Model for Sustainable Urban Design

With Expanded Sections on Distributed Energy Resources

Prepared by:

Sustainable Energy Planning Office
Gas Technology Institute

Prepared for:

Oak Ridge National Laboratory
Under Contract # 4000021368

GTI Project # 30803-23 / 88018 / 65952

Primary Authors:

Una McGeough
Doug Newman
Jay Wrobel

FEBRUARY 28, 2004

DISCLAIMER

TABLE OF CONTENTS

PURPOSE & CONTENT

Today, 80% of the U.S. population lives in urban areas and more than half live within the 25 largest cities. American cities and towns now account for over 80% of our national energy usage and urban development patterns affect approximately 70% of that consumption. This document describes a model design for urban development and redevelopment that will significantly reduce urban energy consumption and enable all American cities to become more sustainable communities.

It is intended for municipal officials, planning commissioners, planners, architects, and private developers interested in building urban communities that are more livable than existing communities.

Section I defines urban sustainability, describes the historical context for the prevailing urban development patterns in the nation today, and identifies several emerging trends that will impact all communities seeking sustainability. Section II discusses the essential linkages between material and energy resource consumption and land use and transportation development patterns. Section III frames the major challenges for urban design and provides proposed solutions, offered by some of the leading experts on the subject from around the world. Section IV translates this expert input into a set of principles and elements suitable for sustainable urban system design in America. Section V provides a case study in which these model principles and elements are applied in a sustainable urban design for one of the nation's most complex metropolitan areas – the San Diego-Tijuana Binational Metropolitan Region. This design also incorporates the latest thinking of experts from a variety of fields with regard to emergent technologies that will enable all cities to become more sustainable in the future. Section VI completes the model design with a framework for strategic urban planning and a set of immediate actions all communities can take to become more sustainable today.

I. URBAN SUSTAINABILITY – DEFINITION & CONTEXT

DEFINITION

The term urban sustainability can be defined as: "the state a metropolitan community reaches once it is able to meet the needs of the present generation without compromising the ability of future generations to meet their own needs." This paraphrases the most commonly accepted definition of sustainable development in the world today. This definition appeared in 1987 when the United Nation's World Commission on Environment and Development published its famous report entitled "*Our Common Future.*" The central thesis of this report is that economic growth and development and environmental preservation are not mutually exclusive objectives but rather are mutually supportive and fundamentally interdependent objectives. Further, the Commission stated that long-term economic development would require "a change in the content of growth, to make it less material- and energy-intensive and more equitable in its impact." This implies that continued economic growth requires the responsible use of all natural and manufactured resources, particularly energy, and a concern for social equity for all inhabitants of a community.

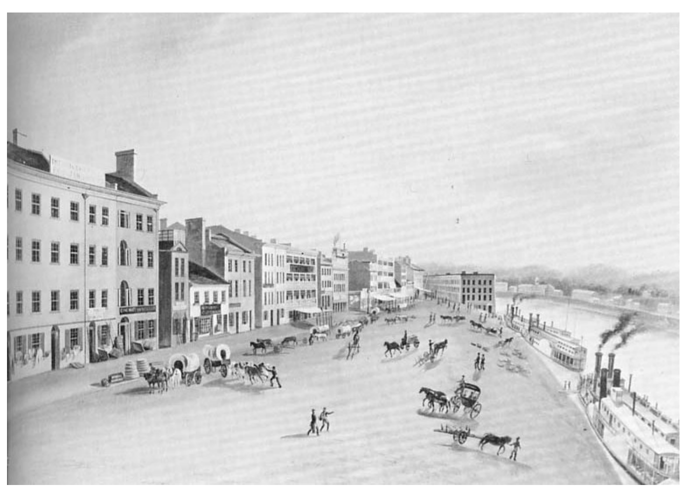
Today, the pursuit of economic prosperity, environmental quality, and an equitable society, or "the 3Es" is among the top priorities for metropolitan communities around the world and across the nation. Increasingly, a concern for the 3Es is also evident in the strategies of enlightened corporate entities as well, as so-called “Triple-Bottom-Line” accounting is now being used to assess corporate performance against these objectives on sustainability indices maintained by Dow Jones and others.

Unfortunately, American cities are not inherently sustainable. Instead of making efficient use of materials and energy in the pursuit of economic development, they inefficiently consume vast quantities of both. And despite many well-intentioned Federal, state, and local programs, social equity among urban populations remains difficult to secure. To comprehend why our cities function in this manner, it is useful to consider the historical forces that have shaped urban form in America over the past 225+ years and the emerging trends that will challenge cities’ abilities to become more sustainable communities. A brief discussion of these historic forces and emerging trends follows.

CONTEXT – AMERICAN METROPOLITAN EVOLUTION

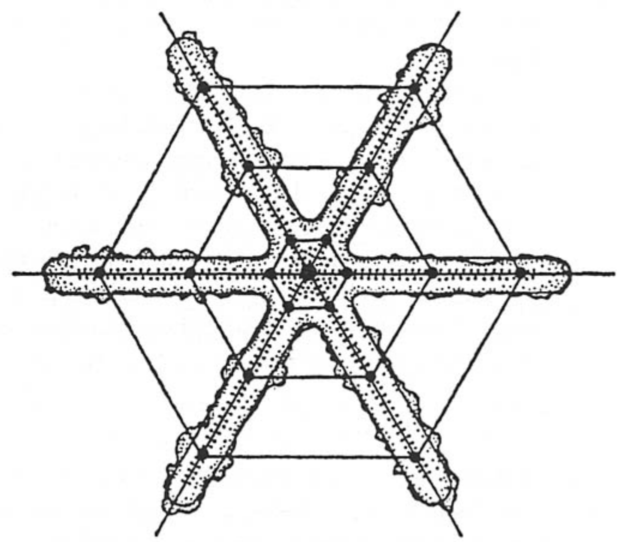
Most urban scholars attribute contemporary urban form to the combination of technological innovations in transportation, energy, and communications and a set of public policies that maximized their spatial impact. As urban development patterns were shaped by these technologies and policies, so also was a national perception of unlimited space, individual land ownership, and material consumption. This general public perception remains with us today, and poses one of the most significant challenges to the nation’s ability to become more sustainable.

During the 17th and 18th centuries, American cities grew along the Atlantic coast and nearby navigable rivers and took a compact urban form in response to the available means of mobility at the time – walking, horseback riding, and horse-drawn vehicles. Travel between urban settlements was by horseback, carriage, or boat. Residences were mixed with commercial enterprises, and both were concentrated around densely populated urban cores, typically centered at the ports. These early cities functioned as centers of commercial trade between the newly established states and distant European markets. The agricultural hinterlands of these cities were still relatively small and thus were supplemental rather than primary elements of the urban economic base. Wood was the primary source of fuel and building materials, and communication was achieved through face-to-face interaction or through messengers who traveled on foot or horseback.



With the dawn of the 19th century, the U.S. embarked upon a massive nation-building campaign that encouraged rapid westward expansion of settlements through the promise of free or very inexpensive lands from the public domain. To aid this expansion, the national government also provided funding for the development of overland roads and canals. Settlements soon appeared along the rivers, taking maximum advantage of water-borne passenger and freight transportation options and waterwheel-powered manufacturing opportunities.

The development of agricultural, mineral, and forestry resources in the hinterlands was also facilitated by the ability to reach distant markets through the rivers and canals that linked the hinterlands to the original port cities. Intra-urban transportation continued to rely on horse-drawn wagons and carriages although horse-drawn streetcars, the first form of true urban mass transit emerged in the early 1800s. Urban form was still relatively concentrated in wooden buildings of mixed use along waterfront centers, although some residential settlement began to spread out along and between the streetcar lines, typically in a radial star-pattern from the city center.



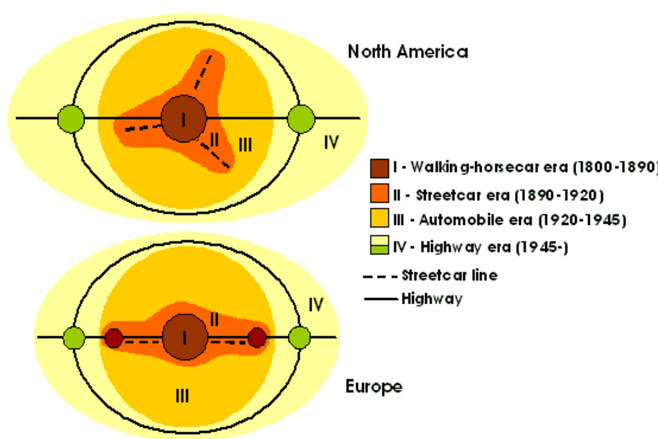
During the second and third decades of the 19th century, technological innovations in steam engines for manufacturing and locomotion spurred the federal government to fund the development of railroads to further the nation's westward expansion. Commerce and urban life were no longer restricted to city centers on waterfronts and were now free to expand overland as settlements developed around every major railroad station. The rails enabled the efficient transportation of agricultural commodities, minerals, fuels, and building materials to reach both new and established settlements from distant hinterlands. Accordingly, national markets appeared for these basic urban essentials, as did interurban markets for the vast array of industrial and commercial products that were being produced as the industrial revolution advanced.

Coal and oil fueled the engines and locomotives that accelerated both urbanization and industrialization of the nation. Natural gas also contributed to urban life during the mid to late 1800s as a fuel for street lamps before most were converted to electricity in the early 1890s. Energizing this new source of street lighting were the first municipal electricity systems, whose transmission and distribution cables enabled physical separation between power generators and the point of consumer use. Specifically, this technological capability meant that the generation of electricity could take place outside of the historic urban centers, and this significantly improved urban air quality.

Electrical transmission and motor technology also enabled power to be sent along the rail lines and boulevards to further energize middle class mobility with the electric streetcar and the development of new residential areas at the city's edge. This same period witnessed the development of the first commuter railroads that enabled wealthy residents to settle beyond the periphery of the cities. The urban poor remained in the central cities. Technological innovations in communications, specifically, the introduction of the telephone in 1876, also played a role in facilitating the further decentralization of commercial and residential concentrations in the central cities. And, although distant commercial enterprises and residential communities began to emerge, most established city centers remained vibrant, if not crowded concentrations of commerce, culture, entertainment, recreation, and residences for a large portion of the newly arriving immigrant populations. As the 20th century got underway however, this would all change dramatically with the widespread introduction of the automobile.

There is not a single technological innovation or a set of associated public policies that has had a more profound effect on urban form than the automobile. Although Karl Benz received the first patent for a modern gas-fueled car in 1886, the impact of the automobile would not be felt in America until 1908 when Henry Ford created his Model-T. Vowing to make his automobile affordable for the masses, Ford created a revolutionary manufacturing and assembly process that enabled him to produce a vehicle every 24 seconds and sell it for as little as $280. By 1927, Ford had sold more than 15,500,000 Model-T vehicles in the U.S. alone. His revolutionary employment practices also had a major impact on American industrialism and labor, as he more than doubled the working wage of his employees over other manufacturers and shortened their work day to just eight hours. As individual car ownership increased, along with more expendable income and leisure time for the average worker, American lifestyles and urbanizations changed dramatically.

The earlier transformations in urban form that had been set in motion, first by horse-drawn and later electric motor driven-streetcars, subways, and elevated trains were accelerated enormously by the arrival of the automobile. The same pathways that served the earlier modes of transportation were now easily extended without the necessity of costly infrastructure and the wide tracts of undeveloped land between the rail corridors could now be accessed and developed as well. The application of gasoline and diesel fueled internal combustion engines to commercial vehicles also greatly accelerated the movement of materials and finished goods across and between the urban centers. Eventually, they would also enable business and industry to expand their facilities and operations on less expensive land at the periphery of cities. Unfortunately, this movement also resulted in the substantial loss of employment opportunities for many urban residents. As residential, commercial, and industrial growth occurred in the interstitial areas and at the periphery of the cities, urban development patterns were transformed from the earlier star-shaped pattern to the now familiar "oil stain" pattern common across most of the United States today.



With the rapid expansion of residential, industrial, and commercial development across the entire urban landscape, congestion became a major problem. In response to the congestion and its impact on economic productivity, the U.S. Department of Commerce issued the "*Zoning Primer,*" published in 1922 by then Secretary of Commerce Herbert Hoover. The primer addressed the need to achieve an orderly placement of compatible land uses and the elimination of incompatible uses. The somewhat 2-dimensional primer laid out a template for the separation of land uses by compatibility type. The template was widely adopted across the nation by municipalities that were empowered by state enabling legislation to control local land uses. Although zoning by local authorities did eliminate incompatible uses, they were often used to exclude lower-income residents from settling in certain neighborhoods by requiring housing to be on large-size lots. This so-called "exclusionary zoning" made a significant contribution to the racial and economic segregation of the growing suburban communities.

The building process of urban decentralization and suburban development was once again rapidly accelerated after the Second World War by several federal policies and incentives in the areas of housing, taxation, and transportation. Among the most significant incentives were federally insured mortgage monies and tax incentives for the construction and purchase of single-family, detached housing and the federal funding and development of the interstate highway system. Low-density housing away from congested urban centers and close to the relocating industrial employers proved to be extremely attractive to middle class and upper middle class residents. The new highways provided easy access between these new suburban settlements and city centers, and this meant that residential settlements could also be established near any on/off ramp, regardless of the local availability of employment. With this new opportunity, the nation witnessed the birth of the so-called "bedroom communities."

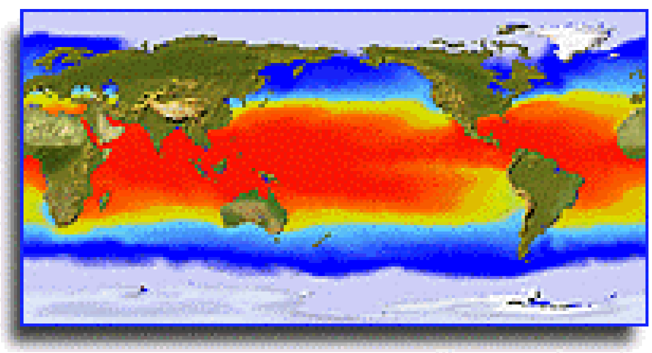
Today, and for the latter half of the 20th century, most of the nation's growth has occurred in low-density, single-use developments, primarily in suburban settlements and in the rural edges of our older central cities. This growth is not sustainable, because it has accelerated the prolific consumption of all natural and manmade resources and particularly energy, as is illustrated in Section II. Additionally, this development claims previous agricultural, forest, and open land and threatens the biodiversity of our communities. Most of our cities struggle to maintain an acceptable level of municipal services while facing decaying urban infrastructure and continually eroding sales and property tax bases, as businesses and residents move to new suburban and fringe communities. These conditions are likely to worsen, as emergent trends will challenge even the most sustainable of communities.

CONTEXT – EMERGING TRENDS

Major trends in demographics, climate conditions, economics and technology will have significant impact on the future direction of urban development in America. The significance of each trend is outlined below and then addressed in detail in the design case study presented in Section V.

Demographics & Land Usage. Currently, 80% of the U.S. population resides in urban areas, and more that half live within our 25 largest metropolitan communities. Today, these communities are experiencing population increases that are projected to continue well into the future, particularly in the west, south, and along our coastlines. As previously mentioned, most of this growth is occurring in the suburban communities surrounding the central cities. This is a particularly significant development because recent data collected by the U.S. Department of Housing and Urban Development (HUD) for its State of the Cities 2000 report indicate that the land area of our metropolitan communities is expanding at roughly twice the rate of the population growth. Given projections for continued population growth, our metropolitan communities will soon face an overwhelming challenge to their sustainability, particularly given the continuation of business-as-usual development patterns.

Climate Change. Although a debate continues in some quarters with regard to its significance, the international scientific community agrees that the global atmosphere is warming and that the principal cause is the collective impact of air emissions from a variety of human activities powered by fossil fuels. The majority of scientists also agree that global warming could have potentially devastating consequences for all life on the planet. Human activities in our largest population centers – the cities – account for the vast majority of global greenhouse gas emissions, and, as the world becomes more urbanized, this phenomenon is expected to grow. This trend is one that literally links the health and well being of U.S. cities with the energy consumption practices of metropolitan communities around the world and vice-versa and is therefore the concern of the entire global community.



Many U.S. cities recognize the imperative to practice more sustainable energy consumption practices and have joined the International Council for Local Environmental Initiatives (ICLEI). This is an international association of local governments committed to seeking tangible improvements in global environmental and sustainable development conditions through cumulative local actions. Participating cities commit to specific reductions of carbon dioxide (CO_2) emission through a comprehensive plan of actions across all municipal functions. Although many U.S. cities have not formally joined the ICLEI organization, some are pursuing similar CO_2 reduction initiatives on their own.

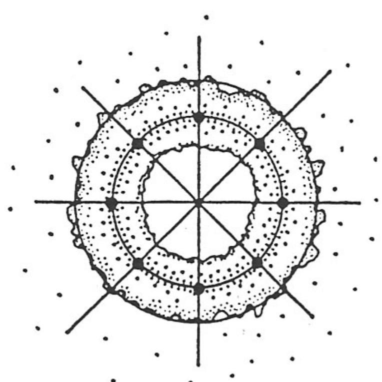
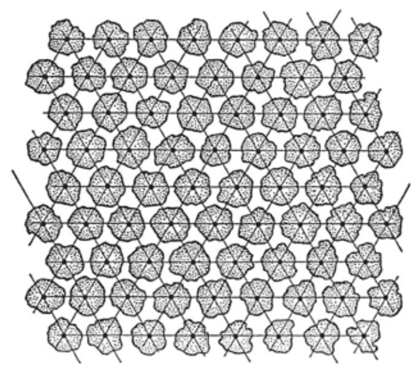
Globalization. In a similar vein to the concern for the phenomenon of global warming, metropolitan communities are increasingly challenged to consider their participation in the growing global marketplace. Innovations in both information and telecommunications technologies have enabled local businesses to operate on a global scale. As more global markets are developed for local services, urban economies will transform and municipal, business and community stakeholders will all have a stake in business opportunities and developments in other parts of the world. And as they do, local economies will be increasingly connected to other municipal and national economies and susceptible to both positive and negative developments in those economies as well. The impact of widespread, telecommunication-based business transactions, as opposed to those requiring the physical movement of people and commodities, will have a significant impact on the future of urban form. Urban designers will be challenged to consider these impacts as more communities respond to these global market opportunities.

Technology. Clearly, we are witnessing another period of technological innovation that is sure to rival and then surpass the explosion of technologies that transformed our cities in the late 1800s and early 1900s. Specifically, advances in energy, information, electronics, telecommunications, medicine, biotechnology, transportation, environmental quality management, building materials, miniaturization, and industrial manufacturing will all quite literally enable us to reorganize urban space altogether. That reorganization will give us an opportunity to change urban functions and to create new relationships between urban residents and their natural environment that will overcome the current structural and perceptual barriers to achieving real urban sustainability in America. Sections IV and V outline this opportunity in some detail and provide evidence for optimism that a more sustainable future is possible.

II. RESOURCE CONSUMPTION, LAND USE & TRANSPORTATION DEVELOPMENT

There are essential linkages between material and energy consumption and urban form, and particularly land use and transportation patterns. We began this document with a quote from the UN World Commission on Environment and Development regarding the essential nature of sustainable economic development. The quote emphasized the need for "…a change in the content of growth, to make it less material-and energy-intensive and more equitable in its impact." This statement captures the essential objective of sustainable urban development and frames the challenge for the designers, planners, and managers of our metropolitan communities.

So, what is the relationship between sustainable urban design and material- and energy-intensity? In a word…Demand! The way we design our residential, commercial, industrial and civic areas and structures, and the way we move between them, directly determine the demand for material and energy resources. Our summary of metropolitan evolution, suggested that American urban development has always been driven by the illusion of a seemingly endless supply of resources and transportation technologies to exploit them. In fact, per capita energy consumption is six times higher in America, than anywhere else in the world. Most of this consumption and of our total national annual energy usage is attributed to urban residential and commercial buildings and the transportation of freight and people between them.

In order to shift from a model of urban development that assumes infinite resources to one that recognizes finite resources, we must alter our present land use and transportation patterns. Land use configurations found in most American cities today, and particularly in their outlying suburban communities, are characterized by low-density, single-purpose uses connected by underutilized mass transit, if any at all. Studies conducted over the past 30 years have shown that this pattern of development is highly energy-inefficient. A few examples illustrate this assertion.

Michael Phillips and Robert Gnaizda conducted a study in the 1970s that examined the material resource intensities of two residential settings – one a single-family, middle-class housing tract in Davis California, the other a multi-family, middle-class apartment complex in nearby San Francisco. They found that the residents of the single-family detached housing drove 4 times farther and consumed 5 times more heating fuel than the residents of the multi-family complex. Additionally, they calculated that the single-family homes consumed 40 times more arable land, 50 times more lumber, 70 times more water and required the service of 5 times as much utility piping as the multi-family homes [1].

Resources	City Apartments	Village Houses	Ratio
Copper pipe	2,000 ft.	10,000 ft.	5
Arable land	5,000 sq. ft.	200,000 sq. ft.	40
Roadway	1,000 sq. yds.	15,000 sq. yds.	15
Concrete	17,000 cu. yds.	9,000 cu. yds.	1/2
Lumber	25,000 board ft.	1,200,000 board ft.	50
Utility pipe	450 ft.	2,500 ft.	5
Daily postal delivery	12 ft.	3,000 ft.	300
Landscaping water	500 gals/day	35,000 gals/day	70
Heating	5,000 BTU/day	27,000 BTU/day	5
Individual auto	25,000 miles/month	90,000 miles/mo.	4

In a similar study, conducted jointly by the Council of Environmental Quality and the U.S. Department of Housing and Urban Development, single-family and multi-family housing were compared in a suburban community setting. The multi-family housing consisted of a mid-rise building with only 33 units to the acre (in contrast to the densities of 50-150 units per acre more typically found in central city settings) and surrounded by an ample lawn and paved parking space. Despite the modest density of the mid-rise building, the single-family housing consumed 4 times more land for streets and roads, 10 times more land for the buildings themselves, and 6 times more metal and concrete than the multi-family housing.

In a more recent study on energy consumption and community form, the U.S. Department of Energy (DOE) concluded that suburban families consume 120 million more British Thermal Units (Btus) and produce 15 tons more carbon dioxide per year than urban families (accounting for transportation, home, and associated infrastructure energy use) [2]. With regard to building construction, DOE has calculated that the nation would save $100 billion per year or 30% in energy costs if the 25 million new housing units and 17 billion square feet of commercial development projected to be built over the next 15 years were to be constructed using sustainable design and energy-efficient technologies and practices.

The spatial location of land uses in relation to public transportation also has a substantial impact on energy usage and related costs. Approximately 65% of U.S. oil consumption and most urban air pollution is attributed to transportation. Just as metropolitan land expansion is advancing at roughly twice the rate of metropolitan population growth, so also are the vehicle miles traveled

(VMT). According to the U.S. Department of Transportation (DOT), between 1980 and 1997, VMT grew 63% or 3 times the rate of population growth for that period [3]. Although net population gains contributed to the expansion in VMT, DOT estimates that 60% of the increase in VMT is directly related to dispersed land use development. Concentration of residential, commercial, and even compatible light industrial uses in mixed-use developments near established public transit corridors could result in dramatic reductions in VMT and substantial cost savings. Evidence for this surfaced in 1996, when an analysis was conducted of regional growth patterns in the San Diego metropolitan area using the PLACE3s model. The analysis concluded that concentrating the projected new growth in higher density developments adjacent to public transit would result in a 6% reduction in annual energy demand and a $50 million annual savings [4].

All of these studies and many others suggest that a more compact urban form, consisting of higher densities, mixed-uses, and their location near major transit systems would result in the consumption of far fewer material and energy resources. This more sustainable form of development would also result in fewer air emissions and greater preservation of our agricultural, forest, and open lands. Relative to the embedded costs of the materials and energy consumed to produce the products we use to build our housing, automobiles, and urban infrastructure, this more sustainable urban form will also reduce the so-called "urban footprint" of our communities.

III. URBAN DESIGN – CHALLENGES & SOLUTIONS

To further explore alternative designs for sustainable urban form, the investigators participated in a unique competition among some of the world's top urban designers, planners and architects, known as the International Competition for Sustainable Urban Design (IC-SUSD). The extraordinary competition was conducted by the International Gas Union and intended to stimulate new thinking and practices in metropolitan design, planning, and management that would result in more livable cities around the world.

Design teams from nine nations participated in the competition. Each team was required to select an actual city within its national border with a population of at least 100,000, as the subject for the design. Prior to formulating the designs, each team conducted an economic, environmental, and socio-political baseline study for its subject city to identify specific challenges to long-term sustainability. The teams then formulated spatial and technological designs that integrated energy, environmental, building, transportation, and social systems in a manner that would achieve sustainability over a 100-year period. The teams were also required to include an evolutionary roadmap that described a feasible path for this transformation during this planning period that would enable their subject cities to become sustainable.

The nine national teams and their selected cities were:

Nation	Subject City	Population
Argentina	Buenos Aires	3 million
Canada	Vancouver	2 million
China	Changshu	295,000
Germany	Berlin	3.5 million
India	Goa / Panjim	113,000
Japan #1	Tokyo – Shinjinku	8 million
Japan #2	Mishima	387,000
Russia	Vologda	300,000
U.S. & Mexico*	San Diego – Tijuana	4.3 million

*Mexico joined the U.S. Team in the formulation of a sustainable urban design for the greater binational metropolitan region that includes the City of San Diego, San Diego County, Tijuana, Tecate, and Rosarito in Baja California (for a combined population of 4.3 million)

Central to each design was a "Total Energy & Environmental System," one that accommodates future growth and development of the subject cities without adverse impact on natural resources or the emission of greenhouse gases to the atmosphere. These total systems integrated state-of-the-art energy and emissions, effluent and solid waste control technologies, along with transportation systems, building construction design elements, and public policies and practices that support sustainable communities. In addition to the future design components of the entries, each included a practical "roadmap" outlining the institutional, economic, social, and technological actions that would lead the community towards sustainability in the short-term (next 5-30 years).

On June 2nd, 2003, the teams met to unveil their designs and to exchange concepts before a blue-ribbon panel/jury of experts [NOTE A]. An analysis of all nine team submissions conducted after the competition revealed remarkable similarities between the designs that had been produced quite independently of each other. These similarities are summarized below as a set of common challenges to, and proposed solutions for, urban sustainability.

