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POTENTIAL AND IMPLEMENTATION STRATEGIES FOR RENEWABLE ENERGY IN THE PLANNED WORLD

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ABSTRACT: The technologies and strategies for achieving goals associated with carbon-reduction and transitioning to a renewable energy future exist, and although they will continue to improve with time, the precedents are sufficiently advanced at the present to allow for major penetrations of renewable energy into mainstream design and societal infrastructures (Aitken 2006). Hence, a focused interdisciplinary collaboration that explores precedents for sustainable building practices and solar energy in architecture and urban design projects in Europe and applies them to the building context of North America is of great value. The goal of this paper is to increase public awareness of the importance of efficient, sustainable energy at the building and community scales. The authors, representing different disciplines including architecture, material science and engineering, and economics, discuss the potential (focusing on energy supply and demand) and implementation (specifically policy and financial strategies) necessary in moving the planned world towards a renewable energy future. The strategies outlined in this paper will assist in furthering understanding of the advantages of a shift in thinking from individual building-scale sustainable design practices to realizing the social and environmental benefits of thinking about renewable energy within our communities.

KEYWORDS: Energy Consumption; Renewable Energy; Potential; Implementation.

"*Rapidly accelerating climate change, caused by greenhouse gas (GhG) emissions, is now fueling dangerous regional and global environmental events. Buildings are responsible for almost half (48%) of all GhG emissions annually and 76% of all electricity generated by US power plants goes to supply the building sector. Therefore, immediate action in design and planning is essential if we are to avoid hazardous climate change*".[1]

Prior to the 1940s and 50s environmentally conscious thinking was inherently a part of our culture. However, the age of cheap oil and technological innovation gave rise to a move away from embracing environmental context as a predominant factor in architectural design and planning. This fluctuating response has been repeated throughout civilization across the world in response to access/constraints on combustible fuels. In fact, throughout the past two millennia societies have tended to move away from renewable energy supply/demand strategies whenever fuel-based resources were essentially unconstrained (e.g. plentiful wood and coal), and return to renewable technologies (e.g. solar) and managed energy demand when fuel resources are perceived to be limited (Butti & Perlin 1980). In the modern era, concerns about fossil fuel availability related to petroleum were surfacing during the mid-1950s. American geophysicist M. King Hubbert proposed a resource theory now known as "Hubbert's Peak" (also referred to as

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[1] Quote taken from the website homepage of Architecture 2030, a non-profit, non-partisan and independent organization, established in response to the global-warming crisis by architect Edward Mazria in 2002. See http://www.architecture2030.org/.

"Peak Oil" or "Oil Rollover," all interchangeably) in 1956, which not only predicted that underground reserves of oil – regardless of geographic location – were finite, but also fairly accurately predicted when conventional oil production would reach maximum production in major oil-producing countries. Although the 1970s oil embargo reminded people (temporarily) of the constraint and insecurity of our fossil-fuel based energy economy, as oil prices dropped design and construction practices returned to "business as usual," with little to no focus on energy conscious design.

The energy constraints of the 1970s and concerns over "Peak Oil" led to a number of important policy actions aimed at reducing consumption of fossil fuels. The Public Utilities Regulatory Policies Act's (PURPA) widest impact was felt in transportation and planning practices, but it affected energy use in buildings as well. At the time of the energy crises, 20% of U.S. electricity was produced using petroleum fuels, and the use of natural gas for power generation was prohibited or severely restricted. One goal of PURPA was to reduce the reliance of the U.S. electricity sector on petroleum fuels. In this sense, PURPA has been quite successful; the U.S. now generates less than 5% of its electricity from oil. Since buildings are a large user of electric power, PURPA effectively shifted energy utilization in buildings towards increased use of fuels other than oil for electricity, though fuel oil is still widely used for home heating, particularly in the Northeastern U.S.

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) outlines the true impacts of our buildings on the environment and therefore defines the new constraints and context that designers today and into the future need to address: unintended climate change by greenhouse gas emissions (GhG), particularly CO_2 derived from anthropogenic activities, that are forcing agents in a global greenhouse warming effect. Hence, society is now encumbered with an additional constraint for combustion-based fuel access tied to GhGs. While the building sector is less dependent on oil than it was in the 1970s, other fossil fuels (coal and natural gas) comprise 70% of the electricity produced in the U.S. The impact of buildings on collective resources and the environment is staggering: buildings in the United States account for 41% of the total energy use, consume over 70% of the electricity produced (using fossil fuels), and about 40% of all CO_2 emissions. As society demands increasing levels of environmental quality (including but not limited to the issues associated with climate change), the costs associated with fossil-based electricity and building systems will increase, as will demand for alternative solutions. Planners and designers of the built environment must educate themselves about this energy transition, and adopt an integrated approach to planning and design in order to minimally affect the natural environment, energy resources, and society.

This paper presents a focused interdisciplinary collaboration that explores precedents for sustainable building practices and renewable energy in architecture and urban design projects in Europe and applies them to the building context of North America. The goal is to increase public awareness of the importance of efficient, sustainable, renewable energy at the building and community scales. The authors, representing different disciplines including architecture, material science and engineering, and economics, discuss the potential (focusing on energy supply and demand) and implementation (specifically policy and financial strategies) necessary in moving the planned world towards a renewable energy future.[2] Demand-side and supply-side strategies are presented through a series of comparative case studies. The purpose of the case studies is to illustrate achievements rather than to promote one solution or strategy as "best" for all contexts. The strategies outlined in this paper will assist in furthering understanding of the advantages of a shift in thinking from individual building-scale sustainable design practices to realizing the social and environmental benefits of thinking about renewable energy within our communities.

