Transit Synergized Development
Framework for a Smart, Low-Carbon, Eco-City

James S. Lee AIA LEED-AP

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December 31, 2012

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Table of Contents

Acknowledgements
Abstract
1. Executive Summary
2. Planning
3. Technology
4. Implementation
5. Case Studies
6. Conclusion
Appendices
References
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The Transit Synergized Development (TSD) model was conceived in 2009 jointly by the author and William Wong, Director of Building Service at the engineering firm Arup. William’s guidance has been invaluable in the journey of turning TSD from a concept into a model. Early collaborators also included Rob Watson, Samuel Huang, Brian Tse and Solomon Huang.

The research has benefited immensely from the individual and collective wisdom of the advisors, whose help in clarifying and integrating the multiple dimensions of this complex, holistic model was invaluable. The author wish to express special thanks to his advisor Chen Xiaohui and her task force who developed a pioneering tool to model “urban energy density.” Task force members include Hua Hairong, Chen Guowei and Qin Xinmei.

The author was also fortunate to have enlisted the help of three talented young research assistants, who provided depth in key areas of the model: distributed energy generation, transit-oriented development and financial modeling, respectively.

Many others have enriched the research with their advice, insight and inspiration, including Bill Browning, Albert Chan, Claudine Cheng, John Cooper, Paul Doherty, Fang Chuanglin, Foo Yang Kwang, Stephen Hammer, Jin Shanlun, Craig Johnston, Lee Eng Lok, Patrick Mazza, Terry Mohn, Pan Haixiao, Sheila Sheridan, Shi Minqi, Tey Peng Kee, Daniel Wang, Wu Jiandong, and Zhao Zhao. The author apologizes for any omissions. To all of them, the author owes a debt of gratitude.

Last but not least, the author wishes to thank the Urban China Initiative for sponsoring this research and for the steadfast support of Co-Chair Jonathan Woetzel, Research Director Zhang Gengtian and Director of Strategic Engagement Eadie Chen, and for the dedicated assistance of Annie Wang, Sisi Luo, Yameng Hu, Angel Huang and others. Their enthusiasm and encouragement have been heart-felt and deeply appreciated.
Abstract

Transit Synergized Development (TSD) is a new model of urban development that aims to transform China’s next generation of transit-ready cities into smart, low-carbon, eco-cities. Cities with mass transit systems form the backbone of China’s “City Clusters”, a strategic network of 170 cities in twenty megaregions that will drive China’s economic development in the 21st century.

TSD unleashes the synergy inherent in designing transit, land use and energy systems holistically, by focusing on the integrated planning, development and management of a nominal 1-km² urban district around a mass-transit station, the “transit district.”

TSD seizes the opportunity created by transit construction to upgrade a city’s energy infrastructure, one transit district at a time. Utilizing IT, energy and environmental technologies, TSD creates an advanced district infrastructure that transforms each transit district into a smart, low-carbon, eco-district. Achieving scale through the transit network, TSD creates a framework on which to build a smart, low-carbon, eco-city and new energy economy.

In fact, TSD’s implementation will go hand in hand with China’s City Cluster strategy, providing a replicable model of sustainable urbanism, scalable from the grass-roots level to the national level – a model of sustainable development “with Chinese characteristics.”

Integrated planning, development and management is the strength of the TSD model. Yet, the high levels of coordination required among multiple stakeholders in private and public sectors present significant challenges to broad adoption of the model.

This study examines the planning, technical and implementation considerations for a successful adoption of TSD in China.

Key Words

1 Executive Summary

Amidst global urbanization and economic globalization, the City Cluster will become China’s new regional unit to participate in global competition and international division of labor. China’s City Cluster development will have a profound impact on our country’s international competitiveness, and the new global economic landscape of the 21st century.

2010 China’s City Cluster Development Report
2010 中国城市群发展报告

In the 12th Five Year planning cycle, China has a historic opportunity to create a new generation of sustainable cities that will help advance China’s leadership in the global economy. To achieve this, cities must adopt an integrated development model that captures the benefits in planning transit, land use and energy systems holistically, incorporates the latest smart, low carbon and green technologies into the city’s infrastructure, and secures long-term, high performance through modern urban management.

Transit Synergized Development (TSD) is an integrated planning, development and management model that focuses on transit-ready cities in China. As it will be articulated in this paper, TSD will help this strategic class of cities to attract capital investment and talents and develop into competitive, world-class, "smart, low-carbon, eco-cities" of the 21st century.

Why Transit Cities?

Transit cities are among the largest, densest, most economically robust cities in China, and its most energy and resource intensive.¹ This is evident from the established criteria for mass transit development in China:

<table>
<thead>
<tr>
<th>Transit System</th>
<th>City Population (Million)</th>
<th>City GDP (Billion RMB)</th>
<th>City Revenue (Billion RMB)</th>
<th>Peak Flow Rate (Pax/Hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Rail (LRT)</td>
<td>1.5</td>
<td>60</td>
<td>6</td>
<td>10,000</td>
</tr>
<tr>
<td>Subway (MRT)</td>
<td>3.0</td>
<td>100</td>
<td>10</td>
<td>30,000</td>
</tr>
</tbody>
</table>

In its 2009 study, Preparing for China’s Urban Billion, the McKinsey Global Institute projected that by 2025, 1 billion Chinese will live in cities, 221 cities will have a population of over a million, energy demand will double, and up to 170 mass transit systems could be built.² Clearly, China’s urbanization will be high density, energy intensive and transit-oriented.

¹ Source: http://finance.sina.com.cn/g/20060413/09342497666.shtml
² McKinsey Global Institute, Preparing for China’s Urban Billion, March 2009
What is Transit Synergized Development?

Transit Synergized Development (TSD) is an model of integrated design, development and management of next-generation transit cities in China that captures the synergy derived from integrating mass transit, district energy and green districts. TSD focuses on “transit districts” (nominal 1 Km² urban districts around transit stops), arguably the energy and resource “hot spots” of the city. TSD leverages the greater scale, density, energy intensity and economic value of development in a transit district to incorporate a new energy infrastructure, green district and green building design, and energy management, transforming each transit hub into an "Energy Hub" and each transit district into a "Smart, Low-Carbon, Eco-District".

Energy Hubs become “Innovation Hubs” that drive technology innovation, economic growth and job creation. They incorporate global best practices in green neighborhood design to create vibrant “Social Hubs” that enhance quality of life. The transit network connects these hubs, providing a framework for creating a "Smart, Low-Carbon, Eco-City", while the new energy infrastructure provides in essence a framework on which to build a new energy economy.