Land Use & Urban Sprawl

The Challenge. Without question, the top concern of all nine teams was the sprawling pattern of development occurring at the periphery of their subject cities and across their greater metropolitan regions. All teams identified issues associated with the loss of prime agricultural, forests and wetlands and with the impact on habitat and the endangerment of species. Environmentally insensitive development practices and uncontrolled/unregulated growth was sited most frequently as a major contributor to the problem. Private development pressures were also cited as formidable challenges, particularly where the economic advantages of residential or commercial development were given greater weight than the preservation of open lands and habitat protection. In almost every case, the teams identified urban sprawl as the greatest single contributor to most of the subordinate challenges identified below.

Proposed Solutions. There were many solutions proposed in the nine team designs but the single most common solution was the establishment of mixed-use, transit oriented development (TOD) and the concentration of new growth and development on the existing urban footprint (or previously developed areas). Urban containment or growth boundaries were also mentioned quite frequently in the designs.

Remarkable in the frequency of its appearance was the concept of concentrating development on existing built areas that would eventually be developed as semi-autonomous communities, villages, or cells. These units of development would be outfitted with and be responsible for maintaining basic life support infrastructure including energy production and localized distribution, supplemental food production, water reclamation and recycling, solid waste recycling, and open space management. These semi-autonomous units were also depicted as centers of employment, entertainment, and small-scale retail. Also common to the concept was the notion that all these units would be served by transit systems that would enable residents to move anywhere in the greater urban region, but the principal mode of travel to day-to-day destinations would be by pedestrian or pedal-powered mobility.

Additionally, many designs proposed the formal establishment of "green cells" or open spaces within the urban boundaries that would be considered off-limits to development. These were commonly suggested to be applied to all potential habitat areas but included, as well, continuous bands of open space that would run throughout the metropolitan community and ultimately connect to exurban or rural green cells. Additionally, these green cells and continuous bands were suggested as a means of stabilizing and restoring water basins and streambeds. Urban agriculture and pocket gardens were also commonly mentioned as a means of ensuring the sanctity of green space within the urban realm. In several cases, the designers suggested the promotion of green cells and forested areas throughout urban communities to act as CO_2 sinks and to reduce the urban heat island effect.

An idea that also appeared regularly, although typically more often in the design roadmap sections, was the notion of adaptive reuse and multiple use of building forms. This concept would entail retrofitting existing public structures such as schools and civic complexes for secondary and tertiary uses during the evenings and weekends. The basic idea was to facilitate the layering of activities into existing structures to maximize the investment in our built environment while avoiding the necessity of building more single-purpose structures on more land.

Population Growth & Decline

The Challenge. Commonly considered the primary driver of the first challenge listed, changes in the demographic profile were the second most prevalent challenge addressed by the nine teams. In five of the cases, the subject cities are experiencing population increases with all of the attendant pressures of and on development, congestion, employment, affordable housing, and environmental quality management systems. The cities of the other four teams are experiencing population declines and either flat or declining birth rates and increasing life spans for the elderly. These teams and their communities face a major challenge of providing adequate health care services for a growing dependent population while the supporting working population is declining.

Proposed Solutions. The most common solution suggested for controlling population growth was indirectly limiting migration to the congested urban area through growth boundaries and more directly through the advocacy of zero-population policies. Both are highly controversial, particularly in the United States, but they are being contemplated and applied in some of the subject cities.

Unsustainable Energy Resources

The Challenge. Six of the nine teams cited an over-reliance on fossil fuels as a major challenge to the future sustainability of their communities. Local and global environmental degradation of air, land, and water associated with the exploration, extraction, processing, delivery, and use of fossil fuels was the primary objection. A lack of public awareness or concern for energy efficiency and conservation was also cited as a major challenge for all nine of the subject cities.

Proposed Solutions. Not surprisingly, all nine teams introduced renewable forms of energy production in their designs for long-term sustainability. The most common renewable energy forms were solar photovoltaic, solar thermal, and metropolitan sources of biogas, particularly waste-to-energy systems using gas from community landfills and municipal wastewater treatment facilities. Other renewable sources mentioned included biomass, geo-thermal, and hydroelectric. In all team designs, hydrogen fuel cells were also featured quite prominently as both stationary and mobile sources of energy. One team did include nuclear as part of its overall future energy mix.

Interestingly, combined cooling, heat, and power (CHP) cogeneration systems were also present in the nine designs, in which distributed generation emerged as the backbone energy system of the future sustainable city (described in greater detail below). Distributed energy systems are entirely logical components of the semi-autonomous development units or "village configuration" that appeared in most of the designs. During the evolutionary periods of development, natural-gas-fueled micro-turbines and advanced engines were identified as bridge technologies until renewable systems would become economical enough to replace them. In connection with these distributed generation systems, several of the design teams included micro-grids, serving the villages and having the capacity for the two-way flow of energy between points of generation and use. This concept was consistent with the incorporation of renewable power generation units into residential and commercial building design and the use of hyper-efficient HVAC equipment, appliances, and lighting systems.

In general, all structures described in the nine designs featured hyper-efficient energy use as a basic building standard, and most included strategic siting of buildings for maximum solar gain, airflow, and the capture of precipitation.

Transportation Congestion & Air Emissions

The Challenge. Driven by urban sprawl and population increases, transportation was recognized as a major challenge in seven of the nine designs. The major concern identified was growing congestion across the entire metropolitan region, particularly along thoroughfares connecting the central cities with their expanding suburbs. The second major concern is, not surprisingly, air emissions and ground-level ozone, particularly in the warmer climates. Of much lower significance, but still of concern, were the impacts of transportation on ambient urban noise levels, resident concerns for access to public transit, and the efficiency and convenience of transit systems.

Proposed Solutions. The uniform response across all team designs was the aggressive promotion of mass transit and again, of transit-oriented development. In most cases elevated or surface light rail, trolley, flexi-bus and mono-rail systems were proposed, while in a few cases subterranean high-speed subways were advanced as solutions to congestion and air emissions. Fuel and propulsion systems proposed included compressed natural gas and liquid natural gas engines, hydrogen fuel cells and battery powered electric motors.

Fossil fueled internal combustion engines were conspicuously absent in the out years of all nine designs. During the transition years of development, the design roadmaps included an array of public excise taxes and other economic disincentives to discourage use of fossil fueled private mobility. Alternately, the same design roadmaps encouraged the use of alternatively fueled and electric vehicles through economic incentives, including proposed tax credits and preferential access to roadways and parking. In addition to these solutions, practically all of the designs included provisions for systemic pedestrian and pedaled-vehicle paths or "pedways" between residential and local commercial and civic structures and plazas.

Degradation of Surface, Ground & Potable Water Supplies

The Challenge. The degradation of surface water and groundwater and the associated inadequacy of potable drinking water supplies was identified as a major challenge among six of the nine subject cities. Both urban and agricultural non-point-source runoff were identified as concerns as well as inadequate control of municipal effluents. Wetlands loss was also commonly cited as an area of concern, as noted earlier.

Proposed Solutions. In most of the designs, comprehensive watershed protection controls and stewardship programs were called for, with specific focus on the protection of critical reservoirs and groundwater recharge areas. Natural wastewater filtration utilizing wetlands was also a common design element, as were initiatives to control urban non-point run-off. The replacement of impervious road and roof surfaces with absorbent turf was also a common feature for runoff control. The U.S.-Mexico team provided a high-tech solution to wastewater management, as will be outlined below. Water reclamation and reuse facilitated by the separation of black and gray water flows by residential and commercial by-piping was common among the designs.

Inadequate Economic Development

The Challenge. In several of the team designs, unemployment, inequitable economic growth, and an inadequate mix of commercial and industrial development were cited as major concerns. In addition, environmentally insensitive industrialization and commercialization were concerns for several design teams.

Proposed Solutions. The uniform design response among teams citing these challenges has included some combination of education, training, and labor-force-enhancement programs and initiatives to attract cleaner industries, including a variety of tax incentives. In several designs, the solution entailed an economic development strategy that would integrate the R&D agendas of local universities with the specific needs of local and target industries interested in developing green technologies and products. This is a particularly timely suggestion, as there is an emerging movement among both universities and industry to begin focusing on so-called "cradle-to-cradle" manufacturing processes and products. The economic development strategies also identified roles for local vocational schools in retraining under- and unemployed workers so they can qualify for jobs in this area of growing industry interest.

Affordable Housing Supply

The Challenge. Closely related to adequate employment is the challenge of ensuring an adequate supply of affordable housing for rapidly growing urban communities. This is a major problem in many American communities, and one that was featured in the joint U.S.-Mexico design team entry.

Proposed Solutions. Among the three teams that cited this challenge, all proposed that municipal governments should make the provision of affordable housing a top priority and aggressively pursue the adaptive reuse of the existing building stock to satisfy the current demand. Additionally, the teams recognized that consumer energy costs play a part in making housing affordable, and therefore they recommended the inclusion of highly efficient energy design and equipment in the rehabilitation of structures for housing in urban communities. Finally, the teams suggested that municipalities must work to establish programs with lending institutions for these newly constructed or reconstructed residences to ensure that targeted groups can qualify for and obtain mortgages under reasonable terms.

Insufficient Governance

The Challenge. Several of the teams identified the lack of an effective form of regional governance as a major challenge to sustainability for their subject cities. Specifically, they cited the challenges of effectively addressing issues related to urban sprawl, the management of regional resources, such as air and watersheds, and the provision of effective regional mass transit. An additional challenge cited was the lack of local control over local issues, particularly those relating to local land uses.

Proposed Solutions. All teams citing this challenge promoted the concept of a regional form of governance over the regional resources and functions listed above. Recognizing that instituting such a body would require time and trust among subordinate jurisdictions, inter-jurisdictional cooperation on a project-by-project basis was proposed. In time, this cooperation would be followed by the development of some form of a regional resources strategy that would be adopted by all local jurisdictions while they still retained independence in their approach to reaching the regionally approved performance targets. With regard to the concern for local community control of local issues, all teams included features that kept as much control as possible at the local level. Solutions included various forms of semi-autonomous neighborhood/village councils that maintained this control and whose representatives would participate in broader district and still broader municipal elective bodies as well.

Unsustainable Building Practices

The Challenge. All of the teams cited unsustainable building materials and practices as a significant challenge to sustainability for their cities. The principal concerns included use of building materials that have high embedded energy cost to produce, buildings that are designed for single-purpose uses, and building designs and construction projects that are simply energy inefficient.

Proposed Solutions. All the teams recognized and incorporated the green building standards such as the Leadership in Energy and Environmental Design (LEED) standards into their guidelines for building construction. Additionally, a couple of teams included detailed descriptions of systems for integrating digital information and monitoring technologies with building HVAC, lighting, and demand-side management controls to conserve energy. With regard to embedded energy costs and recycling of materials, several teams, including the joint U.S.-Mexico team, proposed the integration of highly recyclable elements such as building surfaces and decorative materials consisting of plant fiber and resins that could be recycled for multiple uses. Additionally, teams promoted the concept of sustainable industrial and commercial design practices for manufacturing processes that would reduce waste before the commodities are created.

IV. TOWARD A MODEL FOR SUSTAINABLE URBAN DESIGN: PRINCIPLES & ELEMENTS

The remarkable consensus that emerged in Tokyo among some of the world's leading architects, planners, energy and environmental experts, provides an excellent foundation for a set of sustainable design principles and elements applicable to any American city. This section describes these components and suggests their configuration in an ideal model for sustainable urban design.

PRINCIPLES FOR URBAN SUSTAINABILITY

Five guiding principles for sustainable urban design emerge from both the recent international symposium and literature on the subject. They should be considered strategic-level goals that all subordinate design elements are developed and configured to achieve.

DESIGN PRINCIPLES

- **Sustainable Energy Resources and Practices**. All future public and private community development should be pursued in a manner that maximizes the efficient utilization of energy resources and minimizes or eliminates local and global environmental degradation. In addition to the reduction of CO_2 and other greenhouse gas emissions, future development and use of energy resources in our cities should also consider direct and indirect impacts on the aquatic and terrestrial environment and on habitat and biodiversity.

- **Ecological Urban Form and Function.** Our cities must be developed and managed in a fashion that preserves and restores the natural environment for the benefit of human, animal, and plant inhabitants. Additionally, cities should be designed and developed to emulate nature and to maximize the benefit of natural systems such as wind and water flows, sunshine, precipitation, and the absorbency of land and vegetation. Further, urban functions should be managed to reinforce these natural flows and characteristics wherever possible, thereby creating a balance and mutually supportive cycle of interaction between the built and the natural environments.

- **Community-Based Resources Management**. Simply stated, urban sustainability is not possible without the commitment and collective action of the individual neighborhood communities that comprise a metropolitan region. This principle encourages the development of design elements that engage individual neighborhood communities and their residents in as many aspects of natural and human resources management as possible. Shifting part of the management of resources (their acquisition, delivery and post-use handling) from unseen providers, such as utilities and waste disposal services, to end-users creates an entirely different perspective on the use of resources. With community-based resources management, each community, no matter how small, bears responsibility for the efficiency of its practices and has the opportunity to better understand the interrelatedness of water, energy, and waste disposal services.

- **Land Use Optimization.** All cities, regardless of size, will minimize the consumption of natural and human resources by restructuring and more efficiently utilizing the existing urban footprint (developed areas). This can create opportunities for increased social and economic interaction and diversity within our communities. In addition to increasing access to local goods and services, moderate densification of uses promotes a more "walkable" community and provides minimum population densities necessary to support cost-effective urban mass transit systems. Broad public use of these transit systems will dramatically reduce energy consumption, degradation of local ambient air quality, and the emission of greenhouse gases to the atmosphere.
- **Social and Economic Equity.** True sustainability in any community must address more than energy and environmental systems. Environmentally benign systems and technologies must be supported by a social and economic system that offers equivalent access for all residents to affordable housing, social services, and employment and economic development opportunities. Without this social element, efforts to ensure the efficiency of energy resource use and minimize adverse environmental impacts will ultimately be insufficient to assure that the community will sustain itself and prosper. A truly sustainable community does not choose among these attributes. Instead, it integrates its goals and the means for achieving them into a unified and sustainable system.

Unified Design Concept

Taken together, these five principles suggest a unified design concept for urban sustainability. The concept would direct all future urban growth away from ecologically sensitive terrestrial, coastal, and marine areas and toward previously developed areas in ways that that reinforce urban vitality and support the expansion of urban mass transit and its use. Additionally, the concept entails the development of sustainable villages or neighborhood settlements within urban areas. These sustainable villages provide a balance of affordable housing options, employment and economic development opportunities, and access to shopping, education, recreation, and cultural amenities. Fortunately, existing and emerging energy, transportation, building, and environmental control technologies can facilitate this form of sustainable urban development, as described below.

Because there are few opportunities to design new communities from the start, the model below is oriented towards application in existing metropolitan communities of any size. Within these existing communities, opportunities to apply the unified design concept will most frequently be found in areas that are experiencing new growth at the city's edge or in underutilized areas that are being considered for redevelopment. However, the individual design elements and the associated mechanisms presented below are also relevant to opportunities to improve existing development patterns and activity centers within our cities.

Design Elements

There are seven highly interdependent elements of any sustainable urban design. Each corresponds to one of the seven basic systems that support all urban functions. These are: natural systems; land use systems; mobility systems; energy systems; environmental management systems; building design systems; and governance systems. The following text discusses each of these systems and their interrelationships and provides a range of tactical measures that can be taken to maximize their individual contributions toward urban sustainability.

Natural Systems

All sustainable urban design must begin with a thorough comprehension of the immediate physical environment and of the natural forces that shape it. Sustainable design should ensure that the location and character of urban development minimizes all impact on the environment while it harnesses natural forces to reduce material and energy consumption. There are four natural subsystems that must be examined in order to comprehend the natural context for urban development – land, water, climate and habitat. The relevance of each subsystem is provided below.

Land. The first consideration in the urban design process is the carrying capacity of land and its suitability for development. This capacity and suitability will depend on various macro and micro-scale considerations including: topography, geology, soil composition and permeability; and on their interactions with water elements in the natural landscape. Understanding these interactions is essential for all small-scale and large-area development siting determinations.

Water. The essential components of concern here include all surface waters and watercourses, groundwater in underground aquifers, floodplains, and wetlands. Given the composition and topography of land, all waters have a natural direction of flow, velocity, circulation, and carrying capacity. Water quality is directly affected by all of these factors, as are the lives of all human, animal, and plant communities. Given its paramount importance among the natural subsystems, all sustainable urban development must be designed to accommodate the natural characteristics of indigenous water elements.

Climate. Macro-climate considerations such as annual average cloud cover/sunshine; ambient air temperatures; precipitation and air flows have a significant effect on the habitability of any natural area. Additionally, they have a significant impact on the built urban environment, particularly with regards to the use of artificial climate control systems and their associated energy consumption. Sustainable design will help to mitigate the impact of climate extremes on the built environment while it harnesses natural forces to reduce energy consumption.

Habitat. The preceding three natural subsystems create the conditions that enable all habitats to exist. In natural habitats, plants and animals rely on the unimpeded flow and interaction between these three subsystems for food, shelter, and protection. As these conditions are maintained, diverse animal and plant life flourishes. Urban development patterns and practices directly affect habitat and the natural web of life through the direct or inadvertent manipulation of land, water, and air resources.

To accommodate, reinforce, and maximize the potential benefits of natural systems in urban design, an inventory should be taken that characterizes their existence in the urban environment. The inventory should initially be drawn on a regional scale to capture the forces of larger natural systems that affect the urban community. The inventory should map the characteristics of the predominant land forms, watersheds, and the airshed and their large-scale interactions and influence on climate. The plant and animal species and their habitats should be overlaid on the natural systems inventory. Fortunately, for many urban communities, most of this work has been completed and can be obtained from federal, state, and regional natural resource management agencies. For smaller urban design initiatives, these investigations can also be conducted on the county, city, or neighborhood level.

Once the individual resource maps and databases have been compiled, they should be analyzed to identify environmentally sensitive areas that should be protected and the predominant natural subsystem characteristics that would adversely impact or benefit development. The resulting composite base map and narrative would then provide a reference document to be used to guide growth and development initiatives, particularly at the edge of established settlements.

Land Use Systems

The second element in urban design is the designation of various land uses within existing or proposed areas of development. As discussed earlier, no single element in the entire design process will have a more significant effect on the use of material and energy resources than land use planning. The objective of having a unified design for sustainable land use planning is to establish a pattern of ecologically sound and mutually compatible urban land uses that make maximum use of established infrastructure and the flow of natural elements. The various aspects of design and the associated mechanisms that enable a community to reach this objective are described below:

Land Use Analysis. Once the natural systems inventories are completed and ecologically sensitive areas cordoned off, a series of further spatial studies should be conducted to determine the distribution of land that is appropriate for future development. So-called suitability analysis considers topographical slopes, access to roadways, and other physical factors that make an area suitable for development for each particular urban use. Committed lands analysis then analyzes opportunities to focus new development in areas that maximize the use of existing utility infrastructure, thereby producing the greatest operating efficiencies for the utility and value for the customer. Finally, an analysis of "carrying capacity" assesses the natural and built systems and infrastructure capacities relative to lands suitable for additional development. This analysis should assess the average demands of all urban land uses on these systems and infrastructure [5].

Designation of Uses. Once all studies have been completed, lands should be classified, designated, and regulated through zoning for specific uses. There are typically five broad land classifications and a number of sub-classifications. These include:

1. Urban – residential, commercial, industrial, institutional, transportation, communications, and utilities.
2. Agricultural – cropland, orchards, confined feeding, and dairy operations.
3. Forests – evergreen, deciduous, and mixed.
4. Wetlands – forested and non-forested.
5. Barren lands – mines, pits, desert, and nonproductive transitional lands.

Within each of these broad classifications, there are a set of finer level distinctions with regard to activity types and allowable densities. Traditional land use mapping and zoning regulation typically separate activities by type, which, in the case of clearly incompatible uses such as heavy industrial and residential, is quite reasonable. However, the strict separation of all uses by type precludes the opportunity for mixed-use developments that could provide significant reductions in the use of urban materials and energy. Single-purpose zoning necessarily increases vehicle miles traveled, as cited earlier, causing both unnecessary transportation-related energy consumption and air emissions. To address the issues of excessive material and energy consumption and the related environmental impacts, urban communities must revisit their land use designations and zoning maps and consider how to accommodate more efficient forms of urban development.

Sustainable Urban Form. The unified design concept described earlier, that concentrates compatible mixed-use growth in existing built areas and transit corridors, is a more sustainable form of urban development. It can be achieved most easily in existing central cities, where all of the necessary ingredients are present. However, it can also emerge in existing suburban settlements where commercial corridors are already served by surface transit lines. According to Kevin Lynch, perhaps America's most notable urban designer, the key is in identifying and reinforcing the existing urban "nodes, paths and districts" while discouraging unsustainable patterns of growth within urban communities [6]. Lynch has defined urban nodes as "peaks of density, special activity, or access, such as shopping centers and major terminals." His conception allows for the balanced development of mixed-use activities around these nodes and for their emergence in equidistant locations across the urban and suburban landscape. Natural hierarchies of size, density and specialization of uses would emerge among these nodes, creating primary, secondary, and even tertiary centers of development.

Lynch described special districts as "areas of appreciable size associated with memorable activities, character or associations. In particular these include the large institutions, ports…heavy industry, the central business district or other special office districts, the major open spaces or recreation zones, and the special historical areas." All of these areas serve vital economic and social functions and are therefore critical to consider in a sustainable design. Like nodes, many latent special districts exist today in urban communities. By formally designating them as part of a new sustainable urban design, their functions can be further reinforced by the addition of other uses that are similar or complementary in nature.

Kevin Lynch's definition of a path included streets, rail lines, canals, and promenades. Paths are channels for movement of people and goods. His concept differentiated these paths by the roles they serve and, accordingly, could help determine their placement and interaction or separation from one another in a spatial layout. Efficiency of function was a paramount concern, but the perceptual experience of the quality of movement in urban space is also an important factor. That is to say, movement should be fast, flexible, and enjoyable for urban travelers. The placement of these paths in the urban landscape should be determined by existing corridors and their spatial relationships to the hierarchy of nodes and special districts and to the existing and proposed sites for open, recreational, and green spaces.

The redefinition of urban land use classification and zoning, together with the design of essential urban components, such as nodes, special districts, and paths, can enable the creation of a much more material and energy efficient urban form. A form that reduces the need for excessive mobility between areas of separate land uses and activities will also enjoy less congestion, cleaner air and fewer transportation related wastes.

Mobility Systems

For a sustainable form to take shape and thrive, there must be a fundamental restructuring of the present patterns of urban mobility. As has been stated, our heavy dependence on private automobiles has led to unsustainable urban growth. The unified design concept outlined in this document calls for discouraging automobile-dependent urban development. Further, it calls for expanding non-motorized local mobility options and public transportation systems that utilize alternative fuels, vehicles, and fueling infrastructures.

The reduction of fossil-fueled automobile usage is not likely to occur in the very near future, particularly if there is continued technological development in, and market penetration of, hybrid and alternatively fueled vehicles. However, the reduction ultimately must occur. In 20-30 years, high-speed, long-distance private mobility may be provided by electric or fuel-cell-powered vehicles. Once these vehicles are common, the problem of continued lateral expansion of urban land development will persist, along with its inordinate consumption of energy and material.

The most sustainable alternative is to develop an urban form that depends less on long distance mobility and more on local mobility. Converging workplaces, commercial services, retail outlets, and recreational and cultural amenities in close proximity to residential housing will promote local mobility and the development of associated technologies. For example, the recent introduction of the Segway™ and GMs new battery-operated "GEM" neighborhood vehicle are ideally suited for local mobility and suggest an important role for automobile companies to play in supporting more sustainable mobility. Similarly, bicycle usage, extremely popular in more compact European urban communities, is beginning to take hold in communities that are promoting a more sustainable form of growth. However, in truly compact and sustainable communities, walking is not only possible but also the desired alternative for local mobility.

For intra- and inter-urban mobility, public transit systems should be reconsidered and, if necessary, "re-tooled" for greater efficiency, flexibility, and rider convenience. For longer distances, the use of existing rail systems will continue to present a more sustainable option than private automobiles and expansive freeway systems. Rail systems represent significant public and private investments and should not be abandoned. More flexible surface transportation technologies should be explored for intermediate distance travel, between urban nodes and residential neighborhoods. A variety of alternatively fueled vehicles have been demonstrated across the nation and are increasing in numbers in both transit and municipal service vehicle fleets. This trend should be embraced by all communities interested in cleaner ambient air and in reducing municipal contributions to global warming.

Energy Systems

Presently, most electrical energy that reaches our cities is generated at central power plants, often located hundreds of miles away. While this arrangement does not directly emit air pollution into urban air-sheds, emissions from central power plants are still being released into the atmosphere and spent cooling water is being released into the aquatic environment. Many central power plants deliver only about 30% of their input fuel energy to end users. The remaining 70% of the fuel energy is lost at the plant and in transmission. This model of central power plant energy generation and long-distance transmission is, like our current urban form, inherently unsustainable.

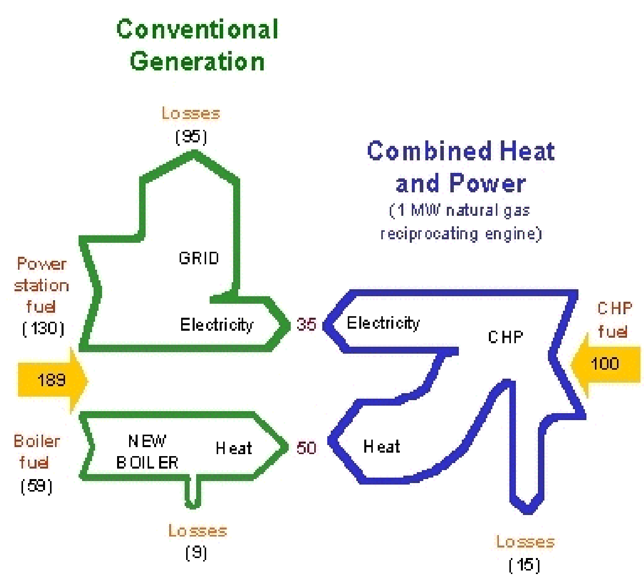
Replacing oil and coal-fueled combustion and steam turbines with more efficient natural-gas-fired combined-cycle turbines at central power plants is a step forward both in terms of operating efficiencies and air emission reductions. However, the proposed model of urban form suggested in this design, would be better served by a different set of clean energy technologies and systems that offer much higher efficiencies, greater reliability, and security. In the parlance of energy planning, these are known as distributed energy resources (DER). Given their importance as the prime mechanisms for energizing more sustainable urban development, an expanded discussion of DER technologies and systems follows.