ENERGY 101: Before discussing approaches for reasonably addressing a shift in the way energy resources are committed to our built environment, we must have a basic understanding of the way that energy is currently transformed and applied in the built environment (consumed). Energy is supplied from a *source* (or *resource:* solar, coal, natural gas, petroleum, nuclear) and, by

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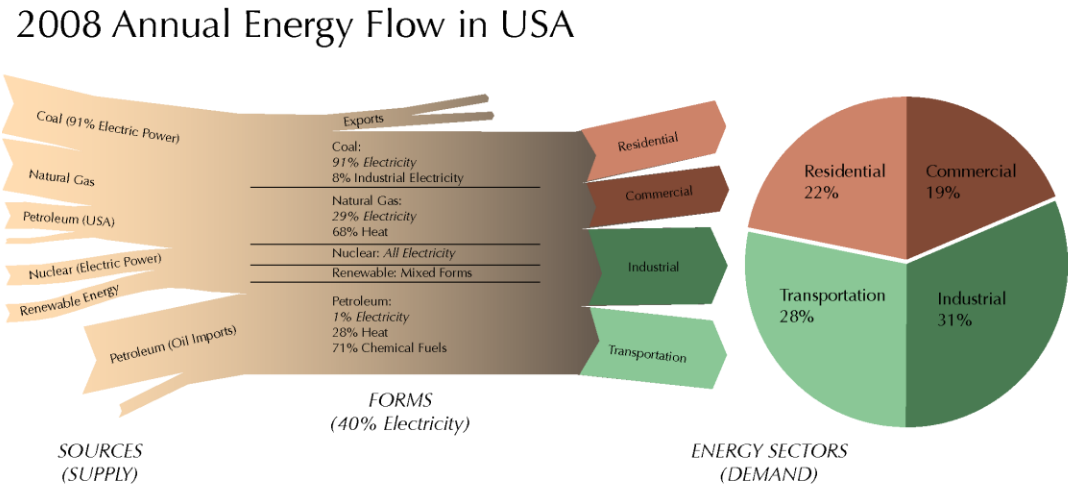
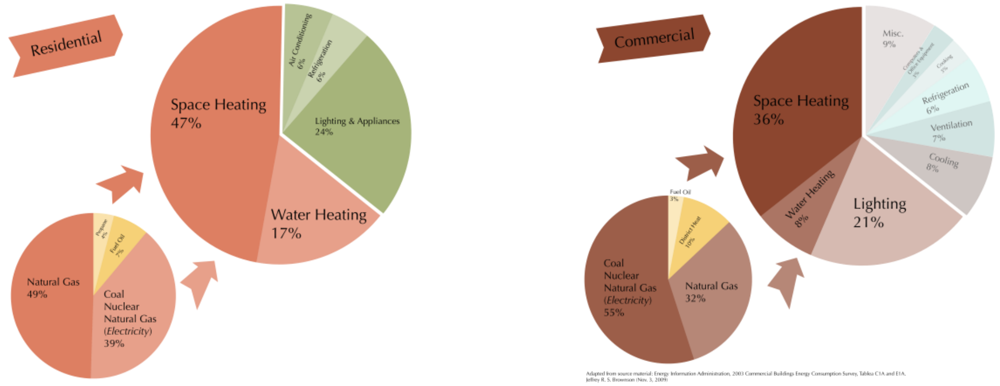
conversion, flows into a different technologically useful *form* (electricity, heat or thermal energy). The demand for these useful energy trans*form*ations is measured according to specific end-use sectors. The four energy demand sectors (Residential, Commercial, Industrial, and Transportation) are demonstrated in Figure 1.



Content adapted from DOE Energy Information Administration www.eia.doe.gov
Jeffrey R. S. Brownson

Figure 1: Sankey diagram (left) and pie chart (right) of sources, used forms, and energy sector use for US annual energy demand in 2008. Content adapted from DOE Energy Information Administration (www.eia.doe.gov).

In residential construction 47% of this energy is dedicated to space heating, 17% for water heating and 24% for lighting and appliances. Refrigeration and air conditioning each account for 6% of the overall demand (Figure 2a). In the commercial sector the majority of energy is devoted to space heating (36%) and lighting (21%), with the remaining electricity dedicated to air conditioning (8%), ventilation, and miscellaneous equipment (Figure 2b). Also displayed in Figure 3, the energy *sources* used for producing electricity and heating/cooling for buildings are generated primarily from nuclear, natural gas, and coal. Note that only 1% of petroleum is converted to electricity as its usable form, the majority (71%) of this source is converted in to chemical forms used primarily for transportation. 31% of energy flow in the US is dedicated to the industrial sector, 19% to the commercial sector and 22% to the residential building sector; the remaining 28% of demand is dedicated to transportation (EIA 2008).



Adapted from source material: Energy Information Administration, 2003 Commercial Buildings Energy Consumption Survey, Tablea C1A and E1A.
Jeffrey R. S. Brownson (Nov. 3, 2009)

Figure 2: Energy sources (small chart) and uses (large chart) for Residential Sector (a) and Commercial Sector (b). Content adapted from source material provided by the Energy Information Administration, 2003 Commercial Buildings Energy Consumption Survey, Tables C1A and E1A.

These figures are fairly consistent throughout North America. In Europe, roughly half of all consumed energy is used to run buildings and 25% is dedicated to transportation (Herzog 1995). Buildings in the EU are responsible for 40% of energy consumption and 36% of CO^2 emissions (EC 2002).

What is not displayed, but equally important, is that energy losses and inefficiencies are inherent in the production and use of energy. Importantly, almost 60% (57.07%) of all energy is wasted during the conversion from source to usable form, primarily in the form of waste heat (LLNL 2008). Therefore, an integrative systems approach to design challenges is necessary, employing strategies that take advantage of all opportunities, eliminating or using waste.

THE CONSUMPTION KEY: Consumption in the built environment, especially related to the life cycle of energy, needs to be considered throughout materials fabrication, construction, use and decommissioning. Global warming potential due to green house gas emissions is high throughout this life cycle. To address these impacts, *life-cycle assessment* (LCA) must be applied as a process-based decision making tool with established goal-oriented criteria. As a tool, LCA can provide comparative metrics to assess the effectiveness of an integrative design process with respect to components and systems of buildings and the planned built environment. Since in both North America and the European Union, 40% of the total energy demand is due to building operation and maintenance (residential and commercial sectors), here we will focus specifically on energy demand (use) related to the heating and cooling of buildings.

