Title

Toward Green TODs

Authors

Ververo, Robert
Sullivan, Cathleen

Publication Date

2010-08-01

INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Toward Green TODs

Robert Cervero and Cathleen Sullivan

WORKING PAPER
UCB-ITS-VWP-2010-7

UC Berkeley Center for Future Urban Transport
A VOLVO Center of Excellence

August 2010

Toward Green TODs

Robert Cervero and Cathleen Sullivan

August 2010

Abstract

Green Transit Oriented Developments (TODs) shrink environmental footprints by reducing Vehicle Kilometers Traveled (VKT) and incorporating green urbanism and architecture in community designs. Synergies from combining TOD and green urbanism derive from: increased densities, which promote transit usage and conserve heating/cooling expenses; mixed land uses which promote non-motorized transportation and limited-range electric vehicles; reduced impervious parking services matched by increased open space and community gardens; and, opportunities for generating solar power from photovoltaics atop rail-stop canopies. The carbon footprints of Green TODs can be 35% less than those of conventional developments. Experiences with Green TODs are reviewed for urban regeneration projects in Sweden, Germany, and Australia. The paper concludes with ideas on moving Green TODs from theory to practice.

1. The Idea of Green TODs

TOD, or Transit-Oriented Development, has gained popularity worldwide as a sustainable form of urbanism (Cervero, 2008; Renne, 2009). It typically features compact and mixed-use activities configured around light or heavy rail stations, interlaced by pedestrian amenities. TODs are one of the more promising tools for breaking the vicious cycle of sprawl and car dependence feeding off each other, replacing it with a virtuous cycle: one where increased transit usage reduces traffic snarls and compact station-area development helps to curb sprawl.

A new ultra-environmentally friendly version of TOD – what I am calling "Green TOD" -- is taking form in several European cities. Green TOD is a marriage of TOD and Green Urbanism (Table 1). The combination can create synergies that yield environmental benefits beyond the sum of what TODs and Green Urbanism offer individually. TOD works on the VKT-reduction side of shrinking a city's environmental footprint – i.e., reducing Vehicle Kilometers Traveled, a direct correlate of energy consumption and tailpipe emissions. VKT declines not only from rail travel by those living and working in TODs but also by converting trips that would be by car to off-site destinations with on-site walking and cycling. Green Urbanism reduces emissions and waste from stationary sources, in the form of green architecture and sustainable community designs (Beatley, 2000; Newman et al., 2009). With Green Urbanism, pocket parks and community gardens replace surface parking. Renewable energy might come from solar and wind as well as bio-fuels created from organic waste and wastewater sludge. Recycling and reuse of materials, insulation, triple-glazed windows, bioswales, and low-impact building materials further shrink the footprint of Green TODs. In combination, the co-benefits of TOD and Green Urbanism can deliver energy self-sufficiency, zero-waste living, and sustainable mobility.

Synergies that accrue from combining TOD and Green Urbanism could occur in several ways:

(1) Higher Densities. The higher community densities needed to fill the trains and buses that serve TODs also reduce heating and cooling expenses from the embedded energy savings of shared-wall construction. The financial savings from lower energy bills and reduced transportation costs create

higher market demand for compact living in green TOD buildings.

(2) Mixed Land Uses. The inter-mixing of housing, shops, restaurants, workplaces, libraries, day-care centers, and other activities place many destinations close together, thus inviting more walking and bicycling – not only to access rail stops but also for neighborhood shopping and socializing. Green TODs might also help to grow infant-industries like the development of lithium-ion electric vehicles (EVs). Limited range EVs can serve a large share of trips in mixed-use settings, not unlike golf-cart communities. One could imagine a future of hydrogen-fueling and electric-battery swap depots in a green community wrapped around a central rail station.

(3) Reduced surface parking and impervious surfaces. Surface parking, which can consume half the land of many suburban multi-family dwelling complexes (Diasa, 2004), is replaced by more green space for play, socializing, and interacting with neighbors (Figure 1). Shrinking parking's footprint reduces heat-island effects and water pollution from oil-stained run-off into streams. Less impervious surfaces of concrete and asphalt help recharge groundwater and replenish urban aquifers, thereby allowing greener and healthier gardens. While the common perception is that TODs appeal to non-traditional households (e.g., singles; young, childless professional couples, empty-nesters and retirees) (Center for TOD, 2008), Green TODs can be kid-friendly. The interiors of projects are given over to communal gardens, playgrounds, tot-lots, and play-inviting open space rather than parked cars. Reducing the car's dominance can lower accident rates, noise levels, and air pollution –and creates much more enjoyable environments for kids to play. Having safe and secure interiors for kids to play becomes a form of defensible space (Newman, 1996), allowing the kind of natural surveillance embraced in the writings of Jane Jacobs (1961) and others.

(4) Solar energy production at stations. With TODs, stations areas are often community hubs, places not only to get on and off of trains and buses but also to congregate, socialize, and take in community life (Cervero, 1998; Bertolini, 1996). Surface train and bus depots often feature overhead canopies that provide shade and weather protection. Photovoltaic panels and even small wind turbines

can be placed atop canopies at stops to generate electricity that is piped into surrounding homes and businesses through a smart grid. Solar energy can also power light-rail cars, and recharge batteries of plug-in hybrids at carsharing depots and electric buses dwelling at stops during low demand period (as currently done with Tindo solar-electric buses in Adelaide, Australia).