Advanced Technologies

Three groups of technologies underpin TSD’s advanced infrastructure:

- **Low-Carbon Technologies**
  - District Energy System delivers efficient cooling, heating and possibly electricity to the entire district.
  - Smart Microgrid facilitates real-time monitoring and management of energy use, promotes renewable energy and EV integration, enables energy data collection and carbon accounting, and provides a building block for a nationwide Smart Grid.
  - Grid Energy Storage uses advanced battery technology to store surplus electricity generated by power plants at night. This helps to shave peak loads, lower carbon emission and improve grid stability.

- **Smart Technologies**
  - A “Digital DNA System” captures the digital data that describes a city, including its infrastructure and buildings, creating a digital profile of the city, its Digital DNA.
  - A “Central Nervous System” includes five layers of data technologies – sensors, transmission, storage, analytics and visualization – that captures, analyzes and displays real-time data of city operations to optimize efficiency and facilitate decision-making.
  - “Smart City”: 5 district-level functions can be optimized with smart technology – Energy, Water, Waste, Transportation and Buildings.

- **Green Technologies**
  - Green buildings improve energy, water and resource efficiency.
  - Green neighborhoods reduce storm water runoff and urban heat island effect, promote mixed use, walkability, social interaction, air and water quality, biodiversity and quality of life.

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3 Use of the term “Energy Hub” courtesy of Patrick Mazza, Research Director, Climate Solutions, Portland, OR
4 Paul Doherty, From Smart Buildings to Smart Cities, Realcomm Advisory, December 2012
“Triple Bottom Line” Benefits

TSD’s integrated design, development and management yield multiple benefits.

- **Energy and Environmental Benefits**
  - Creating a citywide network of Energy Hubs (“Networked Microgrids”) enhances the electric grid’s ability to manage peak loads, improves grid security and increases capital efficiency.

- **Economic Benefits**
  - District energy infrastructure, along with green buildings and energy management, deliver direct benefits to building owners, tenants and residents, including capital efficiency and energy savings.
  - Energy Hubs are also “Innovation Hubs” that generate societal benefits. They help to create new businesses and jobs, diversify the local economy, attract investments and drive economic growth.
  - Creating a smart energy and information infrastructure makes the city more competitive by cutting energy costs, boosting productivity and attracting businesses, investments and talent. It can also offer the city a market differentiator, a branding opportunity.
  - Smart, low-carbon and green technologies, products and services are in demand worldwide. Promoting them in transit cities fosters local economic growth and expansion into global markets.

- **Social Benefits**
  - TSD also transforms transit hubs into “Social Hubs”, vibrant, live-work-play-learn centers that promote social interaction, spark innovation, build a sense of community and foster a greener lifestyle.
  - Promoting compact, walkable neighborhoods with convenient access to transportation, employment, shopping, recreation, open space and other amenities enhances quality of life for residents, reduces urban sprawl and the attendant travel-related energy cost.

TSD’s “Triple Bottom Line” benefits promote sustainability, while providing a catalyst for the city’s energy, economic and social transformation.

**Strategic Significance of the TSD Model**

Transit cities form the backbone of China’s City Clusters (城市群), a strategic network of 170 cities in 20 megaregions that will propel China’s economic growth in the 21st century. (Fig 1-3).

The City Cluster model was formally adopted in China’s 12th Five-Year Plan. 20 city clusters, guided by coordinated economic development strategies, will drive China’s domestic growth, global integration and global competition. In 2010, City Clusters accounted for 21% of China’s land area, 49% of its population, 80% of GDP and 98% of Foreign Direct Investment. Put simply, City Clusters are the “lifeblood of China’s national development.”

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5 “中国城市群可持续发展理论与实践”，方创琳，宋吉涛，蔺雪芹著（科学出版社）
6 “中国城市群发育的新型驱动力研究”，方创琳，王婧（地理研究，第30卷，第2期2011年2月）
“Cluster Cities”, like transit cities, will be among the most populous, energy intensive and resource intensive cities in China. Indeed, they are closely correlated. In 2012, 55 of the 60 transit cities are cluster cities. Clearly, transit cities and cluster cities are both strategic to China. Mitigating their energy and environmental impacts will be critical to their sustainability.

**TSD: A Natural Fit with the China’s City Cluster Model**

TSD complements China’s City Cluster model: both are transit-oriented and network-based. A salient feature of China’s City Cluster model is that economic networks are linked by efficient air, highway and railway networks. Notably, all 30 core cities within the City Clusters are linked by the national high-speed rail network (Fig. 1-4), while key cities within each cluster are linked by inter-city high-speed rail network (Fig. 1-5), and key activity nodes within these cities are linked by subway networks (Fig. 1-6).

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7 Cities that are operating, building or planning transit systems; http://en.wikipedia.org/wiki/Rapid_transit_in_China

8 “中国城市群可持续发展理论与实践”，方创琳，宋吉涛，蔺雪芹等著（科学出版社）
Figure 1-2 China City Clusters Linked by National High-Speed Rail Network

Figure 1-3 Yangtze Delta Cluster Linked by Regional High-Speed Rail

Figure 1-4 Shanghai’s Major Activity Nodes Linked by Subway Network
The highly networked character of the City Clusters implies that local effects, positive or negative, can propagate rapidly through the system. Indeed, Dr. Fang Chuanglin, chief architect of China’s City Cluster model, issues a dire warning: “Any failure of the severely overloaded infrastructure will result in rapid paralysis of the City Clusters, and even the total collapse of the economic system.”

Similar to China’s City Cluster model, TSD is modular and network-based. TSD helps to ensure that the energy hot spots of the cluster cities, namely their transit districts, are transformed into energy- and resource-efficient, low-carbon districts. Through the cascading effect of local, regional and national transit networks, the sustainability benefits of the transit districts are projected to the city, the megaregion, and the entire country.

TSD’s modular and network-based infrastructure offers a high degree of robustness and resilience, providing a solid foundation of sustainability and economic growth for City Clusters at the grassroots level. Therefore, if adopted nationally, TSD can play a pivotal role in the success of China’s City Cluster strategy.

