis a vis designers and builders. Therefore, if Cx becomes institutionalized in commercial-institutional building markets, it may well influence design and construction practices, introducing incentives for designers to better incorporate energy efficiency into the building. Advocates also argue that Cx yields non-energy benefits (NEBs) in terms of improved occupant comfort that could reduce employee turnover, lower O&M and equipment replacement costs, improve indoor air quality (and decrease potential legal liability), and reduce builders' uncertainties about system performance (PECI 1998). All of these are probably of considerable interest to building owners and occupants.

Somewhat related to NEBs is the practice of "post-occupancy evaluation" (POE), which has developed in the environmental design context. POEs are intended to determine whether and to what extent the completed building meets user needs as they were anticipated by the architects and interior designers. POEs are fairly well institutionalized, even in cases when architects in charge find them a distraction from aesthetic goals. While intended to strengthen the commitment of builders to satisfy user needs, POEs pose risks to architects, designers and builders whose work might be found to have been lacking in some sense (McLaughlin 1997)—a poor POE rating could affect reputations if the word got out and it might provide support for liability claims. This fact limits their utility in providing an effective feedback loop from occupant experience to subsequent design. The widespread adoption of POEs would require a significant shift in the usual process—e.g., possibly with some party not now central to the process assuming this responsibility. Clearly, in the cases of both POEs and Cx, a disinterested third party is required to evaluate building performance, and compensation for those services must be provided. Increased support for POEs may follow closely upon greater interest in new Cx initiatives, including the recommissioning and retrocommissioning of

existing buildings, both of which require interaction with occupants and revisiting design intent and decisions made during construction.

5.31 *Research needed to better understand the market transformation potentials of building commissioning and post-occupancy evaluation*

We would like to know who the clients for Cx are, whether building owners see sufficient value in the practice to support it without subsidies from utilities and government agencies, and what if any impacts Cx practice seems to be making on "upstream" activities related to building design and construction practice. The issue of liability and concern for risk may vary across political jurisdictions, which means that Cx might be more attractive (and more rapidly adopted) in jurisdictions with more stringent liability laws. Perhaps POEs would be used less frequently in those areas for the same reason. We would want to ask, then, how California liability laws currently compare those of other states and if they might be modified in ways that could improve the utilization of these practices. If building commissioning do in fact realize their claimed benefits, could government information programs and/or information regulations be used to increase the dissemination and/or the credibility of these results, expanding the market for Cx services and helping builders and owners who use them to enhance their reputation and market shares?

We would like to know the status of POEs in the making of reputations by architects and firms. What part if any do they play in the architect-client relationship? When are they seriously attended to by either party, and when are they only done in a ritualized way (e.g., similar to obligatory, and usually ignored, conference evaluation forms)? Is there a potential to use POEs to provide feedback to other prospective buyers regarding the track record of designers and builders (e.g. a J.D. Powers-style third-party certification approach)? While it would be against the interests of architects to disclose and make publicly available information that might adversely affect their reputations and future business, it is precisely the potential for providing negative feedback about problems that might make POEs or something like them valuable for improving building quality. So we would also want to know what sorts of changes in legal and regulatory rules might help to strengthen the feedback loop to foster iterative improvement.

Other questions involve the relationship between POEs and Cx. Since energy efficiency and other building qualities that reflect user interests are not well represented in design negotiations, both POEs and Cx may be seen as attempts to strengthen the users interest—after the fact, but in ways that subsequent negotiations will have to take into account. There are important differences between POEs and Cx, however. The latter aims at helping to assure that buildings work as they were intended by the designers, while POEs aim at determining

whether or not the designs effectively satisfy user needs. POEs and Cx are not substitutes for one another, rather they appear to be highly complementary. This is because a building may fail to satisfy users either because it was designed poorly or designed well but poorly constructed and operated. Absent a commissioning process that verifies that the latter is not a problem, a POE would, we hypothesize, not be capable of readily distinguishing these two kinds of failures. Likewise, absent a POE, a commissioning that stresses realization of designer's intent would not be capable of determining the extent to which the designers intent satisfied user needs. So an important research question is how these two potentially complementary processes actually relate in practice.