Table 1. Possible Environmental Benefits of Green TODs

TOD ***Mobile Sources***	**Green Urbanism** ***Stationary Sources***
• **Transit Design** World-class transit (trunk & distribution) Station as hub • **Non-motorized access** (bikepaths, ped-ways) • **Bikesharing/Carsharing** • **Minimal Parking** (reduced land consumption, building massing & impervious surfaces) • **Compact, Mixed Uses**	• **Energy self-sufficient** (renewably powered – solar, wind turbines) • **Zero-waste** (recycle; re-use; methane digesters; rainwater collection for irrigation & gray-water use) • **Community gardens** (compost, canopies) • **Buildings**: Green Roofs, Orientation (optimal temperatures), Materials (recycled; low impact)

Figure 1. Green TOD in Rieselfeld, Germany: Gardens and play areas replace surface parking.

As noted, the environmental benefits of TOD by itself, even absent green urbanism and architecture, comes from per capita VKT reductions, courtesy of more transit trips to out-of-neighborhood destinations and more non-motorized travel within (Cervero, 2007; Ewing and Cervero, 2010). However benefits also accrue from policy initiatives like bike-sharing and car-sharing, which research shows prompt residents to shed private cars (Cervero et al., 2007). In TOD settings, bikesharing can solve "the first and last mile problem" – getting to and from stations from origins and destinations that are beyond an easy walk. Sharing bikes becomes all the more attractive when extensive networks of cycleways and paths exist, as borne out by experiences in cities like Copenhagen and Stockholm, where more than 30% of access trips to suburban rail stations are by bicycle, even in inclement weather (Rietveld, 2000; Rietveld and Daniels, 2004). As reviewed in case experiences later in this paper, carsharing also plays a pivotal role in Green TODs. By making the marginal cost of using a car more evident, carsharing prompts "judicious automobility" – members tend to use cars more selectively and when it has clear advantages over alternative modes (e.g., grocery shopping, weekend excursions to the countryside) – and accordingly end up significantly reducing their VKT. The combined effects of substituting car trips for transit, walking, and cycling trips can reduce the VKT per capita of those residing in Green TODs relative to conventional suburban development by an estimated 40% to 50% on the mobility side of the environmental and carbon equation (Cervero, 2007; Ewing and Cervero, 2010; Cervero et al., 2007). Green buildings and green urbanism further reduce energy consumption and carbon emissions from stationary sources relative to conventional development by even higher shares – in the range of 50% to 60%, based on some of the experiences reviewed later in this paper. The synergies of pursuing TOD and green urbanism in combination shrink environmental footprints even more. Back-of-the-envelope calculations suggest reductions in annual CO_2 emissions equivalent per capita among those residing in Green TODs relative to conventional development patterns fall in the 29 to 35 percent range.[1]

[1] This estimate is based on assigning 32 percent of end-use carbon emissions from fossil fuel consumption of urban residents to the surface transportation sector and 22 percent to domestic household consumption, such as for electricity power generation, heating, and cooling. These represent pro-rata estimates of carbon dioxide emissions by end-use sector in the U.S. in 2008, as

Not many TODs have been consciously designed as "Green TODs," certainly not in the United States. More typical are sustainable communities that promote renewable energy and recycle waste and that also have very good transit services. Similarly, many places that bill themselves as eco-communities do not always embrace and showcase public transit to the degree they could. Unlike some of the most successful TODs where the station and its immediate surroundings are often the centerpiece of a community (Cervero, 1998), the stations of eco-neighborhoods are sometimes found on the community's edge.

The next section reviews several case experiences where transit forms the backbone of eco-communities. In these instances, synergies abound from bundling TOD designs with green architecture and green urbanism. In addition to describing the built forms and Green TOD attributes of these places, evidence on environmental benefits is reviewed. The paper concludes with suggestions for moving Green TOD from theory to reality.

2. Case Experiences with Green TOD

The cases reviewed in this section – Hammarby Sjöstad in Stockholm, Sweden; the Rieselfeld and Vauban districts of Freiburg, Gemany; and Kogarah Town Square in Sydney, Australia – come as close to the ideal of a Green TOD as can be found today. Since descriptions and background details of these projects can easily be found on the Internet, the focus here is on isolating elements that make them Green TODs. Where available, statistics on the projects' environmental benefits are presented.

---

recorded by U.S. Environmental Protection Agency (2010). Carbon dioxide represented 85% of human-induced (anthropogenic) greenhouse gas emissions in the U.S. that year. Other savings would accrue that are not explicitly accounted for in these calculations of end-use emissions, such as reduced transportation costs from shipping and marketing food that, as a form of food security, is instead grown in community gardens.

2.1 Hammarby Sjöstad: Stockholm, Sweden

Hammarby, a brownfield redevelopment in the city of Stockholm, is an example, *par excellence*, of marrying TOD and green urbanism. The combination of railway services, car-sharing, and bike-sharing has dramatically reduced vehicle-kilometers traveled of Hammarby Sjöstad's residents and correspondingly greenhouse gas emissions and energy consumption. And the design of an energy self-sufficient and low-waste community has shrunk the project's environmental footprint. Today, residents of Hammarby Sjöstad produce 50% of the power they need by turning recycled wastewater and domestic waste into heating, cooling, and electricity.

The development of Hammarby Sjöstad marked an abrupt shift in Stockholm's urban planning practice. After decades of building new towns on peripheral greenfield sites, Hammarby Sjöstad is one of several "new-towns/in-town" created following Stockholm's 1999 City Plan that set forth a vision of "Build the City Inwards." Consisting of some 160 hectares of brownfield redevelopment, Hammarby Sjöstad today stands as Stockholm's largest urban regeneration projects to date. Table 2 outlines Hammarby Sjöstad's Green TOD features.