A Sustainable Development Model with Chinese Characteristics

Transit cities are strategic to China’s economic growth. Targeting transit districts, the energy “hot spots” and important activity centers of the city, TSD offers a sustainable development solution at the grassroots level that complements China’s City Cluster strategy at the national level. If applied as a policy mandate to all transit cities, TSD could serve to catalyze the energy, technological, urban, social and economic transformation of China. Pragmatic, replicable and scalable, TSD is a sustainable development model with “Chinese characteristics.”

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9 “中国城市群形成发育的新格局及新趋向”，方创琳 （地理科学. 第 31 卷，第 9 期 2011 年 9 月）
10 Brian Walker and David Salt, Resilience Thinking, Island Press - 2006
Planning

Large scale, concentrated development is the hallmark of China’s mode of urbanization. High-density cities require public transportation to mitigate the potentially debilitating impacts of pollution, congestion, productivity loss and reduced quality of life. Currently, 60 cities in China are operating, building or planning mass transit systems (referred to as “transit cities”.)

TSD aims to create a new model for developing transit cities in China, one predicated on integrated land use, transit and energy planning. This section examines TSD’s planning methodology, which incorporates innovations in transit-oriented development, green urbanism and district energy.

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Planning and Design Principles

TSD is a network-based, modular approach to creating a sustainable city. TSD transforms each transit hub into an Energy Hub and each transit district into a low-carbon district. Applying the scaling effect of the transit network, TSD creates the framework for a smart, low-carbon, eco-city.

TSD core concept

TSD defines “transit district” as a nominal 1-km² urban district around a transit station. At the district level, TSD embraces sustainable neighborhood planning principles championed by transit-oriented development, including promoting mixed-use developments around transit nodes, adding parks and public space, bike paths, and pedestrian-friendly walkways to reduce car use, improve air quality and promote social interaction.

Energy Hub

In addition, TSD utilizes the scale, density, energy intensity and economic value of development at transit districts to create the basis for effective district energy systems. The higher economic values associated with transit districts ensure that an advanced energy infrastructure is both justifiable and affordable.
The district energy system creates an “Energy Hub” that delivers energy efficiency services such as aggregating energy supply and demand, providing district heating and cooling, and centralizing energy monitoring and demand-side management (DSM). A strong focus on DSM in turn promotes building energy efficiency, energy consciousness among end-users and improves grid stability. Smart end-users create demand for energy efficiency across the market spectrum: from energy retrofits to technologies such as distributed renewable energy generation. Indeed, Energy Hubs can be a center for energy management and energy upgrade for existing buildings around the transit district, thereby expanding the boundary of the low-carbon district.

**Innovation Hub**

Energy Hubs are also “Innovation Hubs” that can drive technology innovation, economic development and job creation. Coordinated action among a citywide network of Innovation Hubs, organized into specialized economic clusters, can provide the basis for “green growth” strategies focused around smart, low-carbon and green technology sectors.\(^{14}\)

Innovation Hubs are perfect incubation labs to conduct “rapid prototyping” of new energy technologies such as the “Smart Microgrid.” Innovative products could be readily incorporated into energy retrofit projects within the district. And as demand for new technologies, products and services rise over time, it will advance the pace of the city’s economic growth and transformation.

**Social Hub**

Energy Hubs are also “Social Hubs”, vibrant activity centers serving compact, walkable neighborhoods with convenient access to transportation, jobs, shopping and recreation. Social Hubs foster social interaction, sparks innovation and enhances quality of life for residents. Studies have shown that such dynamic environments are magnets for creative talents.\(^ {15}\)

Social Hubs help foster a greener lifestyle. Indeed, with a population of 1.3 billion people, China’s transformation into a sustainable society requires the buy-in of the populace, which is predicated on cultural and behavioral change.

TSD focuses on the grass-roots level, within each city, each neighborhood, indeed within each individual. TSD recognizes the power of “placemaking”, the creation of memorable public spaces that unite people around a larger vision of community, one defined by sustainable neighborhoods, streets, squares and buildings; a community where media amplifies the unique narrative of people and place; a community where abstract concepts of sustainability are transformed into real environments that people can touch, feel and resonate with, indeed, environments that they will love. And this will spark a paradigm shift, for, in the end, “people protect what they love.”\(^ {16}\) TSD’s Social Hubs will create such transformative environments.

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16 Jacques Ives Cousteau, deep-sea explorer and “Custodian of the Sea.”
Transit System Considerations

The three main types of mass transit vary in carrying capacity:

- **MTR** (Metro Rail Transit),
- **LRT** (Light Rail Transit)
- **BRT** (Bus Rapid Transit)

<table>
<thead>
<tr>
<th>Mass Transit Capacity (pax/hr)</th>
<th>BRT</th>
<th>LRT</th>
<th>MRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical</td>
<td>2,000 - 10,000</td>
<td>3,000 - 18,000</td>
<td>13,000 - 41,000</td>
</tr>
<tr>
<td>Maximum</td>
<td>40,000</td>
<td>40,000</td>
<td>80,000</td>
</tr>
<tr>
<td>Bogota/Guangzhou</td>
<td></td>
<td>Manila</td>
<td>Hong Kong</td>
</tr>
</tbody>
</table>

Source: Jennifer Day and Robert Cervero17

In principle, TSD is applicable to MRT, LRT and BRT systems alike, provided sufficient passenger flow exists at their respective transit nodes, since passenger flow creates the concentration of land use that drives higher energy density and economic value, the enablers of TSD districts.

A review of global best practices of T.O.D.18 employing MRT, LRT and BRT systems suggest that passenger flow is a function of the holistic planning of the transit system, taking into consideration the following factors:

- **Modal Shift: turning drivers into riders**
  - Provide better passenger amenities
  - Adopt pedestrian- and bike-friendly design, along with congestion pricing, vehicle quotas and lane reduction to promote non-motorized transport
  - Integrate transit design to offer higher speed and efficiency
  - Deploy ITS (Intelligent Transportation Solutions) to attract smart riders

- **Modal Integration: The “Last Mile” Problem**
  - Improve bicycle integration at transit stops
  - Provide dense transit networks to increase accessibility
  - Provide feeder services and more transportation options

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18 Please see Appendix 4, Best Practices in Transit Oriented Development – by Philip Kreycik.
Transit Synergized Development

- **Integrated Land-Use Planning**
  - Hong Kong, Munich, Tokyo, Vancouver, Singapore and Paris offer best-in-class examples of vibrant new town centers served by multi-modal transport systems.