Reduced energy demand must be endured in response to the necessity for carbon constraints in the planned world and demand-side solutions must be consumption focused. To accomplish sustained improvement, setting benchmarks for reduced energy consumption and continual assessment and improvement is necessary. In recent years, more stringent insulation requirements and improved energy codes have had limited impact, but life cycle energy consumption has changed very little. Two studies, completed almost ten years apart, show that over 93% of all energy and 92% of total global warming potential in the residential building sector could be attributed to home heating and cooling (Blanchard and Reppe 1998, Ochoa et al 2005). In 2005 the average home in the Northeastern United States consumed an average of 168 kWh/m^2 for basic heating and cooling operation. Certification standards, testing for energy performance during construction, and third-party verification of energy performance has successfully improved building performance, with homes designed to meet the requirements of the U.S. Environmental Protection Agency Department of Energy's (DOE) ENERGY STAR program required to be "at least 15% more energy efficient that homes built to the 2004 Internationals Residential Code (IRC), and include additional energy-saving features that typically make them 20-30% more efficient than Standard homes".[3] However, these benchmarks are significantly less than standards set in the European Union. For example, Germany's energy standard is only 70 kWh/m^2; Passivhaus ultra-low energy building standards set annual heating and cooling demand as not more than 15 kWh/m^2 and "combined primary energy consumption of the living area in a European passive house may not exceed 120 kWh/m^2 for heat, hot water and household electricity".[4] See Figure 3.

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[3] See DOE ENERGY STAR http://www.energystar.gov/index.cfm?c=new_homes.hm_index

[4] Refer to Passive House Institute: http://www.passiv.de/07_eng/index_e.html.

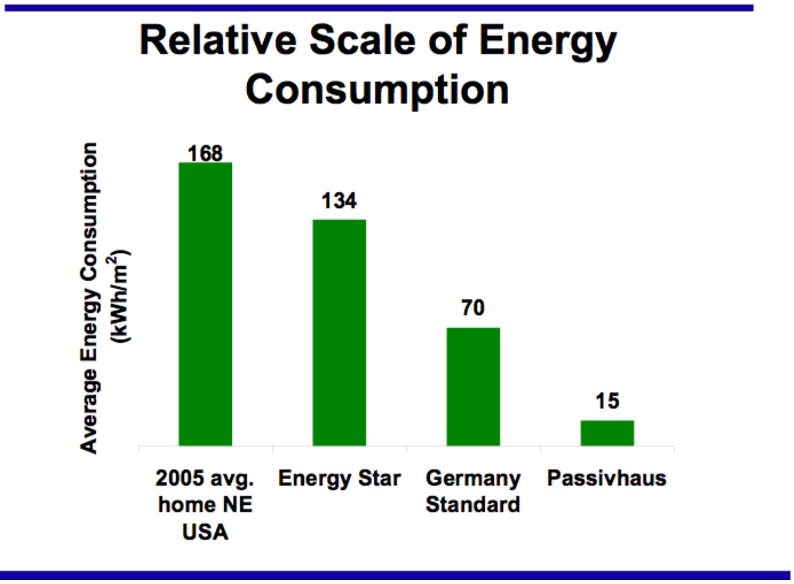

Figure 3: Relative comparison of electrical energy dedicated to heating and cooling of homes (standardized by size in m^2; averages are for energy related to building heating and cooling only).

To successfully set and realize benchmarks for continual improvement, sharing of information and energy performance disclosure is necessary. Internationally, the European Commission's directive on the energy performance of buildings (EPBC), the main legislative instrument at the European Union (EU) level to improve energy performance in buildings, applies minimum requirements for energy performance in new and existing buildings and ensures certification of energy performance through regular inspections of boilers and air conditioning systems in buildings (EC 2002/91). On January 1st, 2006 the Deutsche Energie-Agentur GmbH (the German Energy Agency, dena) "Energy Performance of Buildings" EC directive became effective. Known as the "*Energy Passport,"* the program makes building energy consumption information visible and accessible to everyone. This mandatory program provides information about energy quality and efficiency of a specific building and its components. Similar to the U.S. Environmental Protection Agency's (EPA) ENERGY STAR program labeling system, the *Energy Passport* provides a clear graphic that includes information about energy performance compared to set benchmarks. Unlike ENERGY STAR, a voluntary program, all new and existing buildings in Germany are required to display the dena ENERGIEAUSWEIS *Energy Passport*. Similar legislation in the United States could have the effect of reducing greenhouse gas emissions targets and establishing comprehensive and aggressive national goals and programs for spurring renewable energy and energy efficiency (USGBC Press Release posted July 2010). Currently (July 2010), U.S. Senate committee chairs are drafting new energy/climate legislation. USGBC (United States Green Building Council) is advocating measures that will address the retrofit of existing buildings for improved energy performance; improve, strengthen and enforce efficiency targets in building energy codes; and establish a benchmarking and labeling program for *energy performance disclosure* applicable to both existing building stock and new construction (Sigmon 2010).

CASE STUDIES: Comparing and assessing case study buildings completed in Europe (specifically, Germany) and the U.S. (Northeast) over the last decade reveals both improvements in efficiency and the limitations of accepted development practices in North America. The Commerzbank skyscraper in Frankfurt, Germany and the Hearst Tower near Columbus Circle in midtown Manhattan were design by Foster + Partners, a leading practice in innovative and technologically advanced approaches to high-performance design (refer to fig. 9 for respective geographic locations). Both steel framed buildings contribute to the modern skyline in their respective cities and were completed a decade apart, Commerzbank in 1997 and the Hearst Tower in 2007.

Photo credit: Lisa D. Iulo

Photo courtesy of Lauren Radvansky

Figure 4: *Comparative energy use (for heating and cooling per m^2) of a standard (International Construction Code) commercial building, Commerzbank (CB), left, and Hearst Tower (HT) right.*

The Commerzbank building's base nests into the tight urban site, the tower above makes the building the tallest in the EU at 258.7 meters and 56 floors. The building's design elegantly integrates passive and active performance systems with strict German laws for habitable workspaces. The building massing and floor plan prioritizes spaces that provide natural light and ventilation/thermal comfort over mechanically controlled and isolated office space. A central, triangular atrium runs the height of the building and connects with nine winter gardens that spiral up the building at even intervals. The narrow floor plates allow each office to receive natural light through adjacency to either the exterior wall or the central atrium. Operable windows and stack-effect ventilation through the atrium and themed interior gardens cool and ventilate the building, maintaining a comfortable microclimate – despite the fact that Frankfurt's average temperature is the 2nd warmest in Germany - and enhance the work environment throughout the building.