Green Transportation

A tramway ("Tvärbanan") runs through the heart of the community along a 3-km boulevard (Hammarby Allé and Lugnets Allé) (Figure 2). Taller buildings (mostly 6-8 stories) cluster along the transit spine, and building heights taper with distance from the rail-served corridor. Trams run every 7 minutes in the peak and provide 5-minute connections to Stockholm's metro underground network and commuter trains. Rail stations are well-designed, fully weather protected, and provide real-time arrival information. Hammarby Sjöstad's buses, moreover, run on biogas produced by local wastewater processing.

Parks, walkways and green spaces are also prominent throughout Hammarby Sjöstad. Where possible, the natural landscape has been preserved. Bike lanes run along major boulevards, ample bike parking can be found at every building, and bike and pedestrian bridges cross waterways. Design features that are integral to TOD, like buildings that go up to the sidewalk line (i.e., no set-backs), offer comfortable and secure

Table 2. Green TOD Attributes of Hammerby Sjöstad

Built Environment	Green Transportation		Green Urbanism	
	Infrastructure	Programs & Policies	Energy	Open Space, Water & Stormwater
* Brownfield * Infill * Former Army Barracks •High density along light rail boulevard (8 stories) •TOD: Mixed use with ground-floor retail- wide range of goods and services	* "Tvärbanan" light rail line: 3 stops in District - 5 minutes to major station - 10-30 minutes to all parts of Center City -7-min peak headway * 2 Bus lines * Ferry * Bike lanes & bike and pedestrian bridges * Ample bike parking at every building •Car-sharing- 3 companies, 37 vehicles •Near congestion toll boundary •Pedestrian-friendly design/Complete Streets	• Transit-Boulevard is focus of activity/commerce • Grid streets increase connectivity/ calm traffic • Convenient Bike parking/storage at every building	•Waste converted to energy: - Food waste & wastewater sludge converted to biogas & used for heating - Combustible waste burned for energy & heat -- Paper recycled * Heat recaptured for reuse * Combined heat & power plant • Low-energy construction & energy saving measures - Efficient appliances - Maximum Insulation & triple glazed windows	* Stormwater treatment - Rainwater collection - Maximum permeable surfaces -Purify run-off through soil filtration * Ample open space: - Inner courtyards - Parks - Playgrounds - Green median -Borders large nature reserve with ski slopes * Preservation of existing trees & open space * Reduced water flow faucets & low-flush toilets

walking corridors with clear sight-lines. As in the case of Hammarby Sjöstad, they also bring destinations together, and through side friction end up slowing traffic.

The presence of 3 carsharing companies which together provide access to 37 low-emission vehicles has further reduced the need for owning a car in Hammarby Sjöstad. Also, the project was designed at just 0.25 parking spaces per dwelling unit, though this rate has inched up some in recent years. All commercial parking, moreover, is for a fee, and rates discourage long-term parking. The neighborhood also sits just outside Stockholm's congestion toll boundary, which adds a further incentive to use public transport, walk or bike when heading to the central city.

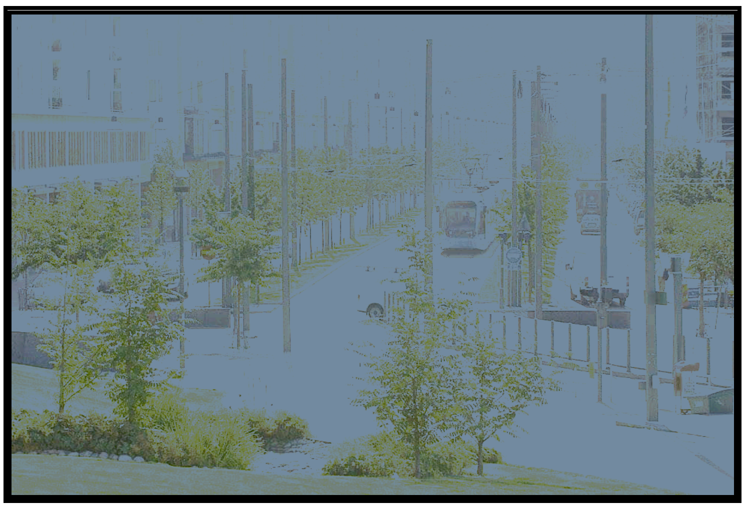

Figure 2. Transit Spine in Hammarby Sjöstad

Green Urbanism

Hammarby Sjöstad's green urbanism is found in energy production, waste and water management, and building designs. The highest standards of energy efficient building are used. All building standards in Sweden are highly energy efficient, being a Nordic country with high heating costs and very high energy prices. The district heating network in Stockholm provides 80 % of all heating needs, substantially reducing energy loss in the heating system. Eighty percent of energy for this heating system comes from renewable sources. The use of district cooling reduces carbon dioxide emissions in Stockholm by about 50,000 tons annually. After heat has been extracted from the warm, purified waste water, the remaining cold water is used for district cooling, such as replacing energy-guzzling, air-conditioning systems in office buildings.

Hammarby Sjöstad's energy platform is cutting edge, even by Stockholm standards. The energy use of buildings in Hammarby Sjöstad has been set at 60 kWh/year, a third less than for the city as a whole. All windows are triple glazed and walls thoroughly insulated. Other conservation measures include extra heat insulation, energy-efficient windows, on-demand ventilation, individual metering of heating and hot water in apartments, electrically efficient installations, lighting control, solar panels, fuel cells, reduced water flow, and low-flush toilets.

The ecological feature of Hammarby Sjöstad that has garnered the most attention is the fully integrated closed loop eco-cycle model. This clever system recycles waste and maximizes the reuse of waste energy and materials for heating, transportation, cooking and electricity. Hammarby Sjöstad's waste management/re-use involves the following:

- Glass, metals and plastics are recycled.
- Combustible waste is incinerated and recycled as heat and electricity.
- Organic waste is composted and turned into soil or converted into biogas.
- All newspaper is recycled into new paper.