With proper planning, both LRT and BRT systems can boost passenger flow at key transit nodes to enable TSD deployment, potentially making TSD applicable to large and medium size cities alike.

**Energy Infrastructure Considerations**

The energy infrastructure requirements for TSD transit districts will depend on climate, availability of local energy sources (e.g. solar, wind, ground-source and water-source heat, natural gas, etc.), energy density of the district (a function of building scale, density and energy intensity), and other factors. While a detailed technical discussion is beyond the scope of this study, a TSD transit district could have the following general structure.

<table>
<thead>
<tr>
<th>Energy Density&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Smart</th>
<th>Low-Carbon</th>
<th>Green&lt;sup&gt;3&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1</strong></td>
<td>Smart Meters, Data Collection</td>
<td>DH/CHP&lt;sup&gt;4&lt;/sup&gt;</td>
<td>China 1-Star</td>
</tr>
<tr>
<td><strong>Level 2</strong></td>
<td>Active Energy Management</td>
<td>District Cooling &amp; Heating/CHP; G/W-SHP&lt;sup&gt;5&lt;/sup&gt;</td>
<td>China 2-Star</td>
</tr>
<tr>
<td><strong>Level 3</strong></td>
<td>Real-time Energy Management</td>
<td>CCHP/DE Generation&lt;sup&gt;6&lt;/sup&gt;; Smart MicroGrid; Renewable Energy and Electric Vehicle Integration; Grid Energy Storage</td>
<td>China 3-Star</td>
</tr>
</tbody>
</table>

1 Level 1: Primarily Residential; Level 2: Mixed Residential/Commercial; Level 3: Primarily Commercial
2 Infrastructure requirements are additive for successive Energy Density levels.
3 Studies suggest that attractive parcels of land warrant higher design standards<sup>19</sup>
4 District Heating or Combined Heat & Power in cold regions
5 Ground/Water Source Heat Pump where available
6 Combined Cooling Heating and Power/Distributed Energy Generation subject to regulatory agreement and availability of gas supply

<sup>19</sup> Please see Appendix 2, section on “Higher Design Standards”.
Adopting an Integrated Planning Approach

TSD is a highly integrated development model predicated on leveraging the massive infrastructure work associated with transit construction to incorporate the main conduits for an Energy Hub, such as the piping for the district energy system.

![Fig. 2-6 Piping for District Cooling and Heating System](source: plaNYC – a Greener, Greater New York)

TSD requires coordinated planning and approvals from various government departments, including:

- National Development and Reform Commission (NDRC)
- Ministry of Construction
- Ministry of Land and Resources
- Department of Energy
- Urban Investment Corporation

Through an integrated planning process, TSD’s planning requirements are incorporated into a district’s Master Plan, Zoning Plan, Infrastructure Plan and factored into Land Auction Plan, the process whereby “unimproved land” is converted into and sold as “improved land.” It must be emphasized that, in this process, time is of the essence.

Fig. 2-7 District Cooling and Heating System Development Process ©iContinuum Group 2012

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Whether the project is planned as a public, a Public-Private Participation (PPP), or a private project, two key provisions should be incorporated within the regulatory framework, the absence of which could seriously compromise the project’s viability:

- A requirement that developers must subscribe to the district energy system.
- An equitable fee structure, including provisions for rate adjustments, third party verification and regulatory oversight.

Where such regulatory and tariff framework are not implemented, District energy projects may experience significant difficulties in implementation as a result of developer “opt out”, or tariff disputes.

**Summary**

TSD is a modular, scalable, network-based model of sustainable urban development. TSD focuses on the transit districts and builds a sustainable city from the “bottom-up”, one transit district at a time. TSD capitalizes on transit construction to introduce a network of district-scale energy infrastructure that can transform the city into a smart, low-carbon, eco-city.

Linking a city’s sustainability agenda to the 30-year build-out cycle of its mass transit system overcomes the typical short-term tendencies inherent in five-year political cycles. Thus, TSD offers a structured path to urban sustainability.

TSD’s network-based model integrates seamlessly with China’s City Cluster model. TSD ensures that a city’s key activity centers, and consequently its energy and resource “hot spots”, are transformed into low-carbon Energy Hubs, creative Innovation Hubs and vibrant Social Hubs. TSD therefore provides a solid foundation of triple-bottom-line sustainability for City Clusters at the grassroots level. In short, TSD can play a critical role in the success of China’s City Cluster strategy.

A good planning framework establishes the necessary conditions for successful implementation of TSD. What is also important is a technology framework that captures the full benefits of a district energy system at the lowest cost. This will be examined next.

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22 In the Zhujiang New Town project in Guangzhou, a major developer within the DES district insisted on building his own in-building HVAC plant, triggering other developers to follow suit.
23 The developer/manager of the Suzhou Industrial Park Dushu Lake (独墅湖) District Cooling and Heating System has encountered land developers’ resistance to the tariff structure, which requires them to pay upfront connection charges equal to three times the cost of an in-building HVAC plant.
3 Technology

“China should seize the opportunity of the new energy revolution, give top priority to replace traditional energy systems, occupy the commanding heights of the global energy economy, and transform China into an energy superpower.”

“中国应该抓住新能源革命机会，优先更换传统的能源系统，提前占领全球能源经济的制高点，实现我国由能源大国向能源强国的跨越。”

Dr. Dong Xiaojun
China National School of Administration
董小君博士
国家行政学院

The confluence of energy and information technologies heralds the dawn of the “Energy Internet”\(^\text{24}\), a new energy regime characterized by distributed generation of renewable energy, smart grids, grid energy storage, electric vehicles, green buildings and “smart consumers.” With this comes a revolutionary shift in energy technology, the economy and society. Welcome to the “Third Industrial Revolution.”\(^\text{25}\)

TSD anticipates this quantum shift in the energy landscape. An integrated design component of TSD’s “Energy Hub” is a new energy infrastructure, with a network of District Energy Systems as its basic framework. This section examines the technology components of this new energy infrastructure.

\(^{25}\) ibid.
“Energy Hub” – An Advanced Energy Infrastructure

The Energy Hub, an advanced energy infrastructure that can aggregate, transform, store and distribute energy for the district, has the following components:

- **District Energy System**
- **Green Buildings**
- **Smart City Platform**
- **Smart Microgrid**
- **Grid Energy Storage**

They transform the transit district into a smart, low-carbon, eco-district.