The Hearst building's faceted glass tower stands 40 stories above a six-story existing Art Deco building designed by Joseph Urban. Although the tower and base are distinct on the exterior, on the interior the innovative structure of the tower penetrates the space inside the historic shell creating a "vast internal plaza".[5] The Hearst Tower was New York City's first LEED-certified skyscraper (certified "Gold" under the *LEED Core and Shell* and *Interior* rating systems by the USGBC) and is regarded as a model sustainable office design. Innovative and artistic feature are integrated into the grand lobby space atrium and contribute to the dynamic environment. The most notable feature is a rainwater harvesting system that collects roof water and stores it in a basement cistern for use in the building's cooling system, for irrigation, and for recirculation in the 3-story tall water sculpture, *Icefall*, which cools and humidifies the lobby air. The fairly conventional office floor plates of the tower provide for improved natural light and exterior views through the combination of perimeter offices and open workspace.

As a result of innovations for heating and especially cooling, the Hearst Tower consumes 26% less energy than similar commercial skyscrapers constructed to meet code. Although constructed 10 years prior to the Hearst Tower, Commerzbank in Frankfurt, Germany is significantly more efficient overall (refer to fig. 4 above). The building consumes 140-150kWh/m^2 for heating and cooling, (by comparison, standard buildings greater than 10 floors consume ~400 kWh/m2 in NE USA. The Hearst Tower consumes approximately ~296 kWh/m^2

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[5] Foster + Partners project website available at http://www.fosterandpartners.com/Projects/1124/Default.aspx (Accessed July 2010).

for heating and cooling). This improved performance is due, in part to a greater acceptable range for climatic comfort, including temperature and humidity, which allowed the design team to explore rigorous passive solutions; 60% of the building is naturally ventilated. Specially adapted plantings in the nine winter gardens help to regulate temperature and humidity. Operable windows allow cross ventilation and night flushing of both common spaces and private offices. Computerized building sensors control building systems but allow for some occupant interaction and control. As of 2008, 100% of the reduced electricity demand for the building is supplied from green power sources.

Innovations in the Hearst Tower provide a precedent for incremental improvement in the environmental impact of large-scale buildings. The publicly accessible atrium symbolically highlights interventions for water and energy conservation, juxtaposing high-tech design solutions within the historic building shell and encouraging tourism. The building also highlights the limitations for reduced energy consumption inherent in current North American development patterns. Ultimately the large floor plates and sealed glazed facades necessitate aggressive HVAC solutions and limit opportunities for consumption reductions in electricity demand and the impact of energy supply including GHG emissions and energy loss.

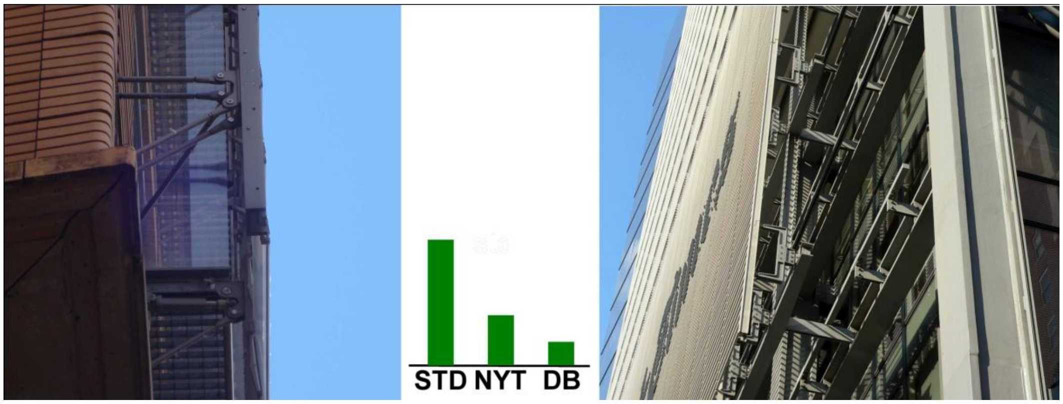

Photo courtesy of Rohan R. Haksar

Photo courtesy of Lauren Radvansky

Figure 5: Comparative energy use (for heating and cooling per m^2*) of a code-compliant Commercial office building (STD), New York Times Building (NYT) on left and Debis Building (DB) on right.*

The Debis Building in Berlin, Germany and the New York Times Building (refer to fig. 9 for geographic locations) both designed by Renzo Piano Building Workshop[6] and, like the Commerzbank Building and Hearst Tower completed in 1997 and 2007 respectively, point out the inherent opportunities that conscious consumption combined with a basic understanding of systems provides for even greater reductions in energy consumption. Both the 21 story high, 44,500 square meter Debis Building and the 52 story, 143,000 square meter New York Times Building illustrate commonly accepted strategies focused on reducing material and energy resource consumption. They are constructed of high-recycled content steel; feature double façade glazed construction for improved energy performance, ventilation and shading; and implement water conservation strategies. Systems integration addresses both energy supply and demand. Both buildings incorporate a combined heating and power (CHP) system.

Basic rules of thermodynamics dictate that during the conversion of energy (power sources into usable electricity), some amount of energy will be wasted, largely in the form of heat emissions. The conversion efficiency of even the most modern fossil power plants is less than 50%, so the amount of waste heat produced during electricity generation is enormous. Generally this waste heat is vented into the atmosphere. As energy sources become scarce and more expensive, wasted heat energy is clearly not desirable. In a CHP cogeneration system waste heat is captured and used. Small system networks for cogeneration provide electric power, heat (for

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[6] Renzo Piano designed The New York Times building in association with FXFOWLE.

space or water heating) and sometimes cooling. The addition of CHP to the already high-performance Debis and New York Times buildings result in a reduction of 80% and 60% energy use for building heating and cooling respectively, as indicated in figure 5 above. Debis building used a total of 75 kWh/m^2 of electricity, half of that required for the Commerzbank Building.

Figure 6: Comparative energy use (for heating and cooling per m^2) of "Green" Affordable Housing at Petersburg Commons (PC), left, and Schlierberg Solar Estate (SS), right.

Two projects, one in the temperate climate zone of North America and the other in Freiberg, Germany highlight the benefits of community-scale solutions (refer to Fig. 9).