The three latter types of waste are dealt with through a stationary vacuum system for solid waste called the "ENVAC system." At each building, residents can deposit waste into vacuum tubes where it is transported to pick-up locations. This minimizes truck traffic through the development, thereby lowering emissions, allowing for narrower streets and less disruption from truck traffic. Waste is also converted into energy for district heating and cooling – in the form of biogas created from treated wastewater (produced in the wastewater treatment plant from digestion of organic waste sludge) and the incineration of combustible waste. In addition, biogas is used to run the buses and biogas cookers are installed in some 1,000 apartments. Solar hot water and solar PV cells are installed on many buildings. Solar panels provide 50% of the hot water needs for many building, although solar installations meet a small share of the development's energy needs due to the Nordic climate.

Also impressive is Hammarby Sjöstad's approach to water management. All storm water, rainwater and snowmelt is collected, purified locally through sand fiber, storm water basins, and green roofs and released in purified form into a lake. A preserved oak forest, ample green surfaces, and planted trees help collect rain water to ensure cleaner air and provide a counterbalance to the dense urban landscape.

Impacts

Based on several environmental impact assessments, secondary data, and interviews, the environmental impacts of Hammarby Sjöstad's form of Green TOD are assessed below.[2] According to the initial assessment, when Hammarby Sjöstad was roughly half built out it had already achieved a 32-39% reduction in overall emissions and pollution (air, soil and water), a 28-42% reduction in non-renewable energy use, and a 33-38% reduction in ground level ozone relative to comparison communities. Buildings and transportation accounted for most of the reduced environmental impacts.

The primary environmental benefit of improvements from Hammarby Sjöstad's buildings came from efficiencies in heating (i.e., recycled organic and combustible waste transformed into heat), use of water, and processing of wastewater. The project's reductions relative to conventional development were: (1) emissions and pollution (air, soil and water) -- 40-46%; non-renewable energy use -- 30-47% ; and water consumption

---

[2] Between 1997 and 2002, a full "Environmental Impact Profile" of Hammerby Sjöstad was commissioned by the City of Stockholm and conducted by Grontmij AB (2008). For drawing comparative insights, a "reference level" was defined: "The reference level used to measure the anticipated reduction in environmental impact in Hammarby Sjöstad is the technology level current in the early 1990s, when planning work on the city district began" (Grontmij, 2008). For our purposes, this reference level can be viewed as conventional new development in the Stockholm region at the time. Hammarby Sjöstad is far more built out today so the results from nearly a decade ago could very well have changed (most likely in the direction of even larger differentials relative to the "reference level" since the project has matured and expanded). At the time the assessment was conducted, approximately 5,000 apartment units had been constructed, less than half of the total development today. This was a full life-cycle evaluation that included energy expenditures and waste tied to site clearance, construction, and operation phases of the development. In 2008, the City of Stockholm also commissioned the Department of Industrial Ecology at the Royal Institute of Technology, KTH, in Stockholm to assess the environmental impacts of Hammarby Sjöstad. The starting point of the evaluation was the environmental program of Hammarby Sjöstad from 1996 and the aim was to gather the most important results and experiences that the City of Stockholm should bring into the planning of new urban districts. Only preliminary results from this second assessment are presently available.

--41-46%. Similar to the rest of Stockholm, 95% of all waste produced by Hammarby Sjöstad's household is reclaimed.

On the transportation side of things, environmental benefits have accrued from Hammarby Sjöstad's relatively high share of non-motorized (walking and bicycling) trips. In 2002, the project's modal splits were: public transport (52%), walking/cycling (27%), and private car (21%) (Grontmij, 2008). Non-car travel shares are thought to be considerably higher today and even in 2002 well exceeded that of comparison suburban neighborhoods of Stockholm with similar incomes (Table 3).[3] Residents' transit modal splits even exceed those of inner-city Stockholm. Also, 62% of Hammarby Sjöstad's households had a car in 2007, down from 66% in 2005 and in line with averages for the denser, core part of Stockholm city (Grontmij, 2008). Studies show that residents' carbon footprint from transportation in 2002 was considerably lower than comparison communities: 438 versus 913 kg CO_2 equivalent/apartment/year (Grontmij, 2008). This is in keeping with the goal of the city of Stockholm to become fossil-fuel free by 2050.

Another barometer of Hammarby Sjöstad's environmental benefits is the relatively healthy local economy – i.e., a higher median household income and lower unemployment rate relative to the city as a whole in 2006. Also, land prices and rents have risen more rapidly over the past decade than most other parts of the Stockholm region. Today, Hammarby Sjöstad is considered to be a relatively desirable and thus more expensive place to live compared to the inner city and other "new towns/in town".

Overall, Hammarby Sjostad has reduced its environmental impact by around one third relative to conventional suburban development in Stockholm. This percent will likely increase over time, at least until Stockholm becomes carbon neutral and fossil free, currently targeted for mid-century.

---

[3] Many residents and employees of Hammarby Sjöstad use a ferry in combination with other modes. The ferry accounts for 24% of all trips to and from Hammarby Sjöstad and has increased walking and bicycling. Modal splits for the ferry are not shown in Table 3 but rather are rolled into trips made by other modes (e.g., walk, bike, bus) since ferries represent one leg of multi-legged (i.e., linked) trips.

Table 3. Mode Splits for Journeys with destination in Stockholm County

	Inner City	Southern Suburbs	Western Suburbs	Hammarby Sjöstad**
Car	17%	39%	43%	21%
Public Transport	36%	28%	23%	52%
Bike/Walk	47%	32%	34%	27%

Source: Grontmij (2008).