Distributed Energy Resources

Distributed energy resources include distributed generation technologies, combined heating and power and district energy systems, demand response and demand side management controls, and energy efficiency mechanisms.

Distributed generation (DG) technologies produce electricity at or near the point-of-use. Specific technologies include: reciprocating engines, gas turbines and micro-turbines, fuel cells, and various renewable technologies including: small wind, mini-hydro, and solar photovoltaic panels. Demand response controls enable DG systems to be used to relieve overloading of the main power grid during peak use demands. In addition to the power generation source, a DG system can include a local-area distribution system or "micro-grid" to provide electricity to more than one nearby facility and interconnection equipment that enables the system to share electricity with a city's main power grid.

Combined heat and power, commonly termed cogeneration or CHP, systems enable the capture of heat released from power generation or industrial processes for use in various heating and cooling purposes. CHP is also referred to as cogeneration. CHP-enhanced DG systems can achieve overall energy efficiencies of 60 to over 80%, twice the efficiency of a central power plant that uses single-cycle gas turbines. CHP's high efficiencies directly translate into lower energy costs for urban consumers. CHP has been applied beneficially in a variety of industrial, commercial, and institutional settings. Many DG technologies are well-suited to CHP applications.



Emissions. Most current installations of DG technologies burn natural gas, which emits significantly less air pollution than other fuels, as well as virtually zero sulfur dioxides (SO_2). For example, natural gas reciprocating engines emit an average of 2.2 lbs of nitrogen oxides (NO_x) per megawatt hour (MWh), and some fuel cells emit as little as 0.01 lbs. of NO_x per MWh. National average emissions for central generating plants, on the other hand, are closer to

5 lbs. NO_x per MWh. In addition, emissions levels of greenhouse gases, namely carbon dioxide (CO_2), from CHP applications of DG technologies are also lower than most fossil fuel powered central plants – especially those that are coal or oil fired – because of the overall increased efficiency of energy conversion. If new CHP applications of distributed generation replace less efficient central power plants, overall CO_2 emissions and energy use will be reduced.

The significance of DER to the unified design concept presented in this document is that they are ideally suited to meet the electrical and thermal energy efficiency needs of urban nodes and special districts. The creation of neighborhood and sub-district scale DG/CHP systems and micro-grids across urban nodes and districts would reinforce the centrality of these new urban centers and result in a more sustainable use of all resources. Prior to a discussion of these systems at a larger scale, we will consider their present-day applications in a variety of common industrial, commercial, residential, and institutional settings.

Industrial CHP. Industrial CHP has a long history of success in the petroleum, primary metals, and pulp and paper industries. Industrial plants are especially well-suited to CHP because they need both process steam and electricity. CHP is a particularly attractive proposition for industries, such as the pulp and paper industry that have fuel available from onsite waste. By using wastes as fuel to provide process steam and electricity onsite, efficiencies are maximized and fuel, electricity, and thermal costs are minimized. CHP has also been successfully implemented in the plastics, steel, and chemical manufacturing industries, among others.

Buildings CHP. An emerging distributed generation application is known as building cooling, heating and power (BCHP). BCHP entails the application of CHP technologies in commercial, residential, or public buildings, where the waste heat is used for required services, rather than for industrial processes. For example, waste heat from electricity generation can be used as the input power for thermally activated technologies, such as absorption air conditioners and dehumidifiers, to generate steam for space heating, or to provide hot water for building laundry, kitchen, or cleaning services. Significant promise exists for BCHP at hospitals, schools and universities, health care facilities, data centers, restaurants, shopping centers, and other institutional and commercial establishments. Multi-family residential and mixed-use buildings like those promoted in the unified design concept, are also benefiting from BCHP applications. Finally, municipal and civic buildings have also installed these technologies for their efficiency, economic, and environmental benefits.

District Energy. The term for the local-area application of CHP technologies is district energy. Larger applications achieve a greater economy-of-scale through aggregation of demand among more than one facility or building. District energy systems have served entire central business districts as well as university and industrial campuses, eliminating the use of individual boilers and air chillers in networked buildings. The obvious benefits to participating electrical and thermal energy users include lower energy and maintenance costs and reduced impact on the environment. District energy systems are particularly well-suited to the clustering of compact mixed-use buildings.

In summary, DG/CHP systems offer the most sustainable means now available for energizing, cooling, heating, and supporting all industrial, commercial, residential, and institutional structures and activities contemplated in the proposed unified design concept. For a more detailed discussion of CHP applications see Appendix 1 of this document.

Environmental Management Systems

Urban solid waste, water, and air pollution control technologies provide for the essential protection of the natural systems upon which all life in a metropolitan region depends. The effective management of solid wastes and municipal wastewater treatment are among the most important, as they can also reduce air emissions and produce energy as well. The integration of these environmental control and energy generation technologies and their connection to DG/CHP micro-grids and networks would constitute the optimal system to support semi-autonomous urban nodes and districts. A brief discussion of this technological integration is provided below.

Municipal Solid Waste / Landfill Gas-to-Power

Today, the U.S. generates more than 230 million tons of municipal solid waste (MSW) annually. 28% of this waste is now recovered and recycled or composted, 15% is used for fuel, and the remaining 57% is disposed of in landfills. These landfills are anaerobic (oxygen-free) environments, where methane is produced by the bacterial decomposition of the organic materials. If uncontrolled, landfill methane can pose an explosion hazard, and it is also a powerful greenhouse gas. Landfill gas also contains volatile organic compounds that contribute to the formation of ground-level ozone.

The Clean Air Act now requires that landfills collect and burn their gas. Landfill owners and operators can flare the gas or utilize it to produce energy for their own use or for commercial sale. Currently, about $^{2}/_{3}$ of the operating landfill gas recovery projects generate power by burning the gas, representing approximately one gigawatt (GW) of power generation capacity nationally. Reciprocating engines or turbines are used in over 90% of the landfill gas-to-power applications. Besides reducing greenhouse gas emissions and the danger of explosion, landfill gas-to-energy projects reduce the cost of compliance with federal regulations, displace electricity produced by fossil fueled-central power plants, and produce power that can be sold at a premium as a "green product." There are now over 300 landfill-to-energy projects in operation across the U.S., with an additional 500 projects planned or under development [7 & 8].

Municipal Wastewater Treatment Facilities Biogas- to-Power

There are more than 15,000 municipal wastewater treatment facilities (MWWTF) in the United States and wastewater treatment is a highly energy intensive process. In fact, approximately 25% of a wastewater utility's operations and maintenance expenses can be attributed to power costs. In recent years, the operating costs of wastewater treatment plants have increased substantially due to increases in the cost of energy. Over the next 15 years, their electricity consumption is expected to increase by 20%, as plants expand treatment capacity to serve growing urban and suburban populations, and as the mandates of the U.S. Safe Drinking Water and Clean Water Acts require additional treatment technologies. These increased costs emphasize the need for conservation and proper energy management in wastewater treatment plants.

The production of methane (biogas) from the decomposition of organic compounds at wastewater treatment plants can offer both economic and environmental quality benefits for urban communities that elect to harvest the gas. For example, a biogas recovery and power generation system at an anaerobic wastewater treatment plant can displace 20% of the plant's operating costs. Residual organic solids from this process can then be burned in methane-fueled ovens and quenched in cooling tanks to produce a vitrified aggregate that can be sold as a building material. Like landfill gas, MWWTF biogas power can be sold at a premium as a green power product. In the past, many small MWWTFs have found biogas recovery to be uneconomical. However, technological advances have now produced many new cost-effective alternatives for these smaller sites. Power generation units, like those from Caterpillar and GE Distributed Power, have been designed to burn a wide variety of gaseous fuels. Micro-turbines and fuel cells have also emerged as options for biogas usage.

Building Systems

Because the reduction of material and energy consumption is central to sustainable urban development, building designs and construction practices that use less material and energy are essential if a community is to become more sustainable.

A more sustainable approach to urban design at the building scale entails, first and foremost, the optimal siting of structures for use of solar energy and for air-flow efficiency. South-facing window panels, solar PV and thermal units, and thermal masses can maximize the availability of natural light, power, hot water, and passive solar heat. Operable windows, awnings, strategically placed wind funnels, and reflective or sodded roofs can enhance natural air circulation, building cooling, precipitation collection, and water run-off control. The use of plant resins and fibers, along with recyclable materials, for solid and fabric surfaces and coverings also make sustainability sense. In general, the use of fully recyclable materials should be sought in as many building applications as is practical.

The incorporation of energy-efficient technologies throughout built structures is essential for reducing energy consumption. Lighting is an obvious area where sustainable design and technologies can conserve significant resources. The need for artificial lighting can be reduced by means of skylights, light tubes, and clerestory windows with sunlight-reflecting shelves. Occupancy sensors and controls can save significant amounts of energy by turning artificial lights off when they are not needed. The use of efficient T-8 tubes and compact fluorescent lights (CFLs) provide as much illumination as conventional incandescent lights while using only 25% as much electricity. These lights also last 10-12 longer, further increasing their value over incandescent lights, particularly for multifamily and mixed-use structures.

Substantial energy savings can be achieved by ensuring that all public and private urban structures install the most efficient technologies available for heating, ventilating, and air conditioning (HVAC). Specifically, the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) recommends the replacement of electric centrifugal chillers with steam or gas-fired absorption chillers or gas-fired internal combustion engine chillers, and the acquisition of variable speed drives for fans and pumps.

Significant savings can be obtained through the installation of HVAC controls, such as:

- **Energy Management Control Systems** that operate HVAC systems automatically, depending on building occupancy and internal/external conditions;
- **Outside Air Economizers** that allow the use of outside air to cool internal space during early morning and late night hours;
- **Variable Speed Fans** that control air supply, depending on the heating and cooling load;
- **Oxygen Trim Control Systems** that control air flow for peak efficiency of boilers.

Landscaping surrounding urban structures such as turfs, herbaceous groundcovers, vines, shrubbery, hedges and trees can also substantially reduce the use of energy resources. They can shade and cool exterior building surfaces during the summer and insulate them during the winter (if they are evergreens). Similarly, their use in conjunction with plazas, parking lots, and other large paved surfaces can significantly reduce ambient surface and air temperatures, thereby reducing the so-called "urban heat island" effect.

Governance Systems

Although governance systems are the last to be listed here, they are by no means the least important. In fact, without strong public leadership, an open and fully participatory process, and a systematic approach to defining, designing and developing a more sustainable urban form, sustainability will not materialize. Therefore, we conclude this section with the essential importance of the elective, policy, and regulatory dimensions of the sustainable urban design effort.

A community's decision to become more sustainable needs to fully resonate with its citizens and the elected officials who represent them. Although progress toward community-wide sustainability will initially be driven by a set of elected officials and private sector leaders, it must ultimately be embraced by the electorate. The participation of all citizens in the adoption of alternate practices and expectations is especially essential to the transformation to urban sustainability.

A community-wide sustainability campaign will not materialize overnight. More likely, it will be an incremental process focused at first on isolated projects and then, increasingly, by more comprehensive initiatives. The unified design concept presented in this document may initially entail a pilot demonstration on a relatively small scale, perhaps just a spatial subset of what could ultimately become a full neighborhood-scale demonstration. Along the way, concrete evidence of the economic, environmental, and social value of sustainable urban development must be collected and promoted throughout the community. In time, momentum will build as successes are celebrated, and the community will realize that it is on the right track. As a more sustainable urban form and community develop, node-by-node and district-by-district, it will become important to establish local leadership and participation structures within the newly emerging centers. Ultimately, some form of local governance should surface to ensure greater citizen connection to, and management of, the day-to-day affairs of their immediate local communities.

Once a vision of community sustainability is articulated, and supporting objectives, performance standards and indicators are created, a formal municipal sustainability policy should be established. Using this policy as a standard, all other municipal policies, regulations, codes, and standards should be reviewed and modified if necessary to ensure maximum conformity. As noted earlier, this must entail a comprehensive restructuring of existing zoning maps, building codes, and, ultimately, the community's general plan. This will clearly be a contentious process, requiring significant compromises, but a historic one as well and one worth adopting for the long-term prosperity of the community and its future inhabitants.

For a more detailed discussion of related governance and community implementation dimensions of sustainable planning, please see GTI's *Blueprint for Urban Sustainability: Integrating Sustainable Energy Practices into Metropolitan Planning*. Copies are available through the GTI website at www.gastechnology.org/sustainability.

V. CASE STUDY: THE SAN DIEGO-TIJUANA BINATIONAL METROPOLITAN REGION

In this section of the report, the foregoing design principles, and elements of urban sustainability are applied to the combined metropolitan regions of San Diego, California and Tijuana, Baja California, Mexico. While the San Diego-Tijuana design is particularly ambitious in its scope, both in time and in space, the same process and principles can guide the development of sustainability for any community in much more immediate time horizons. This is particularly true when broad-based involvement leads to consensus on a vision for the community. We will begin with a brief description of the context for the design.

The design was completed in February 2003 and offered as the official U.S.-Mexico Team entry to the International Competition for Sustainable Urban System Design described in Section III. Given the particularly long planning horizon for that competition – 100 years, the competing teams were encouraged to include in their designs, not only existing technologies for sustainability, but also emerging and future technologies currently in the early stages of research and development. San Diego was originally selected to represent the U.S. in the international competition after it won the preliminary U.S. Competition for Metropolitan Energy Design, conducted by the Gas Technology Institute during 2001 and 2002. The Municipality of Tijuana was added to the design area when it became clear that a truly comprehensive sustainable urban design for the region would require consideration of all settlements sharing the same bioregion and urban economic base. For the same reason, the design area also included the 17 incorporated municipalities of San Diego County with a total land area of 10,880 square kilometers (km^2) and a land area of the Municipality of Tijuana of 1,229 km^2. In accordance with the competition guidelines, the design was structured in three sections:

- An **overview** of the region's current natural characteristics and the multiple environmental, economic, and social challenges it faces in the coming years;
- A 100-year **vision** for sustainability – depicting the Binational Metropolitan Region's ideal state in the year 2103. This section also contains a description of a sustainable energy system that has been integrated with other resource management technologies to provide efficient, economical, and environmentally benign energy utilization;

- A **road map** outlining the governmental, economic, technological, and social developments necessary to realize the region's vision of a sustainable future.

The design team consisted of 185 contributors from more than 85 public, private, and nonprofit organizations in the United States and Mexico. The team followed a comprehensive urban design process over a seven-month period that included 3 phases, 29 tasks, and numerous subtasks [NOTE B].

REGIONAL OVERVIEW

Study Area

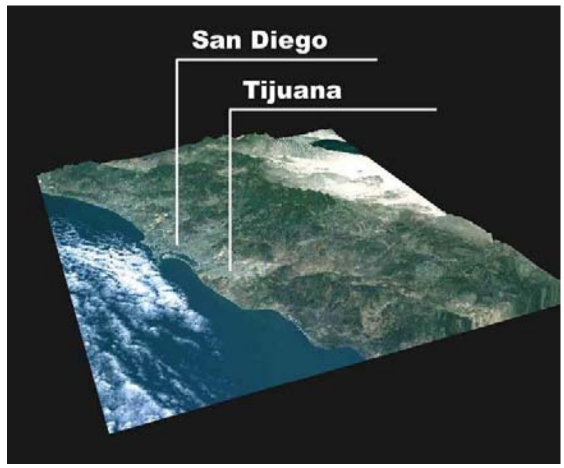


Figure 1: Study Area

The San Diego-Tijuana Binational Metropolitan Region is located on the Pacific coast of North America and includes diverse urban and rural areas of Southern California and northern Baja California (Figure 1). These areas share natural systems in a well-defined ecoregion. The international boundary bifurcates the region into distinct U.S. and Mexican human systems that include elements such as culture, language, family and society, governance, use of urban space, and economic practices. These structures and practices are beginning to converge and harmonize. The study area is anchored by the City of San Diego (1.3 million population) in California, and Tijuana (1.3 million) in Baja California. The study area also includes 17 additional incorporated cities and unincorporated areas within San Diego County, as well as the Mexican cities of Tecate (80,000) and Rosarito (69,000), which are rapidly converging with urbanized areas of Tijuana. The total population of San Diego County is 2.8 million, and the population of the entire region is about 4.3 million people.

The binational study area – more than 12,400 km^2 in extent – has a varied topography. Most of the population is concentrated in the coastal valleys and flat mesas to the west. To the east, there are foothills and mountain ranges with peaks over 1,800 meters in elevation. The region's benign Mediterranean climate produces most of the annual rainfall during the winter months of November through February, with more precipitation in the mountains than on the coast. Variations in topography and rainfall have produced a pattern of many different microclimates and an extraordinarily rich biodiversity. As human populations have occupied the coastal valleys and mesa tops and have spread into the foothills and interior valleys, the impact of urbanization on natural areas has been profound. Today, the region is one of the world's biological "hot spots," based on the large number of threatened and endangered species.

While contained within one natural region, the study area includes two very different human systems that meet at the international border. Mexican culture, Spanish language, and legal traditions based on Roman law contrast with U.S. culture, the English language, and the Common Law legal tradition. The Mexican political and public administration systems are centralized; much of their power is concentrated in the national capital with little devolved to the local entities. U.S. governments are more decentralized, with relatively more power at the local level. Furthermore, the economic asymmetries present in the San Diego-Tijuana border region are significant. The United States is one of the most developed countries of the world, and Mexico is a developing country. The regional economic activity of San Diego is about 20 times that of Tijuana despite similar-sized populations; minimum wages are more than 10 times higher in San Diego than in Tijuana; and local government budgets are about 25 times greater north of the international boundary.

Recent developments have led to a greater convergence between San Diego and Tijuana. Mexico is in the process of decentralization, with more responsibilities being allocated to the local governments. Mexico has made the transition from a central, state-controlled economy to an open economy linked to the United States and Canada through the 1994 North American Free Trade Agreement (NAFTA). This has enabled San Diego and Tijuana to benefit from some complementarities in their respective economic systems through trade, capital, technology, and labor flows. In the regional binational economy, San Diego is the site of much of the knowledge-based industries, such as biotechnology and computer software. It is also the site of capital-intensive manufacturing. Tijuana, however, provides much of the manufacturing base of the region through the well-developed assembly industry *(maquiladoras)*, currently employing some 147,250 workers. Tijuana also supplies 40,000 workers, who reside south of the border and commute to San Diego to work, mainly in service industries and construction. Both San Diego and Tijuana have important tourism industries that are complementary, rather than competitive. Finally, Tijuana and San Diego are geographically isolated from their national capitals, requiring much informal trans-border cooperation to address local problems and opportunities. All of these forces have combined to support economic integration across the border and increase local trans-border cooperation, which will be vital for reshaping the region over the next century.

Despite planning efforts and growth management efforts that date from the 1970s, the Binational Metropolitan Region continues to experience significant population growth, reduced mobility, increased congestion, resource shortages, environmental degradation, economic inequities, and fragmented governance. Ten areas of concern must be addressed in order to sustain the region's quality of life. They are population growth, land scarcity and urban sprawl, habitat and species loss, traffic congestion and air quality degradation, water scarcity and degradation, energy security, housing affordability, solid waste disposal, economic disparity, and fragmented governance.

Population Growth

The most pressing concern is population growth and the challenge of providing adequate services to all residents. By 2030, the region's population is expected to soar to 8 million, which is almost twice the 2003 population. This region is one of the most dynamic in the world in terms of demography. Fueled largely by migration, San Diego is currently growing at 1.7% per year, while the figure for Tijuana is 4.9%. By 2030, a majority of the region's population will live south of the international border. The region's climate, quality of life, and economic opportunities have fueled most of the domestic migration to San Diego. As for Tijuana, its manufacturing and tourism industries, combined with its proximity to San Diego and Southern California, have attracted migrants unable to find similar economic opportunities elsewhere in Mexico. By 2103, the population is likely to increase to 15 million within the Binational Metropolitan Region. Given the expectation of significant advances in the medical sciences and healthcare and the resulting longer life spans, this number could be considerably larger. Such growth far outstrips current infrastructure planning, financing capabilities, and available land. For example, in San Diego County, land zoned for development will be totally consumed by 2018. Using current development projections, Tijuana, whose population constitutes 60% of the projected growth for the Binational Metropolitan Region, will lose most of its ecologically sensitive and agricultural lands by 2025. The combination of continued growth, population expansion, and uncoordinated planning will exacerbate the existing pattern of urban sprawl (Figures 2 & 3). The following problems will only grow worse should current trends continue.

Land Scarcity and Urban Sprawl

Currently, energy-inefficient urban developments plague the region. San Diego's development pattern is designed to accommodate detached single-family residences and automobiles. Tijuana's urban growth is largely unplanned and has spread over the landscape in an ad-hoc fashion. Continuation of these growth patterns will consume all developable land within several decades.

Figure 2: Urban Spatial Pattern 2003

Figure 3: Sprawl Scenario 2103

Habitat and Species Loss

A direct consequence of urban sprawl is the loss of natural habitat and further stress on more than 200 species that are currently threatened or endangered (Figure 4) in this unique ecological region. San Diego has begun to implement a Multiple Species Conservation Program (MSCP) to preserve habitat through land acquisition, but MSCP's ability to raise money for land purchases is far outpaced by developers' ability to acquire these lands for residential and commercial development. Tijuana is only now beginning to plan for habitat and species protection. Furthermore, no trans border protected areas exist to protect flora and fauna corridors in the region.

Figure 4: Ecologically Sensitive Lands

Traffic Congestion and Air Quality Degradation

The growing number of automobiles did not result in greater pollution in San Diego during the last decade of the 20th century due to stricter emissions controls. However, the overall region continues to experience ever more air pollution, congestion, and lost productivity. Consumption of imported liquid fuels continues to increase as the number of vehicles continues to grow. Additionally, access and mobility within the region is inhibited by a lack of alternate transportation options and sprawling development patterns. Growing transportation problems are cited both in San Diego and Tijuana as a factor in declining quality of life.

Water Scarcity and Degradation

Currently, the San Diego-Tijuana Metropolitan Region meets 95% of its regional water demands through costly and distant imported sources from the Colorado River and Northern California. Approximately 50% of the San Diego-Tijuana Region's fresh water is used for non-drinking purposes such as landscape irrigation, commercial enterprise, and industrial processing. Tijuana, although using only about 1/3 as much water per capita as San Diego, will face severe shortages within a decade. Surface waters are contaminated, and the region's aquifers are declining in quality and quantity of water production.

Energy Security

The Binational Metropolitan Region relies on energy imports for a significant portion of current needs. The region depends almost entirely on imported liquid fuels and natural gas for transportation needs and electricity production. California's recent energy crisis created economic disruption and market uncertainty that has temporarily delayed investments in additional infrastructure and the siting of transmission lines. However, electricity demand is expected to resume sharp growth in the region as local economic conditions begin to improve over the next few years. Because local communities are generally opposed to the installation of new power plants in their areas, the region will soon be facing challenges in adequately meeting its future energy needs. San Diego is located at the far southwest corner of the United States and is the effective end of the energy supply infrastructure for liquid fuels, natural gas, and electricity. Tijuana and its surrounding population centers are not connected to the Mexican natural gas distribution infrastructure or electricity grid. Instead, they rely on their connection to the United States through southern San Diego and Imperial counties. San Diego and Tijuana are inextricably linked to the energy infrastructure along the border and the region's energy future relies on regional cooperation and planning. Transitioning from heavy dependence on fossil fuel energy sources to more locally available renewable sources is a high priority for all stakeholders in the region.

Housing Affordability

Both San Diego and Tijuana are in the midst of a long-term shortage of affordable housing. San Diego, due to low wages and high cost of the type of housing constructed, has a chronic shortage of affordable housing – one of the worst in the United States. Tijuana, because of low wages, the lack of a well-developed mortgage market, and rapid population growth, has ongoing housing shortages (as many as 50,000 units), substandard housing, and crowded housing. In Tijuana, much of the housing need is met through self-constructed buildings on land provided by the government. About 60% of Tijuana's urban development is occurring on what were formerly communal agricultural and grazing lands, known as *ejidos*. To meet current population and housing growth needs, *ejidos* are rapidly being privatized and developed in the eastern and southern parts of Tijuana. Many of these areas have substandard infrastructure and communal amenities.

Solid Waste Disposal

Although there is adequate landfill space available in San Diego today, there will be a shortfall in capacity within the next 10 years. Tijuana is in a similar position. The scarcity of land and community opposition to siting alternatives will make future landfill development difficult and continuation of present waste management practices unsustainable.

Economic Disparity

Despite the economic convergence between San Diego and Tijuana, significant disparities remain. The minimum wage in San Diego is at least 10 times higher than the equivalent base wage in Tijuana. Additionally, urban infrastructure investment in San Diego is 20-50 times greater than in neighboring Mexican cities. The Gross Regional Product for San Diego County is $126 billion and the corresponding number for Tijuana is $9.7 billion. Significant reduction in the economic asymmetries across the border will require 2-3 generations. As these asymmetries decrease, it is expected that Tijuana's ability to fund services and infrastructure will improve.

Fragmented Governance

Complex governmental structures inhibit the region's ability to address the many challenges described previously. San Diego has a county government, 17 incorporated cities, and some 200 special purpose districts. In addition, there are more than 20 American Indian tribes, whose reservations have semi-autonomous political status. The layers of state and federal government also produce added complexities. Across the border in Mexico, lines of authority are clearer, but the preponderant power of the federal government and the limited resources of local governments inhibit state and local initiatives. Although political and administrative decentralization is moving forward in Mexico, the process is slow.

Different structures of governance in San Diego and Tijuana, along with U.S. and Mexican federal government preoccupations with sovereignty, have made local trans border cooperation and governance difficult. The major near-term challenge for the region is developing trans border governmental arrangements to address critical regional issues.

The Challenge Ahead

The previous description of basic conditions and issues in the Greater San Diego-Tijuana Binational Metropolitan Region illustrates that a business-as-usual approach will bring deteriorating environmental conditions, congestion, pollution, and other elements that constitute a declining quality of life. The immediate challenge will be to articulate a binational community vision of a sustainable future and the public policies, private stakeholder actions, and collective commitments necessary to realize the vision in the coming century. The next section of the design provides a preliminary vision of a sustainable region in 2103, establishing a set of ideal goals as the focus for a road map of solutions presented in the final section of the design.