The "green" affordable housing at Petersburg Commons in Duncannon, Pennsylvania represents opportunity for conscientious design and planning improvements in conditions indicative of many of the marginalized towns and communities in Northeast North America. Petersburg Commons was planned as a market-rate townhouse subdivision typical of rural Greenfield development and without consideration to orientation or other sustainable planning strategies. The road and infrastructure for the new development and five of eleven planned housing blocks were completed before the original developer pulled out of the project. The site was selected by a local not-for-profit housing authority for the first "green" affordable housing in Pennsylvania, in part because of its proximity within walking distance of the community resources of an established rural town. It was determined early in the design process that, although not ideal in terms of passive solar orientation, the approved land development plan would be respected in the interest of "working within established and prevailing patterns of development" so that the project could provide a "model for responsible development that can be replicated," especially for infill housing (Iulo & Quigley 2007). Completed in 2006, the 14-unit single-family residential project uses fairly conventional building practices, but is energy-efficient (EPA Energy Star certified), resource efficient (using less materials for construction and water for operation), and uses durable materials and details that supported local businesses and labor and require little maintenance by the residents. Simple design strategies, including aligning operable windows and doors and installing rooftop cupolas, allow for natural ventilation and day light deep into the home interiors. Construction cost for these homes was US$95.00/square foot, representing a 6% premium for "green" construction but still much below the average cost for new construction. Overall the resulting homes provide long-term affordability to the homeowners. They are almost 40% more energy efficient than equivalent homes built to code and monthly electric bills (including heating and air conditioning) proved to be 60-80% less than similar projects constructed by the same housing authority.

Solarsiedlung am Schlierberg (in English: Schlierberg Solar Estate), located in Freiburg - known as the solar and ecological capital of Germany, was conceived as a showcase solar development. The project, completed in 2001, was championed by Rolf Disch SolarArchitecktur, the project architect, as a "beacon project" for the *PlusEnergyHouse* concept. Acknowledging that "even low energy buildings consume too much energy, and Passive Houses still emit CO$_2$ into the atmosphere," *PlusEnergyHouse* addresses three goals: "100 percent renewable energy supply, emission-free operation, and a positive energy footprint" (Rolf Disch SolarArchitektur, The PlusEnergy House for Every Community brochure, 13). The solar estate, a car-free community comprised of 50 residential townhouses and a commercial office block (the "Sunship"), is located adjacent to the Vauban redevelopment area, a district planned around responsible community development strategies. Existing regulations for the property dictated optimal, south-facing, orientation of the buildings. Schlieberg Solar Estate buildings utilize PassivHaus (Passive House) standards for insulation and building systems and passive solar shading and ventilation strategies significantly reducing energy demand for the development. A rooftop PV (photovoltaic) system, integrated into the design of the town homes, allow the project to be a net energy generator, producing nearly 3 times the energy demand (all uses consume 2200 kWh/yr of energy and the 445 kWp grid-connected PV system generates 6280 kWh/yr of electrical power). Innovative ownership models for the PV (Solar Fund Freiburg)[7] and an aggressive national feed-in tariff[8] (requiring that utility customers receive preferential electricity rates for electricity generated from renewable energy sources for a period of 20 years) proved solar electric power not only feasible, but also profitable in this context.

Reducing energy demand must be the initial and most important goal in realizing a reduced carbon reality for the planned world. The impact of energy demand must be measured and benchmarked and targets set for reduction in energy use, facilitating a view of consumption as a golf score – the goal: consume as little energy as possible. Building energy audits; improved design strategies, construction methods and efficient technologies; and informed demand-side management (energy consumption) contribute towards this goal. As indicated in the case studies above, once energy demand is reduced - through improved building performance, systems integration, and occupant interaction - further opportunities for eliminating waste (such as CHP) becomes plausible and energy supply including realistic renewable solutions can be explored. The next section of this paper will look at supply-side solutions for renewable energy.

RENEWABLE ENERGY SUPPLY: Responsible and purposeful integration of renewable energy begins with a reduction of loads (energy demands) in the built environment, leading to a balance of renewable sources (supply) and energy sufficient use (demands). Many renewable energy sources can be integrated into building and/or community development projects, generating local power and significantly reducing the “carbon footprint” of the building or complex. On-site generation, in addition to providing a reliable source of green power, offers increased security (including protection from power outages), economic opportunities, and supporting contributions to distribution system infrastructure. As illustrated by the Schlierberg Solar Estate, photovoltaics (PV) offer attractive integration possibilities, even though the current cost of electricity production by solar energy conversion is significantly higher than that produced by coal or nuclear sources. PVs deliver clean (non-CO_2 emitting) electric energy from the ubiquitous solar resource.

The average rate of renewable electricity production potential from the sun is over 200,000 GW of power. In units of energy (TWh: equivalent to one billion KWh, and assuming 30% capacity factor for power production) we observe the annual PV production potential (pp) *in the US alone* can yield 550,000 TWh of renewable electricity. [9] In comparison, the United States consumed 3.8 TWh of electricity in 2008. That the PV production potential in the US is five orders of magnitude (100,000x) *more* than the annual demand for power is often clouded by misconceptions. A prolific misunderstanding arises in conversations: That the northern regions of North America (e.g. Mid-Atlantic states) do not have sufficient solar resources to benefit from solar energy conversion systems such as PV. In fact, the northern United States has significantly better solar conditions than Germany, with similar annual resources to Spain, another European leader in solar energy implementation. Other renewable energy power sources include wind, with

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[7] The Sun Ship Fund, sustainable real estate funds, with “Solarsiedlung GmbH (Solar Settlement Inc.), provided opportunities for individuals or companies to subscribe to shares in the project. Information available at http://www.freiburgersolarfonds.de/

[8] Feed-in tariffs assure return on investment for grid-connected renewable energy projects. In Germany they are defined and administered by the German Renewable Energy Act (EEG). An English translation of EEG 2009 is available at: http://www.bmu.de/files/pdfs/allgemein/application/pdf/eeg_2009_en.pdf

[9] Source: DOE Energy Information Administration http: www.eia.doe.gov. We have converted the rate of production into units of energy: assuming 30% capacity production considering day/night/weather conditions.

an annual production potential (pp) of 10,000 GW (26,000 TWh pp, assuming 30% capacity), geothermal (500 GW: 3,300 TWh pp, assuming 75% capacity), hydropower (140 GW: 490 TWh pp, assuming 40% capacity), and biofuels (80 GW: 560 TWh pp, assuming 80% capacity). Resource maps, indicating geographically specific production potential from renewable energy sources, are available at http://www.nrel.gov/gis/. What makes solar energy unique is the ubiquitous nature of insolation (reducing transmission distances), compared to the more isolated conditions found in resources such as geothermal and hydropower.