### District Energy System

A District Energy System (DES), considered a “strategic infrastructure” in Singapore\(^{26}\), and “a form of urban infrastructure that is indispensable for establishing ideal, environmentally friendly cities” in Japan\(^{27}\), can be a key component of a low-carbon energy infrastructure for the “energy-climate era”\(^{28}\). DES is a core element of the Energy Hub.

DES uses a central plant to house the chilled water and hot water production facilities. The plant distributes chilled and hot water to client buildings through a network of pipes (Fig. 3-1), which transfer energy to client buildings via heat exchangers.

DES delivers multiple, direct benefits to its customers, including capital efficiency and operating cost savings (which could range 10-20%)\(^{29}\) resulting from the economy of scale, density and energy intensity in transit district developments.

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26 http://www.singaporepower.com.sg
27 http://www.mm21dhc.co.jp
28 Thomas Friedman, “Hot, Flat and Crowded”, Picador, November 2009
DES provides a cost-effective platform for integrating new technologies, new customers and also pre-existing energy plants into its service area. Like a seed, a DES can grow and expand a city’s low-carbon zones. For instance, Chicago’s district cooling system grew over a decade into the world’s largest “networked” DCS, supplying efficient cooling to five downtown zones. (Fig. 3-3.)

For a detailed discussion of the many benefits of DES, please see Appendix 4.

- **District Energy Management and Green Buildings**

The DES plays a pivotal role in optimizing energy efficiency across four levels of the energy chain: end-user, building, district and the grid, in an integrated energy management approach (Fig. 3.5). The key is in getting accurate, real-time data of energy flow and being able to fix problems proactively. As well, by sharing energy information with customers, DES can raise awareness of energy usage among end-users, trigger conservation efforts, allow verification of results and spur competition. Engaging “smart users” can result in energy savings, targeted investment in energy efficiency, as well as adoption of better maintenance procedures.

At the same time that DES achieves energy efficiency for the district, such efficiency is predicated on well-built green buildings, specifically designed to improve energy, water and resource efficiency. Green buildings will be mandatory within a TSD District.

- **Smart City Platform**

The DES runs on a digital platform that manages five functional systems within the district, namely its building, energy, water, waste and transportation systems. To do so, the functional parameters of these systems are digitally encoded, and “plugged into” a citywide Smart City Platform as layers of digital information. The Smart City Platform contains the entire digital profile of the city, its Digital DNA[^30].

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[^30]: Paul Doherty, *From Smart Buildings to Smart Cities*, Realcomm Advisory, December 2012
The city’s Digital DNA data, along with real-time system performance data, are fed into a Big Data bank residing in giant server farms, a.k.a. the Cloud. Smart Applications can access that data to offer smart city solutions for specific purposes, such as building energy management, home energy monitoring, energy benchmarking, traffic monitoring, carbon accounting, etc. (Fig. 3-4.)

The city’s central control system actively monitors system performance through data sensors, transmission networks, analytic and visualization software, which acquire, analyze and display information in real-time, allowing city managers to optimize city operations. (Fig. 3-5.)

The Smart City platform provides an overview of all city operations and real-time feedback from its systems. By applying historical data, predictive software and self-learning programs, the city can automatically optimize its performance. For instance, traffic can be managed by time-of-day congestion pricing, or rerouted around a highway accident, resulting in reduced congestion, less pollution, higher productivity and better quality of life.

- **Smart Microgrid**

The new energy era is underpinned by renewable energy, green buildings, electric vehicles, smart grids, energy storage and energy-conscious consumers – the “Six Pillars of the New Energy Era.”

Renewable energy from wind and solar (called Distributed Energy Resources, or DERs) tends to be small scale, intermittent and distributed, requiring a new energy infrastructure to efficiently aggregate, store, transform and redistribute it to buildings, electric cars and consumers.

*District Energy Systems and Smart Microgrids can provide that capability.*

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31 Jeremy Rifkin, *The Third Industrial Revolution*, Palgrave Macmillan – 2011 (The Smart End-User is included by the author as a sixth pillar, given its importance in a populous country like China.)
What is a Smart Microgrid?

A “Smart Microgrid” aggregates and stores renewable energy generated from DERs, then transforms and distributes it to end users in the form of electricity. A microgrid may need to connect to the main grid for back up, which in China’s case would be the State Grid. The connection is made at a single point – the “Point of Common Coupling, PCC”. Therefore, to the State Grid, a microgrid appears as a single DER, vastly simplifying grid management.
Advanced ICT and digital control technology makes microgrids “smart”, enabling them to manage energy supply and demand at end-user sites, improve efficiency and enhance grid security and reliability. Additionally, smart microgrids promote electric vehicle (EV) integration, facilitate energy data collection and carbon accounting.

**Smart Microgrids help to advance China’s energy-climate agenda.**

**What are “Networked Microgrids”?**

Distributed generation (DG) brings complexity and instability to the State Grid, since DGs have different locations, types and characteristics, and renewable energy, by its nature, is unpredictable. Microgrids help to buffer the impact of renewable generation on the main grid, by grouping a wide, dynamic set of DERs into smaller clusters, each controlled through a PCC. PCCs are grouped into “Networked Microgrids” and managed by “dynamic and distributed control methodologies”.32,33 (Fig. 3-7.)

![Networked Microgrids](image)

**Fig. 3-7 Networked Microgrids**

*Source: Terry Mohn*

**Why deploy DES-Microgrids in dense urban settings?**

The DES and the microgrid both serve as a point of aggregation, storage, transformation and distribution of energy for the district. Therefore, a DES coupled with a microgrid can offer complementary and enhanced capabilities for the district, while providing a single PCC to the State Grid.

**A combined DES-Microgrid can provide a powerful building block for China’s national Strong SmartGrid (坚强智能电网).**

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DES-Microgrids target large urban “load centers” where air conditioning systems cause big spikes in electricity demand during peak hours of the day. This is also the time when solar power is at its prime. Here, rooftop solar panels, BIPVs and wind turbines could play a key role in easing summertime peaks, removing stress from the grid and displacing energy from some of the dirtiest and least-efficient power plants in the process. (Fig. 3-8) By aggregating DERs to reduce energy load at targeted “stress points” of a city, DES-Microgrids offer an effective form of “grid acupuncture.”

DES-Microgrids provide real-time ability to coordinate a wide range of DERs, smart appliances, smart homes and smart cars, match supply with demand, and engage consumers to save energy and reduce emissions. A key component of a DES-Microgrid is Grid Energy Storage.