2.2 Rieselfeld and Vauban Districts: Freiburg, Germany

The Rieselfeld and Vauban districts of Germany's greenest city – the historic university town of Freiberg – were conscientiously designed to push the envelope of sustainable urbanism.[4] Both are peripheral redevelopment sites linked to central Freiburg via the region's tramway network (Figure 3). And both embody Freiburg's aim of becoming a "City of Short Distances," one that allows "traffic avoidance," which is accomplished through mixed land-use patterns and near-ubiquitous public transit.

Rieselfeld and Vauban abide by Freiburg's obligatory low-energy building standard of 65 kWh/m^2/year (twice as efficient as Germany's national energy standard). Both districts also generate heat and power through wood-chip-fueled cogeneration plants as well as active (e.g., photovoltaics) and passive (e.g., building orientation and architecture) solar energy. Additionally, both developments have comprehensive storm water management systems that collect rainwater, maximize permeable surfaces through provision of ample green space, parks and playgrounds, and purify run-off through bioswales and other soil filtration systems.

---

[4] Freiburg is known as Germany's solar energy mecca, with the highest solar irradiation in the country. Over the past two decades, the city has pursued a host of environmental strategies in transport, energy efficiency and clean energy production, ecosystem protection and management, and waste and pollution reduction. Thus the Green TODs of Rieselfeld and Vauban are a manifestation of Freiburg's larger campaign to be a zero-waste, energy self-sufficient community. In 1992, Freiburg's City Council established that all houses built on municipal land would abide by rigorous low-energy standards and take advantage of passive and active solar. Today, all non-recyclable waste is either incinerated or fermented for bio-mass energy. The city's volume of garbage is markedly lower than the national average.

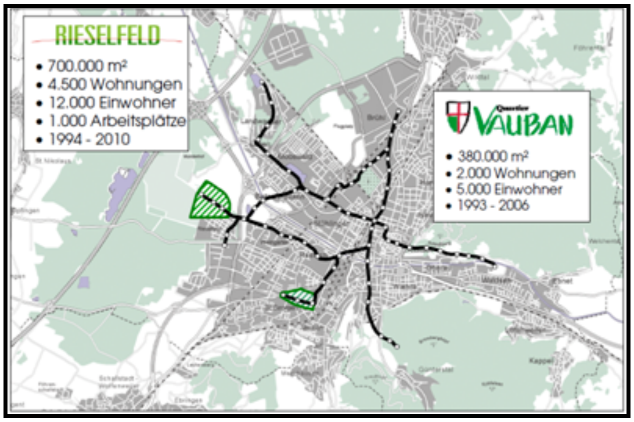

Figure 3. Rieselfeld and Vauban districts of Freiburg, Germany

Rieselfeld

Planned in the early 1990s, Rieselfeld – with a population of 9,100 residents living on 90 hectares – is today nearing completion, around 90% built out. The planned community, which sits on a former wastewater leach field, was designed and marketed specifically for ecologically-minded families. By suburban standards, Rieselfeld has fairly high densities, and through its street designs gives priority to non-auto modes. The community boasts low-energy building construction, a district heating network powered by a combined heat and power plant, decentralized solar energy, and storm water management. Rieselfeld's Green TOD features are summarized in Table 4.

Rieselfeld can be described as "transit-led development" (TLD). A tramway extension to Rieselfeld opened in 1997, a year after the first families had moved in and when there were only 1000 inhabitants. The presence of 3 tramway stations enabled urban growth to wrap itself around rail nodes. With 7-minute peak headways, residents can reach Freiburg's core within 10 minutes.

Reiselfeld is also known for its "barrier-free" living environment, marked by high permeability and connectivity in its layout (Figure 4). Extensive bikeways and ped-ways -- along with narrow streets that slow traffic, a grid pattern, and preferential treatments for trams, buses, pedestrians, and bicycles at intersections -- have promoted sustainable mobility. The district has adopted an uncontrolled "shared space" traffic system that sets maximum car speed at 30 kph and includes many shared "play" streets, which give priority

Table 3. Green TOD Attributes of Rieselfeld District

Built Environment	Green Transportation		Green Urbanism	
	Infrastructure	Programs & Policies	Energy	Open Space, Water & Stormwater
* Brownfield * Contiguous to edge of City * Former wastewater leach field serving as greenbelt * Compact - Highest density along Tramway > 90% multi-family buildings = 5 stories * Mixed use with ground-floor retail	*TOD: main street is 2/3 mile tram corridor * Tram: 3 stops in District * 7-min peak headway * 15-20 minutes to Core * Extensive Bike and Pedestrian paths, access to City center via separated bike paths * Car-sharing * "Barrier-free" living, high permeability/ connectivity * Uncontrolled shared space traffic system: - Shared "play" streets, children have priority * No stop signs, right yield	* Priority for trams, pedestrians & bicycles * Car traffic limited: - Maximum traffic speed 30 kph - Traffic calming & narrow streets - Grid layout prevents cut-through traffic * Convenient bike parking/ storage * Park-and-ride facilities * Parking ratio: 1:1 in underground garages	• Active and Passive Solar (architecture/ orientation & PV) * Low-energy construction * District Heating * Combined Heat and Power Plant (co-generation) * Energy saving measures	• Stormwater Management system: - Rainwater collection - Maximum permeable surfaces - Purify run-off through soil filtration •Ample Open Space: - Inner courtyards - Parks - Playgrounds - Green median - Borders large nature reserve with hiking trails

to children and pedestrians (Figure 5). Absent any stop signs, a right yield system is used at intersections. Active living and physical fitness are promoted by a network of parks, playgrounds, and a natural reserve that surrounds the community.