For the most part, renewable energy systems in the built environment have been limited to single building installations, small-scale applications where energy is used directly. This configuration is generally referred to as "behind the meter generation" and encompasses not only renewable installations such as rooftop photovoltaics, but also emergency power supplies such as backup generators fueled by diesel oil or propane. For renewable energy to have a more significant impact in realizing carbon-neutral goals, installation at the collective (community or development) scale must be considered, in a distributed energy resources (DER) configuration. DER provide benefits of a centralized system, generating and distributing power, but have distinct characteristics that are locally beneficial: 1) DER are smaller in size than typical power plants; 2) they are located near customers and serve individual or small groups of customers; and 3) they are generally modular and scaleable, utilizing off-the-shelf technology that can be scaled up as demand increases (King 2006, 130-131). The remainder of this paper will consider implementation, specifically policy and financial strategies, for renewable energy at the multi-building community scale in the interest of highlighting the opportunities and overcoming barriers to implementation of locally produced, owned, and used renewable energy.

IMPLEMENTATION: *"National policies to promote renewables, such as feed-in tariffs, can provide a positive backdrop and encourage the implementation of individual buildings with renewables. However, when it comes to larger projects such as developments or concentrations of renewable projects within particular areas, local government has a key role to play." (*Munro 2009, 5).

Community-level renewable DER projects, as distinct from individually-owned and used distributed generation, can generally be implemented in one of two physical configurations. In the first configuration (see figure 7a below), the renewable electricity supply is owned by a private developer who leases the land and is granted the right to build and operate the energy project. Developer-owned projects are typically connected to the utility transmission grid, and the developer sells electricity to a power company through the grid rather than directly to the community. In most applications, the community would sign a *Power Purchase Agreement* (PPA) or "energy lease" with the developer, whereby the developer would agree to subsidize the community's purchase of electricity from the power grid. This configuration is beneficial to communities in that it allows them to support renewable energy development and enjoy the benefits of lower electricity costs without having to spend any money up front. The biggest disadvantage to the independent developer model is that lack of ownership also means lack of control in most circumstances. This would preclude communities from integrating a developer-owned project into a community energy management plan, or combined heat and power applications without the consent of the developer. A second disadvantage of the independent-developer model for communities concerned with careful environmental-footprint accounting is that the location of such a renewable energy project within a community *does not* mean that community residents are consuming power from renewable sources. Since the developer's project feeds directly into the utility grid, the community also consumes electricity from the utility grid, and thus receives electrons from the same mix of generation sources (fossil-powered and renewable) as other consumers on the grid.

An alternative configuration is known as the micro-grid model (figure 7b above). There is no universally accepted definition of a micro-grid, which (as will be discussed below in the section on regulation and public policy) itself has been a barrier to the deployment of micro-grids in the US. The discussion here will define a micro-grid as follows

1. Micro-grids provide services to "multiple customers connected on a local network" (King 2005). Examples might be multiple homes in a residential neighborhood or several buildings on a campus or office park property.

2. Customers must be on or contiguous to the site where the power is generated (King 2006, p.64).
3. The micro-grid is linked to the utility distribution network through a single interconnection point. Controls and operating protocols govern the interaction between the micro-grid and the utility grid. The utility may be a net supplier of electricity to the micro-grid, or a net buyer of electricity to the micro-grid (or may simply operate independently).
4. Ideally, a micro-grid would integrate the supply side and the demand side in order to maximize operational efficiency and reliability, and minimize environmental impact. Some definitions of a micro-grid, such as that proposed by the Lawrence Berkeley National Laboratory include combined heat and power services provided by the micro-grid in addition to electricity.

The advantages of a micro-grid for a community-based energy project are primarily in increased community ownership and control of the project. Deployment of micro-grids, however, requires significant technical expertise and capital investment beyond the source of the power supply, since inherent in a micro-grid is the existence of a local electricity distribution network. The public's understanding of the subtle differences between a micro-grid system and the independent-developer model (where renewable generation is located within the community but serves the utility power grid) is critical, particularly surrounding perceptions of wealth containment (within the community) and wealth transfer (outside the community).

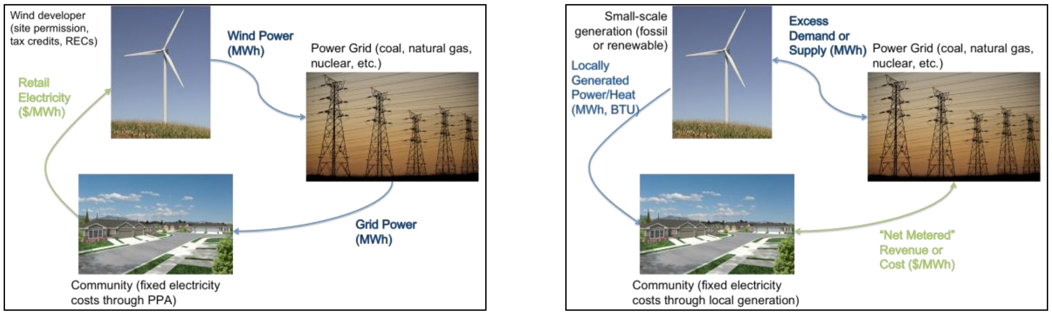

Figure 7: Under the independent-developer model, the community leases land to a renewable energy project that feeds electricity into the power grid. Through a long-term Power Purchase Agreement, the community enjoys a fixed electricity price that is often below-market (illustrated in fig. 7a, left). Figure 7b above on the right illustrates the micro-grid model where the renewable energy project feeds electricity directly into the local distribution grid, serving the community directly. The energy price in the community is determined by the cost of running the renewable energy project. Micro-grid projects may be "net metered" where permitted to sell surplus electricity to the utility grid, and are easier to harmonize with demand-side management than are independent-developer projects.