**Grid Energy Storage**

Large-scale energy storage is a strategic technology of the new energy era. It is an enabling technology for three emerging industries — the smart grid, DG/renewable energy integration, and electric vehicle integration.

Utility scale grid energy storage helps to enhance grid stability. It can facilitate demand-side management, eliminate daily peaks and troughs, synchronize load frequencies and balance load fluctuations, improve equipment efficiency and reduce overall electricity cost.

Grid energy storage can add an important fifth link to the existing power infrastructure: generation, transmission, substation and distribution.

**Along with the DES-Microgrid, Grid Energy Storage is therefore an essential component of the TSD Energy Hub and the State Grid alike.**

34 Chris Neidl, outreach and advocacy coordinator for Solar One, a solar energy advocacy group proposing to turn Manhattan into a giant solar farm, using rooftop PVs and BIPVs on south-facing tall building facades.

What are the market opportunities in DES-Microgrids and Energy Storage?

In China, distributed generation (DG) is projected to reach 150,000 MW by 2020, about 8.5% of total installed capacity. Of this, 130,000 MW or 87%, will be in renewable energy. (Please see Appendix 5.) These goals are modest compared to the EU’s ambitious 20/20/20 targets, suggesting considerable growth potential. And momentum is building. Meanwhile, China’s grid energy storage market is expected to reach ¥40 billion by 2015, soaring to ¥600 billion by 2020.

According to Pike Research, global smart grid investment is expected to reach US$165 billion over the coming years, while cumulative investment in microgrids will grow to about US$7.8 billion by 2015.

Moreover, there will be lateral investment opportunities in the entire value chain of the smart grid system, such as in the utility, corporate, banking and retail industries, to name a few.

Distributed generation, smart grids and grid energy storage have enormous potential in China and worldwide, making a compelling case for China to leverage its development of TSD Energy Hubs to secure first mover advantage in these high-growth sectors.

Summary: building a new energy infrastructure and a new economy

TSD’s Energy Hub is a new energy infrastructure that integrates three important technologies of the new energy era: District Energy System, Smart Microgrid and Grid Energy Storage. This powerful trio will drive district-wide energy efficiency, reduce the carbon footprint of transit districts and promote local economic development.

Citywide, the transit network links Energy Hubs into a robust and resilient network. Each Energy Hub can grow and serve a larger customer base over time. In the process, they create a framework that can transform the city into a smart, low-carbon, eco-city, and help build a new economy.

Fig. 3-10 Transit Network a Transformative Framework

Having examined the technologies underpinning the TSD model, we next consider its implementation aspects.

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36 The European Union’s energy and climate package of 2011 prescribes 3 key objectives for 2020, known as the “20-20-20” targets: 20% reduction in EU greenhouse gas emissions from 1990 levels; raising the share of renewable energy to 20%; 20% improvement in energy efficiency.

37 China’s National Energy Administrator (NEA) plans to build 30 microgrid projects during the period of the 12th Five-Year Plan. In addition, NEA will also release standards and regulations for distributed generation and microgrids in the near future, which could help promote the concept.

Social, environmental and economic development goals are important benefits of the TSD model. However, in the final analysis, the key value proposition of the model is predicated on its ability to deliver energy at a lower cost. That is, the success of the TSD model is predicated on the successful implementation of the Energy Hub, in particular the District Energy System. Accordingly, key considerations in structuring a viable business model include ownership structure, the proportion of public and private sector participation, the operational framework required to deliver and operate a complex energy infrastructure, and the financial structure.

Ownership Structure for District Energy Systems (DES)

There are four basic ownership structures in the context of DES projects:

- Private Project Development (PD) Company: Chicago Downtown
- Public PD: Hong Kong Kai Tak Development
- Public/Private Partnerships (PPP): Singapore Marina Bay, MM21
- Stakeholder-Owned (Community Utility): South Chicago

<table>
<thead>
<tr>
<th>Ownership Structure</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private</td>
<td>- Private sector owns and carries the financial risk</td>
<td>- Higher rates of return are required</td>
</tr>
<tr>
<td></td>
<td>- Professional expertise, project management and operational skills</td>
<td>- Energy charges may be higher</td>
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<tr>
<td></td>
<td>- PPD will own and operate over the long term</td>
<td>- Public sector loses control</td>
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<tr>
<td></td>
<td></td>
<td>- Risk of monopoly abuse</td>
</tr>
<tr>
<td>Public</td>
<td>- Public ownership/control</td>
<td>- Municipality carries the financial risk and the asset on its balance sheet</td>
</tr>
<tr>
<td></td>
<td>- Alignment with public sector social and environmental goals</td>
<td>- Municipality must be rated as fair or better</td>
</tr>
<tr>
<td></td>
<td>- Lower cost financing</td>
<td></td>
</tr>
</tbody>
</table>

### Public-Private Partnership

- Dividends can support the delivery of other services
- Control of future expansion
- Some risk remains with the public sector
- Liabilities are consolidated into public sector accounts
- Has to comply with public sector procurement procedures

### Community

- Close alignment with the socio-environmental goals of the public sector
- Greater flexibility than either wholly public or private approaches
- Able to access capital at public sector rates
- Community carries full risk and liability
- Public sector procurement procedures
- Financing based on strength of community

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**Operational Framework**

The operational roles involved in a district energy project include Design, Build, Own, Operate, and Maintain (DBOOM). These roles carry risks, responsibilities and rewards, and are assigned to the parties that are best able to manage them within the various business models. Due to the complexities of DES, it is reasonable to expect that the DES Developer and Manager roles will not be assumed by specialist firms rather than by the real estate developer.\(^{40}\)

Four operational frameworks will be examined: DBO (Hong Kong Kai Tak Development), BOT (Singapore Marina Bay), BTO (South Chicago), and DBOOM (Chicago Downtown). For clarity, the role of the DES Developer (develop, finance and own) has been separated from that of the DES Manager (operate and maintain).

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\(^{40}\) Albert Chan, Planning Director, Shui On Land, noted emphatically: “Developers are not going to pay for this.”
In a Design Build & Operate (DBO) model (Fig. 4-2), an owner pays the DES Developer to design and build the DES, while the end-users pay the DES Manager energy fees to cover operating costs.

![Fig. 4-2 DBO Model (Hong Kong) – Public Developer](image)

©iContinuum Group 2012

In a Build Operate & Transfer (BOT) model (Fig. 4-3), the DES Developer builds and operates the DES, and recovers both capital and operating costs from end-users during the contract term.