Vision of the Future: Spatial Design and Mobility

An aerial perspective affords a spectacular view of the San Diego-Tijuana Metropolitan Region and its rugged 190-km coastline. The urban footprint of the Region in 2103 is not much larger than a century earlier. The rivers and valleys have been protected and rehabilitated to function as nature preserves, green spaces, and recreational areas. Critical habitats on the mesas have been set aside, and the inland mountainous areas are largely protected areas. The natural functioning of the watersheds of the region has been restored, and the result is a flourishing of vegetation and animal species and improved water quality and water production. Natural filtering processes of riparian and aquatic vegetation have improved the quality of the surface waters and largely eliminated the contamination of the near-shore marine environment.

The sustainable ethic that defines the Binational Metropolitan Region's urban design is evident throughout the landscape. Low-rise coastal development sits behind the brow of the beach, protecting the viewshed and preserving beach access. The establishment of the Binational Multiple Species Conservation Program protects an extraordinary diversity of plants and animals, which coexist alongside dedicated recreational areas. These dedicated land uses include porous areas that allow natural drainage of rainfall to recharge alluvial aquifers along streambeds.

Large, interconnected swaths of community gardens lie within the publicly owned open spaces closest to human settlements, replacing many of the large house lots and private gardens of a century earlier. While these organic gardens supplement the diets of the residents, their primary purpose is to cultivate a sense of community, and to root individual citizens in a concern for one another and for the natural environment.

San Diego-Tijuana has evolved into an articulated Binational Metropolitan Region that enjoys its many natural resources while it maintains a high quality of life. In 2103, this binational metropolis embraces four distinct urban zones, which conform to a resource efficient urban land use plan supported by a comprehensive regional transportation system. These two critical elements – the land use plan and the transportation system – have proved to be the key to the region's singular success in achieving sustainable development. Urban development policies have reinforced these design elements by concentrating growth into targeted urbanized areas of mixed-use development at transit nodes and along transportation corridors. This development pattern is intended to reduce and, in many cases, eliminate the spatial separation among residential, employment, shopping, social, and recreational centers and thereby reduce or eliminate energy consumption and air emissions associated with travel among them. Similarly, preservation policies have led to the designation of significant portions of the Binational Metropolitan Region as agricultural and ecological preserves and green areas. This ecological balance is exemplified by restored environmental assets that include the Tijuana River-Alamar River system, the San Diego River, Chollas Creek, Rose Canyon Creek, and Santa Margarita River in northern San Diego County.

Regional Urban Structure

The efficient use of land has provided a hierarchical structure for four urban zones that consist of cities, villages, and neighborhoods.

Zones. The four urban zones in the region are: (1) Escondido, (2) Sorrento Mesa-University Towne Center, (3) Downtown San Diego, and (4) the International Border Zone (IBZ) (Figure 5). Each zone measures 24-32 km in diameter. Zones are defined primarily by their geographic, social, and economic spheres of influence. Each zone has a population of up to 4 million. The four urban zones contain 60 targeted cities and adjoining areas that will accept and support all future growth in the region.

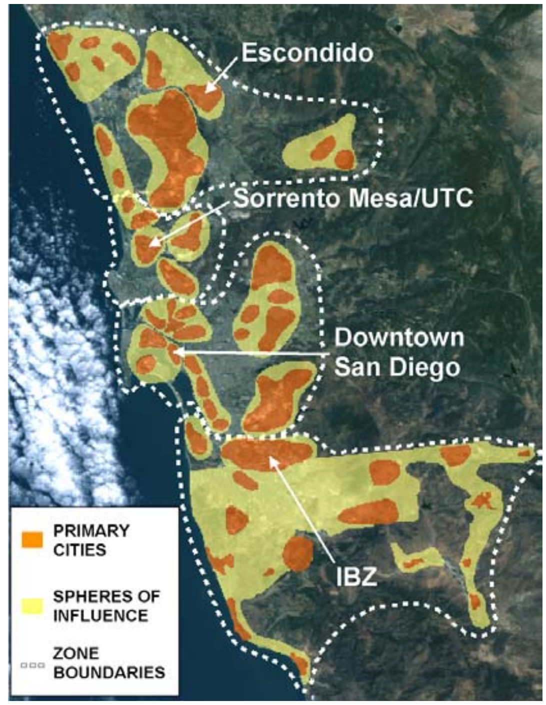


Figure 5: 2103 Urban Zones

Cities. Each of the four zones contains several primary and secondary cities. The primary cities are the locus of economic and cultural activity for their urban zones. The primary cities serve as commercial, employment, and transit hubs, range in size from 16 to 24 km in diameter, and have 725,000 to 1 million residents. The highest intensity land uses are found within the city centers, with residential densities of 308-432 units/hectare (Figure 6). Secondary cities have less-intensity land use, with densities at 70% of primary city centers. Throughout the region, there are remnant areas where traditional residences with individual lots remain, some as parts of historic districts.

Figure 6: Central Business District of a Primary City

Villages. Surrounding the cities are smaller-scale villages. Villages, defined by the geography of mesas, canyons, and drainage courses, provide the physical space for community life and distinctive cultural and historical characteristics. They provide the “sense of place” with which residents identify.

The average village is comprised of about six neighborhoods plus a village center. Villages are approximately 4 km in diameter and have 40,000-65,000 residents. The village center offers a diversity of housing alternatives for approximately 20,000 residents. The village center contains 4-5 story structures with residential densities of 100-185 units/hectare. Highest densities occur at the village core and along the primary commercial/transportation corridors that radiate out to the neighborhoods. Tapering rings of neighborhoods along these corridors support the core of mid-rise residential and commercial buildings. Village residential densities range from 30 to 185 units/hectare, and create a diverse mixture of housing, including a number of detached single-family dwellings that have survived from a century earlier. The village center provides transit connections to the region's larger commercial, employment, retail, and recreational/cultural centers and facilities. Secondary schools, vocational schools, and community colleges are located within or adjacent to the village centers.

The village center is distinguished by a network of green pedestrian boulevards or *paseos* that are connected to the community's common areas. These common areas are designed to meet the varied needs of residents and range from community gardens to formal play areas. The *paseos* serve as linear parkways that lead residents to the edges of the mesas and canyons at the periphery of the village. They also connect habitats throughout the region and serve to promote biodiversity.

Neighborhoods. The neighborhood represents the smallest scale in the regional spatial hierarchy. Design guidelines ensure structures and streets of human scale. Emphasis is placed on *paseos*, greenways, and sidewalks that promote walking and biking as viable alternatives to the use of motorized vehicles. Neighborhood common greens are emphasized to provide outdoor spaces for the clustered residences that face them.

The average neighborhood is 100-125 hectares in size, and has approximately 6,000-11,000 residents. Residential densities range from 120 units/hectare in the neighborhood center to 30 units/hectare at the neighborhood's periphery. A few areas of lower density remain from the previous century. Retail, civic, and office establishments, none of which is higher than two stories, anchor the neighborhood center. The center also features elementary schools, religious institutions, and resource management centers (RMCs). The RMCs provide electric power, heating, cooling, water, and recycling of sanitary and solid wastes for the neighborhood. By co-locating these functions, the neighborhood is able to maximize resource use efficiencies by integrating energy and environmental technologies.

Transportation System

Over the preceding century, new public and private mobility systems evolved to support the new land use plan, which transformed the Binational Metropolitan Region into an inherently more sustainable human settlement. In fact, these two interdependent elements account for most of the gains in energy efficiency, local and global air emissions reduction, waste minimization, and habitat protection. The mobility systems of 2103 consist of new elements and technology that emerged over the course of the 21^{st} century and innovative elements that had been pioneered in Europe, Brazil, and Asia toward the end of the 20^{th} century. A four-tier public mobility system was designed to facilitate travel: (1) to and from the region; (2) between primary cities across the four urban zones; (3) between primary and secondary cities within zones; and (4) between cities and their associated villages and neighborhoods. The private mobility system provides alternative transportation for those willing to pay a premium for transportation-on-demand or who choose to travel beyond the established public transit routes.

In addition to public and private passenger mobility, there is also an inter- and intraregional freight transportation component that has eliminated the substantial traffic congestion, energy consumption, and air emissions associated with surface trucking a century earlier. A description of each tier and the associated clean transportation technologies follows.

Figure 7: Advanced Transportation Technologies

Tier 1. Interregional Mobility. There are three primary means of travel to and from the region in 2103, air, rail, and sea (Figure 7). The principal international airport for the Binational Metropolitan Region is located in Kearney Mesa, within the Sorrento Mesa-University Towne Center Zone. Vertical-take-off-and-landing (VTOL) and blended wing aircraft provide supersonic shuttle service to and from all major urban centers around the world. Co-located at the airport is one of six stations that provide access to the high-speed magnetic levitation rail system linking the four San Diego-Tijuana regional zones to Sacramento in northern California and Ensenada in Baja California (Figure 8). It provides the region's residents with the fastest inter-regional mode of transportation available. One rail station is co-located with the Port of San Diego, which continues in its historic role as the principal facility for ocean travel, although most ocean travel occurs just above the surface of the Pacific as high-speed hovercraft now service most passenger and cargo trips.

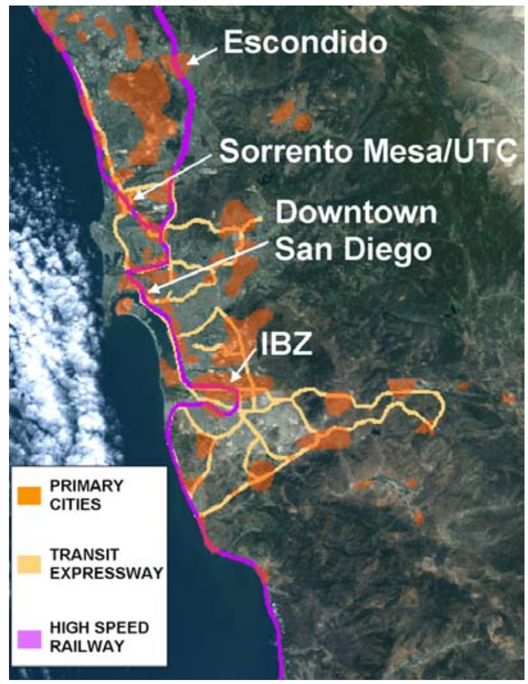


Figure 8: Interregional Transit Network

Figure 9: Tier 2 - High Speed Flex Trolley

Tier 2. Intraregional Mobility. Travel between primary and secondary cities across the entire Binational Metropolitan Region is facilitated by a Regional Rapid Express (RRE) service featuring high-speed (60-80 kph), computer-operated Flex Trolleys (articulated buses) operating on transit-only, magnetic guideways (Figure 9). Stations are located an average of 5-8 km apart, and trolleys serve them at 5-10 minute intervals. The trolleys are propelled by electric motors energized by fuel cells that emit only water vapor.

Tier 3. Intra-Zone City Mobility. Travel between primary and secondary cities and outlying villages within urban zones is provided by a local express service featuring a longer version of the RRE Flex Trolley (Figure 10). These vehicles operate at moderate speeds of 30-50 kph and arrive at stations, spaced every 1.5 km, at 3-5 minute intervals. They travel on dedicated arterial transitways between stations and are guided by the same automated navigation system used in the faster RRE Flex Trolleys.

Figure 10: Tier 3 - Local Express Service Vehicle

Figure 11: Tier 4 - Elevated Feeder Line

Tier 4. City/Village/Neighborhood Mobility. Travel between cities and their associated villages and neighborhoods is facilitated by a 3-part system consisting of: (1) a City-to-Village Tramway; (2) a Village-to-Neighborhood Feeder Line; and (3) an Inner Neighborhood Shuttle Service. The City-to-Village Tramway runs between city and village centers through dense urban corridors along dedicated grade-level lanes. The Tramways are similar in size, guidance, and propulsion characteristics to the RRE and local express vehicles, but they operate at lower speeds of 20 kph. Tramway stations are spaced .5-.8 km apart and are served at 3-5 minute intervals. Residents reach the village center from neighborhood centers through a network of feeder lines (Figure 11). These lines are designed to support medium-speed operations between stations spaced .5-1.0 km apart and served at 1-2 minute peak time intervals. Feeder lines utilize track guidance and linear induction propulsion. For residents living in older low-density communities beyond a comfortable walk to a feeder line, auxiliary shuttles are available. These fuel-cell electric shuttles navigate along magnetically controlled pathways at low speeds. Optical sensors stop the shuttles for loading and unloading.

While the public mobility system was designed to dramatically increase efficient and affordable access throughout the region, the private mobility system was built to provide residents additional flexibility and choice in meeting their transportation needs without contributing to air emissions. The private mobility system centers on the Personal Mobility Vehicle or PMV. These autonomous, computer-guided vehicles utilize both electric-hybrid and induction-charged electric engines. They have replaced most privately owned vehicles and provide point-to-point transportation services on demand. The vehicles operate on clay tracks with imbedded solar-powered guidance transmitters. These tracks are adjacent to the regional and local rapid transit lanes on an extended network of trackways that enable residents to travel virtually anywhere in the region. The vehicles are funded through time-of-day and trip-and-distance user charges. A limited number of vehicles with special configurations are owned by individuals or companies. All vehicles are stored, calibrated, fueled, and maintained within the neighborhood Resources Management Center. The PMVs are available at any time and their numbers are monitored and adjusted to account for the time of day, the day of the week, and special events. A central management system determines the speed for each track and controls the acceleration and braking lanes that enable entry and exit from faster tracks. The computer architecture supporting the management system features multiple redundancies for all command components to ensure` operational integrity and passenger safety.

The guidance technology employs a trajectory map that determines optimal routing and synchronizes a specific vehicle's movements with all other vehicles traveling in the same corridor, thus enabling high-speed merging and travel of vehicles separated by only five centimeters. Two PMV models currently operate in the region:

- Fully automated PMVs. Guided by a region-wide, synchronized computer system, this vehicle is manufactured in a range of sizes providing 2-10-passenger seating capacities. All are handicapped-accessible and offer special options such as luxury finishes, advanced communications, entertainment modules, and a variety of seating, lighting, and tabletop configurations.
- Dual-mode PMVs. Dual-mode units offer the option of manual pilot operation. Travelers use free-range, non-automated routing alternatives to reach leisure destinations well off the beaten path. Larger and heavier commercial and emergency services vehicles use these manual-controlled systems but also conform to the width of the same hardpack clay tracks used by the fully automated PMVs.

In addition to the public and private mobility systems serving the region, there is also a system dedicated to moving industrial and commercial freight. Freight is transported between industrial and commercial facilities within the region by a commercial version of the dual-mode PMV that utilizes the same network of clay tracks. For interregional import and export trips, these commercial vehicles connect to the high-speed magnetic levitation freight rail system that shares the passenger rail right-of-way. This system serves the airport and seaports and links San Diego to commercial centers between Sacramento in northern California and Ensenada in Baja California.

Community of the Future: International Border Zone (IBZ)

While most development is directed to existing urban areas, the U.S.-Mexican border zone, as conceived in our design, reflects the region's new transnational collaborative approach to sustainability through the development of a new urban center straddling the common border (Figures 12, 13, and 14). One of the two primary cities within the International Border Zone provides the intellectual, political, and corporate base needed to advance sustainable development. With corporate, government, and academic partners, the Otay Mesa-Rodríguez primary city center serves as a research, training, demonstration, and venture capital center, matching development needs with funding sources and new technology. This binational resource will share its findings with a world hungry for new ideas and information about sustainable development. It will also market services and technologies needed for sustainable development.

Figure 12: International Border Zone

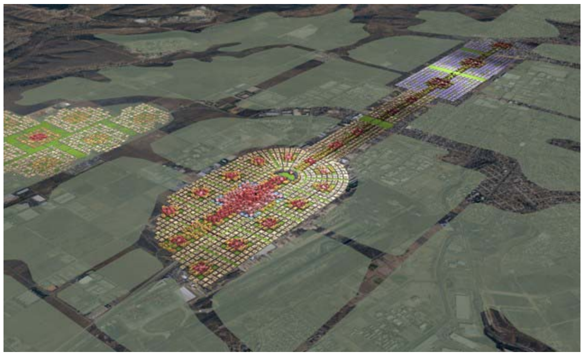


Figure 13: IBZ Primary City

The IBZ is defined by its surrounding environmental corridors and preserves rather than by cultural, historical, or national boundaries. The Tijuana River lies to the south, the Otay River to the north. Otay Mountain and Cerro San Isidro form a natural eastern border while the Tijuana River National Estuarine Research Reserve bounds the IBZ to the west at the Pacific Ocean. The immediate IBZ region is surrounded by more than 80 km^2 of natural reserves and restored open space. The developed area stretches 19 km from east to west and 9 km from north to south. The international border between the United States and Mexico has lost its barrier and restrictive functions, similar to borders within the European Community a century earlier. This is a direct result of the full integration of the economies of the North American region, including free movement of people.

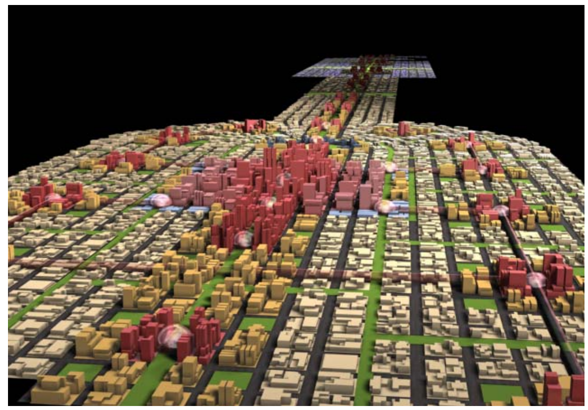


Figure 14: IBZ Primary City Center

The Tijuana River National Estuarine Research Reserve, located between the IBZ primary city and the Pacific Ocean, functions as an international ecopark and resort center. The ecopark's learning and interpretive centers offer visitors an interactive educational experience based on sustainable ecosystems design.

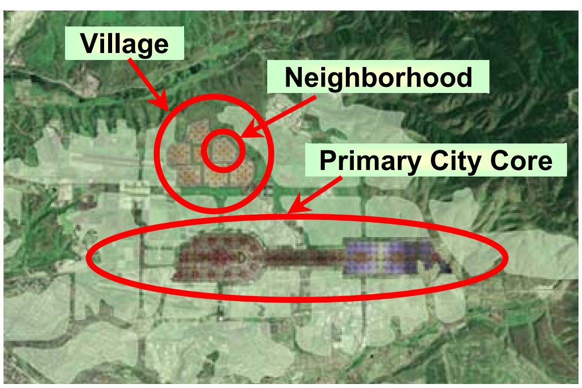


Figure 15: City, Village, Neighborhood Hierarchy

The IBZ is organized in the now-familiar hierarchical pattern of city, village, and neighborhood (Figure 15). Tijuana and the new Otay Mesa-Rodríguez city center represent the two primary cities of the IBZ. These cities are supported by the following secondary cities: Tijuana River Zone-Historic Downtown Center; Matamoros-El Florido; San Antonio de los Buenos-Rosarito; Tecate-Las Palmas Valley; New Port-La Misión; Chula Vista Eastern Urban Center; San Ysidro; and East Otay Mesa. The secondary cities contain residential villages of varying densities that occupy a total of more than 4,047 hectares. Each village consists of 5-6 neighborhoods that are linked to a village center by an arterial roadway for the private PMV system, feeder lines, and shuttle systems. Each village contains 30,000-60,000 dwelling units, depending on the density. The two primary cities each have a population of 1.5 million. The five secondary cities, combined, have an additional population of 2 million.

The Otay Mesa-Rodríguez primary city is a high-density, mixed-use development. It serves as the international business, financial, cultural, and civic center of the IBZ and a magnet for the headquarters of major international corporations, drawn to the region by the synergies of the

Mexican and U.S. components of this binational regional economy. The 200-hectare primary city center is expected to accommodate 4 million square meters (m^2) of office space, when fully built out. The East Otay Mesa city center will support the Eco Employment Business Park that contains an additional 3 million m^2 of office space. A tramway with multiple stops (approximately 400 meters apart) provides access between these two cores, as well as among the office and retail buildings along its route (Figures 16 & 17). The transit connection between the cores has been modeled after Las Ramblas of Barcelona. Las Ramblas has a wide central greenway for the recreational enjoyment of its residents and a central corridor for transit, pedestrian, and bicycle traffic. Las Ramblas is bracketed by high-density mixed-use facilities that include housing, ground floor retail, restaurants, and outdoor cafes that have access to the greenway and wide pedestrian sidewalks. The IBZ Center has its identity reinforced by a unique landmark office tower. A similar structure anchors the Eco Employment Center core directly on axis with this tower. The mixed-use core of the employment center contains 10,000 dwelling units with additional retail and office uses.

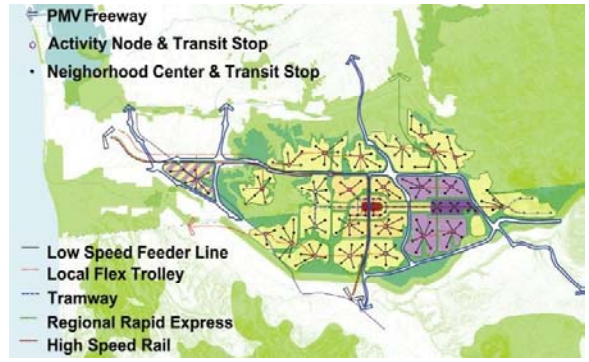


Figure 16: IBZ Transit Network

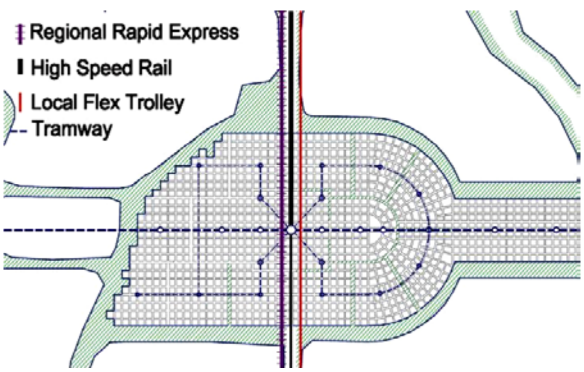


Figure 17: IBZ Primary City Transit Network

The Otay Mesa-Rodríguez City has been designed around an accessible, convenient, and flexible transit system that effectively serves residential densities (ranging from 124-370 dwelling units per hectare) along its routes. As a result, 90% of all trips taken within the city's boundaries utilize this zero emission mode of transportation.

International Border Zone Building Systems

While older buildings in the region have been retrofitted for greater resource efficiency, new buildings in the IBZ are designed for maximum effective use of energy and water. Use of high-technology construction materials and multistory buildings, along with other energy efficiencies and conservation measures, has an overall regional per-capita energy consumption only one-third that of the previous century. This has been accomplished despite the more than threefold increase in the regional population. Automated technologies provide custom environments. Strong infrared-reflecting glass panes are competitively priced and completely recyclable. Some window coatings produce electricity from sunlight; others modify opacity on command, effectively allowing occupants to change window locations on a daily basis if desired.

Most residential units in the IBZ – averaging, about 110 m^2 - are clustered into multifamily structures, although there are some single-family residences. Residential construction involves little more than on-site assembly of prefabricated modular units and enables greater opportunity for saving energy. Every wall, floor, and ceiling unit features fiber-optic and electronic circuitry. Materials are derived from composite recyclable materials such as wood, plant fibers and resins, and glass. Steel and concrete are only used in framing high-rise structures to meet earthquake standards, and most of this material is harvested from old roadways and automobile depositories.

Buildings throughout the IBZ use rooftop wind scoops to funnel air into the cooling systems as well as other design elements for natural air conditioning. Clerestory windows open automatically at night to draw cooler nighttime air and close during the day to maintain comfort levels. Cooling and heating are supplemented by chilled or heated water from the RMC. Hot water is supplied by solar thermal energy with small amounts of other energy used to boost the final delivery temperature. Underground pipes are also used to provide cooling in the summer and serve as heat sinks for heat pumps in the winter months. Hydroponic gardens on the rooftops of large commercial and industrial buildings reduce interior temperatures, provide weather insulation, and moderate interior temperatures. Rooftop gardens also provide cut flowers and produce for local use.

Gray water and black water are reclaimed through advanced filtration technologies that also can desalinate ocean water. Buildings channel rainfall to neighborhood storage basins that service community gardens. As a result of these and other conservation technologies, as well as sustained public awareness, per capita water use has decreased dramatically in the past century.

Sustainable Energy System

In 2103, the Binational Metropolitan Region, along with the rest of the United States and Mexico, is in the midst of a new energy era, one that is dominated by hyper-efficiency in energy consumption and sustainability of energy supplies. Overall per capita energy use and imported energy have decreased to very low levels compared to the energy use of 2003. This was achieved through the integration of energy production with other resource management technologies (such as water, wastewater, and solid waste), building efficiency, distributed generation, and the village design concept. Furthermore, the region's reliance on imported fossil fuels has disappeared in favor of harnessing regionally abundant renewable resources, including ocean, solar, geothermal, wind, and enhanced methane recovery from waste. This transformation was driven by swelling populations in the 21st century, forcing a choice between investing in increased energy delivery, and investing in sustainable practices to reduce energy demand. The San Diego-Tijuana Binational Metropolitan Region chose sustainability, and by 2103, it led the United States and Mexico in energy efficiency and management.

In 2103, the region's spatial design, energy infrastructure, and distribution networks are radically different from the configuration that existed 100 years ago. The energy system of 2103 has three integrated elements: (1) micro-grids that support the energy flow within the villages and neighborhoods, (2) neighborhood Resource Management Centers (RMCs) that operate the micro-grids and balance energy flows, and (3) energy production technologies. Electricity is the sole form of energy delivered to homes and commercial buildings. Most electricity is locally generated from renewable sources, but the region is not completely energy-independent. Several superconducting power lines bring remote energy to the region. The only other energy form in the region is hydrogen, which is used primarily for industry, transportation, and storage in the RMC.

The regional spatial design has established each neighborhood as a largely independent energy network serviced by the RMC via a micro-grid. These micro-grids differ from the electric grids of the 20th or early 21st century. Instead of moving only from centralized generation plants to end-users, electricity now flows in both directions between end users and generation sources, balancing demand with production on an ongoing basis. The RMC's computers manage this give-and-take flow of power.