FINANCIAL CONSIDERATIONS FOR MICRO-GRID INVESTMENT: Electricity systems, large or small, are capital-intensive investments, and typical investments in residential-level or small-scale electricity (such as generators or rooftop solar) have been financed through ordinary loans. Historically, the development of small-scale electric power generation was slowed by the significant cost advantages to building larger central-station power plants. Technological advances have diminished these "economies of scale," and DER in many locations can offer cost savings compared to purchasing grid electricity from the utility.

A number of incentives and other financial instruments beyond the simple power-purchase agreement have emerged recently that can lower the cost of community-owned DER projects in a micro-grid configuration. Tax credits, either *production tax credits* (PTC) or *investment tax credits* (ITC), offered by the federal government, are generally available to private (non-governmental) investors. *Alternative Energy Credits* (AEC) or *Renewable energy credits (RECs),* certificates that are granted to renewable energy facilities, can be bought and sold on the open market in states with renewable portfolio standards (RPS) and can, depending on ownership of the RECs, reduce the costs associated with community renewable energy development. In regions with cap-and-trade programs for greenhouse gases, including Europe and the US Regional Greenhouse Gas Initiative, owners of renewable energy generation may qualify for “carbon credits” that can be sold to the operators of fossil energy plants much in the same way as RECs. The value of these carbon credits has generally been lower than the median value of RECs, particularly in the US. Some US states offer *Energy loans* as a way to lower the upfront costs of installing renewable energy projects typically by offering financing with low interest rates thus lowering the payback period for a renewable energy project.

Net metering is an accounting system for grid-tied renewable energy projects; these projects are provided with credits for surplus electricity that is supplied to the utility grid. Selling excess electricity to the utility is a promising way to reduce the costs of installing community energy projects. Net metering regulations vary widely; although the 2005 US Energy Policy Act encouraged individual states to adopt net metering regulations, not all have done so. Those states that do allow net metering vary widely in the sell-back price as well as the procedures required to register with the utility as a net-metered customer. We have reviewed existing state-level net metering and distributed generation interconnection policies. As indicated in figure 8 below, generally the most advantageous states for grid-connected community energy projects appear to be in the Western US (likely to encourage small-scale solar power) and in the Northeastern US, where electricity prices are high and building utility-scale infrastructure has become increasingly difficult, expensive and contentious (Vajjhala and Fischbeck 2007, 650-671).

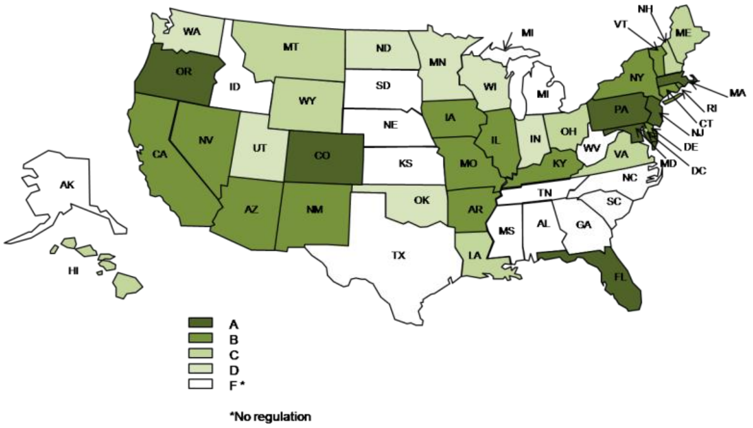

Figure8a: Assessment of state net metering tariffs. An “A” rating indicates the most permissive or advantageous tariff for net-metered DG, while an “F” rating indicates the least permissive or non-existent tariffs for net-metered DG. Source: IREC (2008) and www.dsireusa.org.

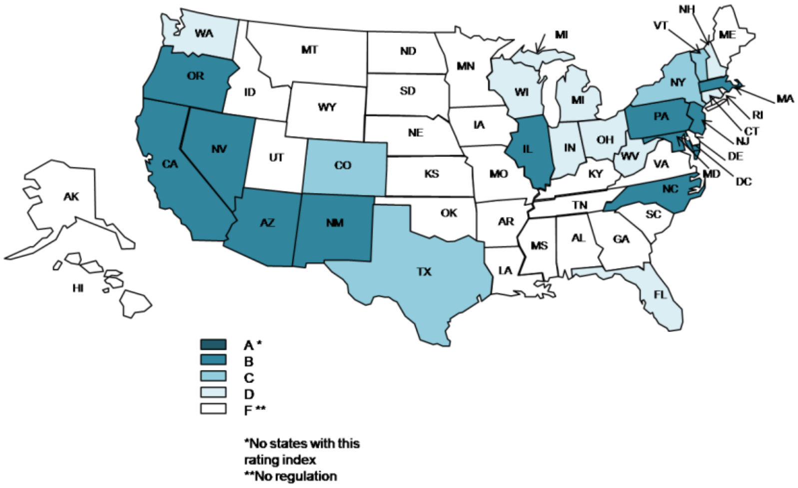

Figure 8b: Assessment of state interconnection regulations and protocols for net-metered DG. Note that no state received an “A” for interconnection of DG. Source: IREC (2008) and

www.dsireusa.org.

THE ROLE OF LOCAL POLICY: Fundamental change in incentives resulting in the realization of more renewable energy generation will rely on increased public awareness and knowledge. In the US, the Federal Energy Regulatory Commission (FERC) has oversight responsibility for regional wholesale electricity markets and high-voltage long-distance electric transmission lines. The FERC has adopted rules and policies that distinguish between "large" power generators and "small" power generators, but even these rules are not terribly relevant to the development of community-scale energy projects since the rules govern interconnection to the high-voltage transmission network, not the local distribution network. In the US, the vast majority of policies relevant to community energy projects developed under the micro-grid model are made by local or state jurisdictions. (One possible exception would be Congressional rules relevant to energy loans. Beyond that, writing a U.S. Congress-person isn't the right strategy.)