![Fig. 4-3 BOT Model (Singapore) – PPP (Regulated Monopoly)](image)

©iContinuum Group 2012
In a Build Transfer & Operate (BTO) model (Fig. 4-4), the DES Developer builds and operates the DES, but recovers the capital costs from 2nd Tier developers during the land sale.

In a variation of the BOT model (Fig. 4-5), a private DES Developer develops, builds and operates the DES, and recovers both capital and operating costs from end-users on an ongoing basis.
**Financial Structure**

Regardless of the operational framework, an intrinsic challenge of a district energy project is its cash flow: high up-front capital costs and long payback period, as illustrated in a the discounted cash flow analysis below of the Hong Kong Kai Tak District Cooling project\(^\text{41}\).

![Discounted Cash Flow Analysis](image)

**Fig. 4-6 Discounted Cash Flow Analysis of Hong Kong Kai Tak DCS**

*Source: Hong Kong Electrical and Mechanical Services Department*

There is also significant risks related to uncertainties in the rate of uptake by customers, which is related to the absorption rate of the underlying real estate, and more fundamentally to whether customers are required to subscribe to the DES. If it is not mandatory for customers to subscribe to the DES, then the project can easily become financially unviable if customer uptake deviates even slightly from forecast, as the diagram below indicates for the Hong Kong Kai Tak project.

![Sensitivity of NPV to Customer Uptake](image)

**Fig. 4-7 Sensitivity of NPV to Customer Uptake**

*(Source: Hong Kong Electrical and Mechanical Services Department)*

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\(^\text{41}\) Hong Kong Electrical and Mechanical Services Department, “Assessment Study for Hong Kong Development District Cooling System”, July 2007 (prepared by Ove Arup & Partners Hong Kong Ltd.)
The strength of the TSD model relates to the fact that properties located near transit nodes typically command higher value and faster absorption rate. Hence they are less risky. Therefore, assuming favorable supply and demand market dynamics, the long-term benefits of the project will outweigh its short-term risks.

**A New Business Model: Integrated (Supply + Demand) Management**

**Improving Overall Energy Efficiency**

A key value proposition of a District Energy System is not only to deliver energy at a lower price, but also to help customers reduce their overall energy expenditure. Smart technologies enable the DES Manager to offer integrated energy management, driving energy efficiency at both ends of the energy supply and demand chain.

A DES manager controls the supply side of the energy equation through means such as reducing pumping cost by closely matching energy supply and demand, optimizing operations under varying utility rates and variable weather conditions, etc. On the customer side, the building systems must be designed to maximize the utilization of energy supplied by the DES. In the case of chilled water, for instance, it is to maximize the \( \Delta T \), the temperature differential between the supply water and return water. In short, the power of a DES lies in its ability to integrate energy supply and demand to deliver maximum energy efficiency for an entire district.

The tool that incentivizes the DES manager and the customer alike to work towards the common goal of saving energy is the tariff structure.
**Tariff Structure**

Tariff structures vary, but most consist of two main components:

- Connection fees, capacity and demand charges repay the fixed costs
- Usage fees repay the variable costs. This fee should be less or equal to what the customer would normally pay for energy if they were to build their own HVAC plant.

The DES relieves the building owner the obligations from having to build his own HVAC plant, and the following attendant risks:

- Capital Risk
- Technical Design Risk
- Construction Risk
- Operational Risk

In transferring these risks to the DES Developer/Manager, it is reasonable for building owners to share in the up-front capital costs of building the DES and in turn benefit from the long-term cost savings.

The diagram below shows the effect of charging customers an upfront connection charge accompanied by a 20% reduction in tariff, resulting in a significant improvement in financial viability. (Please see the Case Study on Hong Kong Kai Tak project.)

![Fig. 4-9 Revised Discounted Cash Flow to Improve Financial Viability](Source: Hong Kong Electrical and Mechanical Services Department)

Successful DES, such as the Minato Mirai 21 (MM21) project in Yokohama, Japan, which began operation in 1989 and has reduced tariffs four time since its inception, reducing charges by 20%. Today, it is priced at the lower end of the market, suggesting that this type of win-win tariff structure is indeed achievable.
Summary: Challenges, Opportunities and a Win-Win Proposition

While an integrated approach is critical to the success of the TSD model, the high levels of coordination required among private and public stakeholders across multiple sectors present formidable challenges to adoption of the model. In China, where government jurisdictions are clearly demarcated, integrated action requires strong leadership from a visionary Mayor or Party Secretary.

Yet, a key strength of the TSD model is that it is modular, adaptable and scalable, allowing it to be implemented over time in tandem with the build-out of a city’s transit system. Thus, TSD may best be seen as a progressive model of development that puts in place a basic infrastructure of DES, green neighborhoods and green buildings, to which more medium-term aspects of the model, such as the Smart Microgrid, Grid Energy Storage, renewable energy generation and EV integration, may be added over time. What is important is to incorporate TSD at the outset of transit system planning as a strategic infrastructure platform to help create a sustainable city and build a low-carbon economy.

At the same time, a sustainable business model must deliver long-term value to society and a win-win proposition for all stakeholders. Such a model is predicated on delivering measurable energy savings to customers. Thus, the DES must structure a business model not from selling more energy but from selling less, and to complement such a model by offering energy efficiency services to customers as a fee-based service.

In short, “Supply Side Efficiency” and “Demand Side Management” should be integral elements of a sustainable business model for a DES.

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42 “一级政府一级权” is a common saying within government, meaning officials must not exceed their mandate.
Case Studies

This section examines two case studies of implementing a DES system (in this case a District Cooling System) in the Southeast Asian context Hong Kong and Singapore. They reflect two different approaches to a market-oriented implementation of DES. They illustrate the complexities of the undertaking and highlight the necessity of putting in place the five essential conditions for implementation, namely, integrated planning, regulatory framework, technical design, energy management and a sound development model.43

Hong Kong Kai Tak Development (KTD) District Cooling System

The DCS, split into two plants, would serve 1.73 million square meters of service area. The HKSAR government initiated the first round of tendering procedures in July 2009. The returned tender prices of both the project costs and the operation costs far exceed the original estimates. A post-tender analysis noted that tenderers might have included a very high risk premium to:

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(a) Cater for uncertainties including price inflation exceeding that allowed under the price adjustments mechanism in the long operation period of 17 years;

(b) Provide allowances for any unexpected site constraints such as possible conflicts with existing underground utilities, as well as the reinforcement works to allow room for future developments on the ground level; and

(c) Provide allowances for any unexpected complication in design and construction of DCS, which is first-of-its-kind in Hong Kong.