Each neighborhood has one RMC that is responsible for the neighborhood's energy needs, and the aggregate of all RMCs constitutes the heart of the region's energy system. The RMC integrates the energy and resource needs of the neighborhood to make it as efficient as possible. As an energy manager, the RMC integrates power production within and between neighborhoods. During periods of excess energy supply, the RMC uses the energy to create hydrogen, recharge energy storage devices for future energy needs, or fuel the personal mobility vehicles (PMVs). During periods of excess electricity demand, the RMC generates power from hydrogen-powered fuel cells, uses power from local energy storage, or draws from the regional electricity Supernetwork, a system of underground superconducting electricity lines that link RMCs to remote electricity supplies. In addition to its role as local energy manager, the RMC is also the central base of operations for the PMV, waste processing, and water supply systems. Thus, traditional energy utilities have evolved from commodities brokers to energy related service providers – running the RMCs and increasing their product range from just energy to include water, waste management, and transportation. (See Appendix 1)

Energy demand-reduction technologies play a critical role in the sustainable energy system of 2103. All structures within the region have been constructed with maximum energy efficiency, including advanced lighting and appliances. Furthermore, each building is designed to be an optimized, renewable distributed-generation system. Solar photovoltaic materials (including roofing, windows, paint, and building materials), micro-hydropower within water pipes, and small wind turbines are part of the overall building design and construction, with requirements to maximize these features codified in building regulations. Smart controls regulate these generation devices to automatically accommodate the energy use needs of the residents. Other energy-saving measures, such as solar water heating, solar shading, and both natural and artificial airflow, are also widely used. This has resulted in net-zero-energy buildings that produce as much power as they consume on an annual basis.

The second energy production source is the RMC itself, which stores excess power from the micro-grid in batteries or converts it into hydrogen. When the micro-grid needs power, the RMC dispatches electricity from its energy storage devices or draws power from the fuel cells of the stored PMVs. The RMC also has other sustainable energy sources given its integration with the waste and water systems. The waste materials provide biological feedstock for hydrogen production as well as methane that can be reformed into hydrogen. The throughput of water allows for the installation of inner pipe hydropower systems within the water trunk lines. Pumped water, stored in the rooftop of the RMC, is heated with solar energy, and is also used to increase the micro-hydropower production. Finally, the RMC is equipped with computing technologies that allow it not only to manage the micro-grid electricity, water, waste, and transportation flows but also to maximize the RMC interaction with other RMCs within the Supernetwork.

The third source of energy for the region is remote electricity production that is sent via superconducting power lines to the Supernetwork. There are many sustainable and renewable electricity production sources outside of the neighborhoods and villages. Just offshore, the vast potential power of the ocean is harnessed through tidal, wave and ocean thermal technologies. Inland areas of the region also provide sustainable electricity generation with wind farms in the mountains and solar farms and geothermal facilities in the desert to the east. Outside of the Greater San Diego-Tijuana Region, sustainable energy such as fusion, solar and wind, and hydrogen-based electricity are available from the North American Energy Security Grid – a superconducting grid that ensures energy supply to the North American Free Trade Area.

Along with the shift in energy supply, energy delivery methods have also radically changed. There are now three distinct forms of electricity delivery in the region. Small energy consumption devices, such as appliances and portable electronics, require so little energy that they are able to operate on wireless energy, based on the concept of wireless communication. The RMC transmits packets of stable potential energy that are converted into usable energy to power these devices. This breakthrough in technology eliminated the need for portable energy sources and home and street wiring for lights or appliances. The wireless energy is supplied by the RMC, which recoups its costs via a monthly energy user fee. The second form of electricity delivery is the micro-grid itself, which connects all buildings in the neighborhood to each other and to the RMC. This micro grid operates to maximize the efficiency of renewable energy before calling on other sustainable energy technologies. Finally, superconducting power lines of the Supernetwork link all RMCs to each other and to remote electricity sources, for a third means of energy delivery.

Hydrogen, the secondary fuel of the region, is used primarily to fuel the transportation system, some niche industrial applications, and for energy storage. It is obtained by electrolysis, reforming, and biological creation. Excess power from the micro-grid is collected by the RMC and used to recharge batteries or to electrolyze water into hydrogen. The waste collection process of the RMC captures methane from organic wastes. This methane is reformed into hydrogen at the RMC to fuel the transportation fleet or produce electrical power. Biotechnology breakthroughs have developed processes of hydrogen creation that utilize genetically engineered microorganisms.

The emergence of local energy production technologies had a huge impact on the economy of Tijuana and its adjacent communities. Superior worker capability, resulting from investments in vocational technology training and technical education in the previous century, enabled these communities to become the dominant market force within NAFTA's new sustainable energy economy. Interestingly, Tijuana's concentration on sustainable energy services also linked it to the concentration on biotechnology in the northern part of the Region. The UTC-Sorrento and Tijuana-IBZ city centers both benefited from the successful bioengineering research and development (R&D) efforts by San Diego and Tijuana universities to produce hydrogen from genetically modified organisms. Similarly, their focus on energy crop development and enhanced biomass conversion to hydrogen through bioengineering played a key role in the entire region's emergence as an internationally known leader in sustainable energy resources and innovation.

The integration of energy and spatial design also helped ease the merging of Tijuana and San Diego into the unified region it is in 2103 and contributed significantly to the economic convergence of Tijuana and San Diego. Through capital investment and high-skill manufacturing of energy products and other advanced technology, Tijuana was able to significantly enhance its income levels and tax base to support public infrastructure and services expenditures.

The current sustainable energy system has provided zero-emission, abundant, reliable, and relatively inexpensive energy since the 2070s. Further, this system has enabled the region to become largely energy independent and fully integrated, north and south, as one sustainable energy market bridging the border.

Sustainable Water Supply and Wastewater Management

In 2103, the region enjoys an adequate supply of potable water as a result of water conservation by households, businesses, landscaping, and agriculture, as well as through water reuse and desalination. By 2103, per-capita use in San Diego was 50% of levels of a century earlier. Tijuana's per-capita use, already low in 2003, declined slightly over the century. Less than 100 years earlier, as much as 95% of the region's water supply was from the Colorado River and other distant sources, and that supply was threatened by declining quality, ecological concerns, and competing uses. Saltwater desalination technologies now are not only economically feasible for the region, but are, along with its sustainable energy resource technologies and services, among the region's most important exports.

Super-efficient desalination plants are also able to produce their own power. Advances in capacitive deionization filtration, membrane-based seawater treatment technologies, and systems miniaturization greatly reduced the energy requirements of desalination. Highly efficient photovoltaic systems allow desalination to be powered primarily by solar electricity produced at the site of the desalination plant. Seawater is pumped from the ocean to inland distribution centers that forward the supply on to the RMCs where it is processed, and the only waste associated with these systems is concentrated salt. Fortunately, this salt has a variety of industrial uses and is mined for valuable materials.

Potable water also comes from the reclamation of urban wastewater in the RMC. Advanced treatment technologies and system miniaturization mean that all water from homes and offices can now be recaptured and reused. Black wastewater (water contaminated by sanitary solids) streams received at the RMC are sent to an anaerobic treatment system that produces a sludge gas consisting of methane (60%), carbon dioxide (20%), and hydrogen (20%) from hydrogen-producing micro-organisms. While the carbon dioxide is sequestered, the methane is used in the vitrifying of organic sludge and also sent to a reforming unit to produce hydrogen for use in fuel cell power generation units and for the PMV system. Grey wastewater streams are electrolyzed to produce additional hydrogen for these systems and pure oxygen for the wastewater sludge decontamination and vitrification process. This process requires no auxiliary energy beyond the initial methane-fueled ignition of the sludge melter, as the organic solids in the sludge maintain the combustion process. The intense heat of the melter transforms the sludge into molten glass, which is then quenched in water, fragmenting the mass into a glass aggregate for use as an additive for a variety of industrial and construction materials. After advanced tertiary treatment, the remaining wastewater is integrated with the desalination process to produce potable water supplies for neighborhood communities. (See Appendix 2)

This recovery technology and reuse practice proves to be more sustainable than the use of sewage treatment sludge as land surface fertilizers, because the new practices permanently remove trace metals and salt from the food chain. They have also eliminated the need for landfill disposal of pathogens and metal-contaminated sludge. These integrated water treatment and energy resource technologies are also found in RMCs serving the industrial centers that require extremely pure water for the electronic manufacturing, biotechnology, and biogenetic industries.

The industrial RMCs replaced energy-inefficient point-of-use industrial pretreatment facilities and provided economies of scale and incentives for similar industries to co-locate within the region.

A critical component of the region's sustainable water resources strategy is water conservation. The conservation ethic among residents has been handed down from generations that date back to the early 2000s, when a crisis in water supply sparked a region-wide call to action. Common water conservation practices were integrated into building designs and included built-in devices to capture and channel rainfall to underground storm water cisterns that replaced old underground parking structures. The captured rainfall is used for landscape irrigation and potable water after treatment in the RMCs. On-site capture and use or treatment of rainfall has eliminated non-point source pollution in storm water runoff and has improved the quality of water in surface streams and the near shore marine areas. Native drought-tolerant plant species and turf varieties dominate public plantings and other landscaping in the region.

The Obsolescence of Waste

In the Greater San Diego-Tijuana Region, landfill-bound solid waste has been reduced to a trickle. Practically every physical commodity is recycled into its constituent components and reused in some fashion. This is due to product engineering that ensures reuse and recyclability of end products. It is also due to manufacturing processes that eliminate or minimize waste and pollution.

A significant economic activity of IBZ is this "green" design and engineering. New products and materials are designed, engineered, and produced in its Eco Business Park, not only for regional use, but also for export to national and international markets. Companies are aggregated in the Eco Business Park so that waste from some manufacturing processes is used as feedstock for other processes.

Following practices that began in the 1990s, many products for homes and businesses – such as carpets – are not purchased but are leased from manufacturers. The advantage of this system is that the manufacturers build products for durability to provide long service and recyclability. The purchase price of many durable goods such as large appliances now includes the cost of manufacturers' take-back programs that enable them to refurbish or recycle appliances at the end of their useful lives.

Products that are not recycled through manufacturers' take-back and leasing programs, along with packaging materials, are collected for composting either at the neighborhood or village level. Of course, all of these non-recyclables, such as wood resin liquid containers and fiber packaging with organic ink, must meet the regional sustainable production code that ensures their composition is, in fact, biodegradable in a specified period of time so as to be useful to the neighborhoods and villages. Products that do not meet these standards are taxed to pay for ultimate disposal. These products include hazardous waste that cannot be eliminated through design and pollution prevention techniques and that must be processed and confined in safe disposal sites.

Economic Integration and Sustainable Development

The significant changes to the Binational Metropolitan Region over the 21st century were driven by the expansion of the regional and global economies. As national economies became incorporated into regional economic blocs such as NAFTA and the EU, regions such as San Diego-Tijuana came to compete on a global scale with other regional economies. In 2003, the Binational Metropolitan Region was the 20th largest economy in the world, with more than $135.7 billion in economic activity. San Diego's economy was then based on high tech R&D industries (biotechnology, digital imaging, computer software, wireless communications, etc.), tourism, defense, and business services. Tijuana's economy was based on manufacturing, tourism, and services. Tijuana, for example, produced 25% of all the television sets sold in the NAFTA market. Although significant economic asymmetries, as seen in wage differentials, were present, there was a clear trend toward convergence of wage levels across the border. Beginning in the 1970s, and accelerating with free trade in the 1990s, by 2033 the differences between the two economies had been reduced to those seen within the European Union in 2000. By 2103 some wage differences remained between Tijuana and San Diego, but they were minimal and served to support complementary economic activities.

San Diego and Tijuana were able to use their different economic strengths and levels of development to enhance the global competitiveness of the region. The knowledge-based sectors of San Diego and the increasingly skilled industrial labor force and manufacturing expertise of Tijuana enabled the region to develop technologies, services, and products for the global marketplace. Through extension of San Diego financial markets to Tijuana, capital became available for the small and medium companies that are crucial in the supply chain for final products. The new economy that emerged in the Binational Metropolitan Region in the 21st century included sectors such as medical technologies, medical devices, biotechnology, digital media, wireless communication, environmental technologies and services, desalination technologies and services, sustainable energy technologies and services, and others. Throughout the century, the emphasis was on the creation of high-value-added jobs, so the tourism industry and other low-wage service sectors receded in relative importance in the regional economy.

This restructuring of the regional economy was accomplished through a number of locally generated initiatives. Local universities (San Diego State University; University of California; Autonomous University of Baja California; Technological Institute of Tijuana; Cetys University; and others), with the support of local governments, chambers of commerce, economic development organizations, and industrial and business organizations, launched a process to transfer technology from research universities to the private sector. An important component of this was to restructure research and teaching activities to support research, development, and training in the high-tech and high-value-added economic clusters.

A second locally generated effort involved restructuring of financial markets to serve Tijuana and San Diego for key activities such as small business loans, business incubator activities, and venture capital. This was particularly instrumental in providing start-up capital to small and medium firms in Tijuana that became a critical part of the supply chain for development and manufacturing of the high tech products. Many of these new products were those used in energy efficiency, desalination, and biotechnology. This local effort to reform financial markets required federal and state legislative and regulatory actions, but it was propelled by private investment capital.

This restructuring of the regional, binational economy accelerated the process of economic convergence and wealth creation at the local level on both sides of the border. In turn, this provided the tax base and private development investment capital to finance key components of the new urban design for the region. The significant economic growth in the century prior to

2103 became increasingly sustainable due to specific policies that encouraged clean energy, waste minimization, water reclamation and reuse, recycling, and protection of natural resources. These policies made economic sense and improved the bottom line of companies while minimizing the impact of economic and urban activities on the natural environment.

Sustainable Social and Governance Systems

In 2103, the San Diego-Tijuana Binational Metropolitan Region's governance is enabled by the influence of shared individual commitment to living a sustainable life. There is a broad consensus among the stakeholders of the region regarding the principles of sustainability that have guided development of the Region over the past 100 years. A widely shared value in participatory governance is most clearly seen at the village level, where sense of community and sense of place are articulated.

The prosperous economy that emerged in the 21st century emphasized creation of knowledge-based industries and high-skill, high-value-added jobs in both the manufacturing and services sectors. This significantly improved income distribution spread prosperity widely among the population and largely eliminated the large class of working poor that characterized the San Diego-Tijuana Region in 2003. The economic engine of the region has created an expanded tax base, providing the financial resources for the new urban infrastructure and redevelopment efforts. The highly productive economy also supported enhancement of urban and social services that improved prosperity and quality of life for all citizens of the region. These services, by 2103, included:

- Efficient and low-cost transportation available to all;
- Parks, recreation areas, green areas, and natural areas for the benefit of all residents;
- Environmental protection and enhancement;
- Affordable and adequate housing for low-income residents;
- A mixed public-private health care system, that reduced costs per capita, significantly improved the health of the population, and retained flexibility and choice;
- An integrated system of education that focused on producing skilled and productive citizens for the region. College, university, and technical education emphasized linkages with the regional economy, developing individuals with skills and knowledge in technical areas, management, and R&D. The formation of human capital became clearly linked to the region's economic and social needs.

The improved healthcare system has also been aided by advances in medical technology, which have extended the average life expectancy well into the late 90s. Home health diagnostic kits began to enter the market during the first part of the 21st century. Low cost, self-administered, and readily available home diagnostics soon evolved into self-help "Medcafes," where residents could access large databases to compare the results of their own tests to those of millions of others. Once diagnosed, an individual could then enter a pharmaceutical code into a system that would dispense the required medicine for an ailment. Traditional doctors and hospitals continue to exist for trauma and extreme medical conditions. The advent of home diagnostics and neighborhood Medcafes has also reduced the need for transportation to medical centers, which was a common practice for thousands of people in 2003.

By 2103, systems of governance in the trans-border region had undergone a remarkable evolution. The increasing scale and complexity of the Binational Metropolitan Region forced region-widespread cooperation to address problems and issues that affected the entire region. This first occurred within San Diego County and then spanned the international border to link with Tijuana in common governance efforts. In 2103, Tijuana has a distinct regional government supplemented by city and village councils and San Diego County has a broad regional government supplemented by city and village councils. This duality of local government preserves local traditions and cultures, yet it allows for regional trans-border collaboration to address regional needs and opportunities in an efficient and timely fashion. Boundary-spanning governance functions are carried out by a series of commissions staffed by personnel designated by San Diego and Tijuana local governments. These commissions have emerged around specific functions such as land use planning, urban service delivery (water, wastewater, energy, and solid waste), and transportation. National and state level representatives to these commissions address issues relating to sovereignty and provide liaison with state and federal agencies.

Sustainable Environment

Despite the addition of millions of people to the region by 2103, the region's environment has improved measurably from a century earlier. The San Diego-Tijuana Binational Metropolitan Region of 2103 enjoys clean surface water and groundwater, clean air, clean beaches and uncontaminated soils. Production of greenhouse gasses, particularly carbon dioxide (CO_2), has been brought under control by the new sustainable energy sources, particularly those used for transportation. Restoration of ecosystems and adequate water for natural vegetation has increased carbon fixation in the region as well. Thus, the Binational Metropolitan Region is participating actively and successfully in global efforts to reduce greenhouse gas emissions and has met the internationally recommended limits. The near-shore marine environment is uncontaminated by land-based sources of pollution and produces a sustainable harvest of marine flora and fauna.

A vigorous conservation, protection, and restoration program for critical habitats and species began in San Diego and spread to Tijuana. As a result, the region's flora, fauna, and all natural resources are in excellent, stable condition. Advancement of the region's sustainability agenda over the preceding century resulted in significant gains in the preservation of habitats and species and protection of open space for recreation. Residents are able to easily access protected areas and open spaces as they are interwoven among all land uses across the Region and serviced by an efficient and flexible transportation system. Management practices encourage direct contact with natural areas through hiking trails, interpretive centers and trails, and picnic areas. This approach is more in tune with the view of nature held by indigenous peoples of the region, rather than typical approaches in the United States in 2003 that advocated separating people and nature.

EVOLUTIONARY ROAD MAP

Introduction

The previous section of this design described a vision for the region in 2103, 100 years into the future. Necessarily, its content is based on speculative notions about how society and technology would develop over the intervening years. This section of the design utilizes that ideal vision as a cardinal compass point – a true North – upon which to chart the evolution of the region to a fully sustainable metropolitan community. Specifically, we suggest scenarios and important benchmarks for key aspects of the Binational Metropolitan Region's progress toward a sustainable urban design. Important achievements and processes – such as society, governance, economy, land use and urban design, energy, transportation, water, and environment – will be noted for each planning period.

There were a number of basic conditions and forces in the San Diego-Tijuana Binational Metropolitan Region of 2003 that became drivers for the change and sustainability that characterized the region a century later in 2103. Part I, Regional Overview, of this design outlined a number of conditions and drivers that had set the region on the path to an unsustainable and declining quality of life. Rapidly growing human population and urban sprawl, water and air pollution, endangered species and habitats, greenhouse gases and global climate change, energy and water crises, increasing congestion in the transportation sector, an unsustainable economy and inequality, a housing crisis, and significant trans-border economic asymmetries all marked a downward trend in livability and sustainability in the Binational Metropolitan Region.

The relatively rapid deterioration in conditions that was well documented by research and well known by different stakeholder groups helped forge a broad political consensus that set the region on the path to sustainability. Stakeholders were able to look back 30-50 years to appreciate how much and how rapidly the quality of life had declined. This helped shape a vision of what the region should be in the future and provided stimulus for immediate action. The action plan for achieving a sustainable Binational Metropolitan Region was accomplished through strategies and concrete actions visualized in planning and implementation periods of roughly 30-35 years. Key actions included public-private partnerships, tax and regulatory incentives, and education and technical support, among others. For most people in the binational community, plans for 100 years in the future did not have much meaning. Instead, a planning horizon of a third of a century was more realistic since many individuals and all of their children would experience the results of efforts at that temporal scale.

The region, then, moved forward to achieve the vision for 2103 in planning periods that were approximately 1/3 of a century each. The evolution of the region was a complex process characterized by simultaneous and interdependent movement and change on many fronts. For example, a strong economy was needed to support transportation developments that were required to implement increased densification and accommodate a growing population. This, in turn, enabled the protection of parks, open spaces, sensitive ecosystems, and habitats. The integration of innovative energy and environmental technologies ultimately supported all of these developments.

Planning Period I, *ca* 2003 to *ca* 2036

Society and Governance I. Deteriorating quality of life encourages stakeholders to forge a broad consensus in the Binational Metropolitan Region to create a 100-year vision and begin concrete steps to implement that vision. The strategic vision is the result of actions by local governments, universities, the private sector, and stakeholder groups that represent the larger society. Formal and informal education begins to focus on basic citizenship skills, technical and scientific education, and sustainability science. The San Diego primary and secondary education systems begin universal Spanish language instruction and the Tijuana counterpart does the same with English. The university systems begin to offer joint undergraduate and graduate courses of study in a range of subjects that include public administration, criminal justice, law, social work, energy management, environmental management, business administration, economics, history, and others. Technical education is enhanced and closely linked with regional needs of business and government. University R&D programs in technology and applications for the future are linked to regional needs and coordinated.

Building on existing cross-border collaboration between government and nongovernmental entities, new multilevel governmental collaborations develop and/or become stronger in areas such as urban planning, transportation planning, water supply and delivery, wastewater treatment, and integrated waste management. These government-to-government collaborative ventures are strengthened as Mexico's governance structure decentralizes and Tijuana acquires more financial resources. At the same time, San Diego County begins consolidating government services and functions to serve the entire county in order to reduce the fragmented nature of the existing local government.

Economy I. Analysis of the binational economy by public and private sector agencies and local universities concludes that the combination of knowledge-based activities and increasingly sophisticated manufacturing expertise in Tijuana offers Tijuana the best opportunities to compete in the global economy. This approach links R&D efforts of local universities with venture capital, engineering, and manufacturing to develop new technologies, products, and services for the regional and global marketplace. These areas include energy, pollution prevention, wastewater treatment and desalination, transportation, and biotechnology products and services. Financial markets are integrated across the border to set the stage for economic integration and convergence.

Land Use and Urban Design I. With the adoption of this design and support of the region's constituents, the region witnesses the first building blocks of the entire system in the first 33-year period. This occurs through the gradual rebuilding and densification of the existing central business districts, commercial corridors, and neighborhoods within the region, upon which many of the future extended urban zones are to develop. Urban planners also lay out future settlement zones and begin to build spatial design concepts to bridge them to the existing energy and transportation infrastructure and to the actual regional growth plans for these systems. In all, four urban zones in the Binational Metropolitan Region emerge, centered on the cities of Escondido, Tijuana, downtown San Diego, and the UTC-Sorrento Mesa area.

Three of the zones – Escondido, UTC-Sorrento Mesa, and San Diego – experience the first attempts to combine transit with redevelopment of their underutilized lands. Kearny Mesa, a secondary city within the UTC-Sorrento Mesa zone, is rebuilt during this period to demonstrate and refine the efficiencies of systems integration, to gain further public approval, and to obtain necessary funding to pursue the development of subsequent zone settlements. Additional redevelopment occurs in the downtown areas of Escondido and San Diego. Downtown San Diego and its supporting city centers are the first to successfully integrate this redevelopment land use and transit strategy.

The IBZ also provides an opportunity to explore culturally distinct and appropriate approaches to affordable housing and new building design and construction practices. Transit-related redevelopment occurs in San Ysidro, while new development occurs in areas south and east of Tijuana. During this period, local, state, and federal governments begin discussions and preliminary planning of the IBZ in cooperation with private development companies and financial institutions. Additionally, regional general plans identify and guide future development into 60 targeted urbanized areas that can support further investment in the regional transit system.

Energy I. Reliance on imported energy supplies, a burgeoning population, and integration with Tijuana demand that the region first reduce its per capita energy use and then develop more local energy supplies. During this first planning period, there are significant reductions in per capita energy use. Energy supply largely remains imported natural gas, oil, and electric power, but the growth of these imports slows. Consumption eventually peaks and then begins to fall. Legislation that promotes the penetration of energy savings devices is enacted. Gasoline use – higher than any other energy source – is reduced by mandates and incentives for hybrid, alternative fuel, and zero emission vehicles. Road congestion control and rerouting strategies also help to decrease regional gasoline consumption. Growth in power use is slowed through new pricing, including time-of-use rates, and widespread implementation of energy-efficient technologies, such as LED lighting, advanced appliances, and peak load management. Efficiencies in heating and industrial processes slow the growth in natural gas demand, but increases in regional power generation and alternative fuel vehicles lead to an overall increase in natural gas use.

Within this period, demand for indigenous energy supplies increases. The region naturally looks to solar, wind, and methane recovery, but the supply is minimal compared to energy needs. To supplement local energy supplies and improve security, the region incorporates distributed generation – mostly natural gas fired – in its long-term energy planning. Utilities incorporate on-site distributed energy technologies to moderate peak power demand and further decrease grid demand and increase overall grid efficiency. This increase in the use of distributed energy systems spurs the development of facilities that combine energy generation and district heating and cooling. These facilities eventually evolve into the RMCs widely used in 2103. Still, significant carbon dioxide emissions persist, raising concerns about global climate change. As a result of these concerns, cap-and-trade regulations are enacted. These regulations lead to the creation of a market for CO_2 emission credits and lead to financial value being ascribed to the emissions, based on the cost of alternative control technologies.

Transportation I. In consort with the development of new land use and energy systems, transportation technologies are developed and deployed. During the first planning period, the region witnesses the development of the interurban high-speed rail system, the intraurban Flex Trolley system, and the dedicated private PMV infrastructure. The necessary rights-of-way are acquired and infrastructure for the high-speed rail and Regional Rapid Express (RRE) are constructed to allow the systems to be operable by the second half of the period. Additionally, the implementation of the Local Express Flex Trolleys and Tramways begin on existing roadways (Figure 18). New city developments, such as Kearny Mesa and the IBZ, enable the systems to be implemented more quickly and serve as further evidence of the systems' efficiency. At the same time, the transit system is introduced into Chula Vista Eastern Urban Center, San Ysidro, Otay Mesa, and East Otay Mesa.

During the first period, the Feeder Systems and neighborhood shuttle systems are developed where the necessary infrastructure becomes available. Elsewhere in the region, the first planning period witnesses the region-wide replacement of traditional internal combustion automobiles by hybrid vehicles from the United States, Japan, Korea, Brazil, Europe, and China. The simultaneous development of additional synthetic fossil and agrifuels complements this new automotive technology boom, as do the first commercially available fuel cell energized vehicles.