State policies on net metering can create winners and losers with respect to specific micro-grid system configurations. Solar photovoltaic power may be penalized under net metering policies that do not base compensation on market prices, since they tend to (or can be configured to) produce more power during times when system demand and market prices are highest.[10] Wind power, on the other hand, may be implicitly rewarded since wind speeds tend to be highest at dusk and at night, when demands and prices are lowest. Other states erect barriers to micro-grid deployment by imposing high costs or restrictions on when interconnection may be allowed. States vary in their legal and technical requirements for interconnection, but the majority of states have poor or non-existent interconnection standards that present barriers to entry for distributed energy resources or micro-grids.

The most important barrier to micro-grid deployment is that no state has a legal definition of a micro-grid. A recent survey of state-level public utility regulators suggested that, in a number of states, micro-grids would have the right to exist and operate as long as the micro-grid would not qualify as a "public utility" under that state's public utility code (King 2005). However, the legal status of the micro-grid could vary depending on the whims of the public utility regulators or the politicians that appoint them. A precise definition would facilitate enacting and enforcing a consistent regulatory policy at the state level, but the regulations governing micro-grids are not there quite yet. We are left with "reading between the lines" to determine which states would be advantageous and disadvantageous for micro-grid development.

The Palamanui development on the Island of Hawai'i (see fig. 9 for location) was a planned mixed-use community that had been designed to meet the goals of multiple constituents (Thomas et al 2009). The developers needed to make a sufficient profit, the Island government wanted the residential housing to be affordable, and the residents wanted comfortable homes and a "net zero energy" community. As part of the community's plan to meet the goal of net zero energy, the development would feature rooftop photovoltaics that would feed surplus peak electricity into the island's utility grid. The community would use a combination of storage and power purchased from the utility grid to meet electricity demand during the evening or on cloudy/rainy days. Peak electricity in Hawai'i is among the most expensive in the US, so excess power sold from the community to the island utility would have improved reliability and lowered costs. The utility, however, argued successfully to the Hawai'i Public Utility Commission that the distribution of electricity within the community and the net-metered interconnection would violate the utility's geographic monopoly franchise. Many of the development's innovative energy supply and management proposals had to be eliminated from the community plan.

Successful variants of the micro-grid model have been implemented in Maine and are planned for Pennsylvania. The Fox Islands community-owned wind project in Maine (www.foxislandswind.net) provides electricity to the island residents and sells surplus power directly to the New England transmission operator through the wholesale market, rather than to an electric distribution utility. The Fox Islands project was able to side-step interconnection

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[10] A rooftop solar panel with a flat orientation will produce the greatest amount of power during the middle of the day, even though system peaks typically occur in the morning and during the late afternoon. Panels can be oriented or creatively designed to match these system peaks. See Brownson et al. (2009).

negotiations with the electric utility because of its relatively large size (4.5 MW) for a community-scale energy project. The island community has begun experimenting with the use of distributed thermal storage to "store" surplus wind power for heating and hot water, thus reducing the need of the island residents to import fuel oil or propane from the mainland.[11]

Pennsylvania is an example of a state where the regulatory environment is flexible enough to allow experimentation with micro-grid systems. (The economics are certainly better in Hawai'i, but the experience with the Palamanui development has shown the regulatory environment to be too restrictive.) The small borough of Smethport, which has a population of approximately 1,700 people, borders the Allegheny National Forest and has been dependent on a highly variable timber industry. Inspired by a similar initiative in the town of Gussing, Austria, Smethport is planning to construct a biomass reactor fueled by low-grade timber (low-value wood that would otherwise be discarded as waste). The plant will provide electricity for the town and district heating for municipal buildings. The economics of the project are appealing, and local technical expertise exists since the municipality owns some of the electric distribution assets within the community. The project will also help the town meet its environmental and economic development goals, since providing fuel for the biomass plant will help support the town's timber workers.

To achieve goals of local renewable energy generation and use, communities will need to devise policy guidelines that are consistent with energy development goals. Zoning regulations and property rights must be designed especially carefully if the desired system is distributed in nature (such as a neighborhood with multiple rooftop solar installations). Homeowner association covenants can also be designed with energy goals in mind. The proposed covenants for the Palamanui development, for example, separated rooftop ownership from control, to ensure the community managers access to homeowner rooftops to install and maintain solar installations.

CONCLUSION: A *New Electricity Paradigm "based on a highly integrated network of advanced technologies including* ***energy efficiency, demand response*** *(which affects the timing rather than the efficiency of usage),* ***renewables*** *such as solar and wind, energy storage, and* ***distributed generation…****Together, these technologies have the potential to make electrical systems more secure, cleaner, and ultimately more cost effective"* (Hansen and Lovins 2010). Towards this end, sustainable development for the planned world must include balanced consideration for both the potential and implementation of renewable energy. Practical solutions must be considered within the context of location and availability of resources.

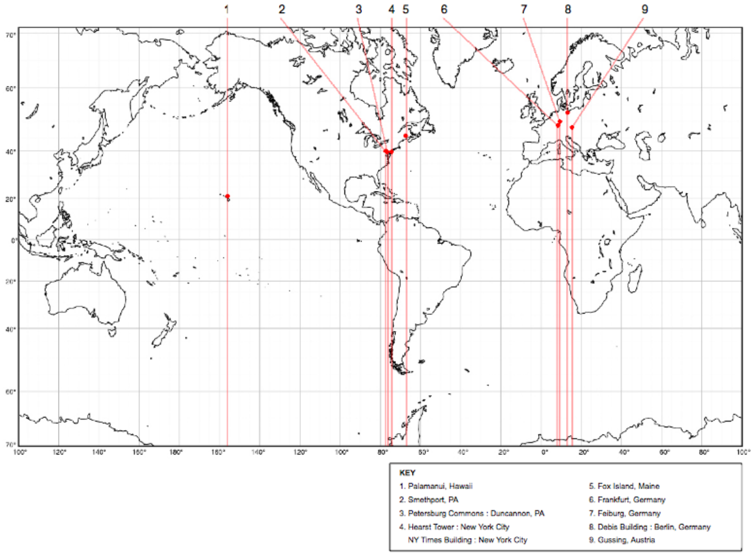

Figure 1: Map, by Rohan R. Haksar, indicating geographic location of case study projects

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[11] See http://www.veecharge.com/projects/fuel_substitution

discussed in this paper.

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