5.4 Trends in Business, Government and Innovation

The organization of work in both private and public sectors is undergoing rapid transformation, with down-sizing, out-sourcing, inter-firm strategic alliances, widespread adoption of new communications technologies, workforce reorganization, flattened hierarchies, and spatial dispersion of operations. All of these developments have implications for building requirements and particularly for construction industry practices. For example, the use of space is quite different in the newer knowledge-based industries (hi-tech, biotech) that grew up around universities and pattern their physical and work organization on academic models. Also, flattened, horizontal, lean, team, process-centered organizations have space needs and spatial organization of work that differ from older, more traditional industries and organizational bureaucracies. In addition, process-centered companies frequently work closely with suppliers and have spaces for subcontractors, and sometimes customers, in their buildings. The boundaries between the organization and the environment to which they are responding are kept purposely low in order to adapt quickly to market, technological, and competitive shifts. Perhaps most importantly, these firms have increasing numbers of workers who are not at a central site. Telecommuting is an accepted and even encouraged way to work, as is "hoteling" (the practice of renting a space equipped with telephones, modem jacks, fax machines and other office equipment to be used much like hotel rooms, but for work, rather than sleep).

Just as the skyscraper reflected the work organization of an industrial age, a post-industrial era will certainly create new sorts of spaces that will reflect and support new ways of working. It will also quite likely encourage new sorts of relationships between commercial property developers, designers, contractors, building owners, and occupants. Large firms with global operations often have their own well-developed building designs that they export in "cookie cutter" fashion to various centers of production and distribution. Firms that lease space may,

nonetheless, specify in great detail the configuration and location of that space, basically dictating the terms of design to the owner and builder.

The organization of the construction process may affect the building that results. For example, "design/build" arrangements in which contractors and subs are involved early in the design process may offer greater opportunities for innovation than the traditional "design/bid" system. Design-build (and now design-build-operate) arrangements can result in greater collaboration and accountability, but the owner may also have even less control over the project. Development of "partnering" relationships by contractors, subs, engineers and architects represents a concentration of experience and shared risk in the design-bid context, however, that may approximate design-build relationships (Godfrey 1996).

A better understanding is needed of the forces of change in the industry and how they impact innovation. In that effort, a differentiation between two approaches to innovation—*technology* innovation and *process* innovation—is useful. The former involves the substitution of new technologies within the existing process framework. This has been the traditional utility energy efficiency program approach—i.e., to provide information and financial incentives to encourage substitution of more energy-efficient technology in building design. Process innovation, on the other hand, involves a change in the development process to encourage optimizing building *quality*—where "quality" is defined in terms of organizational usability, longevity, O&M optimization, adaptability, etc., along with energy efficiency. Advocates of process innovation (e.g., Lovins 1992) argue that it would result in technology innovation, of course. But it would also treat the entire process of development-design-construction-commissioning-operation-decommissioning in a holistic and inclusive way, allowing for the better integration of systems and discovery of innovative solutions that would provide benefits throughout the lifecycle of the building.

5.41 *Research needed to better understand the effects of changing forms of business organization on markets for new commercial buildings*

We would want to know how various trends in business and government might affect demands for new buildings and for new uses of buildings. Are developments in commercial construction such as design-build likely to influence the industry's ability to innovate, and how might efficiency concerns fare under new approaches to design and construction? In a deregulated utility environment, considerable dispersed generation is predicted (Moore 1998). What are the likely effects on efficiency deliberations (by builders, owners and designers) of falling energy prices, dispersed generation potentials and new forms of business organization (e.g., new ownership and leasing arrangements)? To what degree is process innovation encouraged by government in the areas in which it has the most direct control—in the

procurement and operation of government facilities? What are the positive and negative energy efficiency implications in the commercial-institutional building sector of various "good government" initiatives—e.g., that involve the operation of government agencies on business models, that allow agencies to capture profits and savings for their own use, and where the leasing of space for government operations and the subcontracting of government responsibilities are increasingly common? As changes in business organization are reflected in changes in the location of work, we would want to know how practices such as telecommuting, hoteling and flexible office arrangements may affect building owners' and tenants' understanding of the role of the commercial building in the business enterprise, and the ways in which commercial space ought to be shaped to accommodate changing patterns of business and work organization.