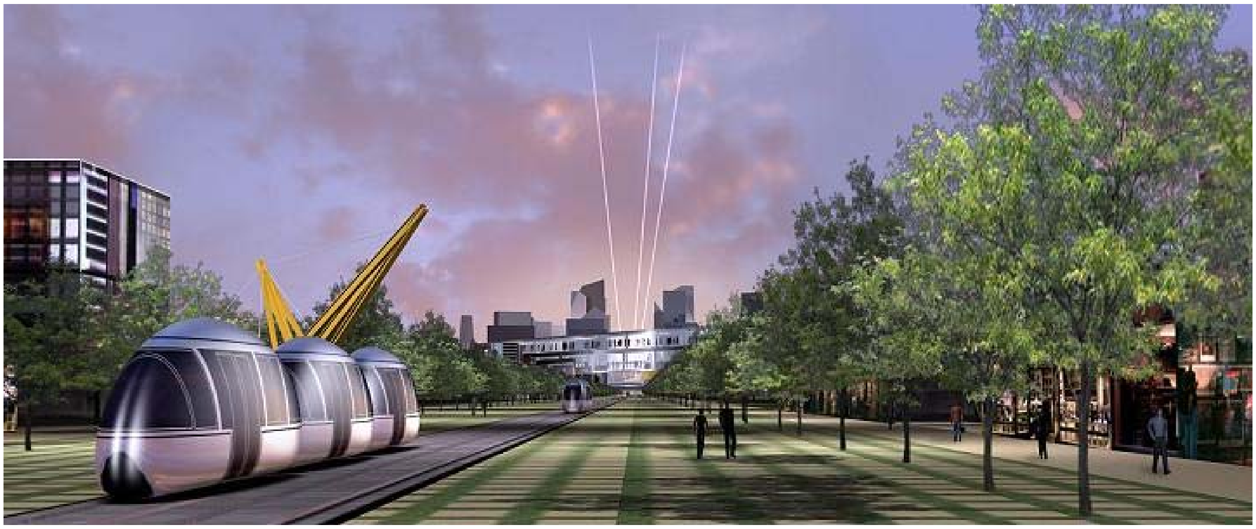


Figure 18: Local Express Flex Trolleys

Although the fleet of private vehicles is cleaner, it is also larger, and, as a result, there is a widespread use of congestion pricing for vehicle corridor access. Other economic disincentive mechanisms to curb private vehicle use and encourage transit use also develop. This is the period in which advances in commercial truck technologies and freight handling reduce both their numbers and their associated air emissions. More specifically, the development of regional railroad connections to seaports, airports, and transit terminals on the outer edge of the region will facilitate these reductions.

These new systems are financed by a combination of transportation fuel taxes and fees, public bonds, public-private mass transit projects, and private concession infrastructure for leasing equipment.

Water I. Perhaps the single greatest technological triumph the region will experience by the 22nd century is the development of a sustainable, regionally sourced, potable water supply. This is made possible by the desalination of its saltwater resources.

The first critical step toward this future state comes in the first planning period when an educational campaign informs and engages the public's interest in increased water conservation and reclamation practices. Simultaneously, the region begins to receive conserved agricultural water from a pipeline just east of its regional boundaries in the Imperial Valley. This temporary water resource is to provide potable water to San Diego County through 2078. This supply amounts to 20% of the demand for this area; the balance is comprised of other imported waters (60%) and local supplies, including recycled water and the first increments from desalination plants. The southern portion of the region – south of the border – continues to rely on imported Colorado River water and indigenous resources during most of this first planning period. Finally, the refinement of desalination technology is more easily utilized in Baja California due to lower installation and maintenance costs, and the technologies become a commercial export of the region.

Environment I. Global warming has been a concern of the San Diego-Tijuana Binational Metropolitan Region since the early 1990s. Although consensus among the scientific community was lacking at the beginning of the 21st century, projections at the time suggested as much as a 3^{o}C increase in surface temperature, and a 33-48 cm rise in sea level in the region by 2100. Beginning in 1994, the City of San Diego launched a variety of initiatives to address this concern, and, by 2001, greenhouse gas emissions were reduced by 83,000 tons. In Tijuana, CO_2 reduction was not aggressively pursued because the average Mexican citizen was responsible for only 1/3 as much per-capita CO_2 emissions as a citizen of the United States.

During the first planning period, continued energy efficiency and advances in physical, chemical, and biological carbon dioxide sequestration technologies lower the overall carbon dioxide emission intensity of the region. However, these gains are offset by increasing transportation-related emissions that account for 50% of all carbon dioxide emissions by 2030.

Planning Period II, *ca* 2037 to *ca* 2070

Society and Governance II. The primary, secondary, and higher education sectors of San Diego and Tijuana increasingly harmonize during the second two-thirds of the century with bilingual Spanish and English education adopted as the norm. Technical education as well as graduate education and pure and applied research programs are seamless across the international boundary and support the integrated economy of the region.

Consolidated government in San Diego County emerges during this period as the delivery of county-wide government services such as social services, water and sewerage, urban planning, and education becomes well established. This consolidation replaces the highly fragmented situation of 2003. Village and neighborhood councils emerge to address strictly local issues. Tijuana's local government, already providing services for the entire municipality, improves service delivery as federal powers devolve to the cities and local financial resources are improved through enhanced bonding capacity and revenue-generating ability through property and other taxes. The strengthening economy supports the considerable local investment required for improving government services. At the neighborhood level, local elected councils address a growing list of local issues such as zoning, parks, and social services delivery.

Across the international boundary, there is increasing collaboration between San Diego and Tijuana local agencies for functions such as water supply, wastewater treatment, transportation planning, and integrated solid waste management. These collaborations begin to acquire permanency as boundary-spanning agencies, with Mexican and U.S. sections that jointly make decisions but that report to the elected governments of San Diego County and Tijuana.

Economy II. Increasingly, the knowledge-based and financial market resources of San Diego are integrated with the advancing sophistication of the manufacturing sector of Tijuana. The financial markets of the region are integrated, providing start-up capital for small and medium firms in Tijuana that are key in the emerging high technology sectors. Due to the creation of high-value-added jobs in Tijuana, wage levels improve significantly. The successful link between San Diego and Tijuana university R&D and high-technology product and service development is strengthened.

Land Use and Urban Design II. During the second planning period, the population growth rate has peaked, but the population continues to grow within the first 30 of the 60 planned urbanized areas in the region. Construction of the new IBZ primary cities is now well underway (Figures 19, 20, and 21). The implementation of the multi-tiered urban design is now widely applied and gaining momentum. The necessary zoning and general plans within each of the four zones are updated to ensure consistent development across the region. The San Diego

International Airport is relocated from its former location near the Central Business District of San Diego to a location at Kearney Mesa, as decided by the community during the first planning period. Additionally, redevelopment within the urban areas of the region is directly tied to the transit plan. The most important land use planning achievement of this period is the concentration of new development into existing neighborhoods, which has been enabled through new policy and regulation as well as incentives for private developers.

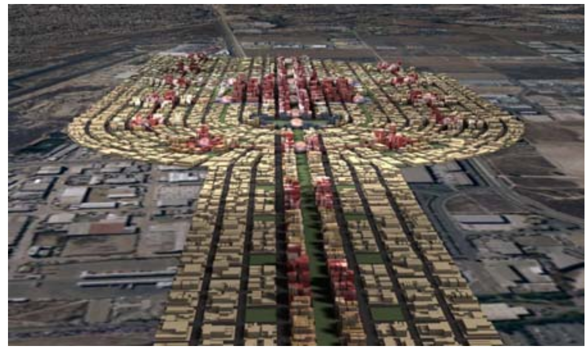


Figure 19: Aerial Approach to IBZ Central Business District

Energy II. During the second planning period, stakeholder consensus and government action toward sustainability further reduce energy intensity and advance the use of renewable energy technologies. The trend of increased energy efficiency continues, and the rewards become evident as the capital stock of vehicles and buildings turn over and energy intensity continues to fall. Research and investment have developed renewable energy sources at a scale to compete economically with traditional energy forms.

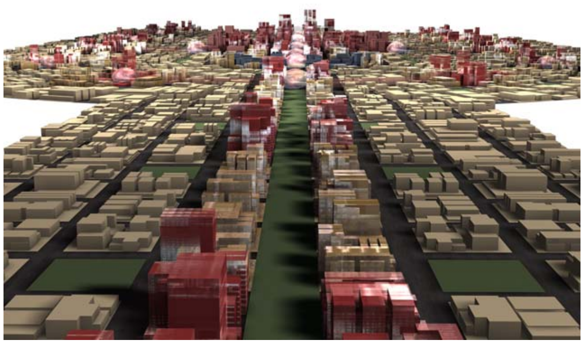


Figure 20: IBZ Central Business District – Primary Corridor

Solar, wind, and methane recovery from wastewater treatment plants, landfills, and farms now provide much of the energy in the region. Hydrogen also emerges during this period, but its use is limited due to continued storage and piping requirements and safety concerns. Photovoltaic (PV) solar cells are now integrated into building systems such as roofs, windows, driveways, and even some exterior wall paints, with the result that most buildings produce as much energy as they use. Around 2060, central power infrastructure costs prove to be higher than the cost of distributed generation (DG) technologies, and transmission pipes and wires begin to disappear.

Significantly reduced peak and base-load demand leaves few large energy consumers, forcing energy utilities to rethink and diversify their business models. They begin to work with the building materials, design, and construction industries to more fully integrate energy producing technologies into building materials and systems, and they participate in the development of micro-grids to aggregate and flatten their energy loads. Utilities begin to shape themselves as service providers, offering energy, telecommunication, video, and other home services.

Figure 21: IBZ Central Business District – Street Level

Fossil fuel usage continues to decline. The accelerated installation of renewable energy sources and carbon dioxide tax legislation drive this trend. The ocean becomes a source of energy as offshore wave, tidal, and ocean thermal power is harnessed and sent to the regional superconducting grid. The region is on the verge of creating a fully sustainable energy supply.

Transportation II. The second period brings about the region-wide implementation of the integrated transit systems and the rise of the PMV networks that connect the primary cities of the urban zones and the first 30 target settlement areas. The second period is most notable for the shift in transit mode from the hybrid automobile to an efficient region-wide transit network and gradual development of the PMV network. The hydrogen fuel-cell-based transit system between zones is now significantly developed and proves to be a more efficient means of travel than the private vehicle. Most importantly, the region's application of the new transit system has become a model of efficiency and has dramatically advanced the elimination of air emissions.

During the second planning period, there is a convergence of hybrid vehicle power plant and home energy system technologies that results in energy sharing between the two power platforms. This convergence results in a de-emphasis on the expansion of an alternative fueling infrastructure that supports private vehicles, which is further complemented by the wider-scale deployment of the PMV system across the region. Ultimately, the public transit system evolves to provide a majority of the region's trips.

Water II. During the second period, advances in desalination technologies, particularly high-speed filtration processes, results in the installation of 3-4 more saltwater filtration plants. Manufactured "fresh" potable drinking water then flows east to the community RMCs. Several water reclamation facilities associated with current sanitary systems also go into operation, providing reclaimed water for community gardens, residential and commercial landscapes, and the regional agricultural areas. A substantial reduction in energy consumption is realized as this occurs, as the production and delivery of water from these sources require only 1 kilowatt hour (kWh) per cubic meter (m^3) or less, as contrasted to 2.6 kWh per m^3 for imported water supplies from Northern California.

Environment II. During the second planning period, the shift to renewable and natural gas energy sources and further advances in carbon dioxide sequestration technology produce acceptable levels of point-source emissions. However, the increasing number of mobile sources remains a challenge, despite increasingly strict emission standards and the dominance of lower emission hybrid vehicles on the market. Transportation accounts for 75% of all emissions and hastens the rapid commercialization of hydrogen fuel cell vehicles and advanced electric battery vehicles.

Planning Period III, *ca* 2071 to *ca* 2103

Society and Governance III. During the third planning period, local government consists of local representative councils, a unified San Diego government, and a unified Tijuana government. The boundary-spanning commissions that began to emerge earlier in the century through trans-border cooperation on specific issues and tasks are consolidated and institutionalized. The commissions have single or multi-purpose functions such as regional transportation, land-use planning, water and wastewater, energy, and social services delivery. They are overseen by the elected governments of San Diego and Tijuana and have appropriate federal and state representatives.

Economy III. Wage levels in San Diego and Tijuana have now converged. The economic base is supported by advanced technology products and services related to the environment, transportation, energy, biotechnology, and desalination. The university-industry link based on targeted education and focused R&D is critical to continuing the strong technological base of the regional economy.

Land Use and Urban Design III. The final period includes the refinement of the urban design incorporating emerging technologies and accommodating the subsequent population growth of the region. Within the urban design, the four zones and their respective primary cities have become fully established, including the new IBZ primary cities that become identified as physical symbols of the region's reputation as a center for sustainable urban system design. The public transit network has guided development along strategic corridors and centers. Each neighborhood and village is completed, with access to all civic, commercial, employment, and educational centers within walking distance or a short ride on the transit system. The urban design has successfully created affordable housing and complementary employment opportunities for all the residents of the region.

Energy III. In the 21st century, the region dramatically reduced energy consumption through energy efficiency and increased regional renewable energy production. By the 22nd century, fossil fuels in the region are finally abandoned in favor of renewable fuels and hydrogen. Additionally, R&D has made fusion energy and limited low voltage wireless energy distribution systems feasible in this planning period. The only imported energy is renewable energy supplied from remote areas within the region as well as fusion, hydrogen from coal and other fossil fuels, and other renewable energy imported to the region via the National Energy Security Grid. Hydrogen has emerged as the portable energy of choice, and electricity is the sole energy source within homes. Renewably derived hydrogen or stored electricity powers all vehicles, resulting in zero-emission travel. The region has evolved from a mega-city into a series of self-reliant communities. Each has its own micro-grid that has integrated all community energy systems. Utilities have expanded their service offerings to include energy, transportation, waste removal, and water supply.

Transportation III. By the end of the final planning period, all 60 targeted settlement areas are now serviced by the PMV system; the hydrogen–fuel-cell-based transit system has also been completed. Transportation-related air emissions have been reduced to practically zero.

Water III. During the final period, the region becomes entirely self-reliant on its desalination and reclamation facilities for all of its potable water needs. Technological advances (such as miniaturization, membrane, and advanced treatment techniques) allow for the decentralization of processing and commingling of waters at multiple levels of treatment within the community and industrial RMCs. Mexico no longer relies on the Colorado River and does not need to draw down its indigenous reserves. Water now flows as freely as people and capital across the border of the fully unified metropolitan region.

Environment III. During the first half of the third planning period, the impact of the sustainable land use plan and the public and private mobility systems begin to produce significant results in the reduction of CO_2 emissions. The successful implementation of the plan adds substantial amounts of green space to the region, and this green space functions as a carbon dioxide sink during most of the year, and, by 2090, the regional goal of 1 metric ton of CO_2 per person is met. As the new paradigm of village living matures, and the latest, sustainable technologies reach

100% penetration, the regional governments set and reach a new target of zero net CO_2 emissions by 2103.

CONCLUSION

Sustainability of the San Diego-Tijuana Binational Metropolitan Region of 2103 will come about because of the current recognition that, without a binational consensus combined with likely technology improvements, quality of life will continue to decline in this rapidly growing area. Fortunately, broad public recognition of the crisis, synergistically combined with new developments in renewable resources and energy efficiencies, will make this vision achievable.

The consensus of stakeholders in the Binational Metropolitan Region provides the political will and direction for policy decisions that will move the region in the appropriate direction for evolution of: the new urban design and building systems; innovative transportation systems; new solutions for water, wastewater, and solid and hazardous waste issues; a new energy system; and delivery of urban, social, and health services. These same policy decisions will move the region into a process of sustainable economic development, based on synergies of the Mexican and U.S. portions of the regional economy that emphasize R&D and advanced technology and services, as well as skilled labor and manufacturing capabilities of the region. The emphasis on sustainable development and the creation of high-value added jobs will improve per capita income levels and will reduce economic asymmetries across the international boundary. At the same time, the regional economy will be competitive on a world scale and will provide the financial resources through private capital and public investment required for the sustainable region of 2103. The region will achieve full integration of capital and labor and collaborative governance across the international border. In this manner, the incremental implementation over the coming decades of innovative systems, technologies, and policies across multiple sectors will culminate in sweeping changes and long-term sustainability for a region that is now confronting many challenges

VI. STRATEGIC PLANNING FRAMEWORK & ACTIONS FOR URBAN SUSTAINABILITY

Section VI completes the model design with a framework for strategic urban planning and set of immediate actions all communities can take to become more sustainable today.

The preceding sections have suggested that historical urban development patterns in America are inherently unsustainable, and that through ecological urban design and the deployment of more efficient urban infrastructure technologies, our communities can become more sustainable. This section now turns to the broader institutional context within which urban design and infrastructure technologies become mechanisms for achieving a community's vision of a sustainable future. This broader context entails the comprehensive community planning process that moves from strategic vision, goals and objectives through to specific tactics, timing and resources necessary for effective implementation. The basic requirements for effective planning are provided below, followed by a description of the process phases and outputs.

Leadership. Perhaps the single most important factor in a successful planning initiative is a fully committed "Champion" or leader. Ideally, this should be one of the community's top elected government officials or a prominent civic leader. This individual must enjoy the respect of their narrower community (i.e. their own business or social circle) and possess the skills and abilities necessary to communicate the essential relevance of sustainability to the larger community. Additionally, this person must be able to build bridges between communities and enable them to realize they all share a common future.

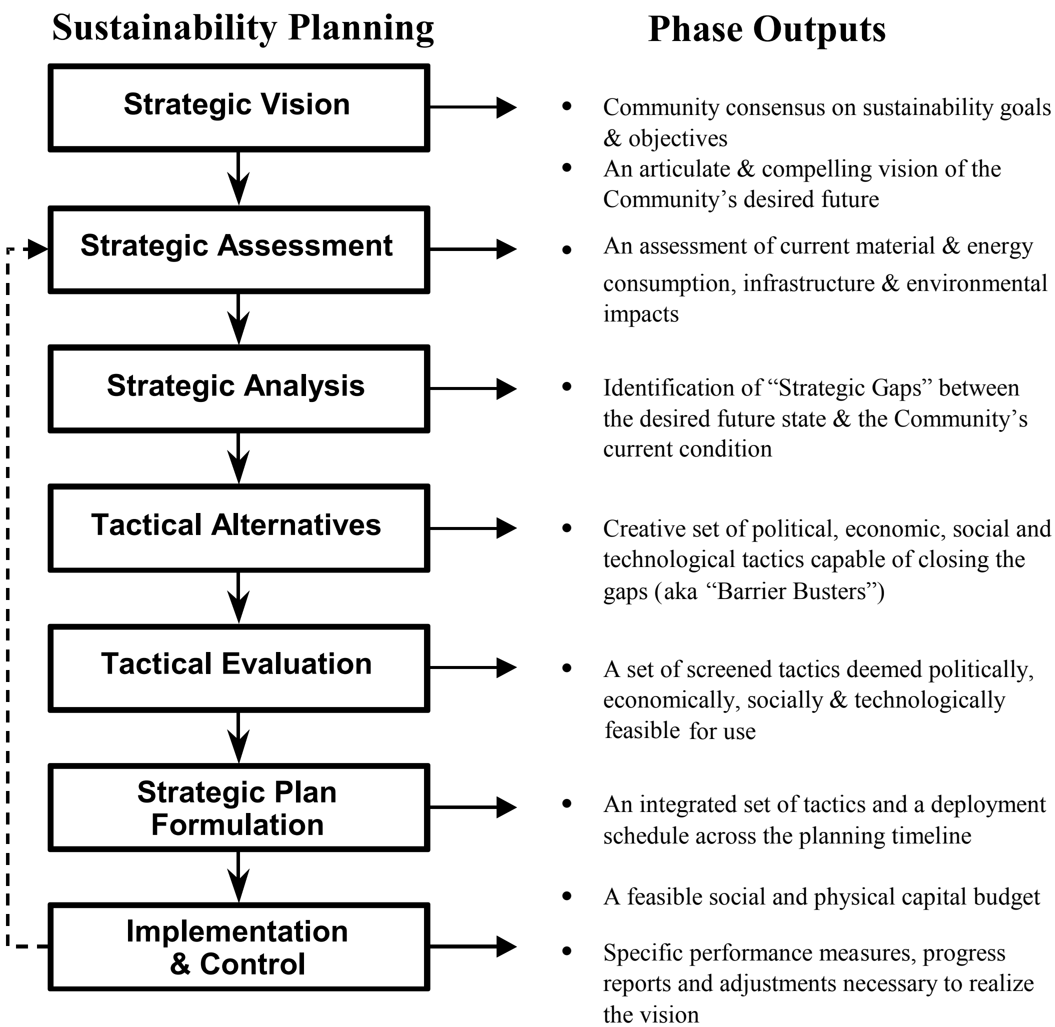
Participation. There must be broad-based community participation. All-inclusive community participation is not required during every phase or at every step in the strategic planning process. Rather, this participation is necessary at pivotal points where an expression of a community's full range of interest is necessary to stake out the boundaries within which consensus is possible. All community members consume material and energy resources and therefore, all must ultimately play a role in the success of the community's effort to achieve sustainability. From a practical perspective, this will entail the targeted participation of discrete community interest and advocacy groups; commercial business; utility and industry organizations; academic, institutional and governmental entities. Obtaining input from these specific groups can be achieved through surveys, focus groups, and interviews. Additionally, community hearings for the general public should be incorporated at strategic points during the consensus-building process, and ultimately referenda should be held to adopt the community's sustainability agenda.

Consensus. The ultimate objective of broad community participation in any planning process is the generation of consensus. Arriving at consensus is an art form in a diverse community, particularly over issues that have been historically viewed as mutually exclusive (e.g.: economic development versus environmental quality). Fortunately, the concept and localized practice of sustainable development proves that these two community objectives can and should be mutually supportive.

The generation of consensus at the beginning of a strategic planning process should focus on what a community wants to achieve, not on how it is to be accomplished. A premature focus on methods (means before ends) is the single greatest error made in consensus building. Once general agreement is reached with regard to the community's future vision, how they move towards it is a matter of collective and creative choice. A variety of structured group processes exist, and these enable communities to define areas of maximum agreement, isolate disagreements, and use creative problem-solving techniques to overcome the disagreements. These processes are readily available and should be identified and used at the outset of the planning process.

Investments. Consensus is particularly important in order to obtain the public and private investments necessary to pursue sustainable community development. Large capital expenditures for alterations in energy technologies and delivery systems, and for alterations in land use and transportation development patterns all entail significant public investments and, therefore, broad public support. A smart investment approach in sustainable community building is to start small. Smaller pilot projects have manageable economic costs, and they can provide success stories that will facilitate future public and private investments.

Incentives. Clearly, a community's pursuit of a sustainable future will require compromises, tradeoffs, and what some may initially consider, sacrifices. In all of these cases, both individual and organizational incentives should be considered and included in the community's plan. Financial and convenience incentives are the most common incentives considered. Similarly, disincentives that target unsustainable practices also need to be included to guide a community towards more sustainable material and energy consumption practices.



Arguably, the most powerful incentives and disincentives take an economic form (e.g.: pricing structures for energy production and use; pricing for parking and access to roadways and mass transit; and community imposed costs for residential, commercial, and industrial development). Social convenience incentives and disincentives can also be used in urban centers to encourage energy-efficient behaviors (e.g.: the use of HOV traffic lanes and spatial siting for public transit facilities to replace structures that support use of privately operated vehicles).

DESCRIPTION OF THE PLANNING PHASES & OUTPUTS

As we have stated, sustainable urban design seeks to organize urban form and function in a manner that reduces the consumption of both material and energy resources. The section that follows describes a strategic planning process any community can use establish a vision of a sustainable future and specific goals, objectives and tactical approaches to achieve it over time.

Strategic Vision. The principal outputs of the first phase include community consensus on sustainability goals and objectives and a compelling vision of the community's desired future. The first step in creating a strategic vision is the identification of stakeholders who must conceptualize it. As noted above, this will entail an inventory of all organizational material and energy consumer groups across all sectors of the community – agricultural, commercial, industrial, residential, institutional, and transportation. Each of these user groups should then be further defined by distinct subgroups or "segments" that have characteristics that are largely exclusive of those held by any other subgroup. The inventory should then identify all relevant representative or advocacy organizations for major segments and additional special interest groups that represent cross-segment concerns.

The second step in the process involves the creation of a "straw sustainability statement". The statement is derived from a more detailed description or vision of how the community would appear if a balance existed between its means of continued growth and development and the maintenance of both local and global environmental quality. Once written, the straw statement is distributed to each stakeholder group for review prior to a series of facilitated community meetings designed to develop a consensus statement and a set of supporting goals for each dimension of the larger vision. Each of these goals/ends should, in turn, be further defined by a set of supporting objectives or conditions to be achieved for the goal to exist. Note: the means of reaching these ends are NOT part of this vision statement, but are addressed in subsequent planning phases.

The vision statement must also identify the timeframe within which this sustainable future is to be achieved. This period of time then constitutes the "planning horizon" for the sustainable development plan. For energy, environmental quality control, and transportation systems infrastructure, a planning horizon of 30 years is typical, given the serviceable life of capital equipment. Once established, the community's sustainability statement should be circulated for broader public comment and input, revision, and adoption as a municipal policy statement to guide not only the rest of the planning process, but the future operations of the community's public services and general governance.

Strategic Assessment. The second phase of the planning process produces an assessment of the current material and energy consumption rates, the technological infrastructure that consumes them, and how that consumption affects the natural environment. The phase begins with a baseline assessment of the community's current energy consumption (diesel fuel, electricity, gasoline, heating oil, natural gas, propane, and renewables) by market sector (as discussed above) and the technologies currently employed to meet the energy demand (power generation facilities and the transmission and distribution infrastructure). Similarly, a baseline assessment is conducted to characterize the average material consumption associated with the construction of residential, commercial and industrial structures and in transportation infrastructure development and maintenance.

The second phase of the assessment entails a qualitative and quantitative inventory of all waste streams produced by the urban infrastructure systems within the community. These waste streams should include all air emissions, water effluents, underground well injections, and solid waste disposal activities. Additionally, known or suspected impacts on sensitive environmental resources (e.g. wetlands, estuaries, forest lands, flyways, green space, and farmland) and habitat should also be assessed. Together, these assessments constitute a profile of the community's current level of resource sustainability.