Figure 4. Rieselfeld District, Freiburg, Germany. Small blocks, ample green spaces, and a tram line runs through the tree-lined center of the village promote walking and cycling.

Figure 5. Rieselfeld's Shared Streets.

Vauban

Situated on 40 hectares of land formerly used as a military barrack and inhabited by 5,000 residents, Vauban is arguably one of the greenest places in the world. The community is a product of a highly participatory grassroots process. A number of activists, feeling that the mobility and energy standards applied in Reiselfeld were insufficient, demanded that a car-free, ultra-low-energy district be built. Soon thereafter

Vauban was born. The first residents formed a collective and occupied the former military barracks. Many still live there today.

Vauban's Green TOD attributes are summarized in Table 4. The district features one of Germany's largest passive house developments and a zero-energy solar village.[5] Vauban's cogeneration plant is fueled by a renewable source of refuse wood-chips. There are also 89 photovoltaic systems throughout the development. Due to its ambitious energy standards, the district performs 90% better than conventional construction in terms of energy use (Siegl, 2010). The combined heat and power plant runs at 90% efficiency compared to a conventional power plant. Additionally, all houses meet and many exceed Freiberg's energy standard of the 65 kWh/year (including Vauban's numerous zero-energy houses and passive houses with solar, which actually produce more energy than they use).

In addition to its ecological design, Vauban is widely known for its car-restricted living (in contrast to Rieselfeld which averages 1.1 parking spaces per dwelling unit). Most of Vauban's streets ban cars, and most housing units have no driveway or garage (Nobis and Welsch, 2003). Cars on the main street are restricted to 30 kph and all other streets are designed for very low-speed travel (5 kph) (Figure 6). Vauban was laid out so that all residents live within 2 minutes of a covered bike-sharing kiosk and 5 minutes of a tram. With the district organized around a tramway spine that is nestled into the streetscape and 7-minute peak headways, transit has a certain omnipresence in Vauban (Figure 7).

Vauban's planners made sure that parking's environmental footprint was limited. All parking is unbundled from the price of units, and fees to purchase a space are quite high at €17,500/space.[6] Seventy percent of dwelling units are "parking-free," and what little parking that does exist is sited in two shared garages on the town's periphery (Figure 8). Both garages are topped off with solar panels.

---

[5] Vauban exceeds Freiburg's low energy standard with a voluntary low-energy building standard of 55 kWh/m^2/year and a passive house standard of 15 kWh/m^2/year.

[6] The planners of Vauban had to work with the City of Freiburg to develop a special waiver from the German National parking standard of one space per dwelling unit. A lot had to be reserved in one corner of the development for a future garage if the need should arise; car-free residents have to reserve a theoretical space in this yet-to-be-built garage at a much lower price of around 3,000€ compared to 17,500€ for an actual parking space.

Table 4. Green TOD Attributes of Vauban District

Built Environment	Green Transportation		Green Urbanism	
	Infrastructure	**Programs & Policies**	**Energy**	**Open Space, Water & Stormwater**
* **Brownfield:** Former military barracks * **Infill** • **Compact** - = 4 stories •**Mixed use** with ground-floor Retail	• **TOD: District** organized around tram spine * **Tram:** 3 stops * 7-min peak headway * Regional rail stop (Future) * 2 buses * 10-15 minutes to City Center by tram/ bus/ bike * **Extensive Bike and Pedestrian paths;** access to City Center via separated bike paths • Network of off-street bike & pedestrian paths provides access to all parts of project	* **Parking restricted:** - **High** parking fees - Unbundled parking -70% of units are "parking-free -Access to parking in 2 shared garages on periphery * **Auto restraints:** - 30 kph on main street - Limited access with very low speeds 5 kph - Street layout allows for very l little car circulation • **Bike Priority:** covered secure bike parking within 2 minutes of every residence • Car-sharing	* Low-energy building— 65 kWh/m²/year standard, Voluntary: 55 kWh/m²/year; Passive house: 15 kWh/m²/year * District Heating • Wood-chip fired Combined Heat and Power Station provides all energy * Solar- 89 PV systems * Zero-energy Solar Village • One of largest passive house developments in Germany	• Bioswales, open-channel-trough system * Rainwater collection • Ample Open Space & permeable surfaces * Filtration of rainwater * Maintain existing tree coverage * Adjacent to creek biotope * Green roofs

Figure 6. Car-free Streets and Solar Array, Main Plaza of Vauban

Figure 7. Vauban's Central Tramway line. Source: Melia (2007)

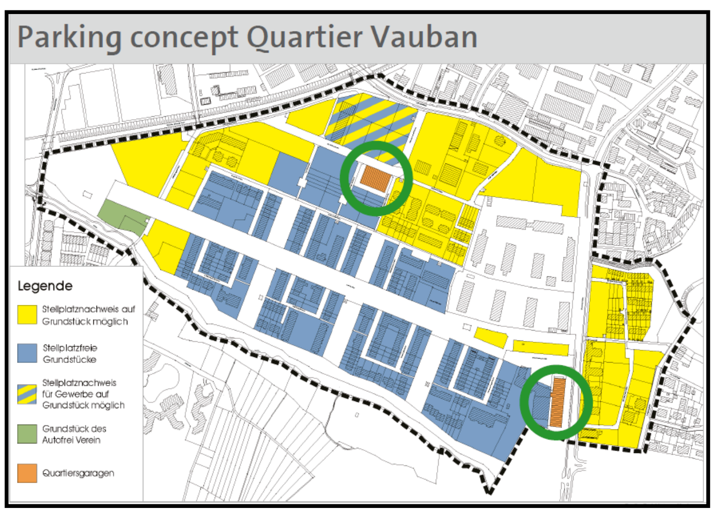

Figure 8: Location of Parking Garages, Vauban. Source: Schick (2009)