6.0 NOTES ON METHODOLOGY

A variety of methodologies appropriate to the research problems outlined above have been considered in the scoping study. Secondary analysis of existing data is often an efficient and cost-effective approach. As in other areas of energy analysis, however, while some useful information on new commercial-institutional building construction can be found in public records and utility surveys, these data are largely descriptive. Other rapid analytic approaches include focus groups and surveys. Both can be useful—the former identifying issues and exploring taken-for-granted knowledge, the latter assessing the extent and distribution of opinions, attitudes and self-reported behaviors in samples drawn from populations of interest. Caution should be exercised in the application of these techniques to the study of complex markets, however. The point of MT research is not to simply identify target market segments, explore consumer preferences, or discover "hot-buttons" and "turn-offs"—as useful as this knowledge might be in the marketing of products. Rather, it is to gain a working knowledge of whole market systems.

The processes at work in commercial buildings markets (and in other complex market systems) involve highly nuanced, multi-party professional/technical negotiations within dynamic and highly networked environments. Careful observation, ethnographic interviewing and case studies are the primary methods indicated for this sort of work. These techniques are somewhat more time-consuming than focus groups and surveys, and the latter (along with secondary analysis) may ultimately be required to explore questions of extent, intensity and distribution of phenomena in populations (e.g., of architectural firms or local market systems). But qualitative and case analysis methods (e.g., ethnographic observation and intensive interviewing over time and over several projects) are required to capture in sufficient detail the

processes involved and the decisions made as they appear to participants. It is also necessary to be mindful of the fact that there are always pieces "missing" from the most knowledgeable participants' perspectives. A recurrent response from knowledgeable industry informants when asked why "good" buildings often "fail" in energy terms, is that "organizational culture" is responsible. This explanation points to organizational and institutional processes that are important to understand before, say, a potentially effective building commissioning promotion effort can be designed. But because industry informants are not trained as social scientists, they are generally not able to use concepts such as organizational culture with any precision. It represents a gloss (albeit an important and suggestive one) on the underlying organizational processes that shape building efficiency—processes that will require disciplined and theory-informed research to unpack. Without the level of detail that ethnographic and case study methods can provide, it will be impossible to formulate and test hypotheses that can be used with confidence in MT program design.

Some examples of empirical research along these lines can be found in the organizational analysis literature (particularly the work on organizational sets, fields and networks—see, e.g., work reported in Powell and DiMaggio 1991), and in the science, technology and society (STS) research literature. Recent studies in the latter area include work on the micro-shaping of design and innovation, sociotechnical systems development, technological trajectories/path dependencies/lock-in, and actor-network theory (for a sampling, see research reported in Bijker, Hughes and Pinch 1989, Bijker and Law 1992, and Dosi et al. 1988). A number of these studies use historical methods, which allow the evolution of technologies (e.g., commercial building practices) to be examined through time. Some employ a comparative framework—generating theoretical insights by looking for regularities and differences across cases (and across industries, societies and time-periods). In commercial buildings research, comparative and historical studies across markets might be indicated if widely differing approaches to energy efficiency are suspected in different market contexts—opening the possibility of local-regional variation in appropriate MT intervention design.

7.0 SCIENTIFIC RESOURCES—STRENGTHENING RESEARCH INFRASTRUCTURE

The scientific resources available to support long-term interdisciplinary research on efficiency markets and their transformation was also assessed in the scoping study. We have identified some fairly serious infrastructural problems that will limit MT research in this and other areas where energy efficiency market transformation might be desirable. The most serious problem involves a lack of research centers with appropriate focus and staffing, limited production of Ph.D-level researchers in appropriate fields and subspecialties, limited

availability of active faculty researchers whose work is closely enough related to MT goals to make it applicable, and institutional disincentives in the academic community to this sort of work. We believe that focused effort is required to strengthen the research infrastructure and to foster the kind of interdisciplinary collaboration and training needed to support MT research. In a subsequent report, we will present a detailed description of the sorts of network-based scientist-practitioner collaboration we believe is required for effective MT research. Here we will simply point to some of the issues and models that will be more fully developed in that report.