Strategic Analysis. The third phase in the planning process identifies strategic gaps between the community's desired future state and its current state, as defined by the previous phase. This analysis begins with the prediction of future population and economic growth across the community's planning horizon. Projections are usually run for 2-3 scenarios of growth, each based on differing assumptions drawn from the specific composition and character of the community's economic base and regional and national growth trends. These projections are then used to predict the additional material and energy demands required to accommodate the growth and the related waste streams and environmental impacts that would result.

Next, the analysis involves a systematic look at the political, economic, social, and technological conditions that have resulted in the community's current sustainability profile. In the political arena, this entails an analysis of all existing metropolitan policies, comprehensive plans, utility infrastructure and transportation plans, zoning and building codes, and other ordinances that manage growth and development. In the economic arena, this entails a look at the pricing structure for energy and its use across all sectors, as well as the relative costs of its externalities. Additionally, an analysis of the current market structure and drivers is also necessary to complete the economic picture.

In the social arena, all public policies that, intentionally or unintentionally, provide incentives or disincentives that result in sub-optimal sustainability should be analyzed. Additionally, an analysis of the current state of public awareness and concern about sustainability should be conducted through some means of survey. In the area of energy technology, the analysis should consider the efficiency of currently deployed generation and energy-use technologies relative to available state-of-the-art technologies. Efficiencies of currently deployed transportation infrastructure and technologies must also be considered, along with associated management practices. A similar capacity and performance analysis must be conducted on all deployed environmental quality control technologies and management practices.

The strategic analysis concludes with a summary report that identifies specific political, economic, social and technological problems, issues, and barriers (so-called PESTs) that have resulted in the community's current condition. This report should also attempt to depict in both qualitative and quantitative terms, the size of the strategic gap that exists between the community's vision of a sustainable future and its present condition or reality. Clearly, this analysis in its most comprehensive form is a large, time-consuming task. Tackling smaller, targeted increments of the analysis may be a more realistic start for some communities and can also yield useful information.

Tactical Alternatives. The fourth phase of the process produces a creative set of potential solutions to the specific PESTs identified in the strategic analysis. A wide variety of structured and unstructured group processes are available (at least 200) to produce creative solutions and specific tactics, from simple nominal group techniques and surveys to more sophisticated consensus-building methods. Most planning firms are practiced in the use of these processes and have expertise in facilitating brainstorming sessions that can assist communities. With respect to energy and environmental systems technologies, expert advice should be sought to ensure that the community fully understands and avails itself of the latest thinking on the subject, particularly as these fields are rapidly changing with the deregulation of energy and increased regulation of pollutant sources. The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, and the U.S. Environmental Protection Agency's Office of Environmental Information can provide assistance to those interested in learning more about current and emerging technologies.

Tactical Evaluation. The fifth phase produces a set of screened tactics that are deemed politically, economically, socially, and technically feasible for potential use. Essentially, this phase entails evaluating each solution and the associated set of tactics by pre-established parameters for community acceptance and minimum performance standards necessary to accommodate projected growth and waste streams.

Additionally, budgetary and temporal considerations are introduced during this evaluation to group the alternatives and tactics according to their potential cost and the time necessary for their development and deployment. The evaluation is conducted in stages of progressively more stringent parameters and standards for each projected growth scenario. The result is a robust set of feasible solutions and tactics rated for use under alternative future conditions and community size.

Strategic Plan Formulation. The sixth phase produces integrated policies, programs, budgets, and deployment schedules necessary to move the community towards its sustainability goals and objectives over the established planning horizon. This is an important phase in which to reintroduce structured public participation, in order to consider necessary tradeoffs between, and priorities for, the content and timing of program elements. Multi-attribute utility modeling and analysis is a particularly useful tool for community decision-making in this regard. Although it has a complicated name, the technique enables the community to establish preferences across a diverse set of program alternatives with varying outputs and develop a final set of priorities that accurately represents the “public’s” collective interests.

<u>IMPORTANT NOTE</u>: An essential aspect of any new plan formulation initiative must be the integration or "linkage" of new planning elements to all relevant existing plans within the community, particularly those that entail human and capital resources necessary for implementation. This imperative is all the more important in sustainable development planning, as its implications cut across and impact most elements of a community's general and capital improvement plans, including: transportation, land use, housing, economic development, public infrastructure projects, etc. Additionally, plans that focus on emergency preparedness, natural hazards reduction/mitigation and public facilities security, must also be linked to a community's sustainability planning initiative, particularly in light of heightened concerns about security. Effective linkages forged between plans that share interdependent elements not only maximize resources but also strengthen the integrity of each.

Implementation and Control. The seventh phase of the planning process produces specific performance measures, methodologies, and reporting systems to manage resources as programs are deployed and to measure the effectiveness of the programs in moving the community towards its goals and objectives. This is a critically important phase in the overall process, as it ensures that the community’s plan for sustainability is a relevant, “living” document. More specifically, it enables the ongoing evaluation of the tactical approach to sustainability, and allows for both major mid-course corrections and minor program element adjustments. This is also the phase where ancillary components of the sustainability initiative that help ensure its ultimate success, can be developed. The single most important component in this regard is an inspiring community education campaign to compel ongoing support, good will, and participation in the long-term effort.

ACTIONS ALL COMMUNITIES CAN TAKE TODAY TO MOVE TOWARDS A MORE SUSTAINABLE FUTURE

The principal investigators of this research support the U.S. Environmental Protection Agency, the International City/County Management Association and the Smart Growth Network in promoting "Smart Growth" development in American communities. The following recommended actions are adapted from Smart Growth principles [9].

Design, Planning & Management

- Engage regional stakeholders in envisioning a sustainable future
- Incorporate sustainable design principles into comprehensive & general plans
- Establish short, mid and long-term sustainability goals, objectives & evaluation criteria for development decision-making
- Make development decisions predictable, fair & cost effective
- Create economic incentives to encourage sustainable development

Energy

- Develop a sustainable energy strategy with corresponding plans, policies & programs for implementation
- Deploy sustainable energy technologies such as cogeneration, distributed generation & renewables & practice efficient energy management
- Develop local sources of recoverable energy including municipal landfills, wastewater treatment & solid waste processing facilities
- Adopt energy efficient building standards

Land Use & Transportation

- Remote mixed-use developments at densities that support regional transit
- Create walkable neighborhoods with a strong sense of place
- Encourage use of alternative fuels, fleets & transit infrastructure
- Strengthen & direct development towards existing communities
- Preserve open space, farmland, natural beauty, habitat & critical environmental areas
- Integrate open space throughout the urban landscape

Housing & Environmental Systems

- Encourage compact building design
- Create a range of housing opportunities & choices
- Provide incentives for higher density housing along transit corridors
- Reward sustainable best management practices by the
- Building design & construction industries
- Reclaim & reuse, where possible, all urban "waste" waters
- Encourage use of products designed to be recycled for multiple uses

NOTES

Note A. Jury for the International Competition for Sustainable Urban Design

The jury impaneled to judge the design submissions consisted of: Dr. Shigeru Itoh, an acclaimed urban design professor of Waseda University in Japan; Dr. Stephen Graham, a noted information technology expert and professor at the University of Newcastle in the UK; Mr. Gary Neale, Chairman, President, and CEO of NiSource in the US; Dr. Haikyung Shin, special correspondent for JoongAng Illbo in Korea; Mr. Cassio Taniguchi, Mayor of Curitiba City in Brazil; and Dr. Ernst Ulrich von Weizsaecker, a member of the German Parliament.

Note B. San Diego-Tijuana Design Project Tasks & Subtasks

Development of Design Parameters

- The design team compiled projected population growth for the metropolitan region over the short-term (10-30 years), mid-term (30-50 years), and long-term (50-100 years) planning periods.
- The design team compiled projected commercial and industrial economic development over the three planning periods, given multiple growth scenarios.
- The design team compiled projected potable drinking water and process water demand in the metropolitan region over the three planning periods.
- The design team compiled projected municipal and industrial wastewater effluent, air emissions, and solid and chemical waste production over the three planning periods.
- The design team compiled projected transportation requirements, based on several growth and development scenarios over the three planning periods.
- The design team compiled projected natural gas, electric, and petroleum energy demand consistent with population and economic growth projections over the three planning periods.
- The design team identified natural resource assets, environmentally sensitive marine, aquatic, and terrestrial habitats, and migration flyways.
- The design team solicited community priorities and preferences regarding near- to mid-term energy and environmental objectives for the Region. The design team prepared a regional outreach and consensus-building strategy that sought to develop political awareness, understanding, and support for the sustainable urban design project.
- The design team compiled various regional jurisdictions into project area base maps suitable for raster or polygon analysis for the following elements: slopes, soils, scenic vistas, biology, waters and wetlands, land-use controls such as zoning districts, and planned land uses.

In all of these efforts, the design team utilized projections and data publicly available through federal, state, regional, and local government agencies.

Development of the Energy & Environmental Systems Plan

- The design team analyzed projected energy demand characteristics for the three planning periods based on projected population estimates and per capita usage provided by energy industry sources.

- The design team analyzed projected air, water, and land impacts of the projected growth and development over the three planning periods based on projected population estimates and per capita usage provided by industry sources.
- Gas Technology Institute (GTI) identified alternative present, emergent, and future technologies and management practices capable of meeting the projected energy demand over the three planning periods.
- GTI identified alternative technologies and management practices capable of meeting the projected pollution control needs over the three planning periods.
- GTI developed an integrated energy and environmental technology systems plan capable of meeting projected demands over the three planning periods (including a focus on renewable resources, waste-to-energy systems, reduction of greenhouse gas emissions, and life-cycle systems planning).
- GTI established optimal spatial relationships between centers of energy generation and use and translated these spatial relationships into proposed land use design parameters.
- GTI quantified the integrated technologies systems facilities and spatial deployment within the established land-use parameters to meet the energy and environmental needs of the region over the three planning periods.
- GTI specified energy transmission and distribution infrastructure requirements, based on established spatial design parameters.
- The design team identified alternative transportation technologies, fuels, and infrastructure capable of meeting demand over the three planning periods.
- The design team prepared an energy-efficient inter-modal transportation framework capable of meeting mobility needs suggested by future energy technology deployment and consequent settlement patterns (including a scheme for optimizing marine port and airport transportation, as well as surface and subsurface transportation).

Formulation of the Comprehensive Land Use Plan

- The design team used geographic information systems (GIS) applications to prepare a "Base Case" urbanization scenario, applying existing urban growth and land use policies to future market demand and available land. The base scenario addressed potential urbanization patterns to meet market demand for land, based on projected population for the region. The scenario described growth patterns for each of the three planning periods.
- GTI and the design team identified current trends and potential developments in information technologies, telecommunications, and biotechnology and their likely impact on the nature of work, and on consequent settlement/development alternatives. The team engaged in roundtable discussions with industry experts and futurists to explore potential future developments that would affect urbanization patterns.
- The design team identified alternative land use and building construction possibilities suggested by current and emergent energy efficiency and green building design technologies and management practices.
- The design team identified alternative land use and building construction possibilities suggested by current and emergent pollution prevention and recycling practices by individuals and institutions.

- The design team identified open space and educational, recreational, and cultural facilities necessary to meet population needs over the three planning periods. The design team incorporated open space and other land-based public facilities and resources into the GIS scenarios as part of the suitability analysis.
- The design team formulated alternative land use designs to optimize the integrated energy and environmental systems plan and the inter-modal transportation system plan.
- GTI and the design team specified a developmental "Roadmap" staged over the three planning periods to guide the Region to sustainability by the year 2103. The roadmap established a systems deployment schedule, a future R&D agenda, and a proposed citizen education campaign to encourage individual involvement in the community's effort to become sustainable.

REFERENCES

1. "New Age Doctrine is Out to Lunch on Three Issues", CoEvolution Quarterly, Phillips & Gnaizda, Summer 1980.
2. "The Energy Yardstick: Using PLACE3s to Create More Sustainable Communities", U.S. DOE, August 1996.
3. "The Energy/Smart Growth Connection", Freidman, May 2001.
4. "The Energy Yardstick: Using PLACE3s to Create More Sustainable Communities", U.S. DOE, August 1996.
5. "Urban Land Use Planning", Kaiser, Godschalk and Chapin, Univ. of Illinois Press, 1995.
6. "The Visual Shape of the Shapeless Metropolis", Kevin Lynch, Courtesy of Institute Archives and Special Collections, MIT Libraries. No Date.
7. "Landfill Methane Recovery", Climate Change Technologies Brochure, US EPA, State and Local Climate Change Program, January 2000.
8. "Municipal Solid Waste in The United States: 2000 Facts and Figures", US EPA, Office of Solid Waste and Emergency Response (5305W), EPA530-R-02-001, June 2002.
9. "Getting to Smart Growth: 100 Policies for Implementation", Smart Growth Network and the International City/County Management Association, January 2001.

For More Information Contact:

Sustainable Energy Planning Office

Gas Technology Institute

847-390-7800

sepo@gastechnology.org

www.gastechnology.org/sustainability

APPENDIX 1: COMBINED HEAT AND POWER SYSTEMS

INTRODUCTION

Processes that capture and reuse waste heat from power generation for water heating, thermal space conditioning, and industrial processes is an old approach to energy efficiency that is gaining renewed interest among energy planners. This approach, termed "Combined Heat and Power" or CHP, (sometimes called "cogeneration") dates to the earliest days of electricity when power was produced locally, and the byproduct-steam was used for nearby commercial and industrial purposes. The shift to remote central power generation began to occur in the early 1900s, driven by public concerns for the effects of coal-fired plant emissions on community health and the advent of consortium utility investors. Since then, CHP has occupied a predominantly niche role in the industrial sector, operating on recoverable energy from wood wastes, petroleum residue, and blast furnace gas.

Technology Spotlight: Combined Heat and Power

"A family of technologies known as combined heat and power (CHP) can achieve energy efficiencies of 80 percent or more in some applications. In addition to environmental benefits, CHP projects offer efficiency and cost savings in a variety of settings, including industrial boilers, energy systems, and small, building-scale applications. At industrial facilities alone, there is potential for an additional 124,000 megawatts (MW) of efficient power from gas-fired CHP, which could result in annual emission reductions of 614,000 tons of NO_x and 44 million metric tons of carbon equivalent. CHP is also one of a group of clean, highly reliable distributed generation technologies that reduce the amount of electricity lost in transmission while eliminating the need to construct expensive power lines to transmit electricity from large central generating plants."

- U.S. National Energy Policy 2001

Recently, large-scale CHP applications serving more than one physical plant – termed "District Energy" systems, have begun to appear on university and hospital campuses and in some downtown central business districts. Many universities now operate their own "powerhouses" that meet the aggregated electricity and space conditioning requirements of campus buildings through a network of underground pipes, replacing separate generators and boilers in each building. These networks have also become the most economical means of meeting the needs of downtown commercial and institutional customers in several major U.S. cities (e.g. St. Paul, Minneapolis, Chicago, New York among others). Together with campus applications, there are now hundreds of district energy systems in place, with more planned for development each year.

The resurgence of CHP is due in large measure to clean natural gas-fired cogeneration technologies that significantly reduce energy-related air emissions. Between 1992 and 2002, the installed capacity of CHP in the United States increased by over 30 gigawatts (see Figure 1) – roughly equivalent to the electricity demand of the state of Texas (http://currentenergy.lbl.gov/tx/). The expansion in installed capacity has occurred in the commercial, industrial, and electric utility sectors as is shown in Figure 2. The large CHP capacity highlighted in the utility category is largely due to user-owned utilities, such as universities and hospitals, as well as gas and electric utility CHP installation programs.

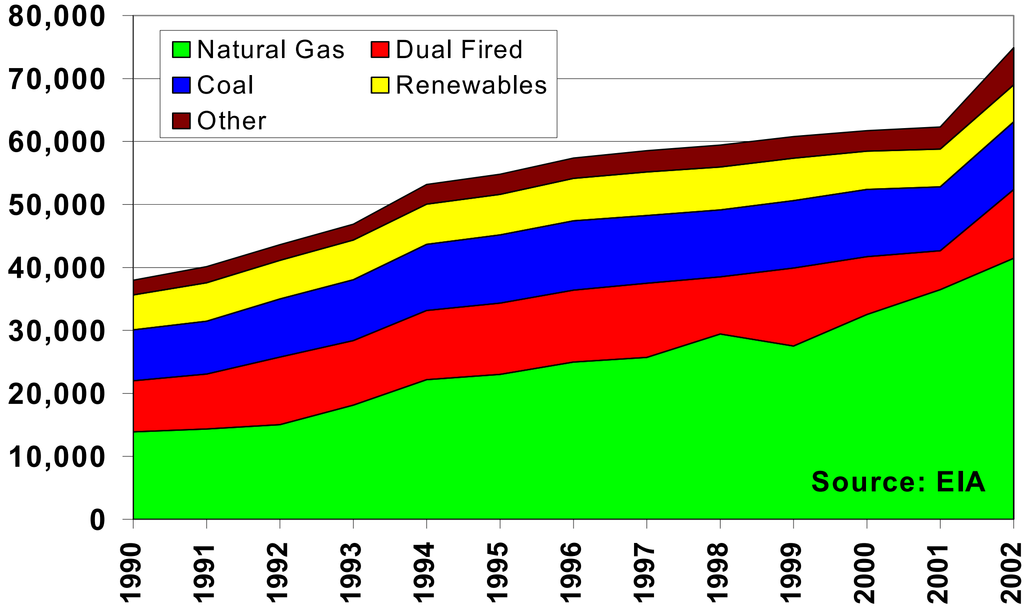


Figure 1. Combined CHP Capacity (MW)

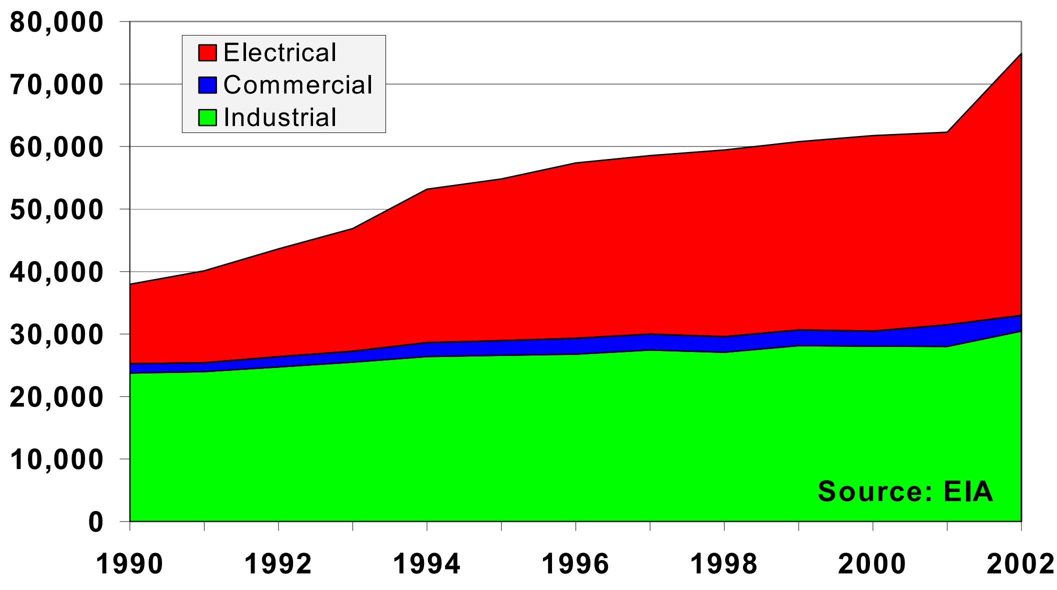


Figure 2. CHP Capacity by sector (MW)

In addition to better air emission performance, CHP technologies operate at much higher energy efficiencies than do most central power stations. (see Figure 3)

Figure 3 illustrates the comparative efficiencies and energy requirements of a CHP system versus a conventional power generation system. To produce the same electricity and heat output (35 and 50 units, respectively) requires fuel inputs of 100 units for a CHP system and 189 units for a conventional system.

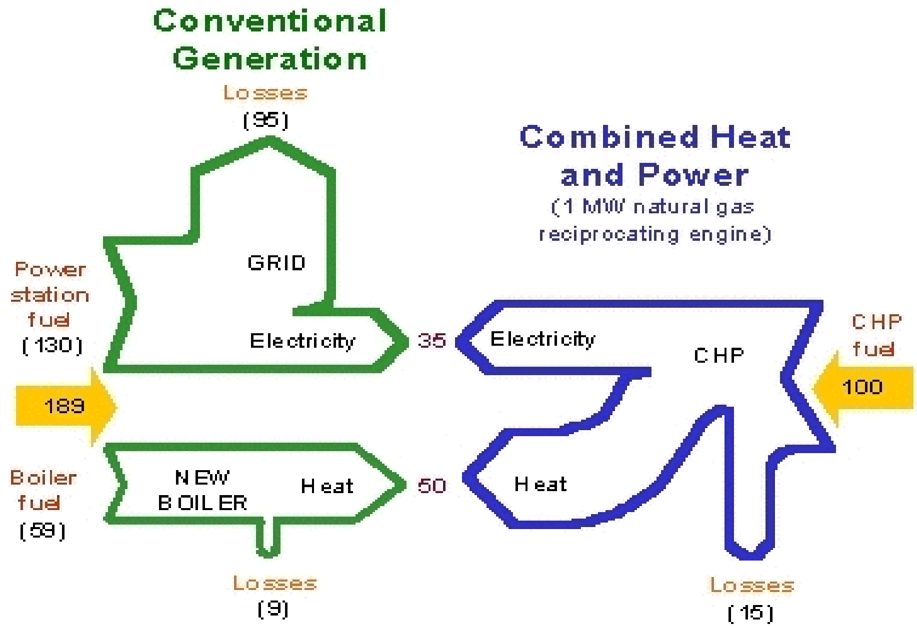


Figure 3. Comparative Fuel Requirements and Losses from Energy Generation Systems

CHARACTERISTICS OF CHP

Efficiency

Single cycle central power plants have low overall fuel use efficiency due to the large quantities of heat that are generated but unused. In contrast, CHP systems capture the generating units' waste heat and apply it to produce additional electricity and to serve heating or cooling purposes. The typical fuel use efficiency of a single cycle power generation plant is only 33 percent, while CHP systems are capable of fuel use efficiencies greater than 85 percent. As a result, fuel consumption, with its attendant emissions of CO_2 and other pollutants, decreases.

Emissions

Power generation emissions differ significantly from state to state based on the central power plants and fuels in use. In general, the Midwest has many large coal plants that produce relatively inexpensive electricity with significant air emissions. Other regions, including Texas and California, have more natural-gas-fueled electricity generation. Power generation emissions also vary by time of day corresponding to the two periods of power consumption – the on-peak period (usually defined as Monday through Friday, 9 am to 9 pm) and the off-peak period (the evening and early morning hours). The additional generating units needed to meet the high levels of peak period demand are typically less efficient, and higher cost, natural-gas-fueled or oil-fueled generators designed for quick starts and fewer operating hours.

In many states, the use of CHP systems during on-peak periods can reduce the demand on central power plants and significantly reduce air emissions. For example, the average on-peak generator in Illinois emits 4.77 lbs of NO_x and 12.32 lbs of SO_x per MWh of electricity produced (see Table 1 and Table 2). If Illinois were to implement the on-peak operation of CHP systems with lower emissions than coal-fired central plants, overall emissions from power generation would be reduced. Furthermore, this approach would also help meet facility heating, cooling, or process requirements that previously were met through other energy sources, thereby further reducing emissions. Many urban areas are in violation of U.S. EPA air quality standards for NO_x, in part due to the high levels of emissions during peak power demand hours, and reducing these emissions could benefit these non-attainment areas (e.g. Chicago). As is illustrated in Figure 1, most new CHP systems are natural gas fired, which have NO_x emission rates below 0.5 lbs/MWh. This asset, combined with energy efficiency gains, can make CHP an effective tool for urban communities striving to meet U.S. EPA air quality requirements.

Table 1. Average Power Generation NO_X Emissions (E-Grid 2002)

	Baseload emission Rate	On-Peak Emission
	>40% utilization	<40% utilization
State	(Lbs/MWh)	(Lbs/MWh)
California	0.58	0.52
Connecticut	1.26	1.80
Illinois	2.49	4.77
Massachusetts	2.07	1.55
New York	1.29	2.07
Texas	2.26	2.49

Table 2. Average Power Generation SO_X Emissions (E-Grid 2002)

	Baseload emission Rate	On-Peak Emission
	> 40% utilization	< 40% utilization
State	(Lbs/MWh)	(Lbs/MWh)
California	0.24	0.02
Connecticut	1.94	3.49
Illinois	4.16	12.32
Massachusetts	5.86	3.81
New York	4.37	2.72
Texas	3.76	0.05

CHP Economics

Combined heat and power systems – and most distributed generation systems – have high upfront capital costs and typically have payback periods of 5 years or more, before accrued energy cost savings begin to exceed the initial capital cost. Table 3 shows typical cost and emission data for natural-gas-fired CHP applications. While these prices have decreased, the initial capital cost is often still a barrier to CHP, as many financers require payback periods of 3 years or less. Furthermore, many utilities have rates and penalties for CHP systems that increase the economic risks of installing the system. As a result, obtaining the many benefits of CHP requires a long-term vision. In the private sector, this often means evaluating the cost of downtime or poor power quality and factoring this into the economic analysis. For municipalities, the challenge can be met through the establishment of sustainable energy planning processes, with longer planning horizons. Also, many federal, state, or even local financing mechanisms can defray the upfront cost of CHP systems, thereby alleviating the pressure on strained city budgets.