With the project scheduled to break ground in 2011, the government took it upon itself to commence the infrastructure works and engaged a consortium consisting of Hip Hing Construction (Builder), and Dalkia (Design and Operate) on a DBO (Design, Built and Operate) contract. It made several significant changes to the project requirements, including mandatory subscription to DES by commercial developments.

(Excerpted from the HK Legislative Council Panel on Environmental Affairs)

On 4 July 2012, LegCo announced:

“Heeding the advice of the Members of the LegCo Panel on Environmental Affairs, we will also require all private non-domestic projects in the KTD to subscribe to the DCS with a view to maximizing the environmental benefits of the project. As we informed Members before, a requirement to connect to the DCS will be prescribed in appropriate provisions in the conditions of sale.”

The proposed legislation also include the following terms44:

- Charges of DCS Service
- Mechanism of annual adjustment of tariff rate
- Tariff review mechanism
- Other charges, e.g. capacity overrun charge, deposit, financial
- Penalties for unpaid charges
- Right of access to buildings for inspection and maintenance
- Improvement notice
- Appeal to the Administrative Appeals Board
- Future DCS – build in flexibility to cover charging for other DCS to be constructed by the Government

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44 Item for public works subcommittee of Finance Committee, PWSC(2010-11)31-19 January 2011
Singapore Marina Bay District Cooling System

District Cooling is a strategic infrastructure for a new business district.

Singapore District Cooling Pte Ltd.
District Cooling as a utility service at Marina Bay District

Background
The District Cooling System (DCS) at Singapore’s Marina Bay was a part of the Master Plan, which called for over 8 Million m² of gross construction, 900 MW of cooling load and 5 DCS Plants, which would be co-located at selected large scale developments.

As of July 2012, two plants have been built. Plant No. 1 at One Raffles Quay (south) has a capacity of 97 MWr. Plant No. 2 at Marina Bay Sands Casino (north) has a capacity of 120 MWr.

Efficiency-Promoting Regulatory Framework
The district cooling system at Singapore’s Marina Bay Business District is regulated by Singapore’s District Cooling Act, and administered by the Energy Market Authority of Singapore (“Authority”). Salient features of the Act include the following:

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45 Singapore District Cooling, “District Cooling as a Utility Service at Marina Bay Business District”, July 2010
46 Singapore District Cooling Act (Chapter 84A), revised 31 July 2002.
A special “DC Zone” establishes the jurisdictional boundary of the Act.

Within the DC Zone, subscription to the district cooling service is mandated for all commercial buildings under the Government’s land sale conditions.

The service provider acts under a license granted by the Authority.

The Act defines the pricing structure and the obligations of both the licensee and the buildings served, with built-in incentives to encourage energy efficiency on both parties, as well as provisions to ensure fairness to both parties.

The Authority acts as the arbiter and defender of the public interest.

Singapore’s District Cooling Act is a unique piece of legislation that facilitates the development of district cooling service as a privately financed and managed public utility. As a Private-Public Partnership (PPP) model, it attracts private capital into the public infrastructure sector, whilst drawing in the managerial expertise and innovative capacity of the private sector. For the government, it builds human and technical capacity to deliver advanced infrastructure services to important socio-economic hubs of the city, thereby enhancing efficiency and competitiveness.

The following sections examine two key aspects of the Act: the regulatory framework and the pricing structure.

**Regulatory Framework**

- Mandated service for commercial premises
- Regulated by Energy Market Authority under District Cooling Act

**Key Principles**

- Regulatory Baseline Revenue = WACC_{Pre-tax} \times RAB + OPEX
- Initial price cap = Benchmark costs of in-building chilled water production
- Revenue shortfall from Baseline for initial years recoverable from excess in subsequent years
- Sharing of efficiency gains after achieving the regulatory return.

The cost of chilled water produced by an in-building Conventional Cooling System (CCS) serves as the Benchmark cost, which the DCS operator cannot exceed. Due to the benefit-sharing scheme inherent in the framework for efficiency improvement, the operator is incentivized to continually pursue economic and energy efficiencies without the need for intrusive regulatory oversight.

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The framework requires the new utility service to be priced at a level no higher than the equivalent costs of chilled water production by building-scale plants employing similar technology. Over time, the district cooling operator is allowed to earn a baseline return based on its invested assets. When the operator has recovered its start-up losses after achieving the critical mass of demand for efficient operation, any efficiency gain above the baseline return shall be shared equally between the operator and its customers. Customers are thus assured of long-term savings while the start-up demand risk associated with a green-field project is also mitigated.

Singapore’s PPP model offers a win-win-win proposition for the government, the DCS developer/manager, and the DCS customers alike. It offers a potential model for the China market.
Conclusion

With the turn of the new century and the dawn of a new energy era, China finds itself at the confluence of three global megatrends: economic globalization, massive urbanization and energy transformation. As discussed in this paper, in order to remain competitive in the world economy, it is critical that China incorporate in its urban development plan goals to build a new generation of smart, low-carbon, eco-cities. China's success in doing so is predicated upon its ability to achieve energy and environmental sustainability, and the implementation of the Transit Synergized Development (TSD) model will be a part of this success.

An integrated model of developing transit-ready cities, TSD is designed to capture the benefits a holistic development process involving the planning of transit, land use and new energy systems. The adoption of the latest smart, low carbon and green technologies will enable cities to achieve an unprecedented level of urban sustainability that will be the hallmark of a new generation city.

In particular, the TSD Energy Hubs, through the implementation of District Energy System, Smart Microgrid and Grid Energy Storage, will create the building blocks for an "Energy Internet," providing an urban infrastructure for a world-class city in the new energy economy.

Modular, flexible, scalable and network-based, the TSD model is not only complimentary to China's City Cluster strategy but it will also help enhance the success of this urban and economic policy. When successfully implemented, TSD will help sustain China's position in the forefront of the world economy.

To further strengthen the leading role of City Clusters in spearheading China’s urbanization and socio-economic development, develop them into ecological, innovative, low-carbon, compact, digital and world-class city clusters.

Dr. Fang Chuanglin
China Academy of Sciences
Chief Architect of China’s Cluster City Strategy