One closely related model is the human dimensions of global change (HDGC) research area, with which MT research shares some interests and problems. HDGC seeks to expand scientific understanding of the cultural, political and institutional systems that interact with technological and environmental systems to produce large-scale, long-lasting ecological change. It represents an effort initiated by natural scientists working on global-scale environmental systems to incorporate the effects of human actions in their models. A National Academy of Sciences panel on HDGC identified a wide range of research needs in this (also inherently interdisciplinary) area, and identified a number of institutional factors (from disciplinary disincentives to lack of graduate student support) responsible for a serious lack of scientific personnel working in this area (Stern, Young and Druckman 1992). Related problems (tenure/promotion realities, lack of research funding, steep learning curves, lack of interdisciplinary experience and collaborative models, lack of student interest and funding, etc.) will limit the ability of CIEE, CEC and similar organizations to rapidly and effectively mount needed MT research that will, in any way, be self-sustaining.

We believe that creative solutions are possible, however, in which researchers and practitioners can work together to build an effective long-term MT research program. During continued scoping work during the Fall of 1998, we will explore collaborative organizational structures and attempt to interest academic researchers in working on interdisciplinary MT research teams. While there are obviously many challenges involved in building the necessary research infrastructure, it is important to note that some quite successful basic/applied research network models have been developed in the natural sciences. These networks have been created through a combination of direct research funding and network-building grants by NSF, NIH, USDA, NIMH, DoD, NASA, DOE, industry, and foundations. Science and Technology Centers (STCs) and Research Training Groups (RTGs) sponsored by NSF, for example, have allowed the rapid development of research in cutting edge interdisciplinary areas (e.g., molecular biology). This has resulted, in some cases, in the reorganization of whole colleges of natural sciences.

In the energy R&D area, CIEE's Alternatives to Compressor Cooling project represents a 5-year research experiment involving close collaboration between engineers, architects, building scientists, and sociologists. Each contributes to the development of a body of new knowledge that all require for successful completion of their parts of the project. Research useful for related topics has been published in the scientific literature and several graduate students have been trained by the project. Washington State University (WSU) has undertaken several projects in which engineers and social scientists are collaborating on studies related to residential ventilation, technology procurement by governments and firms, and the evolution of telework in urban and rural settings. WSU is currently exploring other promising models of interdisciplinary collaboration that might be adapted to allow researchers, students and practitioners to cooperatively design and execute MT research (and test the results), spending some time in face-to-face contact, but most often coordinating their efforts via electronic networks that connect widely dispersed institutions and research sites.

Regardless of the model or models that ultimately best serve the aim of institutionalizing an MT research capacity in support of California MT interventions, we are convinced that academic reward structures virtually require that this be done via a well-supported network of investigators working on related problems, rather than through the traditional pattern of piece-meal support of one-off research contracts.

Encouraging signs can be found, however, in continuing trends and recent developments. The former include expansion of the HDGC international research program into areas such as "ecological modernization" and "industrial transformation"—market-based efforts to encourage the reorganization of industrial production and business activity along more environmentally sustainable lines. The continued research on consumption by European social scientists and energy policy analysts is also encouraging (e.g., see the agenda for the 1999 meetings of the European Council for an Energy Efficient Economy [ECEEE]). New developments include a surprising resurgence of interest in the "human dimensions" of energy use by efficiency advocates at the 1998 American Council for an Energy Efficiency Economy (ACEEE) meetings, and a growing interest in MT analysis by energy research and development agencies in California, the Pacific Northwest and elsewhere (e.g., the CIEE itself, the California Energy Commission, the Northwest Energy Efficiency Alliance [NEEA], and the Energy Center of Wisconsin). The continued evolution of utility deregulation policy on the state and national levels, and concern about energy-based environmental problems (e.g., implementing the Kyoto accords) seem likely to lend support to efforts to enhance MT research capabilities.

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