Table 3. Costs and Emissions of Natural Gas- fired CHP Equipment

	Gas-fired Reciprocating Engines				Gas-fired Turbines			Fuel Cell
Current	Rich burn	Lean burn	Lean burn	Lean burn	Micro-turbine	Turbine	Turbine	PAFC
Capacity (kW)	100	300	800	5000	100	1000	5000	200
DG Installed Cost ($/kW)	$1350	$810	$765	$744	$1485	$1180	$660	$3850
CHP Installed Cost ($/kW)	$1805	$1197	$972	$874	$1765	$1780	$1085	$4500
Efficiency (HHV)	30%	31%	33%	39%	26%	21.9%	27.1%	36%
CHP Efficiency (HHV)	79%	77%	76%	74%	68%	68%	68%	75%
NOx Emissions (lb/MWh) (uncontrolled)	44.3	5.9	2.9	1.5	0.72	2.43	1.16	0.04
NOx Emissions (lb/MWh) (controlled)	0.44	0.5	0.5	0.5	N/A	0.24	0.11	N/A
CO_2 Emissions (lb/MWh)	1365	1321	1241	1050	1535	1887	1510	1135
Source: Energy and Environmental Analysis –" Gas-Fired Distributed Generation Technology Characterizations" 11/02-6/03								

CHP Public Policy

A consistent concern in the CHP (and distributed generation) marketplace is the various market and regulatory hurdles that arise for most projects. These barriers to implementation result in additional costs, delays, or difficulties in dealing with the local utility and connecting to the power distribution network (the "grid"). In addition, a lack of universal interconnection laws and requirements make the procedure of installing CHP systems cumbersome and inefficient. In fact, interconnection barriers have been identified as the principal obstacle to widespread commercialization of CHP, especially for commercial and light industrial applications (see Making Connections report www.nrel.gov/docs/fy00osti/28053.pdf). Overcoming these barriers could provide a level playing field for distributed generation and cogeneration. Eliminating these barriers would ensure that project decisions are made on the basis of accurate evaluation of costs and benefits and not influenced by artificial impediments.

CHP Drivers, Support Efforts, and Applications

Combined heat and power systems have been installed across the U.S. where:

- Large thermal loads exist (hot water, steam or direct process loads);
- Sources of thermal energy are available to produce electricity (for example, using steam turbine Rankine cycles or other technologies to make electricity);
- Recoverable energy sources exist (methane, biomass, bio-gas, etc.); or
- Where the economics of CHP projects present opportunities.

Additionally, new concerns about energy security, reliability and quality have also accelerated the number of CHP installations in: emergency operations centers; medical centers; banks and investment firms; information and telecommunications operations; research laboratories; and anywhere else that the disruption of energy services would result in the loss of life or property.

In addition to the economic and functional need for CHP installations, technical and policy experts representing manufacturers, utilities, building operators, research and development organizations, industry associations, energy service companies (ESCOs), universities, and national laboratories have defined a new vision for power generation that includes smaller generation systems applied to buildings, district energy systems and industry. This vision is spurred by the growing congestion of the established power grid, concern about regional and global emissions, and the need for increased efficiency in energy use.

Besides industry initiatives, federal, state, and local governments have begun efforts to deploy CHP. The U.S. DOE's facilitation of a CHP Roadmap effort and the U.S. EPA's creation of the Combined Heat and Power Partnership have been instrumental in promoting CHP. Federal support for CHP integration, test verification, and demonstration projects in the industrial sector has increased interest in and use of CHP. Regional CHP Application Centers, CHP working groups, the United States Combined Heat and Power Association (USCHPA), International District Energy Association (IDEA), DOE Integration Test Center, and GTI's Distributed Energy Research Center have all made significant contributions toward the accelerated deployment of technologies across all economic sectors. These groups focus on economic- and information-driven processes for increasing CHP understanding, installation, and use. These efforts have reduced several barriers to CHP installations and have led to advances in CHP technology, performance, cost, and ease of entry into new markets.

Industrial CHP

Combined heat and power has a long history of success in certain industries – primarily petroleum, metals, and pulp and paper. Industrial plants are often well suited to CHP because of their need for process heat as well as electricity. Industries that have fuel available from onsite waste (e.g. pulp and paper) are particularly good candidates. By using on-site wood waste as fuel to provide some or all of the facility's process, thermal and electricity requirements, efficiencies are maximized and fuel, electricity, and thermal energy costs are minimized. Combined heat and power approaches have also been successfully implemented in the plastics, steel, and chemical manufacturing industries, among others. Cities can encourage industrial CHP in their jurisdictions by providing technical assistance for siting and permitting, identifying potential emissions and electricity reliability benefits, and providing financial incentives. For example, in the Chicago Industrial Plan, the U.S. Department of Energy and the City of Chicago evaluated sites throughout the metropolitan area on the basis of emissions, grid constraints, and economics, in order to identify large industrial facilities that might be suitable for CHP.

CHP Brewing in the Twin Cities

Rahr Malting has received a grant from the U.S. DOE to test the feasibility of a 20-megawatt CHP system that will use biogas from the barley, wheat, and other organics in the brewing process. The power will meet the demand of the Malting facility and 11,000 surrounding homes. The waste heat will be used for industrial purposes.

CHP for Buildings (BCHP)

Building cooling, heating, and power (BCHP), also referred to as Integrated Energy Systems, is another emerging application of the CHP approach. In a BCHP system, CHP is applied to a commercial building, and the waste heat is used for hot water, space heating, cooling, and humidification and now even illumination, through the use of an integrated gas-fired heat and light system. For example, waste heat from electricity generation can be used as the input energy for thermally activated technologies such as heat-actuated air conditioners and dehumidifiers, to generate steam for space heating, or to provide hot water for laundry, kitchen, or cleaning services. Significant promise exists for BCHP at health-care facilities, data centers, hotels and resorts, schools, restaurants, shopping centers, and other commercial establishments, as well as multifamily residences. Many of these installations are fairly small, and thus more expensive per

> **City of Austin's Fuel Cell**
>
> In Austin, Texas, a $1.2 million fuel cell – which uses natural gas to produce electricity with hot water as a byproduct – was installed in the summer of 2002 to generate electricity at the Rebekah Baines Johnson Dental Clinic, near Town Lake. The fuel cell will provide electricity for the RBJ facility and waste heat from the generator will warm water, displacing the energy presently required to operate a boiler for that purpose. Because it reuses waste heat for another application, the fuel cell – which is about 18 feet long and 10 feet wide – operates at 85 percent overall energy efficiency. It also has minimal emissions.

kilowatt, but packaged and modular systems offering "plug-and-play" installation at significantly lower cost are currently under development. The lower costs and increased standardization of these modular systems will be especially advantageous for commercial franchise chains.

Metropolitan communities have many opportunities to install BCHP systems. Cities seeking to improve energy efficiency or reduce energy use will often first target municipal buildings, such as offices, civic centers, and public schools. Many commercial buildings are considering CHP to provide energy and cost savings, increased energy reliability and security, and improved power quality. For example, data centers and banks need electricity of higher quality and reliability than is usually available from the grid. A BCHP system can serve these needs and simultaneously provide cooling for computer equipment. In many cases, metropolitan communities will assist these facilities as part of an overall sustainable energy plan.

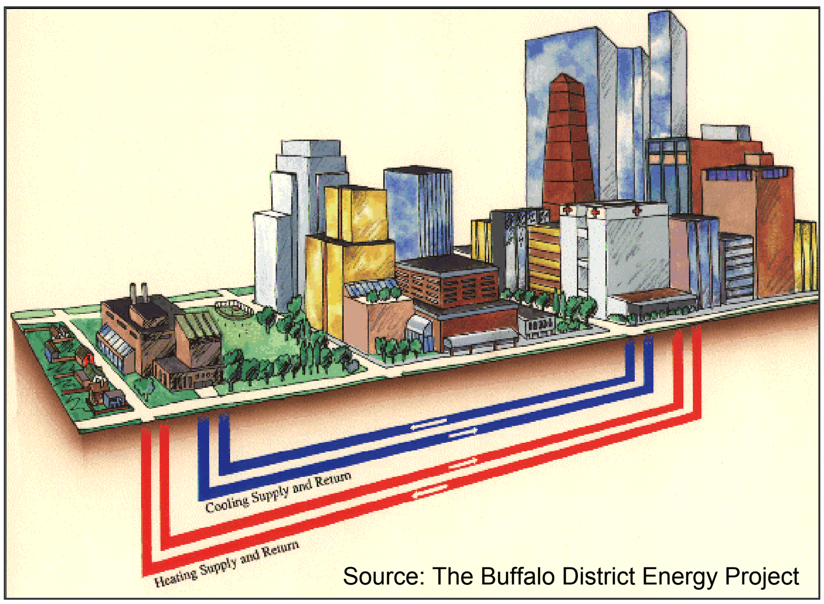


Figure 4: District Energy Systems (Buffalo, NY)

DISTRICT ENERGY

As noted earlier, a CHP system designed to serve a large number of buildings, is called a district energy system. Traditionally, these systems have been installed on educational campuses and within central business districts where the proximity and density of buildings make it economically viable to install the piping networks needed to distribute steam and hot or chilled water (see Figure 4). District energy central plants house utility-grade heating and cooling equipment designed for heavy-duty use. The benefits of district energy include a greater economy of-scale, because of the larger equipment and the potential to serve overlapping energy needs. By aggregating demand and connecting energy delivery points, individual boilers and chillers in buildings are supplanted by a larger off-site system that can increase overall system efficiencies and significantly reduce construction costs. In addition to the benefits of more usable floor space, previously occupied by space-conditioning equipment, individual customers can also avoid ancillary system costs for water treatment, chemical and CFC use, and labor and maintenance expenses. Aggregating demand among different buildings, where diverse customers experience demand peaks at different times, allows equipment to be operated more fully loaded (and more efficiently) than single-building chiller plants.

Municipal District Energy

Traditionally, district heating systems were built to capture and distribute steam from downtown electric generating stations to buildings in the general vicinity. Over time, heating networks expanded to serve hundreds of buildings. Consolidated Edison (Con Ed) still operates one of the first district heating systems and the world's largest steam system in New York City. This system serves more than 1800 buildings, including such landmarks as the Chrysler Building, Rockefeller Center, and Empire State Building and dozens of hospitals. The Con Ed system provides steam in the summer to drive more than 500,000 tons of air conditioning, which significantly reduces peak electric demand on the Manhattan grid. Steam systems operate in many major U.S. cities, including Boston, Philadelphia, Indianapolis, Denver, San Francisco, Minneapolis, and Washington D.C.; and they continue to provide highly reliable heating service to hundreds of buildings. In 1962, the world's first combined downtown district heating *and* cooling began distributing chilled water for air conditioning along with steam for heating to connected customer buildings, in Hartford, Connecticut. Today, the Hartford Steam Company serves nearly 80 percent of the buildings in the city, including local, state and federal government buildings. Following this model, the next eleven downtown district cooling systems were developed by local gas distribution companies in cities such as Pittsburgh, Omaha, Tulsa, Oklahoma City, and Minneapolis to expand summer natural gas loads for steam-driven air conditioning. Some systems, like the Energy Systems Company in Omaha, Nebraska, used mainly natural gas-fired technologies to drive pumps, chillers and condenser pumps.

Mile High Energy System

Xcel Energy, formerly Public Service Company of Colorado, operates a large steam district energy system that dates back to the beginning of the City of Denver. In the mid-1990's, Xcel added district cooling utility service to provide chilled water for air conditioning commercial office buildings and government complexes in downtown Denver. The City and County of Denver currently have 15 buildings covering over 5 million square feet connected to the district energy networks.

Since 1990, nearly thirty new downtown district cooling systems have been developed in North American cities, reflecting a combined investment of nearly $2 billion (see Figure 5). Many of the newer systems integrate large chilled water or ice storage technologies that capitalize on cool outdoor temperatures and low electric rates to produce chilled water or ice at night. More importantly, this approach reduces electric demand during on-peak hours, yielding a flatter electricity demand profile. This is increasingly valuable as power load factors become more important to electricity pricing. Figure 6 shows the impact of district cooling service on the electric demand of a 258,000 square foot commercial office building in downtown Cleveland, Ohio. The red area represents the peak monthly electric demand before district cooling. The blue area, which varies by less than 2 percent between January and July, represents the building's current electric demand, which has been reduced by 46 percent from the prior year's monthly peak.

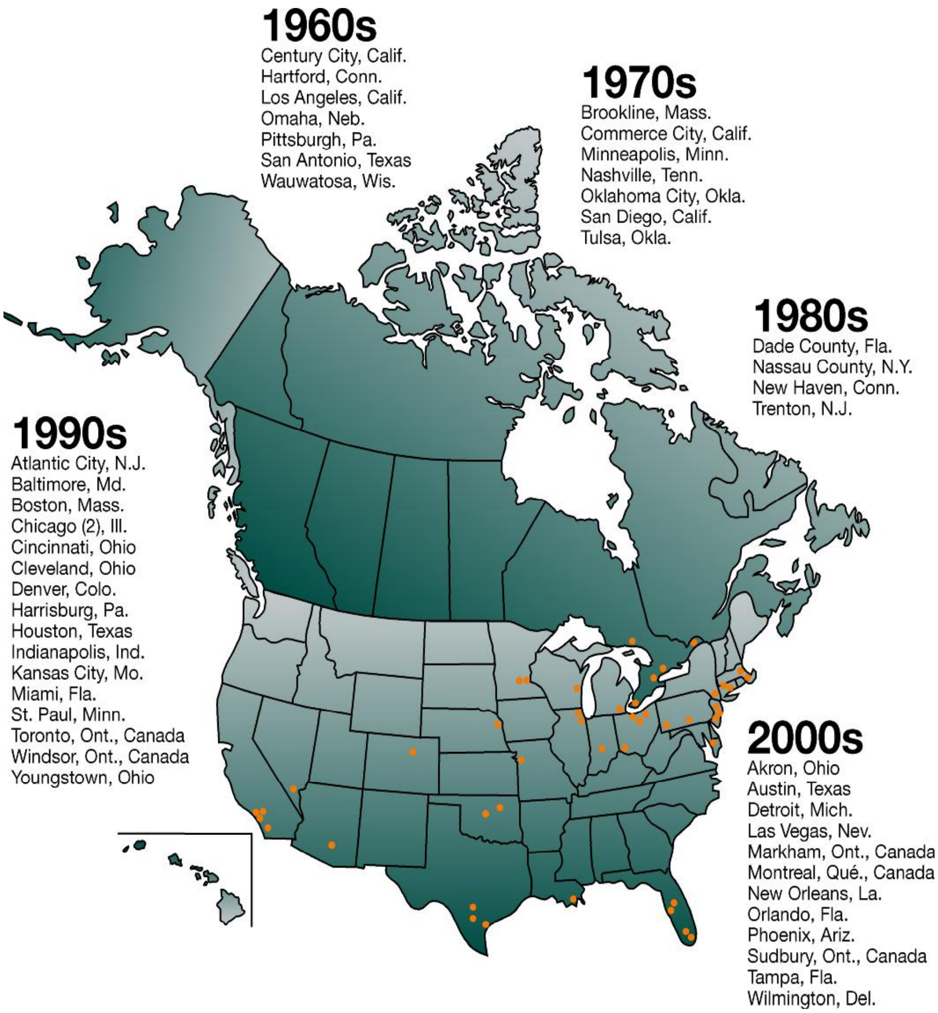


Figure 5 United States District Energy Systems Map

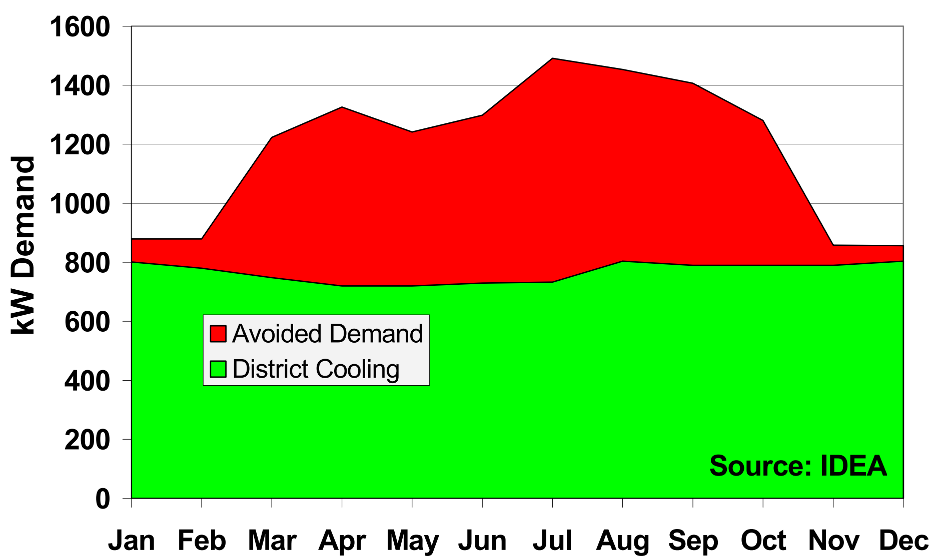


Figure 6: Cuyahoga Savings Center Electricity Demand

CHP on Campus

District energy and CHP are an effective combination on college campuses as the combined heating and power loads can result in highly efficient and economic applications. In 2002-03, IDEA performed a census for the U.S. DOE that identified 967 MW of CHP currently operating on college and university campuses. Data from 160 U.S. campuses revealed district heating systems totaling 4.2 million lbs/hr of heating capacity and cooling systems with 932,400 tons of cooling capacity. Campus energy managers described near-term plans to increase cooling capacity by over 100,000 tons and heating capacity of 800,000 lbs/hr, as well as projects totaling nearly 475 MW of electric generation capacity expansion in the next five years. A recent example is the University of Texas in Austin that has added a 25 MW steam turbine to its CHP facility to bring the total onsite campus generating capacity to 110 MW.

District energy is the preferred method for heating and cooling hundreds of campuses, and the need for these services is growing due to extensive new building construction on campuses nationwide. Increasingly, this space is air conditioned to provide year-round comfort and to serve other clients than the traditional students, teachers, and staff members. Campuses are implementing CHP to: improve fuel efficiency, reduce operating expenses, ensure more reliable energy service for critical research and laboratory facilities, reduce overall emissions, and achieve more sustainable energy practices. Increasingly, many district energy systems are also incorporating renewable sources of energy. For example, UCLA installed a 43 MW CHP facility that uses 4 million cubic feet of landfill gas daily (approx 1/3 of its natural gas fuel supply) for the 234 MMBtu/hr heating plant and 16,600-ton cooling system for a campus measuring over 13 million square feet. By implementing a renewable district energy system, UCLA has reduced overall campus emissions by 34 percent.

DOE Support Leads to World Class Success in District Energy in Twin Cities

About 20 years ago, the U.S. Dept. of Energy and the Minnesota Energy Agency provided key financial and technical support to the feasibility study for modernizing and updating the district energy system in downtown St. Paul. In 2003, a 26 Megawatt CHP facility began being fueled by urban waste wood 95 percent or more of the time, with up to five percent natural gas used to initiate combustion. This facility combines the benefits of fuel flexibility by using biomass energy to provide the principal source of heat for the district energy system and reduces landfill and air emissions. Over 26 million square feet of office space (about 75 percent of downtown St. Paul) is served by district heat and over 9 million square feet is served by district cooling. President George Bush cited District Energy St. Paul (districtenergy.com) as “a model of energy efficiency, reliability and affordability” in his National Energy Plan Announcement in May 2001.

Across the Mississippi River, the Minneapolis Energy Center serves over 40 million square feet of building space in downtown Minneapolis with district heating and over 30 million square feet with district cooling. Minneapolis Energy Center was originally developed in the 1970s by Minnegasco, the local gas distribution utility. Today it is one of the nation’s largest and most successful combined district heating and cooling systems serving a downtown central business district. The parent company of the Minneapolis Energy Center also owns and operates district energy systems in downtown Pittsburgh, Harrisburg, San Diego, and San Francisco.

CHP OUTLOOK - A BRIDGE TECHNOLOGY TO THE FUTURE

As electricity consumption and the associated environmental and economic costs continue to rise, CHP systems can play an increasingly important role in cities that are seeking to reduce overall energy use and prepare for future, zero-emission electricity technologies. Communities seeking to become more sustainable can install on-site CHP systems to capitalize on local energy sources, such as bio-gas and biomass, or sustainable energy sources, such as renewably produced hydrogen for fuel cells.

As well as increasing energy efficiency, CHP gives communities a way to counter the need for expanded electricity transmission and distribution systems. In addition to *customer* installation and operation of CHP systems, U.S. DOE is currently researching opportunities for economically viable *utility* ownership of CHP systems within grid-constrained areas. In such a scenario, the utility would install a CHP system in an industrial or municipal building and contract to sell power, heat, and cooling to the building owner or the tenants. In exchange for providing space and signing a contract, the building owner/tenant receives reliable power and rental income. The utility benefits from the long-term energy services contract as well as avoiding otherwise required power distribution system upgrades. The community benefits from greater energy efficiency; increased local job creation for equipment installation and maintenance; reduced grid congestion, and reduced likelihood of blackouts or power disruptions.

In the coming years, continuing technological improvements will be instrumental in the dissemination of this important approach to energy conversion. As shown in Table 4, performance and cost forecasts for CHP systems indicate that they are projected to improve –in some cases, dramatically – by 2020. The expected cost reductions should overcome today's first cost barrier and increase penetration of CHP applications. Furthermore, addressing the policy concerns discussed in section 3.2 will remove many of the market barriers that CHP currently faces. As a consequence, CHP and district energy applications are poised to be the primary source of electricity, heating, and cooling for buildings of the future.

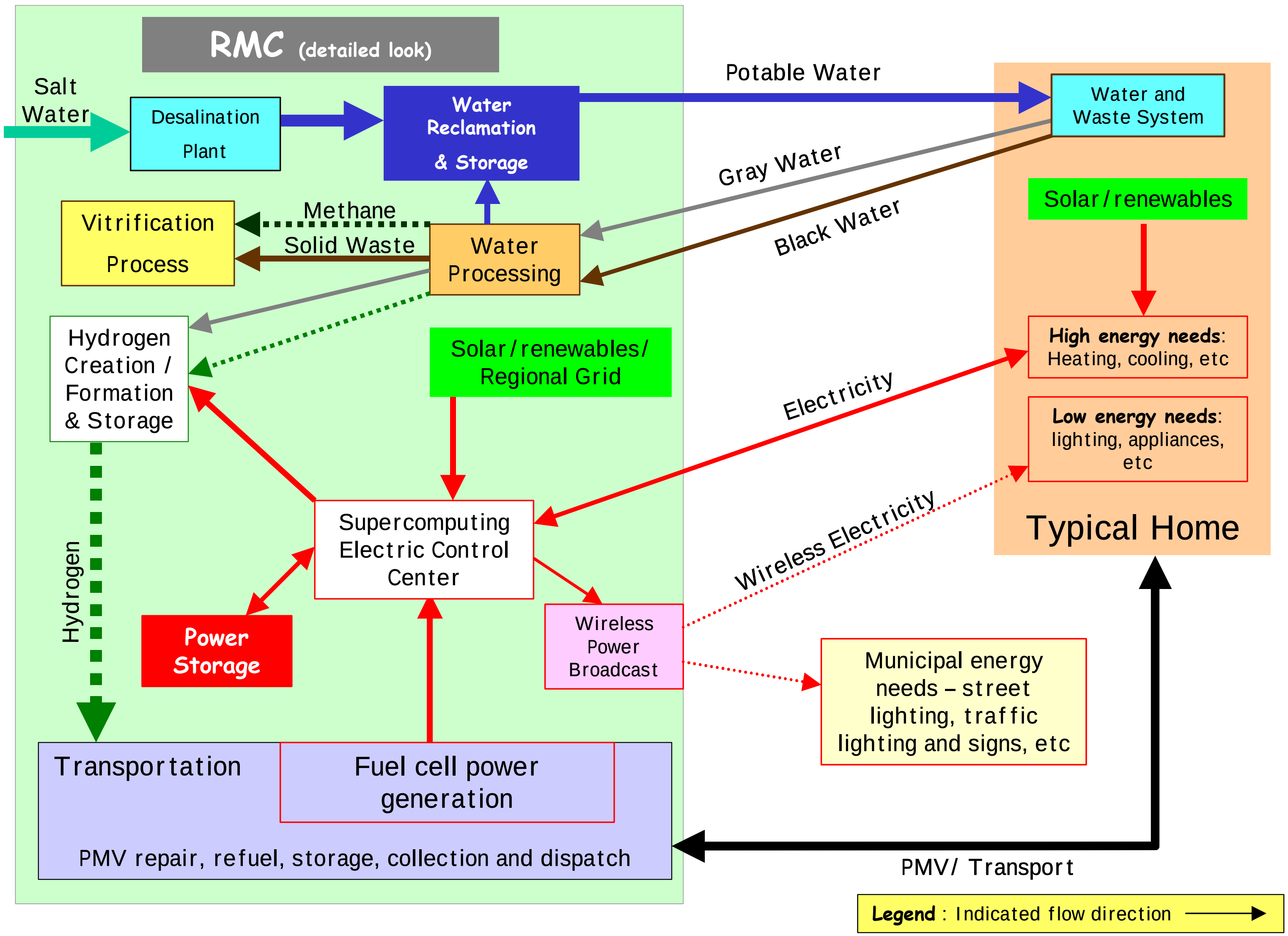
Table 4. 2020 Projected Costs and Emissions of Natural-Gas- Fired CHP Equipment

	Gas-fired Reciprocating Engines				Gas-fired Turbines			Fuel Cell
Advanced Technology Projections	Rich burn	Lean burn	Lean burn	Lean burn	Micro-turbine	Turbine	Turbine	PAFC
Capacity (kW)	100	300	800	5000	160	1000	5000	200
Installed Cost ($/kW)	$1100	$920	$875	$760	$910	$1450	$920	$2450
Efficiency (HHV)	35%	36%	40%	45%	36%	26%	32.1%	38%
CHP Efficiency	86%	84%	84%	79%	72.4%	70%	72%	80%
Source: Energy and Environmental Analysis –" Gas-Fired Distributed Generation Technology Characterizations" 11/02-6/03								

Through the efforts of the U.S. DOE and other domestic energy entities, future energy systems will enable a hydrogen-based economy energized by fuel cells, renewable resources, and other zero-emission technologies. With these energy sources fueling automobiles as well as buildings, the U.S. can move toward reliance on a single fuel and begin to eliminate much redundancy in energy transmission systems that currently carry natural gas, petroleum, coal, and electricity. Further, domestic production of hydrogen can reduce or eliminate U.S. dependency on imported energy.

Finally, as communities consider their development plans for the 21st century, the need for more sustainable practices is evident. Due to significant and persistent environmental and economic impacts, energy production, delivery, and use are primary impediments to sustainability. Combined heat and power systems, however, are ideally suited to sustainable community development patterns and projects that favor mixed land uses, higher densities, and increased utilization of existing urban footprints. Thus, CHP systems form a natural connection between traditional energy technologies and a new framework for community planning that integrates sustainable energy approaches. Successful integration of CHP technologies into today's community energy policies, plans and infrastructure will facilitate the nation's transition to a more sustainable energy future when more advanced technologies and lower emitting fuels are in place.

APPENDIX 2: NEIGHBORHOOD SYSTEMS FLOW



APPENDIX 3: NEIGHBORHOOD WASTE WATER FLOW