Mobility Impacts

The environmental payoff of the pro-transit and bike-ped-friendly policies of Rieselfeld and Vauban are reflected in statistics. Both districts have low auto use and ownership. As shown in Table 5, Reiselfeld residents own fewer cars and use transit more than the typical Freiburg resident. Ninety percent of its residents buy a monthly transit pass. Because residents' travel was last surveyed in 2003 before the tramway had opened, it is difficult to provide an up-to-date account of experiences in Vauban. However, other indicators suggest that Vauban has very low car use. Only 2.2 of every ten Vauban residents own a car (compared to 4.3 for Freiburg as a whole and 3.4 for Reiselfeld).[7] Also, 57% of Vauban's adult residents sold a car upon moving to the district (Sustainability Office, City of Freiburg). It is notable that low car ownership was recorded in Vauban before its tram line opened. This very likely reflected the influences of "self selection" – i.e., the car-free ethic of new residents. However other factors have weighed in as well, including the pro-active promotion of other modes, the provision of a free universal transit pass to some households, and the availability of conveniently located carsharing. Although recent modal split data are not available, the consensus view is that transit use has replaced many bike and walk trips (Siegl, 2010). Most of Vauban's residents buy a monthly transit pass and half buy a German National Rail Pass. Moreover, 75% of car-free households buy the national rail pass, compared to 10% of Germans nationwide (Nobis and Welsch, 2003).

2.3 Kogarah Town Square: Sydney, Australia

While European cities can lay claim to having advanced the art and science of building Green TODs more than anywhere, Sydney's Kogarah Town Square has made pretty good headway. Newman et al. (2009, pp. 120-121) cited it as a sustainable, rail-served, and thriving "mixed-use development consisting of 194 residents, 50,000 square feet of office and retail space, and 35,000 square feet of community space, including a library and town square." Liberal use of photovoltaic collectors and building orientations that maximize thermal in-take, along with the close proximity to a train station, has shrunk the carbon footprint of Kogarah Town Square relative to similar districts in

[7] 19% of residents had never owned a car, 57% gave up car upon moving to Vauban.

Sydney. As with European Green TODs, ample open space wrapped around an attractive and well-lit town center has contributed to the project's attractiveness (Figure 9).

Table 5. Modal Split and Car Ownership Statistics

Mode of Travel:	**Rieselfeld (1999)***	**Vauban (2003)****	**Freiburg (1999)*****	**Region: Baden-Württemberg**
Walk	16%	28% car-owning HHs 33% car-free HHs	23%	
Bike	28%	40% car-owning HHs 51% car-free HHs	27%	
Public Transport	25%	~4-11% (Before tram service commenced)	18%	
Car	31%	28% car-owning HHs 2% for car-free HHs	**Car** 26% **Carpool** 6% 32%	
Car Ownership per 1000 residents (2008)	337	222	431	634

* Broaddus (2009)
** Nobis and Welsch (2003).
*** Schick (2009)

Figure 9. Kogarah Town Square: Sydney, Australia. Traditional architecture, central rail stations, and open civic squares.

3. Conclusion

Green TODs offer a form of urbanism and mobility that could confer appreciable environmental benefits. They emphasize pedestrian, cycling, and transit infrastructure over auto-mobility. They mix land uses which not only bring destinations closer but also creates an active, vibrant street life and interior spaces, instilling a sense of safety and security. And through building designs and resource management systems, they embrace minimal waste, low emissions, and to the degree possible, energy self-sufficiency.

The case experiences reviewed in this paper highlight the potential benefits of Green TOD. While other places in Sweden (e.g., Mälmo), Germany (e.g., the Kronsberg district of Hannover), and Australia (e.g., Adelaide) have made strides in advancing green urbanism and transit-friendly development, places like Hammarby Sjöstad, Rieselfeld, Vauban, and Kogarah have successfully integrated both elements in their community designs. Green TOD, we note, appear to be catching on elsewhere, such as in Jiaxing, China and Kaohsiung, Taiwan. Perhaps the most ambitious version is now taking shape in the deserts of the United Arab Emirates – Masdar City, outside of Abu Dhabi. Besides being car-free and interlaced by rail at the surface level and personal-rapid transit (PRT) and freight-rapid-transit (FRT) below-ground, Masdar City is to be fully energy self-sufficient, courtesy of a massive solar farm on the project's edge. Additionally, all organic waste is to be converted into biomass, all construction materials are being recycled, and over the long term the project is to become completely carbon neutral. Other communities should not necessarily seek to replicate the specific practices of these places but rather adapt principles of Green TOD to local circumstances and constraints.

Moving beyond the rhetoric to the reality of Green TODs will take money, time, and political leadership. The built-in structural forces that work against designing safe, resource-conserving, and pedestrian-friendly districts around transit stations are immense, particularly in countries like the U.S. Barriers are most likely to come down through encouraging real-world examples, such as those reviewed in this paper.

One sensible way to help finance Green TODs is through value capture mechanisms. The degree to which Green TODs create benefits is reflected in land prices, as experienced in Hammarby Sjöstad. Indeed, land sales were the principal means by which early rail systems were financed in the U.S. and much of Europe (Bernick and

Cervero, 1997). Today, Hong Kong recaptures the value-added from rail investments to help finance not only transit infrastructure but the armature of the surrounding community as well, including open spaces, sidewalks, and green corridors (Cervero and Murakami, 2009).

Green TODs will be most effective when planned and designed at a regional level (Cervero, 1998). The Scandinavian model of TODs as "a necklace of pearls" offers high environmental benefits by providing an inter-connected system of walkable, transit-friendly communities. However, not every rail-transit station should become a Green TOD, or even a TOD for that matter. Some function best as busy terminal/transfer points and logistical nodes, with little if any housing, which is a cardinal feature of TOD. Some with poor pedestrian connections, such as stops in the middle of freeway medians, might best be surrounded by surface parking. However for communities aiming to push the envelope of sustainable urbanism and with a physical and social environment conductive to transit-supportive growth, the Green TOD model has much to offer.

Critics are apt to label Green TOD as "social engineering". In truth, many of those living in the suburbs of the United States are "engineered" – forced to drive to get from anywhere to everywhere, a result of segregated and low-density land-use patterns. Green TODs provide consumers with more choices on where to live and how to travel. Increased choices and variety is a good thing, especially given the increasingly diverse and plural make-up of households in America and other affluent societies. We suspect that given the opportunity, more and more middle-class households will opt for Green TODs for lifestyle reasons.

References

Beatley, T. 2000. *Green Urbanism: Learning from European Cities*. Washington, D.C.: Island Press.

Bernick, M. and Cervero, R. 1997. *Transit Villages in the 21st Century*. New York: McGraw-Hill.

Bertolini, L. 1996. Nodes and places: Complexities of Railway Station Redevelopment. *European Planning Studies*, Vol. 4, No. 3, pp. 331-345.

Broaddus, A. 2009. A Tale of Two Eco-Suburbs in Freiburg, Germany: Parking

Provisions and Car Use. *Transportation Research Record* (forthcoming).

Center for TOD, *TOD 101*. 2008. Washington, D.C.: Federal Transit Administration.

Cerfontaine, C. 2007. The Vauban district in Freiburg in Brisgau: living in a holiday destination. *PTI* September/October, pp. 30-33.

Cervero, R. 1998. *The Transit Metropolis: A Global Inquiry*. Washington, D.C.: Island Press.

Cervero, R. 2007. Transit Oriented Development's Ridership Bonus: A Product of Self Selection and Public Policies, *Environment and Planning* A, 39: 2068-2085.

Cervero, R. 2008. Transit-Oriented Development in America: Strategies, Issues, Policy Directions. *New Urbanism and Beyond: Designing Cities for the Future*, T. Haas, ed. New York: Rizzoli, pp. 124-129.

Cervero, R., Golub, A., and Nee, B. 2007. City CarShare: Longer-Term Travel-Demand and Car Ownership Impacts, *Transportation Research Record*, 199: 70-80.

Cervero, R. and Murakami, J. 2009. Rail + Property Development in Hong Kong: Experiences and Extensions, *Urban Studies*, Vol. 46, No. 10, pp. 2019-2043.

Cervero, R., Adkins, A., and Sullivan, C. 2010. Are Suburban TODs Over-parked? *Journal of Public Transportation*, Vol. 13, No. 2, 2010, pp. 47-70.

Daisa, J. 2004. Traffic, Parking, and Transit Oriented Development. *The New Transit Town: Best Practices in Transit-Oriented Development*, Dittmar, H. and Ohland, G., eds. Washington, DC: Island Press, pp. 114-129.

Ewing, R. and Cervero, R. 2010. The Built Environment and Travel: A Meta-Analysis. *Journal of the American Planning Association*.

FWTM (Management and Marketing), City of Freiburg. *Quartier Vauban: A Guided Tour*.

Grontmij, AB. 2008. Report summary -Follow up of environmental impact in Hammarby Sjöstad. Stockholm.

Jacobs, J. 1961. *The Death and Life of Great American Cities*. New York: Random House.

Melia, S. 2007. *On the Road to Sustainability: Transportation and Carfree Living in Freiburg*. Faculty of the Built Environment, UWE Bristol.

Newman, O. 1996. *Creating Defensible Space*. New Brunswick: Center for Urban Policy Research.

Newman, P., Beatley, T. and Boyer, H. 2009. *Resilient Cities: Responding to Peak Oil and Climate Change*. Washington, D.C.: Island Press.

Nobis, C. and Welsch, J. 2003. Mobility management at district level: The impact of ar-reduced districts on mobility behavior. 7th European Conference on Mobility Management, Karlstad, Sweden, May.

Renne, J. 2009. From transit-adjacent to transit-oriented development. *Local Enviornment*, Vol. 14, No. 1, pp. 1-15.

Rieselfeld Projekt Group. 2007. The new district of Rieselfeld. City of Feiburg in Breisgau.

Rietveld, P. 2000. Non-motorized modes in transport systems: A multimodal chain perspective for The Netherlands. Transportation Research D 5:31–36.

Rietveld P, Daniel V. 2004. Determinants of bicycle use: Do municipal policies matter? Transportation Research A 39:531–550.

Scheurer, J. 2001. *Urban Ecology, Innovations in Housing Policy and the Future of Cities: Towards Sustainability in Neighbourhood Communities*. Freemantle, Australia: Murdoch University, Institute for Sustainability and Technology Policy.

Schick, P. 2009. Urban development and transportation planning in Freiburg im Breisgau. Freiburg: unpublished report.

Siegl, K. 2010. The new district of Freiburg-Rieselfeld: a case study of successful, sustainable urban development. Freiburg in Breisgau.

Sustainability Office, City of Freiburg. 2009. *Freiburg: Green City*. Freiburg im Breisgau.

U.S. Environmental Protection Agency. 2010. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008. Washington, D.C.: U.S. Environmental Protection Agency, EPA 430-R-10-006.